CALIFORNIA
DEPARTMENT OF TRANSPORTATION

manual change transmittal

TITLE	APPROVED BY	NO.
DIVISION OF DESIGN HIGHWAY DESIGN MANUAL SIXTH EDITION – CHANGE 03/20/20	JANICE BENTON, Chief	Date Issued: 03/20/20 Page 1 of 1
SUBJECT AREA Table of Contents; List of Figures; List of Tables; Chapters: 60-500, 630, 650, 680, 700, 820-830, 850-880, 900, 1100; and Index	ISSUING UNIT DIVISION OF DESIGN	
SUPERCEDES SEE BELOW FOR SPECIFIC PAGE NUMBERS	DISTRIBUTION **ALL HOLDERS OF THE 6TH EDITION, HIGHWAY DESIGN MANUAL**	

The Table of Contents; List of Figures; List of Tables; Chapters: 60-500, 630, 650, 680, 700, 820-830, 850-880, 900, 1100; and the Index of the Sixth Edition, Highway Design Manual (HDM) have been revised. The changes to the HDM are summarized below with change sheets available on the Department Design website at: https://dot.ca.gov/programs/design/manual-highway-design-manual-hdm. Changes include updates related to curb ramp guidance, airway-highway clearances, bridge barriers and railings, clear recovery zone and recoverable areas, corner sight distance, and ramp widening for trucks. Also, included are clarification language, typographical corrections, reference corrections, and updates to figures.

These changes are effective March 20, 2020 and shall be applied to on-going projects in accordance with HDM Index 82.5 – Effective Date for Implementing Revisions to Design Standards.

HDM Holders are encouraged to use the most recent version of the HDM available on-line at the above website. Should a HDM Holder choose to maintain a paper copy, the Holder is responsible for keeping their paper copy up to date and current. Using the latest version available on-line will ensure proper reference to the latest design standards and guidance. If you would like to be notified automatically of any significant changes or updates to the HDM, go to https://dot.ca.gov/programs/design/manual-highway-design-manual-hdm.

A summary of the most significant revisions made throughout the manual are as follows:

Index 105.5 — **Guidelines for the Location and Design of Curb Ramps, Page 100-10**
Clarification wording is provided so that one curb ramp is required for each pedestrian street crossing.

Figure 202.5B — **Superelevation Transition Terms & Definitons, Page 200-18**
An update to the figure has been provided for accuracy.

Index 207.1, 3 — **Airway-Highway Clearance, Page 200-34**
An update is provided for the Federal Aviation Administration (FAA) requirement of notification of highway construction near an airport or heliport.

Index 208.10 — **Bridge Barriers and Railings, Page 200-42**
Vehicular barriers and combination railings were updated to the Manual for Assessing Safety Hardware (MASH).

Table 302.1 — **Boldface Standards for Paved Shoulder Widths on Highways, Page 300-4**
The existing provision for a 10-foot right shoulder adjacent to abutment walls, etc., now also applies to the left shoulder with the same situation.

Index 305.6(2)	**Separate Roadways, Page 300-19** This section was updated to replace the 23-foot graded area with the clear recovery zone policy. This edit is consistent with the Chapter 300 updated figures to show the clear recovery zone in the cross sections.
Figures 305.6, 307.2, 307.4A, 307.4B, and 307.5	**Figures, Pages 300-20, 22, 23, 24, and 25** These cross sections have been updated to show the clear recovery zone. Additionally, the Side Gutter and the Roadside Channels are also shown.
Index 309.1(2)	**Clear Recovery Zone, Page 300-27** The requirement for a 4:1 or flatter clear recovery zone for embankment slopes is designated as an underlined standard. This requirement is consistent with the AASHTO "Roadside Design Guide."
Index 309.1(4)	**High Speed Rail Clearances, Page 300-29** A minimum shoulder width of 10 feet adjacent to a barrier longitudinal to a high speed rail facility is specified. This standard is correlated to Table 302.1.
Index 309.3	**Tunnel Clearances, Page 300-35** An update is provided pertaining to minimum width and vertical clearance consistent with the AASHTO "A Policy on Design Standards—Interstate System," May 2016.
Index 405.1(2)	**Corner Sight Distance, Page 400-21** The sentence for no obstruction within the clear sight triangle is underlined, consistent with the AASHTO Green Book guidance. Revised wording is also provided to remove redundancy. The Table 405.1A is updated consistent with the 2018 AASHTO Green Book.
Figures 504.2A, 504.2B and 504.3K	**Single Lane Freeway Entrance and Exit, Two-Lane Connectors and Entrance/Exit Ramps, Pages 500-12, 13 and 34** Updated wording specifying the "Entrance Ramp-To-Exit Ramp Spacing" that replaces the "Weaving Length" for accuracy in terminology.
Table 504.3	**Ramp Widening for Trucks, Page 500-16** The table was updated to match the AutoTURN software.
Figure 504.3B	**Typical Successive Freeway Entrance Ramp Metering, Page 500-19** The distance between successive on-ramps has been updated to more accurately account for the Detail A inlet nose shown on the figure.
Index 504.7	**Weaving Sections, Page 500-39** Updated wording specifying the "Entrance Ramp-To-Exit Ramp Spacing" that replaces the "Weaving Length" change in terminology.
Index 631.4	**Open Graded Friction Course, Page 630-1** OGFC is specified as a stormwater treatment Best Management Practice.
Index 680	**Pavement Design for Widening Projects, Page 680-1** This is a new chapter.

Topic 706	**Roadside Management and Vegetation Control, Page 700-6** This Topic has been rewritten.
Index 821.5	**Effects of Tide and Storm, Page 820-3** This Index has been rewritten.
Index 834.3(4)	**Side Gutters within the Clear Recovery Zone, Page 830-7** Guidance is provided that addresses side gutters within the clear recovery zone.
Index 865.2	**Rigid, Page 860-10** Guidance is provided that addresses trapezoidal channels within the clear recovery zone.
Index 883.2(3)	**Sea Level Rise, Page 880-10** This Index has been rewritten.
Chapter 900	**Landscape Architecture Roadsides, Page 900-1** This chapter has been rewritten, including Table 904.5 "Large Tree Setback Requirements on Conventional Highways."

Enclosures available on the Department Design website at: https://dot.ca.gov/programs/design/manual-highway-design-manual-hdm.

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owner but not by other members of the public.

(f) Street--A way or place that is publicly maintained and open for the use of the public to travel. Street includes highway.

(g) Toll Road, Bridge or Tunnel--A highway, bridge, or tunnel open to traffic only upon payment of a toll or fee.

(8) Throughway. A conventional highway or a suburban arterial in developed or developing areas, that is characterized by lower density (not built out) land uses, adjacent undeveloped land or parkland, direct access to abutting property, at-grade intersections, and that may have shoulders with or without curb and gutter.

62.4 Interchanges and Intersections at Grade

(1) Central Island. The raised area in the center of a roundabout around which traffic circulates. The central island does not necessarily need to be circular in shape.

(2) Circulatory Roadway. The curved roadbed that users of a roundabout travel on in a counterclockwise direction around the central island.

(3) Channelization. The separation or regulation of conflicting movements into definite paths of travel by the use of pavement markings, raised islands, or other suitable means to facilitate the safe and orderly movement of vehicles, bicycles and pedestrians.

(4) Convergence Point. The point of convergence occurs where the right ETW of the entrance ramp is one lane width from the right ETW of the freeway.

(5) Crosswalk. Crosswalk is either:

(a) That portion of a roadway included within the prolongation or connection of the boundary lines of sidewalks at intersections where the intersecting roadways meet at approximately right angles, except the prolongation of such lines from an alley across a street.

(b) Any portion of a roadway distinctly indicated for pedestrian crossing by lines or other markings on the surface.

(6) Geometric Design. The arrangement of the visible elements of a road, such as alignment, grades, sight distances, widths, slopes, and other similar elements.

(7) Gore. The area between a through roadway and an exit ramp. This term may also refer to the similar area between a through roadway and a converging entrance ramp.

(8) Grade Separation. A crossing of two highways, highway and local road, or a highway and a railroad at different levels.

(9) Inscribed Circle Diameter. The distance across the circle of a roundabout, inscribed by the outer curb (or edge) of the circulatory roadway. It is the sum of the central island diameter and twice the circulatory roadway width.

(10) Interchange. A system of interconnecting roadways in conjunction with one or more grade separations that provides for the movement of vehicles between two or more roadways on different levels.

(11) Interchange Elements.

(a) Branch Connection--A multilane connection between two freeways.

(b) Freeway-to-freeway Connection--A single or multilane connection between freeways or any two high speed facilities.

(c) Ramp--A connecting roadway between a freeway or expressway and another highway, road, or roadside area.

(12) Intersection. The general area where two or more roadways join or cross, including the roadway and roadside facilities for movements in that area.

(13) Island. A defined area between roadway lanes for control of vehicle movements or for pedestrian refuge. Within an intersection a median or an outer separation is considered an island.

(14) Landscape Buffer/Strip. A planted section adjacent to the legs of a roundabout that

separates users of the roadway from users of the shared use/Class I Bikeway and assists with guiding pedestrians to the designated crossing locations. Also known as "way finding."

(15) *Minimum Turning Radius.* The radius of the path of the outer front wheel of a vehicle making its sharpest turn.

(16) *Offset Left-Turn Lanes.* Left-turn lanes are shifted as far to the left as practical rather than aligning the left-turn lane exactly parallel with and adjacent to the through lane.

(17) *Offtracking.* The difference between the paths of the front and rear wheels of a vehicle as it negotiates a turn.

(18) *Pedestrian Refuge.* A section of pavement or sidewalk, completely surrounded by asphalt or other road materials, where users can stop before completing the crossing of a road.

(19) *Roundabout.* A type of circular intersection with specific geometric and traffic control features that in combination lower speed operations and lower speed differentials among all users immediately prior to, through, and beyond the intersection. Vehicle speed is controlled by deflection in the path of travel, and the "yield upon entry" rule for traffic approaching the roundabout's circulatory roadway. Curves and deflections are introduced that limit operating speeds.

(20) *Splitter Island.* A raised or painted traffic island that separates traffic in opposing directions of travel. They are typically used at roundabouts and on the minor road approaches to an intersection.

(21) *Skew Angle.* The complement of the acute angle between two centerlines which cross.

(22) *Swept width.* The total width needed by the vehicle body to traverse a curve. It is the distance measured along the curve radius from the outer front corner of the body to the inner rear corner of the body as the vehicle traverses around a curve. This width is used to determine lane width and clearance to objects, such as signs, poles, etc., as well as vehicles, bicycles, and pedestrians.

(23) *Tracking width.* The total width needed by the tires to traverse a curve; it is the distance measured along the curve radius from the outer front tire track to the inner rear tire track as the vehicle traverses around a curve. This width is used to determine the minimum width required for the vehicle turning. Consideration for additional width may be needed for other vehicles, bicycles and pedestrians.

(24) *Truck Apron.* The traversable portion of the roundabout central island adjacent to the circulatory roadway that may be needed to accommodate the wheel tracking of large vehicles. A truck apron is sometimes provided on the outside of the circulatory roadway, but cannot encroach upon the pedestrian crossing.

(25) *Weaving Section.* A length of roadway, designed to accommodate two traffic streams merging and diverging within a short distance.

(26) *Wheelbase.* For single-unit vehicles, the distance from the first axle to the single rear axle or, in the case of a tandem or triple set of rear axles, to the center of the group of rear axles. See Topic 404

62.5 Landscape Architecture

(1) *Classified Landscaped Freeway.* A classified landscaped freeway is a planted section of freeway that meets the criteria established by the California Code of Regulations Outdoor Advertising Regulations, Title 4, Division 6. This designation is used in the control and regulation of outdoor advertising displays.

(2) *Park and Ride.* A paved area for parking which provides a connection point for public access to a variety of modal options. See Topic 915.

(3) *Safety Roadside Rest Area System.* The safety roadside rest area system is a component of the highway system providing roadside areas where travelers can stop, rest and manage their travel needs. Planned with consideration of alternative stopping opportunities such as truck stops, commercial services, and vista points, the rest area system provides public stopping opportunities where they are most needed, usually between large towns and at

(4) entrances to major metropolitan areas. See Topic 913.

(5) *Site Furnishings*. Features such as newspaper boxes, bicycle racks, bus shelters, benches, trash receptacles, interpretive panels, art or drinking fountains that occupy space on or alongside pedestrian sidewalks.

(6) *Vista Point.* Typically a paved dedicated area beyond the shoulder that permits travelers to stop and view a scenic area. See Topic 914.

62.6 Right of Way

(1) *Acquisition.* The process of obtaining rights of way.

(2) *Air Rights.* The property rights for the control or specific use of a designated airspace involving a highway.

(3) *Appraisal.* An expert opinion of the market value of property including damages and special benefits, if any, as of a specified date, resulting from an analysis of facts.

(4) *Business District (or Central Business District).* The commercial and often the geographic heart of a city, which may be referred to as "downtown." Usually contains retail stores, theatres, entertainment and convention venues, government buildings, and little or no industry because of the high value of land. Historic sections may be referred to as "old town."

(5) *Condemnation.* The process by which property is acquired for public purposes through legal proceedings under power of eminent domain.

(6) *Control of Access.* The condition where the right of owners or occupants of abutting land or other persons to access in connection with a highway is fully or partially controlled by public authority.

(7) *Easement.* A right to use or control the property of another for designated purposes.

(8) *Eminent Domain.* The power to take private property for public use without the owner's consent upon payment of just compensation.

(9) *Encroachment.* In terms of exceptions and permits, includes, but is not limited to, any structure, object, or activity of any kind or character which is within the State right of way, but it is not a part of the State facility or serving a transportation need.

(10) *Inverse Condemnation.* The legal process which may be initiated by a property owner to compel the payment of just compensation, where the property has been taken for or damaged by a public purpose.

(11) *Negotiation.* The process by which property is sought to be acquired for project purposes through mutual agreement upon the terms for transfer of such property.

(12) *Partial Acquisition.* The acquisition of a portion of a parcel of property.

(13) *Relinquishment.* A transfer of the State's right, title, and interest in and to a highway, or portion thereof, to a city or county.

(14) *Right of Access.* The right of an abutting land owner for entrance to or exit from a public road.

(15) *Severance Damages.* Loss in value of the remainder of a parcel which may result from a partial taking of real property and/or from the project.

(16) *Vacation.* The reversion of title to the owner of the underlying fee where an easement for highway purposes is no longer needed.

62.7 Pavement

The following list of definitions includes terminologies that are commonly used in California as well as selected terms from the "AASHTO Guide for the Design of Pavement Structures" which may be used by FHWA, local agencies, consultants, etc. in pavement engineering reports and research publications.

(1) *Asphalt Concrete.* See Hot Mix Asphalt (HMA).

(2) *Asphalt Rubber.* A blend of asphalt binder, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt binder sufficiently to cause swelling of the rubber particles.

(3) *Asphalt Treated Permeable Base (ATPB).* A highly permeable open-graded mixture of crushed coarse aggregate and asphalt binder placed as the base layer to assure adequate drainage of the structural section, as well as structural support.

(4) *Base.* A layer of selected, processed, and/or treated aggregate material that is placed immediately below the surface course. It provides additional load distribution and contributes to drainage and frost resistance.

(5) *Basement Soil/Material.* See Subgrade.

(6) *Borrow.* Natural soil obtained from sources outside the roadway prism to make up a deficiency in excavation quantities.

(7) *California R-Value.* A measure of resistance to deformation of the soils under saturated conditions and traffic loading as determined by the stabilometer test (CT301). The California R-value, also referred to as R-value, measures the supporting strength of the subgrade and subsequent layers used in the pavement structure. For additional information, see Topic 614.

(8) *Capital Preventive Maintenance.* Typically, Capital Preventive Maintenance (CAPM) consists of work performed to preserve the existing pavement structure utilizing strategies that preserve or extend pavement service life. The CAPM program is divided into pavement preservation and pavement rehabilitation. For further discussion see Topic 603.

(9) *Cement Treated Permeable Base (CTPB).* A highly permeable open-graded mixture of coarse aggregate, portland cement, and water placed as the base layer to provide adequate drainage of the structural section, as well as structural support.

(10) *Composite Pavement.* These are pavements comprised of both rigid and flexible layers. Currently, for purposes of the procedures in this manual, only flexible over rigid composite pavements are considered composite pavements.

(11) *Crack.* Separation of the pavement material due to thermal and moisture variations, consolidation, vehicular loading, or reflections from an underlying pavement joint or separation.

(12) *Crack, Seat, and Overlay (CSO).* A rehabilitation strategy for rigid pavements. CSO practice requires the contractor to crack and seat the rigid pavement slabs, and place a flexible overlay with a pavement reinforcing fabric (PRF) interlayer.

(13) *Crumb Rubber Modifier (CRM).* Scrap rubber produced from scrap tire rubber and other components, if required, and processed for use in wet or dry process modification of asphalt paving.

(14) *Deflection.* The downward vertical movement of a pavement surface due to the application of a load to the surface.

(15) *Dense Graded Asphalt Concrete (DGAC).* See Hot Mix Asphalt (HMA).

(16) *Depression.* Localized low areas of limited size that may or may not be accompanied by cracking.

(17) *Dowel Bar.* A load transfer device in a rigid slab usually consisting of a plain round steel bar.

(18) *Edge Drain System.* A drainage system, consisting of a slotted plastic collector pipe encapsulated in treated permeable material and a filter fabric barrier, with unslotted plastic pipe vents, outlets, and cleanouts, designed to drain both rigid and flexible pavement structures.

(19) *Embankment.* A prism of earth that is constructed from excavated or borrowed natural soil and/or rock, extending from original ground to the grading plane, and designed to provide a stable support for the pavement structure.

(20) *Equivalent Single Axle Loads (ESAL's).* The number of 18-kip standard single axle load repetitions that would have the same damage effect to the pavement as an axle of a specified magnitude and configuration. See Index 613.3 for additional information.

(21) *Flexible Pavement.* Pavements engineered to transmit and distribute vehicle loads to the underlying layers. The highest quality layer is

the surface course (generally asphalt binder mixes) which may or may not incorporate underlying layers of base and subbase. These types of pavements are called "flexible" because the total pavement structure bends or flexes to accommodate deflection bending under vehicle loads. For further discussion, see Chapter 630.

(22) *Grading Plane.* The surface of the basement material upon which the lowest layer of subbase, base, pavement surfacing, or other specified layer, is placed.

(23) *Gravel Factor (G_f).* Refers to the relative strength of a given material compared to a standard gravel subbase material. The cohesiometer values were used to establish the G_f currently used by Caltrans.

(24) *Hot Mix Asphalt (HMA).* Formerly known as asphalt concrete (AC), HMA is a graded asphalt concrete mixture (aggregate and asphalt binder) containing a small percentage of voids which is used primarily as a surface course to provide the structural strength needed to distribute loads to underlying layers of the pavement structure.

(25) *Hot Recycled Asphalt (HRA).* The use of reclaimed flexible pavement which is combined with virgin aggregates, asphalt, and sometimes rejuvenating agents at a central hot-mix plant and placed in the pavement structure in lieu of using all new materials.

(26) *Joint Seals.* Pourable, extrudable or premolded materials that are placed primarily in transverse and longitudinal joints in concrete pavement to deter the entry of water and incompressible materials (such as sand that is broadcast in freeze-thaw areas to improve skid resistance).

(27) *Lean Concrete Base.* Mixture of aggregate, portland cement, water, and optional admixtures, primarily used as a base for portland cement concrete pavement.

(28) *Longitudinal Joint.* A joint normally placed between roadway lanes in rigid pavements to control longitudinal cracking; and the joint between the traveled way and the shoulder.

(29) *Maintenance.* The preservation of the entire roadway, including pavement structure, shoulders, roadsides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

(30) *Open Graded Asphalt Concrete (OGAC).* See Open Graded Friction Course (OGFC).

(31) *Open Graded Friction Course (OGFC).* Formerly known as open graded asphalt concrete (OGAC), OGFC is a wearing course mix consisting of asphalt binder and aggregate with relatively uniform grading and little or no fine aggregate and mineral filler. OGFC is designed to have a large number of void spaces in the compacted mix as compared to hot mix asphalt. For further discussion, see Topic 631.

(32) *Overlay.* An overlay is a layer, usually hot mix asphalt, placed on existing flexible or rigid pavement to restore ride quality, to increase structural strength (load carrying capacity), and to extend the service life.

(33) *Pavement.* The planned, engineered system of layers of specified materials (typically consisting of surface course, base, and subbase) placed over the subgrade soil to support the cumulative vehicle loading anticipated during the design life of the pavement. The pavement is also referred to as the pavement structure and has been referred to as pavement structural section.

(34) *Pavement Design Life.* Also referred to as performance period, pavement design life is the period of time that a newly constructed or rehabilitated pavement is engineered to perform before reaching a condition that requires CAPM, (see Index 603.4). The selected pavement design life varies depending on the characteristics of the highway facility, the objective of the project, and projected vehicle volume and loading.

(35) *Pavement Drainage System.* A drainage system used for both asphalt and rigid pavements consisting of a treated permeable base layer and a collector system which includes a slotted plastic pipe encapsulated in treated permeable material and a filter fabric barrier with unslotted plastic pipe as vents,

outlets and cleanouts to rapidly drain the pavement structure. For further discussion, see Chapter 650.

(36) *Pavement Preservation.* Work done, either by contract or by State forces to preserve the ride quality, safety characteristics, functional serviceability and structural integrity of roadway facilities on the State highway system. For further discussion, see Topic 603.

(37) *Pavement Service Life.* Is the actual period of time that a newly constructed or rehabilitated pavement structure performs satisfactorily before reaching its terminal serviceability or a condition that requires major rehabilitation or reconstruction. Because of the many independent variables involved, pavement service life may be considerably longer or shorter than the design life of the pavement. For further discussion, see Topic 612.

(38) *Pavement Structure.* See Pavement.

(39) *Pumping.* The ejection of base material, either wet or dry, through joints or cracks, or along edges of rigid slabs resulting from vertical movements of the slab under vehicular traffic loading. This phenomena is especially pronounced with saturated structural sections.

(40) *Raveling.* Progressive disintegration of the surface course on asphalt concrete pavement by the dislodgement of aggregate particles and binder.

(41) *Rehabilitation.* Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy, for the specified service life. This might include the partial or complete removal and replacement of portions of the pavement structure. Rehabilitation is divided into pavement rehabilitation activities and roadway rehabilitation activities (see Indexes 603.3 and 603.4).

(42) *Resurfacing.* A supplemental surface layer or replacement layer placed on an existing pavement to restore its riding qualities and/or to increase its structural (load carrying) strength.

(43) *Rigid Pavement.* Pavement engineered with a rigid surface course (typically Portland cement concrete or a variety of specialty cement mixes for rapid strength concretes) which may incorporate underlying layers of stabilized or unstabilized base or subbase materials. These types of pavements rely on the substantially higher stiffness of the rigid slab to distribute the vehicle loads over a relatively wide area of underlying layers and the subgrade. Some rigid slabs have reinforcing steel to help resist cracking due to temperature changes and repetitive loading.

(44) *Roadbed.* The roadbed is that area between the intersection of the upper surface of the roadway and the side slopes or curb lines. The roadbed rises in elevation as each increment or layer of subbase, base or surface course is placed. Where the medians are so wide as to include areas of undisturbed land, a divided highway is considered as including two separate roadbeds.

(45) *Asphalt Rubber Binder.* A blend of asphalt binder modified with crumb rubber modifier (CRM) that may include less than 15 percent CRM by mass.

(46) *Rubberized Hot Mix Asphalt (RHMA).* Formerly known as rubberized asphalt concrete (RAC). RHMA is a material produced for hot mix applications by mixing either asphalt rubber or asphalt rubber binder with graded aggregate. RHMA may be gap- (RHMA-G) or open- (RHMA-O) graded.

(47) *R-value.* See California R-Value.

(48) *Serviceability.* The ability at time of observation of a pavement to serve vehicular traffic (automobiles and trucks) which use the facility. The primary measure of serviceability is the Present Serviceability Index (PSI), which ranges from 0 (impossible road) to 5 (perfect road).

(49) *Settlement.* Localized vertical displacement of the pavement structure due to slippage or consolidation of the underlying foundation,

often resulting in pavement deterioration, cracking and poor ride quality.

(50) *Structural Section.* See Pavement Structure.

(51) *Structural Section Drainage System.* See Pavement Drainage System.

(52) *Subbase.* Unbound aggregate or granular material that is placed on the subgrade as a foundation or working platform for the base. It functions primarily as structural support, but it can also minimize the intrusion of fines from the subgrade into the pavement structure, improve drainage, and minimize frost action damage.

(53) *Subgrade.* Also referred to as basement soil, it is the portion of the roadbed consisting of native or treated soil on which pavement surface course, base, subbase, or a layer of any other material is placed.

(54) *Surface Course.* One or more uppermost layers of the pavement structure engineered to carry and distribute vehicle loads. The surface course typically consists of a weather-resistant flexible or rigid layer, which provides characteristics such as friction, smoothness, resistance to vehicle loads, and drainage. In addition, the surface course minimizes infiltration of surface water into the underlying base, subbase and subgrade. A surface course may be composed of a single layer with one or multiple lifts, or multiple layers of differing materials.

(55) *Tie Bars.* Deformed reinforcing bars placed at intervals that hold rigid pavement slabs in adjoining lanes and exterior lane-to-shoulder joints together and prevent differential vertical and lateral movement.

62.8 Highway Operations

(1) *Annual Average Daily Traffic.* The average 24-hour volume, being the total number during a stated period divided by the number of days in that period. Unless otherwise stated, the period is a year. The term is commonly abbreviated as ADT or AADT.

(2) *Delay.* The time lost while road users are impeded by some element over which the user has no control.

(3) *Density.* The number of vehicles per mile on the traveled way at a given instant.

(4) *Design Vehicles.* See Topic 404.

(5) *Design Volume.* A volume determined for use in design, representing traffic expected to use the highway. Unless otherwise stated, it is an hourly volume.

(6) *Diverging.* The dividing of a single stream of traffic into separate streams.

(7) *Headway.* The time in seconds between consecutive vehicles moving past a point in a given lane, measured front to front.

(8) *Level of Service.* A rating using qualitative measures that characterize operational conditions within a traffic stream and their perception by users.

(9) *Managed Lanes.* Lanes that are proactively managed in response to changing operating conditions in efforts to achieve improved efficiency and performance. Typically employed on highways with increasing recurrent traffic congestion and limited resources.

(a) High-Occupancy Vehicle (HOV) Lanes--An exclusive lane for vehicles carrying the posted number of minimum occupants or carpools, either part time or full time.

(b) High Occupancy Toll (HOT) Lanes--An HOV lane that allows vehicles qualified as carpools to use the facility without a fee, while vehicles containing less than the required number of occupants to pay a toll. Tolls may change based on real time conditions (dynamic) or according to a schedule (static).

(c) Express Toll Lanes--Facilities in which all users are required to pay a toll, although HOVs may be offered a discount. Tolls may be dynamic or static.

(10) *Merging.* The converging of separate streams of traffic into a single stream.

(11) *Running Time.* The time the vehicle is in motion.

(12) *Spacing.* The distance between consecutive vehicles in a given lane, measured front to front.

(13) *Speed.*

(a) Design Speed--A speed selected to establish specific minimum geometric design elements for a particular section of highway or bike path.

(b) Operating Speed--The speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of a representative sample of observed speeds is used most frequently to measure the operating speed associated with a particular location or geometric feature.

(c) Posted Speed--The speed limit determined by law and shown on the speed limit sign.

(d) High Speed – A speed greater than 45 mph.

(e) Low Speed – A speed less than or equal to 45 mph.

(f) Running Speed--The speed over a specified section of highway, being the distance divided by running time. The average for all traffic, or component thereof, is the summation of distances divided by the summation of running times.

(14) *Traffic.* A general term used throughout this manual referring to the passage of people, vehicles and/or bicycles along a transportation route.

(15) *Traffic Control Devices.*

(a) Markings--All pavement and curb markings, object markers, delineators, colored pavements, barricades, channelizing devices, and islands used to convey regulations, guidance, or warning to users.

(b) Sign--Any traffic control device that is intended to communicate specific information to users through a word, symbol and/or arrow legend. Signs do not include highway traffic signals or pavement markings, delineators, or channelizing devices.

(c) Highway Traffic Signal--A power-operated control device by which traffic is warned or directed to take a specific action. These devices do not include signals at toll plazas, power-operated signs, illuminated pavement markers, warning lights, or steady burning electrical lamps.

(d) Changeable Message Sign--An electronic traffic sign used on roadways to give travelers information about traffic congestion, accidents, roadwork zones, speed limits or any dynamic information about current driving conditions.

(16) *Volume.* The number of vehicles passing a given point during a specified period of time.

(17) *Weaving.* The crossing of traffic streams moving in the same general direction accomplished by merging and diverging.

(18) *Ramp Metering.* A vehicular traffic management strategy which utilizes a system of traffic signals on freeway entrance and connector ramps to regulate the volume of vehicles entering a freeway corridor in order to maximize the efficiency of the freeway and thereby minimizing the total delay in the transportation corridor.

62.9 Drainage

See Chapter 800 for definition of drainage terms.

62.10 Users

(1) *Bicycle*. A device propelled via chain, belt or gears, exclusively by human power.

(2) *Bus.* Any vehicle owned or operated by a publicly owned or operated transit system, or operated under contract with a publicly owned or operated transit system, and used to provide to the general public, regularly scheduled transportation for which a fare is charged. A general public paratransit vehicle is not a transit bus.

(3) *Bus Rapid Transit (BRT).* A flexible rubber-tired rapid-transit mode that combines stations, vehicles, services, exclusive running

ways, and Intelligent Transportation System elements into an integrated system with a strong positive identity that evokes a unique image.

(4) *Commuter Rail.* Traditional rapid and heavy rail passenger service intended to provide travel options in suburban and urban areas. Corridor lengths are typically shorter than intercity passenger rail services. Top operating speeds are in the range of 90 to 110 miles per hour. The tracks may or may not be shared with freight trains and typically are in a separate right of way.

(5) *Conventional Rail.* Traditional intercity passenger rail and interregional freight rail. Top operating speeds are in the range of 60 to 110 miles per hour. The tracks may or may not be shared by passenger and freight trains and typically run within their own right of way corridor.

(6) *Design Vehicle*. The largest vehicle commonly expected on a particular roadway. Descriptions of these vehicles are found in Index 404.4.

(7) *Equestrian.* A rider on horseback.

(8) *High Speed Rail.* A type of intercity and interregional passenger rail service that operates significantly faster than conventional rail. Top operating speeds are typically 150 to 220 miles per hour. These trains may be powered by overhead high voltage lines or technologies such as Maglev. The tracks are grade separated within a separate controlled access right of way and may or may not be shared with freight trains.

(9) *Light Rail.* A form of urban transit that uses rail cars on fixed rails in a right of way that may or may not be grade separated. Motorized vehicles and bicycles may share the same transportation corridor. These railcars are typically electrically driven with power supplied from an overhead line rather than an electrified third rail. Top operating speeds are typically 60 miles per hour.

(10) *Pedestrian*. A person who is afoot or who is using any of the following: (a) a means of conveyance propelled by human power other than a bicycle, or (b) an electric personal assistive mobility device. Includes a person who is operating a self-propelled wheelchair, motorized tricycle, or motorized quadricycle and, by reason of physical disability, is otherwise unable to move about as a pedestrian as specified in part (a) above.

(11) *Street Car, Trams or Trolley.* A passenger rail vehicle which runs on tracks along public urban streets and also sometimes on separate rights of way. It may also run between cities and/or towns, and/or partially grade separated structures.

(12) *Transit.* Includes light rail; commuter rail; motorbus; street car, tram, trolley bus; BRT; automated guideway; and demand responsive vehicles. The most common application is for motorbus transit. See Index 404.4 for a description of the design vehicle as related to buses.

(13) *Vehicle.* A device to move, propel or draw a person upon a highway, except a device on rails or propelled exclusively by human power. This definition, abstracted from the CVC, is intended to refer to motor vehicles, excluding those devices necessary to provide mobility to persons with disabilities.

- Principal arterial - main movement (high mobility, limited access) Typically 4 lanes or more;
- Minor arterial - interconnects principal arterials (moderate mobility, limited access) Typically 2 or 3 lanes with turn lanes to benefit through traffic;
- Collectors - connects local roads to arterials (moderate mobility, moderate access) with few businesses; and,
- Local roads and streets - permits access to abutting land (high access, limited mobility).

The California Road System (CRS) maps are the official functional classification maps approved by Federal highway Administration. These maps show functional classification of roads.

(2) *Interstate Highways.* The interstate highway system was originally designed to be high-speed interregional connectors and it is a portion of the National Highway System (NHS). In urban and suburban areas, a large percentage of vehicular traffic is carried on the interstate highway system, rather than on the local arterials and streets.

(3) *State Routes.* The State highway system is described in the California Streets and Highway Code, Division 1, Chapter 2 and they are further defined in this manual in Topic 62.3, Highway Types which provides definitions for freeways, expressways, and highways.

81.5 Access Control

Index 62.3 defines a controlled access highway and a conventional highway. The level of access control plays a part in determining the design standards that are to be utilized when designing a highway. See Index 405.6 for additional access control guidance.

81.6 Design Standards and Highway Context

The design standards were initially established to increase highway mobility and development, promoting a State transportation system that operated at selected levels of service consistent with projected traffic volumes and highway classification. Design standards revolved around FHWA's controlling criteria, evolving over time to more fully consider adjacent community values, local decisions making, and area context.

The design guidance and standards in this manual have been developed with the intent of ensuring that:

- Designers have the ability to design for all modes of travel (vehicular, bicycle, pedestrian, truck and transit); and,
- Designers have the flexibility to tailor a project to the unique circumstances that relate to it and its location, while meeting driver expectation to achieve established project goals.

Designers should balance the interregional transportation needs with the needs of the communities they pass through. The design of projects should, when possible, expand the options for biking, walking, and transit use. In planning and designing projects, the project development team should work with locals that have any livable policies as revitalizing urban centers, building local economies, and preserving historic sites and scenic country roads. The "Main Streets: Flexibility in Planning, Design and Operations" published by the Department should be consulted for additional guidance as should the FHWA publication "Flexibility in Highway Design".

Early consultation and discussion with the Project Delivery Coordinator and the District Design Liaison during the Project Initiation Document (PID) phase is also necessary to avoid issues that may arise later in the project development process. Design Information Bulletin 78 "Design Checklist for the Development of Geometric Plans" is a tool that can be used to identify and discuss design features that may deviate from standard.

Topic 82 - Application of Standards

82.1 Highway Design Manual Standards

(1) *General.* The highway design criteria and policies in this manual provide a guide for the engineer to exercise sound judgment in applying standards, consistent with the above Project Development philosophy, in the design of projects. This guidance allows for flexibility in applying design standards and documenting design decisions that take the context of the

project location into consideration; which enables the designer to tailor the design, as appropriate, for the specific circumstances while maintaining safety.

The design standards used for any project should equal or exceed the minimum given in the Manual to the maximum extent feasible, taking into account costs (initial and life-cycle), traffic volumes, traffic and safety benefits, project goals, travel modes, facility type, right of way, socio-economic and environmental impacts, maintenance, etc. Because design standards have evolved over many years, many existing highways do not conform fully to current standards. It is not intended that current manual standards be applied retroactively to all existing State highways; such is neither warranted nor economically feasible. However, when warranted, upgrading of existing roadway features such as guardrail, lighting, superelevation, roadbed width, etc., should be considered, either as independent projects or as part of larger projects. A record of the decision not to upgrade existing non-standard design features are to be provided through the process described in Index 82.2.

This manual does not address temporary construction features. It is recognized that the construction conditions encountered are so diverse and variable that it is not practical to set geometric criteria. Guidance for use of traffic control devices for temporary construction zones can be found in Part 6 – Temporary Traffic Control of the California Manual on Uniform Traffic Control Devices (California MUTCD). Guidance for the engineering of pavements in temporary construction zones is available in Index 612.6. In this manual, design standards and guidance are described as follows (see Index 82.4 for other procedural requirements):

(2) *Absolute Requirements.* Design guidance related to requirements of law, policy, or statute that do not allow exception are phrased by the use of "must," "is required," "without exception," "are to be," "is to be," "in no event," or a combination of these terms.

(3) *Controlling Criteria.* The FHWA has designated the following ten controlling criteria for projects on the National Highway System (NHS) as comprehensive design standards which cover a multitude of design characteristics, allowing flexibility in application:

- Design Speed
- Lane Width
- Shoulder Width
- Horizontal Curve Radius
- Superelevation Rate
- Stopping Sight Distance
- Maximum Grade
- Cross Slope
- Vertical Clearance
- Design Loading Structural Capacity (non geometric)

Design loading structural capacity criteria applies to all NHS facility types. See the Technical Publications – DES Manuals for further information.

The remaining geometric criteria listed above are applicable to the NHS as follows: (1) On high-speed roadways (Interstate highways, other freeways, and roadways with design speeds of greater than or equal to 50 mph), all the geometric criteria apply. The stopping sight distance criteria applies to horizontal alignments and vertical alignments except for sag vertical curves; and (2) On low-speed roadways (non-freeways with design speeds less than 50 mph), only the design speed criteria applies.

The two speed categories stated above that FHWA designates match the high- and low-speed definitions in Index 62.8(13) when considering that design speed and posted speed are set in 5 mph increments.

The design standards related to the geometric criteria are identified in Table 82.1A among other important geometric standards in this manual regardless of the design speed of the

82.3 FHWA and AASHTO Standards and Policies

The standards in this manual generally conform to the standards and policies set forth in the AASHTO publications, "A Policy on Geometric Design of Highways and Streets" (2018) and "A Policy on Design Standards-Interstate System" (2016). A third AASHTO publication, the latest edition of the "Roadside Design Guide", focuses on creating safer roadsides. These three documents, along with other AASHTO and FHWA publications cited in 23 CFR Ch 1, Part 625, Appendix A, contain most of the current AASHTO policies and standards, and are approved references to be used in conjunction with this manual.

AASHTO policies and standards, which are established as nationwide standards, do not always satisfy California conditions. When standards differ, the instructions in this manual govern, except when necessary for FHWA project approval (Index 108.7, Coordination with the FHWA).

The use of publications and manuals that are developed by organizations other than the FHWA and AASHTO can also provide additional guidance not covered in this manual. The use of such guidance coupled with sound engineering judgment is to be exercised in collaboration with the guidance in this manual.

82.4 Mandatory Procedural Requirements

Required procedures and policies for which Caltrans is responsible, relating to project clearances, permits, licenses, required tests, documentation, value engineering, etc., are indicated by use of the word "must". Procedures and actions to be performed by others (subject to notification by Caltrans), or statements of fact are indicated by the word "will".

82.5 Effective Date for Implementing Revisions to Design Standards

Revisions to design standards will be issued with a stated effective date. It is understood that all projects will be designed to current standards unless a design decision has been approved in accordance with Index 82.2 or otherwise noted by separate Design Memorandum.

On projects where the project development process has started, the following conditions on the effective date of the new or revised standards will be applied:

- For all projects where the PS&E has not been finalized, the new or revised design standards shall be incorporated unless this would impose a significant delay in the project schedule or a significant increase in the project engineering or construction costs. The Project Delivery Coordinator or individual delegated authority must make the final determination on whether to apply the new or previous design standards on a project-by-project basis for roadway features.
- For all projects where the PS&E has been submitted to Headquarters Office Engineer for advertising or the project is under construction, the new or revised standards will be incorporated only if they are identified in the Change Transmittal as requiring special implementation.

For locally-sponsored projects, the Oversight Engineer must inform the funding sponsor within 15 working days of the effective date of any changes in design standards as defined in Index 82.2.

82.6 Design Information Bulletins and Other Caltrans Publications

In addition to the design standards in this manual, Design Information Bulletins (DIBs) establish policies and procedures for the various design specialties of the Department that are in the Division of Design. Some DIBs may eventually become part of this manual, while others are written with the intention to remain as design guidance in the DIB format. References to DIBs are made in this manual by the “base” DIB number only and considered to be the latest version available on the Department Design website. See the Department Design website for further information concerning DIB numbering protocol and postings.

Caution must be exercised when using other Caltrans publications, which provide guidelines for the design of highway facilities, such as HOV lanes. These publications do not contain design standards; moreover, the designs suggested in these publications do not always meet Highway Design Manual Standards. Therefore, all other Caltrans publications must be used in conjunction with this manual.

82.7 Traffic Engineering

The Division of Traffic Operations maintains engineering policy, standards, practices and study warrants to direct and guide decision-making on a broad range of design and traffic engineering features and systems, which are provided to meet the site-specific safety and mobility needs of all highway users.

The infrastructure within a highway or freeway corridor, segment, intersection or interchange is not "complete" for drivers, bicyclists and pedestrians unless it includes the appropriate traffic control devices; traffic safety systems; operational features or strategies; and traffic management elements and or systems. The presence or absence of these traffic elements and systems can have a profound effect on safety and operational performance. As such, they are commonly employed to remediate performance deficiencies and to optimize the overall performance of the "built" highway system.

For additional information visit the Division of Traffic Operations website at http://www.dot.ca.gov/trafficops/

Table 82.1A
Boldface Standards

CHAPTER 100 BASIC DESIGN POLICIES

Topic 101		**Design Speed**
	Index 101.1	Technical Reductions of Design Speed
	101.1	Selection of Design Speed - Local Facilities
	101.1	Selection of Design Speed - Local Facilities - with Connections to State Facilities
	101.2	Design Speed Standards
Topic 104		**Control of Access**
	Index 104.4	Protection of Access Rights(1)

CHAPTER 200 GEOMETRIC DESIGN AND STRUCTURE STANDARDS

Topic 201		**Sight Distance**
	Index 201.1	Stopping Sight Distance Standards
Topic 202		**Superelevation**
	Index 202.2	Standards for Superelevation
	202.7	Superelevation on City Streets and County Roads
Topic 203		**Horizontal Alignment**
	Index 203.1	Horizontal Alignment - Local Facilities
	203.1	Horizontal Alignment and Stopping Sight Distance
	203.2	Standards for Curvature – Minimum Radius
	203.2	Standards for Curvature – Lateral Clearance
Topic 204		**Grade**
	Index 204.1	Standards for Grade - Local Facilities
	204.3	Standards for Grade
	204.8	Vertical Falsework Clearances(1)
Topic 205		**Road Connections and Driveways**
	Index 205.1	Sight Distance Requirements for Access Openings on Expressways
Topic 208		**Bridges, Grade Separation Structures, and Structure Approach Embankment**
	Index 208.1	Bridge Width(1)
	208.4	Bridge Sidewalk (Width)(1)
	208.10	Barriers on Structures with Sidewalks(1)
	208.10	Bridge Approach Railings(1)

CHAPTER 300 GEOMETRIC CROSS SECTION

Topic 301		**Traveled Way Standards**
	Index 301.1	Lane Width
	301.2	Class II Bikeway Lane Width(1)
	301.3	Cross Slopes – New Construction
	301.3	Cross Slopes – Resurfacing or widening
	301.3	Cross Slopes – Unpaved Roadway
	301.3	Algebraic Differences in Cross Slopes
Topic 302		**Shoulder Standards**
	Index 302.1	Shoulder Width
	302.1	Shoulder Width with Rumble Strip
	302.2	Shoulder Cross Slopes -Bridge
	302.2	Shoulder Cross Slopes – Left
	302.2	Shoulder Cross Slopes – Paved Median
	302.2	Shoulder Cross Slopes - Right
Topic 305		**Median Standards**
	Index 305.1	Median Width – Conventional Highways(1)
	305.1	Median Width – Freeways and Expressways(1)

Design exception approval of Boldface Standards for nonfreeway facilities, including local streets and roads at interchanges, has been delegated to the Districts. In addition, some District delegations included Boldface Standards applicable to freeways. See your District Design Delegation Agreement for specific delegation.

(1) Caltrans-only Boldface Standard.

(2) Authority to approve deviations from this Boldface Standard is delegated to the State Pavement Engineer.

Table 82.1A
Boldface Standards (Cont.)

Topic 307 **Cross Sections for State Highways**

Index 307.2 Shoulder Standards for Two-lane Cross Sections for New Construction

Topic 308 **Cross Sections for Roads Under Other Jurisdictions**

Index 308.1 Cross Section Standards for City Streets and County Roads without Connection to State Facilities

308.1 Minimum Width of 2-lane Over-crossing Structures for City Streets and County Roads without Connection to State Facilities(1)

308.1 Cross Section Standards for City Streets and County Roads with Connection to State Facilities

308.1 Two-Lane Local Road Lane Width for City Streets and County Roads within Interchange

308.1 Multi-Lane Local Road Lane Width for City Streets and County Roads within Interchange

308.1 Shoulder Width Standards for City Streets and County Roads Lateral Obstructions

308.1 Shoulder Width Standards for City Streets and County Roads with Curbs and Gutter

308.1 Minimum Width for 2-lane Overcrossing at Interchanges(1)

Topic 309 **Clearances**

Index 309.1 Horizontal Clearances and Stopping Sight Distance

309.1 Horizontal Clearances(1)

309.1 High Speed Rail Clearances – Minimum Shoulder Width

309.2 Vertical Clearances - Minor Structures

309.2 Vertical Clearances - Rural and Single Interstate Routing System

309.3 Horizontal Tunnel Clearances(1)

309.3 Vertical Tunnel Clearances

309.4 Lateral Clearance for Elevated Structures(1)

309.5 Structures Across or Adjacent to Railroads - Vertical Clearance

Topic 310 **Frontage Roads**

Index 310.1 Frontage Road Width Cross Section

CHAPTER 400 INTERSECTIONS AT GRADE

Topic 404 **Design Vehicles**

Index 404.2 Design Vehicle–Traveled Way(1)

Topic 405 **Intersection Design Standards**

Index 405.2 Left-turn Channelization - Lane Width

405.2 Left-turn Channelization - Lane Width – Restricted Urban

405.2 Two-way Left-turn Lane Width

405.3 Right-turn Channelization – Lane and Shoulder Width

CHAPTER 500 TRAFFIC INTERCHANGES

Topic 501 **General**

Index 501.3 Interchange Spacing(1)

Topic 502 **Interchange Types**

Index 502.2 Isolated Off-Ramps and Partial Interchanges(1)

502.3 Route Continuity(1)

Topic 504 **Interchange Design Standards**

Index 504.2 Location of Freeway Entrances & Exits(1)

504.2 Ramp Deceleration Lane and "DL" Distance(1)

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Table 82.1A
Boldface Standards (Cont.)

	504.3	Ramp Lane Width
	504.3	Ramp Shoulder Width
	504.3	Ramp Lane Drop Taper Past the Limit Line(1)
	504.3	Metered Multi-Lane Ramp Lane Drop Taper Past the Limit Line(1)
	504.3	Ramp Meters on Connector Ramps(1)
	504.3	Metered Connector Lane Drop(1)
	504.3	Distance Between Ramp Intersection and Local Road Intersection(1)
	504.4	Freeway-to-freeway Connections – Shoulder Width – 1 and 2-Lane
	504.4	Freeway-to-freeway Connections – Shoulder Width – 3-Lane
	504.7	Minimum Entrance Ramp-to-Exit Ramp Spacing(1)
	504.8	Access Control along Ramps(1)
	504.8	Access Control at Ramp Terminal(1)
	504.8	Access Rights Opposite Ramp Terminals(1)
CHAPTER 610		**PAVEMENT ENGINEERING CONSIDERATIONS**
Topic 612		**Pavement Design Life**
	Index 612.2	Design Life for New Construction and Reconstruction(1), (2)
	612.3	Pavement Design Life for Widening Projects(1), (2)
	612.5	Pavement Design Life for Pavement Roadway Rehabilitation Projects(1), (2)
Topic 613		**Traffic Considerations**
	Index 613.5	Shoulder Traffic Loading Considerations(1), (2)
	613.5	Depth of Shoulder Pavement Structural Section(1), (2)
CHAPTER 620		**RIGID PAVEMENT**
Topic 622		**Engineering Requirements**
	Index 622.5	Transitions and Terminal Anchors for CRCP(1), (2)
	Index 622.7	Dowel Bars and Tie Bars(1) (2)
Topic 625		**Engineering Procedures for Pavement Rehabilitation**
	Index 625.2	Limits of Paving on Resurfacing Projects(1), (2)
Topic 626		**Other Considerations**
	Index 626.2	Tied Rigid Shoulder Standards(1), (2)
	626.2	Tied Rigid Shoulders or Widened Slab Standards(1), (2)
	626.2	Tied Rigid Shoulders or Widened Slab at Ramps and Gore Standard(1), (2)
CHAPTER 630		**FLEXIBLE PAVEMENT**
Topic 635		**Engineering Procedures for Flexible Pavement Rehabilitation**
	Index 635.2	Limits of Paving on Resurfacing Projects(1), (2)
CHAPTER 700		**MISCELLANEOUS STANDARDS**
Topic 701		**Fences**
	Index 701.2	Fences on Freeways and Expressways(1)

Design exception approval of Boldface Standards for nonfreeway facilities, including local streets and roads at interchanges, has been delegated to the Districts. In addition, some District delegations included Boldface Standards applicable to freeways. See your District Design Delegation Agreement for specific delegation.

(1) Caltrans-only Boldface Standard.

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Table 82.1A
Boldface Standards (Cont.)

CHAPTER 900	**LANDSCAPE ARCHITECTURE**
Topic 904	**Planting Design**
Index 904.9	Plant Establishment
Topic 905	**Irrigation Design**
Index 905.2	Water Supply
Topic 912	**Roadside Site Design**
Index 912.1	Freeway Ramp Design
Topic 913	**Safety Roadside Rest Areas**
Index 913.5	Public Pay Telephone
CHAPTER 1000	**BICYCLE TRANSPORTATION DESIGN**
Topic 1003	**Design Criteria**
Index 1003.1	Class I Bikeway Widths(1)
1003.1	Class I Bikeway Shoulder Width(1)
1003.1	Class I Bikeway Horizontal Clearance(1)
1003.1	Class I Bikeway Structure Width(1)
1003.1	Class I Bikeway Vertical Clearance(1)
1003.1	Class I Bikeway Minimum Separation From Edge of Traveled Way(1)
1003.1	Physical Barriers Adjacent to Class I Bikeways(1)
1003.1	Class I Bikeway in Freeway Medians(1)
1003.1	Class I Bikeway Design Speeds(1)
1003.1	Stopping Sight Distance
1003.1	Bikeway Shoulder Slope(1)
1003.1	Obstacle Posts or Bollards in Bicycle Paths(1)
CHAPTER 1100	**HIGHWAY TRAFFIC NOISE ABATEMENT**
Topic 1102	**Design Criteria**
Index 1102.2	Horizontal Clearance to Noise Barrier(1)
1102.2	Noise Barrier on Safety Shape Concrete Barrier(1)

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(1) Caltrans-only Boldface Standard.

(2) Authority to approve deviations from this Boldface Standard is delegated to the State Pavement Engineer.

Table 82.1B
Underlined Standards

CHAPTER 100		**BASIC DESIGN POLICIES**
Topic 101		**Design Speed**
Index	101.1	Selection of Design Speed – Local Facilities
	101.1	Selection of Design Speed – Local Facilities – with Connections to State Facilities
	101.2	Design Speed Standards
Topic 104		**Control of Access**
Index	104.5	Relation of Access Opening to Median Opening
Topic 105		**Pedestrian Facilities**
Index	105.2	Minimum Sidewalk Width – Next to a Building
	105.2	Minimum Sidewalk Width – Not Next to a Building
	105.5	Curb Ramp for each Crossing
Topic 107		**Roadside Installations**
Index	107.1	Standards for Roadway Connections
	107.1	Number of Exits and Entrances Allowed at Roadway Connections
CHAPTER 200		**GEOMETRIC DESIGN AND STRUCTURE STANDARDS**
Topic 201		**Sight Distance**
Index	201.3	Stopping Sight Distance on Sustained Grades
	201.7	Decision Sight Distance
Topic 202		**Superelevation**
Index	202.2	Superelevation on Same Plane for Rural Two-lane Roads
	202.5	Superelevation Transition
	202.5	Superelevation Runoff
	202.5	Superelevation in Restrictive Situations
	202.6	Superelevation of Compound Curves
	202.7	Superelevation on City Streets and County Roads
Topic 203		**Horizontal Alignment**
Index	203.1	Horizontal Alignment – Local Facilities
	203.3	Alignment Consistency and Design Speed
	203.5	Compound Curves
	203.5	Compound Curves on One-Way Roads
	203.6	Reversing Curves – Transition Length
	203.6	Reversing Curves – Transition Rate
Topic 204		**Grade**
Index	204.1	Standards for Grade – Local Facilities
	204.3	Standards for Grade
	204.3	Ramp Grades
	204.4	Vertical Curves – 2 Percent and Greater
	204.4	Vertical Curves – Less Than 2 Percent
	204.5	Decision Sight Distance at Climbing Lane Drops
	204.6	Horizontal and Vertical Curves Consistency in Mountainous or Rolling Terrain
Topic 205		**Road Connections and Driveways**
Index	205.1	Access Opening Spacing on Expressways
	205.1	Access Opening Spacing on Expressways – Location
Topic 206		**Pavement Transitions**
Index	206.3	Lane Drop Transitions
	206.3	Lane Width Reductions
Topic 208		**Bridges, Grade Separation Structures, and Structure Approach Embankment**
Index	208.3	Decking of Bridge Medians
	208.6	Minimum width of Walkway of Pedestrian Overcrossings
	208.6	Minimum Vertical Clearance of Pedestrian Undercrossings
	208.6	Class I Bikeways Exclusive Use

Table 82.1B
Underlined Standards (Cont.)

	208.10	Protective Screening on Overcrossings
	208.10	Bicycle Railing Locations
Topic 210		**Earth Retaining Systems**
	Index 210.6	Cable Railing
CHAPTER 300		**GEOMETRIC CROSS SECTION**
Topic 301		**Traveled Way Standards**
	Index 301.2	Class II Bikeway Lane Width
	301.3	Algebraic Differences of Cross Slopes at Various Locations
Topic 303		**Curbs, Dikes, and Side Gutters**
	303.1	Use of Curb with Posted Speeds of 40 mph and Greater
	303.3	Dike Selection
	303.4	Bulbout Design
Topic 304		**Side Slopes**
	Index 304.1	Side Slopes 4:1 or Flatter
	304.1	18 ft Minimum Catch Distance
Topic 305		**Median Standards**
	Index 305.1	Median Width Freeways and Expressways – Urban
	305.1	Median Width Freeways and Expressways – Rural
	305.1	Median Width Conventional Highways – Urban and Rural Main Streets
	305.1	Median Width Conventional Highways – Climbing or Passing Lanes
	305.2	Median Cross Slopes
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See Index 105.4 for discussion of provisions for persons with disabilities.

(2) Financing.

(a) Freeways--Where the pedestrian grade separation is justified prior to award of the freeway contract, the State should pay the full cost of the pedestrian facility. In some cases, construction of the separation may be deferred; however, where the need has been established to the satisfaction of the Department prior to award of the freeway contract, the State should pay the entire cost of the separation.

Local jurisdictions have control (by zoning and planning) of development that influences pedestrian traffic patterns. Therefore, where a pedestrian grade separation is justified after the award of a freeway contract, the State's share of the total construction cost of the separation should not exceed 50 percent. The State must enter into a cooperative agreement with the local jurisdiction on this basis.

(b) Conventional Highways--Grade separations are not normally provided for either cars or pedestrians on conventional highways. However, in those rare cases where pedestrian use is extensive, where it has been determined that placement and configuration of the grade separation will result in the majority of pedestrians using it, and where the local agency has requested in writing that a pedestrian separation be constructed, an overcrossing may be considered. The State's share of the total construction cost of the pedestrian facility should not exceed 50 percent. The State must enter into a cooperative agreement with the local jurisdiction on this basis.

105.4 Accessibility Requirements

(1) Background.

The requirement to provide equivalent access to facilities for all individuals, regardless of disability, is stated in several laws adopted at both the State and Federal level. Two of the most notable references are The Americans with Disabilities Act of 1990 (ADA) which was enacted by the Federal Government and took effect on January 26, 1992, and Section 4450 of the California Government Code.

(a) Americans with Disabilities Act Highlights.

- Title II of the ADA prohibits discrimination on the basis of disability by state and local governments (public entities). This means that a public entity may not deny the benefits of its programs, activities and services to individuals with disabilities because its facilities are inaccessible. A public entity’s services, programs, or activities, when viewed in their entirety, must be readily accessible to and usable by individuals with disabilities. This standard, known as “program accessibility,” applies to all existing facilities of a public entity.
- Public entities are not necessarily required to make each of their existing facilities accessible. Public entities may achieve program accessibility by a number of methods (e.g., providing transit as opposed to structurally accessible pedestrian facilities). However, in many situations, providing access to facilities through structural methods, such as alteration of existing facilities and acquisition or construction of additional facilities, may be the most efficient method of providing program accessibility.
- Where structural modifications are required to achieve program accessibility, a public entity with 50 or more employees is required to develop a transition plan setting forth the steps necessary to complete such modifications.
- In compliance with the ADA, Title 28 of the Code of Federal regulations (CFR) Part 35 identifies all public entities to be subject to the requirements for ADA regardless of

funding source. It further states that the Uniform Federal Accessibility Standards (UFAS) and the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG) are acceptable design guidelines that may be used. However, FHWA has directed Caltrans to use the ADAAG as the Federal design guidelines for pedestrian accessibility.

(b) California Government Code 4450 et seq. Highlights.

- Sections 4450 (through 4461) of the California Government Code require that buildings, structures, sidewalks, curbs, and related facilities that are constructed using any State funds, or the funds of cities, counties, or other political subdivisions be accessible to and usable by persons with disabilities.

(2) *Policy.*

It is Caltrans policy to:

- Comply with the ADA and the Government Code 4450 et seq. by making all State highway facilities accessible to people with disabilities to the maximum extent feasible. In general, if a project on State right of way is providing a pedestrian facility, then accessibility must be addressed.

(3) *Procedures.*

(a) The engineer will consider pedestrian accessibility needs in the project initiation documents for all projects where applicable.

(b) All State highway projects administered by Caltrans or others with pedestrian facilities must be designed in accordance with the requirements in Design Information Bulletin 82, "Pedestrian Accessibility Guidelines for Highway Projects."

(c) The details of the pedestrian facilities and their relationship to the project as a whole should be discussed with the District Design Liaison for the application of DIB 82, the guidance of this manual, as well as other required design guidance.

ADA compliance must be recorded on the Ready-to-List certification for State-administered projects. Appropriate project records should document the fact that necessary review and approvals have been obtained as required above.

In addition to the above mentioned Design procedures, the Districts and Regions have established procedures for certifying that the project "as-built" complies with the ADA standards in DIB 82 before a project can achieve Construction Contract Acceptance (CCA) or before the Notice of Completion is provided for a permit project.

105.5 Guidelines for the Location and Design of Curb Ramps

(1) *Policy.* On all State highway projects adequate and reasonable access for the safe and convenient movement of persons with disabilities are to be provided across curbs that are constructed or replaced at pedestrian crosswalks. This includes all marked and unmarked crosswalks, as defined in Section 275 of the Vehicle Code.

Access should also be provided at bridge sidewalk approaches and at curbs in the vicinity of pedestrian separation structures.

Where a need is identified at an existing curb on a conventional highway, a curb ramp may be constructed either by others under encroachment permit or by the State.

(2) *Location Guidelines.* When locating curb ramps, designers must consider the position of utilities such as power poles, fire hydrants, street lights, traffic signals, and drainage facilities.

When curb ramps are constructed or reconstructed, one curb ramp should be provided for each pedestrian street crossing. A blended transition that spans the curb return across both pedestrian crossings serves the purpose of two curb ramps. For example, at intersection corners where two pedestrian street crossings are located, two curb ramps should be constructed; if only one pedestrian street crossing is located at a corner, one curb ramp may be constructed. See Index 105.6 for further information. The usage of the one-ramp design should be restricted to those locations where the volume of pedestrians and vehicles making right turns is low. This will reduce the potential frequency of conflicts between turning vehicles and persons with disabilities entering the common crosswalk area to cross either street.

Ramps and/or curb openings should be provided at midblock crosswalks and where pedestrians cross curbed channelization or median islands at intersections. Often, on traffic signalization, channelization, and similar projects, curbs are proposed to be modified only on portions of an existing intersection. In those cases, consideration should be given to installing retrofit curb ramps on all legs of the intersection.

(3) Ramp Design. Curb ramp designs should conform to current Standard Plans. See Index 105.4(3) for review procedures.

105.6 Pedestrian Crossings

There are various standards related to pedestrian crossings in this manual (e.g., the two curb ramps at each corner and pedestrian refuge island standards), as well as in DIB 82 (e.g., the curb ramp requirement) that depend on the existence of a pedestrian crossing as prescribed in the California Vehicle Code (CVC).

Pedestrian facilities that support pedestrian crossings occur at marked and unmarked crosswalks.

Per the CA MUTCD, a marked crosswalk is striped, including at midblock locations. An unmarked crosswalk is not striped and, per the CVC, depends on two elements: 1) it occurs at an intersection, and 2) it occurs where the sidewalk connects to the intersection. Without these two elements, there is no unmarked crosswalk.

Per the CVC, pedestrian crossings are provided across highways as marked or unmarked crosswalks, thereby requiring vehicles to yield to pedestrians (CVC 21950). Two examples in Figure 105.6 clarify the existence of unmarked crosswalks at "T" intersections, but may also apply to four legged intersections. This example is based on the following CVC citations:

- Section 275 - For the definition of crosswalk, see Index 62.4(5). Section 275 describes marked and unmarked crosswalks.
- Section 360 - A highway is a way or place of whatever nature, publicly maintained and open to the use of the public for purposes of vehicular travel. Highway includes street.
- Section 365 - An "intersection" is the area embraced within the prolongations of the lateral curb lines, or, if none, then the lateral boundary lines of the roadways, of two highways which join one another at approximately right angles or the area within which vehicles traveling upon different highways joining at any other angle may come in conflict.
- Section 530 - A "roadway" is that portion of a highway improved, designed, or ordinarily used for vehicular travel.
- Section 555 - A "sidewalk" is that portion of a highway, other than the roadway, set apart by curbs, barriers, markings or other delineation for pedestrian travel.

Topic 106 - Stage Construction and Utilization of Local Roads

106.1 Stage Construction

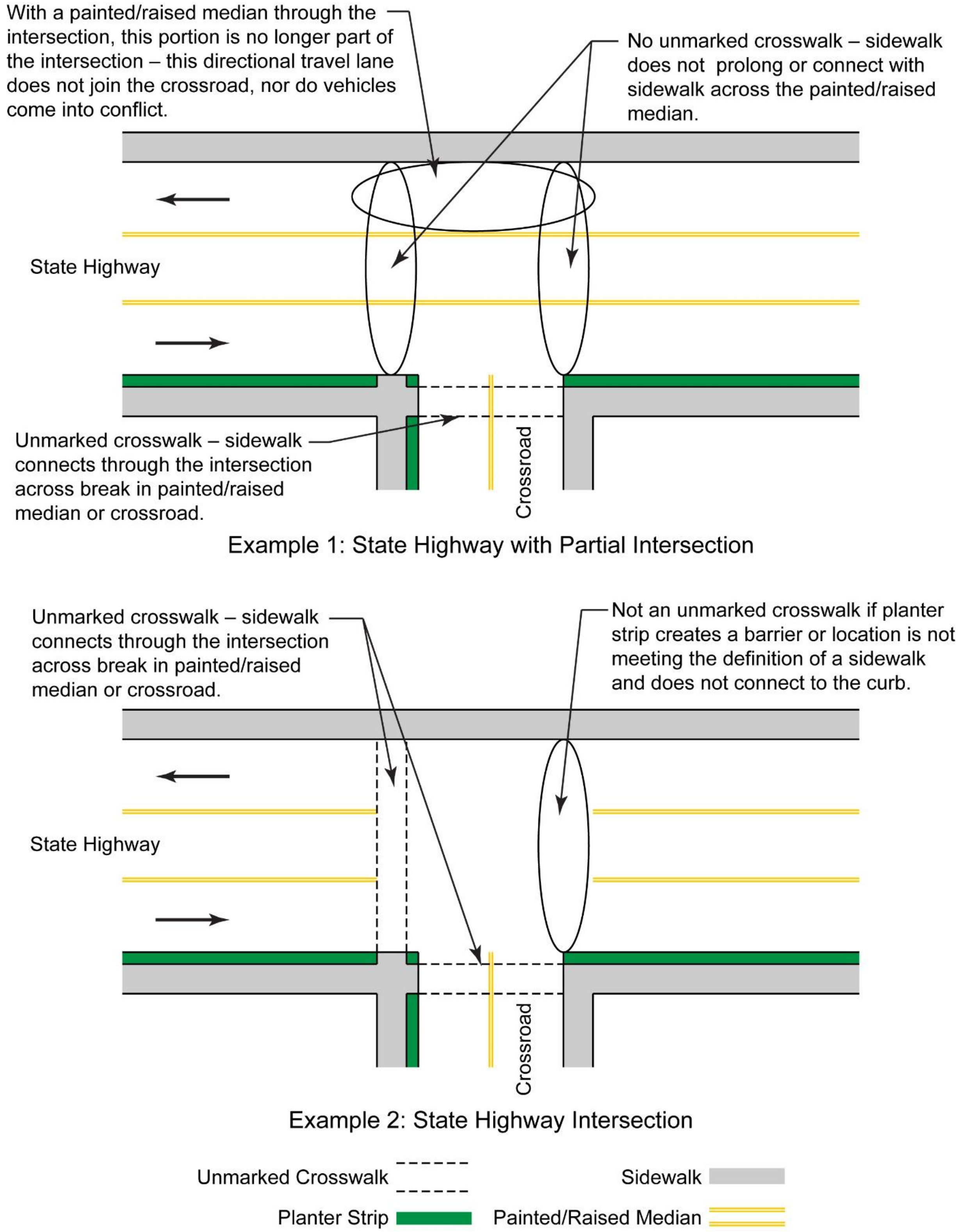
(1) Cost Control Measures. When funds are limited and costs increase, estimated project costs often exceed the amounts available in spite of the best efforts of the engineering staff. At such times the advantages of reducing initial project costs by some form of stage construction should be considered by the Project Delivery Team as an alternative to deferring the entire project. Stage construction may include one or more of the following:

(a) Shorten the proposed improvement, or divide it into segments for construction in successive years;

(b) Reduce number of lanes for initial construction. For example, a 4-lane freeway in a rural area with low current traffic volumes might be staged for two lanes initially with capacity adequate for at

Figure 105.6

Typical Pedestrian Crossings at "T" Intersections



least 10 years after construction. Similarly, a freeway might be constructed initially four or six lanes wide with provision for future widening in the median to meet future traffic needs.

(c) Down scope geometric design features. This last expedient should be considered only as a last resort; geometric features such as alignment, grade, sight distance, weaving, or merging distance, are difficult and expensive to change once constructed. All nonstandard features need to comply with Index 82.2.

A choice among cost reducing alternatives should be made only after weighing the benefits and disadvantages of each, particularly as they apply to interchange designs, which have a substantial effect on cost. See Index 502.3(2) for design considerations regarding freeway interchanges.

106.2 Utilization of Local Roads

In the construction of freeways or other highways by stages or construction units, it frequently becomes necessary to use portions of the local road system at one or more stages prior to completion of the whole route. Usually the local road is used as a traversable connection between the newly completed segment and the existing State highway.

Where such use of a local road is required, it may be handled by:

(a) Temporarily adopting the local road system as a traversable State highway, or

(b) Designating the local road system as a detour until the next or final stage is constructed.

(1) Temporary Adoption of Local Roads as State Routes. Temporary adoption of a local road system as a traversable route requires CTC action. Temporary adoption should be implemented where, for example, one unit of the freeway construction has been completed and the District wishes to route all users over the new roadway without waiting for completion of the next succeeding units, and the use of local roads is necessary to connect the freeway with the old State highway. Temporary adoption is useful where construction of the next freeway unit is a number of years in the future.

Such a temporary CTC adoption makes it legally possible to relinquish the old highway portion superseded by relocation.

Normally, the Department will finance any needed improvement required to accommodate all users during the period the local road system is a traversable State route. Financing by the local agency is not required. However, adoption of the local road by the CTC must precede State financing and construction of the proposed improvements.

When a local facility is adopted as a traversable route, the Department is responsible for all maintenance costs of the local facility unless otherwise provided for under the terms of a cooperative agreement. The Department normally would not assume maintenance until the road is in use as a connection or, when necessary, until the award of an improvement contract.

Formal concurrence of the local agency must be obtained before an adoption action is presented to the CTC.

If the local agency wants more improvements than are needed to accommodate all users during the period when the local road is used as a State highway connection, betterments are to be financed by the local agency. In such cases a cooperative agreement would be necessary to define the responsibilities of each party for construction and maintenance.

(2) Local Roads Used as Detours. In lieu of temporary adoption by the CTC, a local road may be designated a detour to serve as a connection between the end of State highway construction and the old State highway following completion of a State highway construction unit and pending completion of the next unit. Local road detours are useful if the adjoining construction unit is scheduled in a few years or less and the local road connection is short and direct. Adoption by the CTC is not required when a local road is designated as a temporary detour.

Under Section 93 of the Streets and Highways Code, the Department can finance any needed improvements required to accommodate the detour of all users during the period the local road is utilized to provide continuity for State highway users. A cooperative agreement is usually required to establish terms of financing, construction, maintenance, and liability. If the local agency wants more than the minimum work needed to accommodate users on the local road during its use as a State highway, such betterments are to be financed by the local agency.

Section 93 also makes the Department responsible for restoration of the local road or street to its former condition at the conclusion of its use as a detour. The Department is responsible for all reasonable additional maintenance costs incurred by local agencies attributable to the detour. If a betterment is requested by the local agency as a part of restoration it should be done at no cost to the Department.

Topic 107 - Roadside Installations

107.1 Roadway Connections

All connections to vista points, truck weighing or brake inspection stations, safety rest areas, park and ride lots, transit stations or any other connections used by the traveling public, should be constructed to standards commensurate with the standards established for the roadway to which they are connected. On freeways this should include standard acceleration and deceleration lanes and all other design features required by normal ramp connections (Index 504.2). On conventional highways and expressways, the standard public road connection should be the minimum connection (Index 405.7).

Only one means of exit and one means of entry to these installations should be allowed.

107.2 Maintenance and Police Facilities on Freeways

Roadside maintenance yards and police facilities other than truck weighing installations and enforcement areas are not to be provided with direct access to freeways. They should be located on or near a cross road having an interchange which provides for all turning movements. This policy applies to all freeways including Interstate Highways.

Maintenance Vehicle Pullouts (MVPs) provide parking for maintenance workers and other field personnel beyond the edge of shoulder. This improves safety for field personnel by separating them from traffic. It also frees up the shoulder for its intended use. The need and location of MVPs should be determined by the PDT during the Project Initiation Document phase. MVPs should only be provided if it has been determined that maintenance access from outside the state right of way through an access gate or a maintenance trail within the state right of way is not feasible. Where frequent activity of field personnel can be anticipated, such as at a signal control box (See Index 504.3 (2)(j)) or at an irrigation controller, the MVP should be placed upstream of the work site, so that maintenance vehicles can help shield field personnel on foot. If the controller or roadside feature is located within the clear recovery zone, relocating it outside the clear recovery zone should be considered (See Index 309.1). The shoulder adjacent to MVPs should be wide enough for a maintenance vehicle to use for acceleration before merging onto the traveled way. If adequate shoulder width is unattainable, sufficient sight distance from the MVP to upstream traffic should be provided to prevent maintenance vehicles from disrupting traffic flow. When considering drainage alongside a MVP, it is preferable to provide a flow line around the MVP rather than along the edge of shoulder to collect the drainage before the MVP. This will prevent ponding between the MVP and edge of shoulder. See Standard Plan H9 for a typical MVP layout plan and section detail.

107.3 Location of Border Inspection Stations

Other agencies require vehicles entering California to stop at buildings maintained by these agencies for inspection of vehicles and cargoes. No such building, parking area, or roadway adjacent to the parking area at these facilities should be closer than 30 feet from the nearest edge of the ultimate traveled way of the highway.

Topic 108 - Coordination With Other Agencies

108.1 Divided Nonfreeway Facilities

Per Section 144.5 of the Streets and Highways Code, advance notice is required when a conventional highway, which is not a declared freeway, is to be divided or separated into separate roadways, if such division or separation will result in preventing traffic on existing county roads or city streets from making a direct crossing of the State highway at the intersection. In this case, 30 day notice must be given to the City Council or Board of Supervisors having jurisdiction over said roads or streets.

The provisions of Section 144.5 of the Streets and Highways Code are considered as not applying to freeway construction, or to temporary barriers for the purpose of controlling traffic during a limited period of time, as when the highway is undergoing repairs, or is flooded. As to freeway construction, it is considered that the local agency receives ample notice, by virtue of the freeway agreement, of the manner in which all local roads will be affected by the freeway, and that the special notice would therefore be superfluous.

When the notice is required, a letter should be prepared and submitted to the appropriate authorities at least 60 days before road revision will occur. Prior to the submittal of the letter and before plans are completed, the appropriate authorities should be contacted and advised of contemplated plans. The timing of this notice should provide ample opportunity for consideration of any suggestions or objection made. In general, it is intended that the formal notice of intent which is required by law will confirm the final plans which have been developed after discussions with the affected authorities.

The PS&E package should document the date notice was given and the date of reply by the affected local agencies.

The Division of Design must be notified by letter as soon as possible in all cases where controversy develops over the closures to crossing traffic.

108.2 Transit Loading Facilities

(1) *Freeway Application.* These instructions are applicable to projects involving transit loading facilities on freeways as authorized in Section 148 of the Streets and Highways Code. Instructions pertaining to the provisions for mass public transportation facilities in freeway corridors, authorized in Section 150 of the Streets and Highways Code, are covered in other Departmental written directives.

(a) During the early phases of the design process, the District must send to the PUC, governing bodies of local jurisdictions, and common carriers or transit authorities operating in the vicinity, a map showing the proposed location and type of interchanges, with a request for their comments regarding transit loading facilities. The transmittal letter should state that transit loading facilities will be constructed only where they are in the public interest and where the cost is commensurate with the public benefits to be derived from their construction. It should also state that if the agency desires to have transit loading facilities included in the design of the freeway that their reply should include locations for transit stops and any supporting data, such as estimates of the number of transit passengers per day, which would help to justify their request.

(b) Public Meeting and Hearings. No public meeting or hearing is to be held when all of the contacted agencies respond that transit loading facilities are not required on the proposed freeway. The freeway should be designed without transit loading facilities in these cases.

Where any one of the agencies request transit loading facilities on the proposed freeway, the District should hold a public meeting and invite representatives of each agency.

Prior to the public meeting, the District should prepare geometric designs of the transit loading facilities for the purpose of making cost estimates and determining the feasibility of providing the facilities. Transit loading facilities must be approved by the District Director with concurrence from the Project Delivery Coordinator (see Topic 82 for approvals).

(c) Justification. General warrants for the provision of transit loading facilities in terms of cost or number of passengers have not been established. Each case should be considered individually because the number of passengers justifying a transit loading facility may vary greatly between remote rural locations and high volume urban freeways.

Transit stops adjacent to freeways introduce security and operational concerns that may necessitate relocating the stop at an off-freeway location. These concerns go beyond having a facility located next to high speed traffic, but also entail the pedestrian route to the facility through a low density area removed from the general public.

It may be preferable for patrons to board and leave the bus or transit facility at an off-freeway location rather than use stairways or ramps to freeway transit stops. Where existing highways with transit service are incorporated into the freeway right of way, it may be necessary to make provisions for bus service for those passengers who were served along the existing highway. This may be accomplished either by providing freeway bus and/or transit loading facilities or by the bus leaving and re-entering the freeway at interchanges. See "A Policy on Geometric Design of Highways and Streets", AASHTO, and “Guide for Geometric Design of Transit Facilities on Highways and Streets”, AASHTO for a discussion of transit design and bus stop guidelines.

(d) Reports. On projects where all the agencies contacted have expressed the view that transit stops are not needed, a report to the Division of Design is not required. However, a statement to the effect that the PUC, bus companies, and local governmental agencies have been contacted regarding transit stops and have made no request for their provisions should be included in the final environmental document or the PS&E submittal, whichever is appropriate.

For projects where one or more of the agencies involved have requested transit loading facilities either formally or informally during public meeting(s), a complete report should be incorporated in the final environmental document. It should include:

- A map showing the section of freeway involved and the locations at which transit loading facilities are being considered.
- A complete discussion of all public meetings held.
- Data on type of transit service provided, both at present and after completion of the freeway.
- Estimate of cost of each facility, including any additional cost such as right of way or lengthening of structures required to accommodate the facility.
- Number of transit trips or buses per day and the number of on and off passengers per day served by the transit stops and the number estimated to use the proposed facilities.
- District's recommendation as to the provision of transit loading facilities. If the recommendation is in favor of providing transit loading facilities, drawings showing location and tentative geometric designs should be included.

(e) The DES-Structure Design has primary responsibility for the structural design of transit loading facilities involving structures. See Index 210.7. See also DIB 82 for instructions on submitting rail and transit station plans to the Department of General Services – Division of the State Architect (DSA) for review and approval of pedestrian facilities with regard to accessibility features. Accessible paths of travel must be provided to all pedestrian facilities, including shelters, tables, benches, drinking fountains, telephones, vending machines, and information kiosks. The path of travel from designated accessible parking, if applicable, to accessible facilities should be as short and direct as practical, must have an even surface, and must include curb ramps, marked aisles and crosswalks, and other features as required to facilitate use of the facility by individuals using wheelchairs, walkers or other mobility aids. See the Department of General Services, Division of the State Architect, as well as the California Department of Transportation enforce the California Building Code (Title 24) for the various on-site improvements.

(f) A cooperative agreement should be used to document the understanding between the Department and any local agency which desires a transit facility. The agreement covers items such as funding, ownership, maintenance, and legal responsibility.

(g) Detailed design requirements can be obtained from the transit authority having jurisdiction over the transit facility. See Index 504.2(6) for design standards related to bus loading facilities on freeways.

(2) Conventional Highway Application. This guidance is applicable to projects involving transit loading facilities on conventional highways as authorized in Section 148 of the Streets and highways Code. Instructions pertaining to the provisions for Bus Rapid Transit (BRT) in conventional highway corridors are covered in other Departmental policy and directives.

(a) The selection of transit facilities on conventional highways should follow the general outline as noted above for transit facilities on freeways. Transit facilities shall be approved by the District Director as part of the authorizing document (PID or PR).

(b) A cooperative agreement should be used to document the understanding between the Department and any local agency which desires a transit facility. The agreement covers items such as funding, ownership, maintenance, and legal responsibility.

(c) Detailed design requirements can be obtained from the transit authority having jurisdiction over the transit facility.

(d) See also DIB 82 for instructions on submitting rail and transit station plans to the Department of General Services – Division of the State Architect (DS) for review and approval of pedestrian facilities with regard to accessibility features. Accessible paths of travel must be provided to all pedestrian facilities, including shelters, tables, benches, drinking fountains, telephones, vending machines, and information kiosks. The path of travel from designated accessible parking for persons with disabilities, if applicable, to accessible facilities should be as short and direct as practical, must have an even surface, and must include curb ramps, marked aisles, and crosswalks, and other features as required to facilitate use of the facility with wheelchairs, walkers and other mobility aides. See Topic 404 for guidance regarding the Design Vehicle, and Index 626.4(3) for structural section guidance for bus pads.

108.3 Commuter and Light Rail Facilities Within State Right of Way

(1) General. These facilities may cross or operate parallel to a highway or other multi modal facility owned and operated by the Department. The following guidance covers all rail facilities, and all transportation facilities owned and operated by the Department. See the Project Development Procedures Manual for additional information and procedures regarding encroachments within State right of way. See Index 309.1(4) for high speed rail guidance.

(2) Rail Crossings. Ideally, rail crossings of transportation facilities should be grade separated. Grade separations must not impact the ability of the Department to operate and maintain its facilities, which includes the ability to expand the existing transportation facilities in the future. All rail crossings are to be approved

by the District Director. See the California MUTCD for guidance regarding traffic controls for grade crossings.

(3) *Parallel Rail Facilities.* Rail facilities may be sited within Department right of way when feasible alternatives do not exist for separate facilities. As necessary, rail facilities may be located within the median. If rail facilities are located in the median, they must not impact the ability of the Department to reasonably operate and maintain its facilities, which includes the ability to expand the existing transportation facilities in the foreseeable future. All parallel rail facilities are to be approved by the District Director.

(4) *Design Standards*. Transit facilities are to be designed and constructed per the standards contained elsewhere in this manual and exceptions are to be documented as discussed in Chapter 80. The California Public Utilities Commission (CPUC) website also provides design standards and other requirements at https://www.cpuc.ca.gov/crossings.

(5) *Cooperative Agreements*. The design and construction of rail facilities within the Department right of way should be covered in a cooperative agreement. Subsequent maintenance and operations requirements should be addressed in a maintenance agreement or encroachment permit as necessary.

108.4 Bus Loading Facilities

(1) *General.* A bus stop is a marked location for bus loading and unloading. Bus stops may be midblock, adjacent to, but before an intersection (near side) or adjacent to but after an intersection (far side). The far side location is preferred as pedestrians may cross the intersection behind the bus, allowing the bus to re-enter the travel stream following a break in traffic caused by the signal timing.

(2) *Design Standards*. Transit facilities are to be designed and constructed per the standards contained elsewhere in this manual and exceptions are to be documented as discussed in Chapter 80.

Bus stops and busbays (see Index 303.4(3) for busbays) should have pavement structures designed in accordance with Index 626.4(3). See the "Guide for Geometric Design of Transit Facilities on Highways and Streets", AASHTO, for guidance on the selection and design of transit loading facilities.

(3) *Cooperative Agreements.* Close coordination with the transit provider(s) is required for the successful design and operation of bus stops and other transit facilities.

108.5 Bus Rapid Transit

For the purpose of design and coordination, Bus Rapid Transit (BRT) is to be considered the same as commuter and light rail facilities with regards to approvals and design guidance.

BRT often makes use of the existing infrastructure for its operation within State right of way. As a joint user of the State right of way, BRT may not eliminate pedestrian or bicycle facilities. Because of potential conflicts, BRT facilities located on conventional highways and expressways should follow, as appropriate, the guidance for traffic control in the California MUTCD for light rail facilities. Transit Cooperative Report Program (TCRP) Report Numbers 90, 117 and 118 have additional guidance on BRT planning, design, and implementation. BRT located on freeways should be designed in accordance with the HOV Guidelines.

(1) *Design Standards*. Transit facilities are to be designed and constructed per the standards contained elsewhere in this manual, and exceptions are to be documented as discussed in Chapter 80.

(2) *Cooperative Agreements*. The design and construction of BRT facilities within the Department right of way should be covered in a cooperative agreement. Subsequent maintenance and operations requirements should be addressed in a maintenance agreement or encroachment permit as necessary.

108.6 High-Occupancy Toll and Express Toll Lanes

(1) *General*. This guidance is applicable to projects involving High-Occupancy Toll (HOT) and Express Toll Lanes on freeways. These facilities are operated by a regional transportation agency or Caltrans under

statutory authority or with the approval of the California Transportation Commission. The HOV Guidelines are to be consulted when considering the design and operation of these facilities.

(2) *Design Standards*. HOT and Express Toll Lane facilities are to comply with the standards contained elsewhere in this manual. Exceptions are to be documented as discussed in Chapter 80. Therefore, caution must be exercised when using other Department publications such as the HOV Guidelines if conflicts in design standards are identified.

(3) *Cooperative Agreements*. For HOT or Express lane facilities sponsored by a regional transportation agency, a cooperative agreement is to be used to document the understanding between the Department and the regional transportation agency. The agreement must address all matters related to design, construction, maintenance, and operation of the toll facility, including, but not limited to, liability, financing, repair, rehabilitation, and reconstruction. The regional transportation agency must also enter into an agreement with the California Highway Patrol that addresses all law enforcement matters related to the toll facility.

108.7 Coordination with the FHWA

FHWA representatives should be contacted as indicated by the Joint Stewardship and Oversight Agreement.

(1) *General.* As early in the design process as possible, FHWA should be kept informed of proposed activities on Federal-aid routes. See the Appendix of the Project Development Procedures Manual for a complete list of FHWA involvement.

(2) *Approvals.* The District Directors are responsible for obtaining formal FHWA approval for the following items on Federal-aid routes, see the Project Development Procedures Manual and the FHWA Joint Stewardship Oversight Agreement for a more complete list:

(a) Route Adoption. See the Project Development Procedures Manual for a discussion of procedures to be followed to NEPA and design approvals.

(b) Changes in access control lines, changes in locations of connection points, adding connection points, or deleting connection points on the Interstate System (even when no Federal money is involved).

(c) Addition of or changes in locked gates under certain conditions See Index 701.2.

(d) Partial interchanges on the Interstate system. See Index 502.2.

(e) Design-life on Interstates System projects.

Approximately twelve months prior to PS&E submittal, a project review should be arranged by the District with the Project Delivery Coordinator and, as required, the FHWA per the Stewardship & Oversight Agreement, see Index 43.2, to discuss nonparticipating items and unusual or special design features. The importance of early contact is emphasized to avoid delays when final plans are prepared.

For additional information, see the Project Development Procedures Manual.

Topic 109 - Scenic Values in Planning and Design

109.1 Basic Precepts

For any highway, having a pleasing appearance is an important consideration. Scenic values must be considered along with safety, utility, economy, and all the other factors considered in planning and design. This is particularly true of the many portions of the State Highway System situated in areas of natural beauty. The location of the highway, its alignment and profile, the cross section design, and other features should be in harmony with the setting.

109.2 Design Speed

The design speed should be carefully chosen as it is the key element which establishes standards for the horizontal alignment and profile of the highway. These requirements in turn directly influence how well the highway blends into the landscape. Scenic values, particularly in areas of natural scenic beauty must play a part along with the other factors set forth under Index 101.1 in selecting a design speed.

109.3 Aesthetic Factors

Throughout planning and design consider the following:

(a) The location of the highway should be such that the new construction will preserve the natural environment and will lead to and unfold scenic positions. In some cases, additional minor grading not required for roadbed alignment may expose an attractive view or hide an unsightly one.

(b) The general alignment and profile of the highway should fit the character of the area traversed so that unsightly scars of excavation and embankment will be held to a minimum. Curvilinear horizontal alignment should be coordinated with vertical curvature to achieve a pleasing appearance.

(c) Existing vegetation (e.g., trees, specimen plants, diminishing native species or historical plantings) should be preserved and protected to the maximum extent feasible during the planning, design, and construction of transportation projects. Whenever specimen or mature trees are present, a tree survey should be made to provide accurate data on the variety, condition, location, size, and ground elevations of trees affected.

(d) Appropriate replacement planting should be provided when existing planting is removed. When native or specimen trees are removed, replacement planting should reflect the visual importance of the plantings lost.

Provisions for watering and establishment of replacement planting should also be considered. Consult with the District Landscape Architect early in the planning and design process to ensure appropriate conservation and revegetation measures are incorporated.

(e) Existing vegetation such as trees or large brush may be selectively thinned or removed to open up scenic vistas or provide a natural looking boundary between forest and cleared areas. Vegetation removal for aesthetic purposes should be undertaken only with the concurrence of the District Landscape Architect.

(f) Vista points should be provided when views and scenery of outstanding merit occur and feasible sites can be found. (See Topic 914 for site selection criteria.)

(g) Whenever feasible, wide medians and independent roadways should be provided on multilane facilities as these features add scenic interest and relieve the monotony of parallel roadways.

(h) Bridges, tunnels, and walls merit consideration in lieu of prominent excavation and embankment slopes when costs of such alternates are not excessive.

(i) Slopes should be flattened and rounded whenever practical and vegetation provided so that lines of construction are softened.

(j) Structures should be located and designed to give the most pleasing appearance.

(k) Scars from material sites should be avoided. Planting compatible with the surroundings should be undertaken to revegetate such scars when they are unavoidable.

(l) Drainage appurtenances should be so located that erosion, sumps, and debris collection areas are hidden from view or eliminated when site conditions permit.

(m) Interchange areas should be graded as flat as reasonable with slope rounding and contouring to provide graceful, natural looking appearance. The appearance can be further enhanced by planting a vegetative cover appropriate to the locality, being careful to maintain driver visibility.

(n) In locations where graffiti has been excessive, concepts such as limiting accessibility, planting, and surface treatments should be considered to deter graffiti.

(o) Roadsides should be designed to deter weed growth along the traveled way, and to provide for mechanical litter collection.

Topic 110 - Special Considerations

110.1 Design for Overloaded Material Hauling Equipment

Sometimes bid costs can be reduced by allowing the hauling of overloads on a construction contract. The savings may warrant designing structures and structural sections of new roadways to carry the heavier loads and also reconstructing roadbeds used by overloaded material hauling equipment.

In general, hauling of overloads is restricted to the project limits. However, overloads are permitted on portions of existing highways which are to be abandoned, repaired or reconstructed with a new structural section, if the overloads do not affect the design of the reconstructed structural section.

Any overload requirements should be determined before detailed plans are prepared. The District should request from the Division of Engineering Services – Structures Design (DES - SD) the estimated additional cost of the structures to carry overloads and use this information in making economic comparisons.

Factors to be considered in making the comparisons should include the costs of strengthening structures, haul costs, amount of material to be hauled, repair or reconstruction of structural sections, construction of separate haul roads or structures, strengthening of the new structural section, sequence of construction operations, and other pertinent factors. In some cases, consideration should be given for requiring the contractor to construct a separate haul structure over a heavily traveled surface street when large quantities of material are involved.

The comparison and all factors leading to the decision should be complete, fully documented, and retained in the project files.

The design of structures for overloads will normally be governed by one of the following categories:

(1) *Category 1.* Structures definitely planned to carry overloads. This category should be used only when the structures are to be constructed under a separate contract prior to a grading contract and the estimated savings in grading costs exceed the extra structure costs. The District must request the DES - SD to design for the permissible overloading.

(2) *Category 2.* Structures which are designed to allow the contractor the option of strengthening to carry overloads. The contract plans will include alternative details for strengthening the structure and the contractor can decide at the time of bidding whether to haul around the structure, build his own haul road structures, use "legal load" equipment on the unstrengthened structure, or construct the structure in accordance with the strengthened alternative design. The District should notify the DOS regarding structures to have optional designs. Undercrossings, overheads, separations, and stream crossings are most likely to be in this category.

(3) *Category 3.* Structures which will not be designed to carry overloads. Most overcrossing, ramp, and frontage road structures are in this category.

The District should consult with the DOS early in the design phase when determining the design overload category of each bridge in the project. Each case where hauling of overloads is permitted must be specifically described in the Special Provisions. Each structure designed under Categories 1 and 2 must also be designated in the Special Provisions. The design load must not exceed the weight limitation of Section 7-1.02, "Weight Limitations", of the Standard Specifications. The District Director or designated representative must approve the overload category for each structure.

110.2 Control of Water Pollution

Water pollution related to the construction of highways and to the drainage of completed highways should be limited to the maximum extent practicable. This objective should be considered from the early planning, through the detailed design phase, to the end of construction of each project.

Proposed alterations of existing drainage patterns and creation of disturbed soil areas should consider the potential for erosion and siltation. Where interdisciplinary analysis (engineering, biology, geology, chemical) indicates that harmful physical, chemical, or biological pollution of streams, rivers, lakes, reservoirs, coastal waters, or groundwater may occur, preventive measures and practices will be required. These measures include temporary erosion control features during construction, scheduling of work, as well as the permanent facilities to be built under the contract. The control of erosion associated with permanent drainage channels and ditches is covered in Chapter 860, Open Channels. Permanent vegetation erosion control is covered in Topic 906.

The Department's Project Planning and Design Guide identifies the procedures and practices to be employed in order for projects to comply with the Storm Water Management Plan and the National Pollutant Discharge Elimination System Permit, issued by the State Water Resources Control Board.

Districts must initiate contact with the appropriate agencies responsible for water quality as early as feasible in development of transportation projects to ensure full identification of pollution problems, and to ensure full cooperation, understanding, and agreement between the Department and the other agencies. The agencies to be contacted will vary from project to project depending on the nature of the project, the aquatic resources present, and the uses of the water. The agencies that may be interested in a project include but are not limited to the following: U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, California Regional Water Quality Control Boards, California Department of Fish and Game, Flood Control Districts, and local water districts. The District Environmental Unit can provide assistance in determining which agencies should be contacted.

Recommendations for mitigation measures or construction and operational controls contained in the project's Storm Water Data Report should receive full consideration in the development of the project. The Department is legally bound to comply with the appropriate permits as outlined in the California Permit Handbook. The Department is also legally bound to comply with any water quality mitigation measures specified in the project's environmental document. Plans and specifications should reflect water quality protection measures in a manner that is enforceable in contracts.

On almost all projects, early contact should be established between the District project development personnel, Landscape Architecture, biologists, geologists, and other specialists available in the Headquarters Environmental Program, the Division of Engineering Services (DES) Office of Structural Foundations, FHWA, or other Districts, to ensure optimum development of water quality control measures.

Because siltation resulting from erosion is recognized as a major factor in water pollution, continuous efforts should be made to improve erosion control practices.

(1) *Project Planning Phase.* When project planning studies are started, consideration should be given to the items in the following list:

   (a) Identify all waters in the vicinity of a highway project which might affect construction, maintenance and operational activities.

   The environmental factors that might affect preconstruction activities should be looked into for the benefit of the resident engineer and contractor. An example would be relocation of drilling of pile foundations in a sensitive stream to prevent possible impacts.

   (b) Identify for each project all waters, both fresh and saline, surface and underground, where water quality may be affected by the proposed construction.

   (c) Determine if any watersheds, aquifers, wells, reservoirs, lakes, or streams are sources for domestic water supplies.

   (d) Determine if any sensitive fishery, wildlife, recreational, agricultural, or industrial aquatic resources are located in the vicinity of the project.

   (e) Consider possible relocation or realignment that could be made to avoid or minimize the possibility of pollution of existing waters.

   (f) Identify variations in the erosive characteristics of the soils in the area, and consider relocation or grade changes that would minimize erosion.

   (g) Where possible, avoid unstable areas where construction may cause future landslides.

   (h) Identify construction season preference of regulatory agencies.

   (i) Evaluate the need for additional right of way to allow for flatter, less erosive slopes.

(2) *Design Phase.* During the design phase, the items listed above should again be considered. More specific items for consideration are presented in the following checklist:

(a) Provide for the preservation of roadside or median vegetation beyond the limits of construction by special provisions and depiction on the plans. See Index 904.2(1).

(b) Design slopes as flat as is reasonable with slope rounding, landforming/geomorphic grading, contouring, or stepping to minimize erosion and to promote plant growth. Consider retaining walls when practical to reduce slope length and steepness. Remove or excavate, stockpile, and apply topsoil and/or duff on the final slope to improve soil health for plant growth. Contact the District Landscape Architect for more information. See Index 904.2(2) for soil health information.

(c) Provide erosion control to all soil areas to be disturbed by construction activities. Consider the need to require the contractor to apply permanent erosion control in phases, as slopes become substantially complete, instead of allowing all erosion control to be applied at the end of the construction project. Prior to winterizing the project, the designer must plan for temporary erosion control on slopes not substantially complete. Refer to Topic 906 for information on Vegetated Erosion Control.

If a highway planting project is anticipated immediately following roadway construction, disturbed soil areas can-not be left unprotected. The use of mulch could be considered as an erosion control method during the interim. Contact the District Landscape Architect for assistance.

(d) When planning for temporary erosion control, consider the use of vegetation, mulches, fiber mats, fiber rolls, netting, dust palliatives, crust forming chemicals, silt fences, or another procedure that may be necessary to prevent erosion. The District Storm Water Coordinator, District Landscape Architect, and the District Storm Water Unit can assist in the selection and design of temporary erosion control measures.

(e) Design overside drains, surface, subsurface, and cross drains so that they will discharge in locations and in such a manner that surface and subsurface water quality will not be affected. The outlets may require aprons, bank protection, desilting basins, or energy dissipaters.

(f) Provide for adequate fish passage through highway culverts or under bridges when necessary to protect or enhance fishery resources.

(g) Provide bank protection where the highway is adjacent to rivers, streams, lakes, or other bodies of water.

(h) Where required, provide slope protection or channel lining, energy dissipaters, etc. for channel changes.

(i) Where the State has made arrangements for materials, borrow, or disposal sites, grading plans should be provided and revegetation required. Special provisions should require the contractor to furnish plans for grading and replanting of sites.

(j) Check right of way widths for adequate space to reduce slope gradients and minimize slope angles, for rounding at tops of cuts and bottoms of fills, for adequate slope protection ditches and for incorporation of treatment control measures (e.g., infiltration basins, detention basins, traction sand traps). Also consider right of way or encroachment rights for temporary work such as desilting basins, stream diversion, or stream crossing protection.

(k) All ditches should be designed to minimize erosion. These treatments include but are not limited to grass lining, fiber mats, rock lining (with or without geotextile underlayment), and paving. The District Hydraulics Unit can assist with the selection and design of ditch treatment. Consideration should be given to using soil stabilization materials in median ditches or other wide drainage areas that cannot be vegetated.

(l) Temporary construction features for water pollution control that can be predicted should be made a part of the plans, specifications, and contract pay items. Such items as mulching and seeding of slopes, berms, dikes, ditches, pipes, dams, silt fences, settling basins, stream diversion channels, slope drains, and crossings over live streams should be considered. Since all contingencies probably cannot be foreseen, supplemental work funds should be set up for each project. Pay items for temporary erosion control should not be adjusted for increased or decreased quantity.

(m) Special consideration should be given to using vegetated ditches to remove highway runoff pollutants. The District Hydraulics and Landscape Architecture Units can provide assistance in designing and constructing vegetated ditches.

(n) Mandatory order of work clauses sometimes result in increased costs or longer time limits, but they must be considered where their use would eliminate the expense of temporary construction or where they result in earlier protection of erodible areas, or improved handling of site runoff.

(3) Abandonment and Destruction of Water Wells. The abandonment and destruction of water wells within the highway right of way must be handled in accordance with requirements established by statute and by agreement with the Department of Water Resources (DWR) to avoid pollution of underground water and ensure public safety. Sections 13700 to 13806 of the California Water Code deal, in general, with the construction and destruction of wells. Section 24400 to 24404 of the Health and Safety Code require that abandoned wells be covered, filled, or fenced for safety reasons. Statewide standards for construction, maintenance and destruction of water wells, monitoring wells and cathodic protection wells have been issued by the California DWR in Bulletin 74 - 81, "Water Well Standards: State of California", dated December, 1981, and Bulletin 74 - 81", dated January, 1990. Pursuant to these standards and interagency agreement with DWR, the following procedures are to be followed to determine requirements for abandonment and destruction of wells within State highway rights of way.

(a) Before producing water wells within the highway right of way are abandoned, a determination should be made of the possible future uses of the wells. Such future uses include landscape irrigation, safety roadside rest areas, vista points, maintenance facilities, truck weighing facilities, and others.

(b) The District Project Development and Right of Way Branches determine the location of water wells that will be affected by highway construction on a project basis.

(c) The District submits a letter to the Director, Department of Water Resources, 1416 Ninth Street, Sacramento, CA. 95814 Attention: Water Resources Evaluation Section, Division of Resources Development, listing the wells to be abandoned and any information that may be known about them. The letter should include the scheduled PS&E date and the anticipated advertising date for the project. Two copies of a map, or maps, showing the location of each well accurately enough so it can be located in the field should be included with the letter. A copy of this package should also be provided to Headquarters Construction.

(d) DWR will investigate the wells and write a report recommending procedures to be used in destruction of the wells within the highway right of way. The interagency agreement provides for reimbursement of the DWR's cost for these investigations and reports.

(e) DWR will forward its report to the District.

(f) Provisions for destruction of abandoned wells occasioned by highway construction and planting projects must be included in the District PS&E report. The work, usually done by filling and sealing, normally should be included in the contract Special Provisions. Steps must be taken to insure that wells are left in a safe condition between the time the site is acquired by the State and the time the well is sealed.

(g) In some cases, local ordinances or conditions will require the filling and sealing of the well prior to the highway contract in order to leave the well in a safe condition.

(h) The contractor who does the work to abandon the well must file the Notice of Intent (Form DWR 2125) and the Water Well Drillers Report (Form DWR 188) required by the Department of Water Resources.

(i) Also, under California Water Code Section 13801, after January 15, 1990, all cities and counties are required to have adopted ordinances that require prior acquisition of permits for all well construction, reconstruction and destruction and requiring possession of an active C-57 contractor's license as the minimum qualification for persons permitted to work on wells.

(4) Summary. To prevent pollution of all waters that could be affected by a highway construction project, it is desirable to avoid involvement with the water or avoid the construction of erodible features. Since it is seldom possible to avoid all such features, the design of effective erosion and sediment control measures should be included with the project. Material resulting from erosion should either be discharged in locations where no negative environmental impacts will occur, or be deposited in locations that are accessible to maintenance forces for removal. District Landscape Architecture can provide technical assistance in assessing the impacts of erosion and in designing erosion control features.

Project Development personnel should ensure that all aspects of erosion control and other water quality control features considered during design are fully explained to the Resident Engineer. Such data is essential for review of the contractor's water pollution control program. Judgment must be used in differentiating between planned temporary protection features and work which the contractor must perform in order to fulfill their responsibility to protect the work from damage.

To reduce contract change orders and ensure erosion control goals are met, important protection should not be left to the contractor's judgment. It is desirable that all predictable temporary protection measures be incorporated in the plans and specifications and items for payment included in the contract items of work.

Topsoil should be stripped, stockpiled, and restored to disturbed slopes because existing soil nutrients and native seeds contained within the topsoil are beneficial for establishing vegetative cover and controlling erosion.

In addition, the abandonment of water wells must be given special attention in accordance with Section (3) above.

110.3 Control of Air Pollution

Air pollution associated with the construction of highways and to completed highway facilities should be held to the practical minimum. The designer should consider the impacts of haul roads, disposal sites, borrow sites, and other material sources in addition to construction within the highway right of way.

(1) Control of Dust. Many of the items listed under Index 110.2, Control of Water Pollution, are applicable to dust control. Consideration should be given to these items and additional material presented in the following list:

(a) See Index 110.2(2)(a), (c), (d), (k) and (n).

(b) Flat areas not normally susceptible to erosion by water may require erosion control methods such as planting, stabilizing emulsion, protective blankets, etc., to prevent wind erosion.

(c) Cut and or fill slopes can be sources of substantial wind erosion. They will require planting or other control measures even if water erosion is only a minor consideration.

(d) In areas subject to dust or sand storms, vegetative wind breaks should be considered to control dust. Use of soil sealant may also be considered.

(e) Special provisions should be used requiring the contractor to restore material, borrow, or disposal sites, and temporary haul roads to a condition such that their potential as sources of blowing dust or other pollution is no greater than in their original condition. Work for this purpose that can be predicted should be made a part of the PS&E, which should require submission of the contractors plan for grading, seeding, mulching or other appropriate action.

(f) Stockpiling and respreading topsoil may speed revegetation of the roadside and reduce wind erosion. Refer to Index 904.2(2)(a).

(2) *Control of Burning.* Health and Safety Code provisions and rules issued by Air Pollution Control Boards will preclude burning on most highway projects. Off-site disposal of debris must not create contamination problems and should not be specified simply as an expedient resolution of the problem without imposing adequate controls on how such disposal site is to be handled. Designers should seek disposal site locations within the right of way where it will be permissible to dispose of debris. Proper procedures, including compaction and burial, should be specified. Debris should not be disposed of within the normal roadway. Burying within the right of way should be done in such a fashion that the layers of debris will not act as a permeable layer or otherwise be detrimental to the roadway. Acceptable alternates based on economic, aesthetic, safety, and other pertinent considerations should be included in the contract if possible.

On projects where burning will not be permitted and disposal of debris within the right of way is not possible, optional disposal sites should be made available. Information on such site arrangements should be made available in the "Materials Information" furnished to prospective bidders. Reference is made to the applicable portion of Index 111.3 and 111.4 for handling this requirement. Special requirements for disposal of debris and final appearance of the disposal site should be covered in the Special Provisions. The intent of this instruction is that the designer should make sure that prospective bidders have adequate information on which to make a realistic bid on clearing and grubbing.

When feasible, tree trunks, branches, and brush should be reduced to chips and incorporated with the soil, spread on fill slopes, used as a cover mulch or disposed of in other ways compatible with the location. In forest areas where they will not look out of place, limbs and trunks of trees that are too large for chipping may be limbed and cut to straight lengths and the pieces lined up at the toes of the slope. An earth cover may be necessary for aesthetic reasons, or to reduce fire hazards. Under certain conditions salvage of merchantable timber may be desirable, or may be required by right of way commitments. Whenever merchantable timber is to be salvaged, appropriate specifications should be provided. Stumps and unsightly clumps of debris should be chipped or buried in areas where they will not create future problems.

Care should be taken not to block drainage or to interfere with maintenance operations.

Before proposing chipping as the method of disposal, the designer should investigate to determine if plant disease or insect pests will be spread to disease-free or insect-free areas. Procedures to decontaminate such chips before use should be included in the contract if necessary. Designers should seek advice from local experts and County Agricultural Extension Offices to determine the extent of such problems and the procedures and chemicals to be specified.

The U.S. Forest Service and the State Division of Forestry should be contacted during the design stage to ascertain the requirements that these agencies will make upon any disposal methods to be used in areas under their control.

It will be noted that under certain limited conditions the prohibition against burning may be eliminated from the Special Provisions.

There will be some areas of the State where Air Pollution Control Boards may consider issuing a permit for open burning where the effect on air quality is expected to be negligible and few if any residents would be affected. The individual situation should be studied and appropriate special provisions prepared for each project to fully cover all possible methods of disposal of debris that will be available to the contractor.

The local Air Pollution Control Board should be contacted to determine the current regulations.

(3) *Summary.* Special consideration should be given to the direction of prevailing winds or high-velocity winds in relation to possible sources of dust and downwind residential, business, or recreational areas. Every practical means should be incorporated in the design of the highway and in the provisions of the contract to prevent air pollution resulting from highway construction and operation.

110.4 Wetlands Protection

The Nation's wetlands are recognized on both the Federal and State level as a valuable resource. As such, there have been several legislative and administrative actions which provide for special consideration for the preservation of wetlands. These are embodied on the Federal level in Executive Order 11990, DOT Order 5660.1A, Section 404 of the Clean Water Act, including Section 404(b)(1) guidelines, and the NEPA 404 Integration Process for Surface Transportation Projects, and the August 24, 1993 Federal Wetlands Policy. Wetlands are covered on the State level by the Porter-Cologne Water Quality Act and the Resources Agency's Wetlands Policy. The District Environmental Unit can provide assistance with permitting strategies, identifying wetlands, determining project impacts, and recommending mitigation measures, in coordination with the District Landscape Architect.

110.5 Control of Noxious Weeds - Exotic and Invasive Species

Highway corridors provide the opportunity for the transportation of exotic and invasive weed species through the landscape. Species that have the ability to harm the environment, human health or the economy are of particular concern. In response to the impact of exotic and invasive species, Executive Orders 11987, 13112, and 13751 direct Federal Agencies to expand and coordinate efforts to combat the introduction and spread of non-native plants and animals. Grading, excavation, and fill operations during construction may introduce invasive species or promote their spreading. Because of this, the FHWA implemented guidance for State Departments of Transportation for preventing the introduction and controlling the spread of invasive plant species on highway rights of way on transportation improvement projects. District Environmental Unit and Landscape Architecture can provide assistance in identifying invasive or exotic species which should be controlled, and in recommending mitigation or control methods to be included in appropriate highway improvement projects.

110.6 Earthquake Consideration

Earthquakes are naturally occurring events that have a high potential to cause damage and destruction. While it is not possible to completely assure earthquake proof facilities, every attempt should be made to limit potential damage and prevent collapse.

There are certain measures that should be considered when a project is to be constructed in or near a known zone of active faulting.

Early in the route location process, active and inactive faults should be mapped by engineering geologists. A general assessment of the seismic risk of various areas within the study zone should then be prepared. The DOS and Office of Structural Foundations are available to assist in the assessment of seismic risk.

Strong consideration must be given to the location of major interchanges. They must be sited outside of heavily faulted areas unless there are exceptional circumstances that make it impractical to do so. Where close seismic activity is highly probable, consideration should be given to avoiding complex multilevel interchanges in favor of simple designs with low skew, short span structures close to the original ground, and maximum use of embankment. Single span bridges which are designed to tolerate large movements are desirable.

Early recognition of seismic risk may lead the designer to modify alignment or grade in order to minimize high cuts, fills, and bridge structures in the area. Slopes should be made as flat as possible both for embankment stability and to reduce slide potential in cuts. Buttress fills can be constructed to improve cut stability. The DOS and the Office of Structural Foundations, should be consulted early when considering various alternatives to obtain recommendations for mitigating earthquake damage.

When subjected to an earthquake, fills may crack, slump, and settle. In areas of high water table, liquefaction may cause large settlement and shifting of the roadway. It is not economically feasible to entirely prevent this damage. One possible mitigation for existing soils would be to have the contract Special Provisions provide for removal of loose and compressible material from fill foundation areas, particularly in canyons, side hill fills, and ravines and for foundation preparation on existing hillsides at the transition between cut and fill.

No modification is necessary in the design of the pavement structural sections for the purpose of reducing damage due to future earthquakes. Normally it is not possible to reduce this damage, since the structural section cannot be insulated from movements of the ground on which it rests. In active fault areas, consideration should be given to the use of flexible pipes or pipes with flexible couplings for cross drains, roadway drainage and conduits.

Additional expenditure for right of way and construction to make highways and freeways more earthquake resistant in a known active fault area should be kept in balance with the amount of impact on the traveling public if the facility may be put out of service following a disastrous earthquake. Loss of a major interchange, however, may have a tremendous influence on traffic flow and because of the secondary life-safety and economic impacts some additional expenditure may be justified.

110.7 Traffic Control Plans

This section focuses mainly on providing for vehicular traffic through the work zone; however, providing for bicyclists, pedestrians, and transit through the work zone is also necessary when they are not prohibited.

A detailed plan for moving all users of the facility through or around a construction zone must be developed and included in the PS&E for all projects to assure that adequate consideration is given to the safety and convenience of motorists, transit, bicyclists, pedestrians, and workers during construction. Design plans and specifications must be carefully analyzed in conjunction with Traffic, Construction, and Structure personnel (where applicable) to determine in detail the measures required to warn and guide motorists, transit, bicyclists, and pedestrians through the project during the various stages of work. Starting early in the design phase, the project engineer should give continuing attention to this subject, including consideration of the availability of appropriate access to the work site, in order that efficient rates of production can be maintained. In addition to reducing the time the public is exposed to construction operations, the latter effort will help to hold costs to a minimum.

The traffic control plans should be consistent with the California MUTCD, and the philosophies and requirements contained in standard traffic control system plans developed by the Headquarters Division of Traffic Operations for use on State highways and should cover, as appropriate, such items as:

- Signing.
- Flagging.
- Geometrics of detours.
- Methods and devices for delineation and channelization.
- Application and removal of pavement markings.
- Placement and design of barriers and barricades.
- Separation of opposing vehicular traffic streams (See 23 CFR 630J).
- Maximum lengths of lane closures.
- Speed limits and enforcement.
- Use of COZEEP (see Construction Manual Section 2-215).
- Use of pilot cars.
- Construction scheduling.
- Staging and sequencing.
- Length of project under construction at any one time.

- Methods of minimizing construction time without compromising safety.
- Hours of work.
- Storage of equipment and materials.
- Removal of construction debris.
- Treatment of pavement edges.
- Roadway lighting.
- Movement of construction equipment.
- Access for emergency vehicles.
- Clear roadside recovery area.
- Provision for disabled vehicles.
- Surveillance and inspection.
- Needed modifications of above items for inclement weather or darkness.
- Evaluate and provide for as appropriate the needs of bicyclists and pedestrians (including ADA requirements; see Index 105.4).
- Provisions to accommodate continued transit service.
- Consideration of complete facility closure during construction.
- Consideration of ingress/egress requirements for construction vehicles.
- Any other matters appropriate to the safety objective.

Normally, not all the above items will be pertinent to any one traffic control plan. Depending on the complexity of the project and the volume of traffic affected, the data to be included in the traffic control plan can vary from a simple graphic alignment of the various sequences to the inclusion of complete construction details in the plans and special provisions. In any event, the plans should clearly depict the exact sequence of operation, the construction details to be performed, and the traveled way to be used by all modes of traffic during each construction phase. Sufficient alignment data, profiles, plan dimensions, and typical sections should be shown to ensure that the contractor and resident engineer will have no difficulty in providing traffic-handling facilities.

In some cases, where the project includes permanent lighting, it may be helpful to install the lights as an early order of work, so they can function during construction. In other cases, temporary installations of high-level area lighting may be justified.

Temporary roadways with alignment and surfacing consistent with the standards of the road which has just been traveled by the motorist should be provided if physically and economically possible.

Based on assessments of safety benefits, relative risks and cost-effectiveness, consideration should be given to the possibility of including a bid item for continuous traffic surveillance and control during particular periods, such as:

(a) When construction operations are not in progress.

(b) When lane closures longer than a specified length are delineated by cones or other such nonpermanent devices, whether or not construction operations are in progress.

(c) Under other conditions where the risk and consequences of traffic control device failure are deemed sufficient.

Potentially hazardous working conditions must be recognized and full consideration given to the safety of workers as well as the general public during construction. This requirement includes the provision of adequate clearance between public traffic and work areas, work periods, and lane closures based on careful consideration of anticipated vehicle traffic volumes, and minimum exposure time of workers through simplified design and methods.

If a Transportation Management Plan (TMP) is included in the project, the traffic control plans (TCP) may need to be coordinated with the public information campaign and the transportation demand management elements. Any changes in TMP or TCP must be made in harmony for the plans to succeed. The "TMP Guidelines", available from the Headquarters Division of Traffic Operations should be reviewed for further guidance.

Traffic control plans along with other features of the design should be reviewed by the District Safety Review Committee prior to PS&E as discussed in Index 110.8.

The cost of implementing traffic control plans must be included in the project cost estimate, either as one or more separate pay items or as extra work to be paid by force account.

It is recognized that in many cases provisions for traffic control will be dependent on the way the contractor chooses to execute the project, and that the designer may have to make some assumptions as to the staging or sequence of the contractor's operations in order to develop definite temporary traffic control plans. However, safety of the public and the workers as well as public convenience demand that designers give careful consideration to the plans for handling all traffic even though a different plan may be followed ultimately. It is simpler from a contract administration standpoint to change a plan than to add one where none existed. The special provisions should specify that the contractor may develop alternate traffic control plans if they are as sound or better than those provided in the contract PS&E.

See Section 2-30, Traffic, of the Construction Manual for additional factors to be considered in the preparation of traffic control plans.

110.8 Safety Reviews

Formal safety reviews during planning, design and construction have demonstrated that safety-oriented critiques of project plans help to ensure the application of safety standards. An independent team not involved in the design details of the project is generally able to conduct reviews from a fresh perspective. In many cases, this process leads to highly cost-effective modifications that enhance safety for motorists, bicyclists, pedestrians, and highway workers without any material changes in the scope of the project.

(1) *Policy.* During the planning stage all projects must be reviewed by the District Safety Review Committee prior to approval of the appropriate project initiation document (PID).

During design, each major project with an estimated cost over the Minor A limit must be reviewed by the District Safety Review Committee.

Any project, regardless of cost, requiring a Traffic Control Plan must be reviewed by the District Safety Review Committee. During construction, the detection of the need for safety-related changes is the responsibility of construction personnel, as outlined in the Construction Manual.

Safety concepts that are identified during these safety reviews which directly limit the exposure of employees to vehicular and bicycle traffic shall be incorporated into the project unless deletion is approved by the District Director.

(2) *Procedure.* Each District must have a Safety Review Committee, composed of at least one engineer from the Construction, Design, Maintenance, and Traffic functions and should designate one of the members as chairperson. Committee members should familiarize themselves with current standards and instructions on highway safety so that they can identify items in need of correction.

The Committee should conduct at least two design safety reviews of each major project. The Design Project Engineer has the basic responsibility to notify the committee chairperson when a review is needed. The chairperson should schedule a review and coordinate participation by appropriate committee members.

Reviews, evaluating safety from the perspectives of the motorists, bicyclists, and pedestrians, should include qualitative and/or quantitative safety considerations of such items as:

- Exposure of employees to vehicular and bicycle traffic.
- Traffic control plans.
- Transportation Management Plans.
- Traversability of roadsides.
- Elimination or other appropriate treatment of fixed objects.
- Susceptibility to wrong-way moves.
- Safety of construction and maintenance personnel.
- Sight distance.
- ADA design.

- Guardrail.
- Run off road concerns.
- Superelevation, etc.
- Roadside management and maintenance reduction.
- Access to facilities from off of the freeway.
- Maintenance vehicle pull-out locations.

The objective is to identify all elements where safety improvement may be practical and indicate desirable corrective measures. Reviews should be scheduled when the report or plans are far enough along for a review to be fruitful, but early enough to avoid unnecessary delay in the approval of the report or the completion of PS&E.

A simple report should be prepared on the recommendations made by the Safety Committee and the response by the Design Project Engineer. The reports should be included in the project files.

110.9 Value Analysis

The use of Value Analysis techniques should begin early in the project development process and be applied at various milestones throughout the PS&E stage to reduce life-cycle costs. See the Project Development Procedures Manual for additional information.

110.10 Proprietary Items

The use of proprietary items is discouraged in the interest of promoting competitive bidding. If it is determined that a proprietary item is needed and beneficial to the State, their use must be approved by the District Director or by the Deputy District Director of Design (if such approval authority has been specifically delegated by the District Director). The Division Chief of Engineering Services must approve the use of proprietary items on structures and other design elements under their jurisdiction. The Department's guidelines on how to include proprietary items in contract plans are covered in the Office Engineer's Ready to List and Construction Contract Award Guide (RTL Guide) under "Proprietary Products."

On projects that utilize federal funds, the use of proprietary items requires an additional approval through a Public Interest Finding (PIF). A PIF is approved by the Federal Highway Administration (FHWA) Division Office for "High Profile Projects" or by the Division of Budgets, California Federal Resources Engineer for Delegated Projects, in accordance with the Stewardship Agreement. Additional information on the PIF process can be found through the Division of Budgets, Office of Federal Resources.

The use of proprietary materials, methods, or products will not be approved unless:

(a) There is no other known material of equal or better quality that will perform the same function, or

(b) There are overwhelming reasons for using the material or product in the public's interest, which may or may not include cost savings, or

(c) It is essential for synchronization with existing highway or adjoining facilities, or

(d) Such use is on an experimental basis, with a clearly written plan for "follow-up and evaluation."

If the proprietary item is to be used experimentally and there is Federal participation, the request for FHWA approval must be submitted to the Chief, Office of Landscape Architecture Standards and Procedures in the Division of Design. The request must include a Construction Evaluated Work Plan (CEWP), which indicates specific functional managers, and units, which have been assigned responsibility for objective follow-up, evaluation, and documentation of the effectiveness of the proprietary item.

110.11 Conservation of Materials and Energy

Paving materials such as cement, asphalt, and rock products are becoming more scarce and expensive, and the production processes for these materials consume considerable energy. Increasing evidence of the limitation of nonrenewable resources and increasing worldwide consumption of most of these resources require optimal utilization and careful consideration of alternates such as the substitution of more plentiful or renewable resources and the recycling of existing materials.

(1) *Rigid Pavement.* The crushing and reuse of old rigid pavement as aggregate in new rigid or flexible pavement does not now appear to be a cost-effective alternate, primarily because of the availability of good mineral aggregate in most areas of California. However, if this is a feasible option, because of unique project conditions or the potential lack of readily available materials, it may be included in a cost comparison of alternate solutions.

(2) *Flexible Pavement.* Recycling of existing flexible pavement must be considered, in all cases, as an alternative to placing 100 percent new flexible pavement.

(3) *Use of Flexible Pavement Grindings, Chunks and Pieces.* When constructing transportation facilities, the Department frequently uses asphalt in mixed or combined materials such as flexible pavement. The Department also uses recycled flexible grindings and chunks. There is a potential for these materials to reach the waters of the State through erosion or inappropriate placement during construction. Section 5650 of the Fish and Game Code states that it is unlawful to deposit asphalt, other petroleum products, or any material deleterious to fish, plant life, or bird life where they can pass into the waters of the State. In addition, Section 1601 of the Fish and Game Code requires notification to the California Department of Fish and Game (DFG) prior to construction of a project that will result in the disposal or deposition of debris, waste, or other material containing crumbled, flaked, or ground pavement where it can pass into any river, stream, or lake designated by the DFG.

The first step is to determine whether there are waters of the State in proximity to the project that could be affected by the reuse of flexible pavement. Waters of the State include: (1) perennial rivers, streams, or lakes that flow or contain water continuously for all or most of the year; or (2) intermittent lakes that contain water from time to time or intermittent rivers or streams that flow from time to time, stopping and starting at intervals, and may disappear and reappear. Ephemeral streams, which are generally exempt under provisions developed by the Department and DFG, are those that flow only in direct response to rainfall.

The reuse of flexible pavement grindings will normally be consistent with the Fish and Game Code and not require a 1601 Agreement when these materials are placed where they cannot enter the waters of the State. However, there are no set rules as to distances and circumstances applicable to the placement of asphaltic materials adjacent to waters of the State. Placement decisions must be made on case-by-case basis, so that such materials will be placed far enough away from the waters of the State to prevent weather (erosion) or maintenance operations from dislodging the material into State waters. Site-specific factors (i.e., steep slopes) should be given special care. Generally, when flexible pavement grindings are being considered for placement where there is a potential for this material to enter a water body, DFG should be notified to assist in determining whether a 1601 Agreement is appropriate. DFG may require mitigation strategies to prevent the materials from entering the Waters of the State. When in doubt, it is recommended that the DFG be notified.

If there is the potential for reused flexible materials to reach waters of the State through erosion or other means during construction, such work would normally require a 1601 Agreement. Depending on the circumstances, the following mitigation measures should be taken to prevent flexible grindings from entering water bodies:

- The reuse of flexible pavement grindings as fill material and shoulder backing must conform to the California Department of Transportation (Department) Standard Specifications, applicable manuals of instruction, contract provisions, and the MOU described below.
- Flexible chunks and pieces in embankment must be placed above the water table and covered by at least one foot of material.

A Memorandum of Understanding (MOU) dated January 12, 1993, outlines the interim agreement between the DFG and the

Department regarding the use of asphaltic materials. This MOU provides a working agreement to facilitate the Department's continued use of asphaltic materials and avoid potential conflicts with the Fish and Game Code by describing conditions where use of asphalt road construction material by the Department would not conflict with the Fish and Game Code.

Specific Understandings contained in the MOU are:

- Asphalt Use in Embankments

  The Department may use flexible pavement chunks and pieces in embankments when these materials are placed where they will not enter the waters of the State.

- Use of flexible pavement grindings as Shoulder Backing

  The Department may use flexible pavement grindings as shoulder backing when these materials are placed where they will not enter the waters of the State.

- Streambed Alteration Agreements

  The Department will notify the DFG pursuant to Section 1601 of the Fish and Game Code when a project involving the use of asphaltic materials or crumbled, flaked, or ground pavement will alter or result in the deposition of pavement material into a river, stream, or lake designated by the DFG. When the proposed activity incorporates the agreements reached under Section 1601 of the Fish and Game Code, and is consistent with Section 5650 of the Fish and Game Code and this MOU, the DFG will agree to the use of these materials.

There may be circumstances where agreement between the DFG and the Department cannot be reached. Should the two agencies reach an impasse, the agencies enter into a binding arbitration process outlined in Section 1601 of the Fish and Game Code. However, keep in mind that this arbitration process does not exempt the Department from complying with the provisions of the Fish and Game Code. Also it should be noted that this process is time consuming, requiring as much as 72 days or more to complete. Negotiations over the placement of flexible pavement grindings, chunks, and pieces are to take place at the District level as part of the 1601 Agreement process.

110.12 Tunnel Safety Orders

Projects and work activities that include human entry into tunnels, shafts or any of a variety of underground structures to conduct construction activities must address the requirements of the California Code of Regulations (CCR), Title 8, Subchapter 20 – Tunnel Safety Orders (TSO). Activities that can be considered of a maintenance nature, such as cleaning of sediment and debris from culverts or inspection (either condition inspection for design purposes or inspection as a part of construction close-out) of tunnels, shafts or other underground facilities are not affected by these regulations.

TSO requires the Department, as owner of the facility, to request the Department of Industrial Relations, Division of Occupational Safety and Health (Cal-OSHA), Mining and Tunneling Unit, to review and classify tunnels and shafts for the potential presence of flammable gas and vapors prior to bidding. The intent of the TSO regulations are to protect workers from possible injury due to exposure to hazardous conditions. Failure to comply is punishable by fine. The complete TSO regulations are available at the following website: (http://www.dir.ca.gov/title8/sub20.html), with Sections 8403 and 8422 containing information most applicable to project design.

The TSO regulations require classification whenever there is human entry into a facility defined as a tunnel or entry into, or very near the entrance of, a shaft. Some of the common types of activities where human entry is likely and that will typically require classification include:

- Pipe jacking or boring operations
- Culvert rehabilitation
- Large diameter pile construction, as described in the following text
- Pump house vaults

- Cut-and-cover operations connected to ongoing underground construction and are covered in a manner that creates conditions characteristic of underground construction
- Well construction
- Cofferdam excavations
- Deep structure footings/shafts/casings, as described in the following text

Virtually any project that will lead to construction or rehabilitation work within a pipe, caisson, pile or underground structure that is covered by soil is subject to the TSO regulations. This typically applies to underground structures of 30 inches or greater diameter or shaft excavations of 20 feet or more in depth. Since a shaft is defined as any excavation with a depth at least twice its greatest cross section, the regulations will apply to some structure footing or cofferdam excavations.

Cut and cover operations (typical of most pipe, junction structure and underground vault construction) do not fall under the TSO regulations as long as worker entry to the pipe or system (usually for grouting reinforced concrete pipe, tightening bolts on structural plate pipe, etc.) is conducted prior to covering the facility with soil. Connecting new pipe to existing buried pipe or structures does fall under the TSO regulations unless the existing pipe system is physically separated by a bulkhead to prevent entry into the buried portion. Designers must either incorporate requirements for such separation of facilities into the PS&E or they must obtain the required classification from Cal-OSHA. For any project that requires classification, specifications must be included that alert the Contractor to the specific location and classification that Cal-OSHA has provided.

The TSO regulations should be viewed as being in addition to, and not excluding, other requirements as may apply to contractor or Department personnel covered in the Construction Safety Orders (see CCR, Title 8, Subchapter 4, Article 6 at http://www.dir.ca.gov/title8/sub4.html), safety and health procedures for confined spaces (see Chapter 14 of the Caltrans Safety Manual), or any other regulations that may apply to such work.

Prior to PS&E submittal on a project that includes any work defined in CCR Section 8403, a written request must be submitted for classification to the appropriate Mining and Tunneling (M&T) Unit office. Each M&T Unit office covers specific counties as shown on Figure 110.12. Classification must be obtained individually for each separate location on a project. For emergency projects or other short lead-time work, it is recommended that the appropriate M&T Unit office be contacted as soon as possible to discuss means of obtaining classification prior to the start of construction activities.

The request must include all pertinent and necessary data to allow the M&T Unit to classify the situation. The data specified under paragraph (a) of Section 8422 (complete text of Section 8422 reprinted below) is typical of new construction projects, however for culvert rehabilitation and other type of work affecting an existing facility, not all of the indicated items are typically available or necessary for submittal. The appropriate M&T Unit office should be contacted for advice if there is any question regarding data to submit.

In many instances it may not be known during design if there will be human entry into facility types that would meet the definition of a tunnel or shaft. If there is any anticipation that such entry is likely to occur, classification should be requested. As permit acquisition is typically the responsibility of the District, it is imperative that there be close coordination between District and Structures Design staff regarding the inclusion of any facilities in the structures PS&E that could be defined as a tunnel or shaft and have potential for human entry. The following text is taken directly from Section 8422:

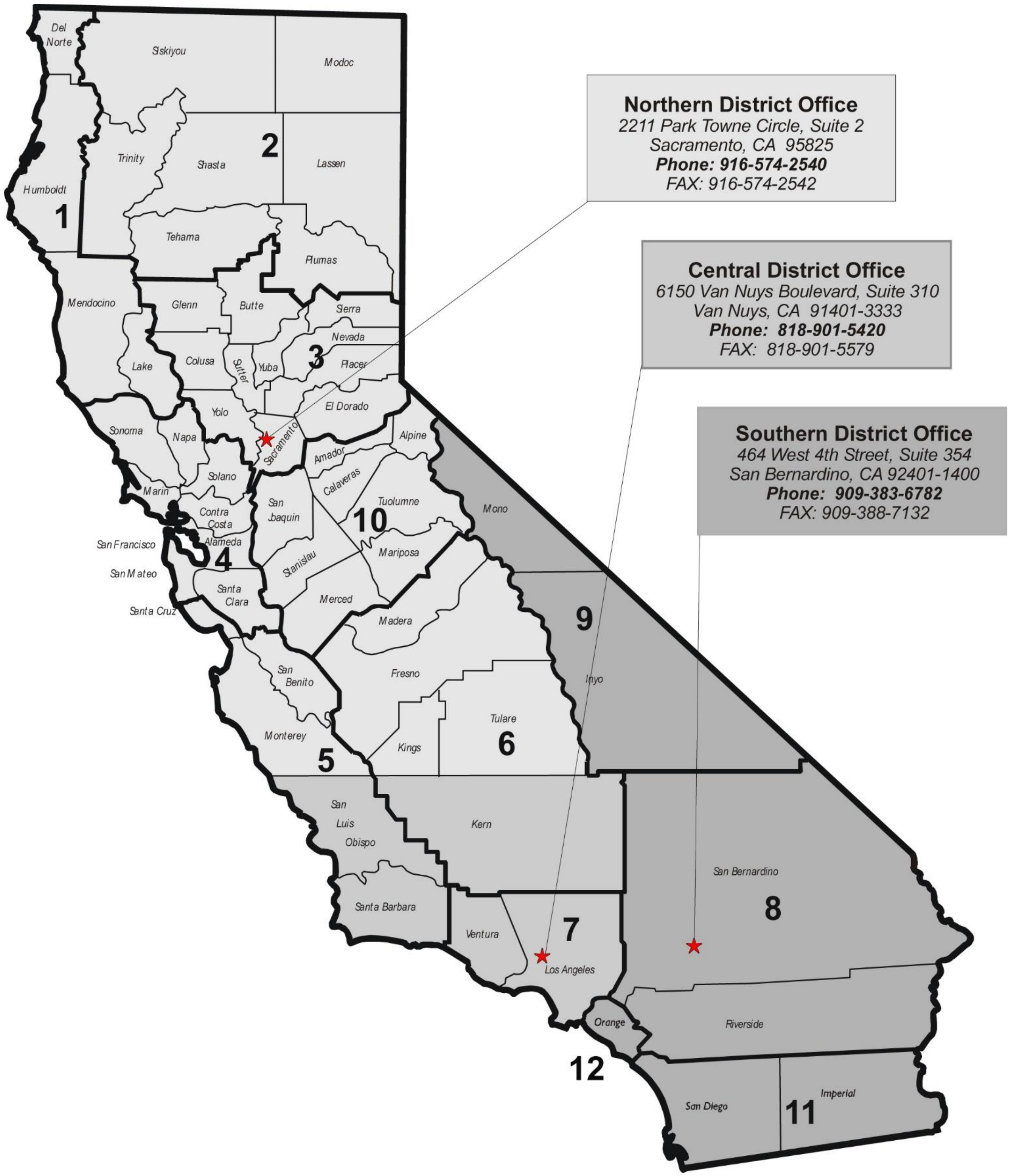
8422 Tunnel Classifications

(a) When the preliminary investigation of a tunnel project is conducted, the owner or agency proposing the construction of the tunnel shall submit the geological information to the Division for review and classification relative to flammable gas or vapors. The preliminary classification shall be obtained from the Division prior to bidding and in all cases prior to actual underground construction. In order to make the evaluation, the following will be required:

(1) Plans and specifications;

(2) Geological report;

Figure 110.12
California Mining and Tunneling Districts



(3) Test bore hole and soil analysis log along the tunnel alignment;

(4) Proximity and identity of existing utilities and abandoned underground tanks.

(5) Recommendation from owner, agency, lessee, or their agent relative to the possibility of encountering flammable gas or vapors;

(6) The Division may require additional drill hole or other geologic data prior to making gas classifications.

(b) The Division shall classify all tunnels or portions of tunnels into one of the following classifications:

(1) Nongassy, which classification shall be applied to tunnels where there is little likelihood of encountering gas during the construction of the tunnel.

(2) Potentially gassy, which classification shall be applied to tunnels where there is a possibility flammable gas or hydrocarbons will be encountered.

(3) Gassy, which classification shall be applied to tunnels where it is likely gas will be encountered or if a concentration greater than 5 percent of the LEL of:

(A) flammable gas has been detected not less than 12 inches from any surface in any open workings with normal ventilation.

(B) flammable petroleum vapors that have been detected not less than 3 inches from any surface in any open workings with normal ventilation.

(4) Extra hazardous, which classification shall be applied to tunnels when the Division finds that there is a serious danger to the safety of employees and:

Flammable gas or petroleum vapor emanating from the strata has been ignited in the tunnel; or

(A) A concentration of 20 percent of the LEL of flammable gas has been detected not less than 12 inches from any surface in any open working with normal ventilation; or

(B) A concentration of 20 percent of LEL petroleum vapors has been detected not less than three inches from any surface in any open workings with normal ventilation.

(c) A notice of the classification and any special orders, rules, special conditions, or regulations to be used shall be prominently posted at the tunnel job site, and all personnel shall be informed of the classification.

(d) The Division shall classify or reclassify any tunnel as gassy or extra hazardous if the preliminary investigation or past experience indicates that any gas or petroleum vapors in hazardous concentrations is likely to be encountered in such tunnel or if the tunnel is connected to a gassy or extra hazardous excavation and may expose employees to a reasonable likelihood of danger.

(e) For the purpose of reclassification and to ensure a proper application of classification, the Division shall be notified immediately if a gas or petroleum vapor exceeds any one of the individual classification limits described in subsection (b) above. No underground works shall advance until reclassification has been made.

(1) A request for declassification may be submitted in writing to the Division by the employer and/or owner's designated agent whenever either of the following conditions occur:

(A) The underground excavation has been completed and/or isolated from the ventilation system and/or other excavations underway, or

(B) The identification of any specific changes and/or conditions that have occurred subsequent to the initial classification criteria such as geological information, bore hole sampling results, underground tanks or utilities, ventilation system, air quality records, and/or evidence of no intrusions of explosive gas or vapor into the underground atmosphere.

NOTE: The Division shall respond within 10 working days for any such request. Also, the Division may request additional information and/or require specific conditions in order to work under a lower level of classification.

Topic 111 - Material Sites and Disposal Sites

111.1 General Policy

The policies and procedures concerning material sites and disposal sites are listed below. For further information concerning selection and procedures for disposal, staging and borrow sites, see DIB 85.

(a) Materials investigations and environmental studies of local materials sources should be made to the extent necessary to provide a basis for study and design. Location and capacity of available disposal sites should be determined for all projects requiring disposal of more than 10,000 cubic yards of clean material. Sites for disposal of any significant amount of material in sensitive areas should be considered only where there is no practical alternative.

(b) Factual information obtained from such investigations should be made readily available to prospective bidders and contractors.

(c) The responsibility for interpreting such information rests with the contractor and not with the State.

(d) Generally, the designation of optional material sites or disposal sites will not be included in the special provisions. Mandatory sites must be designated in the special provisions or Materials Information Handout as provided in Index 111.3 of this manual and Section 2-1.03 of the Standard Specifications. A disposal site within the highway right of way (not necessarily within the project limits) should be provided when deemed in the best interest of the Department as an alternative to an approved site for disposal of water bearing residues generated by grinding or grooving operations, after approval is obtained from the Regional Water Quality Control Board (RWQCB) having jurisdiction over the area.

(e) Material agreements or other arrangements should be made with owners of material sites whenever the absence of such arrangements would result in restriction of competition in bidding, or in other instances where it is in the State's interest that such arrangements be made.

(f) The general policy of Caltrans is to avoid specifying mandatory sources unless data in support of such sources shows certain and substantial savings to the State. Mandatory sources must not be specified on Federal-aid projects except under exceptional circumstances, and prior approval of the FHWA is required. Supporting data in such cases should be submitted as early as possible. This policy also applies to disposal sites.

(g) It is the policy of Caltrans to cooperate with local authorities to the greatest practicable extent in complying with environmental requirements for all projects. Any corrective measures wanted by the local authorities should be provided through the permit process. Any unusual requirements, conditions, or situations should be submitted to the Division of Design for review (see Indexes 110.2 and 110.3).

(h) The use of any materials site requires compliance with environmental laws and regulations, which is normally a part of the project environmental documentation. If the need for a site occurs after approval of the project environmental document, a separate determination of environmental requirements for the materials site may be required.

(i) If the materials site is outside the project limits and exceeds 1-acre in size, or extraction will exceed 1,000 cubic yards, it must comply with the Surface Mining and Reclamation Act of 1975 (SMARA) and be included on the current “AB 3098 List” published by the Department of Conservation before material from that site can be used on a State project. There are limited exceptions to this requirement and the District Materials Engineer should be consulted.

111.2 Investigation of Local Materials Sources

(1) Extent of Explorations. Possible sources of materials should be investigated to the extent necessary to assure that the design of each project is based on the most economical use of available materials compatible with good environmental design practices. Where it can be reasonably assumed that all required materials can be most economically obtained from commercial sources on the current “AB 3098 List”, it should be unnecessary to investigate other sites. In all other cases

material sites should be investigated. Exploration of materials sources should not be restricted to those properties where the owner expresses willingness to enter into agreement with the State. Unless it is definitely known that the owner will under no circumstances permit removal of materials, the site should be considered as a possible source of local materials.

(2) *Geotechnical Design Report or Materials Report.* The Geotechnical Design Report or Materials Report should include complete information on all sites investigated and should discuss the quality, cost, SMARA status, and availability of materials from commercial plants on the current "AB 3098 List". Sufficient sampling of sites must be performed to indicate the character of the material and the elevation of the ground water surface, and to determine changes in the character of the material, both laterally and vertically. Sampling must be done in such a manner that individual samples can be taken from each horizon or layer. Composite samples of two or more different types of material are unsatisfactory, as there is no assurance that the materials would be so combined if the materials source were actually used. Testing of blends of two or more types of materials is permissible, provided the test report clearly indicates the combination tested. The test report must clearly indicate the location of the sample and the depth represented. The fact that materials sites are not designated in the Special Provisions does not reduce the importance of thorough exploration and testing.

As tabulations of test data for local materials will be furnished to prospective bidders, and the test reports may be examined by bidders if they so request, it is important that only factual data be shown on the test report and that no conclusions, opinions, or interpretation of the test data be included. Under "Remarks", give only the pertinent factual information regarding the scalping, crushing, blending, or other laboratory processing performed in preparing samples for testing, and omit any comments as to suitability for any purpose. Any discussion of the quality, suitability, or quantity of material in local materials sites necessary for design purposes should be included in the Geotechnical Design Report or Materials Report, and not noted on the test reports. For any potential materials source explored or tested, all boring and test data must be furnished, including those tests which indicate unsuitable or inferior material.

Materials information to be furnished bidders may include data on a materials source previously investigated for the same project or some other project provided all of the following conditions are met:

(a) There has been no change in test procedures subsequent to the time the earlier tests were made.

(b) The materials source has not been altered by stream action, weathering, or other natural processes.

(c) The material sampled and represented by the tests has not been removed.

(d) There has been no change in SMARA status, or inclusion or exclusion on the "AB 3098 List".

It will be necessary for each District to maintain a filing system such that all preliminary test reports for potential materials sites are readily accessible. This will necessitate preparation of test reports covering all preliminary tests of materials. It will also be essential to maintain some type of materials inventory system, whereby sites in the vicinity of any project can be readily identified and the test reports can be immediately accessible. Filing only by numerical or chronological order will not be permissible.

111.3 Materials Information Furnished to Prospective Bidders

(1) *Materials Information Compilation.* It is the intent that all test data applicable to material sites for a project be furnished to prospective bidders. To obtain uniformity in the "handouts" furnishing this information to prospective bidders, the District Materials Unit should develop the "handout" and the following information must be included:

(a) A cover page entitled, "Materials Information", should show District, County, Route, kilometer post limits, and geographical limits. There should be a note stating where the records, from which the information was compiled, may be inspected. Also, an index, listing investigated material sites, and disposal sites, maps, test reports, tabulation sheets, SMARA status, and agreements is to be shown on the cover page.

(b) A vicinity map showing the location of investigated materials sites and disposal sites in relation to the project.

(c) A map of each material site showing the location and identification of boring or test pits.

(d) A tabulation of the test data for each material site, showing complete information on the location, depth, and processing of each sample tested, together with all test results.

(e) Copies of all options or agreements with owners of the material sites, if such arrangements have been made.

(f) Soil survey sheets or suitable terrain maps showing borings and tests along the highway alignment.

(g) A tabulation of which sites comply with environmental laws and regulations and are included on the current “AB 3098 List”.

(h) Material site grading and reclamation plan and disposal site grading plans, if they have been prepared.

(i) Copies of local use permits and clearances (when they have been obtained by the State) such as environmental clearances, mining permits, Forest Service Fire Regulations, water quality control clearances, etc. If documents are of unusual length, a statement should be included that they have been obtained and are available for inspection at the District office or Sacramento Plans Counter.

Maps, test reports, and other data included in the "Materials Information" must be factual, and should not include any comments, conclusions, or opinions as to the quality, quantity, suitability, depth, or area of the materials in any material site or along the highway.

Reproducible copies of all material to be included in the "Material Information" package should be submitted to the Office Engineer.

The Office Engineer will reproduce the "Materials Information," and copies will be available to prospective bidders upon request in the same manner that plans and special provisions are furnished.

111.4 Materials Arrangements

Materials agreements or other arrangements must be made in accordance with the policy stated under Index 111.1(e).

The determination of when and where materials agreements or other arrangements are to be obtained is the responsibility of the District, see Section 8.25.00.00 of the Right of Way Manual.

The District should also determine the maximum royalty that can be paid economically on the basis of availability of competitive sources.

In preparing agreements, guaranteed quantity provisions should not be included, as the opportunity exists for possible token removal, with the result that the State would be required to pay for the guaranteed quantity even though the material would not actually be removed. Also, requirements that the State perform construction work on the owner's property, such as fences, gates, cattle guards, roads, etc., should be included only when the cost of such items and possible resulting benefits have been properly considered in the derivation of the royalty.

111.5 Procedures for Acquisition of Material Sites and Disposal Sites

These instructions establish procedures to be followed in the purchase of material sites and disposal sites when such purchase is deemed necessary by the District. The steps to be taken are listed in order as follows:

(1) *General Procedure.*

(a) A District report proposing and establishing the necessity for purchase of the site is required. The report should contain the following information:

- The project or projects on which the site is to be used and programming of proposed construction.
- The location and description of the property, zoning, and site restoration/reclamation proposals including necessary vicinity and site maps.
- The amount and quality of material estimated to be available in the site and amount needed for the project or projects, or amount of excess material to be disposed of and the capacity of the site or sites.
- An economic analysis using the estimated purchase price and value of land after removal of material or deposit of excess material. The total estimated savings over other possible alternatives must be clearly demonstrated. Alternatives must be shown from the standpoint of what would have to be done if the site was not purchased. Alternatives could be changes in location or grade as well as alternative sources of material.
- A statement as to whether or not the use of the site should be mandatory, with a separate statement regarding the effect for each proposed project for which mandatory use of the site is considered necessary, including complete justification for the mandatory specification (see Index 111.6). Three copies of each map or other attachment, folded letter size, are required for mandatory sites on all Federal-aid projects.
- A statement of the type of environmental documentation.
- Other justification.

Send one copy to the Division of Design and one copy to DES Materials Engineering and Testing Services for information.

(b) If the project or projects are to have Federal aid, the District will prepare a request, with supporting environmental clearance, for FHWA approval to specify the source as mandatory. One copy of this request should be sent to the Office Engineer and one copy to Division of Design.

(c) If the estimated purchase price is over $300,000, the District should include the item in the STIP and corresponding budget.

(d) When the proposed purchase has been approved, the Project Engineer should notify the District Division of Right of Way, District Environmental Division and the District Materials Unit and request that Right of Way purchase the site (or obtain a Materials Agreement; the Materials Unit should assist in the development of the agreement) and the Environmental Division obtain environmental authorization to proceed.

(e) The District must include the cost of purchase in the proper fiscal year program and/or budget as part of the District targets.

(f) After budgeting, the District must submit an expenditure authorization to cover purchase of the site. This could be concurrent if the project is added to the budget during a fiscal year. The expenditure authorization request should be processed through the District Project Management and Administration Units and obtain District Director approval.

(g) After issuance of an expenditure authorization, the District Division of Right of Way will complete purchase of the site.

(2) *Material and Disposal Sites in Federal Lands.* The applicable sections of the Federal Highway Act of 1958 for procurement of borrow or disposal sites, Sections 107(d) and 317, are set forth in Section 8.18.02.00 of the Right of Way Manual; Section 107(d) applies to the Interstate

System while Section 317 applies to other Federal-aid highways. Whenever Federal public lands are required for a material or a disposal site, and after preliminary negotiations at the local level with the Federal agency having jurisdiction, the District must submit a letter report to the FHWA. This report should observe the requirements of Index 111.5 of this manual and Section 8.18.02.03 of the Right of Way Manual.

Following submittal of the proposal by the District to the FHWA, the latter, acting on behalf of the State transmits the proposal with a favorable recommendation to the Federal agency having control of the site proposal with a favorable recommendation to the Federal agency having control of the site.

See Section 8.18.02.03 of the Right of Way Manual.

111.6 Mandatory Material Sites and Disposal Sites on Federal-aid Projects

The contract provisions must not specify a mandatory site for the disposal of surplus excavated materials unless a particular site is needed for environmental reasons or the site is found to be the most economical for one or more Federal-aid projects. All points listed in Index 111.5(1)(a) and (b) must be covered and one copy of all attachments submitted. Supporting data must be submitted to the FHWA during the project planning phase or early in the project design phase as almost all cases of mandatory sites must go to the FHWA for decision.

Section 635.407 of 23 CFR 635D states in part:

> "The designation of a mandatory material source may be permitted based on environmental considerations, provided the environment would be substantially enhanced without excessive cost."
>
> "The contract provisions ... shall not specify mandatory a site for the disposal of surplus excavated materials unless there is a finding by the State highway agency with the concurrence of the FHWA Division Administrator that such placement is the most economical except that the designation of a mandatory site may be permitted based on environmental considerations, provided the environment would be substantially enhanced without excessive cost."

Topic 112 - Contractor's Yard and Plant Sites

112.1 Policy

The Project Engineer should, during the early design phase of a project, consider the need and availability of sites for the contractor's yards and materials plants. This is particularly important in areas where dust, noise, and access problems could limit the contractor in obtaining sites on their own in a timely manner. Material storage, handling, and recycling in a designated area will encourage transport of materials during non-peak times, reduce the number of delivery trips, and encourage the use of recycled materials. Asphalt concrete recycling projects pose special problems of material storage, access, and plant location; see Index 110.11. Temporary storage areas should be considered for grooving and grinding projects. As a general rule, the use of material sites designated in the Special Provisions should be optional. The Project Engineer should locate and determine the appropriate size for the type of project as optional staging / storage area(s) for the contractor’s use. Should the materials site be desired, the contractor shall provide notice to the Resident Engineer within a designated time period after approval of the contract (30 days would be a minimum, but not more than 60 days except in unusual situations). All environmental requirements must be satisfied and local permits must be obtained prior to submittal of the PS&E. Right of Way, Permits, and Environmental units must be informed early in the process. The contractor will be allowed to use these sites only for work on the designated project(s).

112.2 Locating a Site

The Project Engineer should consult with District Division of Right of Way concerning appropriately sized parcels currently being held in the airspace inventory, nearby property held by Caltrans for future construction, or as excess land. If such space is available in the vicinity of the project, the District Environmental Division should be consulted to determine what environmental requirements are necessary for the use of these properties for the intended purpose. Full restoration of the area is required for re-landscaping and replacement of irrigation or other facilities in the project PS&E. If sufficient space does not appear to be available for yard or plant, the Project Engineer must see that the appropriate wording is placed in the contract Special Provisions.

Topic 113 - Geotechnical Design Report

113.1 Policy

The Project Engineer must review the project initiation document and Preliminary Geotechnical Design Report, if any, to ascertain the scope of geotechnical involvement for a project. A Geotechnical Design Report (GDR) is to be prepared by the Roadway Geotechnical Engineering Branches of the Division of Engineering Services, Geotechnical Services (DES-GS) (or prepared by a consultant with technical oversight by DES-GS) for all projects that involve designs for cut slopes, embankments, earthwork, landslide remediation, retaining walls, groundwater studies, erosion control features, subexcavation and any other studies involving geotechnical investigations and engineering geology. A GDR is not required for projects that solely include those design features described in Index 114.1.

113.2 Content

The GDR is to conform to the "Guidelines for Geotechnical Reports" which is prepared by the Office of Structural Foundations.

113.3 Submittal and Review

Final copies of the GDR are to be submitted to the Project Engineer, District Materials Unit, and the Division of Design. For consultant developed reports, the GDR is to be submitted to DES-GS for review and approval. DES-GS will then transmit the approved GDR to the Project Engineer, District Materials Unit, and the Division of Design.

Topic 114 - Materials Report

114.1 Policy

A Materials Report must be prepared for all projects that involve any of the following components:

- Pavement structure recommendations and/or pavement studies
- Culverts (or other drainage materials)
- Corrosion studies
- Materials disposal sites
- Slide prone areas with erosive soils

The Materials Report may be either a single report or a series of reports that contains one or several of the components listed above. Materials Reports are prepared for project initiation documents, project reports, and PS&E. Materials Report(s) are signed and stamped with an engineer's seal by the engineer in responsible charge for the findings and recommendations. The District Materials Engineer will either prepare the Materials Report or review and accept Materials Report(s) prepared by others. The Material Report is signed by the Registered Engineer that prepared the report.

114.2 Requesting Materials Report(s)

The Project Engineer (or equivalent) is responsible for requesting a Materials Report. The District Materials Engineer can assist the Project Engineer in identifying what components need to be addressed, when to request them, and what information is needed. At a minimum, the following information needs to be included in all requests:

(1) Project location.

(2) Scope of work. Project Engineer should spell out the type of work to be done that will affect materials. If pavements are involved, state type of pavement work. Provide type of project, such as new construction, widening, or rehabilitation. Note if culverts will be installed, extended, or replaced. Note if material or disposal sites are needed, see Topic 111 for criteria.

(3) Proposed design life for pavements and culverts.

(4) Design Designation. Include for projects involving pavement structural enhancements. Does not apply to pavement preservation activities.

(5) Special Considerations or Limitations. Include any information that may affect the materials recommendations. Examples include traffic

management requirements or environmental restrictions.

114.3 Content

All Materials Reports must contain the location of the project, scope of work, and list of special conditions and assumptions used to develop the report. Materials Reports must contain the following information when the applicable activity is included in the scope of the project.

(1) Pavement. At minimum, the Materials Report must document the material data to be used to engineer the pavement structure, including the following:

- Engineering studies, tests, and cores performed to collect data for the project.
- Deflection studies for existing flexible pavement rehabilitation projects (see Index 635.1), and
- Special material requirements that should be incorporated such as justifications for using (or not using) particular materials in the pavement structure.
- Pavement strategy/structural recommendations are not included as part of the Materials Report. See Index 604.2 for discussion on preparation of pavement recommendations.

(2) Drainage Culverts or Other Materials. The Materials Report must contain a sufficient number of alternatives that materially meet or exceed the culvert design life (and other drainage related) standards for the Project Engineer to establish the most maintainable, constructible, and cost effective alternative in conformance with FHWA regulations (23 CFR 635D).

(3) Corrosion. Corrosion studies are necessary when new culverts, culvert rehabilitation, or culvert extensions are part of the scope of the project. Studies should satisfy the requirements of the "Corrosion Guidelines". Copies of the guidelines can be obtained from the Corrosion Technology Branch in DES Materials Engineering and Testing Services or on the DES Materials Engineering and Testing Services website.

(4) Materials or Disposal Sites. See Topic 111 "Material Sites and Disposal Sites" for conditions when sites need to be identified and how to document.

114.4 Preliminary Materials Report

Because resources and/or time are sometimes limited, it is not always possible to complete all the tests and studies necessary for a final Materials Report during the planning/scooping phase. In these instances, a Preliminary Materials Report may be issued using the best information available and good engineering judgment. Accurate traffic projections and design designations are still required for the Preliminary Materials Report. Preliminary Materials Reports should not be used for project reports or PS&E development. When used, Preliminary Materials Reports must document the sources of information used and assumptions made. It must clearly state that the Preliminary Materials Report is to be used for planning and initial cost estimating only and not for final design. The Department Pavement website contains supplemental guidance for developing preliminary pavement structures.

114.5 Review and Retention of Records

A copy of the Draft Materials Report is to be submitted for review and comment to the District Materials Engineer. The District Materials Engineer reviews the document for the Department to assure that it meets the standards, policies, and other requirements found in Department manuals, and supplemental district guidance (Index 604.2(2)). If it is found that the document meets these standards, the District Materials Engineer accepts the Materials Report. If not, the report is returned with comments to the submitter.

After resolution of the comments, a final copy of the Materials Report is submitted to the District Materials Engineer who then furnishes it to the Project Engineer. The original copy of the Materials Report must be permanently retained in the District's project history file and be accessible for review by others when requested.

Topic 115 - Designing for Bicycle Traffic

115.1 General

Under the California Vehicle Code, bicyclists generally have the same rights and duties that motor vehicle drivers do when using the State highway system. For example, they make the same merging and turning movements, they need adequate sight distance, they need access to all destinations, etc. Therefore, designing for bicycle traffic and designing for motor vehicle traffic are similar and based on the same fundamental transportation engineering principles. The main differences between bicycle and motor vehicle operations are lower speed and acceleration capabilities, as well as greater sensitivity to out of direction travel and steep uphill grades. Design guidance that addresses the safety and mobility needs of bicyclists on Class II bikeways (bike lanes) is distributed throughout this manual. See Chapter 1000 for additional bicycle guidance for Class I bikeways (bike paths) and Class III bikeways (bike routes). See Design Information Bulletin (DIB) 89 for Class IV bikeways (separated bikeways) guidance.

All city, county, regional and other local agencies responsible for bikeways or roads except those freeway segments where bicycle travel is prohibited shall follow the bikeway design criteria established in this manual and the California MUTCD, as authorized in the Streets and Highways Code Sections 890.6 and 891(a). However, a local agency may utilize alternative design criteria as prescribed in the Streets and Highways Code Section 891(b). The decision to develop bikeways should be made in consultation and coordination with local agencies responsible for bikeway planning to ensure connectivity and network development.

Generally speaking, bicycle travel can be enhanced by bikeways or improvements to the right-hand portion of roadways, where bicycles are required to travel. When feasible, a wider shoulder than minimum standard should be considered since bicyclists are required to ride to as far to the right as possible, and shoulders provide bicyclists an opportunity to pull over to let faster traffic pass.

All transportation improvements are an opportunity to improve safety, access, and mobility for the bicycle mode of travel.

Topic 116 - Bicyclists and Pedestrians on Freeways

116.1 General

Seldom is a freeway shoulder open to bicycle, pedestrian or other non-motorized travel, but they can be opened for use if certain criteria assessing the safety and convenience of the freeway, as compared with available alternate routes, is met. However, a freeway should not be opened to bicycle or pedestrian use if it is determined to be incompatible. The District Traffic Engineer or designee and the Project Delivery Coordinator must approve any proposals to open freeways to bicyclists, pedestrian or other non-motorized use. See the California MUTCD and CVC Section 21960.

When a new freeway segment is to remain open or existing freeway segment is to be reopened to these modes, it is necessary to evaluate the freeway features for their compatibility with safe and efficient travel, including:

- Shoulder widths
- Drainage grates; see Index 1003.5(2)
- Expansion joints
- Utility access covers on shoulders
- Frequency and spacing of entrance/exit ramps
- Multiple-lane entrance/exit ramps
- Traffic volumes on entrance/exit ramps and on lanes merging into exit ramps
- Sight distance at entrance/exit ramps
- Freeway to freeway interchanges
- The presence and design of rumble strips
- Longitudinal edges and joints

If a freeway segment has no suitable non-freeway alternative and is closed because certain features are considered incompatible, the feasibility of eliminating or reducing the incompatible features should be evaluated. This evaluation may include removal, redesign, replacement, relocation or retrofitting of the incompatible feature, or installation of signing, pavement markings, or other traffic control devices.

Where no reasonable, convenient and safe non-freeway alternative exists within a freeway corridor, the Department should coordinate with local agencies to develop new routes, improve existing routes or provide parallel bicycle and pedestrian facilities within or adjacent to the freeway right of way. See Project Development Procedures Manual Chapter 1, Article 3 (Regional and System Planning) and Chapter 31 (Nonmotorized Transportation Facilities) for discussion of the development of non-freeway transportation alternatives.

radius of curvature and minimum sight distance for that design speed, Figure 201.6 gives the clear distance (m) from centerline of inside lane to the obstruction.

See Index 1003.1(13) for bikeway stopping sight distance on horizontal curve guidance.

When the radius of curvature and the clear distance to a fixed obstruction are known, Figure 201.6 also gives the sight distance for these conditions.

See Index 101.1 for technical reductions in design speed caused by partial or momentary horizontal sight distance restrictions. See Index 203.2 for additional comments on glare screens.

Cuts may be widened where vegetation restricting horizontal sight distance is expected to grow on finished slopes. Widening is an economic trade-off that must be evaluated along with other options. See Topic 902 for sight distance requirements on landscape projects.

201.7 Decision Sight Distance

At certain locations, sight distance greater than stopping sight distance is desirable to allow drivers time for decisions without making last minute erratic maneuvers (see Chapter III of AASHTO, A Policy on Geometric Design of Highways and Streets, for a thorough discussion of the derivation of decision sight distance.)

On freeways and expressways the decision sight distance values in Table 201.7 should be used at lane drops and at off-ramp noses to interchanges, branch connections, safety roadside rest areas, vista points, and inspection stations. When determining decision sight distance on horizontal and vertical curves, Figures 201.4, 201.5, and 201.6 can be used. Figure 201.7 is an expanded version of Figure 201.4 and gives the relationship among length of crest vertical curve, design speed, and algebraic difference in grades for much longer vertical curves than Figure 201.4.

Decision sight distance is measured using the 3 ½-foot eye height and ½-foot object height. See Index 504.2 for sight distance at secondary exits on a collector-distributor road.

Table 201.7
Decision Sight Distance

Design Speed (mph)	Decision Sight Distance (ft)
30	450
35	525
40	600
45	675
50	750
55	865
60	990
65	1,050
70	1,105
75	1,180
80	1,260

Topic 202 - Superelevation

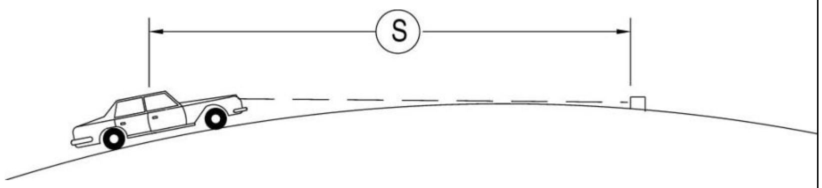
202.1 Basic Criteria

When a vehicle moves in a circular path, it undergoes a centripetal acceleration that acts toward the center of curvature. This force is countered by the perceived centrifugal force experienced by the motorist.

On a superelevated highway, this force is resisted by the vehicle weight component parallel to the superelevated surface and by the side friction developed between the tires and pavement. It is impractical to balance centrifugal force by superelevation alone, because for any given curve radius a certain superelevation rate is exactly correct for only one driving speed. At all other speeds there will be a side thrust either outward or inward, relative to the curve center, which must be offset by side friction.

If the vehicle is not skidding, these forces are in equilibrium as represented by the following simplified curve equation, which is used to design a curve for a comfortable operation at a particular speed:

Figure 201.4
Stopping Sight Distance on Crest Vertical Curves



Drivers eye height is 3 ½ feet.
Object height is ½-foot.

L = Curve Length (feet)

A = Algebraic Grade Difference (%)

S = Sight Distance (feet)

V = Design Speed for "S" in mph

K = Distance in feet required to achieve a 1% change in grade. K value as shown on graph is valid when S < L.

Notes:

- Before using this figure for intersections, branch connections and exits, see Indexes 201.7 and 405.1, and Topic 504.
- See Figure 204.4 for vertical curve formulas.
- See Index 204.4 for minimum length of vertical curve

When S > L	**When S < L**
L = 2S – 1329/A	**L = AS^2 /1329**

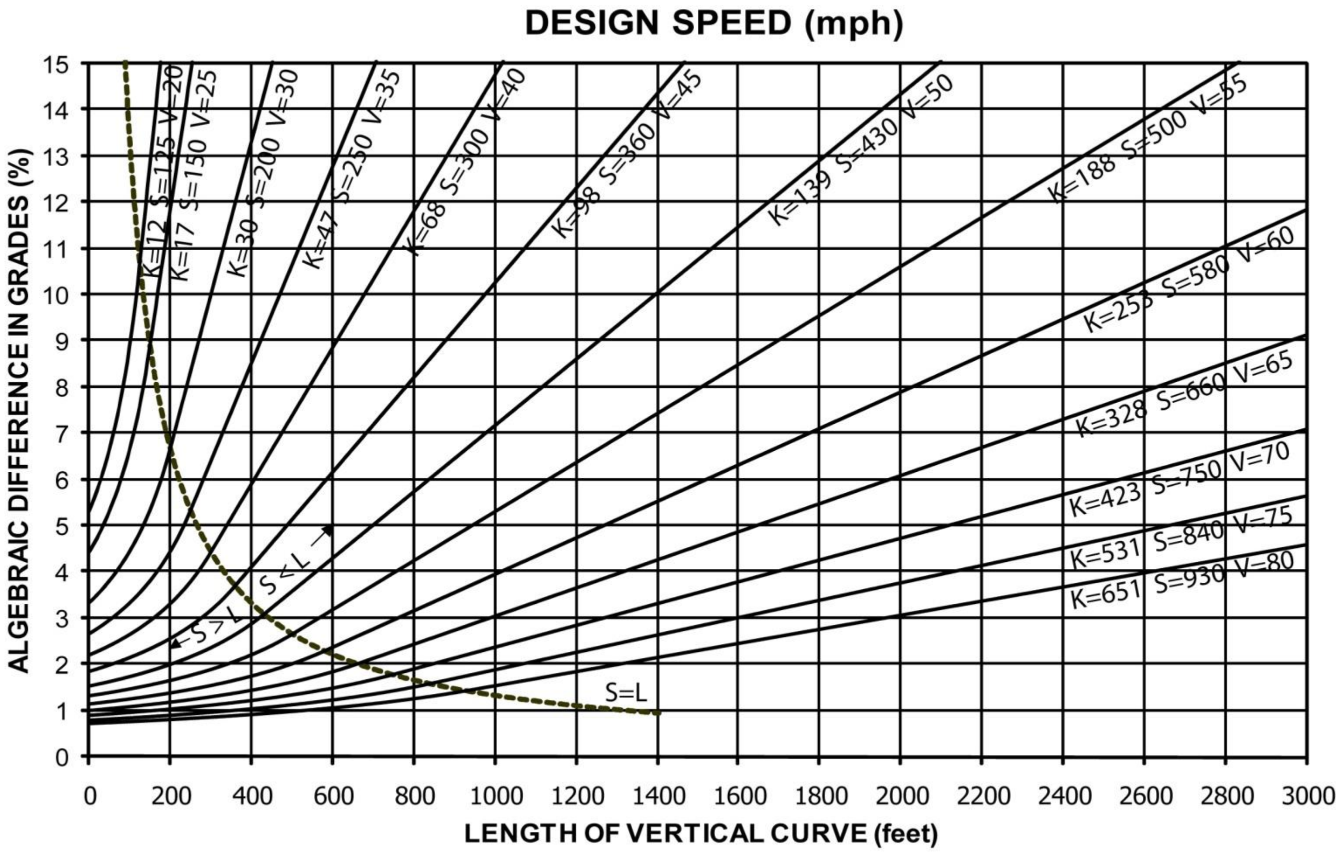
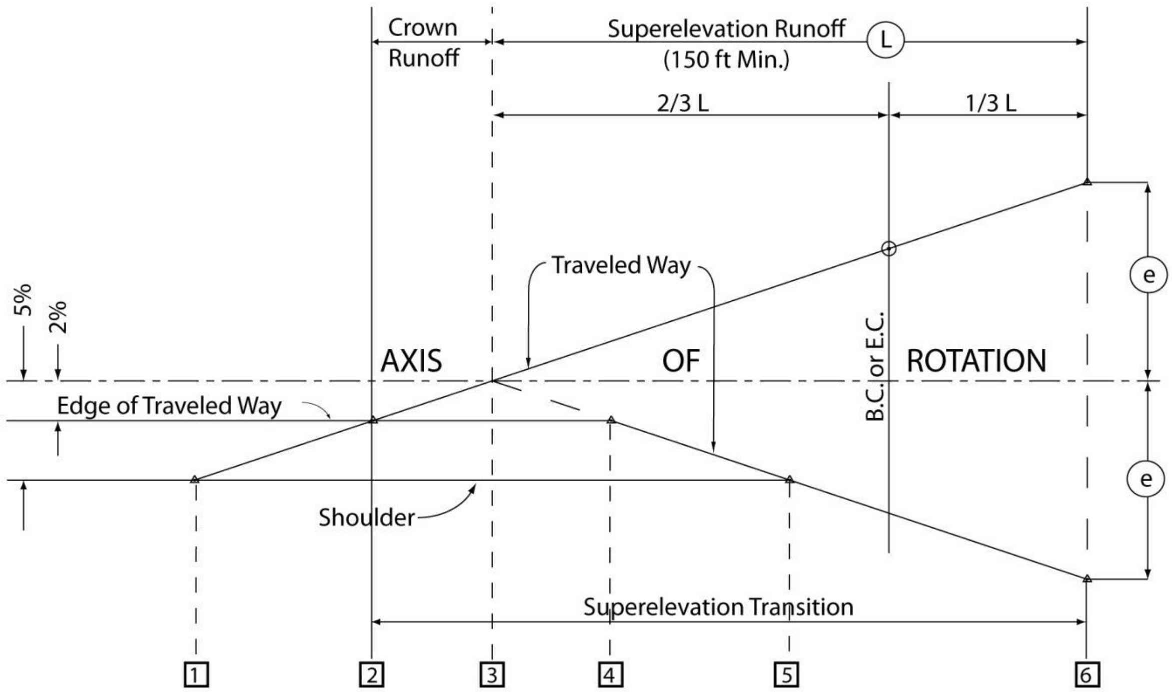


Figure 202.5A
Superelevation Transition

Formulas		Explanation of Terms
2-Lane Roads	L = 2500 e	(L) = Length of Superelevation Runoff - ft
Multilane Roads & Branch Connections	L = 150 De	(e) = Superelevation rate - ft/ft
Ramps Multilane Single Lane	 L = 2500 e if possible L = 2000 e	(D) = Distance from axis of rotation to outside edge of lanes - ft
MINIMUM L = 150 FT		MAXIMUM L = 510 FT

Adjust computed length to nearest 10 ft. length divisible by 3



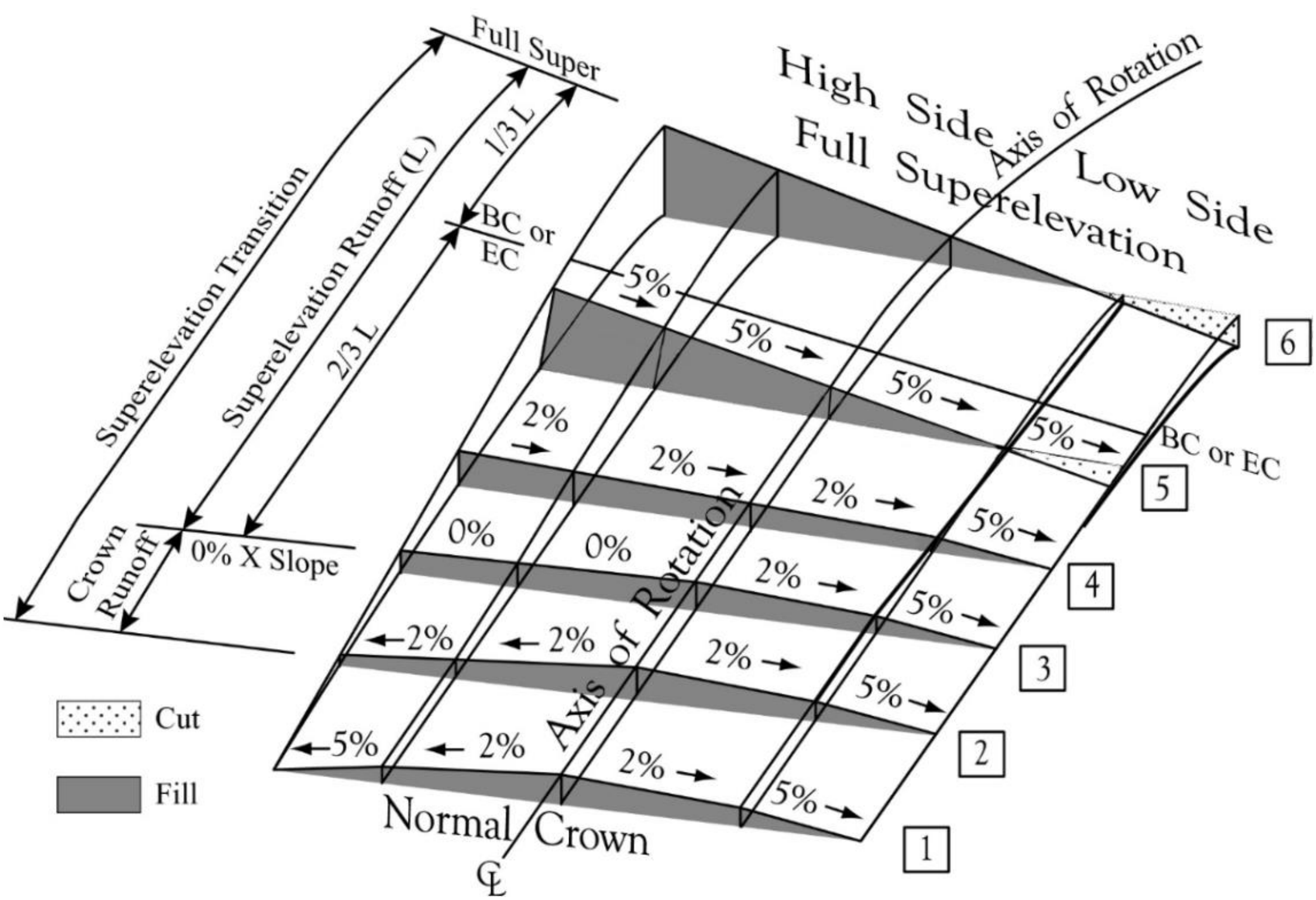
Superelevation Runoff Lengths

Superelevation Rate "e" ft/ft	Length, L (feet) 2-Lane Highways & Multilane Ramps	Single Lane Ramps	Multilane Highways and Branch Connections with Various "D" Widths 24 ft	36 ft	48 ft	51 ft	60 ft	63 ft	75 ft
0.02	150	150	150	150	150	150	180	180	240
0.03	150	150	150	180	210	240	270	270	330
0.04	150	150	150	210	300	300	360	390	450
0.05	150	150	180	270	360	390	450	480	510
0.06	150	150	210	330	450	450	510	510	
0.07	180	150	270	390	510	510			
0.08	210	150	300	450					
0.09	240	180	330	480					
0.10	240	210	360	510					
0.11	270	210	390						
0.12	300	240	420						

For widths of "D" not included in table, use formula above.

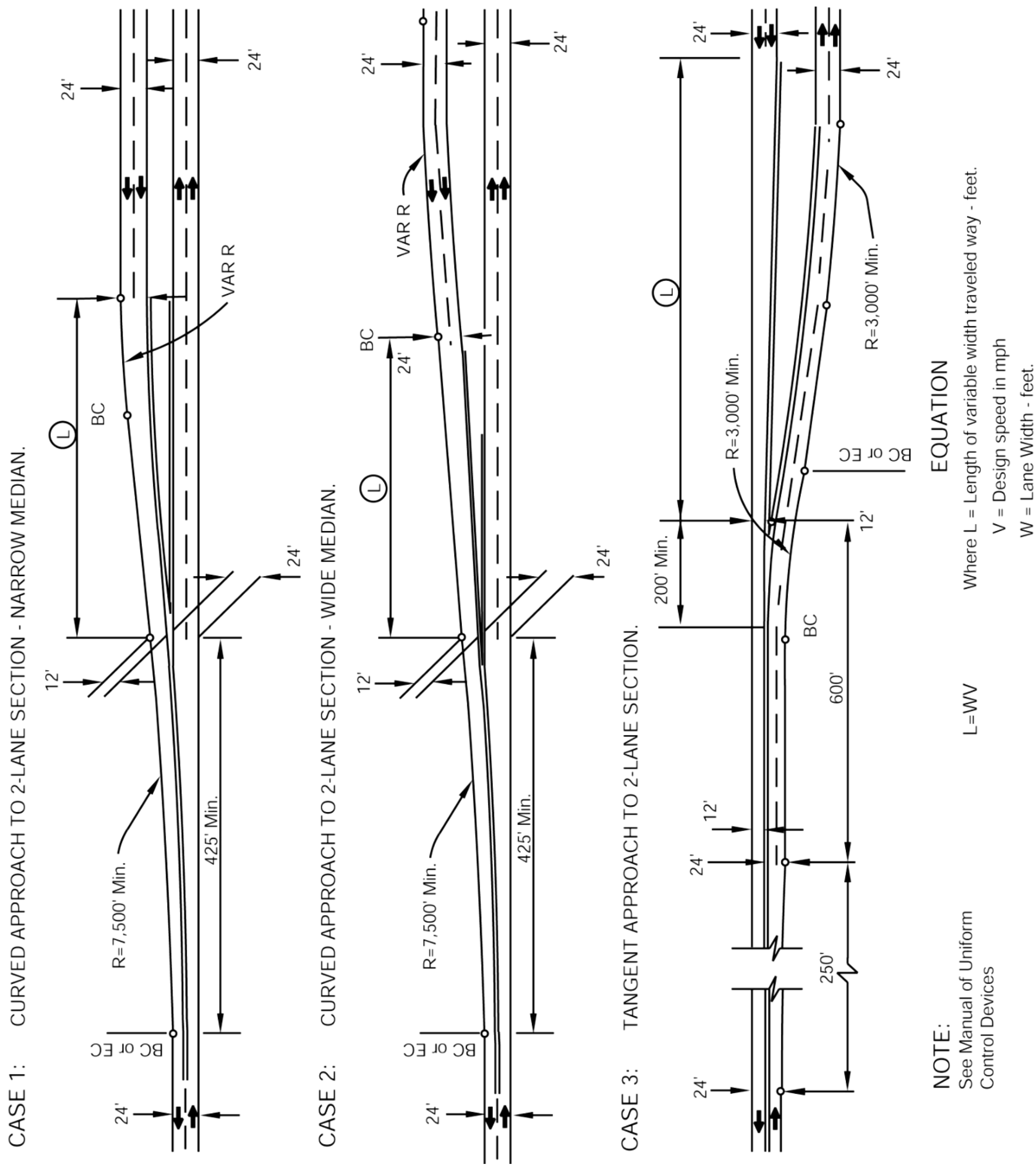
Figure 202.5B
Superelevation Transition Terms & Definitions

Term	Definition
Crown Runoff 2 ↔ 3	The distance from the station where the high side of the superelevating section surfaces are at a cross slope of 2% to where the high side of the section surfaces reaches a cross slope of 0%.
Superelevation Runoff (L) 3 ↔ 6	The distance from the station where the high side of the superelevating section surfaces are at a cross slope of 0% to the station where the entire cross section is at full superelevation.
Superelevation Transition 2 ↔ 6	The distance from the station where the high side of the superelevating sections are crowned at a cross slope of 2% to the station where the entire cross section is at full superelevation. The Crown Runoff Length plus the Superelevation Runoff Length (L) equals the Superelevation Transition Length.
%L On tangent	The percentage of the superelevation runoff length (L) that is outside of the curve (2/3L). See Index 202.5(2).
%L On curve	The percentage of the superelevation runoff length (L) that is within the curve (1/3L). See Index 202.5(2). The % On Tangent and % On curve values must total 100%.



Elements of a Superelevation Transition (Right Curve)

Figure 206.2
Typical Two-lane to Four-lane Transitions



lanes are dropped prior to the merge with the through facility, the recommended taper is 50:1 for design speeds over 45 miles per hour, and the taper distance should be equal to WV for speeds below 45 miles per hour.

The "Ramp Meter Design Guidelines" also provide information on recommended and minimum tapers for ramp lane merges. These guideline values are typically used in retrofit or restricted right-of-way situations, and are acceptable for the specific conditions stated in the guidelines.

Figure 405.9 shows the standard taper to be used for dropping an acceleration lane at a signalized intersection. This taper can also be used when transitioning median acceleration lanes.

Figures 405.2A, B and C show the recommended methods of transitioning pavement back into the median area on conventional highways after the elimination of left-turn lanes.

(3) *Lane Reductions.* At any location where lane widths are being reduced, the minimum length over which to accomplish the transition should be equal to WV. See Index 504.6 for mainline lane reductions at interchanges.

(4) *Shoulder Reduction.* Shoulder reductions should typically occur over a length equal to ¾WV. However, when shoulder widths are being reduced in conjunction with a lane addition or widening (as in Alt. A of Figure 504.3J), the shoulder reduction should be accomplished over the same distance as the addition or widening.

206.4 Temporary Freeway Transitions

It is highly desirable that the design standards for a temporary transition between the end of a freeway construction unit and an existing highway should not change abruptly from the freeway standards. Temporary freeway transitions must be reviewed by the District approval authority or Project Delivery Coordinator, depending upon the current District Design Delegation Agreement.

Topic 207 - Airway-Highway Clearances

207.1 Introduction

(1) *Objects Affecting Navigable Airspace.* An object is considered an obstruction to air navigation if any portion of that object is of a height greater than the approach and transitional surfaces extending outward and upward from the airport runway. These objects include overhead signs, light standards, moving vehicles on the highway and overcrossing structures, equipment used during construction, and plants.

(2) *Reference.* The Federal Aviation Administration (FAA) has published Federal Aviation Regulation (FAR) Part 77 relative to airspace clearance entitled, Safe, Efficient Use, and Preservation of the Navigable Airspace, dated July 21, 2010. This is an approved reference to be used in conjunction with this manual.

207.2 Clearances

(a) Civil Airports--See Figure 207.2A.

(b) Heliports--See Figure 207.2B.

(c) Military Airports--See Figure 207.2C.

(d) Navy Carrier Landing Practice Fields--See Figure 207.2D.

207.3 Submittal of Airway-Highway Clearance Data

The following procedure must be observed in connection with airway-highway clearances in the vicinity of airports and heliports.

Notice to the FAA is required when highway construction is planned near an airport (civil or military) or a heliport. As a practical guide, the need to provide notice to the FAA should be reviewed any time construction or alteration is planned within 5 miles of an airport. A "Notice of Proposed Construction or Alteration" must be submitted to the FAA Administrator when required under criteria listed in Paragraph 77.9 of the latest Federal Aviation Regulations, Part 77. Such notice should be given as soon as highway alignment and grade are firmly established. However, at a minimum except for certain emergency situations outlined in FAR Part

77, the notice must be provided at least 45 days before the start date of the proposed construction or alteration or the date an application for a construction permit is filed, whichever is earlier. It should be noted that these requirements apply to both permanent objects and construction equipment. Electronic filing of FAA Form 7460-1, "Notice of Proposed Construction", is preferred by the FAA. This form and guidance for the submission may be found at https://oeaaa.faa.gov/oeaaa/external/portal.jsp.

When required, four copies of FAA Form 7460-1, and accompanying scaled maps should be sent to:

Mail Processing Center
Federal Aviation Administration
Southwest Regional Office
Obstruction Evaluation Group
10101 Hillwood Parkway
Fort Worth, TX 76177
Fax: (817) 222-5920

Copies of FAA Form 7460-1 may be obtained from the Caltrans, Division of Aeronautics or at https://oeaaa.faa.gov/oeaaa/external/portal.jsp.

The scaled maps accompanying FAA Form 7460-1 should contain the following minimum information.

- Distance from project to nearest runway.
- Elevation of runway thresholds.
- Relationship between the proposed highway horizontal alignment and vertical profile to the nearest runway or heliport primary surface. Include elevations of objects referenced to the elevation of the end of the runway, such as overhead lights, signs, structures, landscaping, and vehicles.

One copy of FAA Form 7460-1 should be forwarded to the Division of Design for information and one copy to the Division of Aeronautics for information and land use compatibility review.

Topic 208 – Bridges, Grade Separation Structures, and Structure Approach Embankment

208.1 Bridge Lane and Shoulder Width

(1) *State Highways.* **The clear width of all bridges, including grade separation structures, shall equal the full width of the traveled way and paved shoulders on the approaches with the following exceptions:**

(a) Bridges to be constructed as replacements on existing 2-lane, 2-way roads shall not have less than a 32-foot wide roadbed for ADT less than 400, and not less than 40-foot wide roadbed for ADT greater than 400. (see Index 307.2).

(b) When the approach shoulder width is less than 4 feet, the minimum offset on each side shall be 4 feet, and shall be documented in accordance with Index 82.2.

The width should be measured normal to the center line between faces of curb or railing measured at the gutter line. For offsets to safety shape barriers see Figure 208.1.

For horizontal and vertical clearances, see Topic 309.

(2) *Roads Under Other Jurisdictions.*

(a) Overcrossing Widths--(See Index 308.1)

(b) Undercrossing Span Lengths--Initial construction should provide for the ultimate requirements. In areas where the local jurisdiction has a definite plan of development, the ultimate right of way width or at least that portion needed for the roadbed and sidewalks should be spanned.

If the undercrossing street or road has no median, one should be provided where necessary to accommodate left-turn lanes or the center piers of the undercrossing structure.

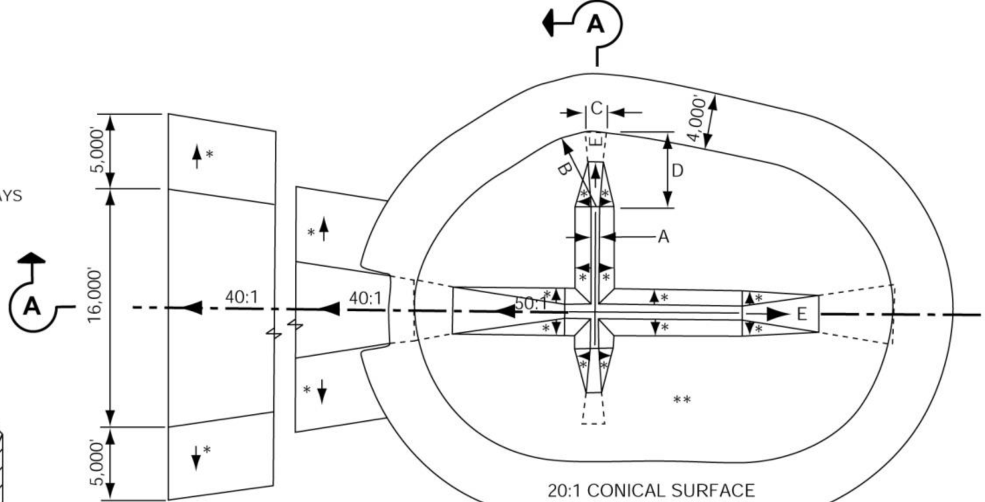
Where it appears that a 2-lane road will be adequate for the foreseeable future, but no right of way width has been established, a minimum span length sufficient for a 40-foot roadbed should be provided. Additional span length should be provided to permit future sidewalks where there is a foreseeable need. If it is reasonably foreseeable that more than two lanes will be required ultimately, a greater width should be spanned.

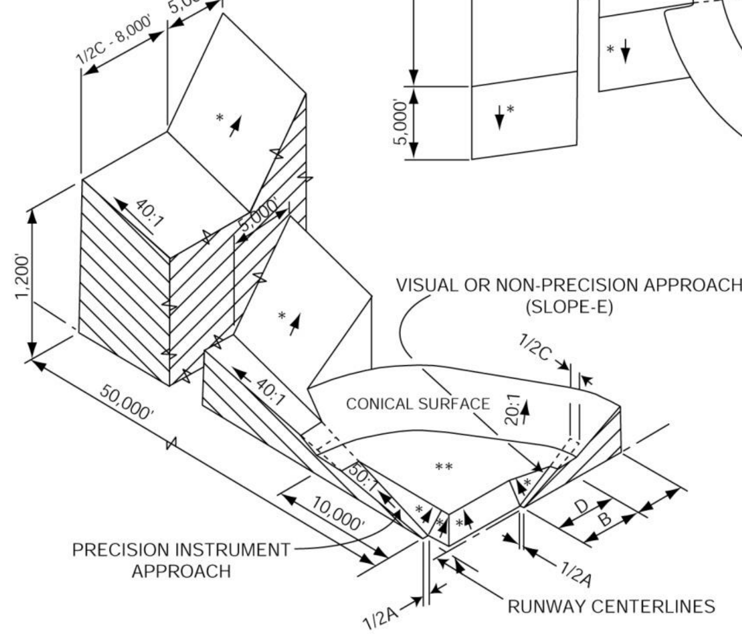
Figure 207.2A
Airway-Highway Clearance Requirements (Civil Airports)

* 7:1

** HORIZONTAL SURFACE 150' ABOVE ESTABLISHED AIRPORT ELEVATION

*** 16'-6" FREEWAYS
15'-0" CONVENTIONAL HIGHWAYS AND LOCAL ROADS
10'-0" PRIVATE ROADS





ISOMETRIC VIEW OF SECTION A-A

RUNWAY STANDARDS						
TYPES OF RUNWAY		VISUAL RUNWAY		NON-PRECISION INSTRUMENT RUNWAY		PRECISION INSTRUMENT RUNWAY
		I	II	I	II	
					III / IV	
DIM	ITEM	DIMENSIONAL STANDARDS (FEET)					
A	WIDTH OF PRIMARY SURFACE AND APPROACH SURFACE WIDTH AT INNER END	250	500	500	500 / 1,000	1,000
B	RADIUS OF HORIZONTAL SURFACE	5,000	5,000	5,000	10,000 / 10,000	10,000
C	APPROACH SURFACE WIDTH AT END	1,250	1,500	2,000	3,500 / 4,000	16,000
D	APPROACH SURFACE LENGTH	5,000	5,000	5,000	10,000 / 10,000	★
E	APPROACH SLOPE	20:1	20:1	20:1	34:1 / 34:1	★

I UTILITY RUNWAY
II RUNWAYS LARGER THAN UTILITY
III VISIBILITY MINIMUMS GREATER THAN 3/4 MILE
IV VISIBILITY MINIMUMS AS LOW AS 3/4 MILE
★ PRECISION INSTRUMENT APPROACH SLOPE IS 50:1 FOR INNER 10,000 FEET AND 40:1 FOR AN ADDITIONAL 40,000 FEET

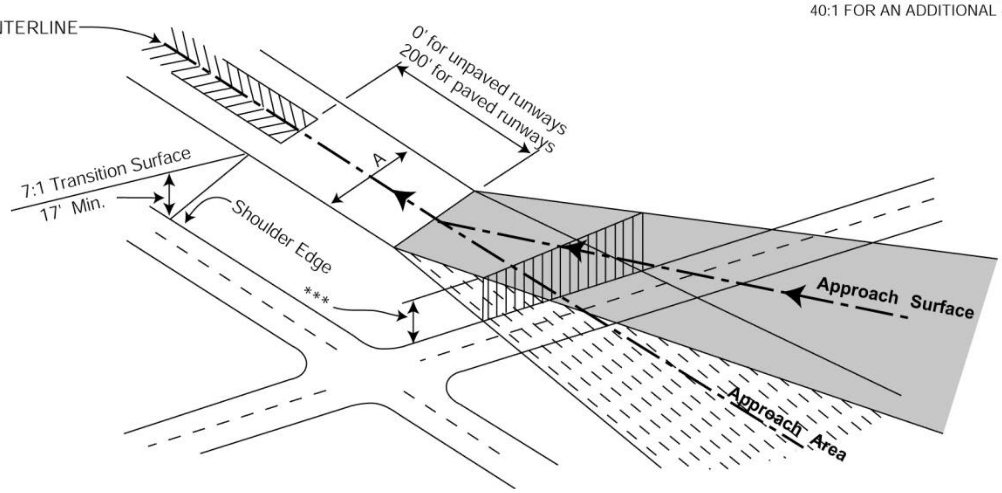
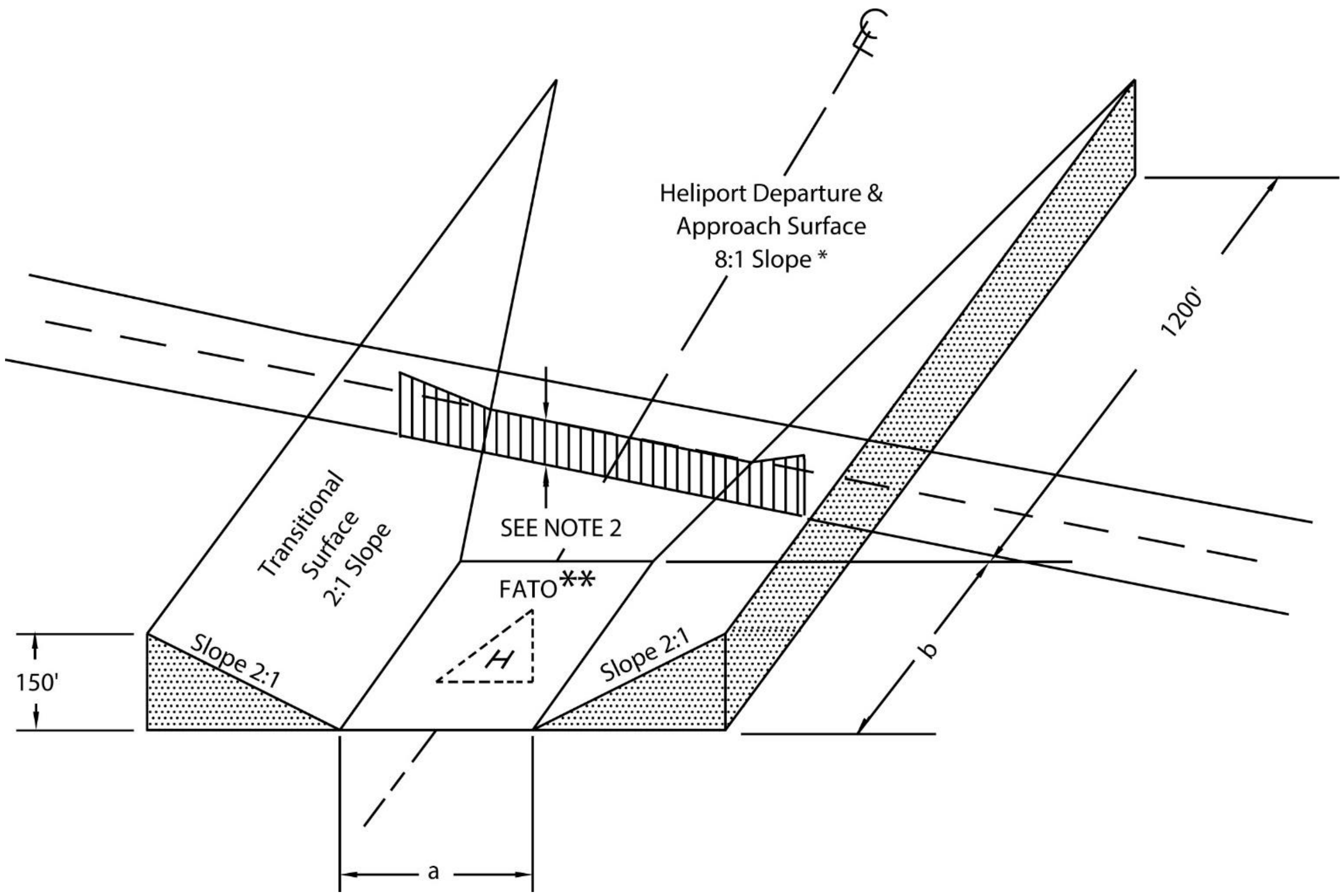


Figure 207.2B
Airway-Highway Clearance Requirements (Heliport)



NOTES:

(1) FATO dimensions “a” and “b” are equal to one and one-half times the overall length of the design helicopter, except for transport category heliports, where “a” equals two times the rotor diameter (100 feet Min.) and “b” equals two-times the rotor diameter (200 feet Min.). Check with heliport owner to verify helicopter category.

(2) Minimum vertical clearance is 17'-0" for freeways and 15'-0" for conventional highways and local roads, and 10'-0" for private roads.

(3) Contact the heliport owner/operator to determine the approved approach/departure paths.

Highway Clearance: Profile at pavement edge near airfield

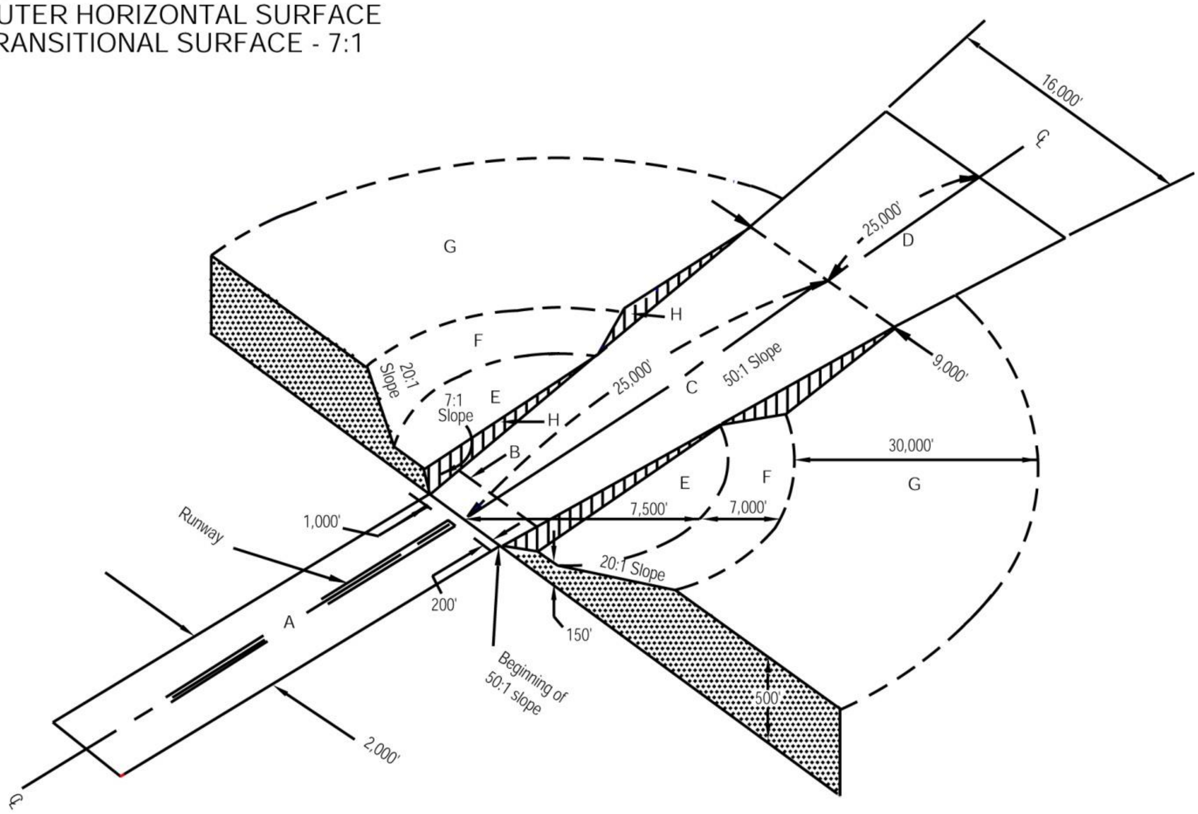
* 10:1 for Military Heliports

** Final Approach/Take Off Area

Figure 207.2C
Airway-Highway Clearance Requirements (Military Airports)

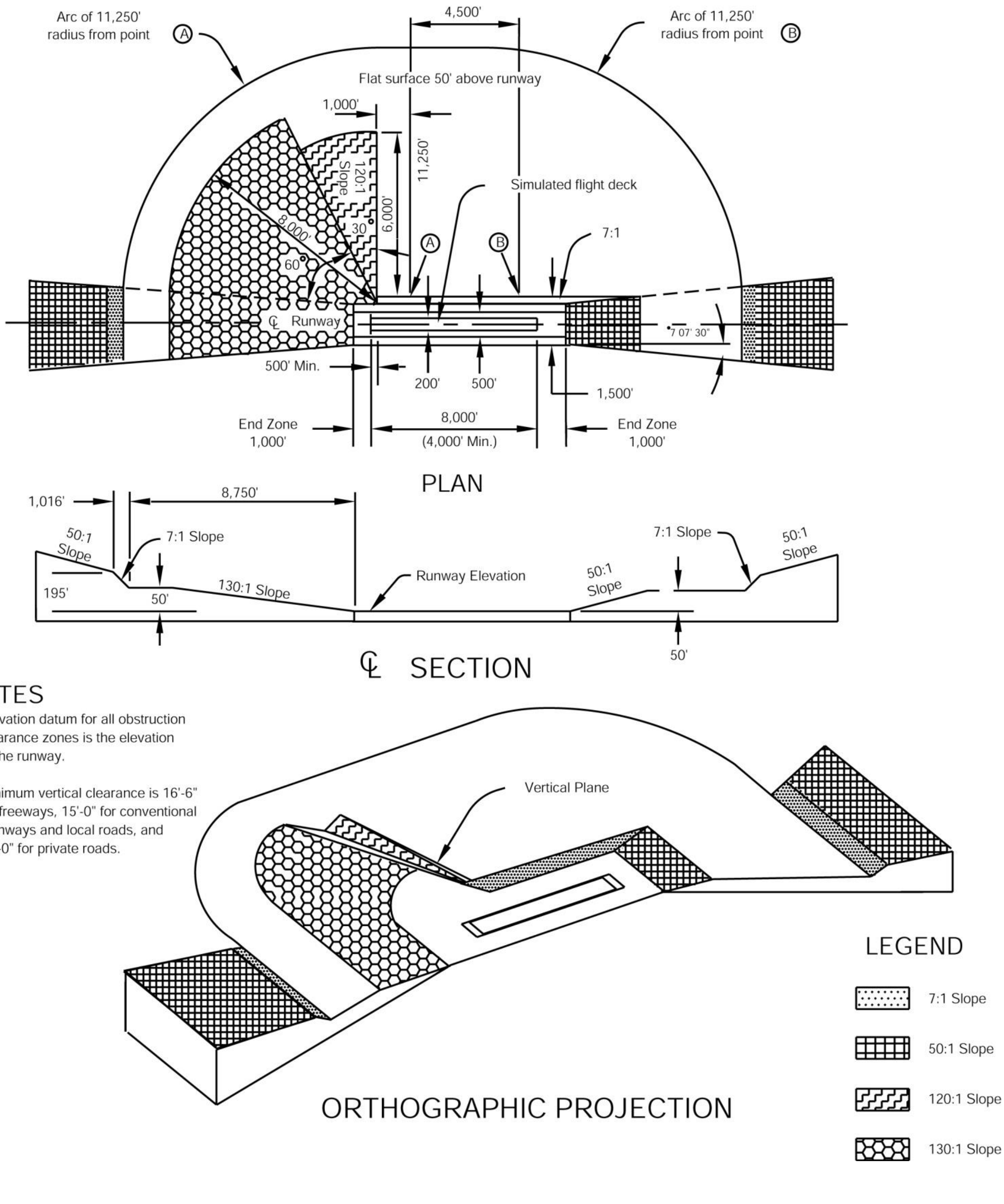
LEGEND

A- PRIMARY SURFACE
B- CLEAR ZONE SURFACE
C- APPROACH - DEPARTURE CLEARANCE SURFACE (GLIDE ANGLE) - 50:1
D- APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E- INNER HORIZONTAL SURFACE
F- CONICAL SURFACE - 20:1
G- OUTER HORIZONTAL SURFACE
H- TRANSITIONAL SURFACE - 7:1



NOTE:
MINIMUM VERTICAL CLEARANCE IS 16'-6" FOR FREEWAYS, 15'-0" FOR CONVENTIONAL HIGHWAYS AND LOCAL ROADS, AND 10'-0" FOR PRIVATE ROADS.

Figure 207.2D
Airway-Highway Clearance Requirements
(Navy Carrier Landing Practice Field)



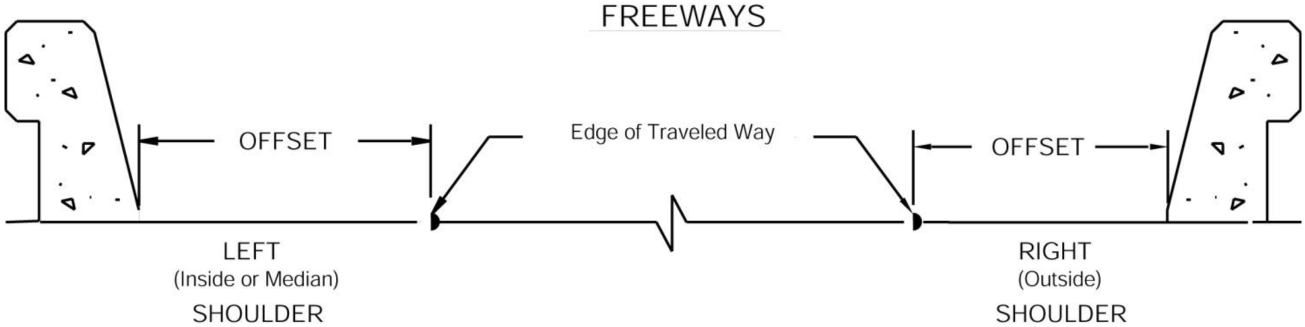
NOTES

1. Elevation datum for all obstruction clearance zones is the elevation of the runway.

2. Minimum vertical clearance is 16'-6" for freeways, 15'-0" for conventional highways and local roads, and 10'-0" for private roads.

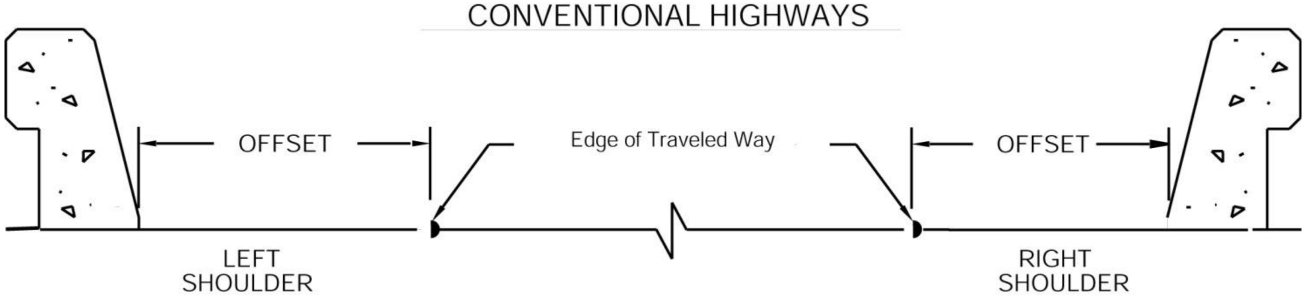
Figure 208.1
Offsets to Safety-Shape Barriers

FREEWAYS



Approach Shoulder Width	Left Shoulder	Right Shoulder
* 2' & 4' (Ramps)	4'	4'
5'	5'	5'
8'	8'	8'
10'	10'	10'

CONVENTIONAL HIGHWAYS



Approach Shoulder Width	Left Shoulder	Right Shoulder
* 2' & 4'	4'	4'
8'	8'	8'

* See Index 208.1(1)(b)

(c) For horizontal and vertical clearances, see Topic 309.

208.2 Cross Slope

The crown is normally centered on the bridge except for one-way bridges where a straight cross slope in one direction should be used. The cross slope should be the same as for the approach pavement (see Index 301.3 and Index 203.9).

208.3 Median

On multilane divided highways a bridge median that is 36 feet wide or less should be decked. Exceptions require individual analysis. See Traffic Safety Systems Guidance for median barrier warrants.

208.4 Bridge Sidewalks

Sidewalks on bridges should be provided wherever there are sidewalks or other pedestrian facilities that follow the highway. **The minimum width of a bridge sidewalk shall be 6 feet.** The recommended width should be 8 feet for pedestrian comfort. Bridges sidewalks in area types (see Index 81.2) with high levels of pedestrian activity may need to be greater than 8 feet (see Figure 208.10B).

208.5 Open End Structures

Embankment end slopes at open end structures should be no steeper than 1½:1 for all highways.

208.6 Bicycle and Pedestrian Overcrossings and Undercrossings

A bicycle overcrossing (BOC) or undercrossing (BUC) is a facility that provides a connection between bikeways or roads open to bicycling. They are considered Class I bikeways, or in certain situations may be considered Class IV bikeways. See Index 1003.1 for Class I bikeway guidance or DIB 89 for Class IV bikeways (separated bikeways) guidance.

A pedestrian overcrossing (POC) or undercrossing (PUC) is a facility that provides a connection between pedestrian walkways.

The minimum width of walkway for pedestrian overcrossing should be 8 feet. The minimum vertical clearance of a pedestrian undercrossing should be 10 feet. Skewed crossings should be avoided.

Class I bikeways are designed for the exclusive use of bicyclists and pedestrians; equestrian access is prohibited. See Chapter 1000 for Class I bikeway design guidance and Index 208.7 for equestrian undercrossing guidance. For additional information about the need to separate bicyclists from equestrian trails, see Index 1003.4.

POC's and PUC's must be designed to comply with DIB 82.

See Topic 309 for vertical clearances.

208.7 Equestrian Undercrossings and Overcrossings

Such structures should normally provide a clear opening 10 feet high and 10 feet wide. Skewed crossings should be avoided. The structure should be straight so the entire length can be seen from each end. Sustained grades should be a maximum of 10 percent. Decomposed granite or similar material should be used for the trail surface. While flexible pavement is permissible, a rigid pavement should not be used. See Index 1003.4 for separation between bicycle paths and equestrian trails. See DIB 82 for when trails are open to pedestrians.

Design guidance for equestrian overcrossings is pending.

208.8 Cattle Passes, Equipment, and Deer Crossings

Private cattle passes and equipment crossings may be constructed when economically justified by a right of way appraisal, as outlined in Section 7.09.09.00 of the Right of Way Manual.

The standard cattle pass should consist of either a standard box culvert with an opening 8 feet wide and 8 feet high or a metal pipe 120 inches in diameter. The invert of metal pipe should be paved with concrete or bituminous paving material.

If equestrian traffic is expected to use the culvert a minimum 10 feet wide by 10 feet high structure may be provided. However, the user of the facility should be contacted to determine the specific requirements.

If conditions indicate a reasonable need for a larger than standard cattle pass, it may be provided if economically justified by the right of way appraisal.

In some cases the installation of equipment or deer crossings is justified on the basis of public interest or need rather than economics. Examples are:

(a) A deer crossing or other structure for environmental protection purposes.

(b) Equipment crossings for the Forest Service or other governmental agencies or as a right of way obligation.

These facilities should be installed where necessary as determined by consultation with the appropriate affected entities.

A clear line of sight should be provided through the structure.

208.9 Railroad Underpasses and Overheads

Generally, it is desirable to construct overheads rather than underpasses whenever it is necessary for a highway and railroad to cross. Railroads should be carried over highways only when there is no other reasonable alternative.

Some undesirable features of underpasses are:

(a) They create bottlenecks for railroad operations.

(b) It is difficult to widen the highway.

(c) Pumping plants are often required to drain the highway.

(d) They are likely to lead to cost participation controversies for initial and future construction.

(e) Shooflies (temporary tracks) are generally required during construction.

(f) Railroads are concerned about the structure maintenance and liability costs they incur.

Advantages of overheads are:

(a) Railroads can use most of their right of way for maintenance.

(b) Overheads can be widened at a relatively low cost and with little difficulty.

(c) Less damage may be incurred in the event of a derailment.

(d) Agreements for design and maintenance can be reached more easily with railroads.

(e) Initial costs are generally lower.

The State, the railroads, and the public in general can usually benefit from the construction of an overhead structure rather than an underpass. See Topic 309 for vertical clearances.

208.10 Bridge Barriers and Railings

(1) *General.* There are four classes of railings, each intended to perform a different function.

(a) Vehicular Barrier Railings--The primary function of these railings is to retain and redirect errant vehicles.

(b) Combination Vehicular Barrier and Pedestrian Railings--These railings perform the dual function of retaining both vehicles and pedestrians on the bridge. They consist of two parts--A concrete parapet barrier, generally with a sidewalk, and metal handrailing or fence-type railing.

(c) Pedestrian Railings--These railings prevent pedestrians from accidentally falling from the structure and, in the case of fence-type railing, reduce the risk of objects being dropped on the roadway below. See DIB 82 for additional requirements.

(d) Bicycle Railings--These railings retain bicycles and riders on the structure. They may be specifically designed for bicycles, or may be a combination type consisting of a vehicular barrier surmounted by a fence or metal handrail.

(2) *Policies.* <u>To reduce the risk of objects being dropped or thrown upon vehicles, protective screening in the form of fence-type railings should be installed along new overcrossing structure sidewalks in urban areas (Sec. 92.6 California Streets and Highways Code)</u>. Screening should be considered for the opposite side of structures having one sidewalk. Screening should be installed at such other locations determined to be appropriate.

Railings and barriers with sidewalks should not be used on structures with posted speeds greater than 45 miles per hour without barrier separation. All structure railings with a sidewalk in the Standard Plans are approved for posted speeds up to 45 miles per hour. **Any use of railings and barriers with sidewalks on**

structures with posted speeds greater than 45 miles per hour shall have a barrier separation between the roadway and the sidewalk. The barrier separation type and the bridge rail selection requires approval by the District Traffic Engineer or designee.

The approved types of railings for use on bridge structures are listed below and illustrated in Figures 208.10A, B, and C. Railing types not listed are no longer in general use; however, they may be specified in those cases where it is desirable to match an existing condition.

The District should specify in the bridge site data submittal the rail type to be used after consideration has been given to the recommendations of the local agency (where applicable) and the DES-SD.

Barriers and railings are denoted by crash testing criteria and crash test level (TL). For more information on the crash test level, see the Traffic Safety Systems Guidance, Table 1, issued by the Division of Traffic Operations.

(3) *Vehicular Barriers.* See Figure 208.10A.

(a) Concrete Barrier Type 836 and 842 are TL-4 systems and satisfy the Manual for Assessing Safety Hardware (MASH 2016)--These vehicular barriers are for general use adjacent to traffic. Figure 208.1 illustrates the position of the barrier relative to the edge of traveled way.

(b) Concrete Barrier Type 80 and bridge metal rail barriers--Use of these barriers is intended in scenic areas where more see-through area is desired than is provided by a solid concrete parapet. These TL-4 barriers satisfy NCHRP Report 350.

(c) California ST-70SM Side Mounted Bridge Rail--This TL-4 steel barrier is 42 inches in height. This vehicular barrier is for general use adjacent to traffic. This barrier is especially useful when there are right-of-way issues or space limitations. This barrier satisfies MASH 2016.

(d) California ST-75 Bridge Rail—This TL-4 steel barrier is 36 inches in vehicular railing height and 42 inches in bicycle railing height. This combination vehicular barrier is for general use adjacent to traffic. This barrier replaces NCHRP Report 350 compliant California ST-70 or California ST-20S Bridge Rails. This barrier satisfies MASH 2016.

(e) Concrete Barrier Type 85—This TL-4 concrete barrier is 36 inches in vehicular railing height and 42 inches in bicycle railing height. This combination vehicular barrier is for general use adjacent to traffic. This barrier replaces NCHRP Report 350 compliant Concrete Barrier Type 80.

(4) *Combination Railings.* See Figure 208.10B.

(a) Concrete Barrier Type 732SW--This is TL-2 bridge railing for general use when sidewalks are provided on a bridge. It must be accompanied with a tubular handrailing or a fence-type railing. See Index 208.4 for minimum width, however, this width may be varied as circumstances require. This barrier satisfies MASH 2016.

(b) Concrete Barrier Type 80SW--Similar to the Concrete Barrier Type 80, modified with a raised integral sidewalk and tubular handrailing. This TL-2 barrier is intended for use in lower speed scenic areas where more see-through area is desired than is provided by a solid concrete parapet. See Index 208.4 for minimum width, however, this width may be varied as circumstances require. This barrier satisfies NCHRP Report 350.

(c) Aesthetic Low Maintenance Guardrail System--This TL-3 system is a combination railing (without integral sidewalk) of an aesthetic see-through bridge railing on a trench footing as an aesthetic low maintenance alternative to guardrail.

(d) Chain Link Railing Type 7--This is the fence-type railing for general use with Type 732SW or Type 80SW barrier railing with sidewalk to reduce the risk of objects being dropped off the edge of a structure. When a sidewalk is provided on one side of a bridge and Type 736 barrier railing on the other side, Type 7 railing may be placed on top of the Type 736 as additional protection from dropped objects. Consideration should be given to the effect of the Type 7 railing on sight distance at the bridge ends and view over the side of the bridge. Lighting fixtures may be provided with Type 7 railings.

(e) Chain Link Railing Type 6--This railing may be used in lieu of Type 7 when special architectural treatment is required. It should not be used on curved alignment because of fabrication difficulties.

(f) Tubular Handrailing--This railing is used with Type 732SW, and Type 80SW to increase the combined rail height for the safety of pedestrians. It should be used in lieu of Type 7 where object dropping will not be a problem or at the ends of bridges to increase sight distance if fence-type railing would restrict sight distance.

(5) Pedestrian Railings. See Figure 208.10C

(a) Chain Link Railing Type 3--This railing is used on pedestrian structures to reduce the risk of objects being dropped on the roadway below.

(b) Chain Link Railing Type 7 (Modified)--This railing is similar to Type 7 except that it is mounted on the structure at the sidewalk level.

(c) Chain Link Railing--This railing is not as high as Types 3 or 7 and therefore, its use is restricted to those locations where object dropping or throwing will not be a problem.

(d) Chain Link Railing (Modification)--Existing railing may be modified for screening under the protective screening policy. The DES-SD should be contacted for details.

(6) Bicycle Railing. The height of bicycle rail shall not be less than 42.0 inches, measured from the top of the riding surface. In some cases the bicycle railing shall be offset 15.0 inches behind the face of the vehicular rail. Contact DES, Office of Design and Technical Services for more information. Pedestrian railings and combination railings consisting of a concrete barrier surmounted by a fence or tubular railing are satisfactory for bicycles, if a minimum 42-inch height is met. Bicycles are not considered to operate on a sidewalk, except in special cases where signs specifically direct cyclists to use a bike path or the sidewalk.

As a general policy, bicycle railings should be installed at the following locations:

(a) On a Class I bikeway, except that a lower rail may be used if a curbed sidewalk, not signed for bicycle use, separates the bikeway from the rail or a shoulder at least 8 feet wide exists on the other side of the rail.

(b) On the outside of a Class II or III bikeway, unless a curbed sidewalk, not signed for bicycle use, separates the bikeway from the rail.

(c) In other locations where the designer deems it reasonable and appropriate.

(7) Bridge Approach Railings. **Approach railings shall be installed at the ends of bridge railings exposed to approach traffic.**

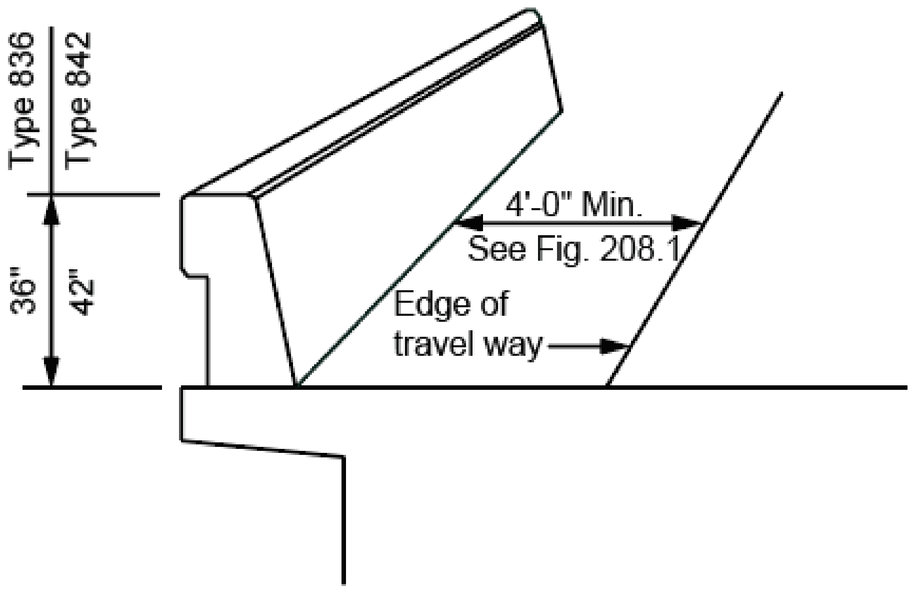
Refer to Traffic Safety Systems Guidance for placement and design criteria of guardrail.

208.11 Structure Approach Embankment

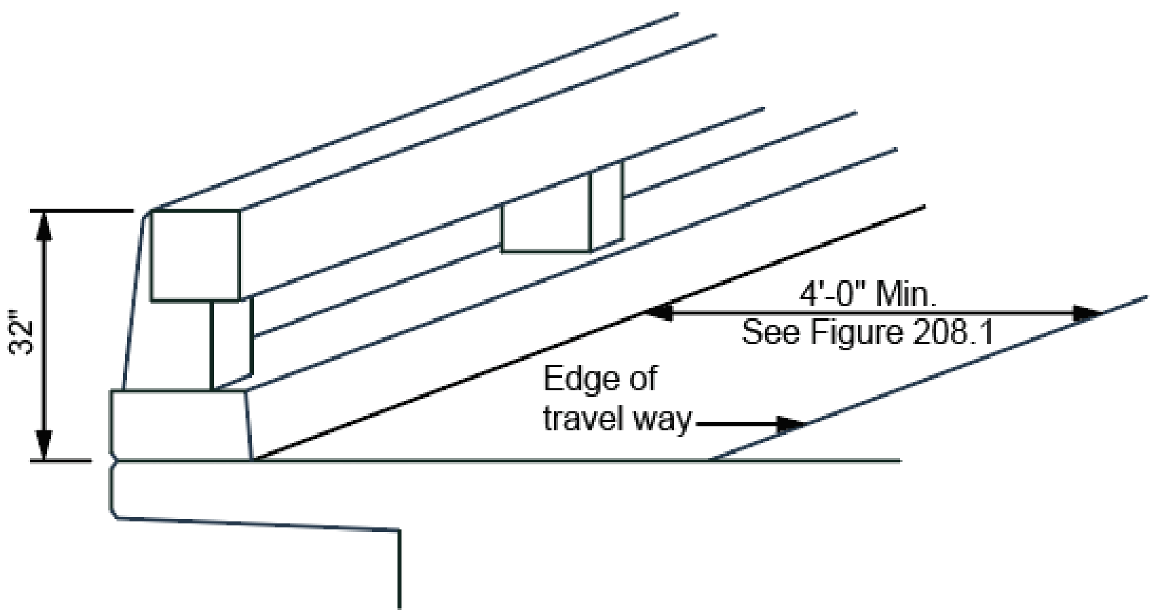
(1) General. Structure approach embankment is that portion of the fill material within approximately 150 feet longitudinally of the structure. Refer to Figure 208.11A for limits, the Standard Specifications, and Standard Special Provisions for more information.

Quality requirements for embankment material are normally specified only in the case of imported borrow. When select material or local borrow for use in structure abutment embankments is shown on the plans, the Resident Engineer (RE) is responsible for assuring the adequacy of the quantity and quality of the specified material. The Project Engineer should include adequate information and guidance in the RE File to assist the RE in fulfilling this responsibility.

Figure 208.10A
Vehicular Railings for Bridge Structures



CONCRETE BARRIERS TYPE 836 AND TYPE 842
(MASH 2016 Compliant)



CONCRETE BARRIER TYPE 80
(NCHRP Report 350 Compliant)

Figure 208.10B
Combination Vehicular Barrier and Pedestrian Railings for Bridge Structures

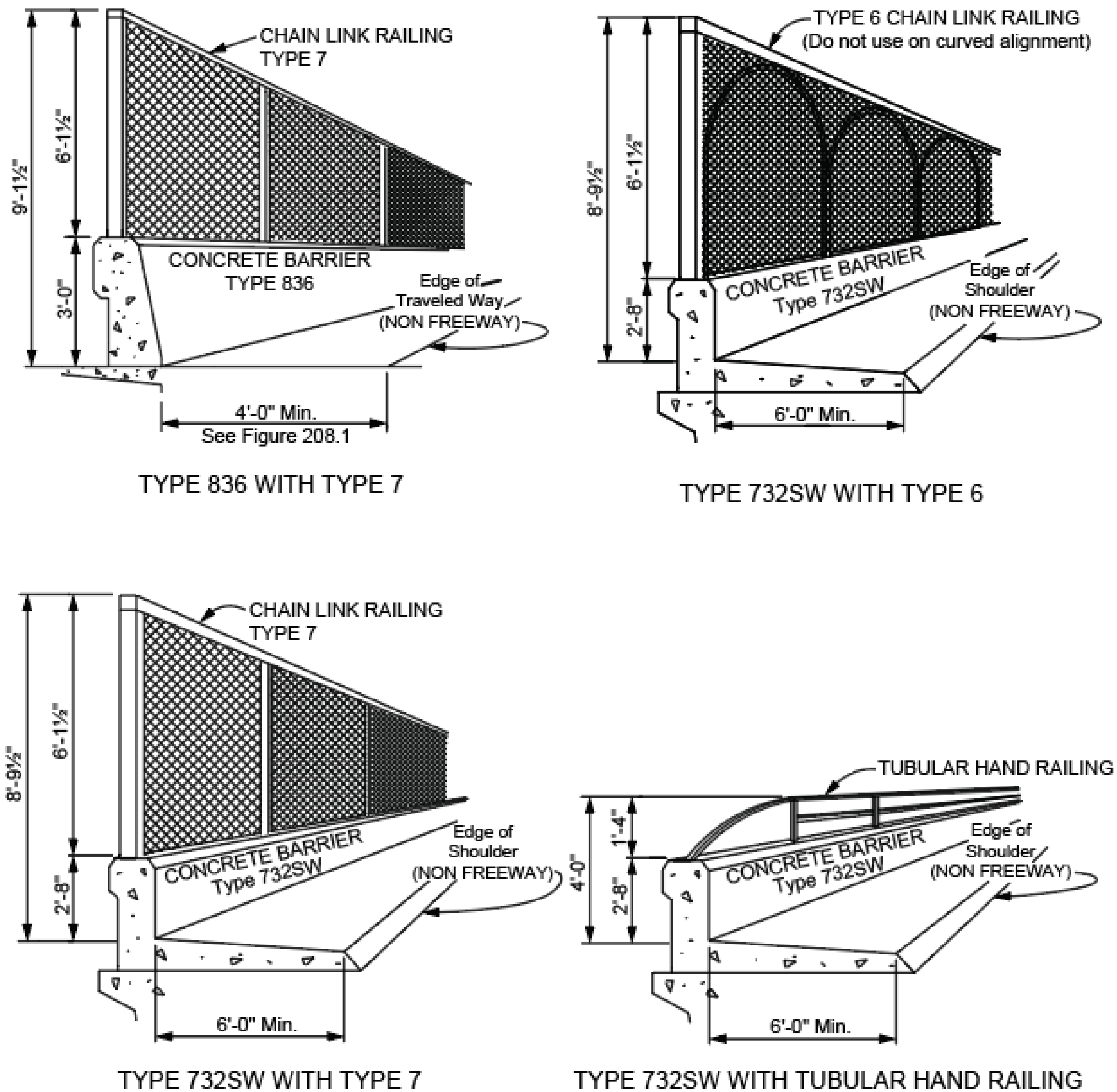
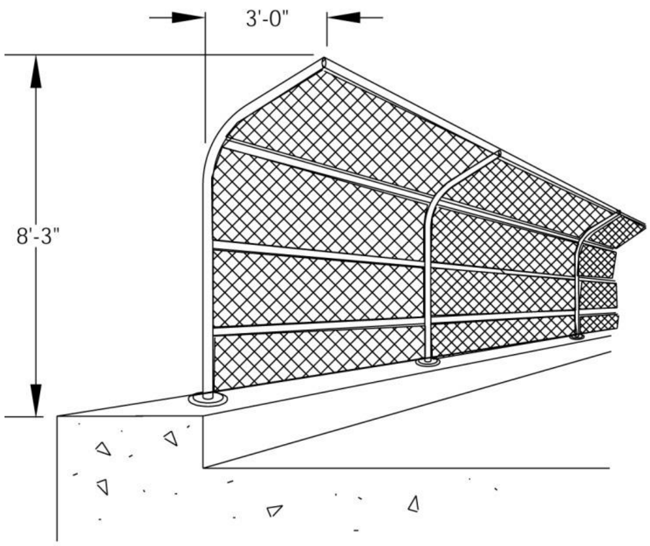
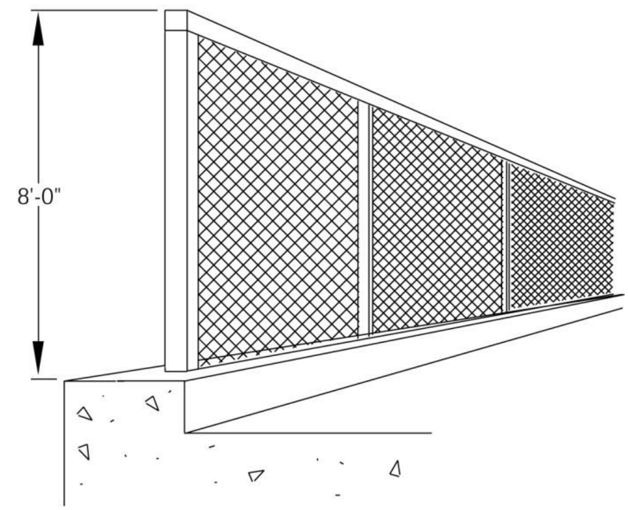


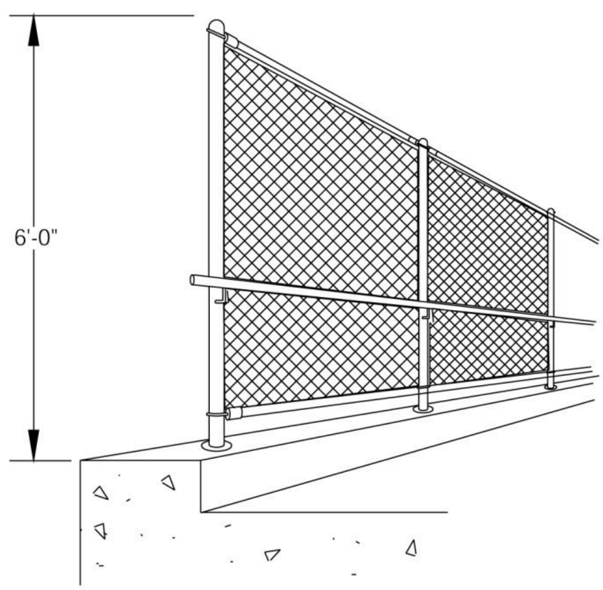
Figure 208.10C
Pedestrian Railings for Bridge Structures



CHAIN LINK RAILING TYPE 3



CHAIN LINK RAILING TYPE 7 (MODIFIED)



CHAIN LINK RAILING

(2) *Foundations and Embankment Design.* Overall performance of the highway approach to the bridge depends, to a significant degree, upon the long-term settlement/consolidation of the approach foundation and structure abutment embankment. A design that minimizes this post construction settlement/consolidation is essential. Factors that influence settlement/consolidation include soil types and depths, static and dynamic loads, ground water level, adjacent operations, and changes in any of the above. The PE must follow the foundation and embankment recommendations by the Division of Engineering Services, Geotechnical Services (DES-GS) and District Materials Engineer (DME). The DME and/or DES-GS must approve any deviations from their recommendations including Construction Change Orders (CCO's).

The relative compaction of material within the embankment limits must be at least 95 percent, except for the outer 5 feet of embankment measured horizontally from the side slope (see Figure 208.11A). The DME and/or OSF may recommend using select material, local and/or imported borrow to assure that the compaction requirements are met and that shrink/swell problems are avoided. They may also recommend a height and duration of embankment surcharge to accelerate foundation consolidation.

Poor quality material, such as expansive soils, must be precluded from structure abutment embankments unless treated. If sufficient quality roadway excavation material is unavailable for constructing of structure abutment embankments, the designer may specify select material, local borrow, or imported borrow to satisfy the design requirements.

(3) *Abutment Drainage.* Special attention must be given to providing a positive drainage system that minimizes the potential for water damage to the structure approach embankment, see Chapter 870 for further details. The Division of Engineering Services (DES), Structures Design (DES-SD) is responsible for the design of the structure approach drainage system, which includes:

- A geocomposite drain covered with filter fabric placed behind both the abutment wall and wingwalls, as indicated in Figure 208.11B.
- A slotted plastic pipe drain, encapsulated with treated permeable material, placed along the base of the inside face of the abutment wall as illustrated in Figure 208.11B.

(4) *Slope Treatment.* See Topic 707, Slope Treatment Under Structures, for guidance regarding the treatment of bridge approach end slopes.

The District Hydraulic Engineer or Project Engineer must design a pipe outlet that ties into the structure approach drainage system as it exits the structure. A pipe outlet system should carry the collected water to a location where it will not cause erosion. Storm Water Best Management Practices should be incorporated. For further information on Storm Water Management, visit the Division of Design Storm Water website.

Coordination with DES is necessary for the exit location of the pipe system. The outlet type should be chosen from the standard edge drain outlet types shown in the Standard Plans or tied into an underground drainage system. The PE must review the drainage design to ensure the adequacy of the drainage ties between the structure approach drainage system and either new or existing drainage facilities. For alternative details, see Bridge Design Aids.

Topic 209 - Structure Approach Slabs

Index 209.1 - Purpose and Application

(1) *Purpose.* The approaches to any structure, new or existing, often present unique geometric, drainage, pavement, and traffic situations that require special considerations.

Structure approach slabs provide a smooth transition between a pavement that is generally

Figure 208.11A

Limits of Structure Approach Embankment Material

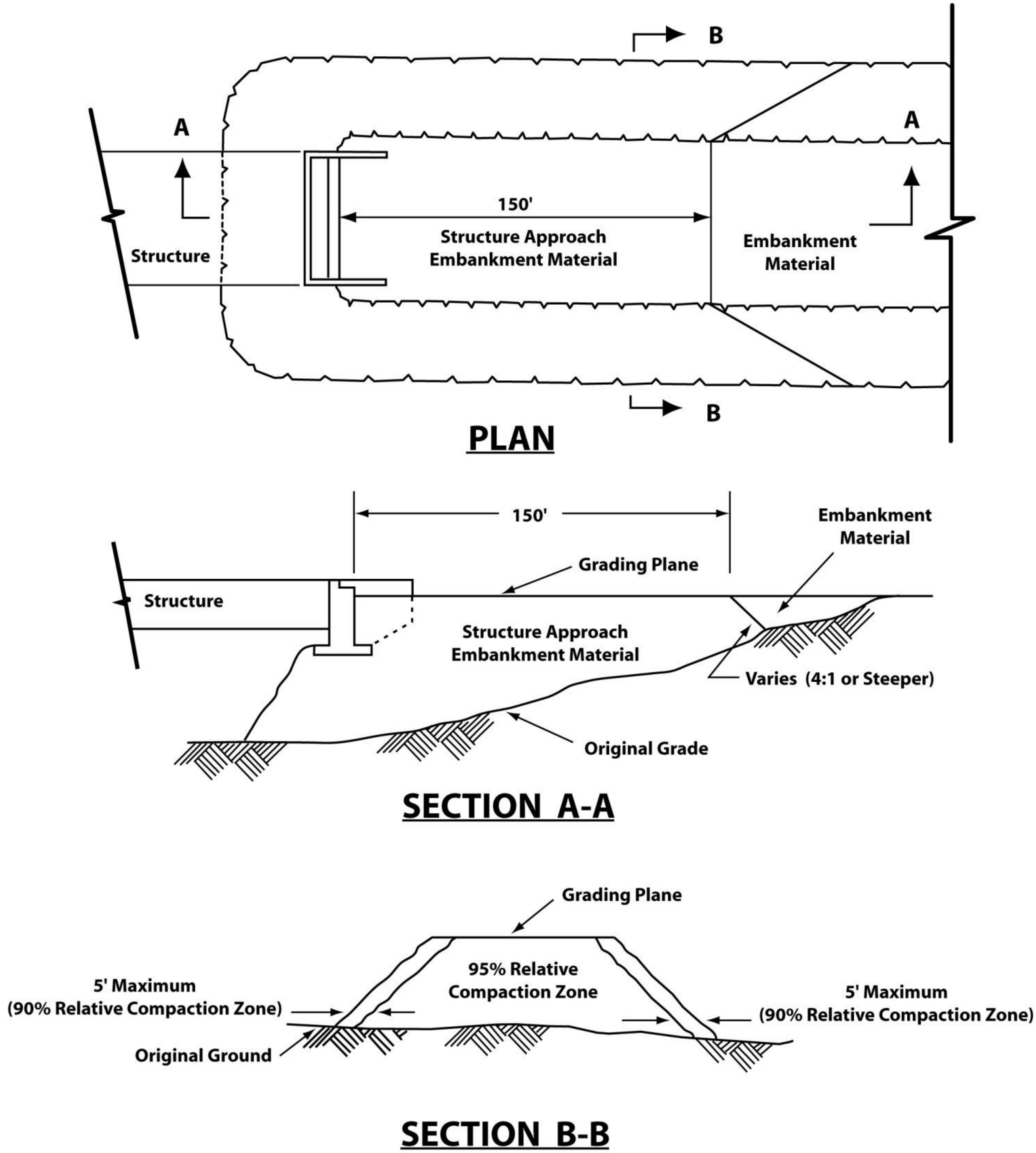
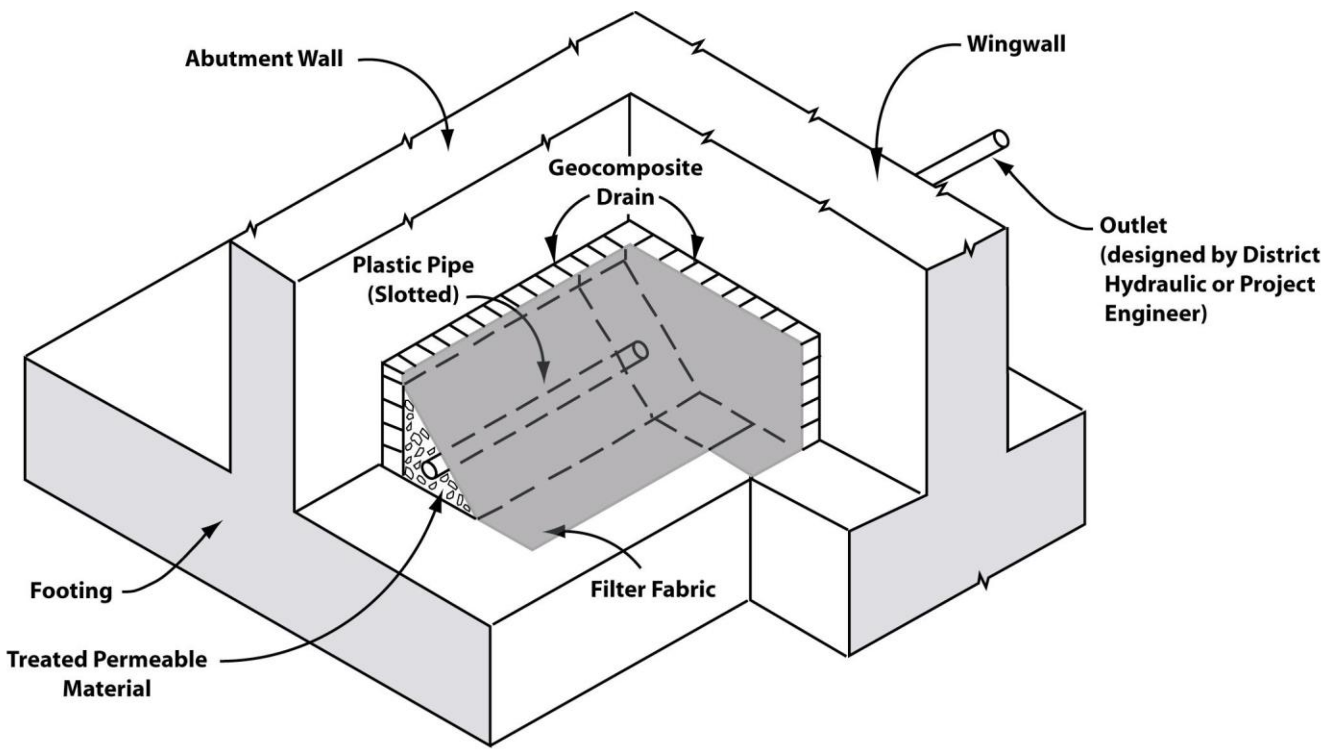


Figure 208.11B
Abutment Drainage Details



NOTES:
1. Applicable to new construction only.
2. Reference Structures Design Standard Detail XS22-17
3. All details shown are designed by the DES except where noted otherwise.
4. Outlet may be in wingwall of abutment wall.

supported on a yielding medium (soil that is subject to consolidation and settlement) and a structure, which is supported on a relatively unyielding foundation (bridge).

These guidelines should be followed in the engineering of all structure approach slab projects involving new construction, reconstruction, widening, preservation, or rehabilitation of structure approaches. They are not, however, a substitute for engineering knowledge, experience, or sound judgment.

(2) *Application.* There are several alternatives that may be considered in the design of a structure approach slab system. These alternatives are designated as Types 45, 30, and 10 structure approach slab systems. Standard details and special provisions for each type of approach slab system can be found on the Structure Design website. Figure 209.1 shows a generic structure approach slab system layout. Structure Design Bridge Memo 5-3 provides the criteria for the selection and design of structure approach slabs. In the event of discrepancies between this manual and Structure Design Bridge Memo 5-3, Memo 5-3 shall govern.

Structure approach slabs extend the full width of the traveled way and shoulders. The Division of Engineering Services (DES) will select the appropriate structure approach slab and provide applicable details, specifications, and an estimate of cost for inclusion in the Plans Specifications and Estimates (PS&E) package. The Project Engineer (PE) must coordinate with structure engineer to assure that the proper structure approach slab is included in the PS&E package.

On new construction projects, overcrossing structures constructed in conjunction with the State highway facility should receive the same considerations as the highway mainline.

209.2 General Considerations

(1) *Field Investigations.* Adequate information must be available early in the project development process if all factors affecting the selection and engineering of a structure approach slab system are to be adequately addressed. A field review will often reveal existing conditions, which must be taken into consideration during the design.

(2) *Load Transfer at Approach Slab/Concrete Pavement Joint*. No matter what structure approach slab alternative is being considered, it is recommended that dowel bars be placed at the transverse joint between the structure approach slab and new rigid pavement to ensure load transfer at the joint. If the structure approach slab is being replaced but the adjacent rigid pavement is not, a dowel bar retrofit is not necessary. The thinner of either the pavement or the structure approach slab will govern placement of the dowel bar at half the thickness of the thinner slab. The standard plans provide other details for transitions from the structure approach slabs to flexible pavement.

(3) *Barriers*. On new construction, the structure approach slab extends laterally to coincide with the edge of structure. Any concrete barriers next to the structure approach slab will therefore need to be placed on top of the structure approach slab are and part of the responsibilities of the structures engineer. The PE should coordinate with structure engineers to coordinate the limits and responsibility for barriers.

(4) *Guardrails*. The extension of the structure approach and sleeper slabs across the full width of the outside shoulder creates a conflict between the outside edge of these slabs and the standard horizontal positioning of some guardrail posts. Consult with district traffic branch if a conflict is encountered. See DES Standard Details and the Standard Plans.

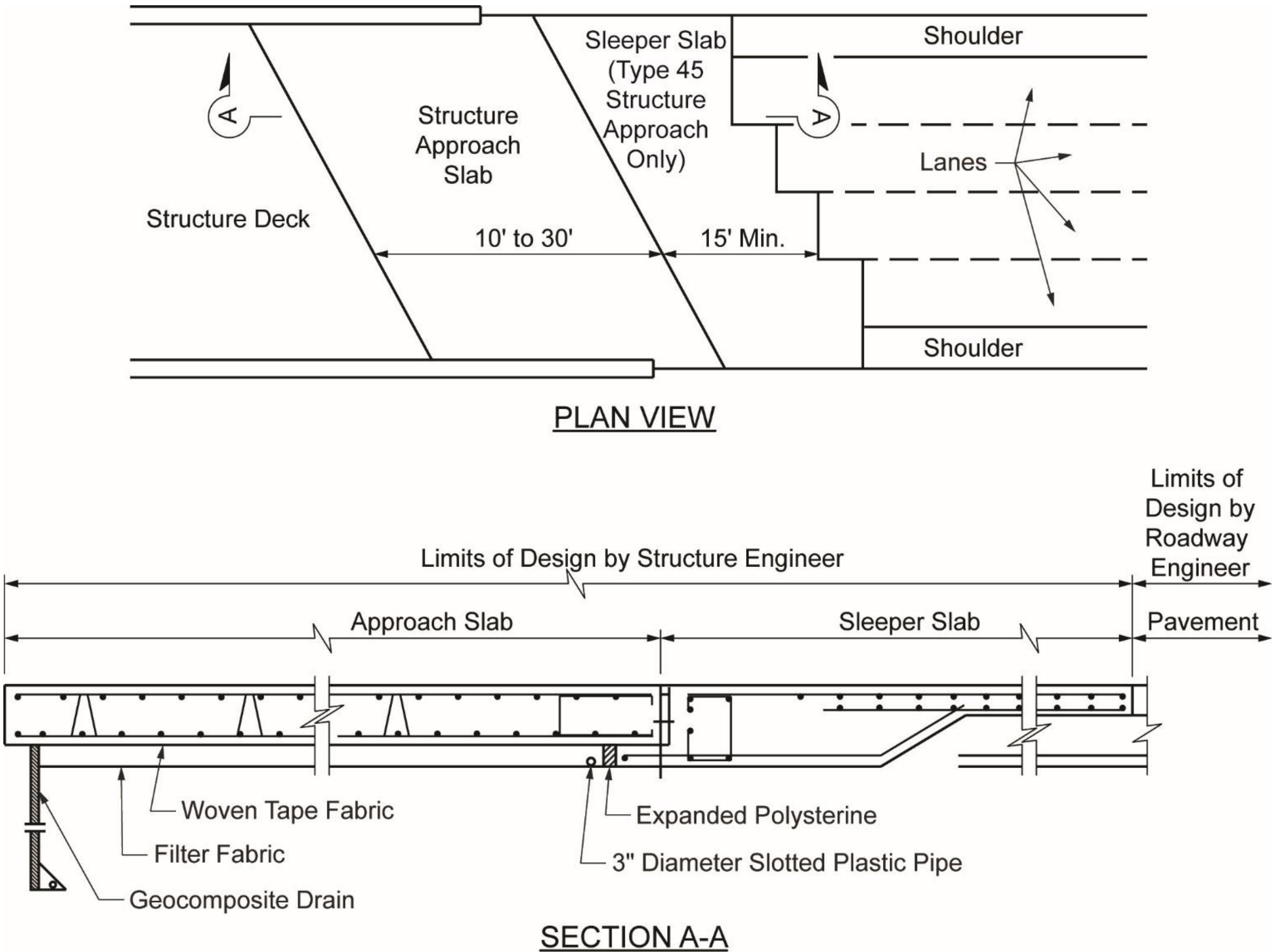
209.3 Structural Approach System Drainage

(1) *Subsurface Drainage*. Figure 209.1 shows the components of the positive structural drainage system. Filter fabric should be placed on the grading plane to minimize contamination of the treated permeable base (TPB) for all types of structure approach systems. The plastic pipe shall have a proper outlet to avoid erosion of

the structure approach embankment. On all new construction projects, regardless of the

Figure 209.1

Structure Approach Slab Layout



type of structure approach slab, provisions for positive drainage of the approach system should be incorporated into the design. See Structures Design Standard Details for requirements. The Districts are responsible for all drainage considerations for the roadway while DES Structures is responsible for structure related drainage. The structure engineer is responsible for engineering of both the approach slab and the drainage system, which normally drain through the wingwall. The highway engineer is responsible for engineering the collection and disposal system, which begins on the outside face of the wingwall.

(2) Surface Drainage. Roadway surface drainage should be intercepted before reaching the approach/sleeper slab. The objective is to keep water away from the structure approach embankment. The surface water, once collected, should be discharged at locations where it will not create erosion. Refer to Chapter 831 for more information.

209.4 Structure Approach Slab Rehabilitation Considerations

(1) Approach Slab Replacement. Approach slabs are replaced only when they exhibit sufficient cracking or patching that they are no longer maintainable as is. Structure Maintenance and Investigations (SMI) typically determines when an approach slab warrants replacement. Approach slabs that otherwise experience only rough ride, subsidence, or minor damage are ground, overlaid, or patched as recommended by SMI. Approach slab repairs are typically funded from one of the bridge repair programs in the SHOPP, but can also be funded from another fund program with the agreement of the Headquarters Program Manager for that program when no other bridge work is involved.

Replacement of a structural approach slabs consists of removing the existing pavement, approach slab, underlying base and subsealing material (if applicable) and then replacing with an appropriate type of structure approach system. Depending on the thickness of the existing surface and base layers to be removed, the minimum 1-foot approach slab thickness may have to be increased. The PE needs to make sure the structure engineer addresses this in their reports, plans, and specifications.

(2) Approach Slab Overlays. Asphalt pavement overlays should not be placed on structure decks and approach slabs without the concurrence of Structures Maintenance and Investigations (SMI). If an overlay is needed, SMI will provide the recommended strategy. If another strategy such as polyester concrete is used, either SMI or the Office of Structure Design (OSD) will provide the design details.

(*3) Structure Approach Slab Drainage*. Typical details for providing positive drainage of a full-width structure approach system are shown in Figure 209.4A. Cross drains are placed at the abutment backwall and at the transverse joint between the existing pavement and the structure approach slab by the structure engineer. A collector/outlet system is placed adjacent to the wingwall at the low side of pavement. The collected water is carried away from the structure approach slab at a location where it will not cause erosion. The PE is responsible for the engineering of the outlet for the structure approach slab drainage. Storm Water Best Management Practices should be considered.

Storm water guidelines are available on the Division of Design, Storm Water website.

The structure approach slab edge details to prevent entry of water at the barrier rail face apply when the wingwalls and/or bridge barrier railing are not being reconstructed.

(4) *Transition Details with Pavement Overlays.* Modification to structure approach slab thicknesses are advantageous when structure approach slabs will be replaced in conjunction with a pavement overlay strategy to promote a smooth transition between structure and pavement. Figure 209.4B, which is applicable to full-width slab replacement, illustrates a method of transitioning from an asphalt overlay thickness to a structure approach slab by tapering the thickness of the structure approach

Figure 209.4A
Structure Approach Drainage Details (Rehabilitation)

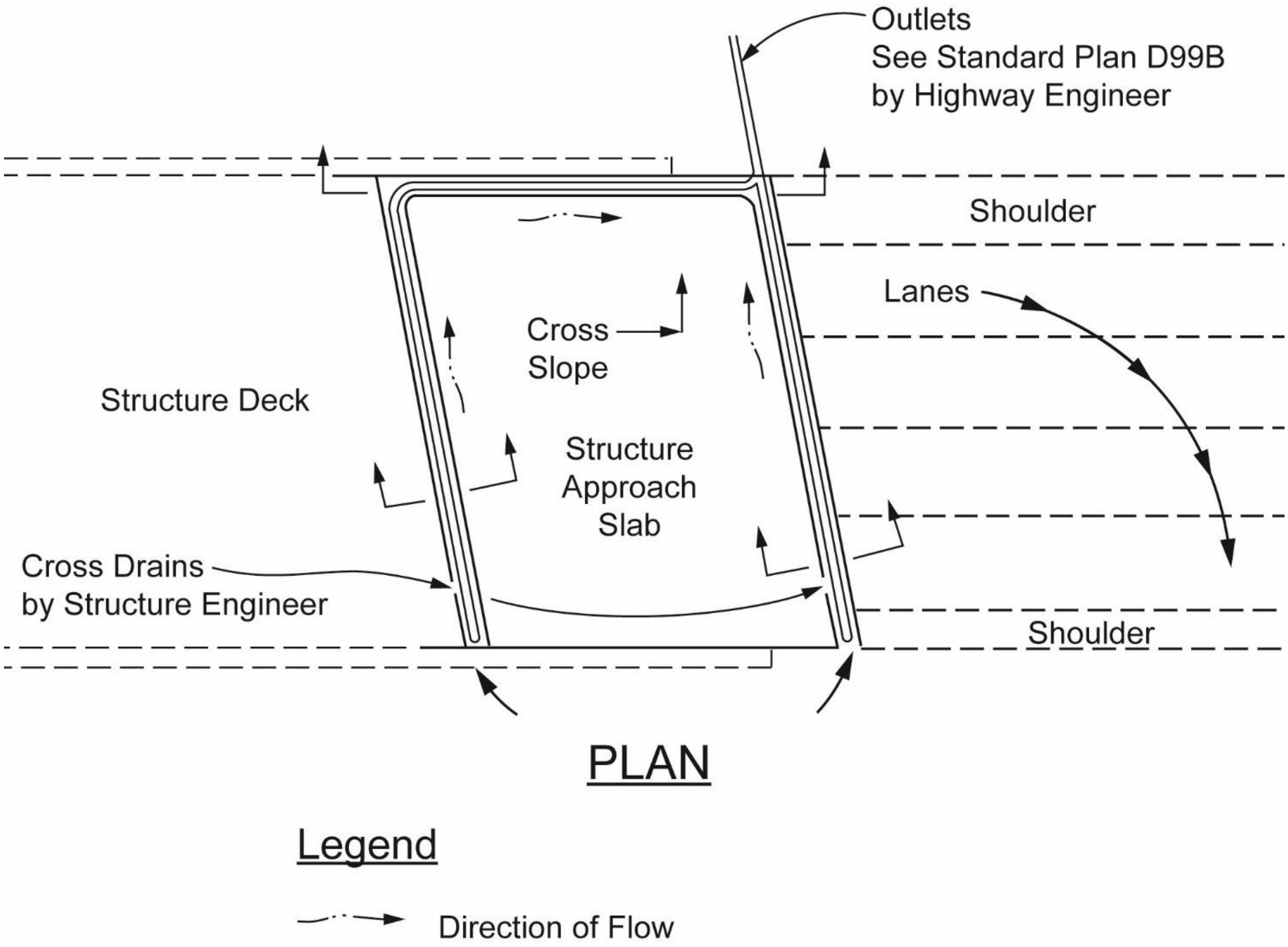
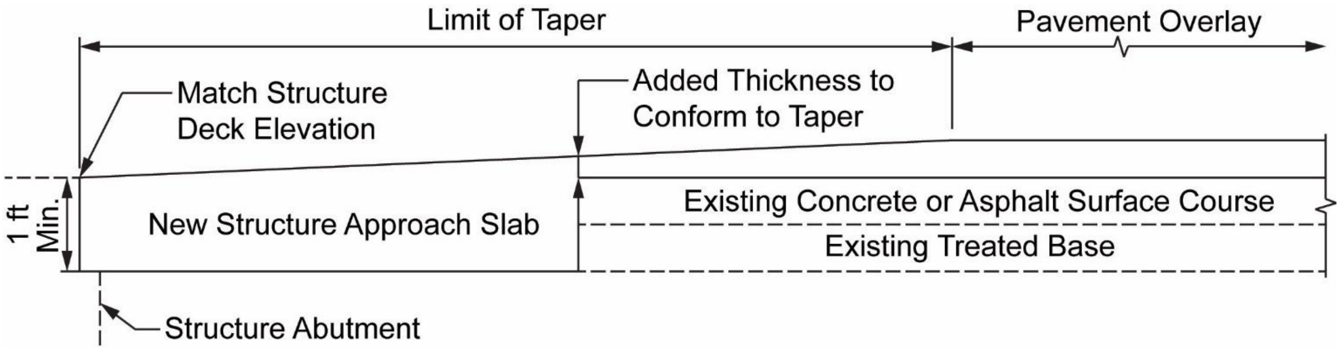


Figure 209.4B
New Structure Approach Pavement Transition Details



slab. Care should be taken in areas with flat grades to avoid creating a ponding condition at the structure abutment.

(5) Traffic Handling. Traffic handling considerations typically preclude full-width construction procedures. Structure approach rehabilitation is therefore usually done under traffic control conditions, which require partial-width construction.

District Division of Traffic Operations should be consulted for guidance on lane closures and traffic handling.

When developing traffic handling plans for structure approach slabs, where replacing markings is necessary, and where there is a need to maintain traffic during construction, the engineer should be aware that pavement joints should not be located underneath any of the wheel paths.

Topic 210 - Reinforced Earth Slopes and Earth Retaining Systems

210.1 Introduction

Constructing roadways on new alignments, widening roadways on an existing alignment, or repairing earth slopes damaged by landslides are situations that may require the use of reinforced earth slopes or earth retaining systems. Using cut and embankment slopes that are configured at slope ratios that are stable without using reinforcement is usually preferred; however, topography, environmental concerns, and right of way (R/W) limitations may require the need for reinforced earth slopes or an earth retaining system.

The need for reinforced earth slopes or an earth retaining system should be identified as early in the project development process as possible, preferably during the Project Initiation Document (PID) phase.

210.2 Construction Methods and Types

(1) Construction Methods

Both reinforced earth slopes and earth retaining systems can be classified by the method in which they are constructed, either top-down or bottom-up.

- "Top-down" construction – This method of construction begins at the top of the reinforced slope or earth retaining system and proceeds in lifts to the bottom of the reinforced slope or earth retaining system.

  If required, reinforcement is inserted into the in situ material during excavation.

- "Bottom-up" construction – This method of construction begins at the bottom of the reinforced slope or earth retaining system, where a footing/leveling pad is constructed, construction then proceeds towards the top of the reinforced slope or earth retaining system. If required, reinforcement is placed behind the face of the reinforced slope or earth retaining system. It should be noted that if a "Retaining Wall" earth retaining system is to be used in a cut situation, a temporary back cut or shoring system is required behind the wall.

The District Project Engineer (PE) should conduct an initial site visit and assessment to determine all potential construction limitations. The preferred construction method is top-down due to the reduced shoring, excavation and backfilling. However, this method is not always available or appropriate based on the physical and geotechnical site conditions. The site should also be examined for R/W or utility constraints that would restrict the type of excavation or limit the use of some equipment. In addition, the accessibility to the site for construction and contractor staging areas should be considered.

Table 210.2 summarizes the various reinforced earth slopes and earth retaining systems that are currently available for use, along with the method in which they are constructed.

Table 210.2
Types of Reinforced Earth Slopes and Earth Retaining Systems[1]

EARTH RETAINING SYSTEM	Construction Method[2]	PS&E By	Typical Facing Material	Recommended Maximum Vertical Height, ft	Ability to Tolerate Differential Settlement[3]
Reinforced Earth Slopes					
Reinforced Embankments	BU	District PE	Vegetation/Soil	160	E
Rock/Soil Anchors	TD	District PE	Soil/Rock	130	E
State Designed Earth Retaining Systems with Standard Plans					
Concrete Cantilever Wall, Type 1 & 1A	BU	District PE	Concrete	36, 12, 22[4]	P
Concrete L-Type Cantilever Wall, Type 5	BU	District PE	Concrete	12[4]	P
Concrete Masonry Wall, Type 6	BU	District PE	Masonry	6[4]	P
Crib Wall: Concrete, Steel	BU	District PE	Concrete, Steel	50, 36, [4]	P
State Designed Earth Retaining Systems Which Require Special Designs					
Standard Plan Walls with modified wall geometry, foundations or loading conditions	BU	Structure PE	Concrete, Steel, Timber	50	P-F
Non-Gravity Cantilevered Walls					
Sheet Pile Wall	TD	Structure PE	Steel	20	F
Soldier Pile Wall with Lagging	TD/BU	Structure PE	Concrete, Steel, Timber	20	F-G
Tangent Soldier Pile Wall	TD/BU	Structure PE	Concrete	30	F
Secant Soldier Pile Wall	TD	Structure PE	Concrete	30	F
Slurry Diaphragm Wall	TD	Structure PE	Concrete, Shotcrete	80[5]	F
Deep Soil Mixing Wall	TD	Structure PE	Shotcrete	80[5]	F-G
Anchored Wall (Structural or Ground Anchors)	TD	Structure PE	Concrete, Steel, Timber	80[6]	F-G
Gravity Walls					
Concrete Gravity Wall	BU	Structure PE	Concrete	6	P
Rock Gravity Wall	BU	District PE	Rock	13	E
Gabion Basket Wall	BU	District PE	Wire & Rock	26	E
Soil Reinforcement Systems					
Mechanically Stabilized Embankment	BU	Structure PE	Concrete	50	G
Salvaged Material Retaining Wall	BU	District PE	Steel, Timber	16	G
Soil Nail Wall	TD	Structure PE	Concrete, Shotcrete	80	F
Tire Anchored Timber Wall	BU	District PE	Timber	32	G
Proprietary Earth Retaining Systems (Pre-approved)					
The list of Pre-approved systems is available at the website shown in Index 210.2(3)(c).					
Proprietary Earth Retaining Systems (Pending)					
These systems are under review by DES-SD. For more information, see Index 210.2(3)(d).					
Experimental State Designed Earth Retaining Systems					
Geosynthetic Reinforced Walls	BU	Structure PE/ District PE	Concrete Blocks, Steel, Vegetation, Fabric	65	E
Mortarless Concrete Blocks Gravity Walls	BU	District PE	Concrete Blocks	8	P

NOTES:
1. Comparative cost data is available from DES-SD.
2. BU = Bottom Up; TD = Top Down
3. E = Excellent; G = Good; F = Fair; P = Poor
4. Maximum Design Height
5. Anchors may be required
6. With lagging

(2) *Reinforced Earth Slopes (PS&E by District PE)*

Reinforced earth slopes incorporate metallic or non-metallic reinforcement in construction of embankments and cut slopes with a slope angle flatter than 70 degrees from the horizontal plane. Reinforced earth slopes should be used in conjunction with erosion mitigation measures to minimize future maintenance costs. The slope face is typically erosion protected with the use of systems such as geosynthetics, bio-stabilization, rock slope protection, or reinforced concrete facing.

(3) *Earth Retaining Systems*

Earth retaining systems can be divided into five major categories depending upon the nature of the design and whether they are designed by the owner (State designed), a Proprietary vendor or a combination thereof. The term "State designed" as referenced herein is utilized to encompass earth retaining systems that are designed by the State or by Local or Private entities on behalf of the State.

No assignment of roles and responsibilities is intended. The five categories are as follows:

(a) State Designed Earth Retaining Systems which utilize Standard Plans (PS&E by District PE).

Standard Plans are available for a variety of earth retaining systems (retaining walls). Loading conditions and foundation requirements are as shown on the Standard Plans. For sites with requirements that are not covered by the Standard Plans, a special design is required. To assure conformance with the specific Standard Plan conditions and requirements, and subsequent completion of the PS&E in a timely fashion, the District PE should request a foundation investigation for each location where a retaining wall is being considered. Retaining walls that utilize Standard Plans are as follows:

- Retaining Wall Types 1 and 1A (Concrete Cantilever). These walls have design heights up to 36 feet and 12 feet respectively, but are most economical below 20 feet. Concrete cantilever walls can accommodate traffic barriers, and drainage facilities efficiently. See Standard Plans for further details.

Retaining Wall Type 5 (Concrete L-Type Cantilever). This wall has a design height up to 12 feet. Although more costly than cantilever walls, these walls may be required where site restrictions do not allow for a footing projection beyond the face of the wall stem. See Standard Plans for further details.

Retaining Wall Type 6 (Concrete Masonry Walls). These walls may be used where the design height of the wall does not exceed 6 feet. These walls are generally less costly than all other standard design walls or gravity walls. Where traffic is adjacent to the top of the wall, guardrail should be set back as noted in the Standard Plans. See Standard Plans or further details.

- Crib Walls. The following types are available:

Concrete Crib Wall - This type of crib wall may be used for design heights up to 50 feet. Concrete crib walls are suited to coastal areas and higher elevations where salt air and deicing salts may limit the service life of other types of crib walls. See Standard Plans or further details.

Steel Crib Wall - This type of crib wall may be used for design heights up to 36 feet. Steel crib walls are light in weight; easily transported and installed; and, therefore, suited for relatively inaccessible installations and for emergency repairs. See Standard Plans for further details.

Concrete crib walls constructed on horizontal alignments with curves or angle points require special details, particularly when the wall face is battered. Because crib wall faces can be climbed, they are not recommended for use in urban locations where they may be accessible to the public.

(b) State Designed Earth Retaining Systems which requires Special Designs.

Some locations will require a special design to accommodate ground contours, traffic, utilities, man-made features, site geology, economics, or aesthetics.

Some special design earth retaining systems are as follows:

- Standard Plan Walls (PS&E by Structure PE). The design loadings, heights, and types of walls in the Standard Plans cover frequent applications for earth retaining systems. However, special designs are necessary if the imposed loading exceeds that shown on the Standard Plan. Railroad live loads; building surcharge; loads imposed by sign structures, electroliers, or noise barriers are examples of loading conditions that will require special designs. Foundation conditions that require pile support for the wall and angle points in the wall geometry necessitate a special design.

- Non-Gravity Cantilevered Walls (PS&E by Structure PE). These walls include sheet pile walls, soldier pile walls with lagging, tangent soldier pile walls, secant soldier pile walls, slurry diaphragm walls, and deep soil mixing walls. These walls are most practical in cut sections and are best suited for situations where excavation for a retaining wall with a footing is impractical because of traffic, utilities, existing buildings, or R/W restrictions. In embankment sections, a non-gravity cantilevered wall is a practical solution for a roadway widening where design heights are less than 15 feet. They are also practical for slip-out corrections. Non-gravity cantilevered walls can consist of concrete, steel, timber, or cemented soil piles that may be either driven into place or placed in drilled holes and trenches.

- Anchored Walls (PS&E by Structure PE). These walls are typically composed of the same elements as non-gravity cantilevered walls, but derive additional lateral resistance from ground anchors (tiebacks), concrete anchors, or pile anchors. These anchors are located behind the potential failure surfaces in the retained soil and are connected to the wall structurally. The method of support and anchorage depends on site conditions, design height, and loading imposed. The cost of these walls is variable depending on earth retaining requirements, site geology, aesthetic consideration, and site restraints, but is generally higher than “Standard Design Walls” for the same wall geometry and loading conditions. Anchored walls may be used to stabilize an unstable site provided that adequate material exists at the site for the anchors. Economical wall heights up to 80 feet are feasible.

- Gravity Wall Systems that require special designs are Concrete Gravity, Rock Gravity, and Gabion Basket Walls. Concrete Gravity Walls (PS&E by Structure PE). Concrete gravity walls are most economical at design heights below 4 feet. However, they may be constructed at heights up to 6 feet. These walls can be used in connection with a cantilever wall if long lengths of wall with design heights of less than 4 feet are required.

- Rock Gravity Walls (PS&E by District PE). Rock gravity walls consist of rocks that are 100 pounds to 200 pounds, stacked on top of each other at slight batter. These walls are typically used in areas where a rock appearance is desirable for aesthetic reasons. Wall heights range from 1 foot 6 inches to 15 feet, but are most economical for heights less than 10 feet.

- Gabion Basket Walls (PS&E by District PE). Gabion basket walls use compartmented units filled with stones and can be constructed up to 26 feet in height. Each unit is a rectangular basket made of galvanized steel wire. The stone fill is 4 inches to 16 inches in size. Gabion basket walls are typically used for soil and stream bank stabilization. Service life of the gabion basket wall is highly dependent on the environment in which they are placed. Corrosion, abrasion, rock impact, fire and vandalism are examples of site-specific factors that would influence the service life of the wall and should be taken into consideration by the District PE during the design of the project. See Standard Plans for further details.

- Soil Reinforcement Systems. Soil reinforcement systems consist of facing elements and soil reinforcing elements incorporated into a compacted or in situ soil mass. The reinforced soil mass functions similar to a gravity wall.

  Soil reinforcing elements can be any material that provides tensile strength and pullout resistance, and possesses satisfactory creep characteristics and service life. Generally, reinforcing elements are steel, but polymeric and fiberglass systems may be used.

  Facing elements for most systems are either reinforced concrete, light gauge steel, or treated wood. Polymeric reinforced walls may be faced with masonry-like elements or even planted with local vegetation. Selection of facing type is governed by aesthetics and service life.

  Special details are required when drainage structures, overhead sign supports or noise barriers on piles are within the reinforced soil mass. Concrete traffic barriers require a special design support slab when used at the top of the facing of these systems. These systems cannot be used where site restrictions do not allow necessary excavation or placement of the soil reinforcing elements.

  Soil reinforcement systems that require special design are as follows:

- Mechanically Stabilized Embankment (MSE) (PS&E by Structure PE). This system uses welded steel wire mats, steel strips or polymeric materials as soil reinforcing elements. The facing elements are precast concrete. In many cases, this system can be constructed using on-site backfill materials.

  When the bottom-up construction method is possible and other conditions permit their use, these systems are generally the most economical choice for wall heights greater than 20 feet. They may also be the most economical system for wall heights in the 10-foot to 20-foot range, depending on the specific project requirements.

  Because of the articulated nature of the facing elements these systems use, they can tolerate greater differential settlement than can monolithic conventional rigid retaining walls, such as concrete cantilever retaining walls.

  Steel elements used in this method are sized to provide sacrificial steel to compensate for anticipated corrosion; and may be galvanized to provide additional protection.

- Salvaged Material Retaining Wall (PS&E by District PE). This system utilizes C-channel sections as soil reinforcement. Galvanized guardrail elements, timber posts or concrete panels are used as facing elements. Often these materials can be salvaged from projects. The District Recycle

Coordinator should be consulted as to the availability of salvaged materials.

- Soil Nail Wall (PS&E by Structure PE). This system reinforces either the original ground or an existing embankment during the excavation process. Soil nailing is always accomplished from the top-down in stages that are typically 4 feet to 6 feet in height. After each stage of excavation, corrosion protected soil reinforcing elements, "soil nails", are placed and grouted into holes which have been drilled at angles into the in situ material. The face of each stage of excavation is protected by a layer of reinforced shotcrete. After the full height of wall has been excavated and reinforced, a finish layer of concrete facing is placed either by the shotcreting method or by casting within a face form.

  When top-down construction is possible and conditions permit its use, soil nail wall systems are generally the most economical choice for wall heights greater than 10 feet. Wall heights in excess of 80 feet are feasible in specific locations.

  Because soil nailing is accomplished concurrent with excavation, and thus results in an unloading of the foundation, there is typically no significant differential settlement.

  Steel "soil nails" used in this method are protected against corrosion either by being epoxy coated or encapsulated within a grout filled corrugated plastic sheath, and surrounded by portland cement grout placed during construction. Soil nail lengths typically range from 80 to 100 percent of the wall height, the actual length depends on the nail spacing used and the competency of the in situ soil.

- Recycled Tire Anchor Timber (TAT) Walls (PS&E by District PE). This system utilizes steel bars with recycled tire sidewalls attached by cross bars as soil reinforcing elements. The facing elements are treated timber. TAT walls have a rustic appearance, which makes them suitable in rural environments. The length of commercially available timber post generally controls the height of wall but heights up to 32 feet are feasible.

(c) Proprietary Earth Retaining Systems (Pre-approved).

These conventional retaining walls, cribwalls, and soil reinforcement systems are designed, manufactured, and marketed by vendors. These systems are termed “proprietary” because they are patented. “Pre-approval” status means that these systems may be listed in the Special Provisions of the project as an Alternative Earth Retaining System (AERS), see Index 210.3, when considered appropriate for a particular location. For a proprietary system to be given “pre-approval” status, the vendor must submit standard plans and design calculations to the Division of Engineering Services – Structure Design (DES-SD) for their review and approval. The Proprietary earth retaining systems that have been pre-approved are included in the Department’s Authorized Material List, located on the following website: http://www.dot.ca.gov/aml/.

Design details and specifications of “pre-approved” proprietary earth retaining systems may be found on the vendor websites listed in the Authorized Material List. New systems are added to the website list once they are pre-approved for use.

(d) Proprietary Earth Retaining Systems (Pending).

The systems in this category have been submitted by vendors to DES-SD for evaluation. Upon approval of DES-SD, pending systems are added to the website list of “pre-approved” proprietary earth retaining systems and included in the project specific Special Provisions.

If a proprietary system is the only retaining system deemed appropriate for use at a specific location, the construction of that system must be justified or designated an experimental construction feature in accordance with existing Departmental Policy concerning sole source purchases. See Index 110.10 for additional guidance on the use of proprietary items.

(e) Experimental State Designed Earth Retaining Systems.

Every earth retaining system is evaluated before being approved for routine use by the Department. Newly introduced designs, unproven combinations of proprietary and non-proprietary designs or products, are considered experimental. Once an experimental system has been evaluated and approved, it will be made available for routine use. The use of these systems is only permitted upon consultation with the Division of Engineering Services – Geotechnical Services (DES-GS).

Some earth retaining systems which are currently considered experimental follow:

- Geosynthetic Reinforced Walls (PS&E by District PE). These systems utilize geosynthetic material as the soil reinforcing elements. The face of these walls can be left exposed if the geosynthetic material has been treated to prevent decay from ultra-violet rays. Concrete panels, mortarless masonry, tar emulsion, or air blown mortar may be used as facing materials or the face may be seeded if a more aesthetic treatment is preferred. Design is by DES-GS.

- Mortarless Concrete Block Gravity Walls (PS&E by District PE). These wall types consist of vertically stacked, dry cast, concrete blocks. This system utilizes the friction and shear developed between the blocks and the combined weight of the blocks to retain the backfill. Some of these walls have been used as erosion protection at abutments and on embankments. They can be used as an aesthetic treatment for geosynthetic material reinforced walls. All of these walls require a batter. Design is by the DES-GS.

210.3 Alternative Earth Retaining Systems (AERS)

Using the Alternative Earth Retaining Systems (AERS) procedure encourages competitive bidding and potentially results in project cost savings. Therefore, AERS must be considered in all projects where earth retaining systems are required.

The AERS procedure may result in one or more earth retaining systems being included in the contract bid package. Under this procedure, a fully detailed State designed earth retaining system will be provided for each location, and will be used as the basis for payment. Additional systems may be presented in the contract documents as alternatives to the fully detailed State design and can be considered for use at specified locations. The fully detailed State designed earth retaining system may be either a Standard Plan system or a special design system. Alternative systems may also be State designed systems, “pre-approved” proprietary systems or experimental systems, as appropriate. The State designed alternative systems, both Standard Plan walls and special design systems, are to be completely designed and specified in the PS&E. Alternative systems are to be listed in the Special Provisions as AERS.

The AERS procedure requires the involvement of the District PE, DES-SD, and the DES-GS. The District PE should submit pertinent site information (site plans, typical sections, etc.) to DES-GS for a feasibility study as early as possible in the project development process.

Under the AERS procedure, parts of the PS&E package which pertain to the earth retaining systems will be prepared as follows:

- Contract plans for State designed systems can be prepared by the District PE (Standard Plan systems), the DES-GS (special design soil reinforcement systems and experimental systems), or the Structure PE (Standard Plan systems and special design systems).

- "Pre-approved" proprietary systems that are determined, based on consultation with DES-SD, to be appropriate alternatives to the State designed earth retaining system, are to be listed in the Special Provisions.
- Specifications and Estimates shall be developed for the fully detailed State designed system, which will be used as the basis for payment.

The earth retaining systems utilizing this procedure are to be measured and paid for by the square yard area of the face of the earth retaining system. Should an AERS be constructed, payment will be made based on the measurements of the State designed system which was designated as the basis of payment. The contract price paid per square yard is for all items of work involved and includes excavation, backfill, drainage system, reinforcing steel, concrete, soil reinforcement, and facing. Any barrier, fence, or railing involved is measured and paid for as separate contract cost items.

210.4 Value Engineering Change Proposal (VECP)

Sometimes Contractors submit proposals for an earth retaining system under Section 4-1.07 of the Standard Specifications, "Value Engineering." The Contractor proposed system may modify or replace the earth retaining system permitted by the contract. The VECP process allows vendors of proprietary earth retaining systems an alternative method for having their systems used prior to obtaining "pre-approval" (see Index 210.2(3)(c)). VECP submittals are administered by the Resident Engineer. However, Contract Change Orders are not to be processed until the VECP is approved by Headquarters Construction with review assistance provided by the District or Structure PE as appropriate.

210.5 Aesthetic Consideration

The profile of the top of wall should be designed to be as pleasing as the site conditions permit. All changes in the slope at the top of cast-in-place concrete walls should be rounded with vertical curves at least 20 feet in length. Abrupt changes in the top of the wall profile should be avoided by using vertical curves, slopes, steps, or combinations thereof. Side slopes may be flattened or other adjustments made to provide a pleasing profile.

Where walls are highly visible, special surface treatments or provisions for landscaping should be considered. The aesthetic treatment of walls should be discussed with the District Landscape Architect and when necessary referred to DES Structure Design Services for additional study by the Office of Transportation Architecture.

The wall area between the grade line and 6 feet above it shall be free of any designed indentations or protrusions that may snag errant vehicles.

When alternative wall types are provided on projects with more than one wall site, any restrictions as to the combination of wall types should be specified in the Special Provisions.

210.6 Safety Railing, Fences, and Concrete Barriers

<u>Cable railing should be installed for employee protection in areas where employees may work adjacent to and above vertical faces of retaining walls, wingwalls, abutments, etc. where the vertical fall is 4 feet or more</u>.

If cable railing is required on a wall which is less than 4 feet 6 inches tall and that wall is located within the clear recovery zone, then the cable railing should be placed behind the wall. See Standard Plan B11-47 for details of cable railing.

Special designs for safety railing may be considered where aesthetic values of the area warrant special treatment. In addition, if the retaining wall is accessible to the public and will have pedestrians or bicycles either above or below the retaining wall, then the provisions of Index 208.10 shall apply.

Concrete barriers may be mounted on top of retaining walls. Details for concrete barriers mounted on top of retaining walls Type 1 through 5 are shown in the Standard Plans. A concrete barrier slab is required if a concrete barrier is to be used at the top of a special design earth retaining system. DES-SD should be contacted for preparation of the plans involved in the special design.

Retaining walls joining right of way fences should be a minimum of 6 feet clear height.

The District PE should examine the proposed retaining wall location in relation to the provisions of Index 309.1 to ensure adequate horizontal clearances to the structure or to determine the type and placement of the appropriate roadside safety devices.

210.7 Design Responsibility

The Structure PE has primary responsibility for the structural design and preparation of the contract documents (PS&E) for special design earth retaining systems involving Standard Plans non-gravity cantilevered walls, anchored walls, concrete and rock gravity walls, mechanically stabilized embankment, and soil nail walls. The DES-GS has primary responsibility for the geotechnical design of all reinforced earth slopes and earth retaining systems. DES-SD will prepare the Specifications and Engineer's Estimate for contracts when the AERS procedure is used. DES-SD reviews and approves standard plan submittals for proprietary earth retaining systems submitted by vendors. DES-SD and DES-GS assist Headquarters Construction in evaluating the VECP submitted by contractors.

Districts may prepare contract plans, specifications, and engineer's estimate for Standard Plan retaining walls provided the foundation conditions and site requirements permit their use. A foundation investigation is required for all reinforced earth slopes and earth retaining systems. PS&E's for slurry walls, deep soil mixing walls, gabion walls, tire anchored timber walls, salvaged material walls, and experimental walls will be prepared by the District PE with assistance from DES-GS. Earth retaining systems may be included in the PS&E as either highway or structure items.

The time required for DES-SD to provide the special design of a retaining system is site and project dependent. Therefore, the request for a special design should be submitted by the District PE to DES-SD as far in advance as possible, but not less than 6 months prior to PS&E delivery. At least 3 months is required to conduct a foundation investigation for an earth retaining system. A site plan, index map, cross sections, vertical and horizontal alignment, and utility and drainage requirements should be sent along with the request.

DES-GS has the responsibility for preparing a feasibility study for AERS. The District PE should submit project site information (site plans, typical sections, etc.) as early in the planning stage as possible so that determination of the most appropriate earth retaining system to use can be made.

210.8 Guidelines for Type Selection and Plan Preparation

(1) *Type Selection.* Type selection for reinforced earth slopes and earth retaining systems should be based on considerations set forth in Index 210.2.

The District PE should request a feasibility study for a reinforced slope or earth retaining system from DES-GS as early as possible in the project development process. After the feasibility study, the District PE should request an Advanced Planning Study (APS) from DES-SD for all special design earth retaining systems that DES-SD may be required to include in the PS&E.

If the District PE decides that the course of action favors an earth retaining system in which the PS&E will be delivered by DES-SD, then a Bridge Site Data Submittal – Non-Standard Retaining Wall/Noise Barrier must be submitted to DES-Structure Design Services & Earthquake Engineering – Preliminary Investigations (PI) Branch. A copy of this submittal will be forwarded to DES-SD and DES-GS by PI.

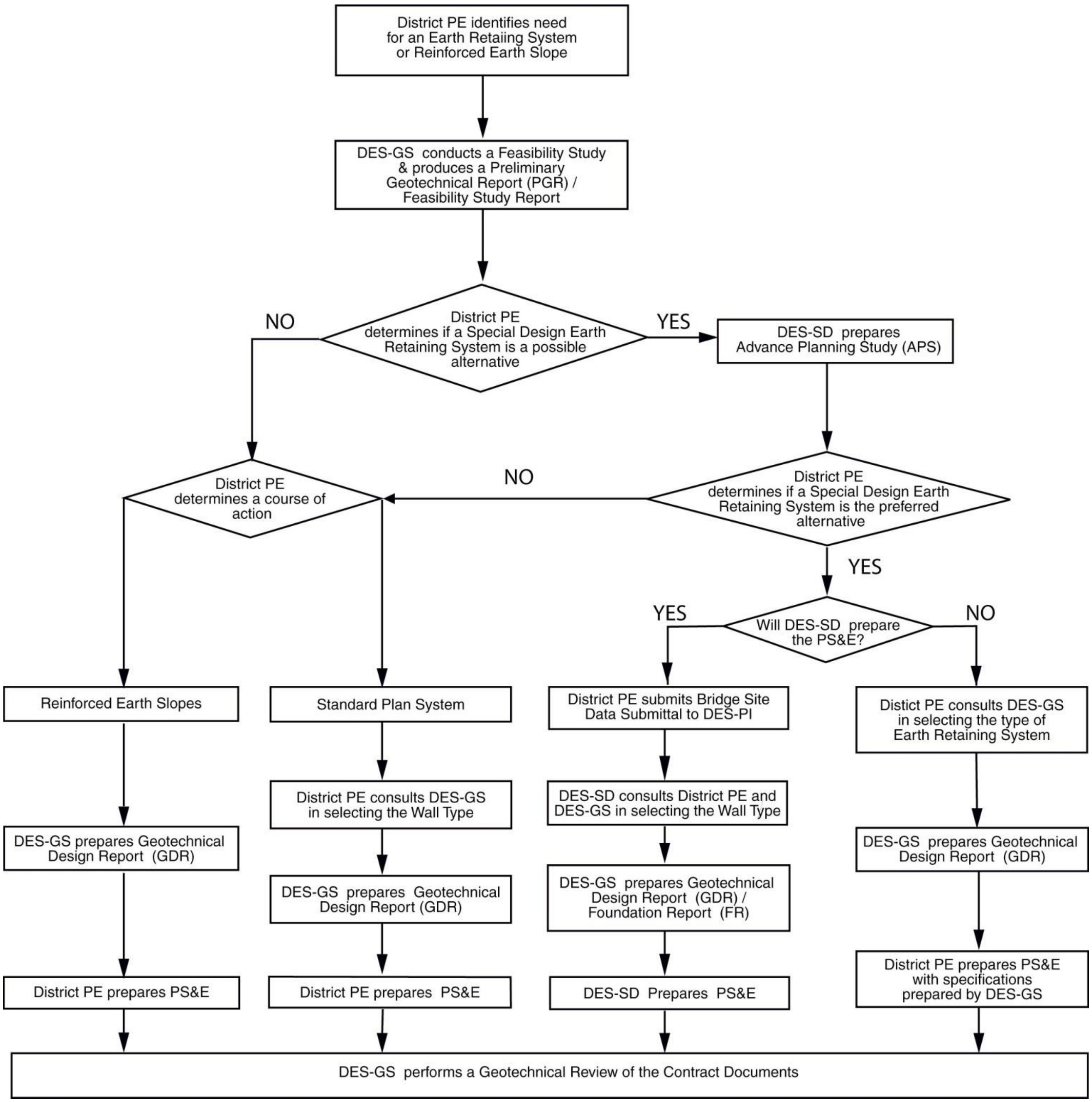
The Structure PE, with input from DES-GS and the District PE, will then type select the appropriate earth retaining system for the site and project. After an earth retaining system has been type selected, then DES-GS will prepare a Geotechnical Design Report.

The process for type selecting and developing the PS&E for reinforced earth slopes and earth retaining systems is set forth in Figure 210.8.

All appropriate State designed and proprietary earth retaining systems should be considered for inclusion in the contract documents to promote competitive bidding, which can result in cost savings.

(2) *Foundation Investigations.* DES-GS should be requested to provide a foundation recommendation for all sites involving a reinforced slope or an earth retaining system. Any log of test boring sheets accompanying the

Figure 210.8
Type Selection and PS&E Process for Reinforced Earth Slopes and Earth Retaining Systems



foundation reports must be included with the contract plans as project information, for the bidders use.

(3) *Earth Retaining Systems with Standard Plans.* The following guidelines should be used to prepare the contract plans for earth retaining systems, which are found in the Standard Plans:

(a) Loads. All wall types selected must be capable of supporting the field surcharge conditions. The design surcharges can be found in the Standard Plans. Deviance from these loadings will require a special design

(b) Footing Steps. For economy and ease of construction of wall Types 1 through 6, the following criteria should be used for layout of footing steps.

- Distance between steps should be in multiples of 8 feet.
- A minimum number of steps should be used even if a slightly higher wall is necessary. Small steps, less than 1 foot in height, should be avoided unless the distance between steps is 96 feet or more. The maximum height of steps should be held to 4 feet. If the footing thickness changes between steps, the bottom of footing elevation should be adjusted so that the top of footing remains at the same elevation.

(c) Sloping Footings. The following criteria should be used for layout of sloping footings.

- The maximum permissible slope for reinforced concrete retaining walls is 3 percent. Maximum footing slope for masonry walls is 2 percent.
- When sloping footings are used, form and joint lines are permitted to be perpendicular and parallel to the footing for ease of construction.
- In cases where vertical electroliers or fence posts are required on top of a wall, the form and joint lines must also be vertical. A sloping footing should not be used in this situation since efficiency of construction would be lost.

Sloping footing grades should be constant for the entire length of the wall. Breaks in footing grade will complicate forming and result in loss of economy. If breaks in footing grade are necessary, a level stepped footing should be used for the entire wall.

- When the top of wall profile of crib walls is constant for the entire length, the bottom of wall profile may be sloped to avoid steps in the top of wall. In this case, all steps to compensate for changes of wall height and original ground profile would be made in the bottom of wall. The maximum permissible slope is 6 percent. If vertical electroliers or fence posts are required on top of the wall, the crib wall should not be sloped. Sloping crib walls are permissible with guard railing with vertical posts.

(d) Wall Joints. General details for required wall joints on wall Types 1, 1A, 2, and 5 are shown on Standard Plan B0-3. Expansion joints, Bridge Detail 3-3, should be shown at maximum intervals of 96 feet. Shorter spaces should be in multiples of 8 feet. Expansion joints generally should be placed near angle points in the wall alignment. When concrete barriers are used on top of retaining walls, the waterstop in the expansion joint must be extended 6 inches into the barrier. This detail should be shown or noted on the wall plans. Weakened plane joints, Bridge Detail 3-2, should be shown at nearly equal spaces between joints.

(e) Drainage. Gutters should be used behind walls in areas where it is necessary to carry off surface water or to prevent scour. Low points in wall vertical alignment or areas between return walls must be drained by downspouts passing through the walls. Standard Plan B3-9 shows typical drainage details. Special design of surface water drainage facilities may be necessary depending on the amount of surface water anticipated. Where ground water is likely to occur in any quantity, special provisions must be made to intercept the flow to prevent inundation of the backfill and unsightly continuous flow through weep holes.

(f) Quantities. When the AERS procedure is not utilized, quantities for each wall item of work are usually developed for payment. The quantities for concrete, expansion joint waterstop, structure excavation, structure backfill, pervious backfill material, concrete barrier or railing, and gutter concrete must also be tabulated. Quantities should be tabulated on the plans for each wall.

(4) Soil Reinforcement Systems. The following guidelines should be used to prepare the contract plans for soil reinforcement systems:

(a) Leveling Pads. Most soil reinforcement systems do not require extensive foundation preparation. It may be necessary, however, to design a concrete leveling pad on which to construct the face elements. A reinforced concrete leveling pad will be required in areas prone to consolidation or frost disturbance.

- Steps in the leveling pad should be the same height as the height of the facing elements or thickness of the soil layer between the soil reinforcement.
- Distance between steps in the leveling pad should be in increments equivalent to the length of individual facing elements.
- A minimum number of steps should be used even if a slightly higher wall is necessary.

(b) Drainage. Gutters should be used behind walls in areas where it is necessary to carry off surface water or to prevent scour. Low points in wall vertical alignment or areas between return walls must be drained by downspouts passing through the walls. Special design of surface water drainage facilities will be necessary and should be prepared by DES-SD. Where ground water is likely to occur in any quantity, special provisions must be made to intercept the flow to prevent inundation of the backfill.

(c) Quantities. When the AERS procedure is not utilized, quantities for each item of work are usually developed for payment. Bid items must include, but not be limited to: excavation and backfill for the embedment depth, soil reinforcement, facing elements, and concrete for leveling pad construction. Additional bid items for inclusion are any drainage system, pervious backfill, concrete barrier, railings, and concrete gutters. Quantities should be tabulated on the plans for each wall.

(5) Earth Retaining Systems. The following miscellaneous details are applicable to all earth retaining systems:

(a) Utilities. Provisions must be made to relocate or otherwise accommodate utilities conflicting with the retaining wall. A utility opening for a Type 1 wall is shown on Standard Plan B3-9. Any other utility openings will require special design details and should be reviewed by DES-SD.

(b) Electroliers and Signs. Details for mounting electroliers and signs on earth retaining systems are designed by DES-SD. Requests for preparation of details should be made at least 3 months in advance of the PS&E submittal to District Officer Engineer date. To accommodate the base plates for overhead signs, a local enlargement may affect the horizontal clearance to both the edge of pavement and the right of way line. This type of enlargement should be considered at the time of establishing the wall layout and a need for a design standard decision document determined. For mounting details, furnish DES-SD a complete cross section of the roadway at the sign and the layout and profile of the earth retaining system.

(c) Fence and Railing Post Pockets. Post pocket details shown for cable railing in the Standard Plans may also be used for mounting chain link fence on top of retaining walls. Special details may be necessary to accommodate the reinforcement in soil reinforcement systems.

(d) Return Walls. Return walls should be considered for use on the ends of the walls to provide a finished appearance. Return walls are necessary when wall offsets are used or when the top of wall is stepped. Return walls for soil reinforcement systems will require special designs to accommodate the overlapping of soil reinforcing elements.

All special wall details such as sign bases, utility openings, drainage features, fences, and concrete barriers should be shown on the plan sheet of the wall concerned or included on a separate sheet with the wall plan sheets. Details should be cross-referenced on the wall sheets to the sheets on which they are shown.

2-lane pavement as one of the divided highway roadbeds.

The maximum algebraic difference in cross slope between same direction traffic lanes of divided highway roadbeds should be 4 percent.

The maximum difference in cross slope between the traveled way and the shoulder should not exceed 8 percent. This applies to new construction as well as pavement overlay projects.

At freeway entrances and exits, the maximum difference in cross slope between adjacent lanes, or between lanes and gore areas, should not exceed 5 percent.

Topic 302 - Highway Shoulder Standards

302.1 Width

The shoulder widths given in Table 302.1 shall be the minimum continuous usable width of paved shoulder on highways. Typically, on-street parking areas in urbanized areas is included in the shoulder.

Class II bikeways are typically part of the shoulder width, see Index 301.2. **Where rumble strips are placed in the shoulder, the shoulder shall be a minimum of 4 feet width to the right of the grooved rumble strip when a vertical element, such as curb or guardrails present or a minimum of 3 feet width when a vertical element is not present.** Shoulder rumble strip must not be placed in the Class II bike lane. Consult the District Traffic Safety Engineer during selection of rumble strip options and with the California MUTCD for markings in combination with rumble strip. Also see Standard Plans for rumble strip details.

See DIB 79 for 2R, 3R, certain storm damage, protective betterment, operational, and safety projects on two-lane and three-lane conventional highways.

See Index 308.1 for shoulder width requirements on city streets or county roads. See shoulder definition, Index 62.1(9).

See Index 1102.2 for shoulder width requirements next to noise Barriers.

When shoulders are less than standard width, see Index 204.5(4) for bicycle turnout considerations.

302.2 Cross Slopes

(1) *General* - **When a roadway crosses a bridge structure, the shoulders shall be in the same plane as the adjacent traveled way**.

(2) *Left Shoulders* - **In depressed median sections, shoulders to the left of traffic shall be sloped at 2 percent away from the traveled way.**

In paved median sections, shoulders to the left of traffic shall be designed in the plane of the traveled way. Maintenance paving beyond the edge of shoulder should be treated as appropriate for the site, but consideration needs to be given to the added runoff and the increased water depth on the pavement (see discussion in Index 831.4(5) "Hydroplaning").

(3) *Right Shoulders*- In normal tangent sections, **shoulders to the right of traffic shall be sloped at 2 percent to 5 percent away from the traveled way.**

The above flexibility in the design of the right shoulder allows the designer the ability to conform to regional needs. Designers shall consider the following during shoulder cross slope design:

- In most areas a 5 percent right shoulder cross slope is desired to most expeditiously remove water from the pavement and to allow gutters to carry a maximum water volume between drainage inlets. The shoulders must have adequate drainage interception to control the "water spread" as discussed in Table 831.3 and Index 831.4. Conveyance of water from the total area transferring drainage and rainwater across each lane and the quantity of intercepting drainage shall also be a consideration in the selection of shoulder cross slope. Hydroplaning is discussed in Index 831.4 (5).
- In locations with snow removal operations it is desirable for right shoulders to slope

Table 302.1
Boldface Standards for Paved Shoulder Widths on Highways

Highway Type	Paved Shoulder Width (ft) Left [8]	Right [8]
Freeways & Expressways		
2 lanes [1]	--	8[6]
4 lanes [1]	5	10
6 or more lanes [1]	10	10
Auxiliary lanes	--	10
Freeway-to-freeway connections		
Single and two-lane connections	5	10
Three-lane connections	10	10
Single-lane ramps	4[2]	8
Multilane ramps	4[2]	8[3]
Multilane undivided	--	10
Collector-Distributor	5	10
Conventional Highways		
Multilane divided		
4-lanes	5	8[7]
6-lanes or more	8	8[7]
Urban areas with posted speeds less than or equal to 45 mph and curbed medians	2[4]	8[7]
Multilane undivided	--	8[7]
2-lane		
RRR	See Index 307.3	
New construction	See Table 307.2	
Slow-moving vehicle lane	--	4[5]
Local Facilities		
Frontage roads	See Index 310.1	
Local facilities crossing State facilities	See Index 308.1	

NOTES:

(1) Total number of lanes in both directions including separate roadways (see Index 305.6). If a lane is added to one side of a 4-lane facility (such as a truck climbing lane) then that side shall have 10 feet left and right shoulders. See Index 62.1.

(2) May be reduced to 2 feet upon concurrence from the Project Delivery Coordinator that a restrictive situation exists. 4 feet preferred in urban areas and/or when ramp is metered. See Index 504.3.

(3) May be reduced to 2 feet or 4 feet (4 feet preferred in urban areas) in the 2-lane section of a non-metered ramp, which transitions from a single lane upon concurrence from the Project Delivery Coordinator that a restrictive situation exists. May be reduced to 2 feet in ramp sections having 3 or more lanes. See Index 504.3.

(4) For posted speeds less than or equal to 35 mph, shoulder may be omitted (see Index 303.5(5)) except where drainage flows toward the curbed median.

(5) On right side of climbing or passing lane section only. See Index 301.2(1) for minimum width if bike lanes are present.

(6) 10-foot shoulders preferred.

(7) Where on-street parking is allowed, 10 feet shoulder width is preferred. Where bus stops are present, 10 feet shoulder width is preferred for the length of the bus stop. If a Class II bikeway is present, minimum shoulder width shall be 8 feet where on street parking is provided plus the minimum required width for the bike lane.

(8) Shoulders adjacent to abutment walls, retaining walls in cut locations, and noise barriers shall be not less than 10 feet wide. See Index 303.4 for minimum shoulder adjacent to bulbouts. See Index 309.1(4) for minimum shoulder width adjacent to high speed rail facilities.

mounted except at low speeds and flat angles of approach.

(2) *Types A1-8, A2-8, and A3-8.* These 8-inch high curbs may be used in lieu of 6-inch curbs when requested by local authorities, if the curb criteria stated under Index 303.1 are satisfied and posted speeds are 35 miles per hour or less. This type of curb may impede curbside passenger loading and may make it more difficult to comply with curb ramp design (see Design Information Bulletin Number 82, “Pedestrian Accessibility Guidelines for Highway Projects”).

(3) *Type H Curb.* This type may be used on bridges where posted speeds are 40 miles per hour or less and where it is desired to match the approach roadway curb. Type H curb is often incorporated into bridge barrier/sidewalk combination railings (See Index 208.10(4)).

These types are sloped curbs:

(4) *Types B1, B2, and B3 Curbs* Types B1-6, B2-6, and B3-6 are 6 inches high. Type B1-4, B2-4, and B3-4 are 4 inches high. Since all have a 1:1½ slope or flatter on the face, they are mounted more easily than Type A curbs. Typical uses of these curbs are for channelization including raised median islands. B2 curb with gutter pan also serves as drainage control.

(5) *Type B4 Curb.* Type B4 curb with gutter pan is 3 inches high and is typically used on ramp gores as described in Index 504.3(11). It may also be appropriate where a lower curb is desirable.

(6) *Type D Curb.* Type D curb is 4 inches or 6 inches high and is typically used for raised traffic islands, collector-distributor separation islands, or raised medians when posted speeds equal or exceed 45 miles per hour.

(7) *Type E Curb*. This essentially is a rolled gutter used only in special drainage situations.

Curbs with gutter pans, along with the shoulder, may provide the principal drainage system for the roadway. Inlets are provided in the gutter pan or curb, or both.

Gutter pans are typically 2 feet wide but may be 1 foot to 4 feet in width, with a cross slope of typically 8.33 percent to increase the hydraulic capacity. Gutter pan cross slopes often need to be modified at curb ramps in order to meet accessibility requirements. See Design Information Bulletin Number 82, “Pedestrian Accessibility Guidelines for Highway Projects” and Standard Plan A88A.

Curbs and gutter pans are cross section elements considered entirely outside the traveled way, see Index 301.1.

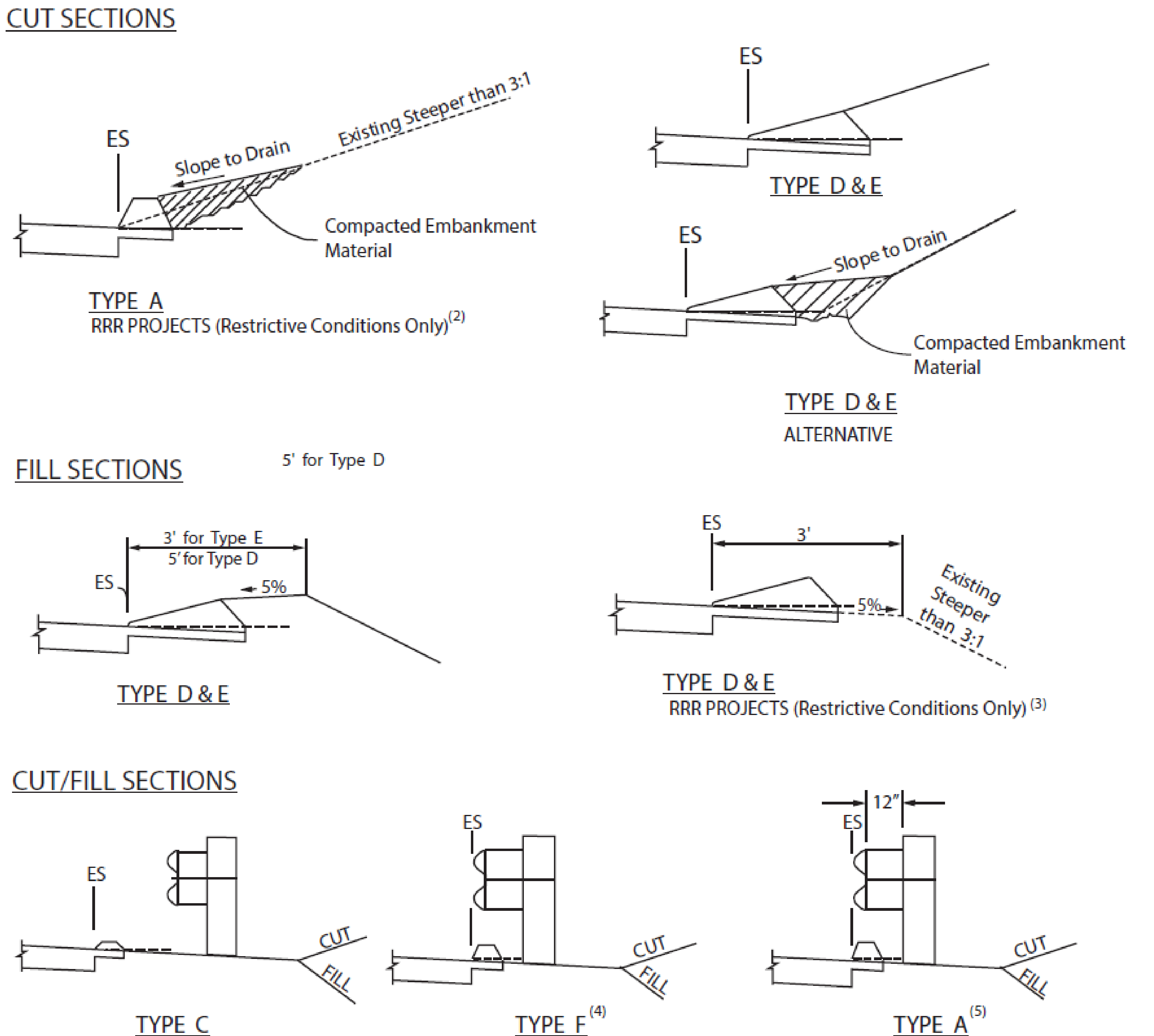
303.3 Dike Types and Uses

Use of dike is intended for drainage control and should not be used in place of curb. Dikes placed adjoining the shoulder, as shown in Figures 307.2, 307.4A, 307.4B, and 307.5, provide a paved triangular gutter within the shoulder area. The dike sections provided on the Standard Plans are approved types to be used as stated below. <u>Dikes should be selected as illustrated in Figure 303.3.</u> Dikes should be designed so that roadway runoff is contained within the limits specified in Index 831.3. For most situations Type E dike is the preferred dike type as discussed below.

(1) *Type A Dike.* This 6-inch high dike is to be used where dike is necessary for drainage underneath guardrail with 12-inch blockout installation. This dike is placed directly under the face of guardrail. Otherwise, the use of Type A dike should be avoided. For RRR projects, Type A dike may be used in cut sections with slopes steeper than 3:1 and where existing conditions do not allow for construction of the wider Type D or E dikes. Compacted embankment material should be placed behind the back of dike as shown in Figure 303.3.

(2) *Type C Dike.* This low dike, 2 inches in height, may be used to confine small concentrations of runoff. The capacity of the shoulder gutter formed by this dike is small. Due to this limited capacity, the need for installing an inlet immediately upstream of the beginning of this dike type should be evaluated. This low dike can be traversed by a vehicle and allows the area beyond the surfaced shoulder to be used as an emergency recovery and parking area. The

Figure 303.3
Dike Type Selection and Placement[1]



Notes: (1) See Standard Plans for additional information and details.
(2) See Index 303.3(1) for restrictive conditions.
(3) See Index 303.3(3) and Index 303.3(4) for restrictive conditions for Types D and E respectively.
(4) Use under guardrail when dike is necessary for drainage control.
(5) Use under guardrail with 12-inch blockouts when dike is necessary for drainage control.

Type C dike is the only dike that may be used in front of guardrail. In such cases, it is not necessary to place compacted embankment material behind Type C dike.

(3) *Type D Dike.* This 6-inch high dike provides about the same capacity as the Type A dike but has the same shape as the Type E dike. The quantity of material in the Type D dike is more than twice that of a Type E dike. It should only be used where there is a need to contain higher volumes of drainage. Compacted embankment material should be placed behind the back of dike as shown in Figure 303.3. For RRR projects that do not widen pavement, compacted embankment material may be omitted on existing fill slopes steeper than 3:1 when there is insufficient room to place the embankment material.

(4) *Type E Dike.* This 4-inch high dike provides more capacity than the Type C dike. Because Type E dike is easier to construct than Type D dike, and has greater drainage capacity than Type C dike, it is the preferred dike type for most installations. Compacted embankment material should be placed behind the back of dike as shown in Figure 303.3. For RRR projects that do not widen pavement, compacted embankment material may be omitted on existing fill slopes steeper than 3:1 where there is insufficient room to place the embankment material.

(5) *Type F Dike.* This 4-inch high dike is to be used where dike is necessary for drainage underneath a guardrail installation. This dike is placed directly under the face of guardrail installations.

303.4 Curb Extensions

(1) *Bulbouts*. A bulbout is an extension of the sidewalk into the roadway when there is marked on-street parking, see Index 402.3. Bulbouts should comply with the guidance provided in Figures 303.4A and B; noting that typical features are shown and that the specific site conditions need to be taken into consideration. Bulbouts provide queuing space and shorten crossing distances, thereby reducing pedestrian conflict time with mainline traffic. By placing the pedestrian entry point closer to traffic, bulbouts improve visibility between motorists, bicyclists, and pedestrians. They are most appropriate for urban conventional highways and Rural Main Streets with posted speeds 35 miles per hour or less. Curb extensions are not to extend into Class II Bikeways (Bike Lanes). The corner curb radii should be the minimum needed to accommodate the design vehicle, see Topic 404.

When used, bulbouts should be placed at all corners of an intersection.

When used at mid-block crossing locations, bulbouts should be used on both sides of the street.

The curb face of the bulbout should be setback a minimum of 2 feet as shown in Figures 303.4A and B. See the California MUTCD for on-street parking signs and markings.

Landscaping and appurtenant facilities located within a bulbout are to comply per Topic 405.

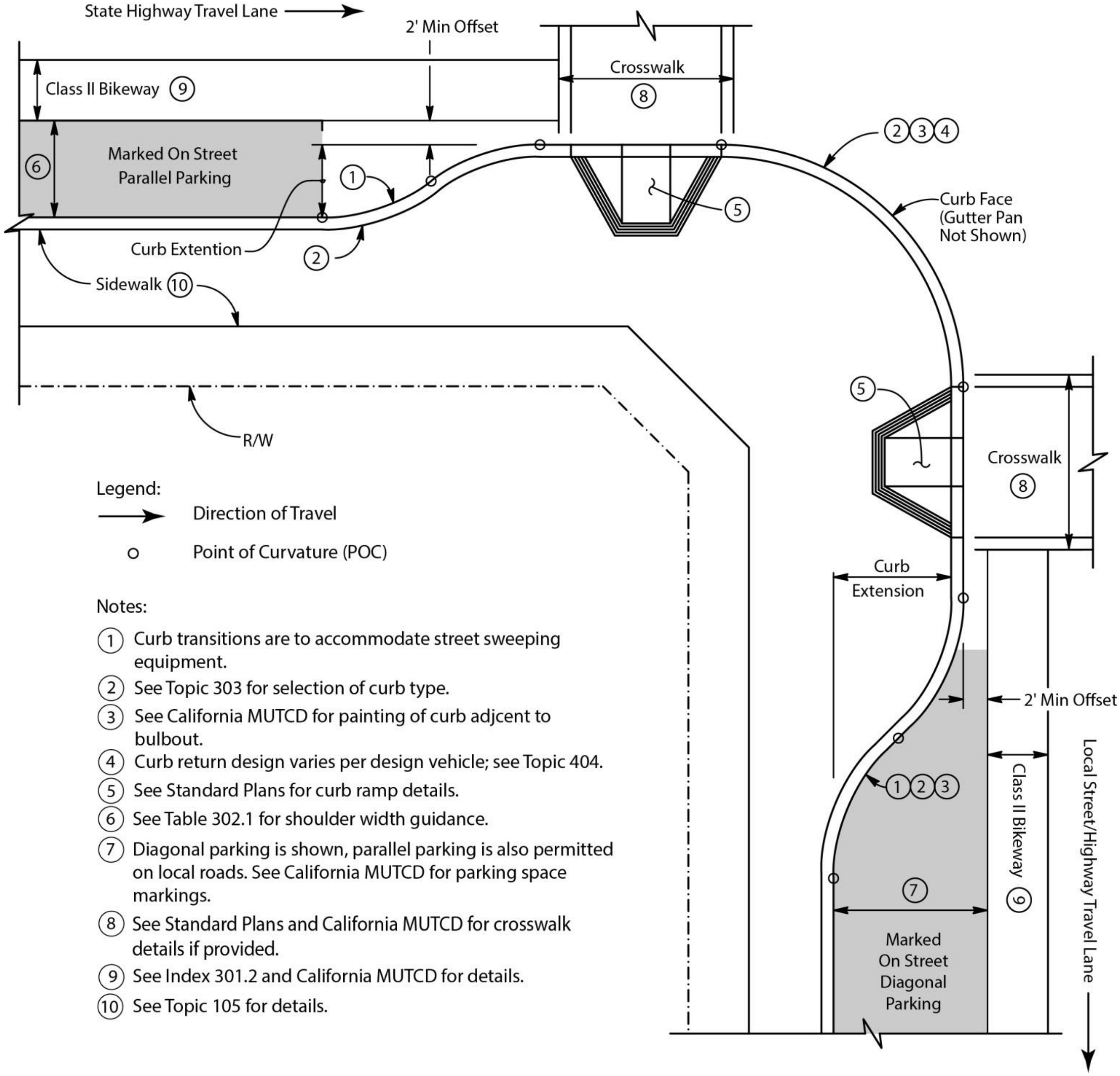
Bulbouts are considered pedestrian facilities and as such, compliance with DIB 82 is required. Avoid bulbouts on facilities where highway grade lines exceed 5 percent.

(2) *Busbulbs.* A busbulb is a bulbout longer than 25 feet which facilitates bus loading and unloading, and provides for enhanced bus mobility. Busbulbs reduce bus dwell times and provide travel time benefits to transit passengers. However, busbulbs can restrict the mobility of vehicular and bicycle traffic because they allow the bus to stop in their traveled way to load and unload passengers. Therefore, their impact on the mobility of the vehicular and bicycle traffic using the facility must be taken into consideration, and pursuant to the California Vehicle Code, busbulbs or other transit stops which require a transit vehicle to stop in the traveled way require approval from the Department. In lieu of a busbulb, a busbay may be considered which will not impact the mobility of the vehicular and bicycle users of the facility.

(3) *Busbays*. A busbay is an indentation in the curb which allows a bus to stop completely outside of vehicular and bicycle lanes.

Figure 303.4A

Typical Bulbout with Class II Bikeway (Bike Lane)



Legend:

→ Direction of Travel

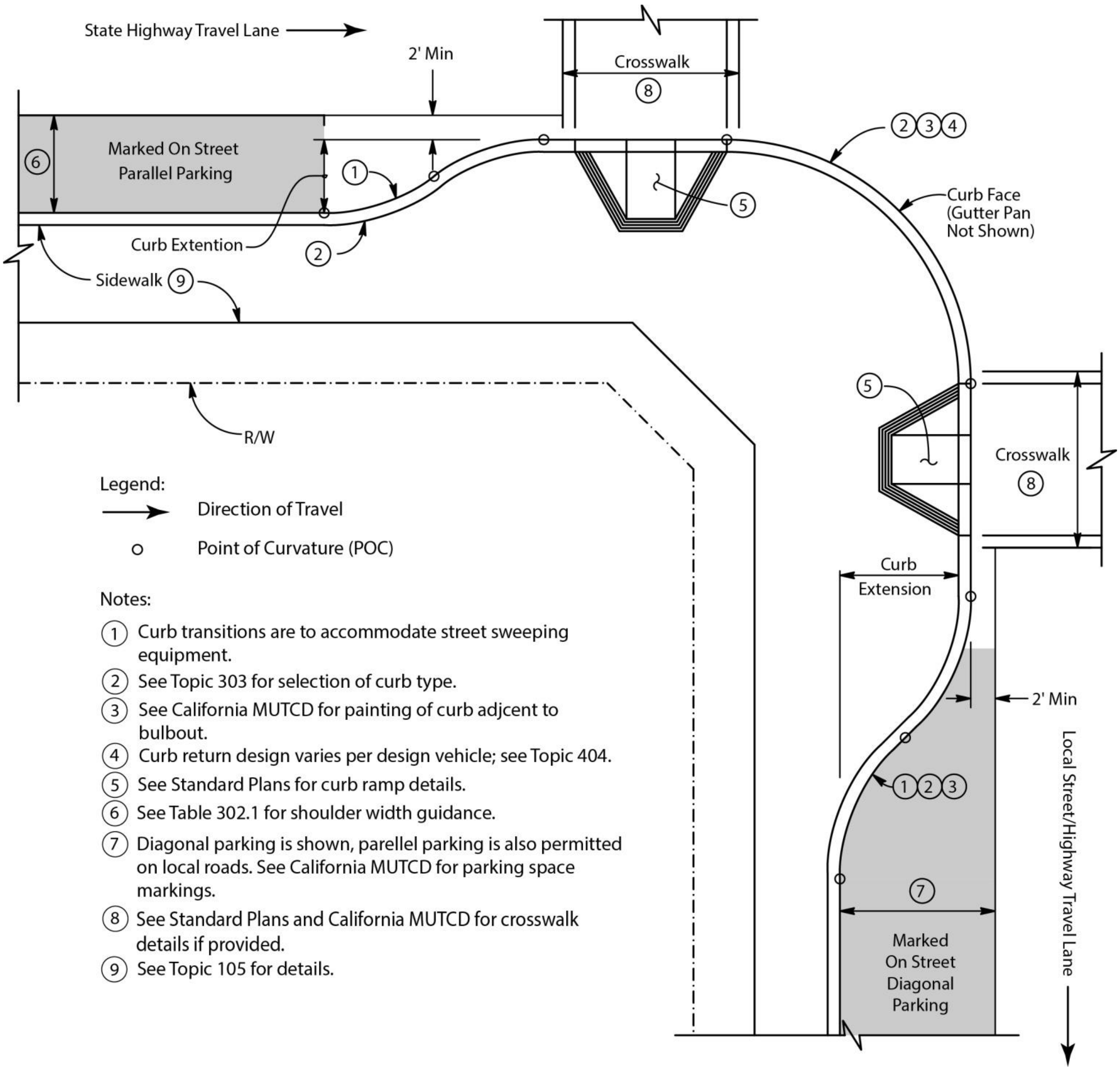
○ Point of Curvature (POC)

Notes:

1. Curb transitions are to accommodate street sweeping equipment.
2. See Topic 303 for selection of curb type.
3. See California MUTCD for painting of curb adjcent to bulbout.
4. Curb return design varies per design vehicle; see Topic 404.
5. See Standard Plans for curb ramp details.
6. See Table 302.1 for shoulder width guidance.
7. Diagonal parking is shown, parallel parking is also permitted on local roads. See California MUTCD for parking space markings.
8. See Standard Plans and California MUTCD for crosswalk details if provided.
9. See Index 301.2 and California MUTCD for details.
10. See Topic 105 for details.

Figure 303.4B

Typical Bulbout without Class II Bikeway (Bike Lane)



Busbays may be created by restricting on street parking.

303.5 Position of Curbs and Dikes

Curbs located at the edge of the traveled way may have some effect on lateral position and speed of moving vehicles, depending on the curb configuration and appearance. Curbs with low, sloped faces may encourage drivers to operate relatively close to them. Curbs with vertical faces may encourage drivers to slow down and/or shy away from them and, therefore, it may be desirable to incorporate some additional roadway width.

All dimensions to curbs (i.e., offsets) are from the near edge of traveled way to bottom face of curb. All dimensions to dikes are from the near edge of traveled way to flow line. Curb and dike offsets should be in accordance with the following:

(1) *Through Lanes.* The offset from the edge of traveled way to the face of curb or dike flow line should be no less than the shoulder width, as set forth in Table 302.1.

(2) *Channelization.* Island curbs used to channelize intersection traffic movements should be positioned as described in Index 405.4.

(3) *Separate Turning Lanes.* Curb offsets to the right of right-turn lanes in urban areas may be reduced to 2 feet if design exception approval for nonstandard shoulder width has been obtained in accordance with Index 82.2. No curb offset is required to the left of left-turn lanes in urban areas unless there is a gutter pan.

(4) *Median Openings.* Median openings (Figure 405.5) should not be separated with curb unless necessary to delineate areas occupied by traffic signal standards.

(5) *Urban Conventional Highways.* When the posted speed is less than or equal to 35 miles per hour, no median curb offset is required if there is no gutter pan.

(6) *Structure Approach Slabs.* When a dike is required to protect the side slope from erosion, it should be placed on the structure approach and sleeper slabs as well as aligned to tie into the end of the structure railing. The guardrail alignment and edge of shoulder govern the positioning of the dike.

When the Type 14 structure approach slab is used, concrete dikes are preferred. Hot mixed asphalt dike will inevitably crack due to expansion and contraction at the approach/sleeper slab joint. A metal dike insert is used to carry the flow across the sealed joint. The insert acts as a water barrier to minimize erosion of the fill slope. Details of the metal dike insert are shown in the structure approach plans provided by the Division of Engineering Services, (DES).

(7) *Bridges and Grade Separation Structures.* When both roadbeds of a curbed divided highway are carried across a single structure, the median curbs on the structure should be in the same location as on adjacent roadways.

(8) *Approach Nose.* The approach nose of islands should also be designed utilizing a parabolic flare, as discussed in Index 405.4.

303.6 Curbs and Dikes on Frontage Roads and Streets

Continuous curbs or dikes are not necessarily required on all frontage roads. Where curbs or dikes are necessary for drainage control or other reasons, they should be consistent with the guidelines established in this topic and placed as shown on Figure 307.4B. Local curb standards should be used when requested by local authorities for roads and streets that will be relinquished to them.

Topic 304 - Side Slopes

304.1 Side Slope Standards

Slopes should be designed as flat as is reasonable. <u>For new construction, widening, or where slopes are otherwise being modified, embankment (fill) slopes should be 4:1 or flatter.</u> Factors affecting slope design are as follows:

(a) *Safety.* Flatter slopes provide better recovery for errant vehicles that may run off the road. A cross slope of 6:1 or flatter is suggested for high speed roadways whenever it is achievable. Cross slopes of 10:1 are desirable.

Embankment slopes 4:1 or flatter are recoverable for vehicles. Drivers who encroach on recoverable slopes can generally stop or slow down enough to return to the traveled way safely. See Index 309.1(2) for information on clear recovery zones.

A slope which is between 3:1 and 4:1 is considered traversable, but not recoverable. Since a high percentage of vehicles will reach the toe of these slopes, the recovery area should be extended beyond the toe of slope. The AASHTO Roadside Design Guide should be consulted for methods of determining the preferred extent of the runout area.

Embankment slopes steeper than 3:1 should be avoided when accessible by traffic. District Traffic, and the AASHTO Roadside Design Guide should be consulted for methods of determining the preferred treatment.

Regardless of slope steepness, it is desirable to round the top of slopes so an encroaching user remains in contact with the ground. Likewise, the toe of slopes should be rounded to prevent users from nosing into the ground.

(b) *Erosion Control.* Slope designs steeper than 4:1 must be approved by the District Landscape Architect in order to assure compliance with the regulations affecting Stormwater Pollution contained in the Federal Clean Water Act (see Index 82.4). Slope steepness and length are two of the most important factors affecting the erodibility of a slope. Slopes should be designed as flat as possible to prevent erosion. However, since there are other factors such as soil type, climate, and exposure to the sun, District Landscape Architecture and the District Stormwater Coordinator must be contacted for erosion control requirements. See Topic 906.

A Storm Water Data Report (SWDR) documents project information and considerations pertaining to Storm Water Best Management Practices (BMPs) and Erosion Control methods. The SWDR is prepared and signed by key personnel (including the District Landscape Architect) at the completion of each phase of a project. By signing the SWDR, the District Landscape Architect approves compliance with the proposed slope designs.

(c) *Structural Integrity.* Slopes steeper than 2:1 require approval of District Maintenance. The Geotechnical Design Report (See Topic 113) will recommend a minimum slope required to prevent slope failure due to soil cohesiveness, loading, slip planes and other global stability type failures. There are other important issues found in the Geotechnical Design Report affecting slope design such as the consistency of the soil likely to be exposed in cuts, identification of the presence of ground water, and recommendations for rock fall.

(d) *Economics.* Economic factors such as purchasing right of way, imported borrow, and environmental impacts frequently play a role in the decision of slope length and steepness. In some cases, the cost of stabilizing, planting, and maintaining steep slopes may exceed the cost of additional grading and right of way to provide a flatter slope.

(e) *Aesthetics.* Flat, gentle, and smooth, well transitioned slopes are visually more satisfying than steep, obvious cuts and fills. In addition, flatter slopes are more easily revegetated, which helps visually integrate the transportation improvement within its surrounding environment. Contact the District Landscape Architect when preparing a contour grading plan.

In light grading where normal slopes catch in a distance less than 18 feet from the edge of the shoulder, a uniform catch point, at least 18 feet from the edge of the shoulder, should be used. This is done not only to improve errant vehicle recovery and aesthetics, but also to reduce grading costs. Uniform slopes wider than 18 feet can be constructed with large production equipment thereby reducing earthwork costs.

Transition slopes should be provided between adjoining cuts and fills. Such slopes should intersect the ground at the uniform catch point line.

In areas where heavy snowfall can be expected, consideration should be given to snow removal problems and snow storage in slope design. It is considered advisable to use flatter slopes in cuts on the southerly side of the roadway where this will provide additional exposure of the pavement to the sun.

304.2 Clearance From Slope to Right of Way Line

The minimum clearance from the right of way line to catch point of a cut or fill slope should be 10 feet for all types of cross sections. When feasible, at least 15 feet should be provided.

Following are minimum clearances recommended for cuts higher than 30 feet:

(a) Twenty feet for cuts from 30 feet to 50 feet high.

(b) Twenty-five feet for cuts from 50 feet to 75 feet high.

(c) One-third the cut height for cuts above 75 feet, but not to exceed a width of 50 feet.

The foregoing clearance standards should apply to all types of cross sections.

304.3 Slope Benches and Cut Widening

The necessity for benches, their width, and vertical spacing should be finalized only after an adequate materials investigation. Since greater user benefits are realized from widening a cut than from benching the slope, benches above grade should be used only where necessary. Benches above grade should be used for such purposes as installation of horizontal drains, control of surface erosion, or intercepting falling rocks. Design of the bench should be compatible with the geotechnical features of the site.

Benches should be at least 20 feet wide and sloped to form a valley at least 1 foot deep with the low point a minimum of 5 feet from the toe of the upper slope. Access for maintenance equipment should be provided to the lowest bench, and if feasible to all higher benches.

In cuts over 150 feet in height, with slopes steeper than 1½:1, a bench above grade may be desirable to intercept rolling rocks. The Division of Engineering Services – Geotechnical Services (DES-GS) should be consulted for assistance in recommending special designs to contain falling and/or rolling rocks.

Cut widening may be necessary:

(a) To provide for drainage along the toe of the slope.

(b) To intercept and store loose material resulting from slides, rock fall, and erosion.

(c) For snow storage in special cases.

(d) To allow for planting.

Where the widened area is greater than that required for the normal gutter or ditch, it should be flush with the edge of the shoulder and sloped upward or downward on a gentle slope, preferably 20:1 in areas of no snow; and downward on a 10:1 slope in snow areas.

304.4 Contour Grading and Slope Rounding

Contour grading, slope rounding and topsoil replacement are important factors in roadside design to help make highway improvements compatible with the surrounding environment while comply with National Pollutant Discharge Elimination System permits (NPDES). Smooth, flowing contours that tie gracefully into the existing adjacent roadside and landforms are visually appealing and conducive to safe vehicle recovery (see Index 304.1), reduce the potential for erosion and stormwater runoff, and reduce roadside maintenance activities while contributing to the long term success of revegetation planting.

Contour grading plans are to be prepared to facilitate anticipated roadside treatments and future maintenance activities. These plans should show flattened slopes where right of way permits. The tops and ends of all cut slopes should be rounded. Rock cut slopes should be irregular where possible to provide a natural appearance and the tops and ends should also be rounded. All slope designs should include consideration of an application of local or imported topsoil and duff to promote the growth of vegetation, improve stormwater pollutant filtration and control erosion. The calculation of the final grade for a project needs to take into account the reapplication of topsoil and duff.

Local topsoil and duff material within the grading limits should be identified on the plans, removed or excavated, stockpiled, and reapplied. This is to be performed on all projects that include grading or earthwork unless the materials are determined to be unsuitable. Refer to Index 904.2(2).

Coordinate the development of contour grading plans including, removal, stockpiling, suitability of material and application of topsoil and duff with the District Landscape Architect. See Index 904.2.

304.5 Stepped Slopes

Stepped cut slopes should be used to encourage material revegetation from the adjacent plants. Stepped slopes are a series of small benches 1 foot to 2 feet wide. Generally, stepped slopes can be used in rippable material on slopes 2:1 or steeper. Steps may be specified for slopes as flat as 3:1. Steps are provided to capture loose material, seed, and moisture. Topsoil should be reapplied to stepped slopes to encourage revegetation.

For appearance, steps on small cuts viewed from the roadway should be cut parallel to the road grade. Runoff is minimized on steps cut parallel to roads with grades up to 10 percent, as long as the natural ravel from construction is left on the steps. Steps less than one-half full should not be cleaned.

High cuts viewed from surrounding areas should be analyzed before a decision is made to form steps parallel to the roadway or horizontal. In some cases, horizontal steps may be more desirable. Special study is also necessary when a sag occurs in the vertical alignment within the cut. In all cases at the ends of cuts, the steps should wrap around the rounded transition.

The detail or contract special provisions should allow about a 20 percent variation, expressed in terms of tenths of a foot. Some irregularity will improve the appearance of the slope by making it appear more natural.

In designing step width, the material's weathering characteristics should generally be considered. Widths over approximately 2 feet should be avoided because of prominence and excessive time to achieve a weathered and natural appearance. Contact the DES-GS and the District Landscape Architect for more information about the width of steps.

Topic 305 - Median Standards

305.1 Width

Median width is expressed as the dimension between inside edges of traveled way, including the inside shoulder. This width is dependent upon the type of facility, costs, topography, and right of way. Consideration may be given to the possible need to construct a wider median than prescribed in Cases (1), (2), and (3), below, in order to provide for future expansion to accommodate:

(a) Public Transit (rail and bus).

(b) Traffic needs more than 20 years after completion of construction.

Median width as presented in Case (1) below applies to new construction, projects to increase mainline capacity and to reconstruction projects. Any recommendation to provide additional median width should be identified and documented as early as possible and must be justified in a project initiation document and/or project report. Attention should be given to such items as initial costs, future costs for outside widening, the likelihood of future needs for added mixed flow or High-Occupancy Vehicle (HOV) lanes, traffic interruption, future mass transit needs and right of way considerations. (For instance, increasing median width may add little to the cost of a project where an entire city block must be acquired in any event.)

Median pedestrian refuge areas at intersections lessen the risk of pedestrian exposure to traffic. See Index 405.4(3) and DIB 82 for pedestrian refuge guidance.

If additional width is justified, the minimum median widths provided below should be increased accordingly.

<u>Minimum median widths for the design year (as described below) should be used in order to accommodate the ultimate highway facility (type and number of lanes):</u>

(1) Freeways and Expressways.

(a) Urban Areas. Where managed lanes (HOV, Express, etc) or transit facilities are planned, the minimum median width should be 62 feet. Where there is little or no likelihood of managed lanes or transit facilities planned for the future, the minimum median width should be 46 feet. However, where physical and economic limitations are such that a 46-foot median cannot be provided at reasonable cost, <u>the</u>

minimum median width for freeways and expressways in urban areas should be 36 feet.

(b) Rural Areas. The minimum median width for freeways and expressways in rural areas should be 62 feet.

(2) Conventional Highways. Appropriate median widths for non-controlled access highways vary widely with the type of facility being designed. In Urban and Rural Main Street areas, the minimum median width for multilane conventional highways should be 12 feet. However, this width would not provide room for left-turn lanes at intersections with raised curb medians, nor left-turn lanes in striped medians with room for pedestrian refuge areas. Posted speed and left shoulder width can also affect median width. See Table 302.1.

Medians refuge areas at pedestrian crosswalks and bicycle path crossings provide a space for pedestrians and bicyclists. They allow these users to cross one direction of traffic at a time. Where medians are provided, they should allow access through them for pedestrians and bicyclists as necessary. Bicycle crossings through paved medians should line up with the bicycle path of travel and not require bicyclists to utilize the pedestrian crosswalk. See Index 405.4 for additional requirements.

Where medians are provided for proposed future two-way left-turn lanes, median widths up to 14 feet may be provided to conform to local agency standards (see Index 405.2). **In rural areas the minimum median width for multilane conventional highways shall be 12 feet.** This provides the minimum space necessary to accommodate a median barrier and 5-foot shoulders. Whenever possible, and where it is appropriate, this minimum width should be increased to 30 feet or greater.

At locations where a climbing or passing lane is added to a 2-lane conventional highway, a 4-foot median (or "soft barrier") between opposing traffic lanes should be used.

(3) Facilities under Restrictive Conditions. Where certain restrictive conditions, including steep mountainous terrain, extreme right of way costs, and/or significant environmental factors are encountered, the basic median widths above may not be attainable. Where such conditions exist, a narrower median, down to the limits given below, may be allowed with adequate justification. (See Index 307.5.)

(a) Freeways and Expressways. **In areas where restrictive conditions prevail the minimum median width shall be 22 feet.**

(b) Conventional Highways. Median widths should be consistent with requirements for two-way left-turn lanes or the need to construct median barriers (as discussed in Index 305.1(2)), but may be reduced or eliminated entirely in extreme situations.

The above stated minimum median widths should be increased at spot locations to accommodate the construction of bridge piers or other planned highway features while maintaining standard cross section elements such as inside shoulder width and horizontal clearance. If a bridge pier is to be located in a tangent section, the additional width should be developed between adjacent horizontal curves; if it is to be located in a curve, then the additional width should be developed within the limits of the curve. Provisions should be made for piers 6 feet wide or wider. Median widths in areas of multilevel interchanges or other major structures should be coordinated with the Division of Engineering Services, Structures Design (DES-SD).

Consideration should also be given to increasing the median width at unsignalized intersections on expressways and divided highways in order to provide a refuge area for large trucks attempting to cross the State route.

In any case, the median width should be the maximum attainable at reasonable cost based on site specific considerations of each project.

See Index 613.5(2)(b) for paved median pavement structure requirements.

305.2 Median Cross Slopes

Unsurfaced medians up to 65 feet wide should be sloped downward from the adjoining shoulders to form a shallow valley in the center. Cross slopes should be 10:1 or flatter; 20:1 being preferred. Slopes as steep as 6:1 are acceptable in exceptional cases when necessary for drainage, stage construction, etc. Cross slopes in medians greater than 65 feet should be treated as separate roadways (see Index 305.6).

Paved medians, including those bordered by curbs, should be crowned at the center, sloping towards the sides at the slope of the adjacent pavement.

305.3 Median Barriers

See Traffic Safety Systems Guidance.

305.4 Median Curbs

See Topic 303 for curb types and usage in medians and Index 405.5(1) for curbs in median openings.

305.5 Paved Medians

(1) *Freeways.*

(a) 6 or More Lanes--Medians 30 feet wide or less should be paved.

(b) 4 Lanes--Medians 22 feet or less in width should be paved. Medians between 22 feet and 30 feet wide should be paved only if a barrier is installed. With a barrier, medians wider than 30 feet should not normally be paved.

Where medians are paved, each half generally should be paved in the same plane as the adjacent traveled way.

(2) *Nonfreeways.* Unplanted curbed medians generally are to be surfaced with minimum 0.15 foot of Portland cement concrete.

For additional information on median cross slopes see Index 305.2.

305.6 Separate Roadways

(1) *General Policy.* Separate grade lines are not considered appropriate for medians less than 65 feet wide (see Index 204.7).

(2) *Median Design.* The cross sections shown in Figure 305.6 include a clear recovery zone that provides maneuvering room for out-of-control users. See Index 309.1(2).

See Index 302.1 for shoulder widths and Index 302.2 for shoulder cross slopes.

Topic 306 - Right of Way

306.1 General Standards

The right of way widths for State highways, including frontage roads to be relinquished, should provide for installation, operation and maintenance of all cross section elements needed depending upon the type of facility, including median, traffic lanes, bicycle lanes, outside shoulders, sidewalks, recovery areas, slopes, sight lines, outer separations, ramps, walls, transit facilities and other essential highway appurtenances. For minimum clearance from the right of way line to the catch point of a cut or fill slope, see Index 304.2. Fixed minimum widths of right of way, except for 2-lane highways, are not specified because dimensions of cross-sectional elements may require narrow widths, and right of way need not be of constant width. The minimum right of way width on new construction for 2-lane highways should be 150 feet.

306.2 Right of Way Through the Public Domain

Right of way widths to be obtained or reserved for highway purposes through lands of the United States Government or the State of California are determined by laws and regulations of the agencies concerned.

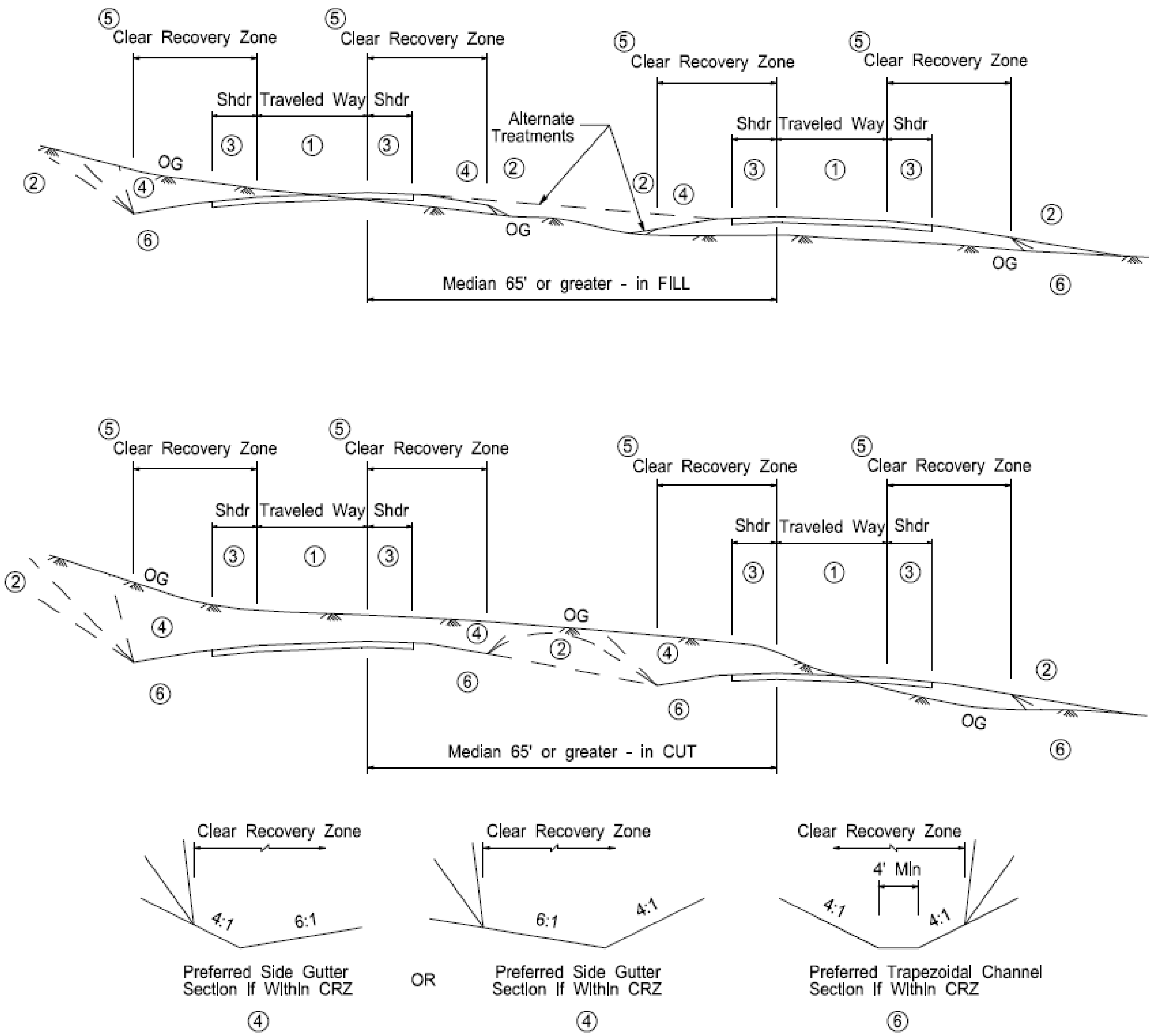
Topic 307 - Cross Sections for State Highways

307.1 Cross Section Selection

The cross section of a State highway is based upon the number of vehicles, including trucks, buses, bicycles, and safety, terrain, transit needs and pedestrians. Other factors such as sidewalks, bike paths and transit facilities, both existing and future should be considered. For 2-lane roads the roadbed width is influenced by the factors discussed under Index 307.2. The roadbed width for multilane facilities should be adequate to provide capacity for

Figure 305.6

Optional Median Designs for Freeways with Separate Roadways



NOTES:

①	CROSS SLOPES	See Index 302.2	④	SIDE GUTTERS	See Index 834.3(3)
②	SIDE SLOPES	See Index 304.1	⑤	CLEAR RECOVERY ZONE	See Index 309.1(2)
③	SHOULDER WIDTH	See Index 302.1	⑩	ROADSIDE CHANNELS	See Topic 860

the design hourly volume based upon capacity considerations discussed under Index 102.1.

When it becomes necessary to widen an existing cross section, e.g., add or widen the paved shoulder or lane, refer to Index 653.2 and Index 662.3 to ensure proper drainage of both the existing and widening structural sections. See also Chapter 680, Pavement Design for Widening Projects.

307.2 Two-lane Cross Sections for New Construction

These standards are to be used for highways on new alignment as well as on existing highways where the width, alignment, grade, or other geometric features are being upgraded.

A 2-lane, 2-way roadbed consists of a 24-foot wide traveled way plus paved shoulders. In order to provide structural support, the minimum paved width of each shoulder should be 2 feet. Shoulders less than 4 feet are not adequate for bicycles. Where 4-foot shoulders are not possible, consideration should be given to providing turnouts for bicycles. See Index 204.5(4) for turnout information. See Topic 1003 and Index 301.2 for information on bicycle design criteria and Figure 307.2 for typical 2-lane cross sections.

Shoulder widths based on design year traffic volumes shall conform to the standards given in Table 307.2.

Table 307.2

Shoulder Widths for Two-lane Roadbed New Construction Projects

Two-way ADT (Design Year)	Shoulder Width(1) (ft)
Less than 400	4(2)
Over 400	8(3)

NOTES:

(1) See Index 302.1 for shoulder requirements when bike lanes are present.
(2) Minimum bridge width is 32 feet (see Index 208.1).
(3) See Index 405.3(2)(a) for shoulder requirements adjacent to right-turn only lanes.

On 2-lane roads with 4-foot shoulders, the shoulder slope may be increased to 7 percent for additional drainage capacity where a dike is used. A design exception to Index 302.2 will be required to document the decision to increase the slope.

Bicycles are not prohibited on conventional highways: therefore, where the shoulder width is 4 feet, the gutter pan width should be reduced to 1 foot, so 3 feet is provided between the traffic lane and the longitudinal joint at the gutter pan. Whenever possible, grate type inlets should not be located in bicycle paths of travel. See Index 837.2(2) for further grate guidance.

307.3 Two-lane Cross Sections for 2R, 3R, and other Projects

Standards and guidelines for two-lane cross sections on resurfacing and restoration (2R) projects and resurfacing, restoration, and rehabilitation (3R) projects are found in DIB 79 and Index 603.4. DIB 79 also includes screening criteria to determining whether the project fits 2R or 3R.

3R design criteria apply to all structure and roadway 3R projects on two-lane conventional highways and three-lane conventional highways not classified as multilane conventional highways.

3R design criteria also apply to certain storm damage, protective betterment, operational, and safety nonfreeway improvement projects that are considered spot locations as described in detail in DIB 79.

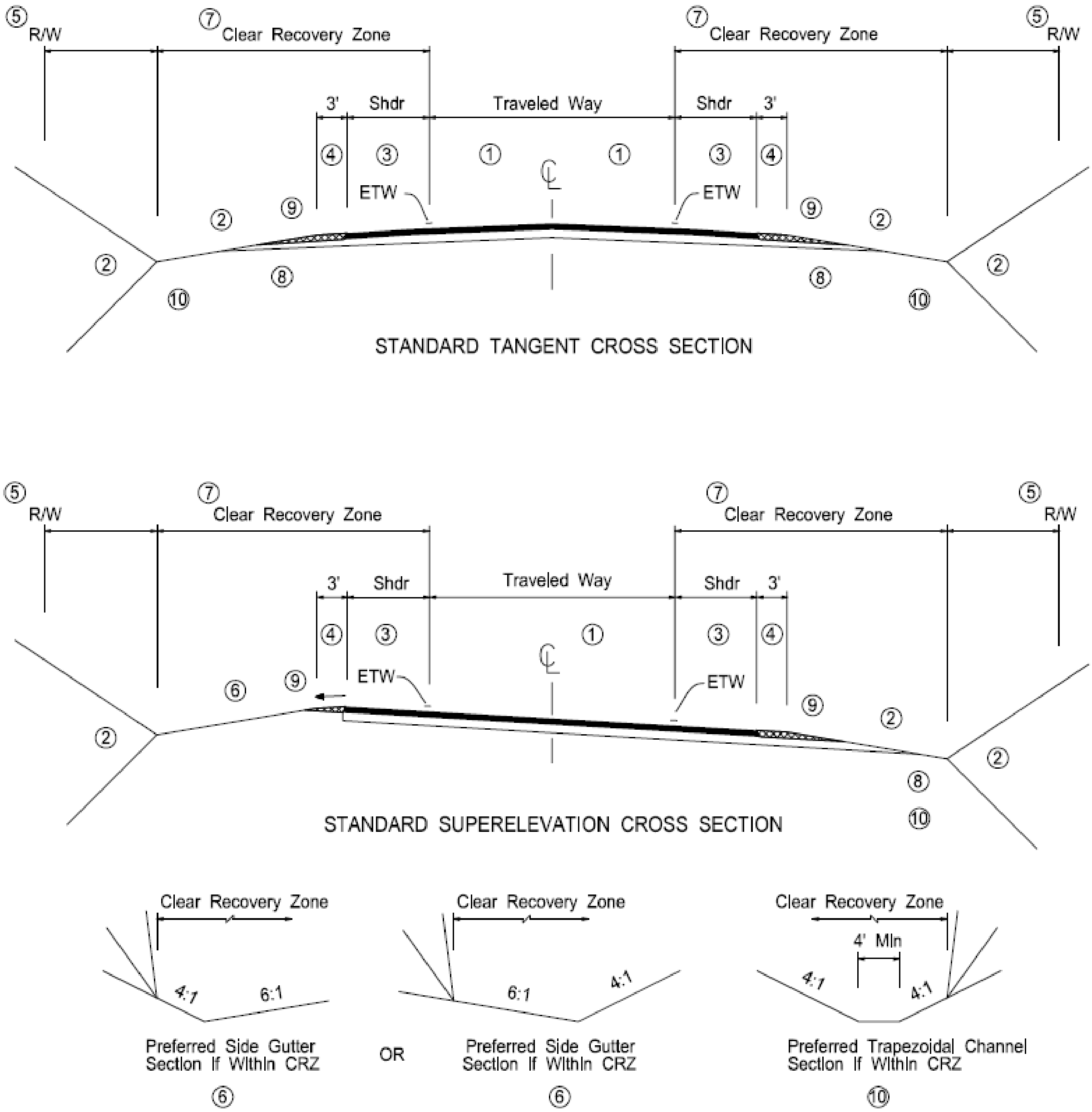
3R criteria apply to geometric design features such as lane and shoulder widths, horizontal and vertical alignment, stopping sight distance, structure width, cross slope, superelevation, side slope, clear recovery zone, curb ramps, pavement edge drop, dike, curb and gutter, and intersections. They may also apply to such features as bike lanes, sidewalk, and drainage.

307.4 Multilane Divided Cross Sections

The general geometric features of multilane divided cross sections are shown in Figures 307.4A and B.

Divided highways may be designed as two separate one-way roads where appropriate to fit the terrain. Economy, pleasing appearance, and safety are factors to be considered in this determination. The alignment of each roadway may be independent of

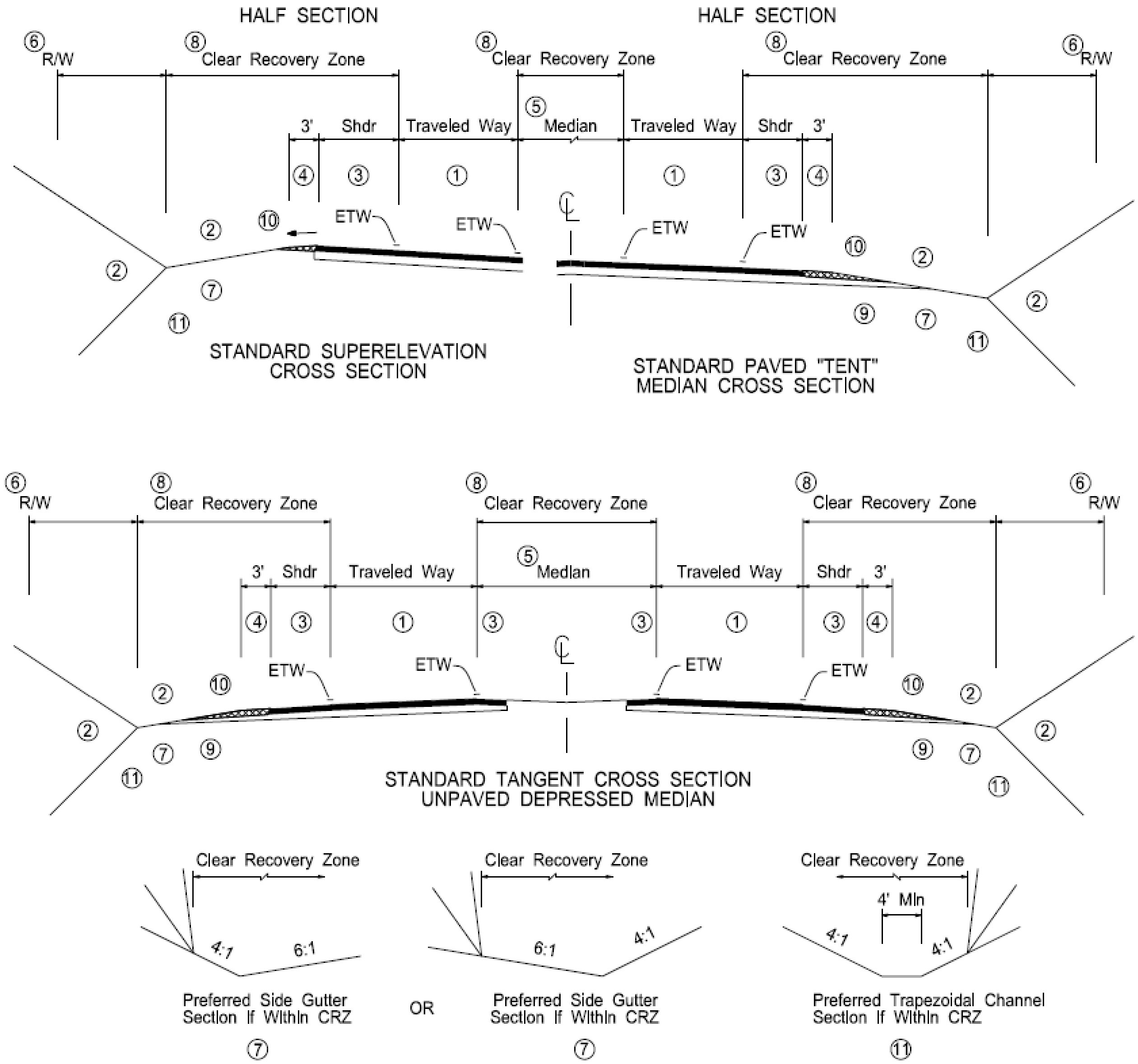
Figure 307.2
Geometric Cross Sections for Two-lane Highways (New Construction)



NOTES:

①	CROSS SLOPES	See Index 302.2	⑥	SIDE GUTTERS	See Index 834.3(3)
②	SIDE SLOPES	See Index 304.1	⑦	CLEAR RECOVERY ZONE	See Index 309.1(2)
③	SHOULDER WIDTH	See Index 302.1	⑧	PAVEMENT DRAINAGE	See Indexes 653.1, 653.2, 662.3
④	DIKE PLACEMENT	See Index 303.3	⑨	SHOULDER BACKING	See Index 672
⑤	RIGHT OF WAY	See Index 306.1 and Index 304.2	⑩	ROADSIDE CHANNELS	See Topic 860

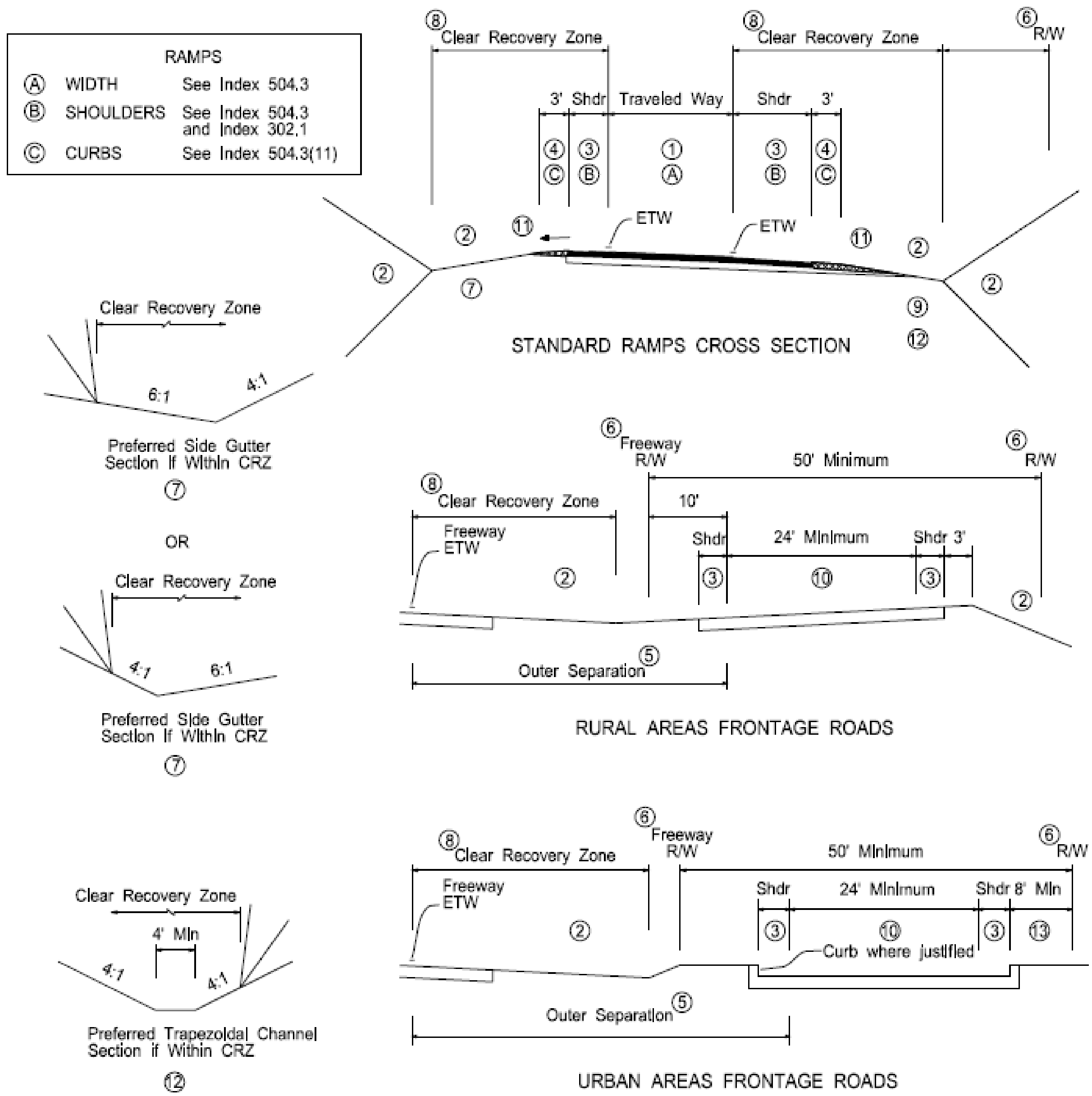
Figure 307.4A
Geometric Cross Sections for Freeways and Expressways



NOTES:

①	CROSS SLOPES	See Index 302.2	⑥	RIGHT OF WAY	See Indexes 306.1, 304.2
②	SIDE SLOPES	See Index 304.1 and Index 304.2	⑦	SIDE GUTTERS	See Index 834.3(3)
③	SHOULDERS WIDTH	See Index 302.1	⑧	CLEAR RECOVERY ZONE	See Index 309.1(2)
	PAVING	See Index 613.5(2)	⑨	PAVEMENT DRAINAGE	See Indexes 653.1, 653.2, 662.3
④	DIKES	See Index 303.3	⑩	SHOULDER BACKING	See Index 672
⑤	MEDIANS WIDTH	See Index 305.1	⑪	ROADSIDE CHANNELS	See Topic 860
	SLOPES	See Index 305.2			
	PAVING	See Index 305.5			
	SEPARATE ROADWAYS	See Index 305.6			

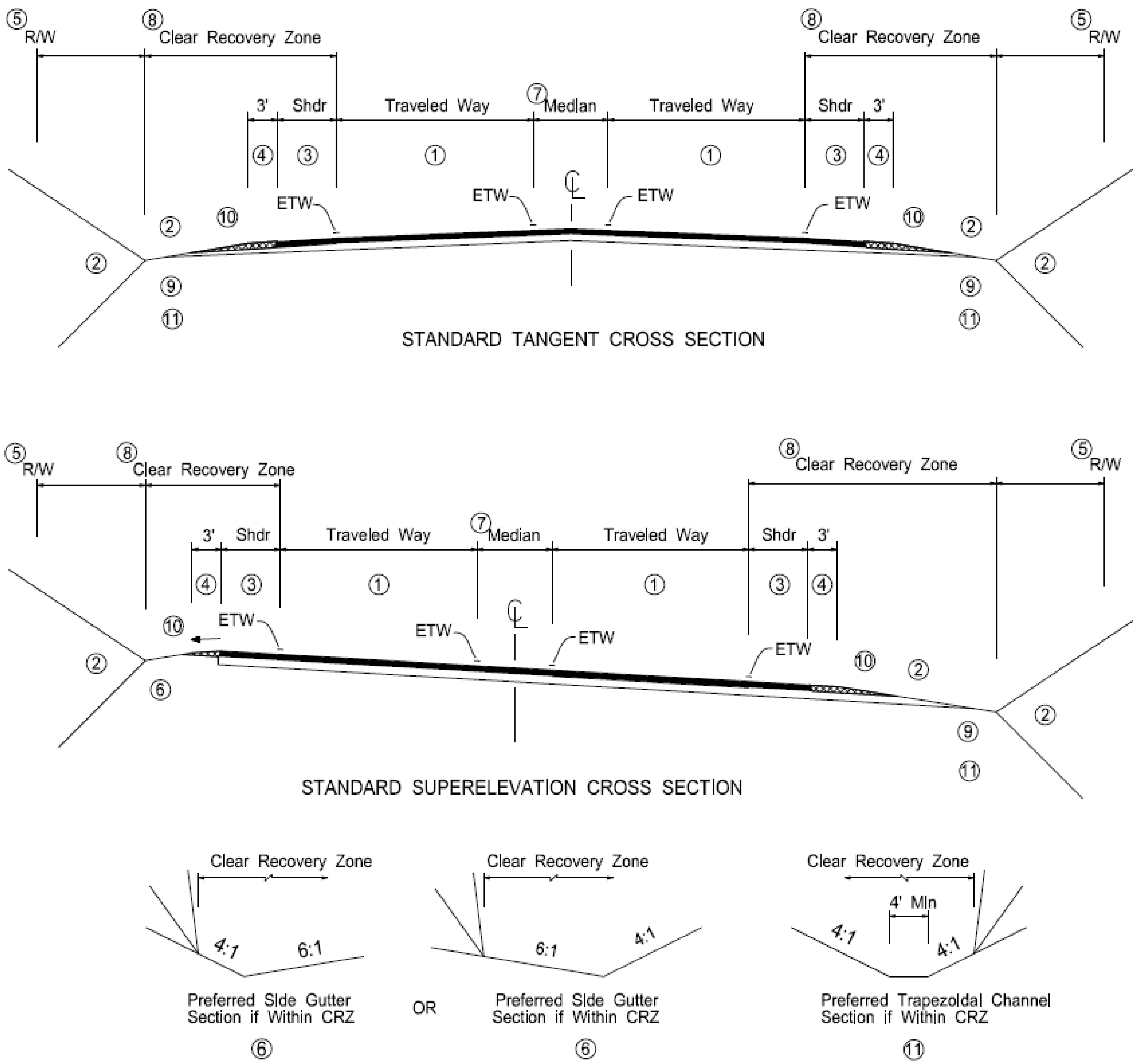
Figure 307.4B
Geometric Cross Sections for Freeways and Expressways



NOTES:

①	CROSS SLOPES	See Index 302.2	⑥	RIGHT OF WAY	See Indexes 306.1, 304.2
②	SIDE SLOPES	See Index 304.1 and Index 304.2	⑦	SIDE GUTTERS	See Index 834.3(3)
③	SHOULDERS WIDTH PAVING	See Index 302.1 See Index 613.5(2)	⑧	CLEAR RECOVERY ZONE	See Index 309.1(2)
④	DIKES	See Index 302.2	⑨	PAVEMENT DRAINAGE	See Indexes 653.1, 653.2, 662.3
⑤	OUTER SEPARATION	See Index 310.2	⑩	CROSS SECTION	See Index 310.1
			⑪	SHOULDER BACKING	See Index 672
			⑫	ROADSIDE CHANNELS	See Topic 860
			⑬	SIDEWALKS	See Index 105.2

Figure 307.5
Geometric Cross Sections for All Paved Multilane Highways



NOTES:					
①	CROSS SLOPES	See Index 302.2	⑥	SIDE GUTTERS	See Index 834.3(3)
②	SIDE SLOPES	See Index 304.1	⑦	MEDIANS	See Index 305.1(3)
③	SHOULDER WIDTH	See Index 302.1	⑧	CLEAR RECOVERY ZONE	See Index 309.1(2)
④	DIKES	See Index 303.3	⑨	PAVEMENT DRAINAGE	See Indexes 653.1, 653.2, 662.3
⑤	RIGHT OF WAY	See Index 306.1 and Index 304.2	⑩	SOULDER BACKING	See Index 672
			⑪	ROADSIDE CHANNELS	See Topic 860

the other (see Indexes 204.8 and 305.6). Optional median designs may be as shown on Figure 305.6. See Index 309.1 (2) for Clear Recovery Zone.

307.5 Multilane All Paved Cross Sections with Special Median Widths

A multilane cross section with a narrow median is illustrated in Figure 307.5. This section is appropriate in special circumstances where a wider median would not be justified. It should not be considered as an alternative to sections with the median widths set forth under Index 305.1. It may be used under the following conditions:

(a) Widening of existing facilities.

(b) Locations where large excavation quantities would result if a multilane roadway cross section with a basic median width were used. Examples are steep mountainous terrain and unstable mountainous areas.

(c) As an alternate cross section on 2-lane roads having frequent sight distance restrictions.

The median width should be selected in accordance with the criteria set forth in Index 305.1(3).

In general, the outside shoulder should be 8 feet wide (10 feet on freeways and expressways) as mandated in Table 302.1. Where large excavation quantities or other factors generate unreasonable costs, 4-foot shoulders may be considered.

However, a design exception is required except where 4-lane passing sections are constructed on 2-lane highways. Where the roadbed width does not contain 8-foot shoulders, emergency parking areas clear of the traveled way should be provided by using daylighted cuts and other widened areas which develop during construction.

307.6 Multilane Cross Sections for 2R and 3R Projects

3R projects on freeways, expressways, and multilane conventional highways are required to meet new construction standards. See Index 309.1 (2) for Clear Recovery Zone.

For additional information on 2R and 3R projects, see DIB 79.

307.7 Reconstruction Projects

Reconstruction projects on freeways, expressways, and conventional highways are required to meet new construction standards.

Topic 308 - Cross Sections for Roads Under Other Jurisdictions

308.1 City Streets and County Roads

The minimum width of local roads and streets that are to be reconstructed as part of a freeway or expressway project should conform to locally adopted standards except as described below.

Where a local facility, not on the NHS, within the State right of way crosses over or under a freeway or expressway but has no connection to the State facility, the minimum design standards for the cross section of the local facility within the State's right of way shall be the local agency adopted standards. If the local facility is on the NHS, AASHTO standards will apply**.** If the local agency has standards that exceed AASHTO standards, then the local agency standards can apply. See the Local Assistance Procedures Manual Chapter 11 for information on design guidance and documentation of design decisions for local assistance projects.

AASHTO standards for local roads and streets are given in AASHTO, A Policy on Geometric Design of Highways and Streets. These standards relate to the functional classification and system characteristics of the local roadway system. See Chapter 1 of these standards for information on the functional classification and system characteristics of roadways.

AASHTO, A Policy on Geometric Design of Highways and Streets, gives minimum lane and shoulder widths. When selecting a cross section, the effects on capacity of commercial vehicles and grades should be considered as discussed under Topic 102 and in the Transportation Research Board, Highway Capacity Manual.

The minimum width of 2-lane overcrossing structures shall not be less than 32 feet face of curb to face of curb.

If the local agency has definite plans to widen the local street either concurrently or within 5 years following freeway construction, the reconstruction to be accomplished by the State should generally conform to the widening planned by the local agency. Stage construction should be considered where the planned widening will occur beyond the 5-year period following freeway construction or where the local agency has a master plan indicating an ultimate width greater than the existing facility. Where an undercrossing is involved, the initial structure construction should provide for ultimate requirements.

Where a local facility crosses over or under a freeway or expressway and connects to the State facility (such as ramp terminal intersections), the minimum design standards for the cross section of the local facility shall be at least equal to those for a conventional highway with the exception that the outside shoulder width shall match the approach roadway, but not less than 4 feet, and as shown below.

Where the 2-lane local facility connects to a freeway within an interchange, the lane width of the local facility shall be 12 feet.

Where a multilane local facility connects to a freeway within an interchange, the outer most lane in each direction of the local facility shall be 12 feet.

Shoulder width shall not be less than 5 feet when railings or other lateral obstructions are adjacent to the right edge of shoulder.

If gutter pans are used, then the minimum shoulder width shall be 3 feet wider than the width of the gutter pan being used.

The minimum width for two-lane overcrossing structures at interchanges shall be 40 feet curb-to-curb.

Topic 309 - Clearances

309.1 Horizontal Clearances for Highways

(1) *General.* The horizontal clearance to all roadside objects should be based on engineering judgment with the objective of maximizing the distance between roadside objects and the edge of traveled way. Engineering judgment should be exercised in order to balance the achievement of horizontal clearance objectives and reduction of maintenance cost and exposure to workers,

with the prudent expenditure of available funds.

Certain yielding types of fixed objects, such as sand filled barrels, guardrail, breakaway wood posts, etc. may encroach within the clear recovery zone (see Index 309.1(2)). While these objects are designed to reduce the severity of accidents, efforts should be made to maximize the distance between any object and the edge of traveled way.

Horizontal clearances are measured from the edge of the traveled way to the nearest point on the obstruction (usually the bottom). Consideration should be given to the planned ultimate traveled way width of the highway facility. **Horizontal clearances greater than those cited below under Subsection (3) - "Minimum Clearances" shall be provided where necessary to meet horizontal stopping sight distance requirements.** See subsection (4) for high speed rail clearance guidance. See discussion on "... technical reductions in design speed..." under Topic 101.

(2) *Clear Recovery Zone (CRZ).* The roadside environment can and should be made as safe as practical. A clear recovery zone is an unobstructed, relatively flat (4:1 or flatter) or gently sloping area beyond the edge of the traveled way which affords the drivers of errant vehicles the opportunity to regain control. <u>For embankment slopes, a clear recovery zone of 4:1 or flatter should apply on all highways with distances referenced in Subsection (2)(a), except if guardrail or barrier is provided.</u> Dike, curb and gutter are acceptable within the clear recovery zone, but there are limitations if used with guardrail. See the Traffic Safety Systems Guidance for information on guardrail and barrier placement. The AASHTO Roadside Design Guide provides detailed design guidance for creating a forgiving roadside environment. See also Index 304.1 regarding side slopes.

See DIB 79 for 2R, 3R, certain storm damage, protective betterment, operational, and safety projects on two-lane and three-lane conventional highways.

The following clear recovery zone widths are the minimum desirable for the type of facility indicated. Consideration should be given to increasing these widths based on traffic volumes, operating speeds, terrain (e.g., steeper than 4:1), horizontal curvature, and costs associated with a particular highway facility:

- Freeways and Expressways – 30 feet
- Conventional Highways – 20 feet*

* On conventional highways with posted speeds less than or equal to 35 miles per hour and curbs, clear recovery zone widths do not apply. See minimum horizontal clearance, Index 309.1(3)(c).

(a) Necessary Highway Features.

Fixed objects, when they are necessary highway features, including, but not limited to, bridge piers, abutments, retaining walls, and noise barriers closer to the edge of traveled way than the distances listed above should be eliminated, moved, redesigned to be made yielding, or shielded in accordance with the following guidelines:

- Fixed objects, when they are necessary highway features, should be eliminated or moved outside the clear recovery zone to a location where they are unlikely to be hit.
- If necessary highway features such as sign posts or light standards cannot be eliminated or moved outside the clear recovery zone, they should be made yielding with a breakaway feature.
- If a fixed object, when they are necessary highway features, cannot be eliminated, moved outside the clear recovery zone, or modified to be made yielding, it should be shielded by guardrail, barrier or a crash cushion.

Shielding and breakaway features must be in conformance with the guidance found in Traffic Safety Systems Guidance. For input on the need for shielding at a specific location, consult District Traffic Operations.

Existing above-ground utilities and existing large trees as defined in Index 904.5(1) should conform to the guidance associated with necessary highway features stated above. When the planting of trees is being considered, see the additional discussion and standards in Chapter 900.

(b) Discretionary Fixed Objects.

Discretionary fixed objects are features or facilities that are not necessary for the safety, maintenance or operation of the highway, but may enhance livability and sustainability. These may include, but are not limited to, transportation art, gateway monuments, solar panels, and memorial/historical plaques or markers. See Subsection (4) for high speed rail clearance guidance. When discretionary fixed objects are constructed on freeways, expressways or conventional highways, they should be located beyond the clear recovery zone at a minimum of 52 feet horizontally or 8 feet vertically up-slope from the planned ultimate edge of traveled way. However, if discretionary fixed objects are to be placed less than the 52 feet horizontally or less than the 8 feet vertically up-slope, they should be made breakaway or shielded behind existing guardrail, barrier or other safety device.

Shielding and breakaway features must be in conformance with the guidance found in Traffic Safety Systems Guidance. For input on the need for shielding at a specific location, consult District Traffic Operations.

Where compliance with the guidelines stated in Subsections (2)(a) and (b) are impractical, the minimum horizontal clearance cited in Subsection (3) Minimum Clearances shall apply to the unshielded fixed object. These minimum horizontal clearances apply to yielding objects as well.

(3) *Minimum Clearances.* **The following minimum horizontal clearances shall apply to all objects that are closer to the edge of traveled way than the clear recovery zone distances listed above:**

(a) **The minimum horizontal clearance to all objects, such as bridge rails and safety-shaped concrete barriers, as well as sand-filled barrels, guardrail, etc., on all freeway and expressway facilities, including auxiliary lanes, ramps, and collector-distributor roads, shall be equal to the standard shoulder width of the highway facility as stated in Table 302.1. A minimum clearance of 4 feet shall be provided where the standard shoulder width is less than 4 feet. Approach rail connections to bridge rail may require special treatment to maintain the standard shoulder width.**

(b) **The minimum horizontal clearance to walls, such as abutment walls, retaining walls in cut locations, and noise barriers on all facilities, including auxiliary lanes, ramps and collector-distributor roads, shall not be less than 10 feet per Table 302.1.**

(c) **On conventional highways, frontage roads, city streets and county roads within the State right of way (all without curbs), the minimum horizontal clearance shall be the standard shoulder width as listed in Tables 302.1 and 307.2, except that a minimum clearance of 4 feet shall be provided where the standard shoulder width is less than 4 feet.** For RRR projects, widths are provided in DIB 79.

On conventional highways with curbs, typically in urban conditions, a minimum horizontal clearance of 1 foot 6 inches should be provided beyond the face of curbs to any obstruction. On curbed highway sections, a minimum clearance of 3 feet should be provided along the curb returns of intersections and near the edges of driveways to allow for design vehicle offtracking (see Topic 404). Where sidewalks are located immediately adjacent to curbs, fixed objects should be located beyond the back of sidewalk to provide an unobstructed area for pedestrians.

In areas without curbs, the face of Type 60 concrete barrier should be constructed integrally at the base of any retaining, pier, or abutment wall which faces traffic and is 15 feet or less from the edge of traveled way (right or left of traffic and measured from the face of wall). See Index 1102.2 for the treatment of noise barriers.

The minimum width of roadway openings between Temporary Railing (Type K) on bridge deck widening projects should be obtained from the HQ Transportation Permit Program.

The HQ Transportation Permit Program must be consulted on the use of the route by overwidth loads.

See Traffic Safety Systems Guidance for other requirements pertaining to clear recovery zone, guardrail at fixed objects and embankments, and crash cushions.

(4) *High Speed Rail Clearances.* When a high speed rail corridor is to be constructed longitudinally to a freeway, expressway or a conventional highway with posted speeds over 40 miles per hour, the nearest fixed object or feature associated with the operation of the rail facility should be located a minimum of 52 feet horizontally from the planned ultimate edge of the traveled way. **The minimum shoulder width adjacent to barrier (longitudinal to the high speed rail) shall be 10 feet, in addition to the fixed objects in Table 302.1 Note (8).** See Index 62.10 for the definition of high speed rail. The terrain and the required highway features between the edge of traveled way and the rail facility to be constructed must be evaluated to determine on a case-by-case basis whether or not shielding behind guardrail, barrier or other safety device in conformance with the guidance found in Traffic Safety Systems Guidance is needed. For input on the need for shielding at a specific location, consult District Traffic Operations.

(5) *Other Transportation Facilities.* Contraflow BRT, light rail facilities, and heavy rail facilities are considered fixed objects and the

Table 309.2A

Minimum Vertical Clearances

	Traveled Way	Shoulder
Freeways and Expressways, New Construction, Lane Additions, Reconstruction and Modification	16½ ft	16½ ft
Freeways and Expressways, Overlay Projects	16 ft	16 ft
All Projects on Conventional Highways and Local Facilities	15 ft	14½ ft
Sign Structures	18 ft	18 ft
Pedestrian, Bicycle Overcrossings, and Minor Structures	Standard + 2 ft See 309.2(2)	
Structures on the Rural and Single Interstate Routing System	See 309.2(3)	

Figure 309.2
Department of Defense
Rural and Single Interstate Routes

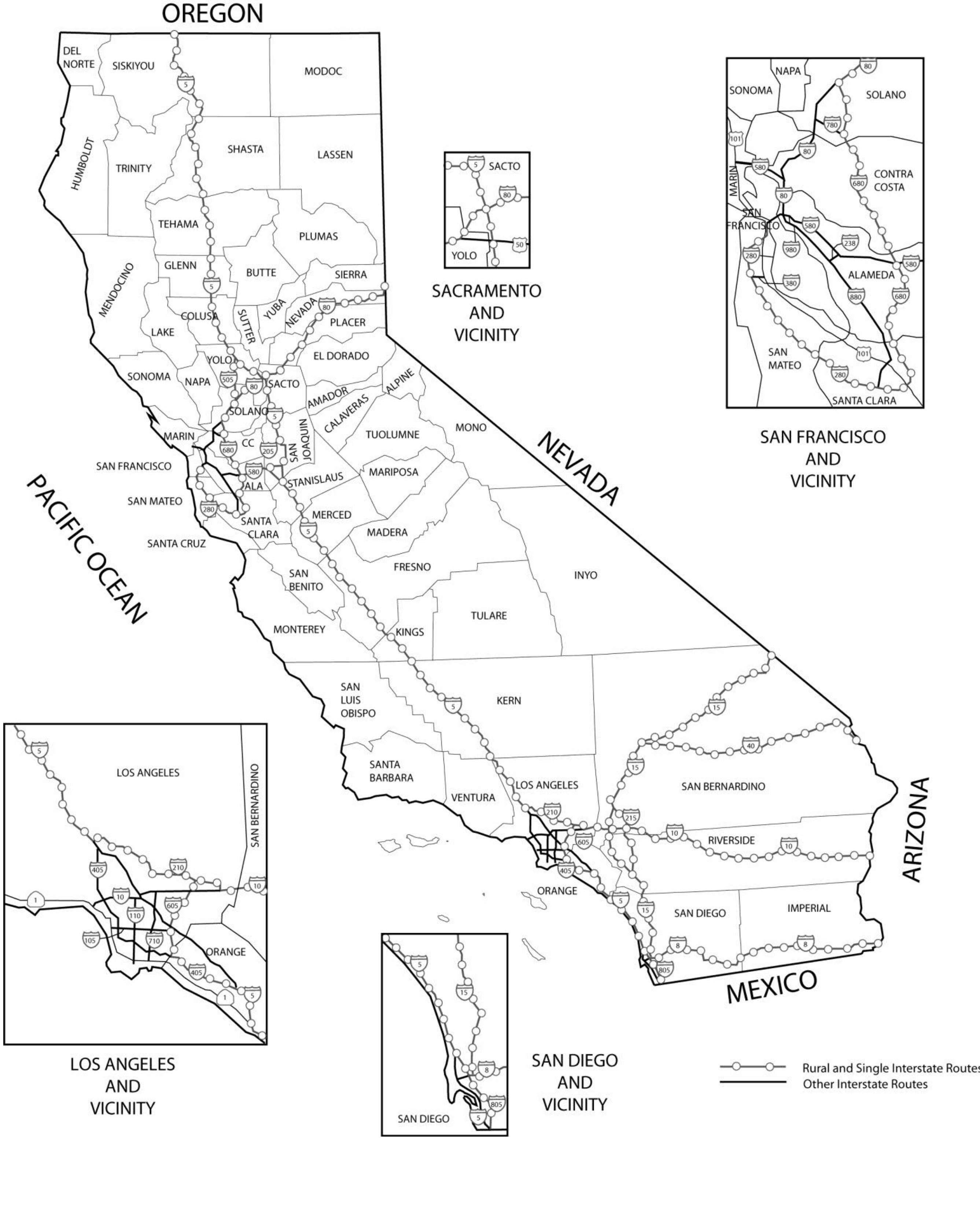


Table 309.2B
California Routes on the Rural and Single Interstate Routing System

ROUTE	FROM	TO
I-5	U. S. Border	I-805 just N. of U. S. Border
I-5	I-805 N. of San Diego	I-405 near El Toro
I-5	I-210 N. of Los Angeles	Oregon State Line
I-8	I-805 near San Diego	Arizona State Line
I-10	I-210 near Pomona	Arizona State Line
I-15	I-8 near San Diego	Nevada State Line
I-40	Junction at I-15 near Barstow	Arizona State Line
I-80	I-680 near Cordelia	Nevada State Line
I-205	Junction at I-580	Junction at I-5
I-210	I-5 N. of Los Angeles	I-10 near Pomona
I-215	I-15 near Temecula	I-15 near Devore
I-280	Junction at I-680 in San Jose	At or near south city limits of San Francisco to provide access to Hunter's Point
I-405	I-5 near El Toro	Palo Verde Avenue just N. of I-605
I-505	Junction at I-80	Junction at I-5
I-580	I-680 near Dublin	Junction at I-5
I-605	I-405 near Seal Beach	I-210
I-680	Junction at I-280 in San Jose	I-80 near Cordelia
I-805	I-5 just N. of U. S. Border	I-5 N. of San Diego

clearances noted in Index 309.1 apply.

Parallel BRT facilities are preferred to have the following minimum separation between lanes:

- Freeways and Expressways** – 4 feet
- Conventional Highways (see also Index 108.5)
  - Posted Speeds over 40 miles per hour – 4 feet
  - Posted Speeds equal or greater than 25 miles per hour and up to 45 miles per hour in an urban environment –2 feet, with curbed separation, 4 feet with 2-foot curbed separation recommended.

** See "A Guide for HOT Lane Development", FHWA, and Caltrans High Occupancy Vehicle Guidelines for additional information.

309.2 Vertical Clearances

(1) Major Structures.

(a) Freeways and Expressways, All construction except overlay projects – **16 feet 6 inches shall be the minimum vertical clearance over the roadbed of the State facility (e.g., main lanes, shoulders, ramps, collector-distributor roads, speed change lanes, etc.).**

(b) Freeways and Expressways, Overlay Projects – **16 feet shall be the minimum vertical clearance over the roadbed of the State facility.**

(c) Conventional Highways, Parkways, and Local Facilities, All Projects – **15 feet shall be the minimum vertical clearance over the traveled way and 14 feet 6 inches shall be the minimum vertical clearance over the shoulders of all portions of the roadbed.**

(2) Minor Structures. **Pedestrian over-crossings shall have a minimum vertical clearance 2 feet greater than the standard for major structures for the State facility in question. Sign structures shall have a vertical clearance of 18 feet over the roadbed of the State facility.**

(3) Rural Interstates and Single Routing in Urban Areas: This subset of the Interstate System is composed of all rural Interstates and a single routing in urban areas. Those routes described in Table 309.2B and Figure 309.2 are given special attention in regards to minimum vertical clearance as a result of agreements between the FHWA and the Department of Defense. **Vertical clearance for structures on this system shall meet the standards listed above for freeways and expressways.** In addition to the standards listed above, vertical clearances of less than 16 feet over any portion of this system must be approved by FHWA in coordination with Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA). Documentation in the form of a Design Standard Decision Document must be submitted to FHWA to obtain approval for less than 16 feet of vertical clearance. Vertical clearances of less than 16 feet over any Interstate will require FHWA/SDDCTEA notification. See http://www.fhwa.dot.gov/design/090415.cfm

(4) General Information. The standards listed above and summarized in Table 309.2A are the minimum allowable on the State highway system for the facility and project type listed. For the purposes of these vertical clearance standards, all projects on the freeway and expressway system other than overlay projects shall be considered to be covered by the "new construction" standard.

When approved by a design exception (see HDM Index 82.2) clearances less than the values given above may be allowed on a case by case basis given adequate justification based upon engineering judgment, economic, environmental or right of way considerations. Typical instances where lesser values may be approved are where the structure is protected by existing lower structures on either side or where a project includes an existing structure that would not be feasible to modify to the current standard. In no case should vertical clearance be reduced below 15 feet over the traveled way or 14 feet 6 inches over the shoulders over any portion of a State highway facility.

Efforts should be made to avoid decreasing the existing vertical clearance whenever possible and consideration should be given to the feasibility of increasing vertical clearance on projects involving structural section removal and replacement. Any project that would reduce vertical clearances below 16 feet 6 inches or lead to an increase in the vertical clearance should be brought to the attention of the Project Delivery Coordinator or District approval authority, depending upon the current District Design Delegation Agreement, the District Permit Engineer and the Regional Permit Manager at the earliest possible date.

The Regional Permit Manager should be informed of any changes (temporary or permanent) in vertical clearance.

(5) *Federal Aid Participation.* Federal-aid participation is normally limited to the following maximum vertical clearances unless there are external controls such as the need to provide for falsework clearance or the vertical clearance is controlled by an adjacent structure in a multi-structure interchange:

(a) Highway Facilities.

- 17 feet over freeways and expressways.
- 15 feet 6 inches over other highways (15 feet over shoulders).
- For pedestrian structures, 2 feet greater than the above values.

(b) Railroad Facilities.

- 23 feet 4 inches over the top of rails for non-electrified rail systems.
- 24 feet 3 inches over the top of rails for existing or proposed 25 kv electrification.
- 26 feet over the top of rails for existing or proposed 50 kv electrification.

These clearances include an allowance for future ballasting of the rail facility. The cost of reconstructing or modifying any existing railroad-highway grade separation structure solely to accommodate electrification will not be eligible for Federal-aid highway fund participation. Where a rail system is not currently electrified, the railroad must have a plan adopted which specifies the intent to electrify the subject rail segment within a reasonable time frame in order to provide clearances in excess of 23 feet 4 inches.

Any exceptions to the clearances listed above should be reviewed with the FHWA early in the design phase to ensure that they will participate in the structure costs. All excessive clearances should be documented in the project files. Documentation must include reasons for exception including the railroad's justification for increased vertical clearance based on an analysis of engineering, operational and/or economic conditions at a specific structure location with appropriate approval by the HQ Right of Way, Railroad Agreement Coordinator and concurrence by the FHWA.

See Index 1003.1(3) for guidance on Class I bikeway vertical clearance.

309.3 Tunnel Clearances

Cross sections for tunnels should match the full paved width of the approach roadways, including shoulders. See Topics 301 and 302.

(1) *Horizontal Clearances.* Tunnel construction is so infrequent and costly that the width should be considered on an individual basis. For the minimum horizontal clearance standards for freeway and expressway tunnels see Index 309.1.

A minimum emergency egress walkway width of 4 feet shall be provided on one side. The emergency egress walkway should be elevated a minimum of 6 inches or separated from the roadway with barrier.

In one-way tunnels on conventional highways the minimum side clearance from the edge of the traveled way shall be 4 feet on the left and 6 feet on the right. For two-way tunnels, this clearance shall be 6 feet on each side. This clearance provides space for bicycle lanes or for bicyclists who want to use the shoulder.

(2) *Vertical Clearances.* **For conventional highways the minimum vertical clearance listed in Index 309.2(1)(c) shall be used. On freeways and expressways, the vertical clearance listed in Index 309.2(1)(a) and (b) shall be used.** Cost weighed against the probability of over-height vehicles will be the determining factors.

309.4 Lateral Clearance for Elevated Structures

Adequate clearance must be provided for maintenance, repair, construction, or reconstruction of adjacent buildings and of the structure; to avoid damage to the structure from a building fire or to buildings from a vehicle fire; to permit operation of equipment for fire fighting and other emergency teams. **The minimum horizontal clearance between elevated highway structures, such as freeway viaducts and ramps, and adjoining buildings or other structures shall be 15 feet for single-deck structures and 20 feet for double-deck structures. Spot encroachments on this clearance shall be approved in accordance with Index 82.2.**

309.5 Structures Across or Adjacent to Railroads

Regulations governing clearances on railroads and street railroads with reference to side and overhead structures, parallel tracks, crossings of public roads, highways, and streets are established by the PUC. The PUC requirements are minimums for all grade separated structures. The railroad clearances are much greater due to operational requirements.

(1) *Normal Horizontal and Vertical Clearances.* Although General Order No. 26-D specifies a minimum vertical clearance of 22 feet 6 inches above tracks on which freight cars not exceeding a height of 15 feet 6 inches are transported, a minimum of 23 feet 4 inches should be used in design to allow for reballasting and normal maintenance of track. Railroads on which freight cars are not operated, should have a minimum vertical clearance of 19 feet. See Index 309.2(5)(b) for FHWA maximums. In establishing the grade line, the District should consult the DES to obtain the depth of structures and false work requirements, if any (see Index 204.8(4)).

Horizontal clearance from piers, abutments, and barriers shall be 25 feet minimum to centerline of track. For clearances less than 25 feet, the piers supporting bridges over the railroads are to be heavy construction or are to be protected by a reinforced concrete crash wall. Piers are to be considered heavy construction if they have a cross-sectional area equal to or greater than that required for the crash wall where the larger of its dimension is parallel to the track.

Crash walls for piers from 12 to 25 feet clearance from the centerline of track are to have a minimum height of 6 feet above the top of rail. Piers less than 12 feet clearance from the centerline of track are to have a minimum crash wall height of 12 feet above the top of rail. Horizontal clearances other than those stated above must be approved by the PUC and concurred by the affected railroad entity. Coordinate early in the design phase of the project with the District Railroad Coordinator when railroad agreements are required.

For future planned track expansion, a minimum horizontal clearance distance of 20 feet between existing and future track centerlines shall be provided for freight tracks and 25 feet for commuter tracks. See Figure 309.5A for typical horizontal railroad clearances and Figure 309.5B for limits of permanent vertical clearance envelope for grade separated structures.

Code of Federal Regulations 646.212(a)(2) provides that if the railroad establishes to the satisfaction of the Department and FHWA that it has definite demand and plans for installation of additional tracks within a reasonable time, for grade separation structures, Federal funds may be used to provide space for more tracks than are in place.

Vertical clearance greater than 23 feet 4 inches may be approved on a site by site basis where justified by the railroad to the satisfaction of the Department and the FHWA. A railroad's justification for increased vertical clearance should be based on an analysis of engineering, operational and/or economic conditions and the need for future tracks at a specific location.

Contact the District Railroad Coordinator for further information.

Table 309.5A
Minimum Vertical Clearances Above Highest Rail

Type of Structure	Type of Operation	
	Normal Freight	No Freight Cars Operated
Highway overhead and other structures including through railroad bridges.	23' – 4"	19' – 0"

At underpasses, General Order No. 26-D establishes a minimum vertical clearance of 15 feet above any public road, highway or street. **However, the greater clearances specified under Index 309.2 shall be used.**

For at grade crossings, all curbs, including median curbs, should be designed with 10 feet of clearance from the track centerline measured normal thereto.

(2) *Off-track Maintenance Clearance.* The 18-foot horizontal clearance is intended for sections of railroad where the railroad company is using or definitely plans to use off-track maintenance equipment. This clearance is provided on one side of the railroad right of way.

On Federal-aid projects, where site conditions are such that off-track maintenance clearance at an overhead is obtained at additional cost, Federal-aid funds may participate in the costs of such overhead designs that provide up to 18 feet 2 inches horizontal clearance on one side of the track. In such cases, the railroad is required to present a statement that off-track maintenance equipment is being used, or is definitely planned to be used, along that section of the railroad right of way crossed by the overhead structure.

(3) *Walkway Clearances Adjacent to Railroads At Grade.* All plans involving construction adjacent to railroads at grade should be such that there is no encroachment on the walkway adjoining the track. Walkway requirements are set forth in General Order No. 118 of the PUC. Where excavations encroach into walkway areas, the contractor is required to construct a temporary walkway with handrail as set forth in the contract special provisions.

(4) *Approval.* All plans involving clearances from a railroad track must be submitted to the railroad for approval as to railroad interests. Such clearances are also subject to approval by the PUC.

To avoid delays, early consideration must be given to railroad requirements when the planning phase is started on a project.

Topic 310 - Frontage Roads

310.1 Cross Section

Frontage roads are normally relinquished to local agencies. When Caltrans and a county or city enter into an agreement (cooperative agreement, freeway agreement, or other type of binding agreement), the CTC may relinquish to the county or city any frontage or service road or outer highway within that city or county. The relinquished right of way (called a collateral facility) should be at least 40 feet wide and have been constructed as part of a State highway project. Index 308.1 gives width criteria for city streets and county roads. These widths are also applicable to frontage roads. **However, the minimum paved 2-lane cross section width including 4-foot shoulders without curb and gutter shall be:**

- **32 feet if 12-foot lanes are to be provided;**
- **30 feet if 11-foot lanes are to be provided.**

The minimum paved 2-lane cross section width, including 5-foot shoulders and curb and gutter shall be:

- **34 feet if 12-foot lanes are to be provided;**
- **32 feet if 11-foot lanes are to be provided.**

310.2 Outer Separation

In urban areas and in mountainous terrain, the width of the outer separation should be a minimum of 26 feet from edge of traveled way to edge of traveled way. A greater width may be used where it is obtainable at reasonable additional cost, for example, on an urban highway centered on a city block and paralleling the street grid.

In rural areas, other than mountainous terrain, the outer separation should be a minimum of 40 feet wide from edge of traveled way to edge of traveled way.

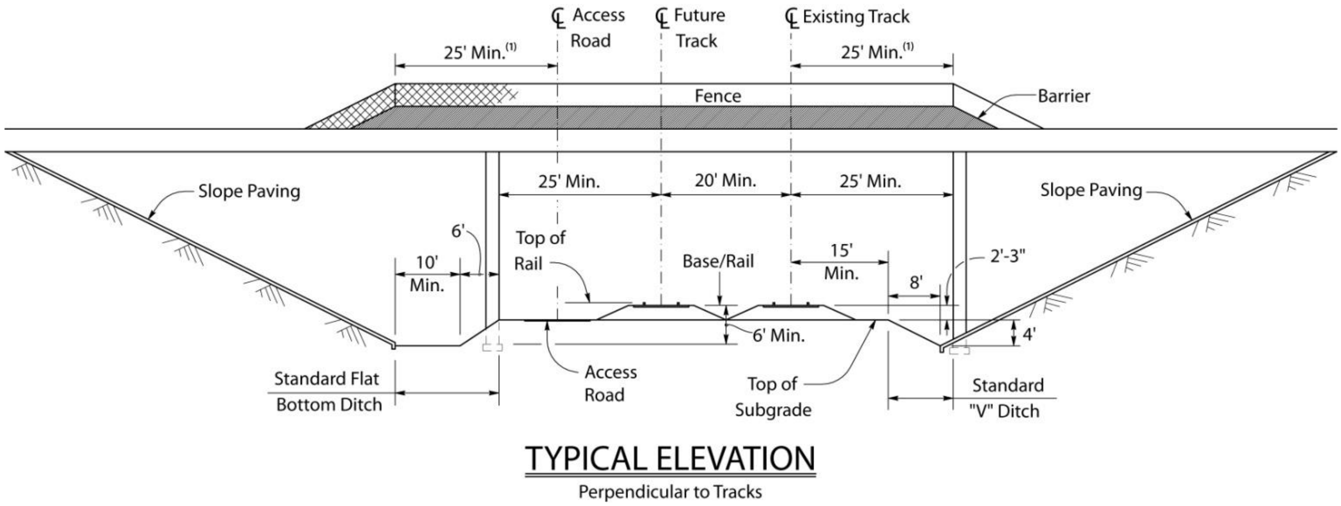
See Figure 307.4B for cross sections of outer separation and frontage road.

310.3 Headlight Glare

Care should be taken when designing new frontage roads to avoid the potential for headlight glare interfering with the vision of motorists, bicyclists, and pedestrians traveling in opposite directions on the frontage roads and in the outer freeway lanes. Consideration should also be given to bike and pedestrians paths. To prevent headlight glare interference on new construction, the preferred measures are for wider outer separations, revised alignment and raised or lowered profiles.

Figure 309.5A

Typical Horizontal Railroad Clearance from Grade Separated Structures



NOTE:

The limits of the fence with barrier rail should extend to the limits of railroad right-of-way or a minimum of 25 feet beyond the centerline of the outermost existing track, future track or access roadway, whichever is greater.

Figure 309.5B

Permanent Railroad Clearance Envelope

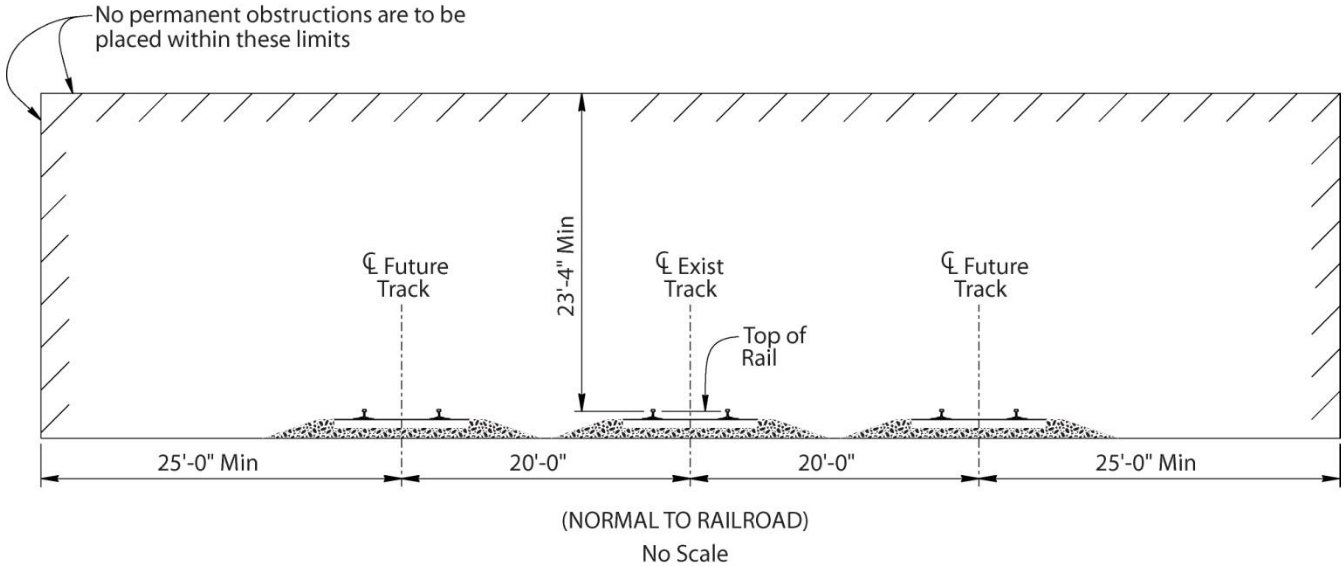


Table 309.5B

Minimum Horizontal Clearances to Centerline of Nearest Track

Type of Structure	Off-track Maintenance Clearance	Tangent Track Clearance	Normal Curved Track [1] Clearance	Curved Track Clearances When Space is Limited[1]	
				Curves of 0° to 12°	Curves of 12° or more
Through railroad bridge	None	8' – 0"[2][4]	9' – 0"[2][4]		
Highway overhead and other structures	18' – 0" clear to face of pier or abutment on side railroad requires for equipment road.	8' – 6"[4]	9' – 6"[4]	8' – 6" (Min.)[3]	8' – 6" + ½"[3] per degree of curve.
Curbs		10' – 0"			

NOTES:

(1) The minimum, in general, is one foot greater than for tangent track.

(2) With approval of P.U.C.

(3) Greater clearance necessary if walkway is required.

(4) Collision walls may be required. See Index 309.5(1).

(4) *Trailer Track* – Semitrailer axle width, measured from outside face of tires.

(5) *Lock To Lock Time* - The time in seconds that an average driver would take under normal driving conditions to turn the steering wheel of a vehicle from the lock position on one side to the lock position on the other side. The default in AutoTurn software is 6 seconds.

(6) *Steering Lock Angle* - The maximum angle that the steering wheels can be turned. It is further defined as the average of the maximum angles made by the left and right steering wheels with the longitudinal axis of the vehicle.

(7) *Articulating Angle* - The maximum angle between the tractor and semitrailer.

Topic 405 - Intersection Design Standards

405.1 Sight Distance

(1) *Stopping Sight Distance.* See Index 201.1 for minimum stopping sight distance requirements.

(2) *Corner Sight Distance*.

(a) General--At unsignalized intersections a substantially clear line of sight should be maintained between the driver of a vehicle, bicyclist or pedestrian stopped on the minor road and the driver of an approaching vehicle on the major road that has no stop. Line of sight for all users should be included in right of way, in order to preserve sight lines.

See DIB 79 for 2R, 3R, certain storm damage, protective betterment, operational, and safety projects on two-lane and three-lane conventional highways.

Adequate time should be provided for the stopped vehicle on the minor road to either cross all lanes of through traffic, cross the near lanes and turn left, or turn right, without requiring through traffic to radically alter their speed. The visibility required for these maneuvers form a clear sight triangle with the corner sight distance b and the crossing distance a_1 or a_2 (see Figure 405.1 as an example of corner sight distance at a two-lane, two-way highway). Dimensions a_1 and a_2 are measured from the decision point to the center of the lane. The actual number of lanes will vary on the major and minor roads. <u>There should be no sight obstruction within the clear sight triangle.</u>

The methodology used for the driver on the minor road that is stopped to complete the necessary maneuver while the approaching vehicle travels at the design speed of the major road is based on gap-acceptance behavior. A 7-1/2 second criterion is applied to a passenger car (including pickup trucks) for a left turn from a stop on the minor road. However, this time gap does not account for a single-unit truck (no semitrailer), a combination truck (see Index 404.4 for truck tractor-semitrailer guidance), a right-turn from a stop, or for a crossing maneuver. See Table 405.1A for the time gap that addresses these situations for the assumed design vehicle making these maneuvers from the minor road.

In determining corner sight distance, a set back distance for the vehicle waiting on the minor road must be assumed as measured from the edge of traveled way of the major road. <u>Set back for the driver of the vehicle on the minor road should be a minimum of 10 feet plus the shoulder width of the major road but not less than 15 feet.</u> The location of the driver's eye for the set back is the decision point per Figure 405.1. Corner sight distance and the driver's eye set back are also illustrated in Figures 405.7 and 504.3I. Line of sight for corner sight distance for passenger cars is to be determined from a 3 and 1/2-foot height at the location of the driver of the vehicle in the center of the minor road lane to a 3 and 1/2-foot object height in the center of the approaching outside lane of the major road. This provides for reciprocal sight by both vehicles. The passenger car driver's eye height should be applied to all minor roads. In addition, a truck driver's eye height of 7.6 feet should be applied to the minor road where applicable. Additionally, if the major road has a median barrier, a 2-foot object height should be used to determine the median barrier set back. A median that is wide enough to accommodate a stopped vehicle should also provide a clear sight triangle.

The minimum corner sight distance (feet) should be determined by the equation: $1.47V_mT_g$, where V_m is the design speed (mph) of the major road and T_g is the time gap (seconds) for the minor road vehicle to enter the major road. The values given in Table 405.1A should be used to determine T_g based on the design vehicle, the type of maneuver, and whether the stopped vehicle's rear wheels are on an upgrade exceeding 3 percent. The distance from the edge of traveled way to the rear wheels at the minor road stop location should be assumed as: 20 feet for a passenger car, 30 feet for a single-unit truck, and 72 feet for a combination truck.

(b) Public Road Intersections (Refer to Topic 205 and Index 405.7); corner sight distance applies, see Table 405.1A.

At signalized intersections the corner sight distances should also be applied whenever possible. Even though traffic flows are designed to move at separate times, unanticipated conflicts can occur due to violation of signal, right turns on red, malfunction of the signal, or use of flashing red/yellow mode.

The minimum value for corner sight distance at signalized intersections should be equal to the stopping sight distance as given in Table 201.1, measured as previously described. This includes an urban driveway that forms a leg of the signalized intersection.

(c) Private Road Intersections (Refer to Index 205.2) and Rural Driveways (Refer to Index 205.4); corner sight distance applies, see Table 405.1A. If signalized, the minimum corner sight distance should be equal to the stopping sight distance as given in Table 201.1, measured as previously described.

(d) Urban Driveways (Refer to Index 205.3); corner sight distance requirements as described above are not applied to urban driveways unless signalized. See Index 405.1(2)(b) underlined standard. If parking is allowed on the major road, parking should be prohibited on both sides of the driveway per the California MUTCD, 3B.19.

(3) *Decision Sight Distance.* At intersections where the State route turns or crosses another State route, the decision sight distance values given in Table 201.7 should be used. In computing and measuring decision sight distance, the 3.5-foot eye height and the 0.5-foot object height should be used, the object being located on the side of the intersection nearest the approaching driver.

The application of the various sight distance requirements for the different types of intersections is summarized in Table 405.1B.

Table 405.1B
Application of Sight Distance Requirements

Intersection Types	Sight Distance		
	Stopping	Corner	Decision
Private Roads	X	X(1)	
Public Streets and Roads	X	X	
Signalized Intersections	X	X(2)	
State Route Inter-sections & Route Direction Changes, with or without Signals	X	X	X

NOTES:

(1) Per Index 405.1(2)(c), the minimum corner sight distance shall be equal to the stopping sight distance as given in Table 201.1. See Index 405.1(2)(a) for setback requirements.

(2) Apply corner sight distance requirements at signalized intersections whenever possible due to unanticipated violations of the signals or malfunctions of the signals. See Index 405.1(2)(b).

Figure 405.1
Corner Sight Distance (b)

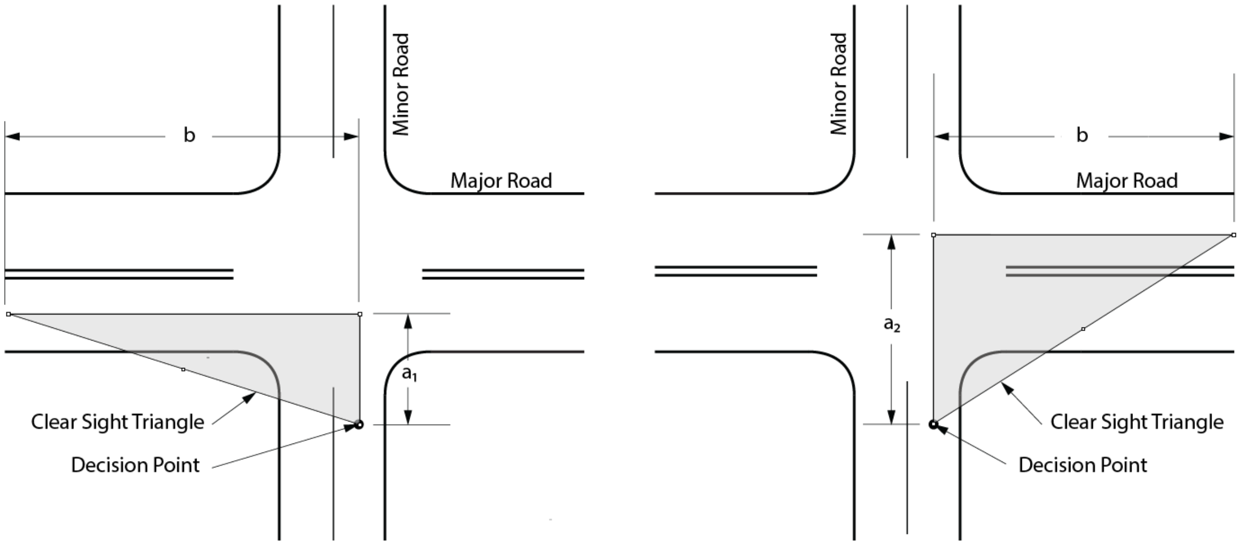


Table 405.1A
Corner Sight Distance Time Gap (T_g) for Unsignalized Intersections

Design Vehicle	Left-turn from Stop (s) [4]	Right-turn from Stop and Crossing Maneuver (s)
Passenger Car	7½	6½
Private Road Intersection		
Rural Driveway		
Single-Unit Truck	9½	8½
Public Road Intersection		
Combination Truck	11½	10½
Major and Minor Roads on Routes:		
National Network		
Terminal or Service Access		
California Legal		
KPRA Advisory		

Notes: Time gaps are for a stopped vehicle to turn left, right or cross a two-lane highway with no median and with minor road grades of 3 percent or less. The table values should be adjusted as follows:

(1) For multilane highways—When crossing or making a left-turn onto a two-way major road with more than two lanes, add 0.5 s for passenger cars or 0.7 s for trucks for each additional lane to be crossed. Median widths should be converted to an equivalent number of lanes in applying the 0.5 s and 0.7 s criteria. For example, an 18-foot wide median is equivalent to 1.5 lanes; this requires an additional 0.75 s for a passenger car to cross or an additional 1.05 s for a truck to cross.

(2) For minor road approach grades—If the minor road approach grade is an upgrade that exceeds 3 percent and the rear wheels of the design vehicle are on the grade exceeding 3 percent, add 0.2 s for each percent grade for left-turns and crossing maneuvers; or add 0.1 s for each percent grade for right-turns. For example, a passenger car is turning right from a minor road and at the stop location its rear wheels are on a 4 percent upgrade; this requires an additional 0.4 s for the right-turn.

(3) Unique situations may necessitate a different design vehicle for a particular minor road than those listed here (e.g., predominant combination trucks out of a rural driveway). Additionally, for intersections at skewed angles less than 60 degrees, a further adjustment is needed. See the AASHTO "A Policy on Geometric Design of Highways and Streets" for guidance.

(4) Time gap for vehicles approaching from the left can be the same as the right-turn from stop maneuver.

(4) *Acceleration Lanes for Turning Moves onto State Highways.* At rural intersections, with "STOP" control on the local cross road, acceleration lanes for left and right turns onto the State facility should be considered. At a minimum, the following features should be evaluated for both the major highway and the cross road:

- divided versus undivided
- number of lanes
- design speed
- gradient
- lane, shoulder and median width
- traffic volume and composition of highway users, including trucks and transit vehicles
- turning volumes
- horizontal curve radii
- sight distance
- proximity of adjacent intersections
- types of adjacent intersections

For additional information and guidance, refer to AASHTO, A Policy on Geometric Design of Highways and Streets, the District Traffic Engineer or designee, the District Design Liaison, and the Project Delivery Coordinator.

405.2 Left-turn Channelization

(1) *General.* The purpose of a left-turn lane is to expedite the movement of through traffic by, controlling the movement of turning traffic, increasing the capacity of the intersection, and improving safety characteristics.

The District Traffic Branch normally establishes the need for left-turn lanes.

(2) *Design Elements.*

(a) Lane Width – **The lane width for both single and double left-turn lanes on State highways shall be 12 feet.**

For conventional State highways with posted speeds less than or equal to 40 miles per hour and AADTT (truck volume) less than 250 per lane that are in urban, city or town centers (rural main streets), the minimum lane width shall be 11 feet.

When considering lane width reductions adjacent to curbed medians, refer to Index 303.5 for guidance on effective roadway width, which may vary depending on drivers' lateral positioning and shy distance from raised curbs.

(b) Approach Taper -- On conventional highways without a median, an approach taper provides space for a left-turn lane by moving traffic laterally to the right. The approach taper is unnecessary where a median is available for the full width of the left-turn lane. Length of the approach taper is given by the formula on Figures 405.2A, B and C.

Figure 405.2A shows a standard left-turn channelization design in which all widening is to the right of approaching traffic and the deceleration lane (see below) begins at the end of the approach taper. This design should be used in all situations where space is available, usually in rural and semi-rural areas or in urban areas with high traffic speeds and/or volumes.

Figures 405.2B and 405.2C show alternate designs foreshortened with the deceleration lane beginning at the 2/3 point of the approach taper so that part of the deceleration takes place in the through traffic lane. Figure 405.2C is shortened further by widening half (or other appropriate fraction) on each side. These designs may be used in urban areas where constraints exist, speeds are moderate and traffic volumes are relatively low.

(c) Bay Taper -- A reversing curve along the left edge of the traveled way directs traffic into the left-turn lane. The length of this bay taper should be short to clearly delineate the left-turn move and to discourage through traffic from drifting into the left-turn lane. Table 405.2A gives offset data for design of bay tapers. In urban areas, lengths of 60 feet and 90 feet are normally used. Where space is restricted and speeds are low, a 60-foot bay taper is appropriate. On rural high-speed highways, a 120-foot length is considered appropriate.

(d) Deceleration Lane Length -- Design speed of the roadway approaching the intersection should be the basis for determining deceleration lane length. It is desirable that deceleration take place entirely off the through traffic lanes. Deceleration lane lengths are given in Table 405.2B; the bay taper length is included. Where partial deceleration is permitted on the through lanes, as in Figures 405.2B and 405.2C, design speeds in Table 405.2B may be reduced

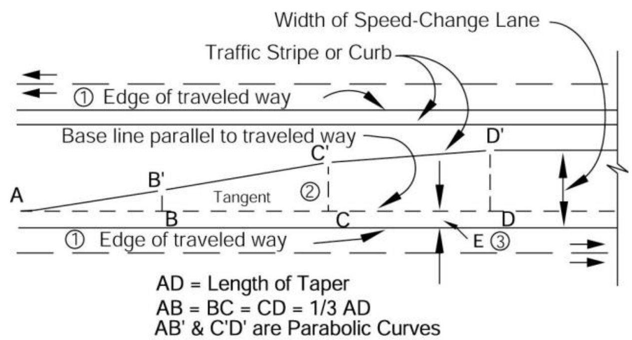
10 miles per hour to 20 miles per hour for a lower entry speed. In urban areas where cross streets are closely spaced and deceleration lengths cannot be achieved, the District Traffic branch should be consulted for guidance.

(e) Storage Length -- At unsignalized intersections, storage length may be based on the number of turning vehicles likely to arrive in an average 2-minute period during the peak hour. At a minimum, space for 2 vehicles should be provided at 25 feet per vehicle. If the peak hour truck traffic is 10 percent or more, space for at least one passenger car and one truck should be provided. Bus usage may require a longer storage length and should be evaluated if their use is anticipated.

At signalized intersections, the storage length may be based on one and one-half to two times the average number of vehicles that would store per signal cycle depending on cycle length, signal phasing, and arrival and departure rates. At a minimum, storage length should be calculated in the same manner as unsignalized intersection. The District Traffic Branch should be consulted for this information.

When determining storage length, the end of the left-turn lane is typically placed at least 3 feet, but not more than 30 feet, from the nearest edge of shoulder of the intersecting roadway. Although often set by the placement of a crosswalk line or limit line, the end of the storage lane should always be located so that the appropriate turning template can be accommodated.

Table 405.2A
Bay Taper for Median Speed-change Lanes



	LENGTH OF TAPER - feet			OFFSET DISTANCE			
	60	90	120	DD' = 10'	DD' = 11'	DD' = 12'	
	Distance From Point "A"						
	-	-	-	0.00	0.00	0.00	
	5	7.5	10.0	0.16	0.17	0.19	
	10	15.0	20.0	0.62	0.69	0.75	
	15	22.5	30.0	1.41	1.55	1.69	
B'	20	30.0	40.0	2.50	2.75	3.00	B'
	30	45.0	60.0	5.00	5.50	6.00	
C'	40	60.0	80.0	7.50	8.25	9.00	C'
	45	67.5	90.0	8.59	9.45	10.31	
	50	75.0	100.0	9.38	10.31	11.25	
	55	82.5	110.0	9.84	10.83	11.81	
	60	90.0	120.0	10.00	11.00	12.00	

NOTES:

(1) The table gives offsets from a base line parallel to the edge of traveled way at intervals measured from point "A". Add "E" for measurements from edge of traveled way.

(2) Where edge of traveled way is a curve, neither base line nor taper between B & C will be a tangent. Use proportional offsets from B to C.

(3) The offset "E" is usually 2 ft along edge of traveled way for curbed medians; Use "E" = 0 ft. for striped medians.

Table 405.2B
Deceleration Lane Length

Design Speed (mph)	Length to Stop (ft)
30	235
40	315
50	435
60	530

(3) *Double Left-turn Lanes.* At signalized intersections on multilane conventional highways and on multilane ramp terminals, double left-turn lanes should be considered if the left-turn demand is 300 vehicles per hour or more. The lane widths and other design elements of left-turn lanes given under Index 405.2(2) applies to double as well as single left-turn lanes.

The design of double left-turn lanes can be accomplished by adding one or two lanes in the median. See "Complete Intersections: A Guide to Reconstructing Intersections and Interchanges for Bicyclists and Pedestrians", published by Headquarters, Division of Traffic Operations, for the various treatments of double left-turn lanes.

(4) *Two-way Left-turn Lane (TWLTL).* The TWLTL consists of a striped lane in the median of an arterial and is devised to address the special capacity and safety problems associated with high-density strip development. It can be used on 2-lane highways as well as multilane highways. Normally, the District Traffic Operations Branch should determine the need for a TWLTL.

The minimum width for a TWLTL shall be 12 feet (see Index 301.1). The preferred width is 14 feet. Wider TWLTL's are occasionally provided to conform with local agency standards. However, TWLTL's wider than 14 feet are not recommended, and in no case should the width of a TWLTL exceed 16 feet. Additional width may encourage drivers in opposite directions to use the TWLTL simultaneously.

405.3 Right-turn Channelization

(1) *General.* For right-turning traffic, delays are less critical and conflicts less severe than for left-turning traffic. Nevertheless, right-turn lanes can be justified on the basis of capacity, analysis, and crash experience.

In rural areas a history of high speed rear-end collisions may warrant the addition of a right-turn lane.

In urban areas other factors may contribute to the need such as:

- High volumes of right-turning traffic causing backup and delay on the through lanes.
- Conflicts between crossing pedestrians and right-turning vehicles and bicycles.
- Frequent rear-end and sideswipe collisions involving right-turning vehicles.

Where right-turn channelization is proposed, lower speed right-turn lanes should be provided to reduce the likelihood of conflicts between vehicles, pedestrians, and bicyclists.

(2) *Design Elements.*

(a) Lane and Shoulder Width--**Index 301.1 shall be used for right-turn lane width requirements. Shoulder width shall be a minimum of 4 feet.** Although not desirable, lane and shoulder widths less than those given above can be considered for right-turn lanes under the following conditions pursuant to Index 82.2:

- In urban, city or town centers (rural main streets) with posted speeds less than 40 miles per hour in severely constrained situations, if truck or bus use is low, consideration may be given to reducing the right-turn lane width to 10 feet.
- Shoulder widths may also be considered for reduction under constricted situations. Whenever possible, at least a 2-foot shoulder should be provided where the right-turn lane is adjacent to a curb. Entire omission of the shoulder should only be considered in constrained situations and where an 11-foot lane can be constructed.

  Gutter pans can be included within a shoulder, but cannot be included as part of the travel lane width. Additional right of way for a future right-turn lane should be considered when an intersection is being designed.

exiting traffic from crossing into the path of approaching traffic. The splitter island width should be a minimum of 6 feet at the pedestrian crossing to adequately provide refuge for pedestrians.

Posted speeds on the approach roadway greater than or equal to 45 miles per hour require the splitter island length, as measured from the inscribed circle diameter, to be 200 feet. In some instances, a longer splitter island may be desirable. Concrete curb is to be provided on the right side of the approach roadway equal to the length of the splitter island from the inscribed circle diameter.

(14) Access Control.

The access control standards in Index 504.3(3) and 504.8 apply to roundabouts at interchange ramp intersections. The dimensions shown in Index 504.8 are to be measured from the inscribed circle diameter.

Driveways should not be placed within 100 feet from the inscribed circle diameter.

(15) Lighting.

Lighting is required at all roundabouts. See NCHRP Report 672 Chapter 8, the Traffic Manual Chapter 9 as well as consult with the District Traffic Safety Engineer.

(16) Landscaping.

Landscaping should be designed such that drivers and bicyclists can observe the signing and shape of the roundabout as they approach, allowing adequate visibility for making decisions within the roundabout. The landscaping of the central island can enhance the intersection by making it a focal point, by promoting lower speeds and by breaking the headlight glare of oncoming vehicles or bicycles. It is desirable to create a domed or mounded central island, between 3.5 to 6 feet high, to increase the visibility of the intersection on the approach. Contact the District Landscape Architecture Unit to provide technical assistance in designing the roundabout landscaping. See Chapter 900 for additional Landscape Architecture requirements.

(17) Vertical Clearance.

The vertical clearance guidance provided in Index 309.2 applies to roundabouts.

(18) Drainage Design.

See Chapter 800 to 890 for further guidance.

(19) Maintenance.

Contact the District Maintenance Engineer and appropriate Regional Manager for maintenance strategies and practices including seasonal operations, maintenance resources, and specialized equipment. Maintenance responsibilities may also include multiple state, county, and city agencies where coordination of maintenance efforts and funding is needed.

Consider maintenance of the central island. Provide a maintenance vehicle pullout within the central island beyond the truck apron, so maintenance vehicles will not conflict with circulating trucks.

(20) Snow Areas.

In climate regions where snowfall requires the use of snow removal equipment, consider the equipment to be used. Design ICD's as well as entrance and exit geometry to accommodate snow removal equipment and plow limitations. Check with District Maintenance for their requirements and limitations. Geometric elements to consider that facilitate snow removal are; mountable curb, tapering the ends of curbs down to allow plows to ride over curbs, plowing accommodation in both directions, providing snow storage space within the central island, and providing minimum entry/exit widths to accommodate the plow blade. Mountable curb may be used if sidewalk/shared use path is not contiguous to the curb. Provide a planter or textured pavement between the path and the roadway. Snow storage areas must be designed to prevent snow melt from entering the circulating lanes where it can freeze. Snow storage areas must not block pedestrian paths.

(21) Utilities.

Utility access openings (manholes) should not be located within the traveled way within the boundary of the roundabout. Roundabouts do not have shoulders to accommodate traffic while manholes are accessed. Manholes should not be allowed within the circulating roadway to avoid closing down the intersection during access. If a manhole is absolutely necessary within the boundary of the inscribed diameter, place it in the central island and off of the truck apron. Provide a maintenance vehicle pullout to allow access to the manhole without blocking truck traffic.

Topic 406 - Ramp Intersection Capacity Analysis

The following procedure for ramp intersection analysis may be used to estimate the capacity of any signalized intersection where the phasing is relatively simple. It is useful in analyzing the need for additional turning and through traffic lanes. For a more complete analysis refer to the Highway Capacity Manual.

(a) Ramp Intersection Analysis--For the typical local street interchange there is usually a critical intersection of a ramp and the crossroads that establishes the capacity of the interchange. The capacity of a point where lanes of traffic intersect is 1500 vehicles per hour. This is expressed as intersecting lane vehicles per hour (ILV/hr). Table 406 gives values of ILV/hr for various traffic flow conditions.

If a single-lane approach at a normal intersection has a demand volume of 1000 vph, for example, then the intersecting single-lane approach volume cannot exceed 500 vph without delay.

The three examples that follow illustrate the simplicity of analyzing ramp intersections using this 1500 ILV/hr concept.

(b) Diamond Interchange--The critical intersection of a diamond type interchange must accommodate demands of three conflicting travel paths. As traffic volumes approach capacity, signalization will be needed. For the spread diamond (Figure 406A), basic capacity analysis is made on the assumption that 3-phase signalization is employed. For the tight diamond (Figure 406B), it is assumed that 4-phase signal timing is used.

(c) 2 Quadrant Cloverleaf--Because this interchange design (Figure 406C) permits 2-phase signalization, it will have higher capacities on the approach roadways. The critical intersection is shared two ways instead of three ways as in the diamond case.

Table 406

Vehicle Traffic Flow Conditions at Intersections at Various Levels of Operation

ILV/hr	Description
< 1200:	Stable flow with slight, but acceptable delay. Occasional signal loading may develop. Free midblock operations.
1200-1500:	Unstable flow with considerable delays possible. Some vehicles occasionally wait two or more cycles to pass through the intersection. Continuous backup occurs on some approaches.
1500 (Capacity):	Stop-and-go operation with severe delay and heavy congestion(1). Traffic volume is limited by maximum discharge rates of each phase. Continuous backup in varying degrees occurs on all approaches. Where downstream capacity is restrictive, mainline congestion can impede orderly discharge through the intersection.

NOTE:

(1) The amount of congestion depends on how much the ILV/hr value exceeds 1500. Observed flow rates will normally not exceed 1500 ILV/hr, and the excess will be delayed in a queue.

section, geometric design and intersection control of ramp termini, location of separation structures, closing of local roads, frontage road construction, bicycle and pedestrian facilities and work on local roads. Particularly close involvement should occur during preparation of the project initiation document and project report (see the Project Development Procedures Manual). Such reviews can be particularly valuable when exceptions to design standards are being considered and alternatives are being sought. The geometric features of all interchanges or modifications to existing interchanges must be approved by the Project Delivery Coordinator.

Topic 504 - Interchange Design Standards

504.1 General

Topic 504 discusses the standards that pertain to both local service interchanges (various ramp configurations) and freeway-to-freeway connections. The design standards, policies and practices covered in Indexes 504.2, and 504.5 through 504.8 are typically common to both ramp and connector interchange types. Indexes 504.3 and 504.4 separately discuss ramp standards and freeway-to-freeway connector standards, respectively.

504.2 Freeway Entrances and Exits

(1) *Basic Policy.* **All freeway entrances and exits, except for direct connections with median High-Occupancy Vehicle (HOV) lanes, Express Toll lanes or BRT lanes, shall connect to the right of through traffic.**

(2) *Standard Designs.* Design of freeway entrances and exits should conform to the standard designs illustrated in Figure 504.2A-B (single lane), and Figure 504.3K (two-lane entrances and exits) and/or Figure 504.4 (diverging branch connections), as appropriate.

The minimum deceleration length shown on Figure 504.2B shall be provided prior to the first curve beyond the exit nose to assure adequate distance for vehicles to decelerate before entering the curve. The same standard should apply for the first curve after the exit from a collector-distributor road. The range of minimum "DL" (distance) vs. "R" (radius) is given in the table in Figure 504.2B. Strong consideration should be given to lengthening the "DL" distance given in the table when the subsequent curve is a descending loop or hook ramp, or if the upstream condition is a sustained downgrade (see AASHTO, A Policy on Geometric Design of Highways and Streets, for additional information).

The exit nose shown on Figure 504.2B may be located downstream of the 23-foot dimension; however, the maximum paved width between the mainline and ramp shoulder edges should be 20 feet. Also, see pavement cross slope requirements in Index 504.2(5).

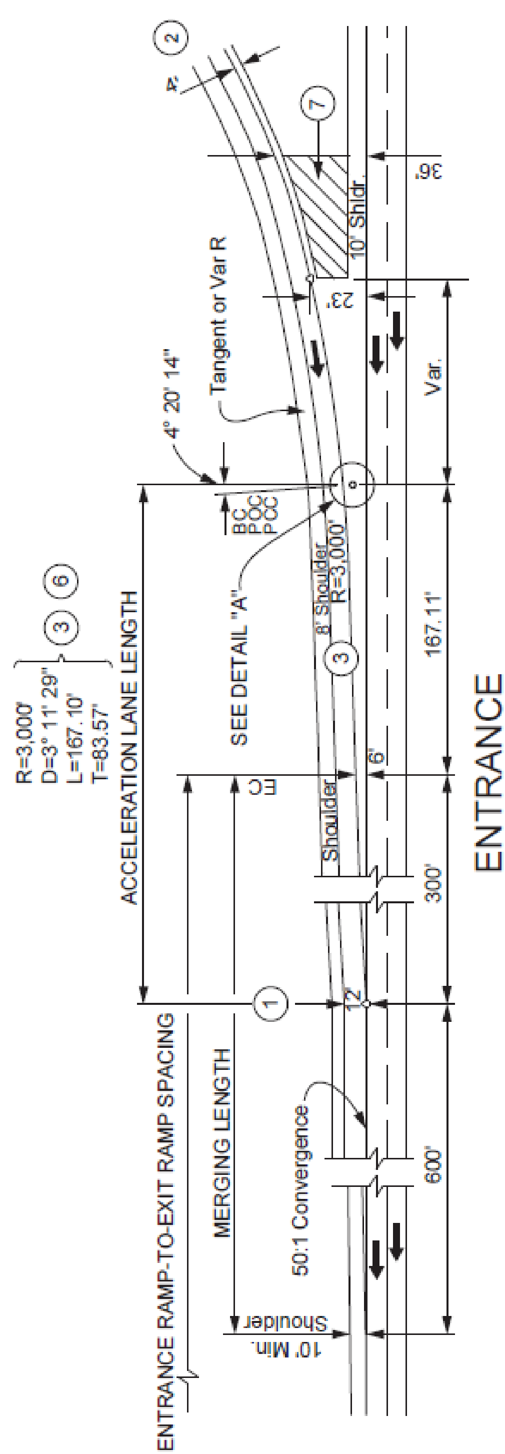
Contrasting surface treatment beyond the gore pavement should be provided on both entrance and exit ramps as shown on Figures 504.2A, 504.2B, and 504.3K. This treatment can both enhance aesthetics and minimize maintenance efforts. It should be designed so that a driver will be able to identify and differentiate the contrasting surface treatment from the pavement areas that are intended for regular or occasional vehicular use (e.g., traveled way, shoulders, paved gore, etc.).

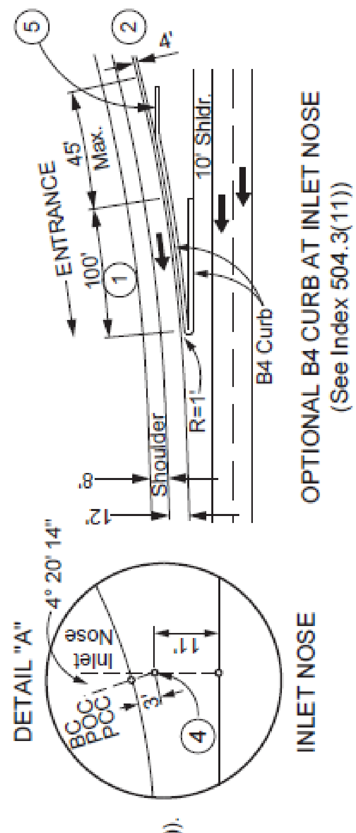
Consult with the District Landscape Architect, District Materials Engineer, and District Maintenance Engineer to determine the appropriate contrasting surface treatment of the facility at a specific location.

Refer to the HOV Guidelines for additional information specific to direct connections to HOV lanes.

(3) *Location on a Curve.* Freeway entrances and exits should be located on tangent sections wherever possible in order to provide maximum sight distance and optimum traffic operation. Where curve locations are necessary, the ramp entrance and exit tapers should be curved also. The radius of the exit taper should be about the same as the freeway edge of traveled way in order to develop the same degree of divergence as the standard design (see Figure 504.2C).

Figure 504.2A
Single Lane Freeway Entrance





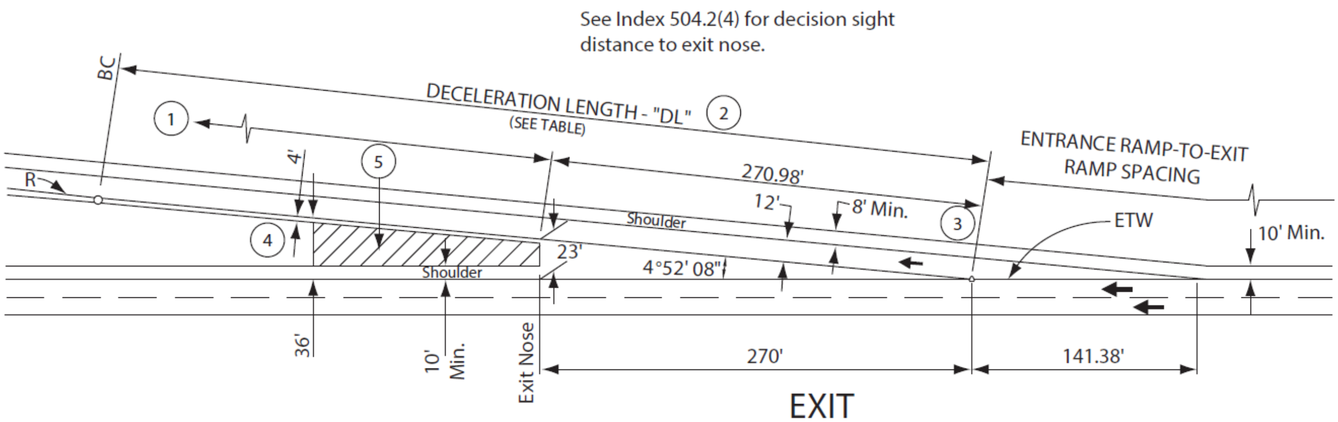
NOTES:

1. On freeway to freeway connections the right paved shoulder shall be 10' - Table 302.1.
2. On single- and two-lane freeway to freeway connections, the left paved shoulder shall be 5' - Table 302.1.
3. When freeway is not on tangent alignment, select radius to approximate same degree of convergence (see Index 504.2(3)).
4. Locate as if it were to be center of a 1' radius curb nose.
5. 1:15 (longitudinal to lateral) Flare, 45' long - Table 405.4.
6. 2% superelevation may be acceptable for the 3,000' radius curve on entrance ramps.
7. Contrasting surface treatment (See Index 504.2(2)).
8. See Index 504.2(7) for pedestrian and bicycle ramp crossings on freeways where bicycle or pedestrian travel is not prohibited.

See Index 302.1 for shoulder width standards.

Figure 504.2B

Single Lane Freeway Exit



R (ft)	Min. DL (ft) (2)
Less than 300	570
300 - 499	470
500 - 999	420
1,000 & over	270

NOTES:

1. Minimum length between exit nose and end of ramp is 525' for full stop at end of ramp.
2. "DL" distance should be lengthened for descending, short radius curves, or if entered from a sustained downgrade.
3. On freeway to freeway connections the right paved shoulder shall be 10'. - Table 302.1
4. On single- and two-lane freeway to freeway connections the left paved shoulder shall be 5'. - Table 302.1
5. Contrasting surface treatment (See Index 504.2(2))

See Index 302.1 for shoulder width standards.

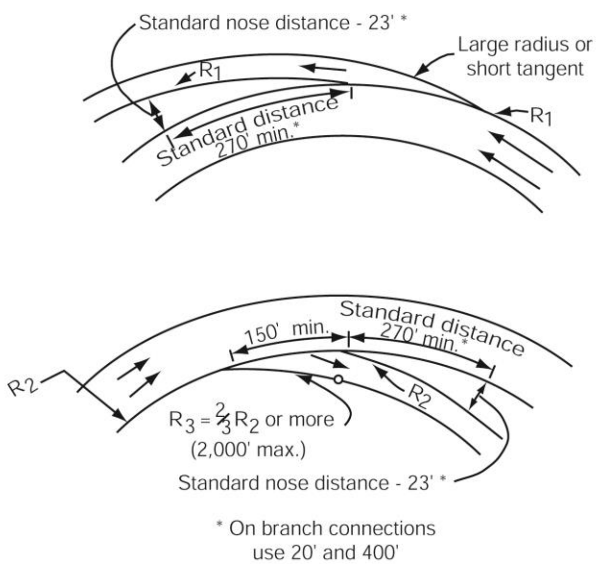
On entrance ramps the distance from the inlet nose (14-foot point) to the end of the acceleration lane taper should equal the sum of the distances shown on Figure 504.2A. The 50:1 (longitudinal to lateral) taper may be curved to fit the conditions, and the 3,000-foot radius curve may be adjusted (see Figure 504.2A, note 3).

When an exit must be located where physical restrictions to visibility cannot be corrected by cut widening or object removal, an auxiliary lane in advance of the exit should be provided. The length of auxiliary lane should be a minimum 600 feet, 1,000 feet preferred.

(4) *Design Speed Considerations.* In the design of interchanges it is important to provide vertical and horizontal alignment standards which are consistent with driving conditions expected on branch connections. Sight distance on crest vertical curves should be consistent with expected approach speeds.

(a) Freeway Exit--The design speed at the exit nose should be 50 miles per hour or greater for both ramps and branch connections.

Figure 504.2C
Location of Freeway Ramps on a Curve



Decision sight distance given in Table 201.7 should be provided at freeway exits and branch connectors. At secondary exits on collector-distributor roads, a minimum of 600 feet of decision sight distance should be provided. In all cases, sight distance is measured to the center of ramp lane right of the nose.

(b) Freeway Entrance--The design speed at the inlet nose should be consistent with approach alignment standards. If the approach is a branch connection or diamond ramp with high alignment standards, the design speed should be at least 50 miles per hour.

(c) Ramps--See Index 504.3(1)(a).

(d) Freeway-to-Freeway Connections--See Index 504.4(2).

(5) *Grades.* Grades for freeway entrances and exits are controlled primarily by the requirements of sight distance. Ramp profile grades should not exceed 8 percent with the exception of descending entrance ramps and ascending exit ramps, where a 1 percent steeper grade is allowed. However, the 1 percent steeper grade should be avoided on descending loops to minimize overdriving of the ramp (see Index 504.3 (8)).

Profile grade considerations are of particular concern through entrance and exit gore areas. In some instances the profile of the ramp or connector, or a combination of profile and cross slope, is sufficiently different than that of the freeway through lanes that grade breaks across the gore may become necessary. Where adjacent lanes or lanes and paved gore areas at freeway entrances and exits are not in the same plane, the algebraic difference in pavement cross slope should not exceed 5 percent (see Index 301.3). The paved gore area is typically that area between the diverging or converging edge of traveled ways and the 23-foot point.

In addition to the effects of terrain, grade lines are also controlled by structure clearances (see Indexes 204.6 and 309.2). Grade lines for overcrossing and undercrossing roadways should conform to the requirements of HDM Topic 104 Roads Under Other Jurisdictions.

(a) Freeway Exits--Vertical curves located just beyond the exit nose should be designed with a minimum 50 miles per hour stopping sight distance. Beyond this point, progressively lower design speeds may be used to accommodate loop ramps and other geometric features.

Ascending off-ramps should join the crossroads on a reasonably flat grade to expedite truck starts from a stopped condition. If the ramp ends in a crest vertical curve, the last 50 feet of the ramp should be on a 5 percent grade or less. There may be cases where a drainage feature is necessary to prevent crossroads water from draining onto the ramp.

On descending off-ramps, the sag vertical curve at the ramp terminal should be a minimum of 100 feet in length.

(b) Freeway Entrances--Entrance profiles should approximately parallel the profile of the freeway for at least 100 feet prior to the inlet nose to provide intervisibility in merging situations. The vertical curve at the inlet nose should be consistent with approach alignment standards.

Where truck volumes (three-axle or more) exceed 20 vehicles per hour on ascending entrance ramps to freeways and expressways with sustained upgrades exceeding 2 percent, a 1,500-foot length of auxiliary lane should be provided in order to ensure satisfactory operating conditions. Additional length may be warranted based on the thorough analysis of the site specific grades, traffic volumes, and calculated speeds; and after consultation with the District Traffic Safety Engineer or designee and the Project Delivery Coordinator or District Design Liaison. Also, see Index 204.5 "Sustained Grades".

(6) Bus Stops. See Index 108.2 and 303.4 for general information.

(7) Bicycle and Pedestrian Conditions. On freeways where bicycle or pedestrian travel is not prohibited, provisions need to be made at interchanges to accommodate bicyclists and pedestrians. See Topic 116 and the California MUTCD for additional guidance.

504.3 Ramps

(1) General.

(a) Design Speed--When ramps terminate at an intersection at which all traffic is expected to make a turning movement, the minimum design speed along the ramp should be 25 miles per hour. When a "through" movement is provided at the ramp terminus, the minimum ramp design speed should meet or exceed the design speed of the highway facility for which the through movement is provided. The design speed along the ramp will vary depending on alignment and controls at each end of the ramp. An acceptable approach is to set design speeds of 25 miles per hour and 50 miles per hour at the ramp terminus and exit nose, respectively, the appropriate design speed for any intermediate point on the ramp is then based on its location relative to those two points. When short radius curves with relatively lower design speeds are used, the vertical sight distance should be consistent with approach vehicle speeds. See Index 504.2(4) for additional information regarding design speed for ramps.

(b) Lane Width--**Ramp lanes shall be a minimum of 12 feet in width. Where ramps have curve radii of 350 feet or less, measured along the outside edge of traveled way for single lane ramps or along the outside lane line for multilane ramps, with a central angle greater than 60 degrees, the single ramp lane, or the lane furthest to the right if the ramp is multilane, shall be widened in accordance with Table 504.3 in order to accommodate large truck wheel paths.** See Topic 404. Consideration may be given to widening more than one lane on a multilane ramp with short radius curves if there is a likelihood of considerable transit or truck usage of that lane.

Table 504.3
Ramp Widening for Trucks

Ramp Radius (ft)	Widening (ft)	Lane Width (ft)
<150	8	20
150 – 179	5	17
180 – 209	4	16
210 – 249	3	15
250 – 299	2	14
-300 – 350	1	13
>350	0	12

(c) Shoulder Width--**Shoulder widths for ramps shall be as indicated in Table 302.1.** Typical ramp shoulder widths are 4 feet on the left and 8 feet on the right.

(d) Lane Drops--Typically, lane drops are to be accomplished over a distance equal to WV. Where ramps are metered, the recommended lane drop taper past the meter limit line is 50 to 1 (longitudinal to lateral). Depending on approach geometry and speed, the lane drop transition between the limit line and the 6-foot separation point should be accomplished with a taper of between 30:1 and 50:1 (longitudinal to lateral). This is further explained in Index 504.3(2)(b) for metered multilane entrance ramps. **However, the lane drop taper past the limit line shall not be less than 15 to 1.**

Lane drop tapers should not extend beyond the 6-foot point without the provision of an auxiliary lane.

(e) Lane Additions -- Lane additions to ramps are usually accomplished by use of a 120-foot bay taper. See Table 405.2A for the geometrics of bay tapers.

(2) Ramp Metering

Caltrans Deputy Directive (DD) No. 35-R1, Ramp Metering, contains the statewide policy for ramp metering which delegates responsibility for its implementation in part through the Ramp Metering Design Manual (RMDM). DD 35-R1 specifies that provisions for entrance ramp metering shall be included in any project that proposes additional capacity, modification of an existing interchange, or construction of a new interchange, within the freeway corridors identified in the Ramp Metering Development Plan (RMDP), regardless of funding source. Projects designed for new or existing freeway segments experiencing recurring traffic congestion and/or a high frequency of vehicle collisions may include provisions for entrance ramp metering, whether or not the freeway segment locations are listed in the RMDP.

All geometric designs for ramp metering installations must be discussed with the Project Delivery Coordinator or District Design Liaison. Design features or elements which deviate from design standards require the approvals described in Index 82.2.

See the RMDM for ramp metering guidance, procedures, and policies to be used in conjunction with the guidance in this manual. Where traffic-related ramp metering guidance is noted in this Chapter, reference is made to the RMDM for exception instructions and further information.

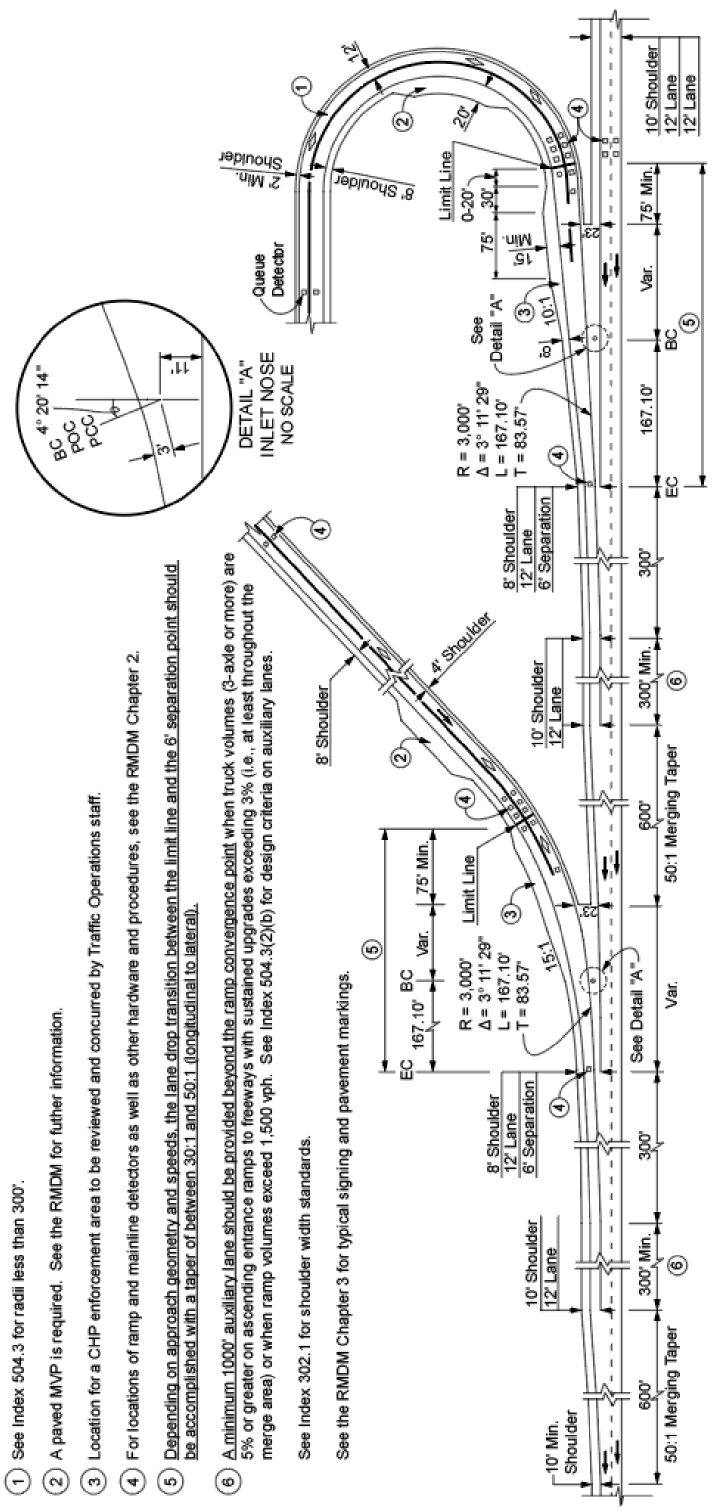
Geometric ramp design for operational improvement projects which include ramp metering should be based on current peak-hour traffic volume. If this current data is not available it should be obtained before proceeding with design. Peak hour traffic data from the annual Caltrans Traffic Volumes book is not adequate for this application.

The design advice and typical designs that follow should not be directly applied to ramp meter installation projects, especially retrofit designs. Every effort should be made by the designer to exceed the recommended minimum standards provided herein, where conditions are not restrictive.

(a) Metered Freeway Entrance Ramps (1 General Purpose (GP) + 1 HOV Preferential Lane)

According to the RMDM, a High-Occupancy Vehicle (HOV) preferential lane shall be provided where ramp meters are installed, and each HOV preferential

Figure 504.3B
Typical Successive Freeway Entrance Ramp Metering
(1 GP Lane + 1 HOV Preferential Lane)



NOTES:

(1) See Index 504.3 for radii less than 300'.

(2) A paved MVP is required. See the RMDM for futher information.

(3) Location for a CHP enforcement area to be reviewed and concurred by Traffic Operations staff.

(4) For locations of ramp and mainline detectors as well as other hardware and procedures, see the RMDM Chapter 2.

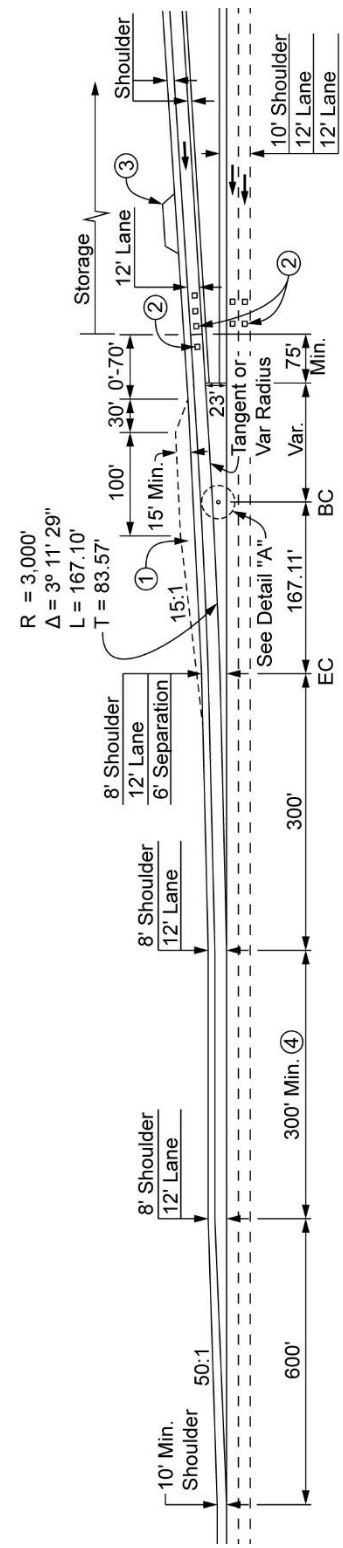
(5) Depending on approach geometry and speeds, the lane drop transition between the limit line and the 6' separation point should be accomplished with a taper of between 30:1 and 50:1 (longitudinal to lateral).

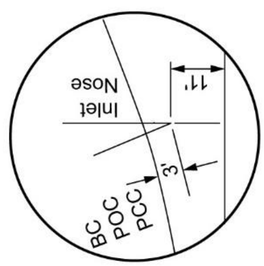
(6) A minimum 1000' auxiliary lane should be provided beyond the ramp convergence point when truck volumes (3-axle or more) are 5% or greater on ascending entrance ramps to freeways with sustained upgrades exceeding 3% (i.e., at least throughout the merge area) or when ramp volumes exceed 1,500 vph. See Index 504.3(2)(b) for design criteria on auxiliary lanes.

See Index 302.1 for shoulder width standards.

See the RMDM Chapter 3 for typical signing and pavement markings.

Figure 504.3C
Restrictive Condition Freeway Entrance Ramp Metering
(1 GP Lane)





DETAIL "A"
INLET NOSE
NO SCALE

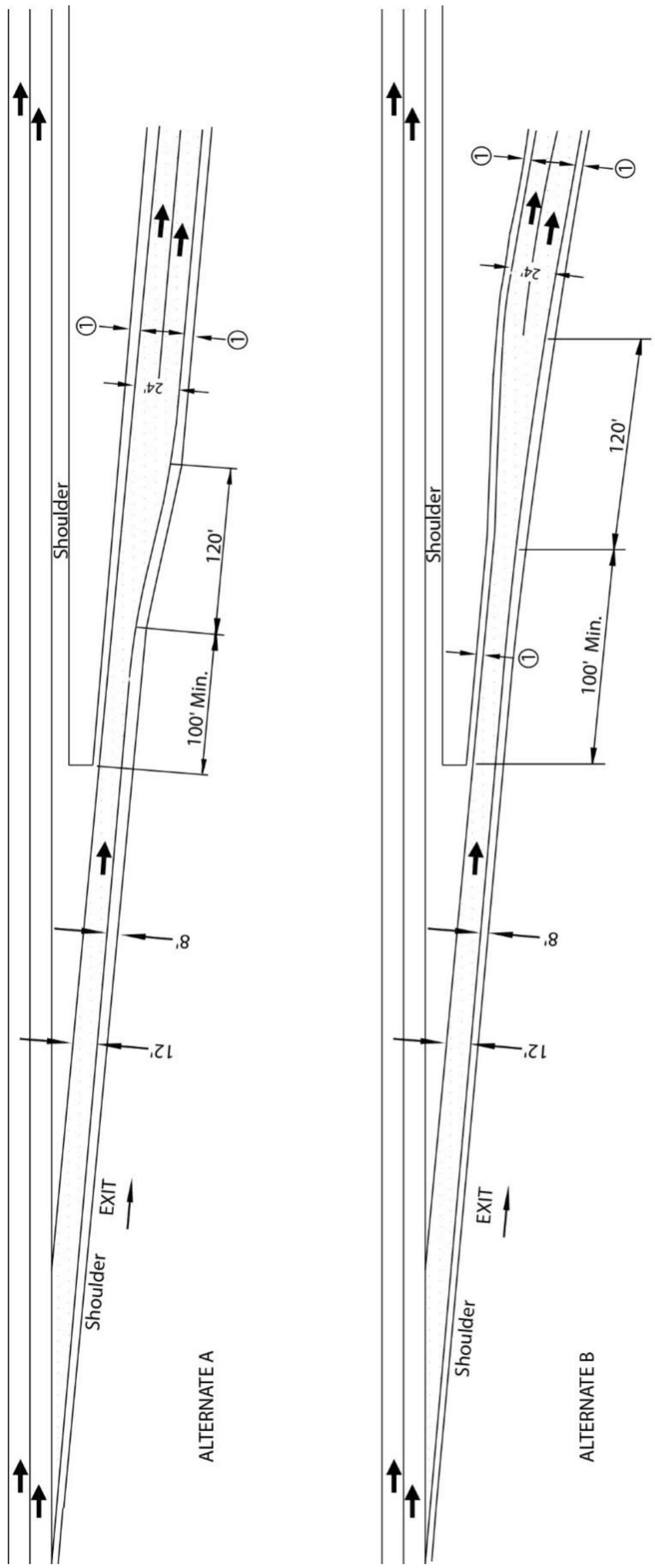
NOTES:

1. Location for CHP enforcement area to be reviewed and concurred by Traffic Operations staff.
2. For locations of ramp and mainline detectors as well as other hardware and procedures, see the RMDM Chapter 2.
3. A paved MVP is required. See the RMDM for further information.
4. In restrictive conditions, a minimum 500-foot axuiliary lane should be provided beyond the ramp convergence point when truck volumes (3-axle or more) are 5% or greater on ascending entrance ramps to freeways with sustained upgrades exceeding 3% (i.e., at least throughout the merge area).

See Index 302.1 for shoulder width standards.

See the RMDM Chapter 3 for typical signing and pavement markings.

Figure 504.3J
Transition to Two-lane Exit Ramp

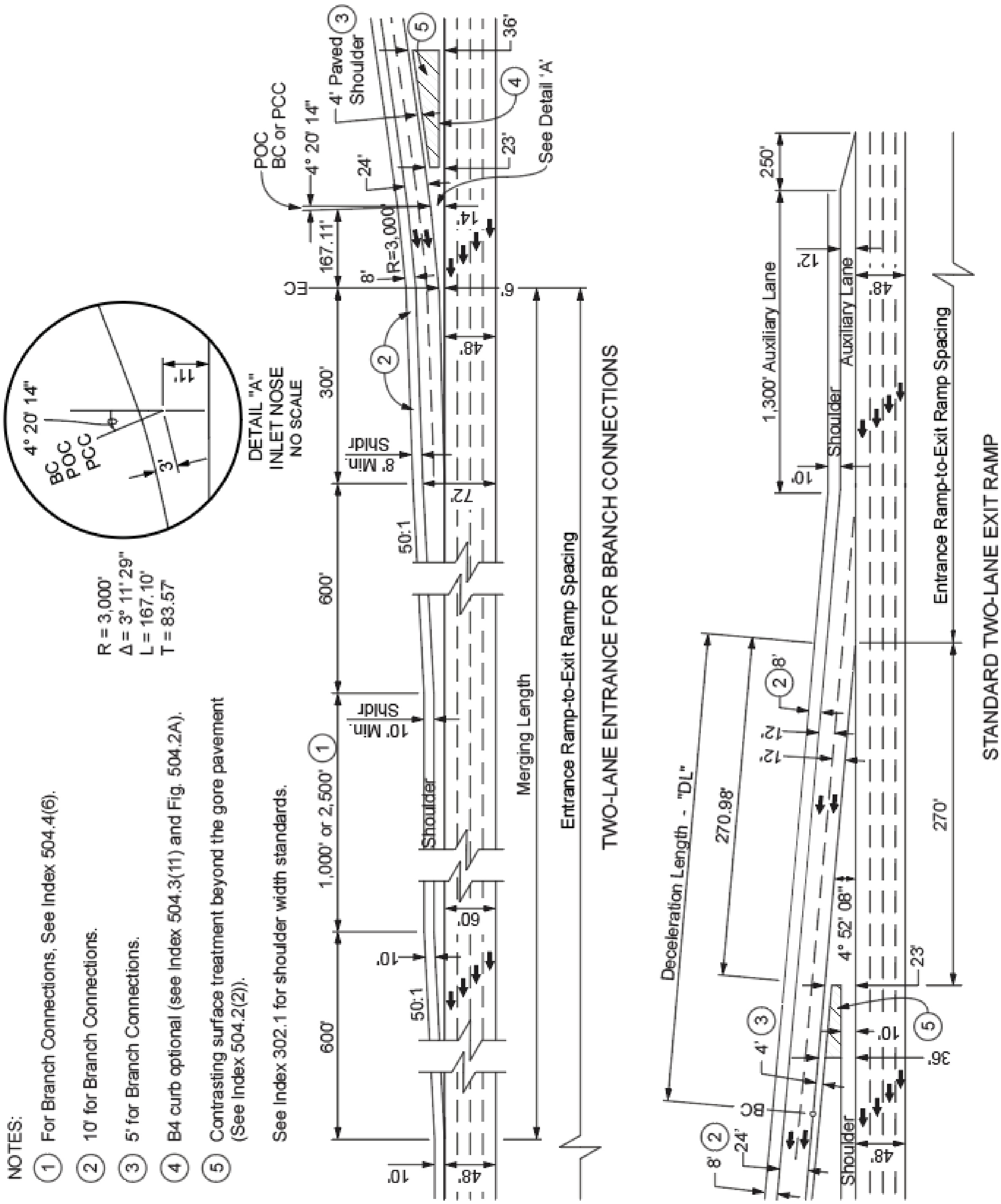


NOTES:

① See Index 302.1 for shoulder width standards. If shoulder reductions occur, see Index 206.3(4) for transitions.

Figure 504.3K

Two-Lane Connectors and Entrance/Exit Ramps



the gore cross slope would be greater than allowed in Index 504.2(5). When the optional B4 curb is used at the entrance ramp inlet nose, the shoulder adjacent to the curb should be the same width as the ramp shoulder approaching the curb. The B4 gutter pan can be included as part of the shoulder width. As stated in Index 405.4(2), curbs are typically discouraged where posted speeds are over 40 miles per hour. Curbs at gore areas must be determined on a case-by-case basis.

(c) Curbs may be used where necessary at the ramp connection with the local street for the protection of pedestrians, for channelization, and to provide compatibility with the local facility.

(d) The Type E curb may be used only in special drainage situations, for example, where drainage parallels and flows against the face of a retaining wall.

In general, curbs should not be used on the high side of ramps or in off-ramp gore areas except at collector-distributor roads. The off-tracking of trucks should be analyzed when considering curbs on ramps.

(12) *Dikes.* Dikes may be used where necessary to control drainage. For additional information see Index 303.3.

504.4 Freeway-to-Freeway Connections

(1) *General*. All of the design criteria discussed in Indexes 501.3, 504.2 and 504.3 apply to freeway to freeway connectors, except as discussed or modified below.

(2) *Design Speed*. <u>The design speed for single lane directional and all branch connections should be a minimum of 50 miles per hour</u>. <u>When smaller radius curves, with lower design speeds, are used the vertical sight distance should be consistent with approaching vehicle speeds</u>. Design speed for loop connectors should be consistent with the radii guidance discussed in Index 504.3(8).

(3) *Grades*. <u>The maximum profile grade on freeway-to-freeway connections should not exceed 6 percent</u>. Flatter grades and longer vertical curves than those used on ramps are needed to obtain increased stopping sight distance for higher design speeds.

(4) *Shoulder Width.*

(a) Single-lane and Two-lane Connections--**The width of shoulders on single-lane and two-lane (except as described below) freeway-to-freeway connectors shall be 5 feet on the left and 10 feet on the right. A single lane freeway-to-freeway connector that has been widened to two lanes solely to provide passing opportunities and not due to capacity requirements shall have a 5-foot left shoulder and at least a 5-foot right shoulder** (see Index 504.4(5)).

(b) Three-lane Connections--**The width of shoulders on three-lane connectors shall be 10 feet on both the left and right sides.**

(5) *Single-lane Connections.* Freeway-to-freeway connectors may be single lane or multilane. <u>Where design year volume is between 900 and 1500 equivalent passenger cars per hour, initial construction should provide a single lane connection with the capability of adding an additional lane</u>. <u>Single lane directional connectors should be designed using the general configurations shown on Figure 504.2A and 504.2B, but utilizing the flatter divergence angle shown in Figure 504.4</u>. Single lane loop connectors may use a diverge angle of as much as that shown on Figure 504.2B for ramps, if necessary. The choice will depend upon interchange configuration and driver expectancy. <u>Single lane connectors in excess of 1,000 feet in length should be widened to two lanes to provide for passing maneuvers</u> (see Index 504.4(4)).

(6) *Branch Connections*. A branch connection is defined as a multilane connection between two freeways. <u>A branch connection should be provided when the design year volume exceeds 1500 equivalent passenger cars per hour</u>.

<u>Merging branch connections should be designed as shown in Figure 504.3K</u>. <u>Diverging branch connections should be designed as shown in Figure 504.4</u>. The diverging branch connection leaves the main

freeway lanes on a flatter angle shown in Figure 504.4 than the standard 2-lane ramp exit connection shown in Figure 504.3K. The standard ramp exit connects to a local street. The diverging branch connection connects to another freeway and has a flatter angle that allows a higher departure speed.

At a branch merge, a 2,500-foot length of auxiliary lane should be provided beyond the merge of one lane of the inlet, except where it does not appear that capacity on the freeway will be reached until five or more years after the 20 year design period. In this case the length of auxiliary lane should be a minimum of 1,000 feet. For diverging connections where less than capacity conditions beyond the design year are anticipated, the length of auxiliary lane in advance of the exit should be 1,300 feet.

(7) *Lane Drops.* The lane drop taper on a freeway-to-freeway connector should not be less than WV.

(8) *Metering.* Any decision to meter freeway-to-freeway connectors must be carefully considered as driver expectancy on these types of facilities is for high-speed uninterrupted flow. If metering is anticipated on a connector, discussions with the Project Delivery Coordinator and the District Traffic Engineer or designee should take place as early as possible. Issues of particular concern are adequate deceleration lengths to the end of the queue, potential need to widen shoulders if sight distance is restricted (particularly on-ramps with 5-foot shoulders on each side), and the potential for queuing back onto the freeway.

504.5 Auxiliary Lanes

In order to ensure satisfactory operating conditions, auxiliary lanes may be added to the basic width of traveled way.

Where an entrance ramp of one interchange is closely followed by an exit ramp of another interchange, the acceleration and deceleration lanes should be joined with an auxiliary lane. Auxiliary lanes are frequently used when the entrance ramp-to-exit ramp spacing, measured as shown in Figure 504.2A, is less than 2,000 feet. Where interchanges are more widely spaced and ramp volumes are high, the need for an auxiliary lane between the interchanges should be determined in accordance with Index 504.7.

Auxiliary lanes may be used for the orientation of traffic at 2-lane ramps or branch connections as illustrated on Figure 504.3K and Figure 504.4. The length and number of auxiliary lanes in advance of 2-lane exits are based on percentages of turning traffic and a weaving analysis.

Auxiliary lanes should be considered on all freeway entrance ramps with significant truck volumes. The grade, volumes and speeds should be analyzed to determine the need for auxiliary lanes. An auxiliary lane would allow entrance ramp traffic to accelerate to a higher speed before merging with mainline traffic, or simply provide more opportunity to merge. See Index 504.2 for specific requirements.

504.6 Mainline Lane Reduction at Interchanges

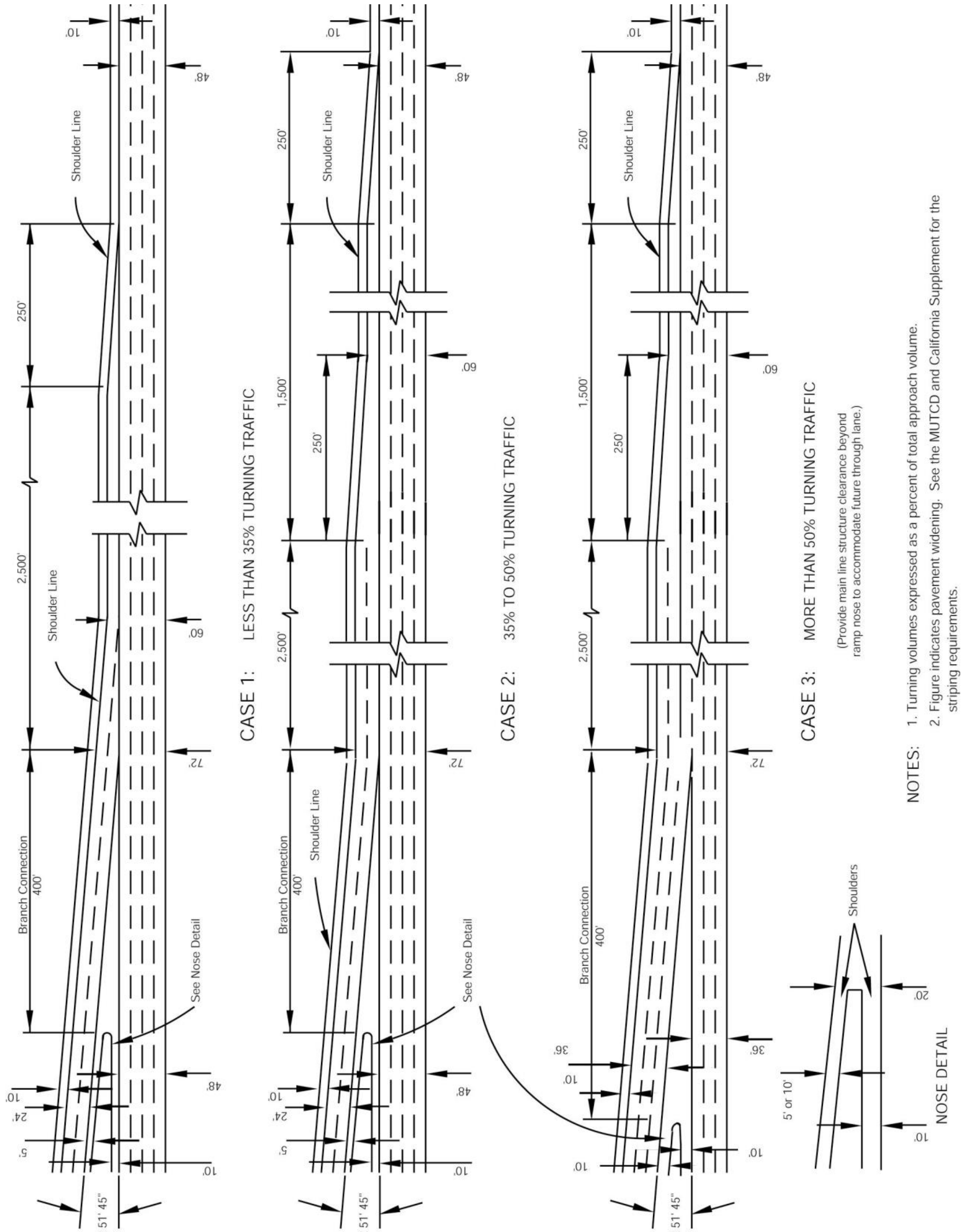
The basic number of mainline lanes should not be dropped through a local service interchange. The same standard should also be applied to freeway-to-freeway interchanges where less than 35 percent of the traffic is turning (see Figure 504.4). Where more than 35 percent of the freeway traffic is turning, consideration may be given to reducing the number of lanes. No decision to reduce the number of lanes should be made without the approval of the District Traffic Operations Unit. Additionally, adequate structure clearance (both horizontal and vertical) should be provided to accommodate future construction of the dropped lane if required.

Where the reduction in traffic volumes is sufficient to warrant a decrease in the basic number of lanes, a preferred location for the lane drop is beyond the influence of an interchange and preferably at least one-half mile from the nearest exit or inlet nose. It is desirable to drop the right lane on tangent alignment with a straight or sag profile so vehicles can merge left with good visibility to the pavement markings in the merge area (see Index 201.7).

504.7 Weaving Sections

A weaving section is a length of one-way roadway where vehicles are crossing paths, changing lanes, or merging with through traffic as they enter or exit a freeway or collector-distributer road.

Figure 504.4
Diverging Branch Connections



A single weaving section has an inlet at the upstream end and an exit at the downstream end. A multiple weaving section is characterized by more than one point of entry followed by one or more points of exit.

A rough approximation for adequate length of a weaving section is one foot of length per weaving vehicle per hour. This rate will approximately provide a Level of Service (LOS) C.

There are various methods for analyzing weaving sections. Two methods which provide valid results are described below.

The Leisch method, which is usually considered the easiest to use, is illustrated in Figure 504.7A. This method was developed by Jack Leisch & Associates and may be used to determine the length of weaving sections for both freeways and collector-distributor roads. The Leisch weaving charts determine the level of service for the weaving volumes for the length of the weaving section from the first panel on the lower left of the chart. The analysis is dependent on whether the section is balanced or unbalanced, as defined in Figure 504.7B. The level of service for the total volume over all lanes of the weaving section is then found from the panels on the right of the chart. The weaving chart should not be extrapolated.

Pages 234-238 of the 1965 Highway Capacity Manual (HCM) provide a method for determining the adequacy of weaving sections near single lane ramps. It is often referred to as the LOS D method. This method is also documented in Traffic Bulletin 4 which is available from the District Division of Traffic Operations. The LOS D method can be used to project volumes along a weaving section. These volumes can be compared to the capacities along the same weaving section.

Volumes in passenger car equivalents per hour (PCEPH) should be adjusted for freeway grade and truck volumes. Table 504.7C and Figures 504.7D and E are reprinted from the 1965 HCM and provide information regarding vehicle distribution by lane.

The results obtained from Figure 504.7A (the Leisch Method) for single-lane ramps with an auxiliary lane and weaving rates exceeding 2500 PCEPH should be checked using the LOS D method.

Weaving capacity analyses other than those described above should not be used on California highways. Other methods, such as the one contained in the 1994 HCM, may not always produce accurate results.

The criteria contained within this Index apply to:

- New interchanges.
- Modifications to existing interchanges including access control revisions for new ramps or the relocation/elimination of existing ramps.
- Projects to increase mainline capacity when existing interchanges do not meet interchange spacing requirements.

Weaving sections in urban areas should be designed for LOS C or D. Weaving sections in rural areas should be designed for LOS B or C. Design rates for lane balanced weaving sections where at least one ramp or connector will be two lanes should not result in a LOS lower than the middle of LOS D using Figure 504.7A. Mainline through capacity is optimized when weaving movements operate at least one level of service better than the mainline level of service. In determining acceptable hourly operating volumes, peak hour factors should be used.

Between interchanges, the minimum entrance ramp-to-exit ramp spacing, measured as shown on Figures 504.2A and 504.2B shall be 2,000 feet in urban areas, 5,000 feet outside urban areas, and 5,000 feet between freeway-to-freeway interchanges and other interchanges. The volumes used must be volumes unconstrained by metering regardless of whether metering will be used. It should be noted that a weaving analysis must be considered over an entire freeway segment as weaving can be affected by other nearby ramps.

The District Traffic Operations Branch should be consulted for difficult weaving analysis problems.

504.8 Access Control

Access rights shall be acquired along interchange ramps to their junction with the nearest public road. At such junctions, for new construction, access control should extend 100 feet beyond the end of the curb return or ramp radius in urban areas and 300 feet in rural areas, or as far as necessary to ensure that entry onto the facility does not impair operational characteristics. **Access control shall**

extend at least 50 feet beyond the end of the curb return, ramp radius, or taper.

Typical examples of access control at interchanges are shown in Figure 504.8. These illustrations do not presume to cover all situations or to indicate the most desirable designs for all cases. When there is state-owned access control on both sides of a local road, a maintenance agreement may be needed.

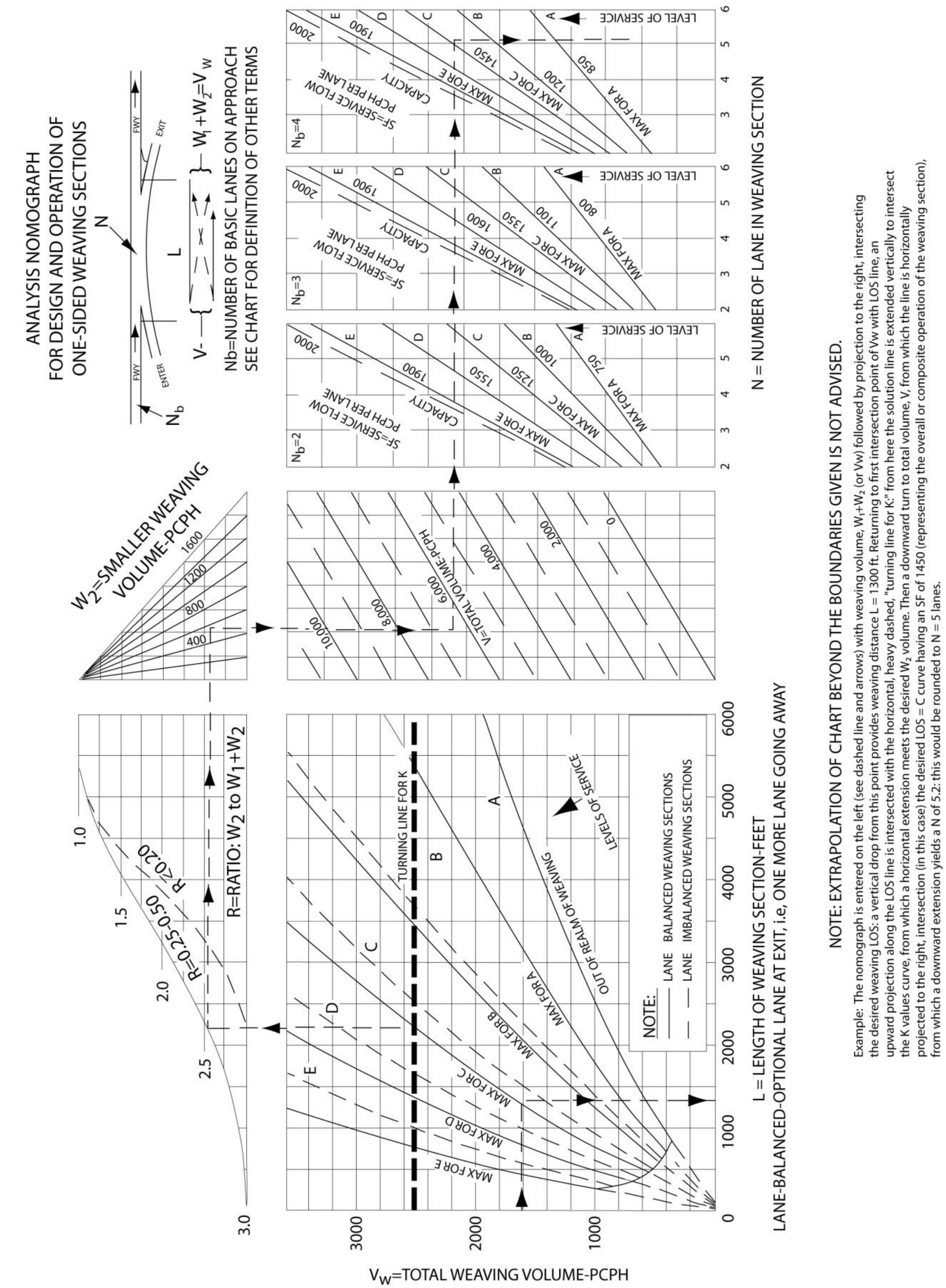
For new construction or major reconstruction, access rights shall be acquired on the opposite side of the local road from ramp terminals to preclude driveways or local roads within the ramp intersection. This access control would limit the volume of traffic and the number of phases at the intersection of the ramp and local facility, thereby optimizing capacity and operation of the ramp. Through a combination of access control and the use of raised median islands along the local facility, right–in/right-out access may be permitted beyond 200 feet from the ramp intersection. The length of access control on both sides of the local facility should match. See Index 504.3(3) for further ramp intersection guidance on the crossroads.

In Case 2 consider private ownership within the loop only if access to the property is an adequate distance from the ramp junction to preserve operational integrity.

In Case 3 if the crossroads is near the ramp junction at the local road, full access control should be acquired on the local road from the junction to the intersection with the crossroad.

Case 6 represents a slip ramp design. If the ramp is perpendicular to the local/frontage road refer to Case 3. In Case 6 if the crossroad is near the ramp junction to the local/frontage road, access control should be acquired on the opposite side of the local road from the junction.

Figure 504.7A
Design Curve for Freeway and Collector Weaving



CHAPTER 630
FLEXIBLE PAVEMENT

Topic 631 - Types of Flexible Pavements & Materials

Index 631.1 - Hot Mix Asphalt (HMA)

HMA consists of a mixture of asphalt binder and a graded aggregate ranging from coarse to very fine particles. HMA is classified by type depending on the specified aggregate gradation and mix design criteria appropriate for the project conditions. The Department uses the following types of HMA based on the aggregate gradation: (1) Dense Graded HMA, (2) Gap Graded HMA, and (3) Open Graded Friction Course.

HMA types are found in the Standard Specifications and Standard Special Provisions.

631.2 Dense Graded HMA

Dense graded HMA is the most common mix used as a structural surface course. The aggregate is uniformly graded to provide for a stable and impermeable surface. The aggregate can be treated and the asphalt binder can be modified. HMA could be made from new or recycled material. Examples of recycled asphalt include, but are not limited to reclaimed asphalt pavement and cold in-place recycling. The Department uses one type of dense graded HMA: HMA-Type A.

631.3 Rubberized Hot Mixed Asphalt Gap Graded (RHMA-G)

Gap graded HMA is used to meet Public Resources Code section 42703 that specifies specific amounts of crumb rubber modifier (CRM) usage in HMA. To meet the Public Resources Code, regular asphalt binder is substituted with the asphalt rubber binder (that contains CRM) in pavement products to create rubberized HMA (RHMA) product in which the regular asphalt binder of the HMA is substituted with asphalt rubber binder. Known as the wet process, CRM is mixed with asphalt binder at specified temperature and mixing time to create asphalt rubber binder. The aggregate is gap graded to create space between the aggregate particles to accommodate asphalt rubber binder. The Department uses only one type of gap graded HMA: Rubberized Hot Mix Asphalt-Gap-graded (RHMA-G). RHMA-G is used as a structural surface course. RHMA is commonly specified to retard reflection cracking, resist thermal stresses created by wide temperature fluctuations and add elasticity to a structural overlay. RHMA-G is used as a structural surface course up to a maximum thickness of 0.20 foot. Because of maximum thickness requirements, if a thicker surface layer or overlay is called for, then a HMA layer of a predetermined thickness should be placed prior to placing the RHMA surface course. The minimum thickness for RHMA-G is 0.10 foot. RHMA layer should only be placed over a HMA or concrete surface course and not on an aggregate base. Do not place conventional HMA over a new RHMA unless it is HMA-O.

631.4 Open Graded Friction Course (OGFC)

OGFC; formerly known as open graded asphalt concrete (OGAC), is a non-structural wearing course placed primarily on asphalt pavement. The aggregate is open graded to provide for high permeability. The primary reason for using OGFC is the improvement of wet weather skid resistance, reduced water splash and spray, reduced night time wet pavement glare, and as a stormwater treatment Best Management Practice (BMP). Secondary benefits include better visibility of pavement delineation (pavement markings and pavement markers) during wet weather conditions. Three types of non-structural OGFC are used on asphalt pavement: Hot Mix Asphalt-Open-graded (HMA-O), Rubberized Hot Mix Asphalt-Open-Graded (RHMA-O), and Rubberized Hot Mix Asphalt-Open-graded-High Binder (RHMA-O-HB). HMA-O is occasionally placed on rigid pavements. The difference between RHMA-O and RHMA-G is in the gradation of the aggregate; while the difference between RHMA-O and RHMA-O-HB is in the amount of binder content. The maximum thickness of RHMA-O or RHMA-O-HB is 0.15 foot.

Rubberized OGFC (RHMA- O or RHMA-O-HB) is recommended unless it is documented that RHMA-O or RHMA-O-HB are not suitable due to availability, cost, constructability, or environmental factors (such as a stormwater treatment BMP for

National Pollutant Discharge Elimination System (NPDES) compliance). RHMA-O and RHMA-O-HB are not expected to provide a water quality benefit. The project engineer should balance the competing requirement of recycled crumb rubber goals with those for stormwater treatment and document in the project report. Coordinate with the district pavements engineer and NPDES coordinator to determine if both goals are on target for compliance. It is undesirable to place RHMA-O in areas that will not allow surface water to drain. As an example, a surface that is milled only on the traveled way and not on the shoulder forms a "bathtub" section that can trap water beneath the surface of the traveled way. To prevent this effect, HMA should be placed on the milled surface (traveled way only) and OGFC should be placed over the entire cross section of the road (traveled way and shoulders).

For additional information and applicability of OGFC in new construction and rehabilitation projects refer to OGFC Guideline available on the Department Pavement website. Also, see Maintenance Technical Advisory Guide (MTAG) for additional information and use of OGFC in pavement preservation. If OGFC is proposed as a stormwater treatment BMP, see OGFC Stormwater Treatment BMP Guidance on the Design website.

631.5 Rubberized HMA (RHMA) Use

Currently, three RHMA products are used: gap-graded (RHMA-G), open-graded (RHMA-O), and open-graded-high binder (RHMA-O-HB) mixes.

The minimum thickness for RHMA (any type) should be 0.10 foot for rehabilitation and pavement preservation projects. These RHMA products are considered to be the asphalt pavement surface courses of choice for a project unless it is documented that RHMA is not suitable due to availability, cost, constructability or environmental factors (Treatment BMP). The following describes situations where RHMA should not be used:

- When RHMA project quantities are 1,000 tons or less or staged construction operations require less than 1,000 tons of RHMA per stage. This is due to the higher costs associated with mobilizing an asphalt rubber blending plant. The 1,000-ton minimum does not apply in Los Angeles/Inland Empire areas due to the availability of several HMA production plants that have full time RHMA blending plants on site.
- When the ambient temperatures forecasted at the time of placement will be below 45°F.
- Where the roadway elevation is above 3,000 feet.
- When the project has a Caltrans NPDES permit requirement for treatment BMPs (only applicable for RHMA-O or RHMA-O-HB exception).

For additional information on and applicability of RHMA in new construction and rehabilitation projects refer to Asphalt Rubber Usage Guide available on the Pavement website.

631.6 Other Types of Flexible Pavement Surface Courses

There are other types of flexible pavement surface courses such as cold mix, Resin Pavement, and Sulphur Extended Hot Mix Asphalt. The other types of pavements are either used for maintenance treatments or not currently used on State highways. For pavement preservation and other maintenance treatments refer to the Caltrans Maintenance Manual and MTAG.

631.7 Warm Mix Asphalt Technology

HMA may be produced using the Warm Mix Asphalt (WMA) technology. The Department has a permissive specification which allows contractors to use WMA technology as compaction aid. The Department has an approved list of WMA additives technology and WMA water injection technology. Ambient and surface temperature requirements for both the WMA additives and WMA water injection technologies are specified in the standard specifications. The designer with reasonable assurance of these ambient and surface temperatures should specify WMA additives technology to avoid unnecessary conflicts and delays with marginal temperatures conditions on actual paving day.

Where ambient and surface temperatures are not issues, WMA may still be specified if other conditions such as long haul and coastal and windy conditions justify its use as compaction aid.

RHMA-G may be placed when ambient air or surface temperature is between 45°F and 49.9°F provided that WMA additives technology is specified.

WMA does not change the design parameters representative of HMA. Therefore, all design methods discussed in this chapter using hot mix asphalt are also applicable to warm mix asphalt products.

631.8 Pavement Interlayers

Pavement interlayers are used with asphalt pavement as a means to retard reflective cracks from existing pavement into the new flexible layer, prevent water infiltration deeper into the pavement structure, and enhance pavement structural strength. Two types of pavement interlayers are:

- Rubberized Pavement Interlayers (RPI); also known as Rubberized Stress Absorbing Membrane Interlayer (SAMI-R); which is simply a rubberized chip seal.
- Geosynthetic Pavement Interlayer (GPI). GPI consists mainly of asphalt-saturated geotextile (also called fabric), but other geosynthetic planar products such as paving grids and paving geocomposites (grid attached to geotextile) are also used. Refer to Standard Specifications for the various GPI types.

Sound engineering judgment is required when considering the use of a pavement interlayers. The following must be considered:

- Consideration should be given to areas that may prohibit surface water from draining out the sides of the overlay, thus forming a "bathtub" section.
- Since pavement interlayer can act as a moisture barrier, it should be used with caution in hot environments where it could prevent underlying moisture from evaporating.
- When placed on an existing pavement, preparation is required to prevent excess stress on the membrane. This includes sealing cracks wider than ¼ inch and repairing potholes and localized failures.

A pavement interlayer may be placed between layers of new flexible pavement, such as on an asphalt leveling course, or on the surface of an existing flexible pavement. A GPI should not be placed directly on coarse surfaces such as a chip seal, OGFC, areas of numerous rough patches, or on a pavement that has been cold planed. As an example, coarse surfaces may penetrate the paving fabric and the paving asphalt binder used to saturate the fabric may collect in the voids or valleys leaving areas of the fabric dry. For the GPI to be effective in these areas, use a layer of HMA prior to the placement of the GPI.

GPI is ineffective in the following applications:

- For providing added structural strength when placed in combination with new flexible pavement.
- In the reduction of thermal cracking of the new flexible pavement overlay.

When using a GPI, care must be taken to specify a product that can withstand temperatures of the asphalt placed above it, particularly for RHMA. Detailed information for selecting appropriate type of pavement interlayer to use can be found in the MTAG on the Department Pavement website.

Topic 632 – Asphalt Binder

632.1 Binder Classification

Asphalt binders are most commonly characterized by their physical properties which directly affect asphalt pavement field performance. Although asphalt binder viscosity grading is still common, new binder tests and specifications have been developed to more accurately characterize temperature extremes which pavements in the field are expected to withstand. These tests and specifications are particularly designed to address three specific asphalt pavement distress types: permanent deformation (rutting), fatigue cracking, and low temperature cracking.

In the past, unmodified asphalt binders were classified using viscosity grading based on the Aged Residue (AR) System and Performance Based Asphalt (PBA) binder system. Beginning January 1, 2006, the Department switched to the nationally recognized Performance Grade (PG) System for conventional binders. Effective January 1, 2013, the Department has graded modified binders as Performance Graded Modified (PG-M) binder. Binder modification is achieved using either crumb rubber, polymers, or both.

Performance grading is based on the concept that asphalt binder properties should be related to the conditions under which the binder is used. PG asphalt binders are selected to meet expected climatic conditions as well as traffic speed and volume. Therefore, the PG system uses a common set of tests to measure physical properties of the binder that can be directly related to field performance of the pavement at its service temperatures. For example, a binder identified as PG 64-10 (64 minus 10) must meet certain performance criteria at an average seven-day maximum pavement temperature of 64°C and also at a minimum pavement temperature of –10°C.

Although modified asphalt binder is more expensive than unmodified binder, it can provide improved performance and durability for sensitive climate conditions. While unmodified binder is adequate for most applications, improved resistance to rutting, thermal cracking, fatigue damage, stripping, and temperature susceptibility have led polymer modified binders to be substituted for unmodified asphalt binders in many paving and maintenance applications.

632.2 Binder Selection

Table 632.1 provides the binder grade that is to be used for each climatic region for general application. For HMA, values are given for typical and special conditions. For a few select applications such as dikes and tack coats, PG binder requirements are found in the applicable Standard Specifications or Standard Special Provisions.

For locations of each pavement climate region see Topic 615.

Binder selection based on climate region is crucial for improving the pavement resistance to temperature extremes during its service life; which in turn is critical in controlling thermal cracking and other distress types affected by temperature.

Special conditions in Table 632.1 are defined as those roadways or portion of roadways that need additional attention due to conditions such as:

- Heavy truck/bus traffic (over 10 million ESALs for 20 years).
- Truck/bus stopping areas (parking area, rest area, loading area, etc.).
- Truck/bus stop-and-go areas (intersections, metered ramps, ramps to and from Truck Scales, etc.).
- Truck/bus climbing and descending lanes.

The final decision as to whether a roadway meets the criteria for special conditions rests with the District. It should be noted that even though special binder grades help meet the flexible pavement requirements for high truck/bus use areas, they should not be considered as the only measure needed to meet these special conditions. The District Materials Engineer should be consulted for additional recommendations for these locations.

For more detailed information on PG binder selection, refer to the Pavement website.

Topic 633 - Engineering Procedures for New Construction and Reconstruction

633.1 Empirical Method

The empirical procedures and practices found in this chapter are based on research and field experimentation undertaken by Caltrans and AASHTO. These procedures were calibrated for pavement design lives of 10 to 20 years and Traffic Index (TI) ranging from 5.0 to 12. Extrapolations and supplemental requirements were subsequently developed to address longer pavement design lives and higher Traffic Indices. Details on mix design and other requirements for these procedures are provided in the Standard Specifications and Standard Special Provisions. Alterations to the requirements in these documents can impact the performance of the pavement structure and the performance values found in this chapter.

The data needed to engineer a flexible pavement using the Caltrans empirical method are California R-value of the subgrade and the Traffic Index (TI) determined for the desired design life. Engineering of the flexible pavement is based on a relationship between the gravel equivalent (or equivalency) GE

Table 632.1

Asphalt Binder Performance Grade Selection

Climate Region (6)	Binder Grade for Hot Mixed Asphalt (HMA)(1), (2)				
	Dense Graded HMA		Open Graded HMA		Gap and Open Graded Rubberized Hot Mix Asphalt (RHMA)
			Placement Temperature		
	Typical	Special(3)	> 70°F	≤ 70°F	
South Coast Central Coast Inland Valley	PG 64-10	PG 70-10 or PG 64-28 M	PG 64-10	PG 58-34 M	PG 64-16
North Coast	PG 64-16	PG 64-28 M	PG 64-16	PG 58-34 M	PG 64-16
Low Mountain South Mountain	PG 64-16	PG 64-28 M	PG 64-16	PG 58-34 M	PG 64-16
High Mountain High Desert	PG 64-28	PG 58-34 M(4)	PG 64-28	PG 58-34 M	PG 58-22
Desert	PG 70-10	PG 64-28 M	PG 70-10	PG 58-34 M or PG 64-28 M(5)	PG 64-16

NOTES:

(1) PG= Performance Grade

(2) M = Modified (Polymers, crumb rubber, or both)

(3) PG 76-22 M may be specified for conventional dense graded hot mix asphalt for special conditions in all climate regions when specifically requested by the District Materials Engineer.

(4) PG 64-28 M may be specified when particularly requested by the District Materials Engineer.

(5) Consult with the District Materials Engineer for which binder grade to use.

(6) Refer to Topic 615 for determining climate region for project.

of the pavement structural materials, TI, and the California R-value of the underlying material. The relationship was developed by Caltrans through research and field experimentation.

The procedures and rules governing flexible pavement engineering are as follows (Sample calculations are provided on the Department Pavement website):

(1) *Procedures for Engineering Multiple Layered Flexible Pavement.* The Department's empirical method, commonly referred to as the Hveem or R-value method, for determining design thicknesses of the structural layers of flexible pavement structure involves the determination of the following design parameters:

Traffic Index (TI),

- California R-value (R),
- Gravel Equivalent (GE), and
- Gravel Factor (G_f).

Once TI, R, GE, and G_f are determined, then the design thickness of each structural layer is determined using the Hveem method. These design parameters and the Hveem design method are discussed in the following paragraphs:

(a) As discussed in Index 613.3(3), the TI is a measure of the cumulative number of ESALs expected during the design life of the pavement structure. The TI is determined to the nearest 0.5 using the equation given in Index 613.3(3) or from Table 613.3C.

(b) The California R-value is a measure of resistance of soils to deformation under wheel loading and saturated soils conditions. The California R-value is determined as discussed in Index 614.3.

(c) The gravel equivalent (GE) of each layer or the entire flexible pavement structure is the equivalent thickness of gravel (aggregate subbase) that would be required to prevent permanent deformation in the underlying layer or layers due to cumulative traffic loads anticipated during the design life of the pavement structure. The GE requirement of the entire flexible pavement or each layer is calculated using the following equation:

$$GE = 0.0032 \times TI \times (100 - R)$$

Where:

GE = Gravel Equivalent in feet,

TI = Traffic Index, and

R = California R-value of the material below the layer or layers for which the GE is being calculated.

The GE requirement of each type of material used in the flexible pavement structure is determined for each structural layer, starting with the surface course and proceeding downward to base and subbase as needed. For pavements that include base and/or subbase, a safety factor of 0.20 foot is added to the GE requirement for the surface course to compensate for construction tolerances allowed by the contract specifications. Since the safety factor is not intended to increase the GE of the overall pavement, a compensating thickness is subtracted from the subbase layer (or base layer if there is no subbase). For pavements that are full depth asphalt, a safety factor of 0.10 foot is added to the required GE of the pavement structure. When determining the appropriate safety factor to be added, Hot Mix Asphalt Base (HMAB) and Asphalt Treated Permeable Base (ATPB) should be considered as part of the surface course.

(d) The gravel factor (G_f) of pavement structural material is the relative strength of that material compared to gravel (i.e., aggregate subbase). Gravel factor for HMA decreases as TI increases, and also increases with HMA thickness greater than 0.5 foot. The G_f of HMA varies with layer thickness (t) for any given TI as follows:

t ≤ 0.50 ft	$G_f = \frac{5.67}{TI^{1/2}}$
t > 0.50 ft	$G_f = 7.00 \times \frac{t^{1/3}}{TI^{1/2}}$

These equations are valid for TI's ranging from 5 to 15. For TI's greater than 15, use a rigid or composite pavement or contact the Headquarters Division of Maintenance-Pavement Program for special design options. For TI's less than 5, use a TI = 5. For base and subbase materials, G_f is only dependent on the material type. Typical gravel factors for HMA of thickness equal to or less than 0.5 foot, and various types of base and subbase materials, are provided in Table 633.1. Additional information on G_f for base and subbase materials are provided in Table 663.3.

(e) The design thickness of each structural layer of flexible pavement is obtained either by dividing the GE by the appropriate G_f for that layer material, or from Table 633.1. The layer thickness determined by dividing GE by G_f is rounded up to the next higher value in 0.05-foot increments.

$$\text{Thickness (t)} = \frac{\text{GE}}{\text{G}_\text{f}}$$

The minimum thickness of any asphalt layer should not be less than three times the maximum aggregate size. Also, the minimum thickness of the dense graded HMA surface course should not be less than 0.15 foot. The limit thicknesses for placing HMA for each TI, and the limit thickness for each type of base and subbase materials are shown in Table 633.1

Base and subbase materials, other than ATPB, should each have a minimum thickness of 0.35 foot. When the calculated thickness of base or subbase material is less than the desired 0.35 foot minimum thickness, either: (a) increase the thickness to the minimum without changing the thickness of the overlying layers, or (b) eliminate the layer and increase the thickness of the overlying layers to compensate for the reduction in GE.

Generally, the layer thickness of Lime Stabilized Soil (LSS) and Cement Stabilized Soil (CSS) should be limited with 0.65 foot as the minimum and 2 feet as the maximum. A surface layer placed directly on the LSS or CSS should have a thickness of at least 0.25 foot.

The thicknesses determined by the procedures outlined in this section are not intended to preclude other combinations and thicknesses of materials. Adjustments to the thickness of the various materials may be made to accommodate construction restrictions or practices, and minimize costs, provided the minimum thicknesses, maximum thicknesses, and minimum GE requirements (including safety factors) of the entire pavement structure and each layer are as specified.

Whereas the empirical method and Table 633.1 do not provide for RHMA-G material, it is possible to substitute the top 0.15 to 0.20 foot of the design HMA thickness with an equal thickness of RHMA-G.

(2) *Procedures for Full Depth Hot Mix Asphalt.* Full depth hot mix asphalt applies when the pavement structure is comprised entirely of a flexible surface layer in lieu of base and subbase. The flexible surface layer may be comprised of a single or multiple types of flexible pavements including HMA, RHMA, interlayers, special asphalt binders, or different mix designs. Considerations regarding worker safety, short construction windows, the amount of area to be paved, or temporary repairs may make it desirable in some instances to reduce the total thickness of the pavement by placing full depth hot mix asphalt. Full depth hot mix asphalt also is less affected by moisture or frost, does not let moisture build up in the subgrade, provides no permeable layers that entrap water, and is a more uniform pavement structure. Use the standard equation in Index 633.1(1) with the California R-value of the subgrade to calculate the GE for the entire pavement structure based on TI and the subgrade R-value. Increase this GE by adding the safety factor of 0.10 foot to obtain the required GE for the flexible pavement. Then refer to Table 633.1, select the closest layer thickness for

Table 633.1
Gravel Equivalents (GE) and Thickness of Structural Layers (ft)

Actual Layer Thickness (ft) [5]	HMA[1], [2]											Base and Subbase [3], [4]					
	Traffic Index (TI)											TI is not a factor					
	5.0 & below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	14.5 15.0	LCB	CTPB; CTB (Cl. A)	ATPB	CTB (Cl. B)	AB	AS
	G_f (For HMA thickness equal to or less than 0.5 ft, G_f decreases with TI) [6]											G_f (Constant for any base or subbase material irrespective of TI or thickness)					
	2.54	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.46	1.9	1.7	1.4	1.2	1.1	1.0
	GE for HMA layer (ft)											GE for Base or Subbase layer (ft)					
0.10	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.15	--	--	--	--	--	--
0.15	0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.22	--	--	--	--	--	--
0.20	0.51	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.29	--	--	--	--	--	--
0.25	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.37	--	--	0.35	--	--	--
0.30	0.76	0.69	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.45	0.44	--	--	0.42	--	--	--
0.35	0.89	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.51	0.67	0.60	0.49	0.42	0.39	0.35
0.40	1.01	0.93	0.86	0.80	0.76	0.72	0.68	0.65	0.63	0.61	0.59	0.76	0.68	0.56	0.48	0.44	0.40
0.45	1.14	1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.66	0.86	0.77	0.63	0.54	0.50	0.45
0.50	1.27	1.16	1.07	1.00	0.94	0.90	0.85	0.82	0.79	0.76	0.73	0.95	0.85	0.70	0.60	0.55	0.50
0.55	1.41	1.29	1.19	1.12	1.05	1.00	0.95	0.91	0.87	0.84	0.81	1.05	0.94	0.77	0.66	0.61	0.55
0.60	1.58	1.45	1.34	1.25	1.18	1.12	1.07	1.02	0.98	0.95	0.91	1.14	1.02	0.84	0.72	0.66	0.60
0.65	1.76	1.61	1.49	1.39	1.31	1.25	1.19	1.14	1.09	1.05	1.02	1.24	1.11	0.91	0.78	0.72	0.65
0.70	--	1.78	1.64	1.54	1.45	1.38	1.31	1.26	1.21	1.16	1.12	1.33	1.19	--	0.84	0.77	0.70
0.75	--	1.95	1.80	1.69	1.59	1.51	1.44	1.38	1.32	1.27	1.23	1.43	1.28	--	0.90	0.83	0.75
0.80	--	2.12	1.96	1.84	1.73	1.64	1.57	1.50	1.44	1.39	1.34	1.52	1.36	--	0.96	0.88	0.80
0.85	--	--	2.13	1.99	1.88	1.78	1.70	1.63	1.56	1.51	1.46	1.62	1.45	--	1.02	0.94	0.85
0.90	--	--	2.30	2.15	2.03	1.92	1.83	1.76	1.69	1.63	1.57	1.71	1.53	--	1.08	0.99	0.90
0.95	--	--	--	2.31	2.18	2.07	1.97	1.89	1.81	1.75	1.69	1.81	1.62	--	1.14	1.05	0.95
1.00	--	--	--	2.47	2.33	2.21	2.11	2.02	1.94	1.87	1.81	1.90	1.70	--	1.20	1.10	1.00
1.05	--	--	--	2.64	2.49	2.36	2.25	2.16	2.07	2.00	1.93	2.00	1.79	--	1.26	1.16	1.05
1.10	--	--	--	--	2.65	2.51	2.40	2.29	2.20	2.12	2.05	--	--	--	--	--	1.10
1.15	--	--	--	--	2.81	2.67	2.54	2.43	2.34	2.25	2.18	--	--	--	--	--	1.15
1.20	--	--	--	--	2.98	2.82	2.69	2.58	2.48	2.39	2.30	--	--	--	--	--	1.20
1.25	--	--	--	--	--	2.98	2.84	2.72	2.61	2.52	2.43	--	--	--	--	--	1.25
1.30	--	--	--	--	--	3.14	2.99	2.87	2.75	2.65	2.56	--	--	--	--	--	1.30
1.35	--	--	--	--	--	3.30	3.15	3.01	2.90	2.79	2.70	--	--	--	--	--	--
1.40	--	--	--	--	--	--	3.31	3.16	3.04	2.93	2.83	--	--	--	--	--	--
1.45	--	--	--	--	--	--	3.46	3.32	3.19	3.07	2.97	--	--	--	--	--	--
1.50	--	--	--	--	--	--	3.62	3.47	3.33	3.21	3.10	--	--	--	--	--	--
1.55	--	--	--	--	--	--	--	3.62	3.48	3.36	3.24	--	--	--	--	--	--
1.60	--	--	--	--	--	--	--	3.78	3.63	3.50	3.38	--	--	--	--	--	--
1.65	--	--	--	--	--	--	--	3.94	3.79	3.65	3.52	--	--	--	--	--	--
1.70	--	--	--	--	--	--	--	--	3.94	3.80	3.67	--	--	--	--	--	--
1.75	--	--	--	--	--	--	--	--	4.09	3.95	3.81	--	--	--	--	--	--
1.80	--	--	--	--	--	--	--	--	4.25	4.10	3.96	--	--	--	--	--	--
1.85	--	--	--	--	--	--	--	--	--	4.25	4.10	--	--	--	--	--	--
1.90	--	--	--	--	--	--	--	--	--	4.40	4.25	--	--	--	--	--	--
1.95	--	--	--	--	--	--	--	--	--	4.56	4.40	--	--	--	--	--	--
2.00	--	--	--	--	--	--	--	--	--	--	4.55	--	--	--	--	--	--

NOTES:
(1) Open Graded Friction Course (conventional and rubberized) is a non-structural wearing course and provides no structural value.
(2) Top portion of HMA surface layer (maximum 0.20 ft.) may be replaced with equivalent RHMA-G thickness. See Topic 631.3 for additional details.
(3) See Table 663.3 for additional information on Gravel Factors (G_f) and California R-values for base and subbase materials.
(4) When using Hot Mix Asphalt Base (HMAB), the HMAB is considered as part of the HMA layer. Therefore, the HMAB will be assigned the same G_f as the remainder of the HMA in the pavement structure.
(5) For HMA layer, select TI range, then go down to the appropriate GE and across to the thickness column. For base and subbase layer, select material type, then go down to the appropriate GE and across to the thickness column.
(6) These G_f values are for TIs shown and HMA thickness equal to or less than 0.5 foot only. For HMA thickness greater than 0.5 foot, appropriate G_f should be determined using the equation in Index 633.1(1)(d).

conventional hot mix asphalt, and determine the adjusted GE that it provides. The GE of the safety factor is not removed in this design. Adjust the final thickness as needed when using other types of materials than hot mix asphalt. The top 0.15 to 0.2 foot of the HMA thickness can be substituted with an equal thickness of RHMA-G.

A Treated Permeable Base (TPB) layer may be placed below full depth hot mix asphalt on widening projects to perpetuate or match, an existing TPB layer for continuity of drainage. Reduce the GE of the surface layer by the amount of GE provided by the TPB. In no case should the initial GE of the surface layer over the TPB be less than 40 percent of the GE required over the subbase as calculated by the standard engineering equation. When there is no subbase, use 50 for the California R-value for this calculation. In cases where a working platform will be used, the GE of the working platform is subtracted from the GE of the surface layer.

The empirical "new construction" and reconstruction design procedure has been encoded in a computer program CalFP available for download on the Department's website.

(3) *Pavement Design for Design Life Greater than 20 Years.* The above pavement design procedures are based on an empirical method valid for a twenty-year design life. For pavement design lives greater than twenty years, in addition to using a TI for that longer design life, provisions should be made to increase material durability and other appropriate measures to protect pavement layers from degradation.

The following enhancements shall be incorporated into all flexible pavements designed using the empirical method with a design life greater than twenty years:

(a) Use the design procedure for full depth hot mix asphalt described above to determine the minimum thickness of conventional HMA for flexible pavement. Use the TI for the longer design life in the analysis. If the longer-life TI is greater than 15, the empirical procedure can't be used. Consult with the Pavement Program for other design methods such as the mechanistic-empirical method or other design options.

(b) Place subgrade enhancement geotextile (SEGT) on the subgrade for California R-values less than 40. Refer to Chapter Topic 665 for SEGT class selection. If the subgrade requires chemical stabilization using approved stabilizing agent such as lime or cement, the SEGT will not be needed.

(c) Place a minimum 0.50 foot of Class 2 Aggregate Base (AB) layer underneath the flexible pavement. This AB layer acts as a working platform. The AB layer must not be considered part of the pavement structural design and cannot be used to reduce the thickness of the full depth hot mix asphalt layer.

(d) Use RHMA-G (0.15 to 0.20 foot) or a PG-PM binder (minimum 0.20 foot) at the top of the surface layer. The rubberized or polymer modified HMA must be substituted on an equal thickness basis.

(e) Use a non-structural wearing course above the surface layer (minimum 0.10 foot). See Index 602.1(5) and Topic 631 for further details.

This procedure does not require advanced performance testing of the hot mix asphalt materials discussed in Index 633.2. Instead the conventional mix design of the HMA and RHMA-G is performed based on Standard Specification (Section 39).

As an alternative to the above design procedure, the mechanistic-empirical (ME) method may be used, offering a wider selection of pavement structures besides full depth structure. Refer to Index 633.2 for more details.

(4) *Alternate Procedures and Materials.* At times, experimental design procedures and/or alternative materials are proposed as part of the design or construction. See Topic 606 for further discussion. The Mechanistic-Empirical (ME) method can also be used for new pavement design when the empirical procedure

is not applicable such as when design life exceeds 20 years, traffic index exceeds 15, and/or when using non-standard materials. Refer to Index 633.2.

633.2 Mechanistic-Empirical Method

(1) *Application.* For information on Mechanistic-Empirical design application and requirements, see Index 606.3(2)(b).

(2) *Method.* The Mechanistic-Empirical (ME) method integrates the effect of traffic loading and climate on the various layers of pavement structure at various time increments during the analyzed service life. For "new construction" design, a trial pavement structure comprised of multiple layer types and thicknesses is selected and then analyzed with the ME method over a large number of time steps to determine the time it takes for the pavement to reach fatigue cracking, rutting, and ride quality performance thresholds. This typically requires a vast number of computations requiring fast computers. Therefore, the ME method is more of an analysis than a design procedure. The trial pavement structure may be obtained with the help of the Caltrans empirical R-value procedure discussed in Index 633.1.

Unlike the empirical method, the ME procedure is capable of designing flexible pavement structures for more than 20 years of service. The ME method offers additional benefits over the empirical procedure including:

- Capturing the special performance benefits of materials such as enhanced or modified HMA (e.g., PG grade specifications and polymer modified) that were not available at the time of developing the empirical method.
- Analyzing the effect of future maintenance and rehabilitation treatments on the performance and life extension of the pavement.
- Incorporating detailed traffic loading characteristics by using axle load spectra.
- Accounting for the effect of climate on pavement performance.
- Determining how and when the pavement will develop certain types of distresses or deterioration in ride quality
- The consideration of design reliability by incorporating statistical variabilities associated with construction quality, material properties, climate, and traffic.
- Because the ME procedure can account for project specific information, it generally results in reduced initial cost of design and overall life cycle costs.

The ME method for designing or analyzing flexible pavement for "new construction" or reconstruction requires the following:

(a) CalME Software – In collaboration with the University of California Pavement Research Center (UCPRC), Caltrans has

developed CalME, the ME software for flexible pavement design and rehabilitation in California. Inputs to the CalME software include:

- Pavement design life,
- Traffic index (TI) corresponding to design life,
- Project location (district, county, route No., post mile limits),
- Trial pavement structure to be analyzed consisting of a number of pre-selected layers, materials, and subgrade soil pertaining to the project,
- HMA materials characterization (material constants) through lab testing or by selection from the CalME database (depending on project testing level discussed in item (b) below),
- Performance criteria or thresholds such as percentage cracking, total rut depth, and International Roughness Index (IRI), and
- Design reliability.

Specifying project location in CalME assigns both climate zone(s) for the project (see Topic 615) and axle load spectrum or spectra (see Index 613.4).

(b) Project Testing Levels – The project testing level determines the extent of testing required as follows:

- Level AAA – All HMAs (Type A and RHMA-G) planned for use in the pavement structure need to be lab-tested using specialized advanced test methods and ME-related materials parameters obtained and uploaded to CalME.
- Level AA – HMAs to be used in the surface structural layer must be lab-tested and ME-related materials parameters obtained and uploaded to CalME.
- Level A – The standard materials library available in CalME can be used for all HMAs. In this case the engineer will consider similarities between the HMA planned for use on the project and the HMAs available in the library and select the closest HMA types.

Note that the above testing requirements represent minimums, that is, the Engineer may consider advanced laboratory testing for all HMAs for a Level A project.

When designing projects using Caltrans' ME procedure, the testing level is selected based on the project Traffic Index (TI) and design life. Table 633.2 provides the criteria for selecting ME testing level. Note that the testing levels shown in Table 633.2 are considered minimum standards. For example, the design engineer may use Level AAA design for a project that only requires Level A.

Table 633.2
Selecting ME Project Testing Level

Design Life	Corresponding Design Year TI Range	Project Testing Level (1)
20 years	≤11.5	A
	≥12.0	AA
40 years	≤9.0	A
	9.5 to 13.5	AA
	≥14.0	AAA

NOTE:

(1) See Index 633.2(2)(b) for the descriptions of project design and testing levels.

(c) Performance Criteria – The performance factors are the thresholds for total fatigue cracking (flexural and reflection in the asphalt layer), total rut depth measured at the pavement surface (assumed to be equal to the combined rut depths of all layers), and IRI that must not be exceeded during the design life of the proposed pavement structure. The pavement is said to have failed as soon as one of these thresholds has been reached. Whereas Caltrans is currently working on developing final values for these factors, the following thresholds should be used in the interim when designing asphalt pavements using the CalME procedure:

- Cracking = 5 percent (or 0.15 ft/ft^2),
- Rut depth = 0.4 inch (down rut),
- IRI = 170 in/mile.

(d) Reliability – All design and analysis using CalME must be performed using the reliability concept. In CalME, reliability analysis is performed with the Monte Carlo Simulation method. A minimum of 100 simulations are needed to determine the minimum reliability of the final design. When evaluating preliminary designs a lower number of simulations may be used (e.g., 10) to expedite the simulations. On average, 10 simulations may take up to one minute using a desktop computer. The reliability for a given project is assigned based on the project testing levels shown in Table 633.3.

Table 633.3
Minimum Reliability Depending on Project Testing Level

Project Design & Testing Level (1)	Minimum Reliability (%)
Level A	95
Level AA	90
Level AAA	85

NOTE:

(1) See Index 633.2(2)(b) for the description of project testing levels.

If the trial design is found to pass all the criteria, then the Engineer may gradually reduce the thickness of one or more layers and re-run the CalME analysis. Several iterations may be done to optimize the pavement structure design.

(e) Materials Information – The HMA material information may be selected from the CalME standard library or laboratory testing on the HMA is conducted and material parameters relevant to the tested HMA are generated and uploaded to the CalME database. Whether materials parameters are obtained through testing of from existing materials database depends on the project testing level discussed in (b) above.

Unbound materials such as aggregate base, aggregate subbase, subgrades and other chemically stabilized bases and subbases do not at this time require any advanced testing for evaluating their strength and permanent deformation characteristics as needed for ME design and analysis. Selecting these materials in the CalME software will upload recommended resilient modulus and other performance properties needed in the ME analysis. The resilient modulus values of the various pavement materials are given in Chapter 660 (Table 666.1A and Table 666.1B).

(f) Laboratory Testing – The ME procedure in CalME requires HMA performance be specified. If testing level requires advanced laboratory testing of the HMA materials, the critical performance properties of the HMAs to be used on the project are evaluated from the following two standard laboratory tests:

- AASHTO T 320: "Repetitive shear deformation for asphalt concrete rutting characterization." This test characterizes the HMA permanent deformation (rutting) performance.
- AASHTO T 321: "Repetitive four-point beam bending for asphalt fatigue characterization." This test evaluates the HMA fatigue performance and flexural stiffness master curve.

The level of testing selected for the project determines whether testing of all or some of the HMA materials needs to be conducted with these two AASHTO tests or the use of the existing materials database would be sufficient.

The fatigue, rutting and stiffness parameters used in the ME method are derived from the lab test results of the HMA materials by numerical fitting of the test data to ME performance models.

(g) Additional Guidance – Additional information on the Caltrans ME methodology and guidelines on the use of CalME can be found on the "ME Designer's Corner" link on the internal Department Pavement website or by contacting the Headquarters Pavement Program Office Chief.

Topic 634 - Engineering Procedures for Flexible Pavement Preservation

634.1 Preventive Maintenance

For details regarding preventive maintenance strategies for flexible pavement, see the "Maintenance Technical Advisory Guide" on the Department Pavement website. Deflection studies are not performed for preventive maintenance projects.

634.2 Capital Preventive Maintenance (CAPM)

(1) *Warrants.* A CAPM project is warranted if any of the following criteria are met:

- 11-29 percent Alligator 'B' and 0 to 10 percent patching, or
- 1-10 percent Alligator 'B' and > 10 percent patching, or
- 0 percent Alligator 'B' crack and > 15 percent patching International Roughness Index (IRI) >170 inches per mile with no to minor distress

(2) *Strategies.* CAPM strategies include the following options:

(a) When the IRI is less than or equal to 170 inches per mile, use 0.20 foot of RHMA-G or 0.20 foot of HMA. The preferred alternative is 0.20 foot of RHMA-G but a 0.25 foot overlay is permissible if 1 inch gradation HMA is to be used on the project.

For CAPM projects with an IRI greater than 170 inches per mile, the standard design is to place a 0.25-foot asphalt overlay in two lifts consisting of 0.10 foot HMA (leveling course) followed by 0.15 foot HMA or preferably 0.15 RHMA-G overlay.

(b) Cold-in-place recycling (CIR) is an acceptable CAPM strategy for surfaced distressed pavement with little to no base failure regardless of IRI. Cold-in-place and recycle between 0.25 foot and 0.35 foot of the existing asphalt pavement and then cap with 0.15 foot HMA overlay or preferably 0.15 foot RHMA-G overlay.

(c) Existing pavement may be milled or cold planed down to the depth of the overlay prior to placing the overlay for any of the above strategies. Situations where milling or cold planing may be beneficial or even necessary are to improve ride quality, maintain profile grade, maintain vertical clearance, or to taper (transition) to match an existing pavement or bridge surface.

(d) Non-structural wearing courses such as open graded friction courses, chips seals, or thin overlays not to exceed 0.10 foot (0.12 foot in North Coast Climate Region) in thickness may be added to the strategies listed above.

(e) Pavement interlayers may be used in conjunction with the strategies listed above.

(f) Partial or full depth replacements (i.e., digouts) not to exceed 20 percent of the

CAPM pavement costs may be included as well. Digouts should be designed to provide a minimum of 20 years added service life.

(g) Preventive maintenance strategies may be used in lieu of the above strategies when IRI is less than 170 inches per mile and they will extend pavement service life a minimum of 10 years until the next CAPM project is warranted.

(h) CAPM strategies for OGFC, HMA-O used as a stormwater treatment BMP should replace in kind.

(3) *Smoothness.* For an asphalt pavement CAPM project with an IRI less than 170 inches per mile at the time of PS&E, a 0.20 foot or less single lift overlay is used; which should improve ride quality to an IRI of 75 inches per mile or less. RHMA-G overlay is preferred over HMA overlay. For CAPM projects with an IRI greater than 170 inches per mile the standard practice is to use a 0.25 foot overlay placed in two lifts. A 0.25 foot two-lift overlay strategy should restore the ride quality to an IRI

of 60 inches per mile or less. It is preferred to place 0.10 foot HMA first followed by 0.15 foot RHMA-G.

(4) *Testing.* Deflection studies are not required for CAPM projects. The roadway rehabilitation requirements for overlays (see Index 635.2(1)) and preparation of existing pavement surface (Index 635.2(8)) apply to CAPM projects. Additional details and information regarding CAPM policies and strategies can be found in Design Information Bulletin 81 "Capital Preventive Maintenance Guidelines."

Topic 635 - Engineering Procedures for Flexible Pavement Rehabilitation

635.1 Rehabilitation Warrants

Locations where overall Alligator 'B' cracking exceeds the thresholds for CAPM are eligible for rehabilitation. When Alligator 'B' cracking is less than or equal to 50 percent, perform a life-cycle cost analysis (LCCA) in accordance with the requirements of Topic 619 comparing flexible pavement rehabilitation strategy versus a CAPM strategy. Pursue a CAPM strategy when CAPM has the lowest life-cycle cost.

635.2 Empirical Method

(1) *General.* The methods presented in this topic are based on rehabilitation studies for a ten-year design life with extrapolations for twenty-year design life. For design lives greater than twenty years, use the Mechanistic-Empirical (ME) design method or contact the Headquarters Office of Asphalt Pavements for assistance.

Because there are potential variations in materials and environment that could affect the performance of both the existing pavement and the rehabilitation strategy, it is difficult to develop precise and firm practices and procedures that cover all possibilities for the rehabilitation of pavements. Therefore, the pavement engineer should consult with the District Materials Engineer and other pertinent experts who are familiar with engineering, construction, materials, and maintenance of pavements in the geographical area of the project for additional requirements or limitations than those listed in this manual.

Flexible pavement rehabilitation strategies are divided into four categories:

- Overlay,
- Mill and Overlay,
- Full Depth Reclamation and Overlay, and
- Remove and Replace.

Flexible pavement rehabilitation designs using the empirical method are governed by one of the following three criteria:

- Structural adequacy,
- Reflective crack retardation, or
- Ride quality.

On overlay projects, the entire traveled way and paved shoulder shall be overlaid. Not only does this help provide a smoother finished surface, it also benefits bicyclists and pedestrians when they need to use the shoulder.

(2) *Data Collection.* Developing a rehabilitation strategy using the empirical method requires collecting background data as well as field data. The Pavement Condition Report (PCR) or other most recent surface distress data collected for the pavements within the project limits such as the automated pavement condition survey (APCS) available on the Department Pavement website. Ground penetrating radar data (iGPR) is also available on the Department Pavement website, as-built plans, and traffic data are some of the important resources needed for developing rehabilitation strategy recommendations. A thorough field investigation of the pavement surface condition, combined with a current deflection study and coring, knowledge of the subsurface conditions, thicknesses and types of existing flexible pavement layers, and a review of drainage conditions are all necessary for developing a set of appropriate rehabilitation strategies.

(3) *Deflection Studies.* Deflection studies along with core data are essential in evaluating the

structural adequacy of the existing pavement. A deflection study is the process of selecting deflection test sections, measuring pavement surface deflections, and calculating statistical deflection values as described in California Test Method 356 for flexible pavement deflection measurements. The test method can be obtained from the Materials Engineering and Testing Services website.

To provide reliable rehabilitation strategies, deflection studies should be done no more than 18 months prior to the start of construction.

The following steps are required to complete a deflection study for use in developing rehabilitation designs of an existing flexible pavement using the empirical method:

(a) Test Sections:

Test sections are portions of a roadway considered to be representative of roadway conditions being studied for rehabilitation. California Test Method 356 provides information on selecting test sections and different testing devices. Test sections should be determined in the field based on safe operation and true representation of pavement sections. Test sections can be determined either by the test operator or by the pavement engineer in the field.

Occasionally, a return to a project site may be required for additional testing after reviewing the initial deflection data in the office.

Individual deflection readings for each test section should be reviewed prior to determining statistical values. This review may locate possible areas that are not representative of the entire test section. An example would be a localized failure with a very high deflection. It may be more cost effective to repair the various failed sections prior to rehabilitation. Thus, the high deflection values in the repaired areas would not be included when calculating statistical values for the representative test sections.

(b) Mean and 80th Percentile Deflections:

The mean deflection level for a test section is determined by dividing the sum of individual deflection measurements by the number of the deflections:

$$\overline{D} = \frac{\sum_{i=1}^{N} D_i}{N}$$

Where:

$\overline{D}$ = mean deflection for a test section, in inches,

D_i = an individual measured surface deflection in the test section, in inches, and

N = number of measurements in the test section

The 80th percentile deflection value represents a deflection level at which approximately 80 percent of all deflections are less than the calculated value and 20 percent are greater than the value. Therefore, a strategy based on 80th percentile deflection will provide thicker rehabilitation than using the mean value.

For simplicity, a normal distribution has been used to find the 80th percentile deflection using the following equation:

$$D_{80} = \overline{D} + 0.84 \times s_D$$

Where:

D_{80} = 80th percentile of the measured surface deflections for a test section, in inches, and

s_D = standard deviation of all test points for a test section, in inches

$$s_D = \sqrt{\frac{\sum_{i=1}^{N} (D_i - \overline{D})^2}{N-1}}$$

D_{80} is typically calculated as part of the deflection study done by the test operator. The pavement engineer should verify that the D_{80} results provided by the operator are accurate.

(d) Grouping:

Adjacent test sections may be grouped and analyzed together. There may be one or several groups within the project.

A group is a collection of test sections that have similar engineering parameters. Test sections can be grouped if they have all of the following conditions:

- Average D_{80} that vary less than 0.01 inch.
- Average existing total HMA thickness that vary less than 0.10 foot.
- Similar base material.
- Similar TI.

Once groups have been identified, D_{80} and existing surface layer thickness of each group can be found by averaging the respective values of test sections within that group.

An alternative to the grouping method outlined above is to analyze each test section individually and then group them based on the results of analysis. This way, all the test sections that have similar rehabilitation strategies would fall into the same group.

(4) *Procedure for Flexible Overlay on Existing Flexible Pavement.* The overlay thickness is determined to satisfy structural adequacy, reflective cracking retardation, and ride quality criteria. Therefore, for each criterion, the overlay thickness needed is determined, and finally the thickest overlay is selected to satisfy all criteria. The procedure is described below:

(a) Overlay Thickness to Address Structural Adequacy. The goal is to find the minimum thickness of overlay necessary to provide structural strength for the pavement to be able to carry the load till the end of design life. Pavement condition, thickness of surface layer, measured deflections, and the project TI provide the majority of the information used for determining structural adequacy of an existing flexible pavement. Structural adequacy is determined using the procedure described in the following paragraphs.

- Determine the Tolerable Deflection at the Surface (TDS). The term “Tolerable Deflection” refers to the level beyond which repeated deflections of that magnitude produce fatigue failure prior to reaching the end of design life. TDS is obtained from Table 635.2A by knowing the existing total thickness of the flexible layer and TI. For existing flexible pavement over a treated base, use TI and the TDS values in the row for Treated Base (TB) found in Table 635.2A
- The existing base is considered treated if it meets all of the following conditions:

  (1) It is concrete base (including previously built concrete pavement), Lean Concrete Base (LCB), or Class A Cement Treated Base (CTB-A).

  (2) Its depth is equal to or greater than 0.35 foot.

  (3) The D_{80} is less than 0.015 inch.
- For each group compare the TDS to the 80th percentile deflection value D_{80} averaged for the group.
- If the average D_{80} is greater than the TDS, determine the required percent reduction in deflection at the surface (PRD) to restore structural adequacy as follows:

$$\text{PRD} = \left(\frac{\text{Average } D_{80} \text{ - TDS}}{\text{Average } D_{80}}\right) \times 100$$

Where:

PRD = Percent Reduction in Deflection required at the surface, as percent

TDS = Tolerable Deflection at the Surface, in inches

Average D_{80} = mean of the 80th percentile of the deflections for each group, in inches.

Table 635.2A

Tolerable Deflections at the Surface (TDS) in 0.001 inches

Exist. HMA thick (ft)	Traffic Index (TI)											
	5	6	7	8	9	10	11	12	13	14	15	16
0.00	66	51	41	34	29	25	22	19	17	15	14	13
0.05	61	47	38	31	27	23	20	18	16	14	13	12
0.10	57	44	35	29	25	21	19	16	15	13	12	11
0.15	53	41	33	27	23	20	17	15	14	12	11	10
0.20	49	38	31	25	21	18	16	14	13	12	10	10
0.25	46	35	28	24	20	17	15	13	12	11	10	9
0.30	43	33	27	22	19	16	14	12	11	10	9	8
0.35	40	31	25	20	17	15	13	12	10	9	8	8
0.40	37	29	23	19	16	14	12	11	10	9	8	7
0.45	35	27	21	18	15	13	11	10	9	8	7	7
0.50 (1)	32	25	20	17	14	12	11	9	8	8	7	6
TB (2)	27	21	17	14	12	10	9	8	7	6	6	5
	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
0.00	58	45	37	31	27	23	20	18	16	15	13	12
0.05	53	42	34	29	25	21	19	17	15	14	12	11
0.10	50	39	32	27	23	20	18	16	14	13	11	11
0.15	46	36	30	25	21	19	16	14	13	12	11	10
0.20	43	34	28	23	20	17	15	14	12	11	10	9
0.25	40	32	26	22	19	16	14	13	11	10	9	8
0.30	37	29	24	20	17	15	13	12	11	9	9	8
0.35	35	27	22	19	16	14	12	11	10	9	8	7
0.40	32	26	21	18	15	13	11	10	9	8	8	7
0.45	30	24	20	16	14	12	11	9	9	8	7	6
0.50 (1)	28	22	18	15	13	11	10	9	8	7	7	6
TB (2)	24	19	15	13	11	10	8	7	7	6	5	5

NOTES:

(1) For an HMA thickness greater than 0.50 ft use the 0.50 ft depth.

(2) Use the TB (treated base) line to represent treated base materials, regardless of the thickness of the HMA layer.

Table 635.2B
Gravel Equivalence Needed to Reduce Surface Deflection

Percent Reduction In Deflection (PRD or PRM) (1)	GE (in feet) For HMA Overlay Design	Percent Reduction In Deflection (PRD or PRM) (1)	GE (in feet) For HMA Overlay Design
5	0.02	46	0.55
6	0.02	47	0.57
7	0.02	48	0.59
8	0.02	49	0.61
9	0.03	50	0.63
10	0.03	51	0.66
11	0.04	52	0.68
12	0.05	53	0.70
13	0.05	54	0.72
14	0.06	55	0.74
15	0.07	56	0.76
16	0.08	57	0.79
17	0.09	58	0.81
18	0.09	59	0.83
19	0.10	60	0.85
20	0.11	61	0.87
21	0.12	62	0.89
22	0.14	63	0.91
23	0.15	64	0.94
24	0.16	65	0.96
25	0.18	66	0.98
26	0.19	67	1.00
27	0.20	68	1.02
28	0.21	69	1.04
29	0.23	70	1.06
30	0.24	71	1.09
31	0.26	72	1.11
32	0.28	73	1.13
33	0.29	74	1.15
34	0.31	75	1.17
35	0.33	76	1.19
36	0.35	77	1.22
37	0.37	78	1.24
38	0.38	79	1.26
39	0.40	80	1.28
40	0.42	81	1.30
41	0.44	82	1.32
42	0.46	83	1.34
43	0.48	84	1.37
44	0.51	85	1.39
45	0.53	86	1.41

Note: (1) PRD is Percent Reduction in Deflection at the surface.
PRM is Percent Reduction in deflection at the Milled depth.

- Using the calculated PRD and Table 635.2B, determine the GE required to reduce the deflections to less than the tolerable level.
- Divide the GE obtained from Table 635.2B by the appropriate G_f for the overlay material to determine the required thickness of the overlay.

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

Commonly used materials and their gravel factors (G_f) for flexible pavement rehabilitation are presented in Table 635.2C.

- RHMA-G is preferred over HMA as the overlay material. RHMA-G could substitute on 1:1 basis up to 0.20 ft of the top HMA overlay thickness designed for structural adequacy.

(b) Overlay Thickness to Address Reflective Cracking Retardation. The goal is to find the minimum thickness of overlay necessary to keep cracks in the existing flexible pavement from reflecting intro and propagating upward into the new overlay surface during the pavement design life. Retarding the propagation of cracks is an important factor to consider when engineering flexible pavement overlays

Table 635.2C
Commonly Used G_f for Flexible Pavement Rehabilitation

Material	G_f (1)
Hot Mix Asphalt Overlay	1.9
Cold in-Place Recycled Asphalt	1.5
HMA Below the Analytical Depth (2)	1.4

NOTES:

(1) For G_f of bases and subbases see Table 663.1B.

(2) Analytical depth is defined in 635.2(6)(a).

The procedures for determining overlay requirement for reflective cracking retardation is based on the following procedure and rules:

- For flexible pavements over untreated bases (e.g., aggregate base, aggregate subbase), the minimum HMA overlay thickness for a twenty-year design life should be no less than 65 percent of the thickness of the existing total asphalt concrete thickness, but does not need to exceed 0.45 foot. These thickness limits are based on the original ten-year limits of the HMA overlay thickness being half of the existing total asphalt concrete thickness up to 0.35 foot, increased by an additional 25 percent to account for the additional 10 years of service.
- For flexible pavements over treated bases (as defined in the previous section on structural adequacy), a minimum HMA overlay of 0.45 foot should be used for a twenty-year design life. An exception is when the underlying material is a thick rigid layer (0.65 foot or more) such as an overlaid jointed plain concrete pavement that was not cracked and seated, a minimum HMA overlay thickness of 0.60 foot should be used for twenty-year design.

The overlay thickness designed to prevent reflective cracking requires extensive engineering judgement to select the necessary thickness for final design. Thicker sections may be warranted. Factors to be considered that might necessitate a thicker overlay are:

(1) Type, sizes, and amounts of surface cracks.

(2) Extent of localized failures.

(3) Existing performance material and age.

(4) Thickness and performance of previous rehabilitation strategy.

(5) Environmental factors.

(6) Anticipated future traffic loads (Traffic Index).

As always, sound engineering judgment will be necessary for final decisions. Final decision for when to use more than the minimum requirements found in this manual rests with the District.

- Adjust overlay thickness for alternative materials. A thickness equivalency of not more than 1:2 is given to the RHMA-G when compared to the HMA for reflective crack retardation. The thickness of the RHMA-G alternative must be based on the HMA thickness determined for reflective crack retardation. The equivalencies are tabulated in Table 635.2D.

- A Geosynthetic Pavement Interlayer (GPI) placed under HMA that is designed for reflective crack retardation provides the equivalent of 0.10 foot of HMA. This allows the engineer to decrease the new profile grade and also save on HMA materials. The reduced thickness of HMA can be further reduced with the use of RHMA-G as the overlay material using Table 635.2D for converting thicknesses. Ensure that the melting point of the GPI to be used on the project exceeds the RHMA-G placement temperature. Refer to Standard Specifications for selection of GPI.

- If a rubberized pavement interlayer (RPI) is placed under a non-rubberized hot mix asphalt overlay designed for reflective crack retardation, the equivalence of a RPI in terms of HMA thickness depends upon the type of base material under the existing pavement. When the base is a treated material, an RPI placed under HMA is considered to be equivalent to 0.10 foot of HMA. When the base is an untreated material RPI is equivalent to 0.15 foot of HMA.

- Wearing courses are not included in the thickness used to address reflective cracking.

(c) Overlay Thickness to Address Ride Quality. Ride quality is evaluated based on the pavement surface smoothness. The Department records smoothness as part of the Annual Pavement Condition Survey using the International Roughness Index (IRI). According to FHWA, the IRI value that most motorists consider uncomfortable for flexible pavement is 170 inches per mile. When IRI measurements are 170 inches per mile or greater, the engineer must address ride quality. The entire project can be divided into groups of multiple segments that will be individually analyzed for ride quality.

To improve ride quality, place a minimum of 0.25 foot overlay in two lifts. Because this overlay addresses ride quality, it does not matter whether HMA or RHMA-G is used, although the latter is preferred. This could be performed using either:

- the placement of 0.10 foot HMA followed by 0.15 foot HMA, or

- the placement of 0.10 foot HMA first followed by 0.15 foot RHMA-G.

A non-structural wearing course may be included in the ride quality thickness.

Pavement interlayers do not have any effect on ride quality.

Table 635.2D
Reflective Crack Retardation Equivalencies (Thickness in feet)

HMA(1)	RHMA-G	RHMA-G over RPI
0.15	0.10	
0.20	0.10	
0.25	0.15	
0.30	0.15	
0.35	• 0.15 if crack width <1/8 inch • 0.20 if crack width ≥1/8 inch or underlying material CTB, LCB, or rigid pavement	• N/A for crack width <1/8 inch • 0.10 if crack width ≥1/8 inch and underlying material untreated • 0.15 if crack width ≥1/8 inch and underlying material CTB, LCB, or rigid pavement
0.45	0.15 over 0.15 HMA	0.20

NOTE:

(1) See Index 635.2(5)(b) for minimum and maximum HMA thicknesses recommended by the Department for reflective crack retardation on flexible pavements.

(d) Final Overlay Thickness and Governing Criterion. The overlay thickness requirements obtained to address the three design criteria are compared and the greatest thickness is selected as the overlay thickness. The criterion that yielded the greatest thickness is the governing design criterion. It is possible that more than one criterion can govern the design. Ride quality will ultimately govern the rehabilitation strategy if the requirements for structural adequacy and reflective crack retardation are less than 0.25 foot HMA.

It is advised that the comparison is made based on HMA thicknesses before conversion to RHMA-G equivalents or with inclusion of interlayers. Once the greatest HMA thickness was determined, conversion to RHMA-G equivalent and use of interlayers can be done.

Examples of design calculations for flexible overlay thickness on existing flexible pavement are available on the Department Pavement website.

(5) *Mill and Overlay Rehabilitation Design Procedure for Flexible Pavement.* Mill and Overlay is the removal of part of the surface course of an existing flexible pavement and placement of an overlay. Since existing pavement thicknesses will have slight variations throughout the project length, leave at least the bottom 0.15 foot of the existing surface course intact to ensure the milling machine does not loosen the base material or contaminate the recycled mix if used. If removal of the entire surface course layer and any portion of the base are required, use the procedure in Index 635.2(7).

(a) Design for Structural Adequacy. The design procedure for determining the structural adequacy for Mill and Overlay strategies are the same as those for basic overlays found in Index 635.2(1), with the exception of the following:

- TDS is determined using the thickness of the existing pavement prior to milling.
- Deflections are measured at the surface and adjusted to the milled depth.

The engineer must consider milling down to the "analytical depth". The analytical depth is defined as the least of:

- The milled depth where the percent reduction in deflection required at the milled depth (PRM) reaches 70 percent.

- 0.50 foot.
- The depth to the bottom of the existing HMA layer.

The percent reduction in deflection required at the milled depth is based on research that determined that the deflection increases by 12 percent for each additional 0.10 foot of milled depth up to the analytical depth. Once the analytical depth is reached, the existing HMA material below it is considered to be of questionable structural integrity and hence is assigned a G_f of 1.4. Since it is not known at what milled depth the 70 percent PRM level or analytical depth will be reached, an iterative type of calculation is required.

Using the thickness of the existing HMA layer, the TI, and base material type, determine the TDS from Table 635.2A. The deflection at the milled depth is found from the equation:

$$\text{DM} = \text{D}_{80} + \left[12\% \times \left(\frac{\text{Mill Depth}}{0.10\text{ ft}}\right) \times \text{D}_{80}\right]$$

Where:

D_{80} = 80th percentile deflection in inches.

Mill Depth = the depth of the milling in feet.

DM = the calculated deflection at the milled depth in inches.

Then, PRM is calculated from:

$$\text{PRM} = \left(\frac{\text{DM-TDS}}{\text{DM}}\right) \times 100$$

Where:

PRM = Percent Reduction in deflection required at the Milled depth.

TDS = Tolerable Deflection at the Surface in inches.

Utilizing the calculated PRM value, go to Table 635.2B to get the total GE required to be placed on top of the milled pavement surface. The total GE required to reduce the measured deflection to the tolerable level is a combination of:

- The GE determined from the overlay calculations, and
- The GE required to replace the material removed by the milling process.

If the milling goes below the analytical depth, the "Additional GE" that is required to replace the existing HMA below the analytical depth is calculated by multiplying the G_f of 1.4 by the milled depth below the analytical depth:

$$\text{Additional GE} = 1.4 \times \left(\begin{matrix}\text{milled depth below} \\ \text{the analytical depth}\end{matrix}\right)$$

To determine the total GE for the overlay, the "Additional GE" below the analytical depth is added to the required GE above the analytical depth (found from Table 635.2B). As stated in Index 633.1(1)(d), the required minimum thickness of the overlay is determined by dividing the total GE by the G_f of the new overlay material.

$$\text{Thickness (t)} = \frac{\text{GE}}{\text{G}_\text{f}}$$

Since Cold In-Place Recycled Asphalt (CIR) has low resistance to abrasion, if the milled material is to be replaced with CIR, the CIR layer must be covered with a wearing surface shortly after the recycling process. To determine the required thickness of the cap layer, first determine the GE of the CIR layer:

$$\text{GE}_\text{CIR} = (\text{CIR Thickness}) \times \text{G}_\text{f CIR}$$

Where:

GE_{CIR} = Gravel Equivalent of the CIR.

$G_{f\,CIR}$ = Gravel Factor of CIR = (1.5, see Table 635.2C).

The thickness of the cap layer is determined as follows:

$$\text{Cap Layer Thickness} = \frac{\text{GE}_\text{TOTAL} - \text{GE}_\text{CIR}}{\text{G}_\text{f}}$$

Where:

GE_{TOTAL} = Total GE requirement of CIR and cap layers.

G_f = Gravel Factor of the cap material.

It is recommended to round up to get the CIR and cap layer thicknesses. If the cap layer is OGFC, its thickness should not be considered in pavement structure design.

(b) Design for Reflective Cracking Retardation. The minimum thickness for reflective cracking retardation is determined using the same procedures used for reflective cracking for overlays found in Index 635.2(5)(b) except that the thickness is determined based on the remaining surface layer rather than the initial surface layer.

(c) Design for Ride Quality. Milling the existing surface and overlaying with new surface of at least 0.25 foot in two lifts is considered sufficient to smooth out a rough pavement. Either HMA or HMA and RHMA-G can be used. Refer to Index 635.2(4)(c) for lift placement.

(6) *Full Depth Reclamation Rehabilitation Design Procedure for Flexible Pavements.* Full Depth Reclamation (FDR) transforms distressed existing asphalt into stabilized base to receive a new structural surface layer. The FDR process pulverizes existing asphalt and a portion of the underlying material, while simultaneously mixing with additives (cement or foamed asphalt) and water in one pass. After pulverization and mixing, the material is compacted, graded, and overlaid. FDR can treat a variety of project conditions, but is most cost effective for cracked pavement surfaces requiring digouts of 20 percent or more by paving area. The general steps for designing flexible pavement with FDR are as follows:

(a) Determine the FDR design thickness from the maximum existing asphalt depth and a portion of underlying material (this example assumes AB). Swelling of pulverized material must also be considered.

(b) Determine the required gravel equivalent for the entire pavement structure (GE_{Total}) using Index 633.1 based on the TI and subgrade R-value. This requires that the existing pavement structure be known and subgrade soil has been characterized for R-value. The calculated required GE_{Total} must be increased by 0.10 foot to compensate for possible construction tolerances. The GE_{Total} demand must be supplied by the individual gravel equivalent of each structural layer in the final pavement section. Therefore,

$$GE_{Total} = GE_{HMA} + GE_{FDR} + GE_{AB}$$

Where:

GE_{Total} = The total GE required based on TI and R-value of subgrade.

GE_{HMA} = Gravel equivalent provided by the HMA overlay.

GE_{FDR} = Gravel equivalent provided by the FDR layer.

GE_{AB} = Gravel equivalent provided by the remaining AB after recycling all the existing asphalt concrete and portion of the AB layer. If all the existing AB layer has been reclaimed, then this GE_{AB} = 0. If there is a subbase layer, then it must be included.

(c) Determine GE_{FDR} with the following equation:

$$GE_{FDR} = (\text{FDR Layer Thickness}) \times G_{f\,FDR}$$

Where, "FDR Layer Thickness" is the final compacted thickness of the FDR layer, and $G_{f\,FDR}$ is the gravel factor of the FDR material. The final FDR layer thickness is determined from the initial planned reclamation depth plus an additional 7 percent swell that occurs due to reclamation. As an example, if the initial planned reclamation depth is 0.80 foot, the final FDR depth can be 0.80 × 1.07 = 0.85 foot. The $G_{f\,FDR}$ is dependent on the additive used to stabilize the reclaimed material, as follows:

- If the additive is cement, then the $G_{f\,FDR}$ is dependent on the unconfined compressive strength (UCS) of the compacted FDR materials. Refer to the equation in Index 663.3 for determining $G_{f\,FDR}$ based on UCS.

Therefore, $G_{f\,FDR}$ is dependent on the amount of cement used up to a value of 1.7.

- If the additive is foamed asphalt, then $G_{f\,FDR} = 1.4$.

(d) Determine the GE_{AB} of the remaining AB layer (if any). The gravel factor of remaining AB ($G_{f\,AB}$) is assumed to be equal to 1.0 (a reduction from the typical 1.1 value). This is done as follows:

$$GE_{AB} = (\text{AB Thickness}) \times G_{f\,AB}$$

The "AB thickness" is the average remaining thickness of the AB layer after FDR is done.

(e) Determine the GE_{HMA} required that would be provided by the structural HMA overlay as follows:

$$GE_{HMA} = GE_{Total} - GE_{FDR} - GE_{AB}$$

(f) Calculate the required HMA overlay thickness to be placed over the FDR layer. This is done using the equation:

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

Where GE_{HMA} is calculated in (5) above, and $GE_{f\ HMA}$ is determined from Table 633.1 based on the TI. Round up the overlay thickness to the nearest 0.05 foot. Up to 0.20 foot of the top HMA thickness may be substituted with an equivalent thickness of RHMA-G.

(6) *Design Procedure of Rehabilitation of Flexible Pavement with Pulverization.* Pulverization is a roadway rehabilitation strategy that involves in-place transformation, in one pass, of an existing distressed asphalt concrete layer (reclaimed asphalt pavement, RAP) and some of the existing base layer into a uniformly blended, well-graded granular base material suitable for a new flexible pavement structure. The pulverized material mix is often referred to as Pulverized Aggregate Base (PAB) with physical properties comparable to those of new Class 2 AB. The FDR design procedure described in (6) above is used to determine the required HMA overlay thickness. The only difference is in the selection of an appropriate gravel factor representing the PAB materials ($G_{f\,PAB}$) which depends on the percentage of RAP in the PAB mix (i.e., depends on pulverization depth). The $G_{f\,PAB}$ is selected as follows:

- $G_{f\,PAB} = 1.2$, if RAP ≥ 60 percent of the pulverized material mix.
- $G_{f\,PAB} = 1.1$, if RAP< 60 percent of the mix.
- $G_{f\,PAB} = 1.2$, if PAB is treated with cement regardless of RAP content.

For more specific information on the pulverization strategy, see the technical guidance on the Department Pavement website.

(7) *Design Procedure for Flexible Pavements Using Remove and Replace.* The "Remove and Replace" strategy consists of removing the entire surface layer and part or all of the base and subbase material. The entire removed depth is then replaced with a new flexible or rigid pavement structure. The Remove and Replace strategy is most often used when:

- It is not possible to maintain the existing profile grade using Mill and Overlay.
- Existing base and or subbase material is failing and needs to be replaced.
- It is the most cost effective strategy based on life-cycle cost analysis.

Remove and Replace covers a variety of strategies. The discussion found here provides some general rules and minimum requirements for Remove and Replace strategies in general. For more specific information see the technical guidance on the Department Pavement website.

Because the existing surface layer is removed, only structural adequacy needs to be addressed for Remove and Replace. The following are available options:

(a) Partial Depth Removal. When only a portion of the existing depth is being removed, consideration needs to be given to the strength of the remaining pavement structure. Because the pavement has been stressed and has been subject to contamination from fines and other materials over time, it does not have the same strength (GE) as new material. Currently, for partial depth removals, the most effective engineering method is to determine the theoretical deflection of the remaining material otherwise known as DM See Index 635.2(5) for further Mill and Replace strategy information. It should be noted that the greater the depth of removal, the less accurate the determination might be of the calculated deflections.

Using deflections for Remove and Replace strategies is also less accurate if a bulldozer or a scraper is used to remove the material under the pavement instead of a milling machine. This method of removing material disturbs the integrity of the in-place material from which the deflections were measured.

Because of these issues, the DME may require reduced GE from what is found in this manual or additional pavement thickness. Final determination of what GE is used rests with the District.

It is recommended that if the removal depth is more than 1 foot, determine the pavement thickness and layers using the method for new or reconstructed pavements discussed in Index 633.1. If the pavement structure is being replaced with rigid pavement, the resulting total pavement structure (including existing pavement left in place) cannot be less than the minimum values found in the rigid pavement catalog in Topic 623.

The analysis used for partial depth Remove and Replace with flexible pavement is similar to the Mill and Overlay analysis. The procedure is as follows:

(1) Consider milling down to what is called the analytical depth. This is an iterative type of calculation since it is not known at what milling depth the analytical depth will be reached.

(2) Use the thickness of the existing HMA layer, the design TI and base material in Table 635.2A to determine the TDS. Then find the DM knowing D_{80} and the mill depth. Use DM and TDS to find the percent reduction in deflection at the milled depth (PRM).

(3) Utilizing this calculated PRM value go to Table 635.2B to obtain the GE required to be placed on top of the milled surface. When the milled depth reaches the analytical depth, the analysis changes. The GE for the material milled below the analytical depth is added to the GE required at the analytical depth. The GE for each layer is calculated by multiplying G_f by the thickness of the layer milled.

(4) Determine the required minimum thickness of HMA needed by dividing the sum of the GE's by the G_f of the new HMA (see equation below.)

$$\text{Thickness (t)} = \frac{\text{GE}}{\text{G}_\text{f}}$$

For the Remove and Replace method, use the G_f for the new HMA commensurate with the TI and HMA thickness found in Table 633.1. The total HMA thickness can be solved for each 0.05 foot of material milled until the desired profile is reached. Round the replacement thickness to the nearest 0.05 foot.

(5) Adjust thicknesses as needed for alternate materials.

(b) Full Depth Removal. When material is removed all the way to the subgrade, the Remove and Replace strategy should be engineered using the same procedures used for new construction found in Index 633.1.

(8) Computer Program. All the rehabilitation procedures based on deflection testing discussed above have been encoded in a computer program called *CalAC* that can be downloaded from the Department Pavement website.

(9) Procedure for Concrete Overlay on Existing Flexible Pavement. For concrete overlay strategies (sometimes referred to as whitetopping), only structural adequacy needs to be addressed. To address structural

adequacy, use the tables in Index 623.1 to determine the thickness of the rigid layer. Then existing HMA layer may be considered as the base for the concrete overlay. The overlay should be thick enough to be considered a structural layer. Therefore, thin or ultrathin concrete layers (< 0.65 foot) do not qualify as concrete overlay. To provide a smooth and level grade for the concrete overlay surface layer, place a 0.10 foot to 0.15 foot HMA (leveling course) on top of the existing flexible layer.

(10) *Preparation of Existing Pavement.* Existing pavement distresses should be repaired before overlaying the pavement. Cracks wider than ¼ inch should be sealed; loose pavement removed/replaced; and localized failures such as potholes repaired. Localized failure repairs should be designed to provide a minimum design life to match the pavement design life for the project, but no less than 20 years, even for CAPM projects. Undesirable material such as bleeding seal coats or excessive crack sealant should be removed before paving. Existing thermoplastic traffic striping and raised pavement markers should also be removed. Routing cracks before applying crack sealant has been found to be beneficial. The width of the routing should be ¼ inch wider than the crack width. The depth should be equal to the width of the routing plus ¼ inch. In order to alleviate the potential bump in the overlay from the crack sealant, leave the crack sealant ¼ inch below grade to allow for expansion (i.e., recess fill). The Materials Report should include a reminder of these preparations. Additional discussion of repairing existing pavement can be found on the Department Pavement website.

(11) *Choosing the Rehabilitation Strategy.* The final strategy should be chosen based on pavement life-cycle cost analysis (LCCA). The strategy should also meet other considerations such as constructability, maintenance, and the other requirements found in Chapter 610.

635.3 Rehabilitation of Existing RHMA-G Surfaced Flexible Pavements

The empirical method discussed above was primarily developed for determining rehabilitation requirement for an existing dense-graded HMA surfaced flexible pavement. The concept of tolerable deflection at the pavement surface given in Table 635.2A represents the allowable deflection values necessary for an existing dense-graded HMA surface that the pavement must exhibit to be able to provide the desired service for the remaining service life. The tolerable deflection concept ensures that the asphalt pavement responds "elastically" when subjected to wheel loads; which is a requirement to prevent permanent deformation (rutting) and cracking.

Many flexible pavements that received RHMA-G overlays in the past are either due or will be soon due for rehabilitation. These existing pavements with an old RHMA-G surfacing pose a challenge to the pavement designer with regard to the validity of deflection data collected on such surfaces; and thus the validity of the empirical rehabilitation procedure. This is because the tolerable deflection given in Table 635.2A represents values for dense graded HMA surfaces which tend to be denser (and stiffer) than RHMA-G surfaces. Therefore, the validity of using these tolerable deflection values for designing rehabilitation strategies of an existing RHMA-G surfaced flexible pavement may be questionable. Therefore, deflection testing of existing RHMA-G surfaced flexible pavements may not be necessary when the empirical procedure is selected for rehabilitation design.

An alternative design method is based on the ME methodology (Index 635.4). While this method can overcome the empirical validity challenge described above; the designer may be limited in selecting the rehabilitation strategy for the pavement. In this regard, RHMA-G layers are known to be more permeable than dense graded HMA; therefore infiltrating water can reside in them causing stripping and adversely impacting the integrity of the overlay on top. For this reason, the Department prohibits overlaying RHMA-G surfaces. Therefore, the designer must select an RHMA-G overlay instead of HMA overlay on top of an existing RHMA-G surfaced pavement.

The Department has initiated theoretical and field research to better understand the behavior of "old" RHMA-G surfaces. This research will shed more light on two aspects related to old RHMA-G material:

- Whether RHMA-G material stiffness with time, thus exhibiting the same elastic characteristics under load as that of an old HMA. This finding would be important because it will validate the use of the tolerable deflection and testing over old RHMA-G surfaced pavement for use in the empirical rehabilitation design method.
- Whether RHMA-G material loses its permeability properties as it ages and thus approaches the same permeability level of an old HMA. This finding is also important since it enables the designer to select any asphaltic overlay material type (HMA or RHMA-G).

As this research has not been completed yet, the ME method may be the only resort for the designer at this time. Alternatively, some engineering judgment may have to be exercised with the empirical procedure to improve its validity. Consult with the Pavement Program, Office of Asphalt Pavements for assistance.

635.4 Mechanistic-Empirical Method

(1) Application. For information on Mechanistic-Empirical (ME) Design application and requirements, see Index 606.3(2)(b).

(2) Procedure. The ME method can be used to engineer rehabilitation strategies for existing flexible pavements. Unlike the empirical design procedure, the ME method is capable of designing rehabilitation strategies for more than 20 years of service.

Other benefits of the ME method over the empirical procedure are discussed in Index 633.2.

The ME procedure for flexible pavement rehabilitation involves the following:

(a) Engineering Criteria - Similar to "new construction" and reconstruction design, inputs to the ME design procedure for flexible pavement rehabilitation include detailed information on climate, traffic, existing pavement structure, and desired service life.

(b) Data Collection - Information on the existing pavement structure is obtained from cores, ground penetrating radar (GPR), and as-built records. In addition, Falling Weight Deflectometer (FWD) deflection testing is conducted on the pavement to obtain deflection basin data. The deflection data is used to assess in-situ strength (in terms of resilient modulus) of each of the existing pavement layers (including subgrade) needed for evaluating rehabilitation requirements using the ME method. The numerical back-calculation method used to obtain the resilient moduli of existing pavement layers is briefly discussed in Index 635.3(2)(c).

(c) In-Situ Resilient Moduli Evaluation Using Back-calculation - The method of back-calculation relies on using the multilayer elastic theory (MLET) and a numerical search algorithm to determine the resilient modulus of each layer of an existing pavement structure based on deflection basin data collected from the pavement. A deflection basin describes the deflection measured on the pavement surface as a function of distance from the applied load. For additional information on the theory of back-calculation and description of CalBack procedures refer to the link "ME Designer's Corner" located on the internal Department Pavement website or by contacting the Headquarters Pavement Program Office Chief.

- For a pavement structure with known layer thicknesses, resilient moduli, Poisson's ratios, load magnitude and pressure, the MLET is typically used to compute the primary responses (stress, strain, and displacement) at any point within the three-dimensional pavement structure. This type of calculation is called "forward" calculation because the resilient modulus of each layer is known and stresses, strains, and displacements are the unknowns that are being calculated.
- In the back-calculation method, the MLET is used in a "reverse" manner to back-calculate the resilient modulus of each layer. In this method, vertical displacement (deflection) measured

with FWD at various locations on the pavement surface caused by a known load magnitude and loading pressure, along with known layer thicknesses at the test locations obtained from cores, GPR, or as-built plans and reasonably assumed Poisson's ratios for each of the pavement layers are all used in the MLET in a "reverse" manner to calculate the resilient modulus of each layer.

- A numerical search algorithm is used in the back-calculation process to ensure that the modulus of each layer is determined within a specified error tolerance. In the search algorithm, the resilient modulus of each known layer is initially assumed and the MLET "forward" calculation is performed to calculate surface deflections at various locations along the deflection basin (at the specified deflection sensor locations from the center of the load). The vertical displacements calculated with MLET and the corresponding measured deflections at same locations are then compared, and the error difference (usually percentage difference) is used to adjust the assumed moduli values. This analysis is repeated many times until the calculated surface deflections become close to measured values within the required error tolerance.
- Because the iterative numerical search algorithm cannot be conducted without computers, the Department with its research partner UCPRC has developed a software for in-situ resilient moduli back-calculation (called CalBack). CalBack uses deflection data obtained from FWD testing along with layer information (layer thicknesses and materials types) to back-calculate resilient moduli of all layers including subgrade.

(d) Mechanistic-Empirical Analysis - The ME method analyzes a proposed rehabilitation treatment for the three performance criteria (total cracking, total rutting, and IRI) discussed in Index 633.2(2)(b). The engineer starts with a trial rehabilitation design (e.g., by specifying overlay material type and thickness) along with the known existing layer configurations and back-calculated layer moduli, then analyzes the design using the ME procedure encoded in the CalME program. Depending on the performances predicted with CalME the engineer adjusts the rehabilitation design and repeatedly re-runs the analysis until an optimal design is reached. The asphalt material data needed in the analysis may be selected from the CalME standard library or based on laboratory testing of the HMA(s) as discussed in Index 633.2(2)(e). The rehabilitation design must achieve the required reliability level for the project as discussed in in Index 633.2(2)(c).

Topic 636 - Other Considerations

636.1 Traveled Way

(1) Mainline. No additional considerations.

(2) Ramps and Connectors. Rigid pavement should be considered for freeway-to-freeway connectors and ramps near major commercial or industrial areas (TI > 14.0), truck terminals, and all truck weighing and inspection facilities.

(3) Ramp Termini. Distress is compounded on flexible pavement ramp termini by the dissolving action of oil drippings combined with the braking of trucks. Separate pavement strategies should be developed for these ramps that may include thicker pavement structures, special asphalt binders, aggregate sizes, or mix designs. Rigid pavement can also be considered for exit ramp termini where there is a potential for shoving or rutting. At a minimum, rigid pavement should be considered for exit ramp termini of flexible pavement ramps where a significant volume of trucks is anticipated (TI > 11.5). For the engineering of rigid pavement ramp termini, see Index 626.1(3).

636.2 Shoulders

The TI for shoulders is given in Index 613.5(2). See Index 1003.5(1) for surface quality guidance for bicyclists.

636.3 Intersections

Where intersections have "STOP" control or traffic signals, special attention is needed to the engineering of flexible pavements to minimize shoving and rutting of the surface caused by trucks braking, and early failure of detector loops. Separate pavement strategies should be developed for these intersections that may include thicker pavement structures, special asphalt binders, aggregate sizes, or mix designs. Rigid pavement is another alternative for these locations. For additional information see Index 626.3. For further assistance on this subject, consult with the District Materials Engineer or Headquarters Division of Maintenance – Pavement Program.

636.4 Roadside Facilities

(1) *Safety Roadside Rest Areas.* Safety factors for the empirical method should be applied to the ramp pavement but not for the other areas.

For truck parking areas, where pavement will be subjected to truck starting/stopping and oil drippings which can soften asphalt binders, separate flexible pavement structures which may include thicker structural sections, alternative asphalt binders, aggregate sizes, or mix designs should be considered. Rigid pavement should also be considered.

(2) *Park & Ride Facilities.* Due to the unpredictability of traffic, it is not practical to design a new park and ride facility based on traffic projections. Therefore, standard structures based on typical traffic loads have been adopted. Table 636.4 provides layer thicknesses based on previous practices.

These pavement structures are minimal, but are considered adequate since additional flexible surfacing can be added later, if needed, without the exposure to traffic or traffic-handling problems typically encountered on a roadway. If project site-specific traffic information is available, it should be used with the standard engineering design procedures discussed in Topic 633 and Topic 635 to design a new or rehabilitate existing pavement structures. A design life of 20 years may be selected for roadside facilities. Refer to Topic 612.

(3) *Bus Pads.* Use rigid or composite pavement strategies for bus pads.

Table 636.4
Minimum Pavement Structures for Park & Ride Facilities

California R-value of the Subgrade Soil	Thickness of Layers	
	HMA [2] (ft)	AB (ft)
Less than 40 [1] (two options)	0.25	0
	0.15	0.35
Greater than or equal to 40 but less than 60	0.15	0
Greater than or equal to 60	Penetration Treatment [3]	

NOTES:

(1) Check for expansive soil and possible need for treatment per Index 614.4.

(2) Place HMA in one lift to provide for maximum density.

(3) Penetration Treatment is the application of a liquid asphalt or dust palliative on compacted roadbed material. See Standard Specifications.

Topic 637 - Engineering Analysis Software

Software programs for designing flexible pavements using the procedures discussed in this chapter can be found on the Department Pavement website. These programs employ the procedures and requirements for flexible pavement engineering enabling the engineer to compare numerous combinations of materials in seeking the most cost effective pavement structure.

CHAPTER 650
PAVEMENT DRAINAGE

Topic 651 - General Considerations

Index 651.1 - Impacts of Drainage on Pavement

Saturation of the pavement or underlying subgrade, or both, generally results in a decrease in strength or ability to support heavy axle loads. Potential problems associated with saturation of the structural section and subgrade include:

- Pumping action.
- Differential expansion (swelling) of expansive subgrade.
- Frost damage in freeze-thaw areas.
- Erosion and piping of fine materials creating voids which result in the loss of subgrade support.
- Icing of pavement surface from upward seepage.
- Stripping of asphalt concrete aggregates.
- Accelerated oxidation of asphalt binder.

Water can enter the pavement as surface water through cracks, joints, and pavement infiltration, and as groundwater from an intercepted aquifer, a high water table, or a localized spring. These sources of water should be considered and provisions should be made to handle both. The pavement structure drainage system, which is engineered to handle surface water inflow, is generally separated from the subsurface drainage system that is engineered to accommodate encroaching subsurface water. This chapter covers surface water drainage while the subsurface drainage system is covered in Chapter 840.

651.2 Drainage System Components and Requirements

The basic components of a pavement structural section drainage system are:

(1) *Drainage Layer.* A treated permeable base (TPB) drainage layer may be useful where it is necessary to drain water beneath the pavement. A TPB requires the use of edge drains or some other method of draining water out and away from the pavement; otherwise the collected water will become trapped. If a TPB drainage layer is used, it should be placed immediately below the surface layer for interception of surface water that enters the pavement. The drainage layer limits are shown in Figure 651.2A. Further information for TPB can be found in Index 662.3.

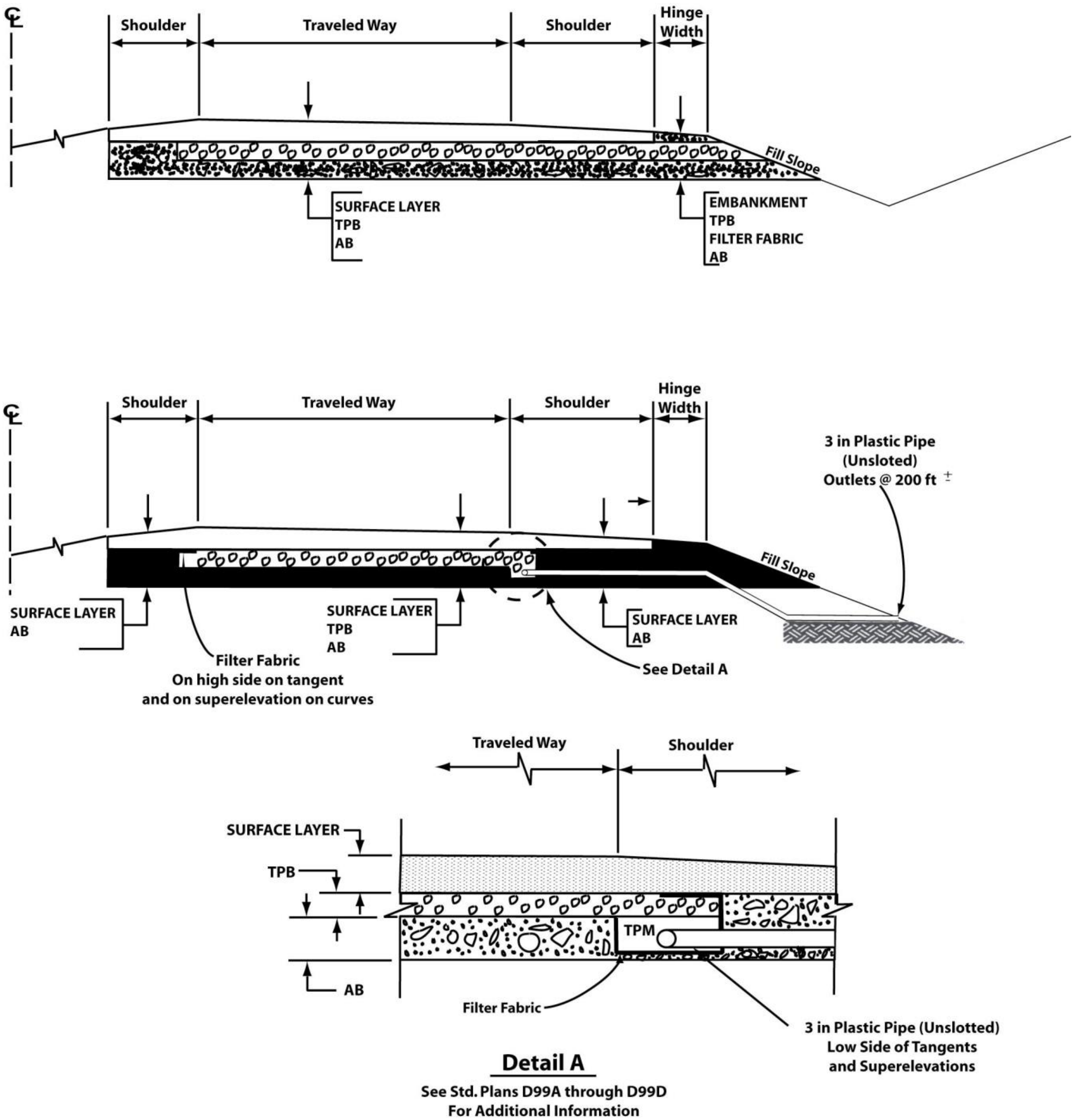
When there is concern that the infiltrating surface water may saturate and soften the underlying subbase or subgrade (due either to exposure during construction operations or under service conditions), a filter fabric or other suitable membrane should be utilized and applied to the base, subbase, or subgrade on which the TPB layer is placed to prevent migration of fines and contamination of the TPB layer by the underlying material.

When using TPB, special attention should be given to drainage details wherever water flowing in the TPB encounters impermeable abutting pavement layers, a structure approach slab, a sleeper slab, a pavement end anchor/transition, or a pressure relief joint. In any of these cases, a cross drain interceptor should be provided. Details of cross drain interceptors at various locations are shown in Figure 651.2B. The cross drain outlets should be tied into the longitudinal edge drain collector and outlet system with provision for maintenance access to allow cleaning.

In some situations, underground water from landscape irrigation or other sources may tend to saturate the existing slow-draining layers, thereby creating the potential for pumping and pavement damage. In this case, the pavement should be engineered to provide for removal of such water when reconstruction is required.

(2) *Collector System.* If constraints exist or where it is not practical to drain water out of the pavement by other means, a collector system should be provided to drain water from the drainage layer. Collector systems include a 3-inch slotted plastic pipe edge drain installed in a longitudinal collector trench as shown in Figure 651.2A. In areas where the profile grade

Figure 651.2A
Typical Section with Treated Permeable Base Drainage Layer



NOTES:

(1) Section shown is a half-section of a divided highway. An edge drain collector and outlet system should be provided if insufficient Right of Way precludes a retention basin.

(2) This figure is only intended to show typical pavement details. See the following for further information:
   - (a) Chapter 300 for geometric cross section details.
   - (b) Index 309.1(2) for clear recovery zone guidance.
   - (c) Chapter 680 for widening.

CHAPTER 680

PAVEMENT DESIGN FOR WIDENING PROJECTS

Topic 681 – Pavement Widening Overview

Index 681.1 – Background

(1) *Purpose* - Pavement widening involves the construction of additional width to improve traffic flow and increase capacity on an existing highway facility or to improve existing features such as the inclusion of shoulders, turn lanes, and passing lanes. Pavement widening projects create unique issues for pavement engineers such as what is the best structure to build for the widening and how to tie or build next to existing pavement. This Chapter provides instructions and guidance for selecting pavement type, design standards, and details for pavement widening projects.

(2) *Types of Pavement Widening Projects* - Pavement widening may involve the following types of pavement projects:

- Adding travel lanes (including bus or bicycle lanes), auxiliary lanes, climbing or passing lanes, etc.,
- Adding shoulders, pullouts for maintenance/transit traffic; or
- Widening existing lanes, shoulders or pullouts.

When planning widening projects such as lane or shoulder additions, the existing adjacent pavement condition should be investigated to determine if the measures discussed in Index 682.3 are needed to combine rehabilitation or pavement preservation work with widening.

Topic 682 – Design Considerations

682.1 Standards

Besides pavement engineering discussed in Chapter 610, pavement widening presents additional challenges in pavement design. These include the following:

- A uniform foundation across the new and existing pavement structure to accommodate both pavement drainage and fatigue performance.
- Existing pavement is adequate to sustain traffic loads expected during the design life of the new pavement widening structure.
- Continuity of existing pavement structure drainage system.

Oftentimes, because existing pavements may have been designed decades earlier for lower traffic loads than are currently experienced, their thicknesses may not only be less than those of the new widened pavements but are often worn and in some cases exhibit minor or major distress. These issues could considerably affect the service life and drainage of both the existing and new pavement structures. To ensure both drainage and design life standards are met, drainage conditions and structural capacity of both existing and new pavement structures should be evaluated and taken into account during the planning and scoping phases of a widening project.

682.2 Pre-Design Evaluation

Pavement widening requires a careful evaluation of the existing and proposed new widened pavement structures to ensure adequate performance under expected traffic loads, provide a consistent foundation across new and existing pavements, and perpetuate pavement drainage. The following pre-design evaluations are recommended to ensure that pavement widening projects are designed and constructed to meet these performance requirements.

- Review as-built records of the existing pavement structure such as the as-built material properties, mix designs, and layer thicknesses. In some instances, layer thicknesses from Ground Penetrating Radar (GPR) may also be available.
- Review the current pavement condition survey data.
- Conduct field evaluations including obtaining pavement cores and where applicable

performing Falling Weight Deflectometer (FWD) survey to determine the following:

(1) Existing material properties and layer thicknesses

(2) Layer deflection and moduli (for use in asphalt pavement design)

(3) Soil properties including subgrade strength and subgrade moduli, and obtain samples for laboratory investigation if needed.

(4) Detection of moisture in the existing base

In instances where the existing pavement is in good condition and does not require rehabilitation, the most essential evaluations are the review of as-built records and current pavement condition survey data.

682.3 Pre-Design Considerations

The following pre-design considerations are recommended when designing a pavement widening project.

(1) *Consistent and Cost-effective Overall Pavement Structure* - The engineer needs to consider what characteristics are important for both the new and existing pavement in order to provide a consistent, cost-effective, and functioning structure for the overall pavement. This includes taking into account how the new pavement will perform as well as doing a life-cycle cost analysis of how and when the new and existing pavements will be maintained.

(2) *Rehabilitation or Pavement Preservation of Existing Pavement with the Widening Project* - It is not often cost-effective nor desirable to widen a highway without correcting ride quality and structural distress in adjacent pavement structure when that work is needed. During planning and scoping of widening projects, it is necessary to thoroughly evaluate the existing adjacent pavement structure to determine if rehabilitation or pavement preservation is needed in conjunction with the widening. This involves a review of the current pavement condition survey data in conjunction with a field investigation of the existing roadway. The review should be done during the project initiation phase and updated during the design phase because the pavement condition may have deteriorated during the intervening time. If rehabilitation or pavement preservation is warranted, combining rehabilitation or pavement preservation work with widening is strongly encouraged.

(3) *Future Traffic Delay and Long-Term Costs* - Combining widening with rehabilitation or pavement preservation work on existing pavement can minimize future traffic delay and long-term costs. If the adjacent existing lane warrants rehabilitation, the lane should be rehabilitated in conjunction with the widening and brought up to the same life expectancy as the new widened portion of the roadway (see Index 612.3. In certain circumstances, the District may defer the pavement rehabilitation work and program it as a separate project, but this should be done in coordination with Headquarters Pavement Reviewers and the Project Delivery Coordinators (for non-delegated projects per the District Design delegation Agreement). If the adjacent lane does not need to be rehabilitated, an appropriate pavement preservation treatment should be applied to provide a uniform surface for maintenance of existing and widened sections.

Pavement preservation and rehabilitation work that should be included with widening projects for concrete and asphalt pavements are discussed in Index 682.4(1)(b) and 682.4(2)(c) respectively.

682.4 Scoping, Estimating, and Detailing

The following design criteria are provided to aid in scoping, estimating, and detailing pavement widening projects. As per Index 82.1(1), these requirements should be viewed as minimum criteria for determining how much work to do on existing pavements. Because each widening project has different pavement engineering and performance issues, early and frequent involvement of Headquarters Pavement Reviewers is recommended to appropriately address what features to include and how to ensure the following design criteria are met.

(1) *Pavement Structure Requirements* - The following minimum requirements should apply when designing pavement structures for widening projects.

(a) If a widening project causes the traffic lanes to lay partially on existing pavement and new pavement, then the engineer should ensure that the pavement type and structure are consistent across the lane. Avoid creating lanes that are partially asphalt, concrete or composite as this will wear at different rates and increase future maintenance costs and worker exposure on the lane.

(b) Remove the existing pavement up to the lane line of the existing adjacent truck permitted lane and replace it as part of the new widening pavement structure if:

(1) The traffic load capacity of the existing pavement measured in ESALs is more than 90 percent of the predicted need,

(2) The existing pavement is in good condition as identified in the pavement condition survey), and

(3) The new widening is adding less than 2 lanes and the width of widening the proposed lane is 9 feet or less.

In these situations, the proposed widened pavement structure may match the existing pavement and, where needed, a preservation treatment applied as discussed in Index 682.4(1)(b) and (2)(c). Otherwise, it is preferable to construct new lane(s) to new construction standards and remove existing pavement as needed to accommodate the predicted need.

(2) Widening of Concrete Roadways - The following design standards should apply when widening concrete roadways:

(a) Place longitudinal joints at location of proposed lane lines (or ultimate lane line if project is an interim stage of an ultimate project) except as noted below:

(1) Place the longitudinal construction joint between the existing pavement and the new widened section, 0.5 foot from the lane line for truck permitted lanes and from the edge of existing concrete for all other widening in traveled way except for auxiliary lanes next to truck permitted lanes where widening should match existing edge (See Figure 682.4A). Relocating the joint also allows for a clean joint by minimizing spalling and undulations in the existing joint. For truck permitted lanes, relocating the longitudinal joint 0.5 foot outside the lane will provide a uniform section of concrete to distribute truck loads and provide lateral support for the truck lane when longitudinal isolation joint is used. This will assure the performance of the pavement over its design life.

(2) Additional requirements and details for tying adjacent concrete slabs can be found in Index 622 and the Standard Plans.

(3) When existing longitudinal joints and proposed or ultimate lane lines do not line up, it is preferable to construct longitudinal pavement joints between new and existing concrete (particularly isolation joints) in non-truck permitted lanes.

(b) Do not place or leave slabs less than 8 feet wide in truck permitted lanes or joints within 2 feet of wheel paths. The reduced width of the slab will lead to early cracking of the pavement.

(c) When widening contiguous to concrete pavement in good condition, a pavement preservation strategy in conjunction with widening is recommended if warranted, including grinding the existing rigid pavement where warranted. This provides a smooth riding surface and can eliminate old striping and pavement markings. Grinding the lane next to the proposed widening is required when the existing International Roughness Index (IRI) exceeds 90 inches per mile in order to provide a smooth platform for the paving machine to construct the adjacent pavement structure. Pavement preservation strategies are discussed in Index 603.3 and in the *Concrete Pavement Guide*. Additional information on procedures for concrete pavement preservation can also be found in Topic 624.

(d) For concrete pavement that will require rehabilitation within ten years, the widening project should consider future compatibility of the proposed structure with the eventual concrete pavement rehabilitation strategy. Pavement rehabilitation strategies are discussed in Index 603.4 and procedures for concrete pavement rehabilitation can be found in Index 625.1.

(e) If the existing adjacent pavement to remain was a previously cracked, seated, and asphalt overlaid concrete roadway, then the new pavement structure for the widening project should match the structural layers of the existing pavement. This is done by placing asphalt concrete over a concrete base or lean concrete base thick enough to match the concrete layer in the existing pavement. Excluding any cement treated base, the thickness of the new concrete base should not be less than 0.35-feet. Where needed to match existing or add structural capacity, the new pavement structure should include an aggregate base or subbase. To provide a uniform surface for the widening and existing pavement, mill and replace 0.15 foot of the existing asphalt surface course~~.~~ or if the new asphalt concrete surface course required for the new pavement structure is thicker than the existing, the existing shall be overlaid a minimum of 0.15 feet to match the top surface of the new asphalt concrete layer. Figure 682.4B shows a typical pavement widening structure adjacent to existing previously cracked, seated and asphalt overlaid concrete pavement.

(3) *Widening of Asphalt Roadways* - The following design standards should apply when widening asphalt roadways:

(a) When widening asphalt pavement, continuity with the existing pavement should be provided whenever it is economically feasible. At a minimum, the design should use compatible materials and provide for adequate drainage underneath the existing pavement. This may require constructing the top of subgrade for the widening at the same or lower elevation than the existing subgrade, and extending underdrains from the edge of the existing pavement to an outlet beyond the new pavement structure.

(b) When widening adjacent to existing asphalt pavement that is in good condition, a pavement preservation strategy in conjunction with widening such as placing a non-structural wearing course over the widening and existing pavement should be done. This provides a surface with a uniform appearance, a surface course with equivalent future maintenance requirements, a clean surface for new striping configurations, as well as elimination of pavement joints which are susceptible to water intrusion and early fatigue failure.

If the new asphalt concrete surface course required for the new pavement structure is thicker than the existing, the existing shall be overlaid a minimum of 0.15 feet to match the top surface of the new asphalt concrete layer.

If the existing pavement exhibits oxidation, raveling, or minor cracking, it is recommended to mill 0.15 foot of the existing asphalt surface and overlay across the entire existing pavement and new section as shown in Figure 682.4C. The overlay joint should be offset 1.0 foot from the underlying vertical interface between existing and new pavement to improve the impermeability of the interface in the short-term. (The underlying vertical interface at the widening will eventually cause reflective cracking through to the surface.)

Pavement preservation strategies are discussed in Topic 634 and in the Maintenance Technical Advisory Guide (MTAG). Additional information on procedures for asphalt pavement preservation can also be found in Index 603.3.

(c) For asphalt pavement exhibiting major distress that need rehabilitation work, the widening project should include an appropriate pavement rehabilitation strategy for the existing pavement structure at least in the lane adjacent to the widening to obtain a smooth riding surface. In such cases, project scoping and other engineering decisions should take into account cost as well as other project considerations such as traffic safety to determine whether pavement rehabilitation of the existing roadway should be included with the pavement widening project. Pavement rehabilitation strategies are discussed in Topic 635 and procedures for asphalt pavement roadway rehabilitation can be found in Index 603.4.

(d) Widening of asphalt roadways with concrete should not be done except in the following cases:

(1) Concrete pavement will be placed across all the truck permitted lanes.

(2) The concrete pavement joint will be located at the proposed lane line (or ultimate lane line if project is just an interim stage of an ultimate project)

(3) There is a funded project to replace the existing lanes with concrete within the next 10 years.

When an asphalt roadway is widened with concrete the existing asphalt pavement should be replaced with concrete and at the same time the entire pavement should be overlaid or, at a minimum, designed to be overlaid with concrete in the future.

(4) *Drainage of Pavement Widening Structure:* Perpetuate pavement drainage in accordance with Chapter 650. The pavement structure of the widening should be designed where feasible to provide a path for subsurface water drainage to the edge of pavement. If it is not feasible to accomplish this, then consult with Headquarters Pavement Reviewers for other options.

682.5 Other Considerations

In addition to the foregoing design considerations, the following measures should be taken into account when constructing a pavement widening project.

(1) *Crack Sealing* - An aggressive crack sealing program will limit the amount of precipitation runoff from entering into the structure. Consideration should be given to using geosynthetic pavement interlayers over the joint between new and existing pavement prior to applying the full-width overlay to delay reflective cracking.

(2) *Treatment of the Subgrade* - Treatment of the subgrade under the widened section is recommended as an effective strategy to reduce moisture fluctuations at the new pavement edge which in turn should reduce the potential for longitudinal edge cracking. An alternative to treatment of the subgrade may be to use a subgrade enhancement at the subgrade/base interface. Treatment should be accomplished below the level of the old asphalt base.

(3) *Selection of the Base Material* - Selection of the new base material should be based on laboratory evaluation of both new and existing materials to compare the moisture susceptibility of each. Preferably, the moisture susceptibility of the existing and new base materials should be about the same. A material that is more highly moisture susceptible may draw moisture from both the original section and from outside the structure. A material that is less moisture susceptible may send moisture into the original base, particularly during the original curing process. It should also be noted that premature problems can be experienced when pavements with asphalt bases are widened with different base material, especially cement treated base. Cracks form at the longitudinal joint and moisture ingress often leads to rapid deterioration of the existing section.

(4) *Treated Base Sections* - Other considerations will closely parallel those discussed in Index 662.2 for treated base materials. There are cases where it may be desirable to use full-depth HMA for the widening to expedite construction, even though the base for the existing pavement was cement-treated material. This strategy should not cause subsurface moisture flow problems ("bath tub" effect) provided that the cement treated base is not moisture susceptible. Laboratory

evaluation of core samples will determine the degree of moisture susceptibility of the existing base.

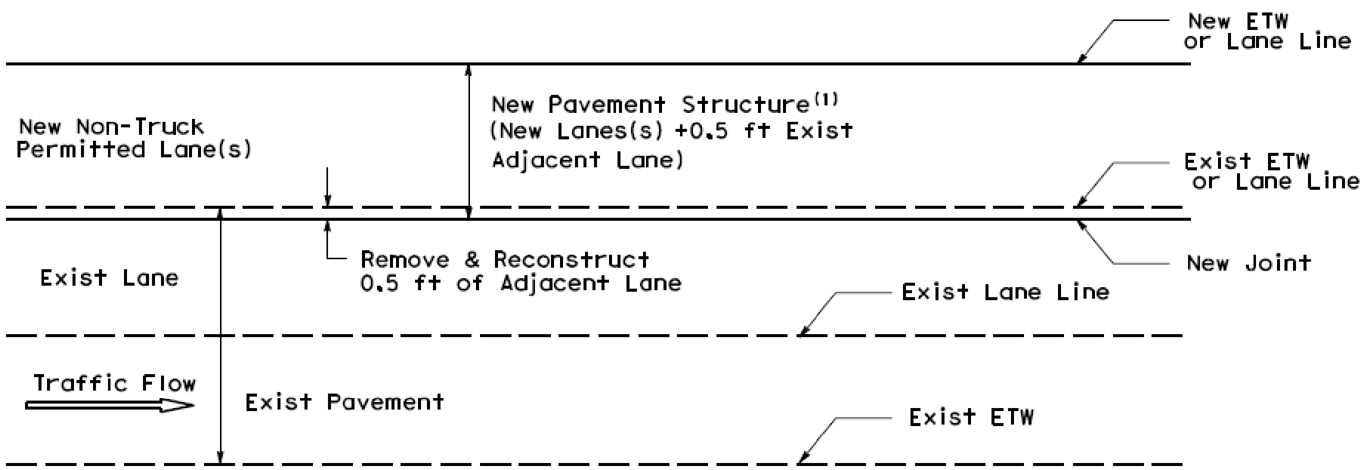
682.6 Life-Cycle Cost Analysis for Widening Projects

In addition to selecting the type of pavement for the widening project, as discussed in Topic 619, life-cycle cost analysis is a key component in determining how best to maintain both new and existing pavements over time and whether it is better to design the widening to match the life of the existing pavement or plan for the upgrading of the existing pavement to match the new pavement. When doing a life-cycle cost analysis for pavement widening, it is often best to perform the life-cycle cost analysis on how best to maintain the existing pavement first since the type and condition of the existing pavement will often influence the engineering of the new pavement. Life-cycle cost analysis is discussed further in Topic 619 and the Life-Cycle Cost Analysis Procedures Manual.

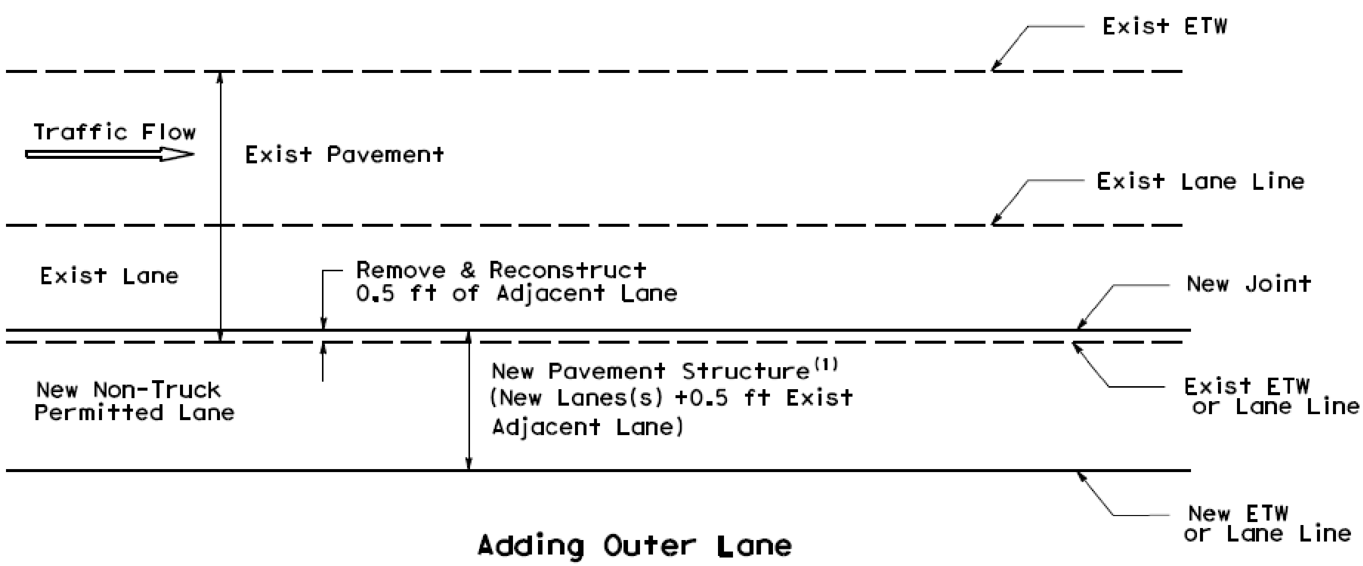
Figure 682.4A

Typical Concrete Pavement Widening

Median Lane and Outer Lane



Adding Median Lane



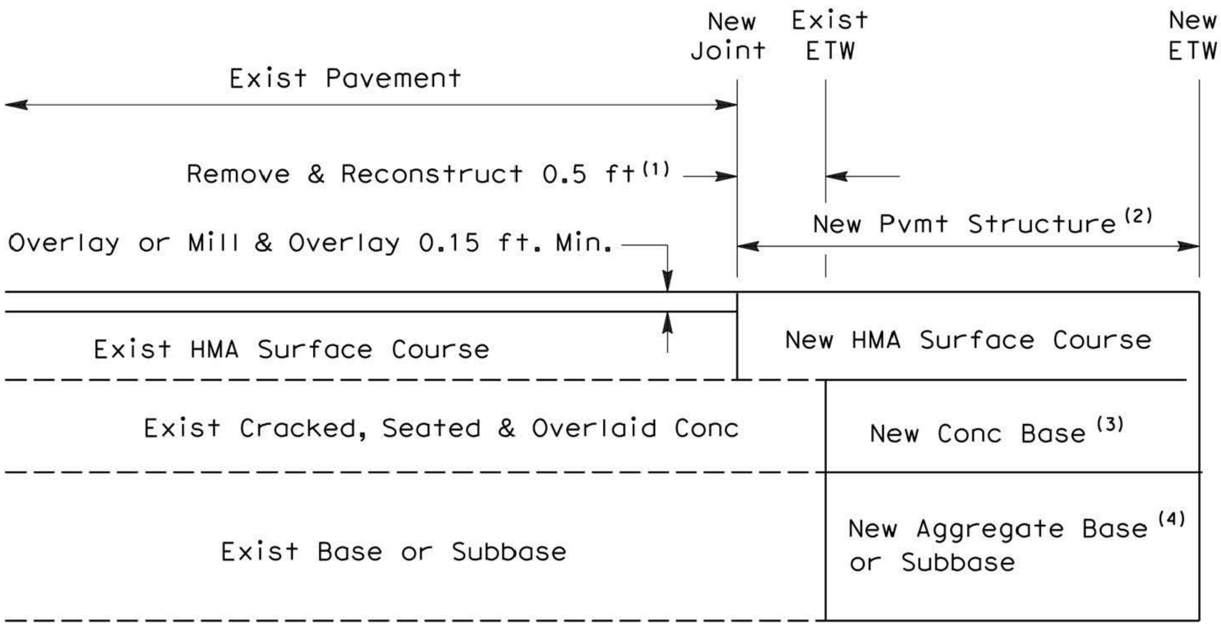
Adding Outer Lane

NOTES:

(1) See Index 623.1 and Tables 623.1B – M for details on concrete pavement structure design.

Figure 682.4B

Widening Previously Cracked, Seated, and HMA Overlay Concrete Pavement in Good Condition



NOTES:

(1) See Figures 682.4A for additional details.

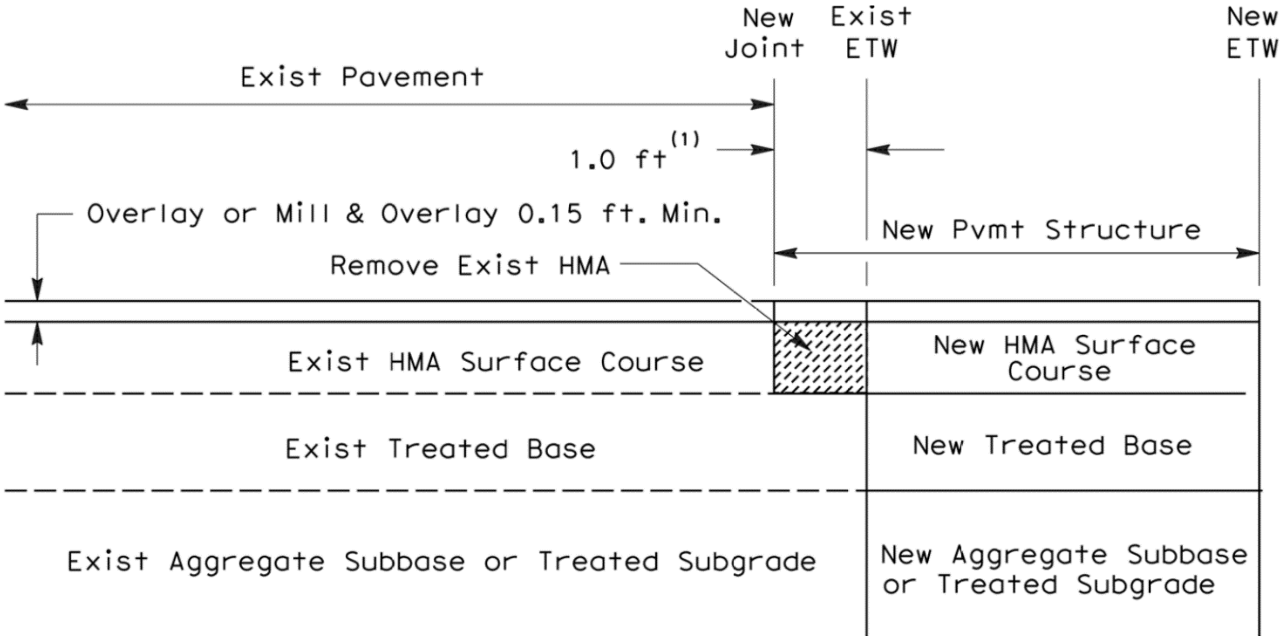
(2) Match the structural layers of the existing pavement for situations described in section 682.4 (2) (e).

(3) Match thickness of adjacent concrete but not less than 0.35 feet.

(4) When needed to match existing treated base, granular base/sub base, or add structural capacity.

Figure 682.4C

Widening Asphalt Pavement in Good Condition



NOTES:

(1) Offset overlay joint by 1.0 feet from the underlying vertical interface between existing and new pavement.

CHAPTER 680

PAVEMENT DESIGN FOR WIDENING PROJECTS

Topic 681 – Pavement Widening Overview

Index 681.1 – Background

(1) *Purpose* - Pavement widening involves the construction of additional width to improve traffic flow and increase capacity on an existing highway facility or to improve existing features such as the inclusion of shoulders, turn lanes, and passing lanes. Pavement widening projects create unique issues for pavement engineers such as what is the best structure to build for the widening and how to tie or build next to existing pavement. This Chapter provides instructions and guidance for selecting pavement type, design standards, and details for pavement widening projects.

(2) *Types of Pavement Widening Projects* - Pavement widening may involve the following types of pavement projects:

- Adding travel lanes (including bus or bicycle lanes), auxiliary lanes, climbing or passing lanes, etc.,
- Adding shoulders, pullouts for maintenance/transit traffic; or
- Widening existing lanes, shoulders or pullouts.

When planning widening projects such as lane or shoulder additions, the existing adjacent pavement condition should be investigated to determine if the measures discussed in Index 682.3 are needed to combine rehabilitation or pavement preservation work with widening.

Topic 682 – Design Considerations

682.1 Standards

Besides pavement engineering discussed in Chapter 610, pavement widening presents additional challenges in pavement design. These include the following:

- A uniform foundation across the new and existing pavement structure to accommodate both pavement drainage and fatigue performance.
- Existing pavement is adequate to sustain traffic loads expected during the design life of the new pavement widening structure.
- Continuity of existing pavement structure drainage system.

Oftentimes, because existing pavements may have been designed decades earlier for lower traffic loads than are currently experienced, their thicknesses may not only be less than those of the new widened pavements but are often worn and in some cases exhibit minor or major distress. These issues could considerably affect the service life and drainage of both the existing and new pavement structures. To ensure both drainage and design life standards are met, drainage conditions and structural capacity of both existing and new pavement structures should be evaluated and taken into account during the planning and scoping phases of a widening project.

682.2 Pre-Design Evaluation

Pavement widening requires a careful evaluation of the existing and proposed new widened pavement structures to ensure adequate performance under expected traffic loads, provide a consistent foundation across new and existing pavements, and perpetuate pavement drainage. The following pre-design evaluations are recommended to ensure that pavement widening projects are designed and constructed to meet these performance requirements.

- Review as-built records of the existing pavement structure such as the as-built material properties, mix designs, and layer thicknesses. In some instances, layer thicknesses from Ground Penetrating Radar (GPR) may also be available.
- Review the current pavement condition survey data.
- Conduct field evaluations including obtaining pavement cores and where applicable

performing Falling Weight Deflectometer (FWD) survey to determine the following:

(1) Existing material properties and layer thicknesses

(2) Layer deflection and moduli (for use in asphalt pavement design)

(3) Soil properties including subgrade strength and subgrade moduli, and obtain samples for laboratory investigation if needed.

(4) Detection of moisture in the existing base

In instances where the existing pavement is in good condition and does not require rehabilitation, the most essential evaluations are the review of as-built records and current pavement condition survey data.

682.3 Pre-Design Considerations

The following pre-design considerations are recommended when designing a pavement widening project.

(1) *Consistent and Cost-effective Overall Pavement Structure* - The engineer needs to consider what characteristics are important for both the new and existing pavement in order to provide a consistent, cost-effective, and functioning structure for the overall pavement. This includes taking into account how the new pavement will perform as well as doing a life-cycle cost analysis of how and when the new and existing pavements will be maintained.

(2) *Rehabilitation or Pavement Preservation of Existing Pavement with the Widening Project* - It is not often cost-effective nor desirable to widen a highway without correcting ride quality and structural distress in adjacent pavement structure when that work is needed. During planning and scoping of widening projects, it is necessary to thoroughly evaluate the existing adjacent pavement structure to determine if rehabilitation or pavement preservation is needed in conjunction with the widening. This involves a review of the current pavement condition survey data in conjunction with a field investigation of the existing roadway. The review should be done during the project initiation phase and updated during the design phase because the pavement condition may have deteriorated during the intervening time. If rehabilitation or pavement preservation is warranted, combining rehabilitation or pavement preservation work with widening is strongly encouraged.

(3) *Future Traffic Delay and Long-Term Costs* - Combining widening with rehabilitation or pavement preservation work on existing pavement can minimize future traffic delay and long-term costs. If the adjacent existing lane warrants rehabilitation, the lane should be rehabilitated in conjunction with the widening and brought up to the same life expectancy as the new widened portion of the roadway (see Index 612.3. In certain circumstances, the District may defer the pavement rehabilitation work and program it as a separate project, but this should be done in coordination with Headquarters Pavement Reviewers and the Project Delivery Coordinators (for non-delegated projects per the District Design delegation Agreement). If the adjacent lane does not need to be rehabilitated, an appropriate pavement preservation treatment should be applied to provide a uniform surface for maintenance of existing and widened sections.

Pavement preservation and rehabilitation work that should be included with widening projects for concrete and asphalt pavements are discussed in Index 682.4(1)(b) and 682.4(2)(c) respectively.

682.4 Scoping, Estimating, and Detailing

The following design criteria are provided to aid in scoping, estimating, and detailing pavement widening projects. As per Index 82.1(1), these requirements should be viewed as minimum criteria for determining how much work to do on existing pavements. Because each widening project has different pavement engineering and performance issues, early and frequent involvement of Headquarters Pavement Reviewers is recommended to appropriately address what features to include and how to ensure the following design criteria are met.

(1) *Pavement Structure Requirements* - The following minimum requirements should apply when designing pavement structures for widening projects.

(a) If a widening project causes the traffic lanes to lay partially on existing pavement and new pavement, then the engineer should ensure that the pavement type and structure are consistent across the lane. Avoid creating lanes that are partially asphalt, concrete or composite as this will wear at different rates and increase future maintenance costs and worker exposure on the lane.

(b) Remove the existing pavement up to the lane line of the existing adjacent truck permitted lane and replace it as part of the new widening pavement structure if:

(1) The traffic load capacity of the existing pavement measured in ESALs is more than 90 percent of the predicted need,

(2) The existing pavement is in good condition as identified in the pavement condition survey), and

(3) The new widening is adding less than 2 lanes and the width of widening the proposed lane is 9 feet or less.

In these situations, the proposed widened pavement structure may match the existing pavement and, where needed, a preservation treatment applied as discussed in Index 682.4(1)(b) and (2)(c). Otherwise, it is preferable to construct new lane(s) to new construction standards and remove existing pavement as needed to accommodate the predicted need.

(2) Widening of Concrete Roadways - The following design standards should apply when widening concrete roadways:

(a) Place longitudinal joints at location of proposed lane lines (or ultimate lane line if project is an interim stage of an ultimate project) except as noted below:

(1) Place the longitudinal construction joint between the existing pavement and the new widened section, 0.5 foot from the lane line for truck permitted lanes and from the edge of existing concrete for all other widening in traveled way except for auxiliary lanes next to truck permitted lanes where widening should match existing edge (See Figure 682.4A). Relocating the joint also allows for a clean joint by minimizing spalling and undulations in the existing joint. For truck permitted lanes, relocating the longitudinal joint 0.5 foot outside the lane will provide a uniform section of concrete to distribute truck loads and provide lateral support for the truck lane when longitudinal isolation joint is used. This will assure the performance of the pavement over its design life.

(2) Additional requirements and details for tying adjacent concrete slabs can be found in Index 622 and the Standard Plans.

(3) When existing longitudinal joints and proposed or ultimate lane lines do not line up, it is preferable to construct longitudinal pavement joints between new and existing concrete (particularly isolation joints) in non-truck permitted lanes.

(b) Do not place or leave slabs less than 8 feet wide in truck permitted lanes or joints within 2 feet of wheel paths. The reduced width of the slab will lead to early cracking of the pavement.

(c) When widening contiguous to concrete pavement in good condition, a pavement preservation strategy in conjunction with widening is recommended if warranted, including grinding the existing rigid pavement where warranted. This provides a smooth riding surface and can eliminate old striping and pavement markings. Grinding the lane next to the proposed widening is required when the existing International Roughness Index (IRI) exceeds 90 inches per mile in order to provide a smooth platform for the paving machine to construct the adjacent pavement structure. Pavement preservation strategies are discussed in Index 603.3 and in the *Concrete Pavement Guide*. Additional information on procedures for concrete pavement preservation can also be found in Topic 624.

(d) For concrete pavement that will require rehabilitation within ten years, the widening project should consider future compatibility of the proposed structure with the eventual concrete pavement rehabilitation strategy. Pavement rehabilitation strategies are discussed in Index 603.4 and procedures for concrete pavement rehabilitation can be found in Index 625.1.

(e) If the existing adjacent pavement to remain was a previously cracked, seated, and asphalt overlaid concrete roadway, then the new pavement structure for the widening project should match the structural layers of the existing pavement. This is done by placing asphalt concrete over a concrete base or lean concrete base thick enough to match the concrete layer in the existing pavement. Excluding any cement treated base, the thickness of the new concrete base should not be less than 0.35-feet. Where needed to match existing or add structural capacity, the new pavement structure should include an aggregate base or subbase. To provide a uniform surface for the widening and existing pavement, mill and replace 0.15 foot of the existing asphalt surface course~~.~~ or if the new asphalt concrete surface course required for the new pavement structure is thicker than the existing, the existing shall be overlaid a minimum of 0.15 feet to match the top surface of the new asphalt concrete layer. Figure 682.4B shows a typical pavement widening structure adjacent to existing previously cracked, seated and asphalt overlaid concrete pavement.

(3) *Widening of Asphalt Roadways* - The following design standards should apply when widening asphalt roadways:

(a) When widening asphalt pavement, continuity with the existing pavement should be provided whenever it is economically feasible. At a minimum, the design should use compatible materials and provide for adequate drainage underneath the existing pavement. This may require constructing the top of subgrade for the widening at the same or lower elevation than the existing subgrade, and extending underdrains from the edge of the existing pavement to an outlet beyond the new pavement structure.

(b) When widening adjacent to existing asphalt pavement that is in good condition, a pavement preservation strategy in conjunction with widening such as placing a non-structural wearing course over the widening and existing pavement should be done. This provides a surface with a uniform appearance, a surface course with equivalent future maintenance requirements, a clean surface for new striping configurations, as well as elimination of pavement joints which are susceptible to water intrusion and early fatigue failure.

If the new asphalt concrete surface course required for the new pavement structure is thicker than the existing, the existing shall be overlaid a minimum of 0.15 feet to match the top surface of the new asphalt concrete layer.

If the existing pavement exhibits oxidation, raveling, or minor cracking, it is recommended to mill 0.15 foot of the existing asphalt surface and overlay across the entire existing pavement and new section as shown in Figure 682.4C. The overlay joint should be offset 1.0 foot from the underlying vertical interface between existing and new pavement to improve the impermeability of the interface in the short-term. (The underlying vertical interface at the widening will eventually cause reflective cracking through to the surface.)

Pavement preservation strategies are discussed in Topic 634 and in the Maintenance Technical Advisory Guide (MTAG). Additional information on procedures for asphalt pavement preservation can also be found in Index 603.3.

(c) For asphalt pavement exhibiting major distress that need rehabilitation work, the widening project should include an appropriate pavement rehabilitation strategy for the existing pavement structure at least in the lane adjacent to the widening to obtain a smooth riding surface. In such cases, project scoping and other engineering decisions should take into account cost as well as other project considerations such as traffic safety to determine whether pavement rehabilitation of the existing roadway should be included with the pavement widening project. Pavement rehabilitation strategies are discussed in Topic 635 and procedures for asphalt pavement roadway rehabilitation can be found in Index 603.4.

(d) Widening of asphalt roadways with concrete should not be done except in the following cases:

(1) Concrete pavement will be placed across all the truck permitted lanes.

(2) The concrete pavement joint will be located at the proposed lane line (or ultimate lane line if project is just an interim stage of an ultimate project)

(3) There is a funded project to replace the existing lanes with concrete within the next 10 years.

When an asphalt roadway is widened with concrete the existing asphalt pavement should be replaced with concrete and at the same time the entire pavement should be overlaid or, at a minimum, designed to be overlaid with concrete in the future.

(4) *Drainage of Pavement Widening Structure:* Perpetuate pavement drainage in accordance with Chapter 650. The pavement structure of the widening should be designed where feasible to provide a path for subsurface water drainage to the edge of pavement. If it is not feasible to accomplish this, then consult with Headquarters Pavement Reviewers for other options.

682.5 Other Considerations

In addition to the foregoing design considerations, the following measures should be taken into account when constructing a pavement widening project.

(1) *Crack Sealing* - An aggressive crack sealing program will limit the amount of precipitation runoff from entering into the structure. Consideration should be given to using geosynthetic pavement interlayers over the joint between new and existing pavement prior to applying the full-width overlay to delay reflective cracking.

(2) *Treatment of the Subgrade* - Treatment of the subgrade under the widened section is recommended as an effective strategy to reduce moisture fluctuations at the new pavement edge which in turn should reduce the potential for longitudinal edge cracking. An alternative to treatment of the subgrade may be to use a subgrade enhancement at the subgrade/base interface. Treatment should be accomplished below the level of the old asphalt base.

(3) *Selection of the Base Material* - Selection of the new base material should be based on laboratory evaluation of both new and existing materials to compare the moisture susceptibility of each. Preferably, the moisture susceptibility of the existing and new base materials should be about the same. A material that is more highly moisture susceptible may draw moisture from both the original section and from outside the structure. A material that is less moisture susceptible may send moisture into the original base, particularly during the original curing process. It should also be noted that premature problems can be experienced when pavements with asphalt bases are widened with different base material, especially cement treated base. Cracks form at the longitudinal joint and moisture ingress often leads to rapid deterioration of the existing section.

(4) *Treated Base Sections* - Other considerations will closely parallel those discussed in Index 662.2 for treated base materials. There are cases where it may be desirable to use full-depth HMA for the widening to expedite construction, even though the base for the existing pavement was cement-treated material. This strategy should not cause subsurface moisture flow problems (“bath tub” effect) provided that the cement treated base is not moisture susceptible. Laboratory

evaluation of core samples will determine the degree of moisture susceptibility of the existing base.

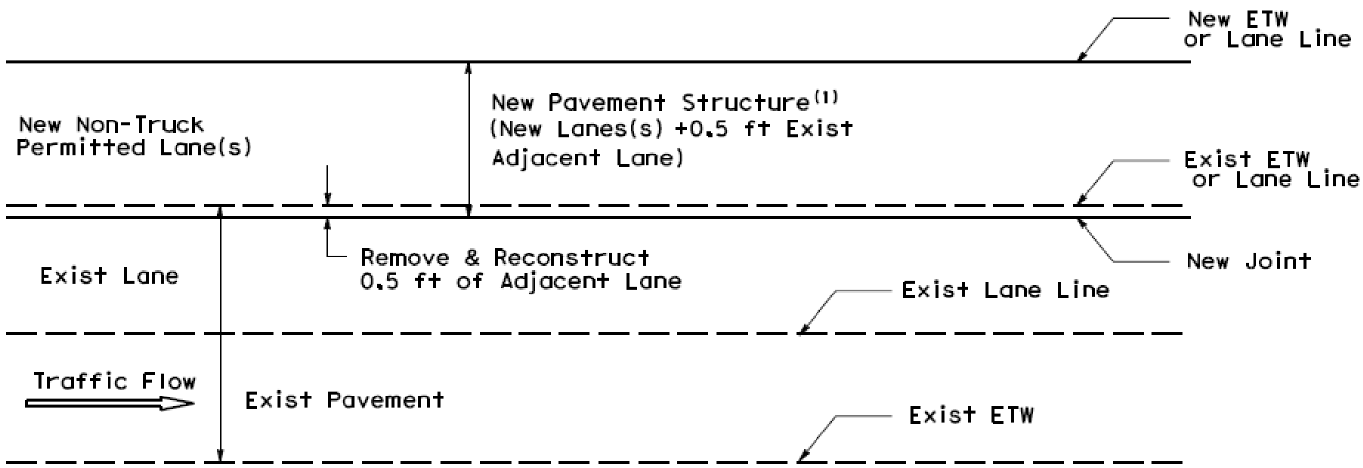
682.6 Life-Cycle Cost Analysis for Widening Projects

In addition to selecting the type of pavement for the widening project, as discussed in Topic 619, life-cycle cost analysis is a key component in determining how best to maintain both new and existing pavements over time and whether it is better to design the widening to match the life of the existing pavement or plan for the upgrading of the existing pavement to match the new pavement. When doing a life-cycle cost analysis for pavement widening, it is often best to perform the life-cycle cost analysis on how best to maintain the existing pavement first since the type and condition of the existing pavement will often influence the engineering of the new pavement. Life-cycle cost analysis is discussed further in Topic 619 and the Life-Cycle Cost Analysis Procedures Manual.

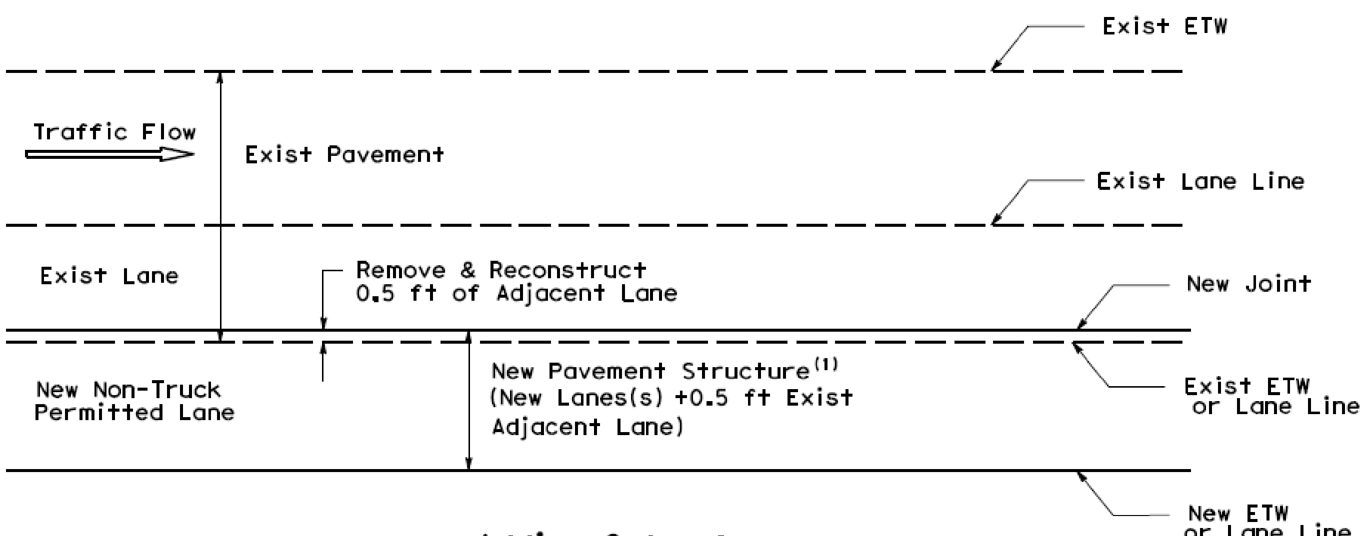
Figure 682.4A

Typical Concrete Pavement Widening

Median Lane and Outer Lane



Adding Median Lane



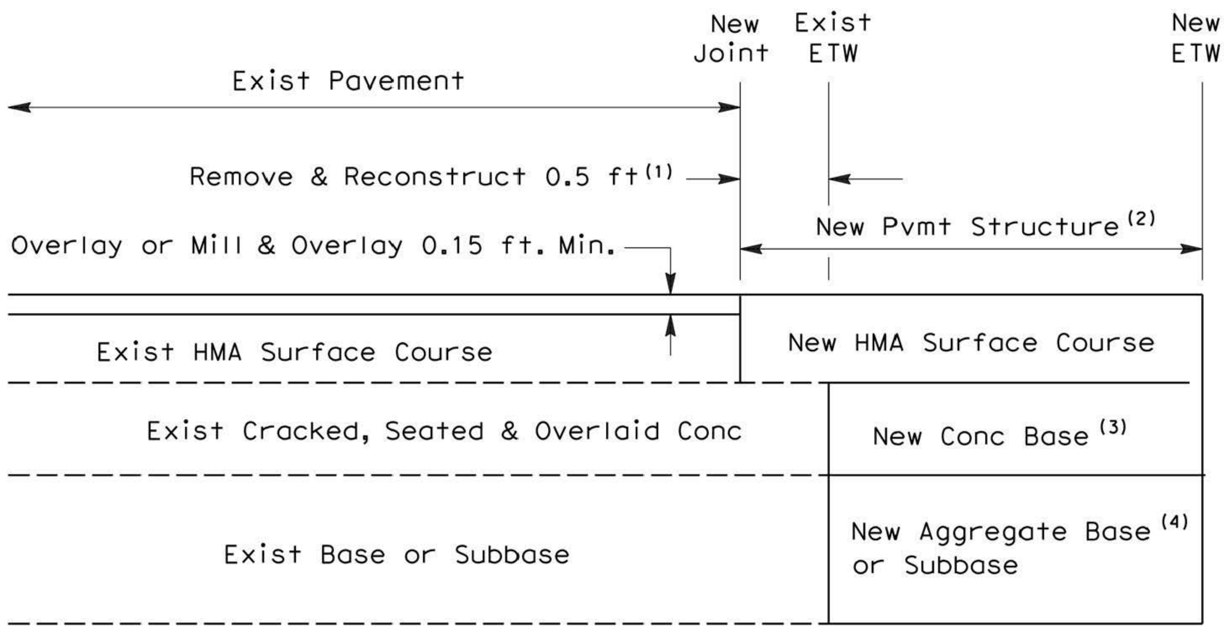
Adding Outer Lane

NOTES:

(1) See Index 623.1 and Tables 623.1B – M for details on concrete pavement structure design.

Figure 682.4B

Widening Previously Cracked, Seated, and HMA Overlay Concrete Pavement in Good Condition



NOTES:

(1) See Figures 682.4A for additional details.

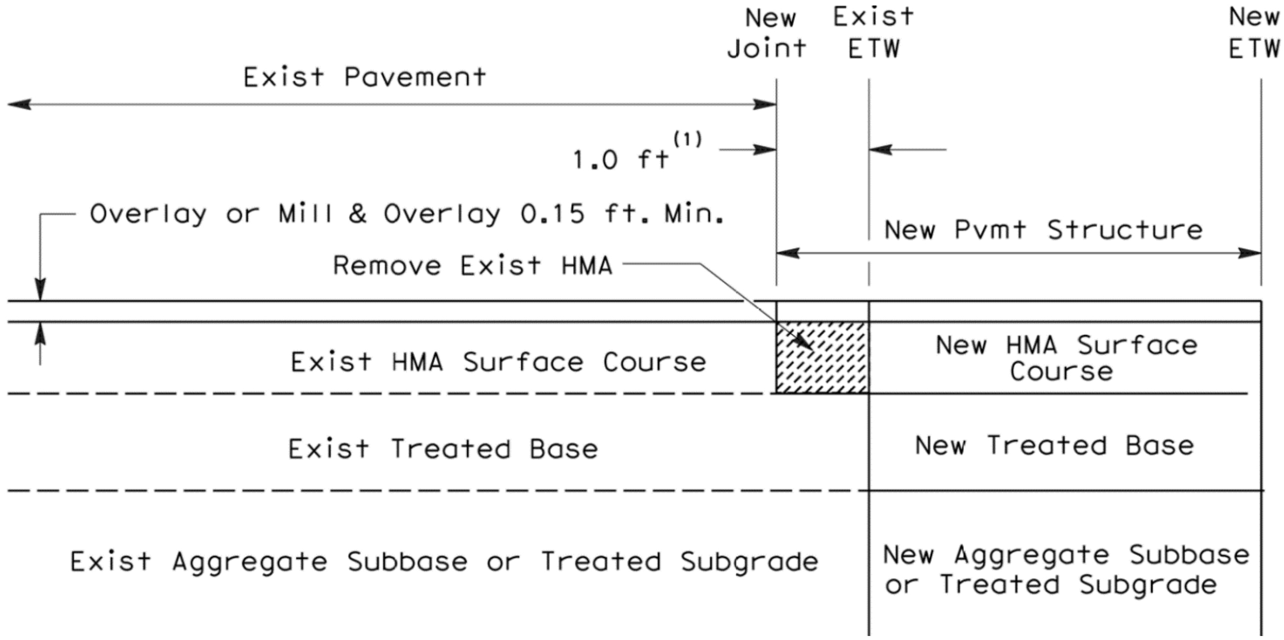
(2) Match the structural layers of the existing pavement for situations described in section 682.4 (2) (e).

(3) Match thickness of adjacent concrete but not less than 0.35 feet.

(4) When needed to match existing treated base, granular base/sub base, or add structural capacity.

Figure 682.4C

Widening Asphalt Pavement in Good Condition



NOTES:

(1) Offset overlay joint by 1.0 feet from the underlying vertical interface between existing and new pavement.

CHAPTER 700
MISCELLANEOUS STANDARDS

Topic 701 - Fences

Index 701.1 - Type, Intent and Purpose of Fences

(1) *Purpose of Fences.* Fences constructed by the Department serve the purposes of either establishing control of access, providing visual demarcation or re-establishing private property lines.

Where the purpose of the fence is access control, installation is intended to establish that access is restricted; such fencing is not intended to serve as a complete physical barrier. The adjacent private property owner will assume responsibility for the construction of any fencing or other facilities necessary to contain their personal property.

(2) *Type and Intent of Fences.* The type and intent of fences should be as described herein and in the Standard Plans and Standard Specifications.

Fence materials, including gates, installed anywhere within the State right of way are considered Departmental fences and are owned, controlled and maintained by Caltrans forces.

As a right of way consideration, Caltrans may construct fences and gates outside the State right of way. Fences and gates constructed outside the State right of way are considered private fences and are owned, controlled and maintained by the external property owner where Caltrans retains neither rights nor obligations for such fences once constructed.

(a) Fences for freeway and expressway access control are Departmental fences commonly placed immediately inside the State right of way to help enforce observance of the acquired access rights. See Index 701.2 for more detailed guidance.

(b) Median fences are Departmental fences constructed to help prevent indiscriminate crossings of the median by vehicles or pedestrians. These fences are a subset of freeway and expressway access control fences. See Index 701.2 for more detailed guidance.

(c) Private fences may be constructed adjacent to conventional highways if provided via right of way agreement. Placement is typically parallel to the State right of way and outside Caltrans property. See Index 701.3 for more detailed guidance.

Private fences may also be allowed within Caltrans right of way to restrict access to a private facility crossing or as an aesthetic enhancement of Departmental fence. Neither of these situations is common and should be avoided if possible. See Indexes 701.2(3)(e) and 701.3.

(d) Temporary fences are commonly used during project construction to temporarily control access and/or create a visual screen. Temporary fences are also commonly used during reconstruction of either Departmental or private fences. See Index 701.4 for more detailed guidance.

(e) Environmentally Sensitive Area (ESA) fence is a specialty type of temporary Departmental fence, placed within the limits of a construction project and used to identify the location of sensitive biologic resources while establishing a visible boundary. Orange fabric is used to ensure contractor personnel awareness of the ESA location. See Index 701.5 for more detailed guidance.

(f) Species protection fences are Departmental fences placed within Caltrans right of way and used to prohibit movement of specific threatened or endangered species onto the highway. These fences are unique in composition to the species being addressed. Species protection fences may be placed for either permanent or temporary applications. See Indexes 701.2(3)(b) and 701.5 for more detailed guidance.

(g) Enclosure fences are Departmental fences of various types used to secure the perimeter around equipment storage areas from theft or vandalism, provide a perimeter around maintenance stations or other facilities, or otherwise enclose areas intended for

Caltrans use. See Index 701.5 for more information.

701.2 Freeway and Expressway Access Control Fence

(1) *Placement.* **Departmental fences shall be provided on freeways and expressways to control access, except as otherwise provided under paragraph (3)(e) below.** Freeway fencing or equivalent access control should extend to the limit of the legal access control on local streets at ramp termini.

(2) *Standard Fence Types.* The standard types of freeway fence are:

(a) Chain Link Fencing--Type CL-6 fence or equivalent access control should be used along the right of way and in the outer separation in urban or developed areas.

(b) Other Fencing--In rural areas, fences on freeways normally should be either Barbed Wire, (Type BW), or Wire Mesh, (Type WM), on either wood or metal posts. Wood posts may be more aesthetic than metal posts, depending on the surrounding terrain.

(c) Median Fencing--Type CL-4 fence, with the distance from the ground to the bottom tension wire increased to 6 inches, should be used where median fencing is required.

(3) *Exceptions to Standard Fence Types.*

(a) If walls or fences equal to or better than the standard fence in durability, maintenance requirements, and dimensions exist along the right of way line, the standard fence may be omitted or removed. To avoid a gap in the access control, standard fences should be securely joined to the existing fence or wall at its terminals, if the access control line extends beyond these points.

(b) Fences of special design may be installed where needed for wild animal control.

(c) In special cases, where improvements are scattered, the area is aesthetically sensitive, and a lower fence would be in keeping with the height of adjacent property fence, a Type CL-4 fence may be substituted for Type CL-6 along the right of way in locations where Type CL-6 would otherwise be used.

(d) Fencing may be omitted in remote areas where access control appears unnecessary.

(e) In special cases, nonstandard fencing may be considered at freeway ramp terminals on local streets when the adjacent property either is, or is proposed to be, developed in such a way that the owner feels that standard fencing is aesthetically objectionable. If it is concluded that the objection is valid, a more compatible facility may be substituted, subject to the following controls:

- Preference should be given to retaining the standard fence along the ramp to the end of the curb return or beginning of the taper on the local road. Where this is not reasonable, there may be substituted a fence or wall of equal or better durability and utility that is at least 4 feet high relative to the grade of freeway right of way line. Walls, ornamental iron fences with closely spaced members, or chain link fences are examples of acceptable possibilities.
- Along the local road, beyond the end of the curb return or the beginning of the taper, a facility of somewhat lower standards may be employed, if considered appropriate. The minimum allowable height is 2.5 feet above the grade at the edge of the right of way. In addition to the fence types suitable for use along the ramp, split rail fences, wooden picket fences, and permanent planter boxes are examples of possibilities. The intent is to delineate the access control line and discourage access violations in an effective manner.
- Generally, all costs for the removal of the existing freeway fence and the installation and future maintenance of a nonstandard fence are to be the property owner's responsibility under the terms of the encroachment permit authorizing the substitution. On new construction, the property owner is to assume similar costs and responsibilities subject to a credit for the value of a standard fence.

(4) *Location of Fences.* Normally, fences on freeways should be placed adjacent to, but on the freeway side of the right of way line.

Fences in the outer separation normally should be placed as shown in Figure 307.4B so that the area outside of the fence may be relinquished to the local agency.

When viewed at a flat angle, chain link fencing restricts sight distance. This fact should be considered in the location of such fencing at intersections. To eliminate hand maintenance, right-angle jogs should be avoided.

(5) *Locked Gates.* Locked gates may be provided in access control fences in special situations. A proposal for a locked gate must address a necessity. Although openings controlled by locked gates do not constitute access openings in the usual sense of access control, they must be shown on the plans. When locked gates are proposed there must be a specific reason for each gate. All gates must be kept locked and secured. Locked gates fall into two categories:

(a) Locked gates to be used exclusively for access by highway maintenance forces do not require FHWA approval and may be approved by the District Director. The integrity and security of this access must always be assured. Maintenance forces must also keep gates locked when not being used for the access of persons or equipment. When locked gates are to be used exclusively by highway maintenance forces, one or more of the following criteria apply:

- A circuitous route would be eliminated.
- The gate access would minimize the exposure of maintenance workers to highway traffic.
- Parking is available outside the gate.
- The gate would allow slow moving equipment to be kept off the highway.
- The site is not accessible to maintenance personal or equipment from the freeway.

(b) Proposals for locked gates to be used by utility companies must be submitted to the District Director for approval. The gate submittal must present all pertinent facts and alternate solutions.

Locked gates to be used by other public agencies or by non-utility entities require FHWA approval if the gate is on an Interstate route.

When proposals for locked gates requiring FHWA approval are included in the plans for new construction, including landscaping projects, FHWA approval of such gates will be included in FHWA approval of the project PS&E. Subsequent installations requiring FHWA approval must be submitted separately to FHWA by the Division of Design after approval by the Chief, Division of Design.

701.3 Private Fences

(1) *Placement.* Caltrans will construct or pay the cost of fences on private property only as a right of way consideration to mitigate damages. Caltrans' construction of such fences should be limited to:

(a) The reconstruction or replacement of existing fences.

(b) The construction of fences across property that had been previously enclosed by fences.

These criteria apply to all private as well as public lands.

(2) *Private Fences Inside the State Right of Way.* Private fences may be constructed within the State right of way via Encroachment Permit to restrict access to facilities (e.g., canals) crossing under or through Department-owned property. A Maintenance Agreement must be executed to provide for future maintenance of the fence and allow access to the private utility.

701.4 Temporary Fences

(1) *Placement.* Temporary fences are located where necessary in accordance with construction contractor activities and where the right of way rights have been acquired.

(2) *Types of Fences*. Temporary fence design should conform to the needs of the situation and the length of time to be used. In most access control or demarcation applications the fence fabric will conform to permanent fence standards, while lesser requirements may apply to posts and post footings to more readily accommodate removal when no longer needed.

Temporary fence used during reconstruction of private fences must be of a type adequate to meet the permanent private fence purposes.

701.5 Other Fences

(1) *ESA and Species Protection Fences*. District Environmental Unit staff must specify the required placement limits and locations for ESA and species protection fences.

ESA fence material requirements are described in Section 14 of the Standard Specifications.

Species protection fences will be uniquely designed to meet the needs of the target species. District Environmental staff will provide information on the necessary design parameters. In many instances, species protection fence will be able to be directly attached to existing freeway or expressway access control fence and thus preclude the need for separate posts. Where species protection fence is to be constructed along conventional highways, it must be constructed inside the State right of way and should not be attached to any private fence that may exist.

(2) *Enclosure Fences*. Because these fences are commonly intended to provide security for Caltrans facilities, the facility type and location will often dictate the fence design to be used. Standard chain link (CL-6) fence is most common, but additions (barbed wire extension arms) or alternative designs may be considered. When slats are included as an element of the design, wind forces are considered and a resulting increase in the size and depth of embedment of fence posts as well as an increase in the size of the concrete footing occurs. See the Standard Plans for further details including post size and footing dimensions for various fence heights.

Typically District Maintenance or Traffic Operations will specify any unique design requirements for enclosure fences as they will assume responsibility after construction.

Topic 702 - Miscellaneous Traffic Items

702.1 References

(1) *Guardrail and Crash Cushions.* See Traffic Safety Systems Guidance.

(2) *Markers.* See Part 3 of the California Manual on Uniform Traffic Control Devices (California MUTCD).

(3) *Truck Escape Ramps.* See Traffic Bulletin No. 24, (1986) and the NCHRP Report 178.

(4) *Mailboxes.* See the AASHTO Roadside Design Guide, 3rd Edition, Chapter 11, "Erecting Mailboxes on Streets and Highways."

Topic 703 - Special Structures and Installation

703.1 Truck Weighing Facilities

The Division of Traffic Operations coordinates the design and construction of truck weighing facilities with the California Highway Patrol in Sacramento. Typical plans showing geometric details of these facilities are available from the Headquarters Division of Traffic Operations. Districts should refer truck weighing facility maintenance issues to their District maintenance units.

See Index 107.1 for additional details on roadway connections for truck weighing facilities.

703.2 Rockfall Restraining Nets

Rockfall Restraining Nets are protective devices designed to control large rockfall events and prevent rock from reaching the traveled way. The systems consist of rectangular panels of woven wire rope vertically supported by steel posts and designed with frictional brake elements capable of absorbing and dissipating high energies. For additional information on the characteristics and applications for rockfall restraining nets, designers should contact the Division of Engineering Services - Geotechnical Services (DES-GS).

Topic 704 - Contrast Treatment

704.1 Policy

In general, delineation should be composed of the standard patterns discussed in Part 3 of the California MUTCD.

Markings include lines and markings applied to the pavement, raised pavement markers, delineators, object markers, and special pavement treatments.

Contrast treatment is designed primarily to provide a black color contrast with an adjacent white surface. Normally, contrast treatment should be used only in special cases such as the following:

(a) To provide continuity of surface texture for the guidance of drivers through construction areas.

(b) To provide added emphasis on an existing facility where driver behavior has demonstrated that standard signs and markings have proven inadequate.

When contrast treatment is applied, a slurry seal should be used.

See Part 3 of the California MUTCD for additional information on contrast treatment.

Topic 705 - Materials and Color Selection

705.1 Special Treatments and Materials

Special materials or treatments, such as painted concrete, or vinyl-clad fences, are sometimes proposed for aesthetic reasons, or to comply with special requirements.

The following guidelines are to be used for the selection of these items:

(a) Concrete should not be painted unless exceptional circumstances exist, due to the continuing and expensive maintenance required. Concrete subject to unintentional staining should be textured during construction to minimize the visibility of stains, if other methods of controlling stain-producing runoff or dripping cannot be accomplished.

(b) Vinyl-clad fences are sometimes specified for aesthetic reasons. The cost of this material is higher than that of galvanized steel. Special consideration should be given to the life-cycle cost and maintainability of vinyl-clad fencing prior to selection for use. The use of black or green vinyl-clad mesh for access control fencing, safety fencing at the top of retaining walls, and pedestrian overcrossing fencing is acceptable.

705.2 Colors for Steel Structures

Colors for steel bridges and steel sign structures may be green, gray, or neutral tones of brown, tan, or light blue.

Criteria for selection of colors are:

(a) General continuity along any given route.

(b) Coordination of color schemes with adjacent Districts for interdistrict routes.

(c) Requests from local agencies for improvement of aesthetics in their community.

Color selection for steel bridges should be mutually satisfactory to the Division of Engineering Services and the District. The Division of Engineering Services (DES) will initiate the color selection process by submitting the proposed color to the District Landscape Architect for review. The color for steel sign structures will be selected by the District Landscape Architect.

Topic 706 - Roadside Management and Vegetation Control

706.1 Roadside Management

Consider the full life-cycle cost of transportation improvements including the long-term cost of maintenance. The design alternative with the lowest initial construction cost may not be the best solution if this approach will include high recurring maintenance costs. Designers should strive to select design approaches that do not require extensive recurring long-term activities.

The design should contribute to the safety of Department maintenance workers by incorporating techniques that eliminate or reduce worker exposure to traffic. See Index 901.2.

The following conditions must be considered in projects:

- Guardrail, including standard railing, terminal system end treatments, guard railing at structure approach and departures, and at fixed objects should include vegetation control. For more detailed information regarding placement of vegetation control consult with both the District Landscape Architect and District Maintenance. See the Standard Plans for vegetation control.
- Thrie beam barrier, including single thrie beam barrier, double thrie beam barrier, at structure approach and at fixed objects should include vegetation control. For more detailed information regarding placement of vegetation control consult with both the District Landscape Architect and District Maintenance. See the Standard Plans for vegetation control.
- Unpaved narrow strips often result from the construction of noise barriers or concrete barriers beyond the paved shoulder edge. Unpaved strips 15 feet or less in width, parallel and immediately adjacent to the roadway, should be paved to the barrier or wall. Paving these areas eliminates the need for manual vegetation control, and allows automated equipment to remove litter and debris. Pavement requirements are consistent with the guidance contained in this manual. Contrasting surface treatment such as markings, delineation, or color may also be provided so drivers can distinguish these areas from those intended for vehicular use. Consult with the District Landscape Architect for contrasting surface selection.
- Unpaved areas greater than 15 feet in width may include vegetation control techniques such as weed control mats, patterned asphalt or stamped concrete paving, or the planting of low maintenance vegetation such as native grasses. Consult the District Landscape Architect and District Maintenance to select an appropriate vegetation control technique.
- Noise barriers should be designed with a textured aesthetic treatment and/or planted with vines to reduce maintenance required to control graffiti. Index 904.7 contains information of the planting on noise barriers.
- Unpaved area beyond the gore pavement should be paved as per Index 504.2(2).
- When placing roadside facilities that require recurring maintenance, the designer should strive to include improvements that facilitate safe maintenance access such as maintenance vehicle pullouts, maintenance access paths, walk gates and vehicle gates. It is preferred that access be provided from outside the right-of-way for all facilities that require maintenance access.
- When placing noise barriers in areas with a narrow right of way, the designer should consider locating a concrete safety shape barrier 3 feet from the face of the noise barrier to provide protected maintenance access.

Formal safety reviews for roadside management issues should be accomplished as discussed in Index 110.8. Consult the District Landscape Architect and District Maintenance unit early during design development to identify and address potential roadside management issues, such as avoiding the redundant placement of roadside facilities, or allow for the consolidation of roadside facilities.

706.2 Vegetation Control

Weed control fabric or preemergent chemicals may be placed under pavement to prevent weed growth through medians, traffic islands, and other paved areas.

The Division of Maintenance is responsible for the selection of herbicides. Approval is required for any changes from the currently approved Standard Specifications and Standard Special Provisions for pesticides and herbicides.

Since preemergents may be transported by water, they should be mixed with surfactants to prevent affects on environmentally sensitive areas, habitat, native vegetation, landscape plantings, agricultural crops, adjacent residential, commercial or recreation areas, streams, or water bodies.

Before specifying preemergents, the District Landscape Architect and District Landscape Specialist should be consulted to determine the possibility of future planting.

Topic 707 - Slope Treatment Under Structures

707.1 Policy

Structure end slope should be treated to:

(a) Protect slopes from erosion.

(b) Improve aesthetics.

(c) Reduce long term maintenance costs.

Caltrans maintenance, landscape architecture, materials, design, and other affected units will furnish input to determine slope treatment needed at each site. Local agency input should be obtained for urban undercrossings.

All types of slope treatments require adequate drainage facilities for water from the upper roadway. Inadequate drainage is a major source of slope erosion.

707.2 Guidelines for Slope Treatment

(a) Full slope paving shall be installed where it is anticipated that erosion by pedestrians, wind, storm water, or other causes will occur. High landscape maintenance costs caused by inadequate moisture, sunlight, instability to establish vegetation etc., may also justify the use of full slope paving in lieu of planting. The District Landscape Architect will provide aesthetic input slope paving and identify irrigation conduit location(s).

(b) Landscaped structure end slopes may be justified when adjacent slopes are landscaped and when landscaping is compatible with adjacent development. Conditions must exist where plants would have a strong likelihood of survival.

(c) Bare slopes have minimum initial costs and higher maintenance costs which vary with the site. Bare structure end slopes may be justified at rural sites and other areas where anticipated maintenance activity will be low and there is little likelihood for erosion. Appropriate drainage design is critical when slopes are left bare.

(d) Adequate drainage facilities must be provided to prevent saturation of abutment foundation materials and damage to slope treatment.

(e) Additional protection may be required at stream crossings to provide for flow velocity.

707.3 Procedure

Based on consultation with the District Landscape Architect and Structures Bridge Architect and in consideration of economic and aesthetic factors, the District will determine, and set forth with the bridge site plan submittal, the type of slope treatment indicating whether:

(a) The Division of Engineering Services is to design the slope treatment with the bridge and include the cost in the Structure items; or

(b) The District will design the slope treatment and include the details with the road plans.

objectionable velocities resulting in abrasion of the culvert itself or in downstream erosion. In most cases, provided the culvert is not flowing under pressure, an increase in the culvert size does not appreciably change the outlet velocities.

(2) *Tailwater.* The term, tailwater, refers to the water located just downstream from a structure. Its depth or height is dependent upon the downstream topography and other influences. High tailwater could submerge the culvert outlet.

821.5 Effects of Tide and Storm

Culvert outfalls and bridge openings located where they may be influenced by ocean tides require special attention to adequately describe the 1% probability of exceedance event.

Detailed statistical analysis and use of unsteady flow models, including two-dimensional models, provide the most accurate approach to describing the combined effects of tidal and meteorological events. Such special studies are likely warranted for major hydraulic structures (See HEC-25, Volume 2, October 2014 - "Highways in the Coastal Environment: Assessing Extreme Events"), but would typically be too costly and time consuming for lesser facilities. If the risk factors and costs associated with a failure of the drainage facility (such as, bridge or culvert) located in a tidal environment do not support conducting such a detailed analysis, the following guidance can be used to select ocean or bay water levels and flood events to adequately estimate the 1% Annual Exceedance Probability (AEP). However, the effect of climate change or sea-level rise is not included in this analysis. Sea-level rise needs to be evaluated for all coastal facilities using Section 883.2 ("Design High Water, Design Wave Height and Sea-Level Rise") of this manual or any other appropriate method.

The daily maximum ocean water levels vary significantly on a fortnightly basis with the spring-neap cycle, where the highest daily maximum water levels occur during spring tides and the lowest daily maximum water levels occur during neap tides. The annualized probability of the daily maximum ocean water level $\hat{\eta}_T$, with a return period T year, that may exceed a certain elevation can be expressed using a stage-frequency relationship. Such a relationship has been developed using the water level data received from the National Oceanic and Atmospheric Administration (NOAA) tide gauge stations located in the California coast. These gauge stations typically record water levels every six minutes, and those measurements account for all the combined astronomical, meteorological and climatic effects that have influenced the water levels in the coastal regions of California. The NOAA has periodically verified those ocean water levels for multi-decadal periods which are referred to as "tidal epochs." The basis for developing the Annual Exceedance Probability (AEP) for ocean water levels reaching or exceeding a particular elevation in a day is first, finding the ratio of the total number of daily maximums water levels that reach or exceed that elevation over the total number of daily maximum water level measurements in each year and then averaging the result over the years that make up the period of record of that tide gauge. Finally, these processes are repeated for a range of elevations to develop a continuous relationship with the corresponding AEP. Figure 821.1 shows an example of the continuous distribution where the daily maximum ocean water level for outer San Francisco Bay is plotted against the AEP expressed in percentage. This curve has been derived based on NOAA tide gauge station 9414290 for period of record June 30, 1854 to present. AEP for some tidal datums are also shown here. For this location, the annual probability of the daily maximum ocean water level exceeding the Mean High Water (MHW) is 73%. It is to be noted that all tidal datums in this analysis are based on the tidal epoch 1983 to 2001. Daily maximum ocean water levels are primarily determined by the astronomic ocean tides which again are controlled by the orbital mechanics of the earth, moon, and sun. These astronomic processes are completely independent of rainfall, snowmelt or watershed management practices that directly influence streamflow. Since the ocean water level and flood are two statistically independent variables, the annual compound probability would be the product of the probabilities of these two events, as shown below:

$$P(Q_T, \hat{\eta}_T) = P(\hat{\eta}_T) \cdot P(Q_T)$$

- $P(\hat{\eta}_T)$ is the annual exceedance probability of the daily maximum ocean water level
- $P(Q_T)$ is the annual exceedance probability of the daily maximum streamflow
- $P(Q_T, \hat{\eta}_T)$ is the annual exceedance probability of these two events that may occur simultaneously at a specific location
- T is the return period, also known as recurrence interval, of each of the above probabilities expressed in year

Since the compound probability of 1% is of interest, then

$$0.01 = P(\hat{\eta}_T) \cdot P(Q_T).$$

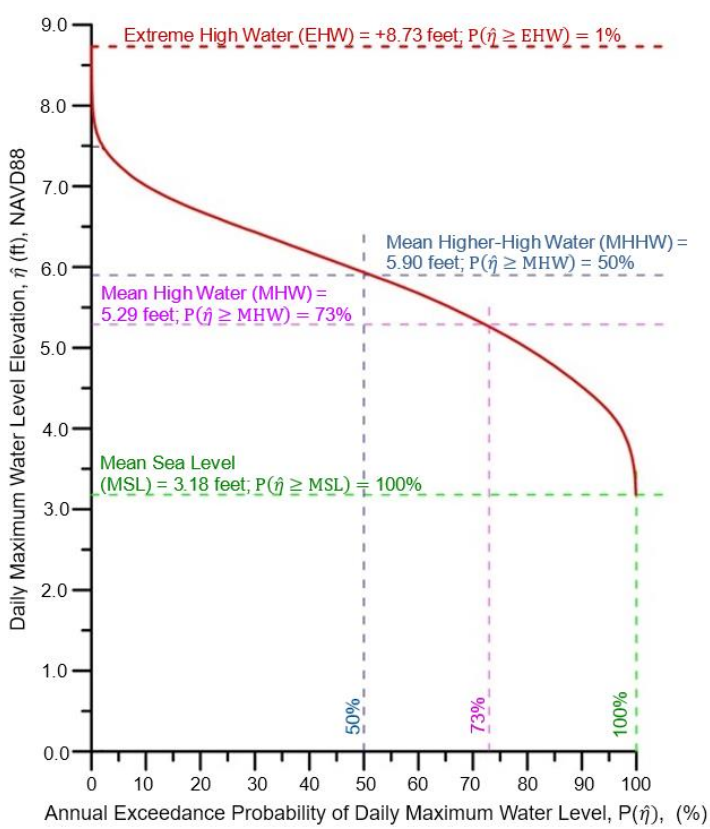
The annual exceedance probability of streamflow $P(Q_T)$ is the reciprocal of the corresponding return period expressed in year, or $\frac{1}{T}$. Using the above equation, a compound probability of 1% would occur when:

$$P(\hat{\eta}_T) = 0.01 \times T \text{ or } T\%$$

In other words, when an 1% AEP of these two events is jointly achieved, the numeric value of the flood recurrence interval expressed in year is the same as the annual exceedance probability of the daily maximum ocean water level expressed in percentage. Therefore, if the return period of any flood event is selected using the numeric value in the X-axis of Figure 821.1, the value in the Y-axis of the curve would represent the tailwater level such that the compound probability of these two events to occur concurrently in a year has a 1% chance of exceedance. Likewise, if any water level is chosen from the Y-axis, the corresponding value in the X-axis would represent the return period of the flood expressed in year, where the compound AEP is 1%.

Figure 821.1

Annual exceedance probability (AEP) of daily maximum ocean water level



For instance, when determining the backwater effect by a hydraulic structure near outer San Francisco Bay, any of the following pairs of boundary conditions obtained from Figure 821.1 would represent the compound probability exceedance of 1%:

- 100-year flow and a tailwater level of 3.18 feet
- 73-year flow and a tailwater level of 5.29 feet
- 50-year flow and a tailwater level of 5.90 feet

Figure 821.1 can also be interpreted as the one-percent compound frequency curve for this location, if we consider the numeric value of the X-axis as the flood recurrence period in year, instead of % AEP of the water levels.

There exists a wide variation in ocean water levels across the State of California, particularly when comparing water levels on the exposed open coastline with those in the bays, estuaries and semi-enclosed water bodies. Consequently, there is a great deal of variation among the one-percent compound frequency curves calculated from tide gauge stations on the open coast versus those in the bays. Figure 821.2 identifies a map of open coast and bayfront water level provinces and corresponding NOAA tide gauge stations for the state of California. For the purpose of this analysis, it has been considered that the available NOAA gauge data in each province reflect the tidal conditions at the geographic centroid of that province. The length of a province along the coast and the location of its boundaries are independent of the proximity of the gauge station in the host province, but rather is determined by the spacings between co-tidal lines. Co-tidal lines are the lines of constant tidal phase or lines joining points at which a given tidal phase (such as, mean high water or mean low water) would occur simultaneously. There is approximately a 2-hour tidal phase interval between the California/Mexican border and the California/Oregon border. The province boundaries are designated up-coast and down-coast, as proceeding from north to south or west to east on the open coast; and from outer-bay to inner-bay along the bayfront coasts. The extent of an open coast province has been determined in such a way that the tidal phase interval between the up-coast and down-coast boundary is 15-minute. For the bayfront coastlines, divisions between provinces inside of San Francisco Bay were determined by hydrodynamic tidal simulations (Barnard, et al., 2013; Elias et al, 2013)[1]; and inside San Diego Bay, tidal exchange modeling by Largier, (1995)[2] and Chadwick (1997)[3] were used to establish province boundaries. For each water level province shown in Figure 821.2, a one-percent compound frequency curve has been generated using the tidal level data of the corresponding gauge station. There are eight water level provinces (such as 1, 2, 2a, 3, 4, 5, 6 and 7) on the open coastline of California, and six additional provinces (such as 8, 9, 9a, 10, 11, & 12) on bayfront coastlines and estuaries in San Francisco Bay and in San Diego Bay. The corresponding one-percent compound frequency (or 1% compound AEP) curves are shown in Figure 821.3A through Figure 821.3N.

Table 821.1 lists the latitude and longitude of the boundaries of the water-level provinces and the controlling gauge stations. For each water-level province, the last column in Table 821.1 provides a characteristic length scale *λ*, and a distance-averaging length scale *L*. The characteristic length of each province represents the tidal propagation path length based on a 15-minute tidal phase interval. The distance averaging length scale *L* nominally represents the distance from the coastal centroid of the province to its boundaries. It is important to note that these distances are measured as the gross running length of shoreline (exclusive of the interior perimeter of minor embayments) for provinces on the open coast, or the distance along the axis of a bay between the end-points or apexes of provinces distributed around the shorelines of the semi-enclosed bays; such as, San Francisco Bay and San Diego Bay.

[1] Barnard, P.L., Jaffe, B.E., Schoellhamer, D.H., 2013. Preface for Special Issue of Marine Geology. Marine Geology Special Issue on Sediment Transport and Geomorphic Evolution in the San Francisco Bay Coastal System, 345, 1-2. https://doi.org/10.1016/j.margeo.2013.09.010.
Elias, E., Hansen, J., and Erikson, L.H. 2013. "San Francisco Bay Basic Tide Model", doi: 10.5066/F7DN4330.

[2] Largier, J., 1995, "A study of the circulation of water in San Diego Bay for the purpose of assessing, monitoring and managing the transport and potential accumulation of pollutants and sediment in San Diego Bay", submitted to California Water Resources Control Board, 19 pp. + app.

[3] Chadwick, D.B. 1997. Tidal Exchange at the Bay-Ocean Boundary. Ph.D. diss., University of California, San Diego.

Figure 821.2

California Open Coast and Bayfront Water Level Province Map

Note: Province 2a is a sub-cell of Province 2 and covers the coastal area around the entrance to San Francisco Bay, as well as the outer Bay; while Province 9a covers the Sacramento Delta east of the Carquinez Bridge.

Table 821.1

Boundaries, Locations and Length Scales of Water-level Provinces

Province	Up-Coast Boundary[1]	Down-Coast Boundary[2]	Location of Controlling Gauge Station	Length Scale[3], miles
Province 1	lat: 41°59'45.33"N long: 124°12'43.62"W	lat: 41°32'9.90"N long: 124° 4'55.46"W	lat: 41°44'37.19"N long: 124°11'52.59"W	λ =36 L = 18
Province 2	lat: 41°32'9.90"N long: 124° 4'55.46"W	lat: 38°17'38.86"N long: 122°59'57.35"W	lat: 40°44'28.90"N long: 124°12'54.10"W	λ =255 L = 127.5
Province 2a (San Francisco Bay Coastal)	lat: 38°17'38.86"N long: 122°59'57.35"W	lat: 37° 7'8.27"N long: 122°19'39.53"W	lat: 37°48'22.04"N long: 122°28'35.29"W	λ = 105 L = 52.3
Province 3	lat: 37° 7'8.27"N long: 122°19'39.53"W	lat: 35°14'43.93"N long: 120°54'10.12"W	lat: 36°36'27.43"N long: 121°53'31.85"W	λ =189 L = 94.5
Province 4	lat: 35°14'43.93"N long: 120°54'10.12"W	lat: 34°25'55.54"N long: 119°57'29.38"W	lat: 35°10'27.20"N long: 120°44'4.86"W	λ =106 L = 53
Province 5	lat: 34°25'55.54"N long: 119°57'29.38"W	lat: 34° 5'2.13"N long: 119° 3'41.57"W	lat: 34°24'15.93"N long: 119°41'33.24"W	λ = 62 L = 31
Province 6	lat: 34° 5'2.13"N long: 119° 3'41.57"W	lat: 33°44'16.64"N long: 118° 6'54.40"W	lat: 33°43'10.11"N long: 118°16'0.81"W	λ = 77 L = 38.5
Province 7	lat: 33°44'16.64"N long: 118° 6'54.40"W	lat: 32°31'42.37"N long: 117° 7'25.39"W	lat: 32°52'1.21"N long: 117°15'26.68"W	λ = 109 L = 54.5
Province 8	lat: 37°56'15.75"N long: 122°27'9.39"W	lat: 37°43'19.90"N long: 122°15'2.10"W	lat: 37°47'15.14"N long: 122°15'56.10"W	λ = 24.6 (East) λ = 9.2 (West) L = 12.3 (East) L = 4.6 (West)
Province 9	lat: 38° 8'31.45"N long: 122°23'57.87"W	lat: 37°56'15.75"N long: 122°27'9.39"W	lat: 38° 0'40.21"N long: 122°21'55.35"W	λ = 27.6 (North) λ = 15.2 (South) L = 13.8 (North) L = 7.6 (South)
Province 9a (Sacramento River Delta)	lat: 38° 3'31.02"N long: 122°15'51.88"W	lat: 38° 3'45.65"N long: 121°47'53.96"W	lat: 38° 3'31.75"N long: 122° 0'48.71"W	λ = 66.6 L = 33.3
Province 10	lat: 37°42'55.22"N long: 122°21'48.55"W	lat: 37°26'49.58"N long: 122° 1'6.19"W	lat: 37°30'45.72"N long: 122°12'35.64"W	λ = 65.8 L = 32.9
Province 11	lat: 32°43'27.47"N long: 117°13'36.47"W	lat: 32°40'36.43"N long: 117° 9'14.13"W	lat: 32°42'57.65"N long: 117°10'25.25"W	λ = 7.2 (East), λ = 5.4 (West) L = 3.6 (East) L = 2.7 (West)
Province 12	lat: 32°40'36.43"N long: 117° 9'14.13"W	lat: 32°35'57.83"N long: 117° 6'56.35"W	lat: 32°35'57.83"N long: 117° 6'56.35"W	λ = 15.6 L = 7.8

Notes: (1) On open coastlines, Up-Coast refers to the northern boundary; in bays, Up-Coast refers to the outer bay.
(2) On open coastlines, Down-Coast refers to the southern boundary; in bays, Down-Coast refers to inner bay.
(3) On open coastlines, λ = gross running length of province coastline exclusive of the interior perimeter of minor embayment; in bays, λ = tidal propagation length of the province; L = weighted averaging distance.

Figure 821.3A

**One-Percent Compound Frequency Curve for Province 1,
(Based on NOAA # 9419750, Crescent City)**

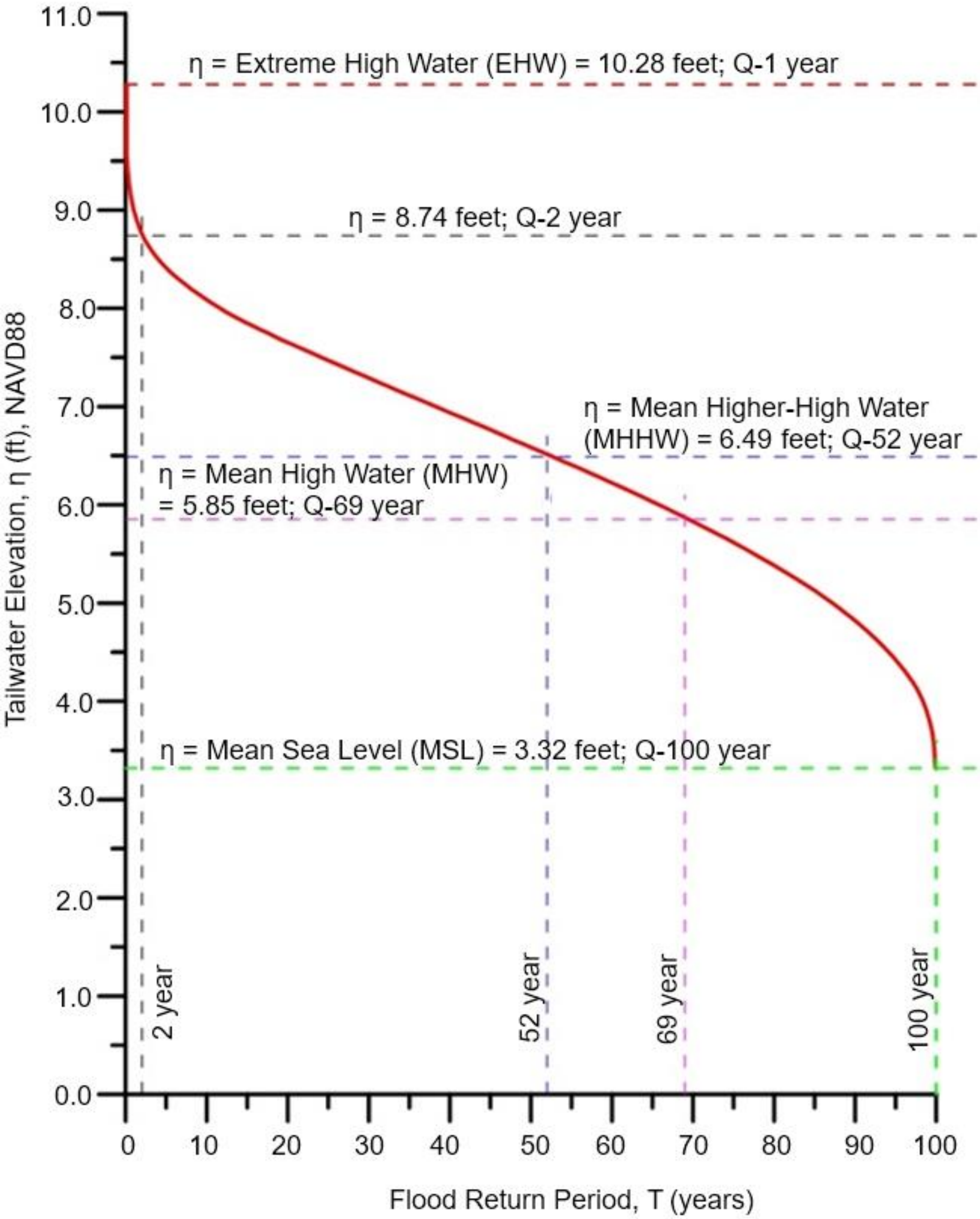


Figure 821.3B

One-Percent Compound Frequency Curve for Province 2, (Based on NOAA # 9418767, North Spit, Humboldt)

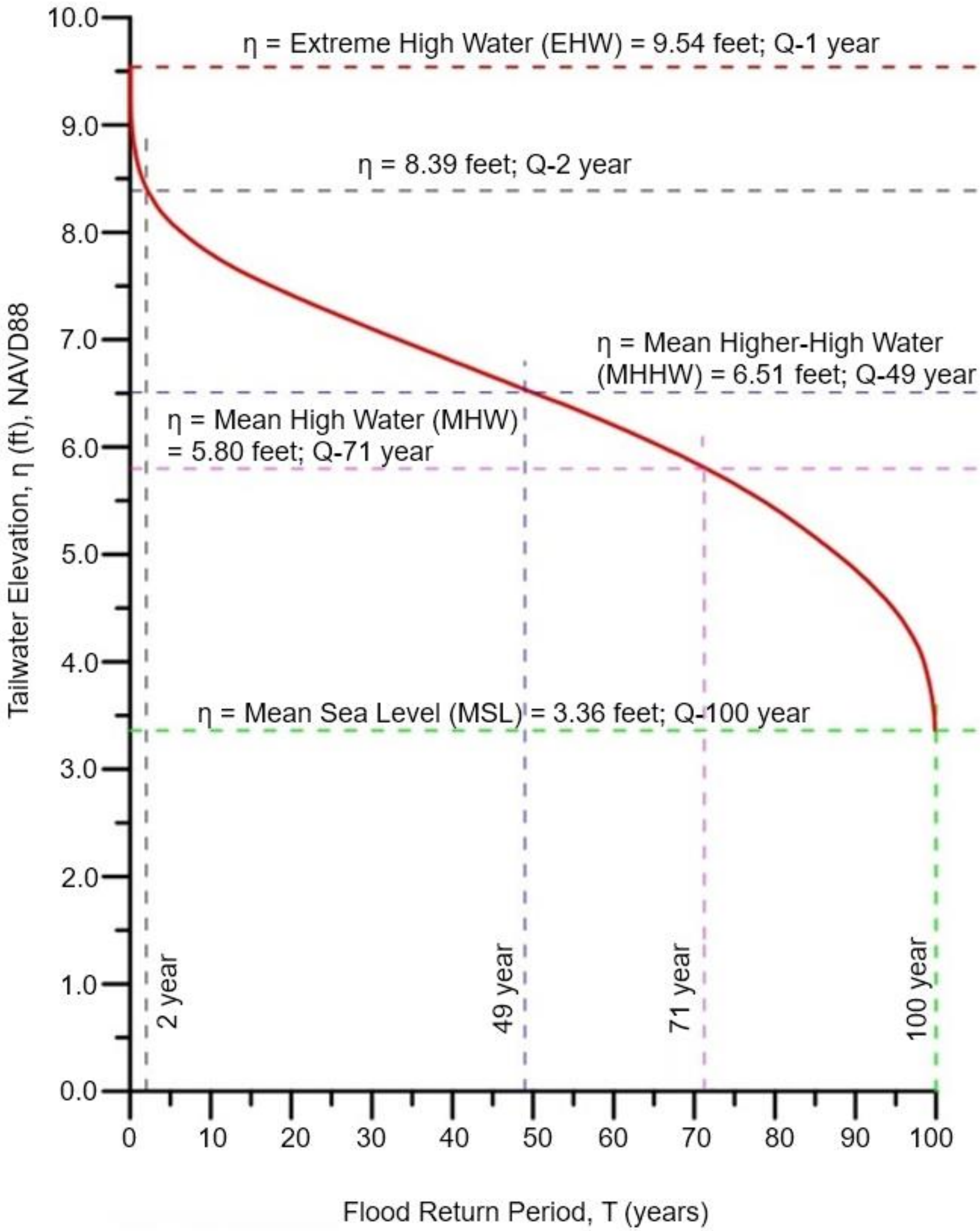


Figure 821.3C

One-Percent Compound Frequency Curve for Province 2a, (Based on NOAA # 9414290, Golden Gate Bridge)

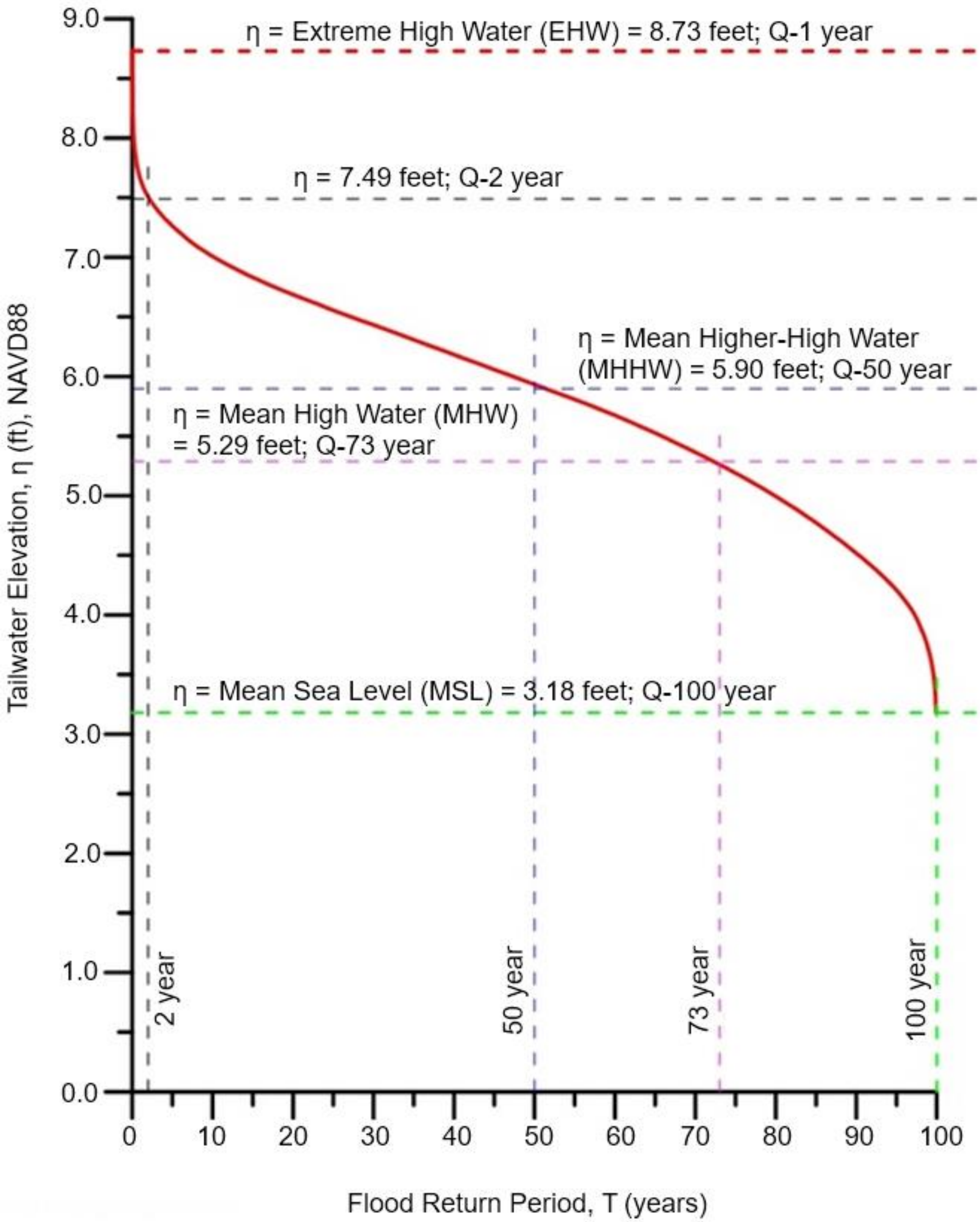


Figure 821.3D

One-Percent Compound Frequency Curve for Province 3, (Based on NOAA # 9413450, Monterey)

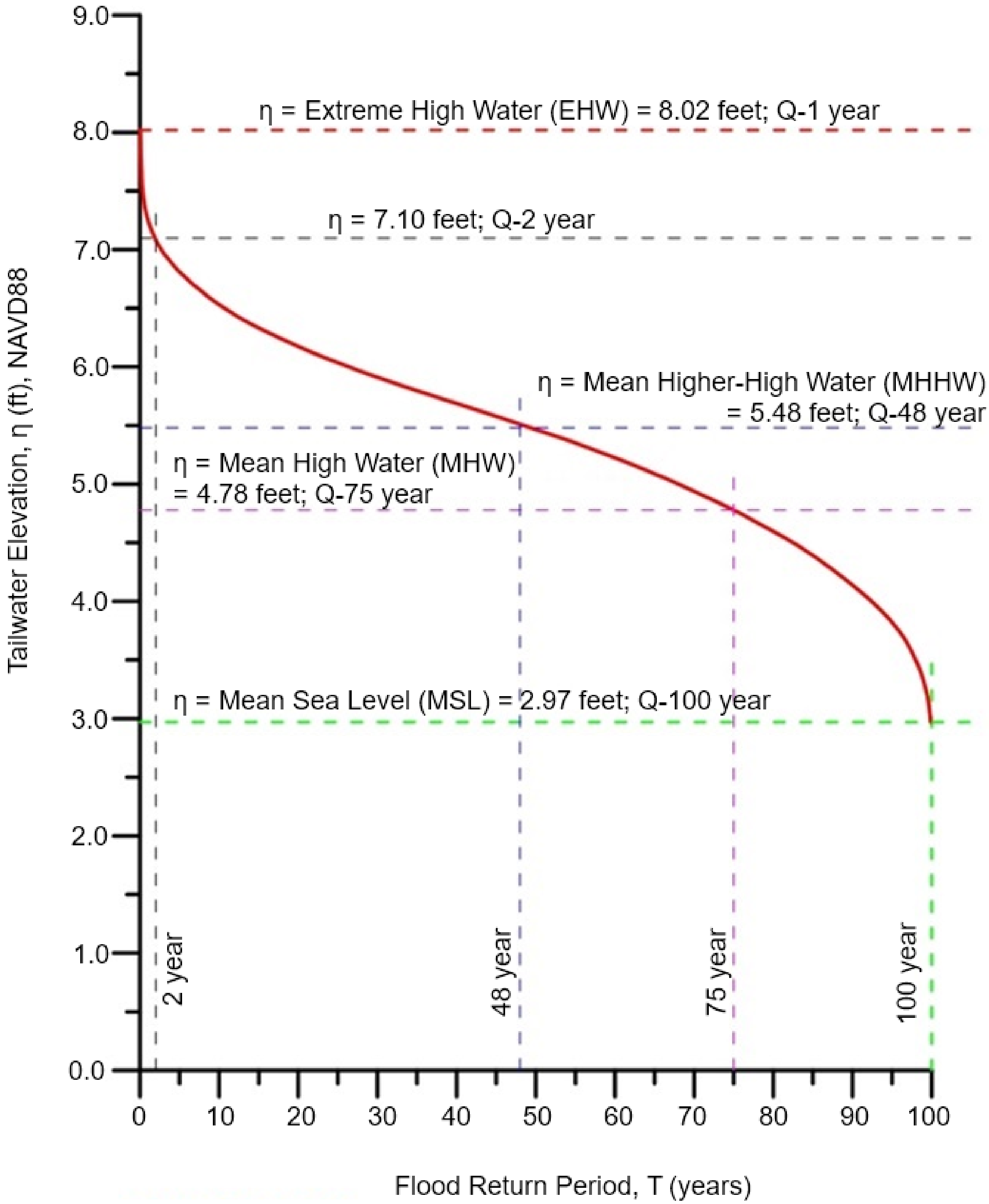


Figure 821.3E

One-Percent Compound Frequency Curve for Province 4, (Based on NOAA # 9412110, Port San Luis)

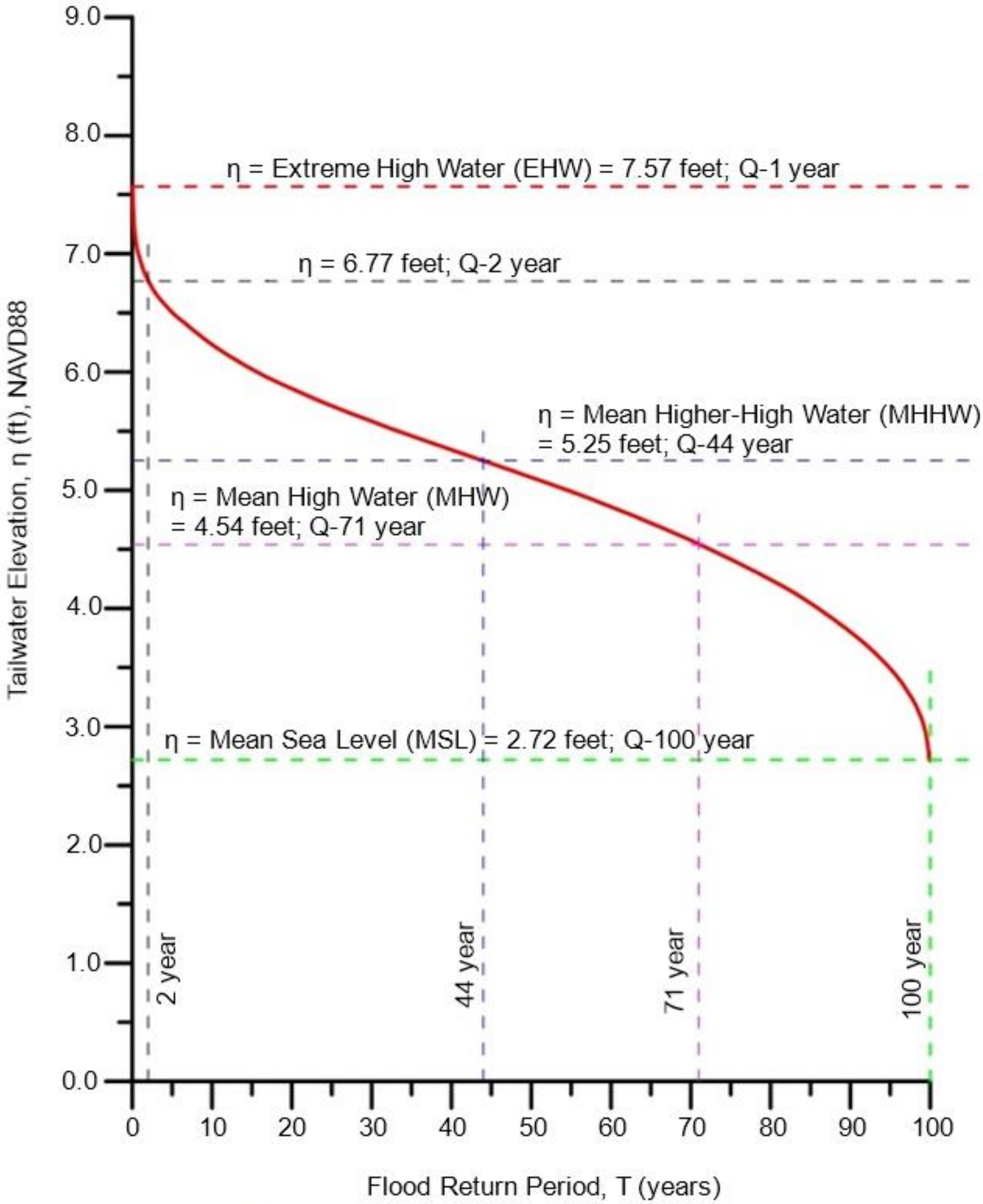


Figure 821.3F

**One-Percent Compound Frequency Curve for Province 5,
(Based on NOAA # 9411340, Santa Barbara)**

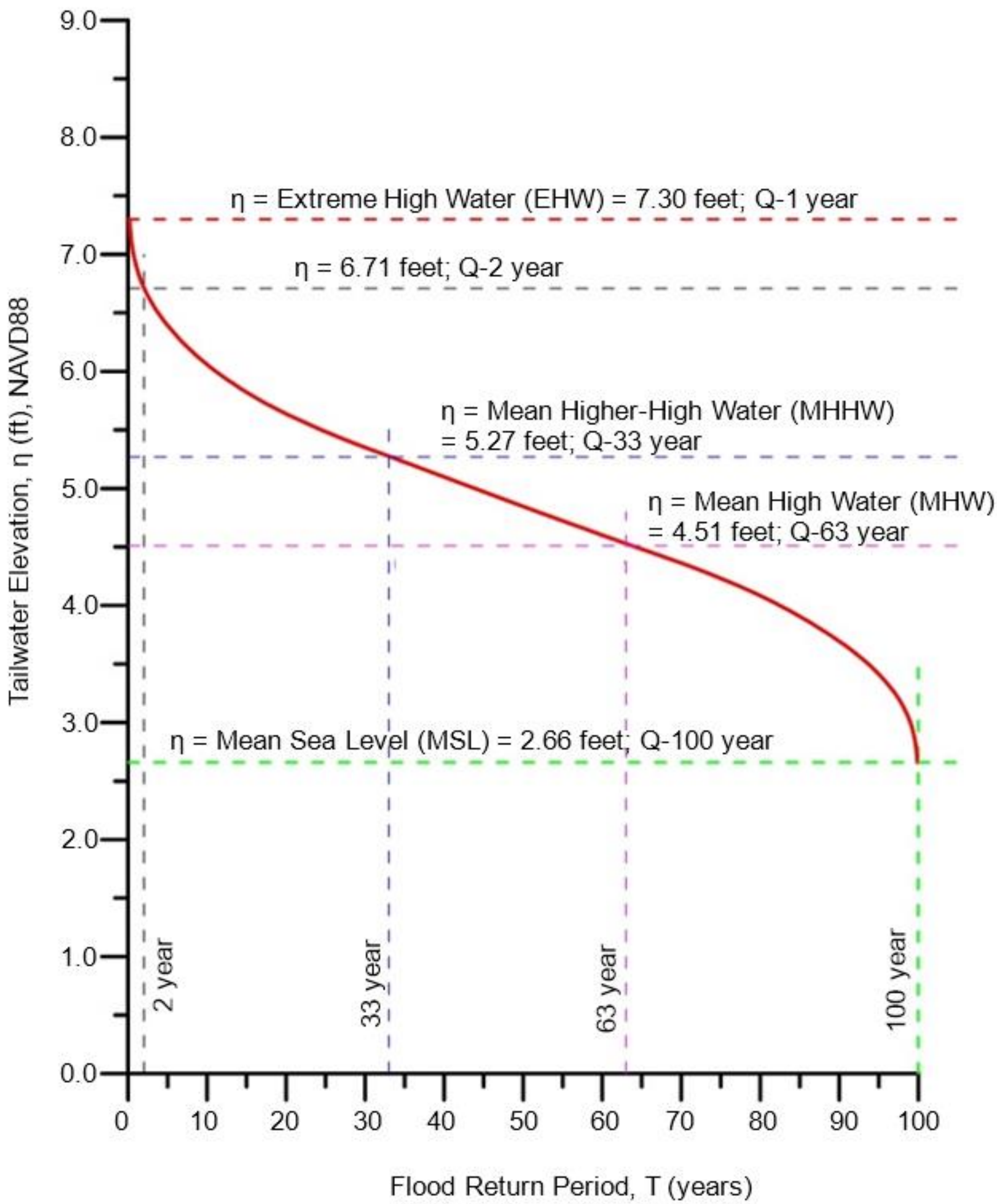


Figure 821.3G

One-Percent Compound Frequency Curve for Province 6, (Based on NOAA # 9410660, Los Angeles)

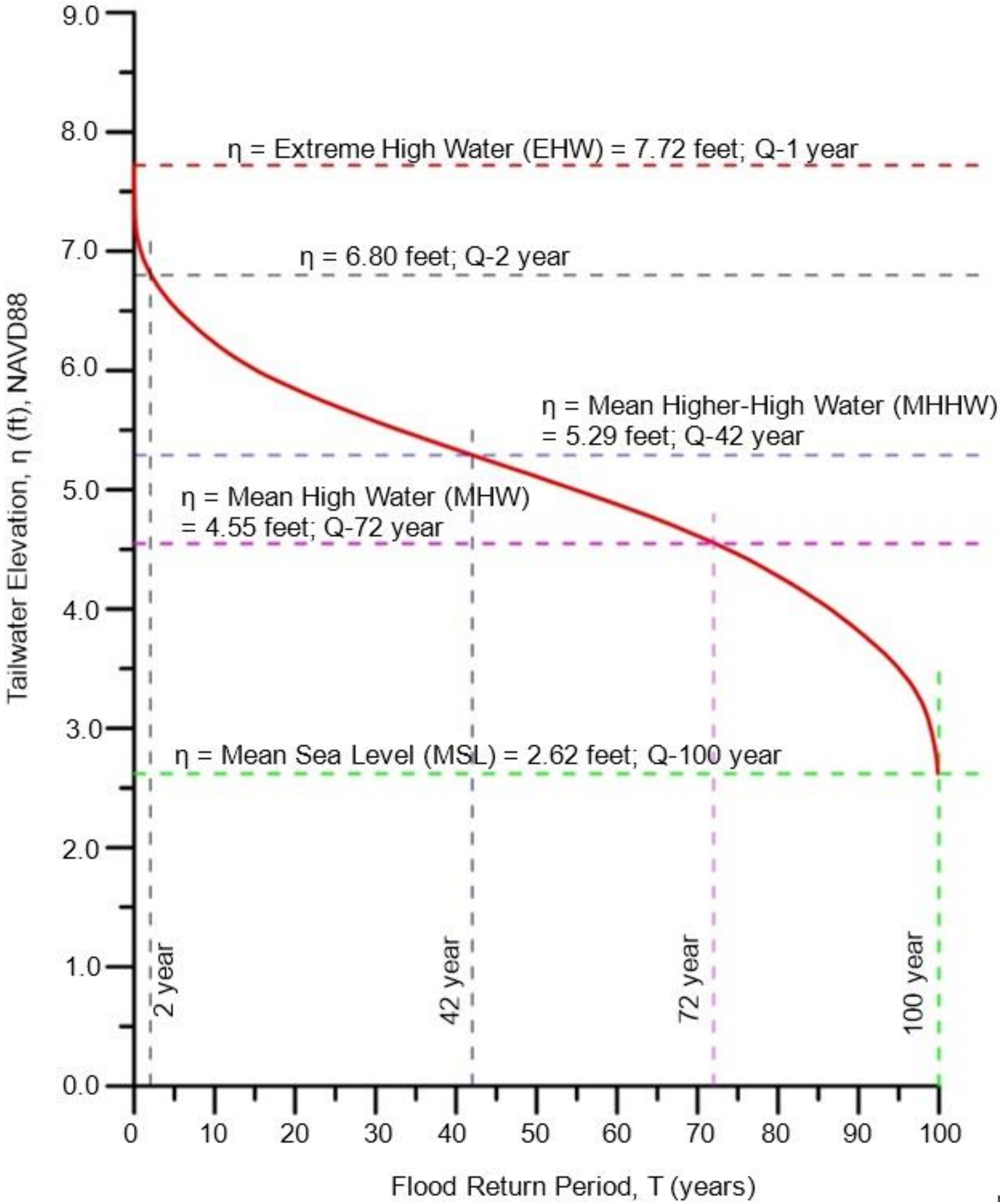


Figure 821.3H

One-Percent Compound Frequency Curve for Province 7, (Based on NOAA # 9410230, La Jolla Scripps Pier)

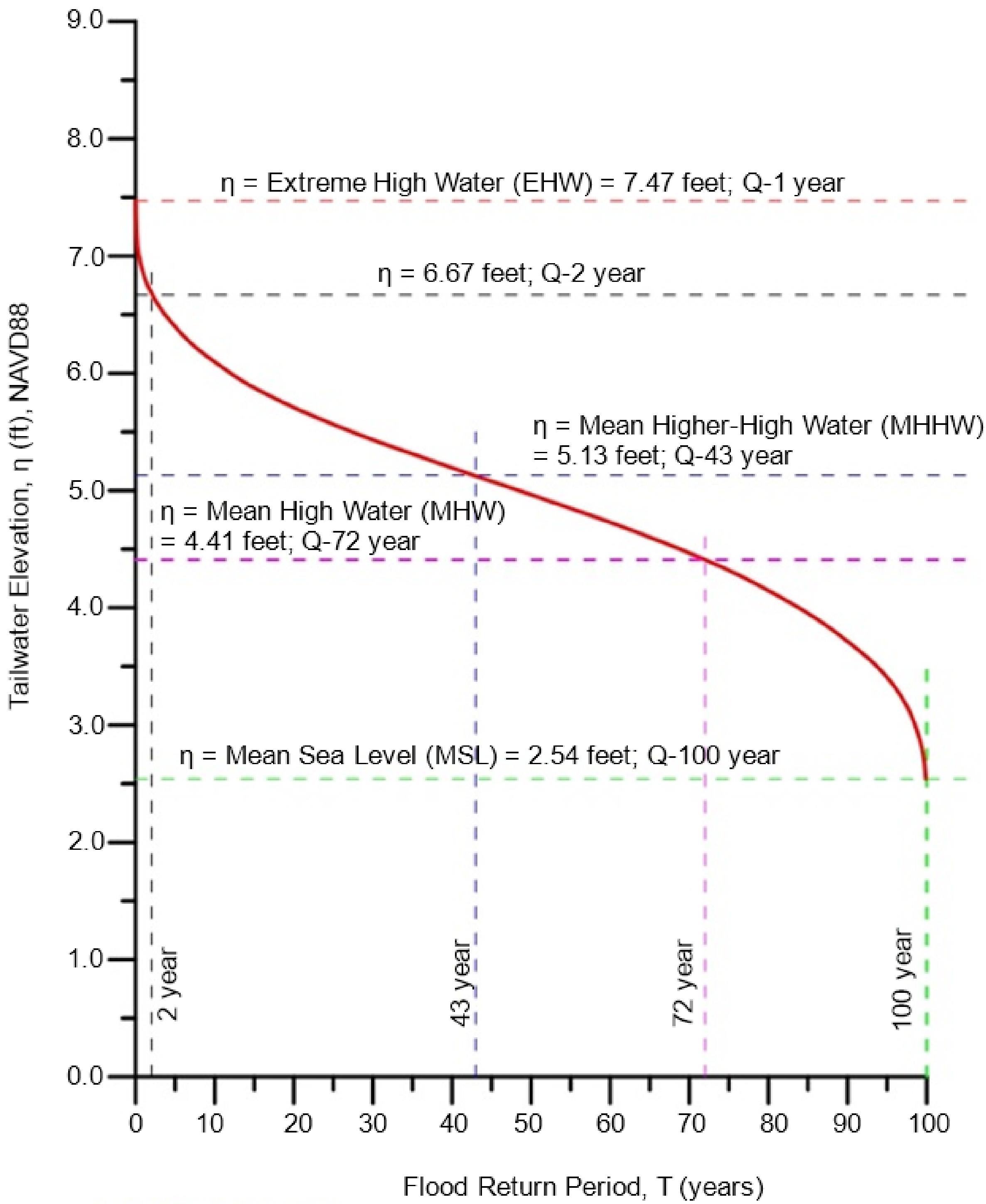


Figure 821.3I

One-Percent Compound Frequency Curve for Province 8, (Based on NOAA # 9414750, Alameda)

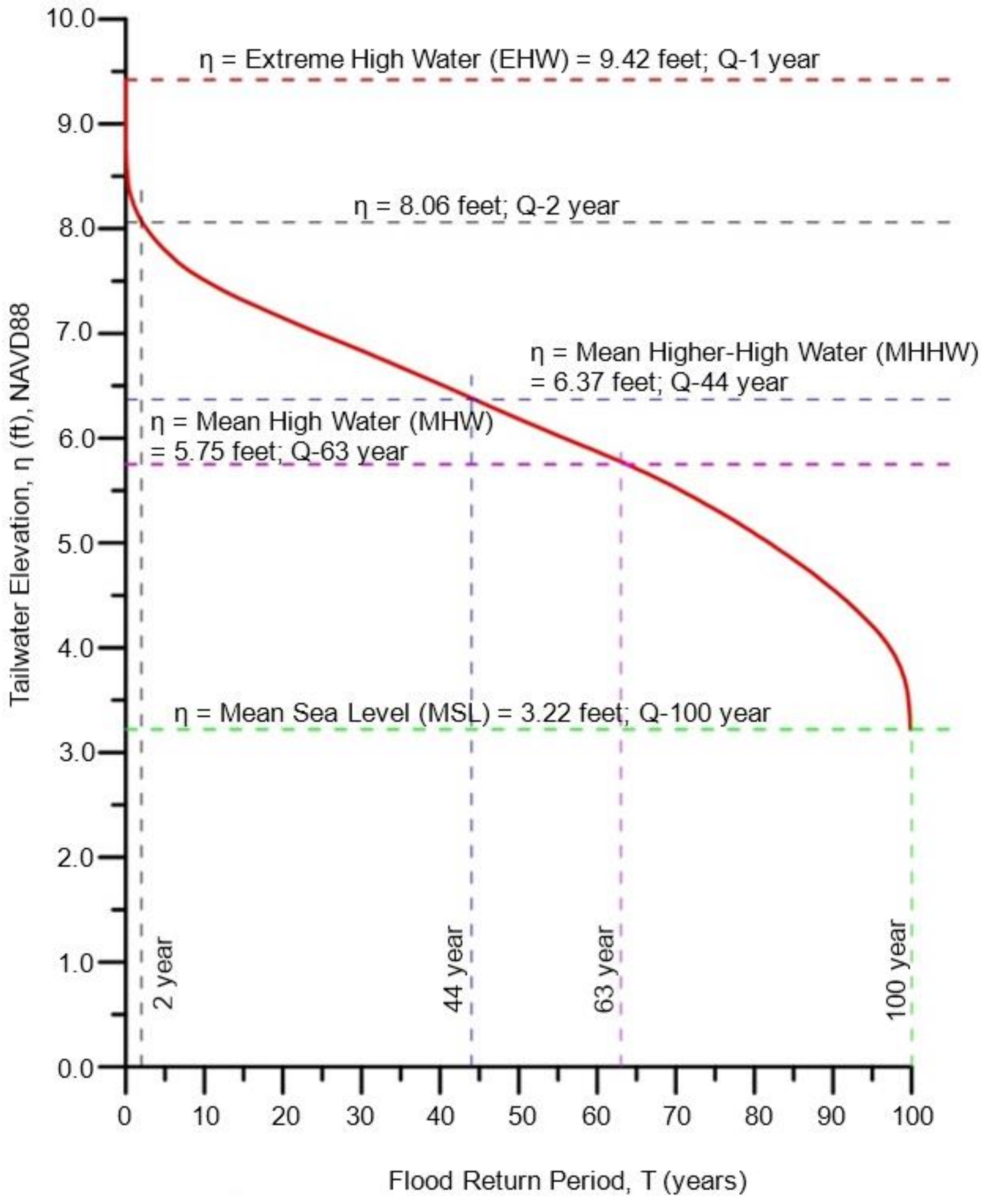


Figure 821.3J

One-Percent Compound Frequency Curve for Province 9, (Based on NOAA # 9415056, Pinole Point, San Pablo Bay)

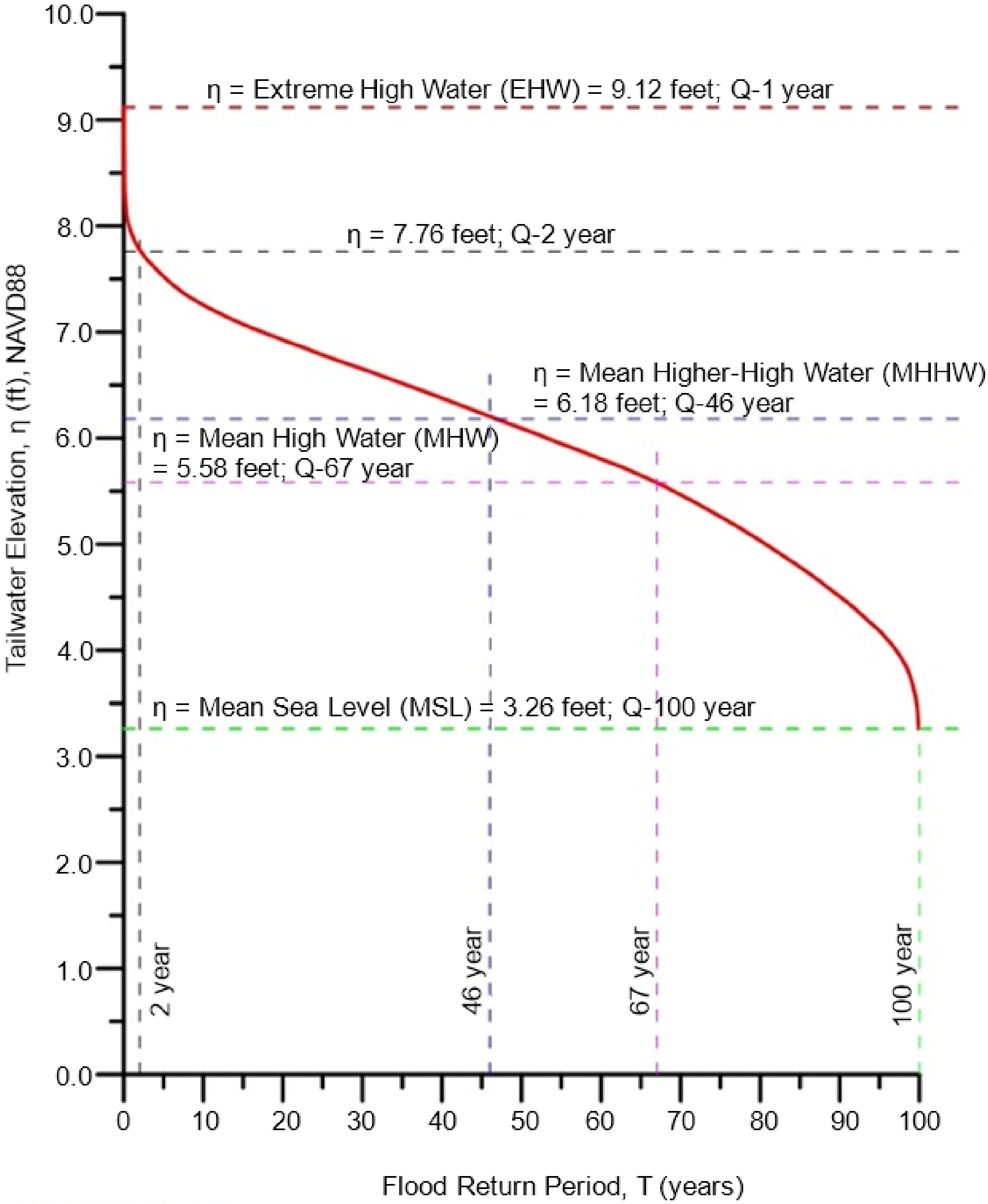


Figure 821.3K

One-Percent Compound Frequency Curve for Province 9a, (Based on NOAA # 9415144, Port Chicago)

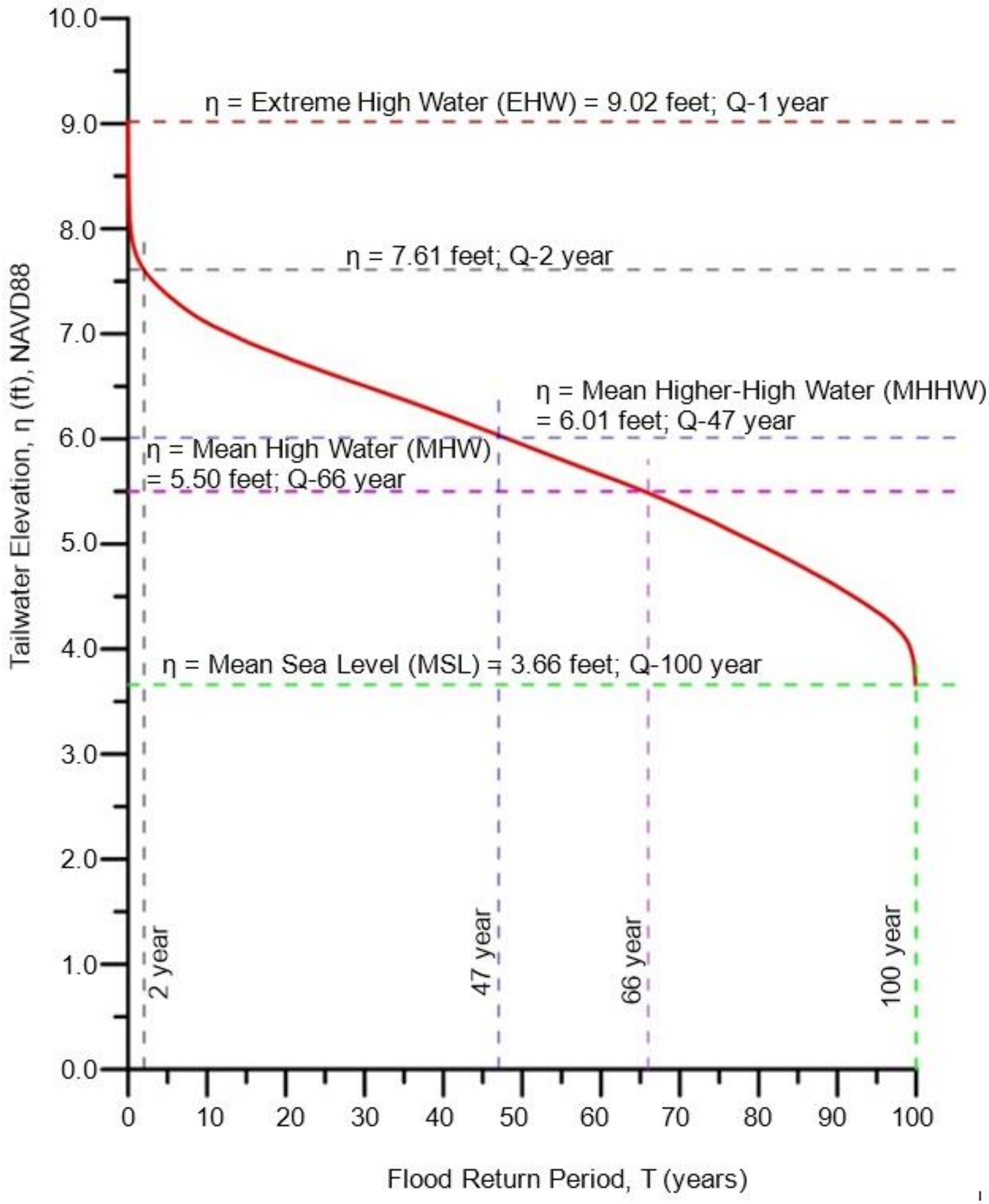


Figure 821.3L

One-Percent Compound Frequency Curve for Province 10, (Based on NOAA # 9414523, Redwood City)

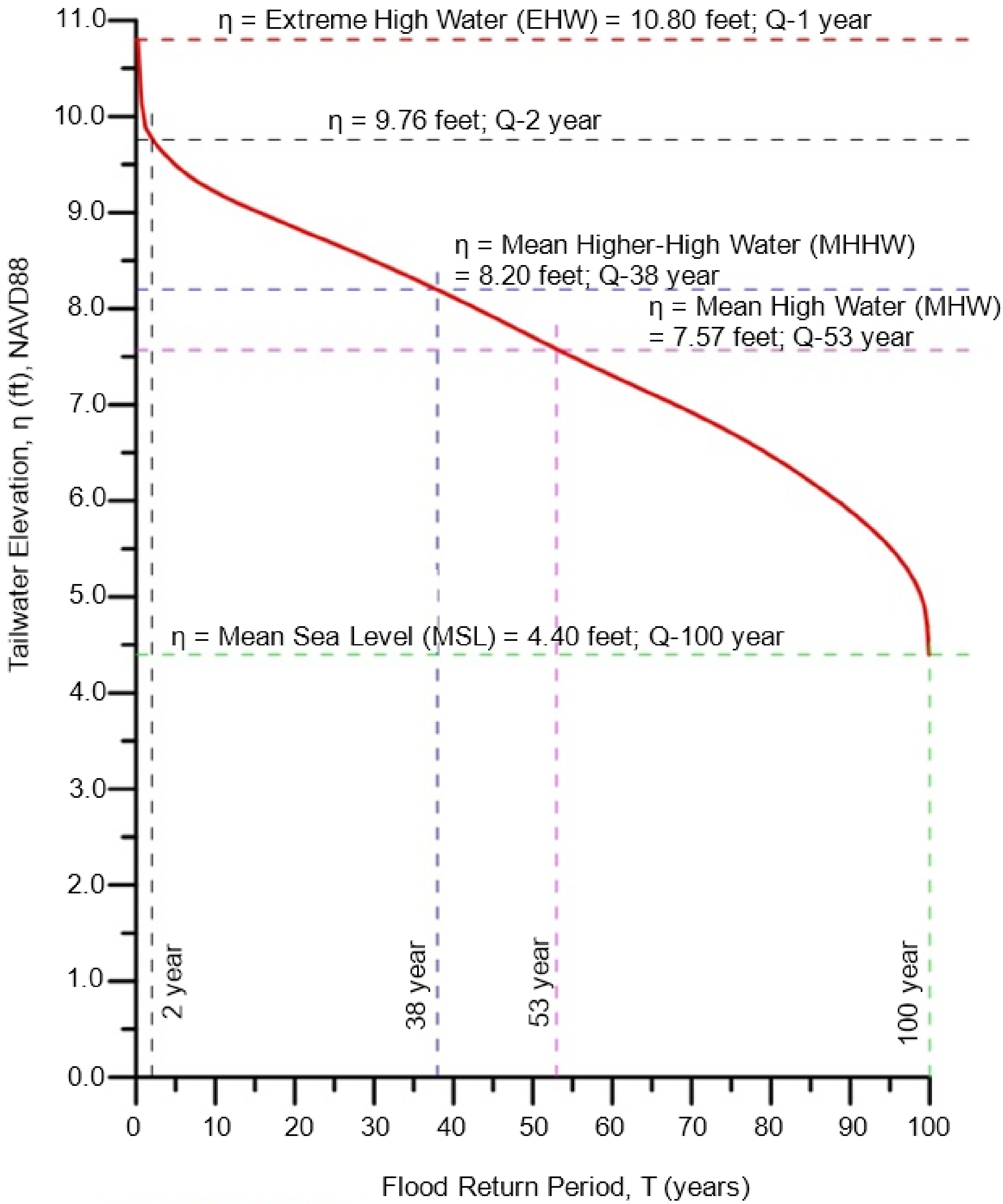


Figure 821.3M

One-Percent Compound Frequency Curve for Province 11, (Based on NOAA # 9410170, San Diego Bay, Navy Pier)

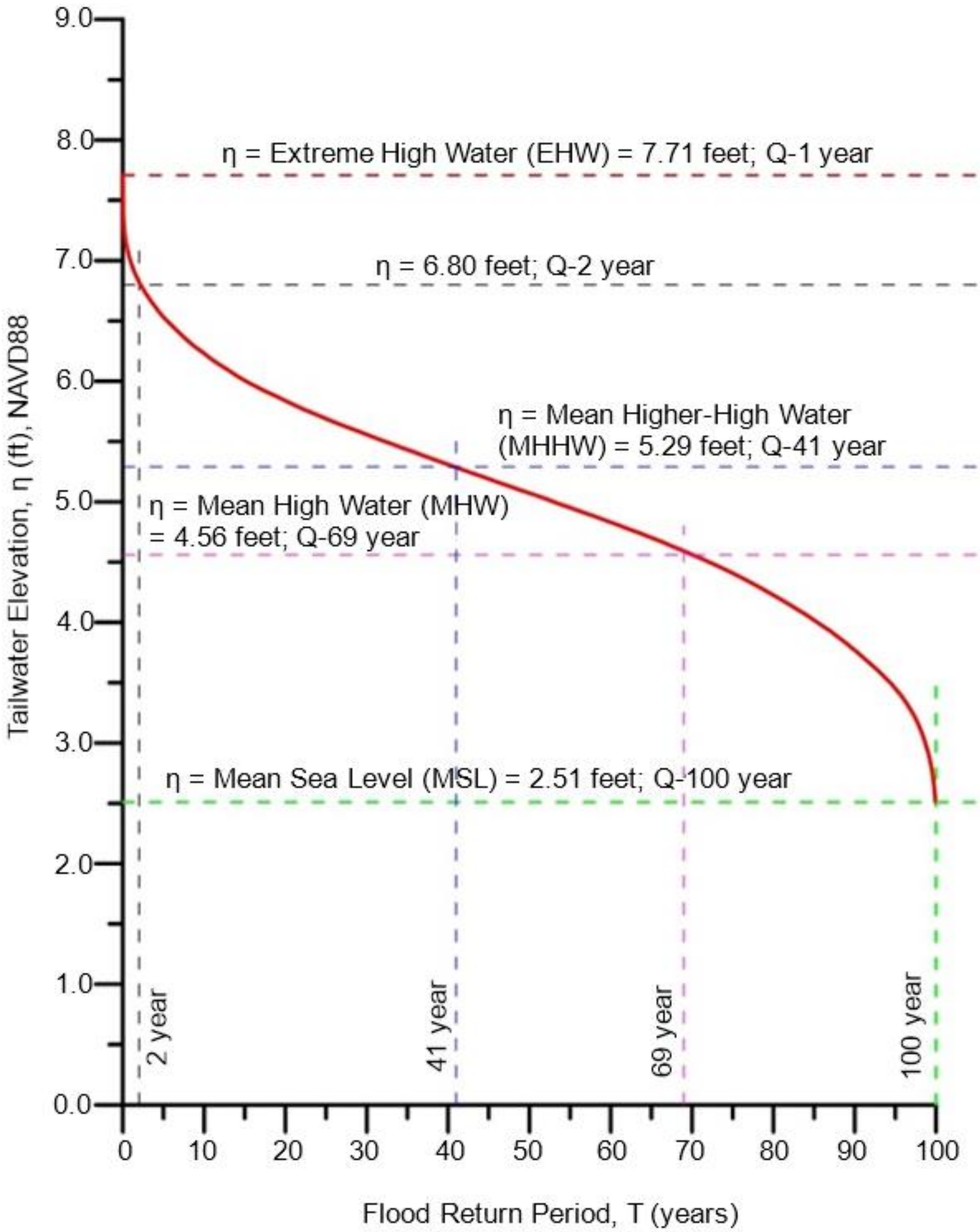
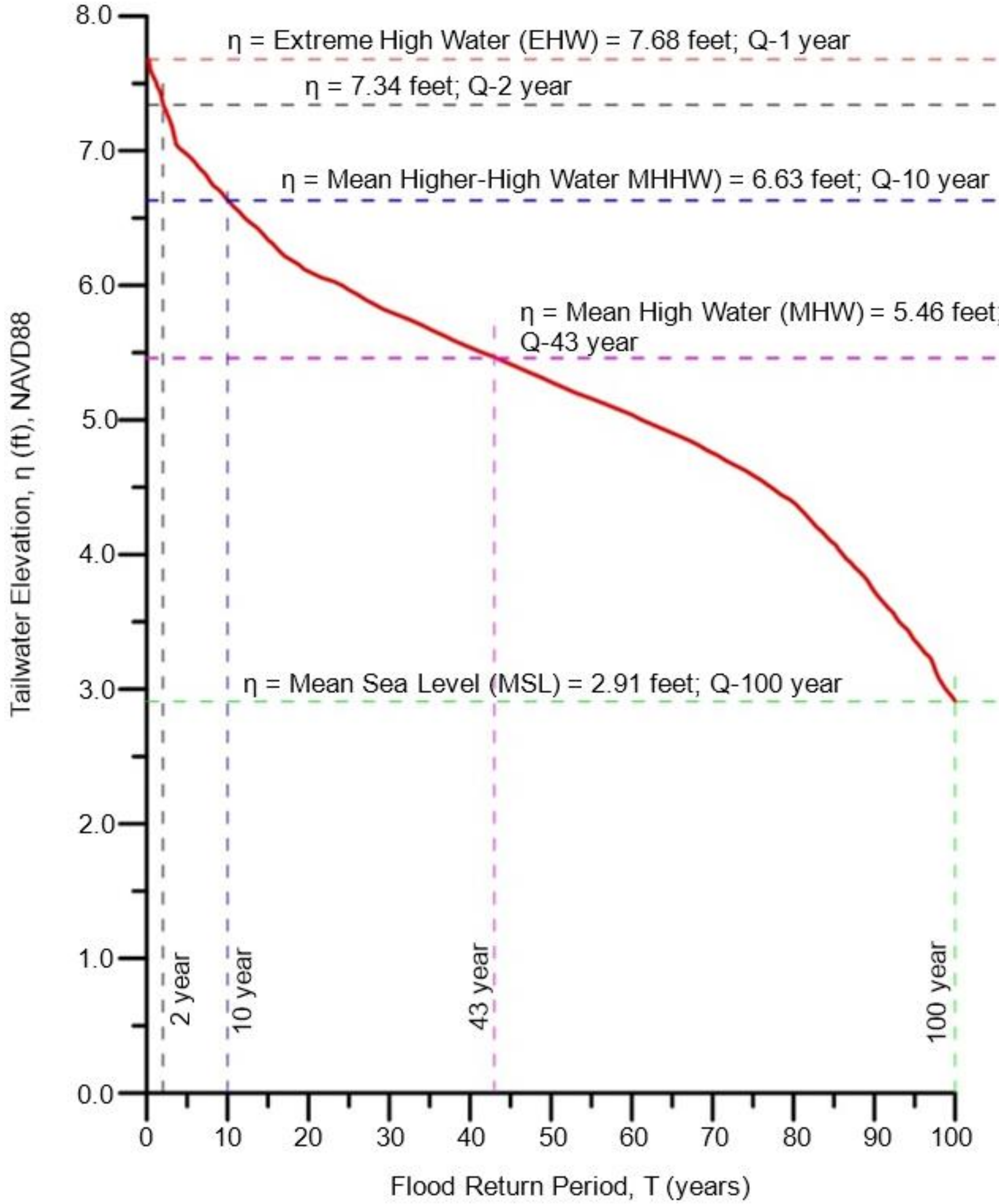


Figure 821.3N

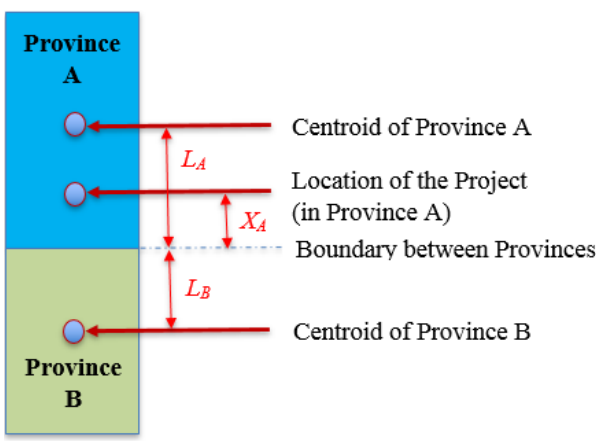
One-Percent Compound Frequency Curve for Province 12, (Based on Otay River Sonde)



The following provides guidance on how the tailwater level at a project location can be determined based on the one-percent compound frequency curves described above. Let us consider, Province A and Province B are two neighboring provinces, and the distance from the centroid of the province to the boundary is L_A and L_B, respectively, as shown in Figure 821.4. The project site is located at a distance X_A from the boundary within Province A.

Figure 821.4

Distances needed to guide interpolation



Depending on the proximity of the project site to the centroid of the host province and to the province boundary, either of the following approaches may be used to determine the tailwater level at the project site:

- If the project site is relatively far from the neighboring province boundary and close to the centroid of the host province, i.e. $X_A > \frac{3}{4}L_A$, the one-percent compound frequency curve of only the host province (in this case Province A) will be considered.

- If the project site is relatively closer to the boundary and further away from the centroid of the host province, i.e. $X_A \leq \frac{3}{4}L_A$, the one-percent curves of both the host province and the neighboring province will be used. If for a particular streamflow event the tailwater level for these two provinces obtained from the curves is η_A and η_B, respectively, then the tailwater level at the project site, $\bar{\eta}$, is determined using the following equation of distance-weighted interpolation:

$$\bar{\eta} = K_x\eta_A + (1 - K_x)\eta_B$$

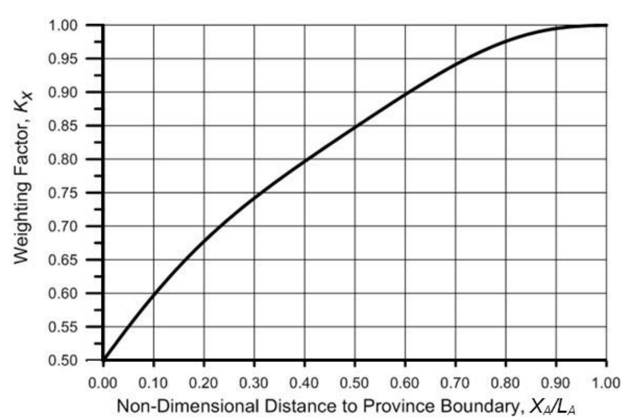
Here, the term K_x is the distance weighted factor, which is determined from the non-dimensional distance of the project site from the nearest province boundary or $\frac{X_A}{L_A}$, using Figure 821.5 or the following equation:

$$K_x = 0.5086205534 + 0.8853233677\frac{X_A}{L_A} - 0.3871675236\left(\frac{X_A}{L_A}\right)^2$$

If a project is located closed to the province boundary the term K_x approaches to 0.5 and the distance-weighted average solution becomes the arithmetic mean of η_A , and η_B. As the project site becomes further away from the province boundary and closer to the centroid of the host province, K_x approaches to 1.0, the solution converges on that of the host province, ($\bar{\eta} \rightarrow \eta_A$).

Figure 821.5

Weighting factor, K_x for interpolation



Two examples are provided below, which are loosely based on reality, the reader should be aware of that aspects of the example data are fictional and have been created for instructional purposes only. In general, the discharge in a stream at different return periods can be easily estimated using StreamStats or other methods described in Topic 819 of this manual. In a tidal environment, for a certain flow event, the corresponding tailwater can be obtained using the above-described method, where the compound annual exceedance probability would be 1%. Any set of flow and tailwater data can be used as boundary conditions to determine the upstream water level and the flow velocity. For the hydraulic analysis of a culvert or bridge, at least two sets of boundary conditions, such as 100-year and 50-year discharges should be considered, and the design should be based on the worst-case scenario. The designer must use discretion in selecting the return periods of the discharge. The tailwater levels in these examples do not include sea-level rise (SLR) which needs to be evaluated for all facilities in a coastal environment. The estimated SLR should be added to the tailwater level during the design process.

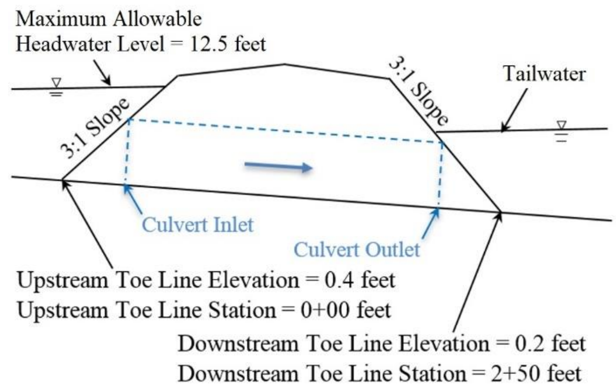
(1) Example 1

A straight culvert with no inlet depression needs to be designed on Highway 1 in San Luis Obispo County. The following hydrology data (using StreamStats or U.S.G.S Regional Regression Equation (see Index 819.2(2)) and site specifications were provided:

- 50-year Discharge = 251 cfs
- 100-year Discharge = 315 cfs

The maximum allowable upstream water level elevation or headwater level (HW) = 12.5 feet (NAVD88). The coordinates of the upstream toe line are = 35°25'02.01" N and 120°52'30.80" W.

The figure below shows the profile of the culvert.

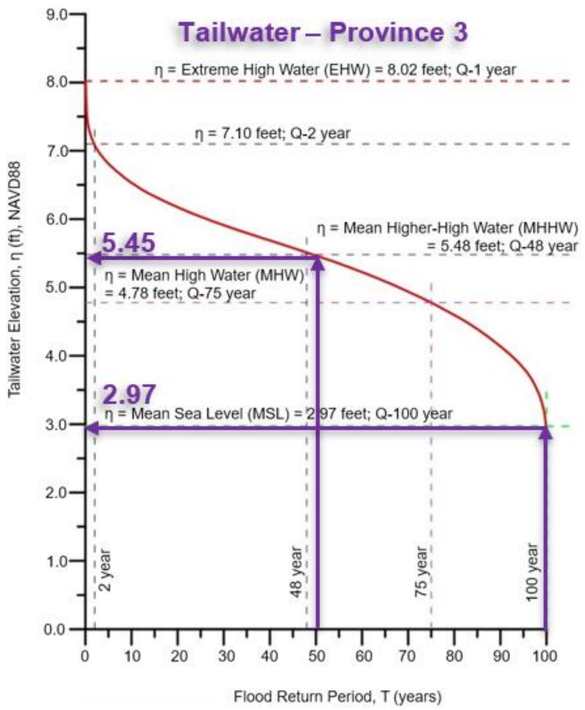


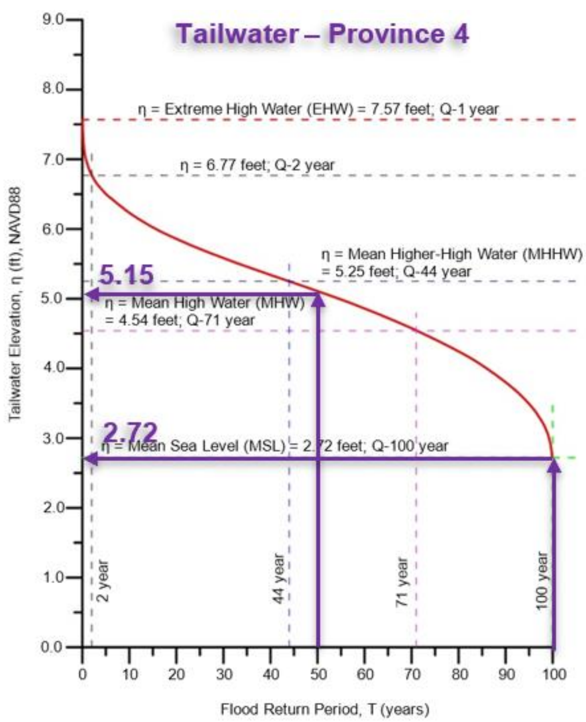
Step 1: Obtain the Tailwater Depth for the corresponding discharge to represent a 1% probability of exceedance event

The project site is in Province 3, near the boundary with Province 4 as shown in the following figure.

The distance from the centroid of the Province 3 and the boundary between Provinces 3 and 4 (L_3) is 94.5 miles (From Table 821.1). The province boundary points could be loaded in a mapping software, such as Google Earth® or ArcGIS®, to measure the running distance along the coastline. It is to be noted that, while measuring distance, the distance path should be relatively smooth and small interior of embayments in the coastlines should be ignored. The distance from the project site to the boundary (X_3) is about 12 miles. Here, $\frac{X_3}{L_3} = \frac{12}{94.5} = 0.127$. Since $X_3 < \frac{3}{4}L_3$, the project location can be considered as close to the province boundary.

Therefore, an interpolation of the tailwater levels (η values) between Province 3 and Province 4 is needed. The tailwater elevation of both provinces for each discharge scenario is obtained based on the corresponding one-percent compound frequency curve per Figure 821.3D and Figure 821.3E (as shown in the following two figures).





Using $\frac{X_3}{L_3} = 0.127$ in the equation for distance-weighted factor or Figure 821.5, we get $K_x = 0.615$. Once K_x is determined, the tailwater at the project location for each discharge event can be calculated using the equation of distance-weighted interpolation (as below):

$$\bar{\eta}\,(50-\text{year}) = 0.615 \times 5.45 + (1-0.615) \times 5.15 = 5.33 \text{ feet}$$

$$\bar{\eta}\,(100-\text{year}) = 0.615 \times 2.97 + (1-0.615) \times 2.72 = 2.87 \text{ feet}$$

To summarize the above findings, at the project site, either of the two scenarios of boundary conditions shown in the following table would have a compound probability of exceedance of one percent.

Scenario 1		Scenario 2	
50-year Discharge	251 cfs	100-year Discharge	315 cfs
Tailwater Elevation (TW)	5.33 feet, NAVD88	Tailwater Elevation (TW)	2.87 feet, NAVD88

Step 2: Using Standard Plans, select a primary culvert shape, material, size, and entrance configuration.

Trial 1: Use a single barrel Precast Reinforced Concrete Pipe of 6 feet inner diameter. Let us assume the entrance of the culvert has a beveled edge (1:1).

Step 3: Calculate the Station and Elevation at Culvert Inlet and Outlet

The Station at the Culvert Inlet = Upstream Toe Line Station + Culvert Diameter × Embankment Slope = $0 + 6 \times 3 = 18$ feet

The Station at the Culvert Outlet = Downstream Toe Line Station – Culvert Diameter × Embankment Slope = $250 - 6 \times 3 = 232$ feet

The slope of Culvert = Difference in elevation between upstream and downstream toe line/Distance between upstream and downstream toe line = $\frac{(0.2-0.4)}{250} = -0.0008$

Culvert Inlet Elevation = Upstream Toe Line Elevation – Culvert Slope × (Culvert Diameter + Thickness of the Headwall) $= 0.4 - 0.0008 \times (6 + 0.5) \approx 0.4$ feet

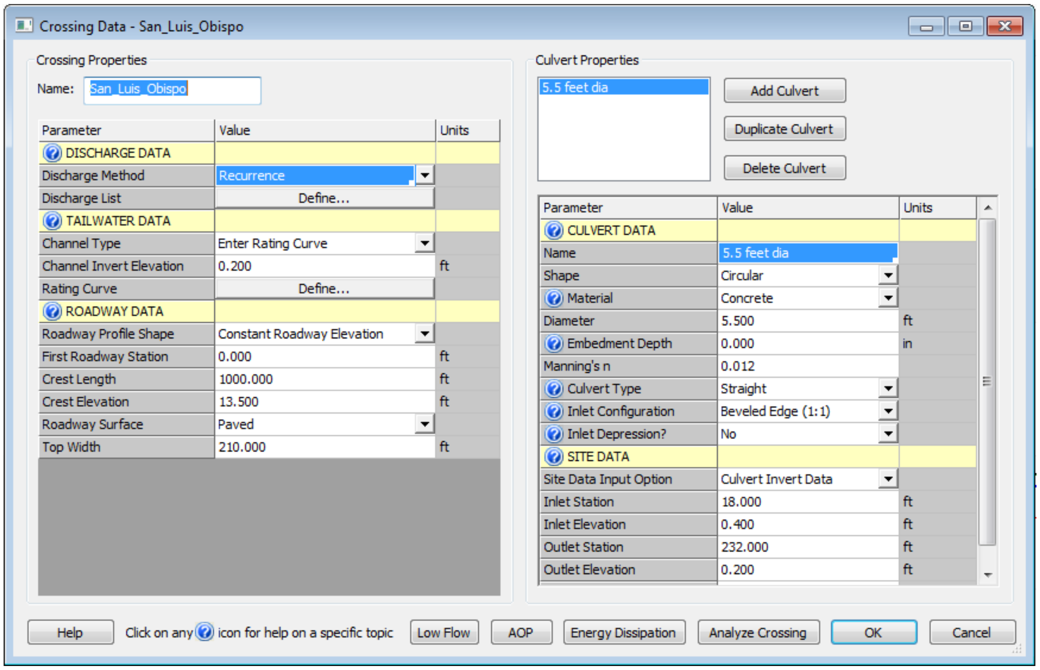
Culvert Outlet Elevation = Downstream Toe Line Elevation + Culvert Slope × (Culvert Diameter + Thickness of the Headwall) $= 0.2 + 0.0008 \times (6 + 0.5) \approx 0.2$ feet

Step 4: Enter data into a Culvert Software (e.g. HY-8):

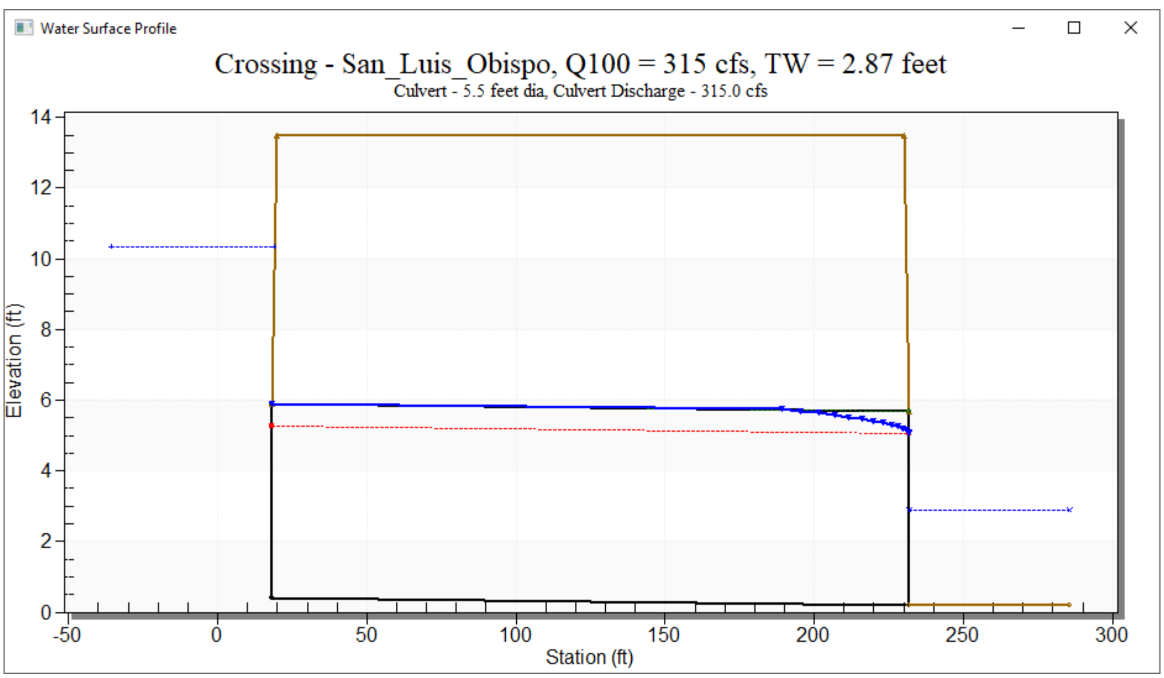
Enter the data into a culvert software (e.g. HY-8), repeat Steps 2 through 3 for several other culvert configurations and use that software to calculate Headwater (HW) for each scenario of 1% probability of exceedance. The calculated HW is then checked against the maximum allowable HW. If the calculated hydraulic condition for any scenario exceeds the allowable conditions, the configuration must be rejected and a larger size culvert and/or an efficient inlet should be considered to achieve a suitable hydraulic condition. Following table shows the culvert configuration in each trial, and the corresponding headwater and outlet velocity computed using HY-8. Final configuration could change after adding the SLR to the tailwater level.

Trials	**Culvert Configuration**	**Calculated Headwater and Outlet Velocity**		
		Scenario 1 (Q_{50} = 251 cfs, Tailwater Elevation = 5.33 feet, NAVD88)	**Scenario 2 (Q_{100} = 315 cfs, Tailwater Elevation = 2.87 feet, NAVD88)**	**Comments**
Trial 1	6.0 feet diameter RCP, beveled edge (1:1)	Headwater Elevation 7.63 ft, Velocity 9.75 ft/sec, (Inlet Control)	Headwater 8.95 feet, Velocity 12.89 ft/sec, (Outlet Control)	Much below the Allowable HW
Trial 2	5.0 feet diameter RCP, beveled edge (1:1)	Headwater 10.06 ft, Velocity 12.78 ft/sec, (Outlet Control)	Headwater 12.81 ft, Velocity 16.40 ft/sec (Inlet Control)	Exceeded Allowable HW for Scenario 2
Trial 3	5.5 feet diameter RCP, beveled edge (1:1)	Headwater 8.46 feet, Velocity 10.84 ft/sec, (Outlet Control)	Headwater 10.33 feet, Velocity 14.20 ft/sec, (Inlet Control)	**Selected**

Following figure shows the HY-8 input data.



Following figure shows the output profile of the configuration that is selected in the current design.



(2) Example 2

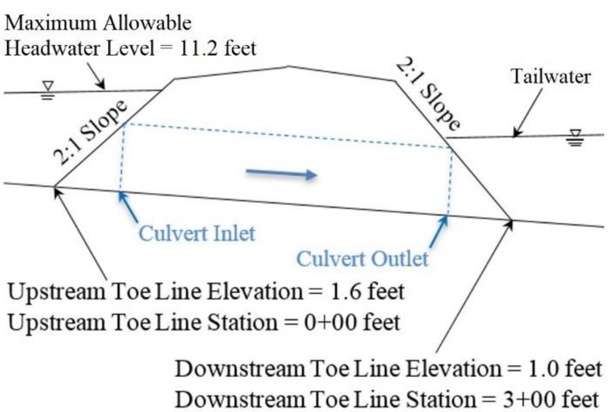
A straight culvert with no inlet depression needs to be designed on State Route 101 in San Mateo County. The following hydrology data using StreamStats or U.S.G.S Regional Regression Equation (see Index 819.2(2)) and site specifications were provided.

- 50-year Discharge = 29.3 cfs
- 100-year Discharge = 35.7 cfs

The maximum allowable upstream water level elevation or headwater level = 11.20 feet (NAVD88).

The coordinates of the upstream toe line are = 37°41'53.57"N and 122°23'34.79"W.

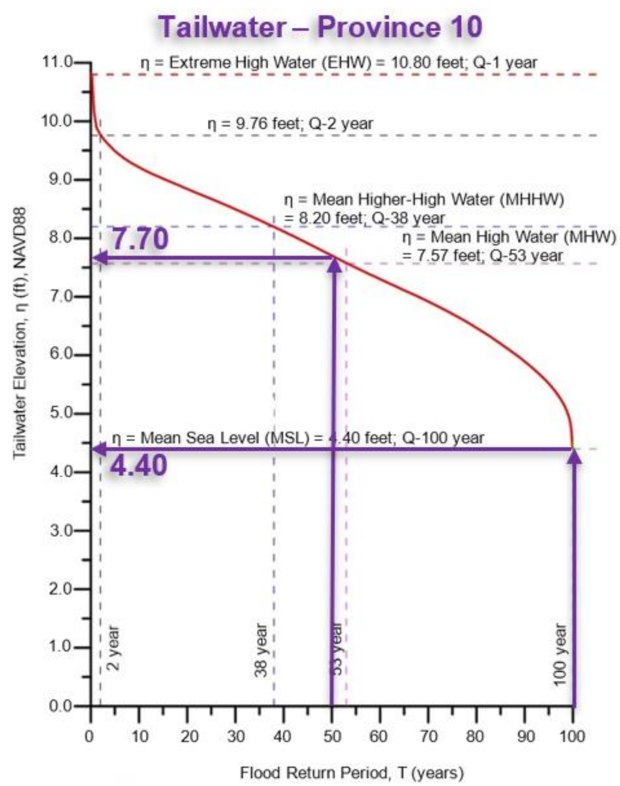
Following figure shows the profile of the culvert.

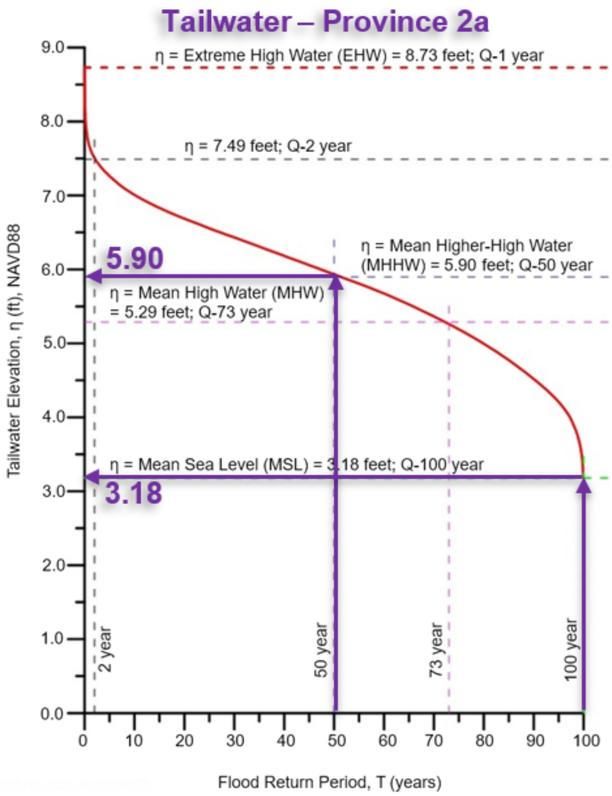


Step 1: Obtain the Tailwater Depth for the corresponding discharge to represent a 1% probability of exceedance event.

The project site is in Province 10, near the boundary with Province 2a as shown in the following figure.

The tailwater elevation for these two provinces at each discharge event is obtained based on the corresponding one-percent compound frequency curve per Figure 821.3C and Figure 821.3L as shown in the following two figures.





The distance from the centroid of the Province 10 and the boundary between Province 10 and Province 2a (L_{10}) is 32.9 miles (From Table 821.1). The distance measured from the project site to the boundary (X_{10}) is 2 miles.

Here, $\frac{X_{10}}{L_{10}} = \frac{2}{32.9} = 0.061$.Since $X_{10} < \frac{3}{4}L_{10}$, the project location can be considered as close to the province boundary. An interpolation of the tailwater levels (η values) between Province 10 and Province 2a is needed.

Using $\frac{X_{10}}{L_{10}} = 0.061$ in the equation for distance-weighted factor or Figure 821.5, we get $K_x = 0.562$. Once K_x is determined, the tailwater at the project location for each discharge event can be calculated using the equation of distance-weighted interpolation (as below):

$$\bar{\eta}\,(50 - \text{year}) = 0.562 \times 7.70 + (1 - 0.562) \times 5.90 = 6.91 \text{ feet}$$

$$\bar{\eta}\,(100 - \text{year}) = 0.562 \times 4.40 + (1 - 0.562) \times 3.18 = 3.87 \text{ feet}$$

To summarize the above findings, at the project site, either of the two scenarios of boundary conditions, as shown in the following table, would have a compound probability of exceedance of one percent.

Scenario 1		**Scenario 2**	
50-year Discharge	29.3 cfs	100-year Discharge	35.7 cfs
Tailwater Elevation (TW)	6.91 feet, NAVD88	Tailwater Elevation (TW)	3.87 feet, NAVD88

Step 2: Using Standard Plans, select a primary culvert shape, material, size, and entrance configuration.

Trial 1: Use a single corrugated steel Pipe of 3 feet inner diameter. Let us assume the entrance of the culvert has a square edge with headwall.

Step 3: Calculate the Station and Elevation at Culvert Inlet and Outlet

The Station at the Culvert Inlet = Upstream Toe Line Station + Culvert Diameter × Embankment Slope = $0 + 3 \times 2 = 6$ feet

Station at the Culvert Outlet = Downstream Toe Line Station – Culvert Diameter × Embankment Slope = $300 - 3 \times 2 = 294$ feet

The slope of Culvert = Difference in elevation between upstream and downstream toe line/Distance between upstream and downstream toe line = $\frac{(1.0-1.6)}{300} = -0.002$

Culvert Inlet Elevation = Upstream Toe Line Elevation – Culvert Slope × (Culvert Diameter + Thickness of the Headwall) = $1.6 - 0.002 \times (3 + 0.5) \approx 1.6$ feet

Culvert Outlet Elevation = Downstream Toe Line Elevation + Culvert Slope x (Culvert Height +

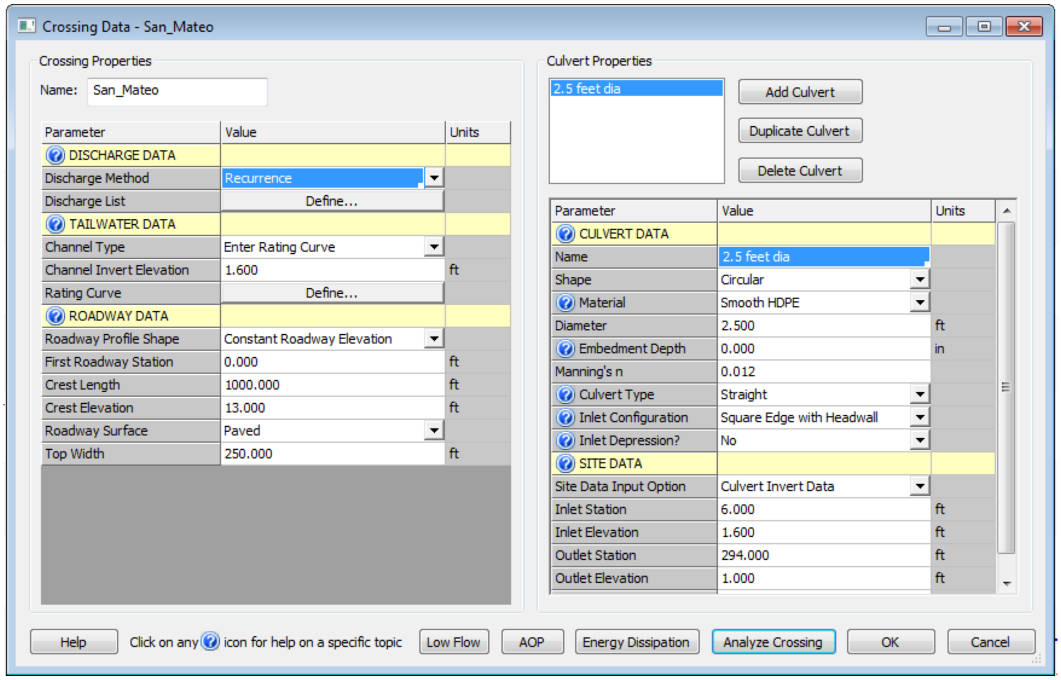
Thickness of the Headwall) $= 1.0 + 0.002 \times (3 + 0.5) \approx 1.0$ feet

Step 4: Enter data in to a Culvert Software (e.g. HY-8)

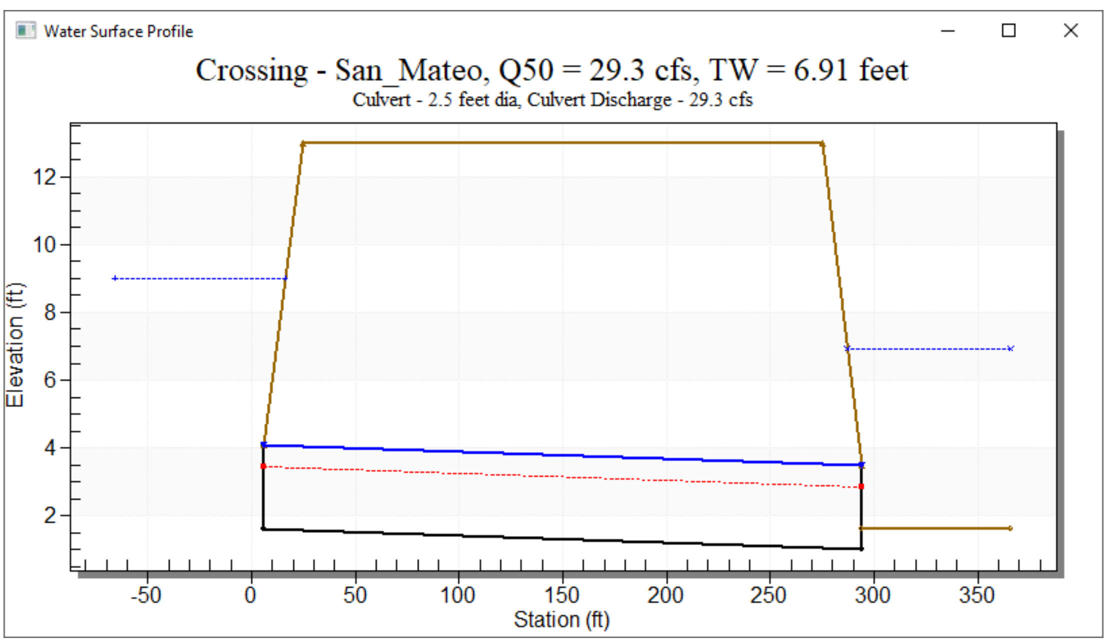
Similar to the previous example, enter the data in a culvert software (e.g. HY-8), repeat Steps 2 through 3 for several other culvert configurations and use that software to calculate Headwater (HW) for each scenario of 1% probability of exceedance. The calculated HW is then checked against the maximum allowable Headwater. If the calculated hydraulic condition for any scenario exceeds the allowable conditions, the configuration must be rejected, and a larger size culvert and/or an efficient inlet should be considered to achieve a suitable hydraulic condition. Following table shows the culvert configuration in each trial and the corresponding headwater and outlet velocity computed using HY-8. Final configuration could change after adding the SLR to the tailwater level.

Trials	Culvert Configuration	Calculated Headwater and Outlet Velocity		
		Scenario 1 (Q_{50} = 29.3 cfs, Tailwater Elevation = 6.91 feet)	Scenario 2 (Q_{100} = 35.7 cfs, Tailwater Elevation = 3.87 feet)	Comments
Trial 1	3 feet diameter HDPE, square edge with headwall	Headwater Elevation 7.78 ft, Velocity 4.15 ft/sec, (Outlet Control)	Headwater 5.09 feet, Velocity 5.13 ft/sec, (Outlet Control)	Much below the Allowable HW
Trial 2	2.0 feet diameter HDPE, square edge with headwall	Headwater 13.03 ft, Velocity 9.33 ft/sec, (Outlet Control)	Headwater 12.95 ft, Velocity 11.36 ft/sec (Outlet Control)	Exceeded Allowable HW
Trial 3	2.5 feet diameter HDPE, square edge with headwall	Headwater 8.99 feet, Velocity 5.97 ft/sec, (Outlet Control)	Headwater 6.95 feet, Velocity 7.27 ft/sec, (Outlet Control)	**Selected**

Figure below shows the HY-8 input data.



Following figure shows the output profile of the configuration that is selected in the current design.



Topic 822 - Debris Control

822.1 Introduction

Debris, if allowed to accumulate either within a culvert or at its inlet, can adversely affect the hydraulic performance of the facility. Damage to the roadway and to upstream property may result from debris obstructing the flow into the culvert. Coordination with district maintenance forces can help in identifying areas with high debris potential and in setting requirements for debris removal where necessary.

The use of any device that can trap debris must be thoroughly examined prior to its use. In addition to the more common problem of debris accumulation at the culvert entrance, the use of safety end grates or other appurtenances can also lead to debris accumulation within the culvert at the outlet end. Evaluation of this possibility, and appropriate preventive action, must be made if such end treatment is proposed.

822.2 Debris Control Methods

There are two methods of handling debris:

(1) *Passing Through Culvert.* If economically feasible, culverts should be designed to pass debris. Culverts which pass debris often have a higher construction cost. On the other hand, retaining solids upstream from the entrance by means of a debris control structure often involves substantial maintenance cost and could negatively affect fish passage. An economic comparison which includes evaluation of long term maintenance costs should be made to determine the most reasonable and cost effective method of handling.

(2) *Interception.* If it is not economical to pass debris, it should be retained upstream from the entrance by means of a debris control structure or the use of a debris basin when the facility is located in the vicinity of alluvial fans.

If drift and debris are retained upstream, a riser or chimney may be required. This is a vertical extension to the culvert which provides relief when the main entrance is plugged. The increased head should not be allowed to develop excessive velocities or cause pressure which might induce leakage in the culvert.

If debris control structures are used, access must be provided for maintenance equipment to reach the site. This can best be handled by coordination and field review with district maintenance staff. Details of a pipe riser with debris rack cage are shown on Standard Plan D93C. See FHWA Hydraulic Engineering Circular No. 9, "Debris-Control Structures" for further information.

The use of an upstream debris basin and downstream concrete lined channels, has often been used by Local Agencies for managing flood flows on alluvial fans in urbanized areas. Experience has shown that this approach is effective, however, the costs of building and maintaining such facilities is high with a potential for sediment inflows greater than anticipated.

The District Hydraulics Engineer should be consulted if a debris basin is being considered for interception in the vicinity of an alluvial fan.

822.3 Economics

Debris problems do not occur at all suspected locations. It is often more economical to construct debris control structures after problems develop. An assessment of potential damage due to debris clogging if protection is not provided should be the basis of design.

822.4 Classification of Debris

In order to properly determine methods for debris control, an evaluation of the characteristics of debris within flood flows must be made. Debris can be either floating, suspended in the flood flow, or dragged/rolled along the channel bottom. Typically, a flood event will deposit debris from all of these types.

The FHWA Hydraulic Engineering Circular No. 9 contains a debris classification system to aid the designer in selecting the appropriate type of debris control structure.

822.5 Types of Debris Control Structures

The FHWA Hydraulic Engineering Circular No. 9, "Debris-Control Structures", shows types of debris control structures and provides a guide for selecting the type of structure suitable for various debris classifications.

Topic 823 - Culvert Location

823.1 Introduction

The culvert usually should be located so that the thalweg of the stream to be accommodated, approaches and exits at the approximate centerline of the culvert. However, for economic reasons, as a general rule, small skews should be eliminated, moderate skews retained and large skews reduced.

Since the culvert typically acts as a constriction, local velocities will increase through the barrel and in the vicinity of the outlet. The location and design must be also sensitive to the environment (fish passage etc).

As a general rule, flood waters should be conducted under the highway at first opportunity minimizing scour of embankment and entrapment of debris. Therefore, culverts should be placed at each defined swale to limit carryover of drainage from one watershed to another.

823.2 Alignment and Slope

The ideal culvert placement is on straight alignment and constant slope. Variations from a straight alignment should be only to accommodate unusual conditions. Where conditions require deviations from the tangent alignment, abrupt changes in direction or slope should be avoided in order to maintain the hydraulic efficiency, and avoid excessive maintenance. Angle points may be permissible in the absence of abrasives in the flow; otherwise, curves should be used. When angle points are unavoidable, maintenance access may be necessary. See Index 838.5 for manhole location criteria.

Curvature in pipe culverts is obtained by a series of angle points. Whenever conditions require these angle points in culvert barrels, the number of angle points must be specified either in the plans or in the special provisions. The angle can vary depending upon conditions at the site, hydraulic requirements, and purpose of the culvert. The angle point requirement is particularly pertinent if there is a likelihood that structural steel plate pipe will be used. The structural steel plate pipe fabricator must know what the required miters are in order for the plates to be fabricated satisfactorily. Manufacturers' literature should be consulted to be sure that what is being specified can be fabricated without excessive cost.

Ordinarily the grade line should coincide with the existing streambed. Deviations from this practice are permissible under the following conditions:

(a) On flat grades where sedimentation may occur, place the culvert inlet and outlet above the streambed but on the same slope. The distance above the streambed depends on the size length and amount of sediment anticipated.

    If possible, a slope should be used that is sufficient to develop self-cleaning velocities.

(b) Under high fills, anticipate greater settlement under the center than the sides of the fill. Where settlement is anticipated, provisions should be made for camber.

(c) In steep sloping areas such as on hillsides, the overfill heights can be reduced by designing the culvert on a slope flatter than natural slope. However, a slope should be used to maintain a velocity sufficient to carry the bedload. A spillway or downdrain can be provided at the outlet. Outlet protection should be provided to prevent undermining. For the downdrain type of installation, consideration must be given to anchorage. This design is appropriate only where substantial savings will be realized.

Topic 824 - Culvert Type Selection

824.1 Introduction

A culvert is a hydraulically short conduit which conveys stream flow through a roadway embankment or past some other type of flow obstruction. Culverts are constructed from a variety of materials and are available in many different shapes and configurations. Culvert selection factors include roadway profiles, channel characteristics, flood damage evaluations, construction and maintenance costs, and estimates of service life.

824.2 Shape and Cross Section

(1) Numerous cross-sectional shapes are available. The most commonly used shapes include circular, box (rectangular), elliptical, pipe-arch, and arch. The shape selection is based on the cost of construction, the limitation on upstream water surface elevation, roadway embankment height, and hydraulic performance.

(2) *Multiple Barrels.* In general, the spacing of pipes in a multiple installation, measured between outside surfaces, should be at least half the nominal diameter with a minimum of 2 feet.

See Standard Plan D89 for multiple pipe headwall details.

Additional clearance between pipes is required to accommodate flared end sections. See Standard Plans, D94A & B for width of flared end sections.

Topic 825 - Hydraulic Design of Culverts

825.1 Introduction

After the design discharge, (Q), has been estimated, the conveyance of this water must be investigated. This aspect is referred to as hydraulic design.

The highway culvert is a special type of hydraulic structure. An exact theoretical analysis of culvert flow is extremely complex because the flow is usually non-uniform with regions of both gradually varying and rapidly varying flow. Hydraulic jumps often form inside or downstream of the culvert barrel. As the flow rate and tailwater elevations change, the flow type within the barrel changes. An exact hydraulic analysis therefore involves backwater and drawdown calculations, energy and momentum balance, and application of the results of hydraulic studies.

An extensive hydraulic analysis is usually impractical and not warranted for the design of most highway culverts. The culvert design procedures presented herein and in the referenced publications are accurate, in terms of head, to within plus or minus 10 percent.

825.2 Culvert Flow

The types of flow and control used in the design of highway culverts are:

- Inlet Control - Most culverts operate under inlet control which occurs when the culvert barrel is capable of carrying more flow than the inlet will accept. Supercritical flow is usually encountered within the culvert barrel. When the outlet is submerged under inlet control, a hydraulic jump will occur within the barrel.
- Outlet Control - Outlet control occurs when the culvert barrel is not capable of conveying as much flow as the inlet will accept. Culverts under outlet control generally function with submerged outlets and subcritical flow within the culvert barrel. However, it is possible for the culvert to function with an unsubmerged outlet under outlet control where flow passes through critical depth in the vicinity of the outlet.

For each type of control, different factors and formulas are used to compute the hydraulic capacity of a culvert. Under inlet control, the cross sectional area of the culvert, inlet geometry, and elevation of headwater at entrance are of primary importance. Outlet control involves the additional consideration of the tailwater elevation of the outlet channel and the slope, roughness and length of the culvert barrel. A discussion of these two types of control with charts for selecting a culvert size for a given set of conditions is included in the FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts."

825.3 Computer Programs

Numerous calculator and computer programs are available to aid in the design and analysis of highway culverts. The major advantages of these programs over the traditional hand calculation method are:

- Increased accuracy over charts and nomographs.

- Rapid comparison of alternative sizes and inlet configurations.

Familiarity with culvert hydraulics and traditional methods of solution is necessary to provide a solid basis for designers to take advantage of the speed, accuracy, and increased capabilities of hydraulic design computer programs.

The hydraulic design calculator and computer programs available from the FHWA are more fully described in HDS No. 5, "Hydraulic Design of Highway Culverts."

The HY8 culvert hydraulics program provides interactive culvert analysis. Given all of the appropriate data, the program will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user-defined culverts.

The logic of HY8 involves calculating the inlet and outlet control headwater elevations for the given flow. The elevations are then compared and the larger of the two is used as the controlling elevation. In cases where the headwater elevation is greater than the top elevation of the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. In the cases where the culvert is not full for any part of its length, open channel computations are performed.

825.4 Coefficient of Roughness

Suggested Manning's n values for culvert design are given in Table 852.1.

Topic 826 - Entrance Design

826.1 Introduction

The size and shape of the entrance are among the factors that control the level of ponding at the entrance. Devices such as rounded or beveled lips and expanded entrances help maintain the velocity of approach, increase the culvert capacity, and may lower costs by permitting a smaller sized culvert to be used.

The inherent characteristics of common entrance treatments are discussed in Index 826.4. End treatment on large culverts is an important consideration. Selecting an appropriate end treatment for a specific type of culvert and location requires the application of sound engineering judgment.

The FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts" combines culvert design information previously contained in HEC No. 5, No. 10, and No. 13. The hydraulic performance of various entrance types is described in HDS No. 5.

826.2 End Treatment Policy

The recommended end treatment for small culverts is the prefabricated flared end section. For safety, aesthetic, and economic reasons, flared end sections should be used at both entrance and outlet whenever feasible instead of headwalls.

End treatment, either flared end section or headwall, is required for circular culverts 60 inches or more in diameter and for pipe arches of equivalent size.

826.3 Conventional Entrance Designs

The inlet edge configuration is one of the prime factors influencing the hydraulic performance of a culvert operating in inlet control. The following entrance types are frequently used.

(1) *Projecting Barrel.* A thin edge projecting inlet can cause a severe contraction of the flow. The effective cross sectional area of the barrel may be reduced to about one half the actual available barrel area.

The projecting barrel has no end treatment and is the least desirable hydraulically. It is economical but its appearance is not pleasing and use should be limited to culverts with low velocity flows where head conservation, traffic safety, and appearance are not important considerations.

Typical installations include an equalizer culvert where ponding beyond the control of the highway facility occurs on both sides of the highway or where the flow is too small to fill the minimum culvert opening.

The projecting entrance inhibits culvert efficiency. In some situations, the outlet end may project beyond the fill, thus providing security against erosion at less expense than bank protection work.

Projecting ends may prove a maintenance nuisance, particularly when clearance to right of way fence is limited.

(2) *Flared End Sections.* This end treatment provides approximately the same hydraulic performance as a square-edge headwall and is used to retain the embankment, improve the aesthetics, and enhance safety. Because prefabricated flared end sections provide better traffic safety features and are considered more attractive than headwalls they are to be used instead of headwalls whenever feasible.

Details of prefabricated flared end sections for circular pipe in sizes 12 inches through 84 inches in diameter and pipe arches of equivalent size are shown on Standard Plans D94A & B.

(3) *Headwalls and Wingwalls.* This end treatment may be required at the culvert entrance for the following reasons:

- To improve hydraulic efficiency.
- To retain the embankment and reduce erosion of slopes.
- To provide structural stability to the culvert ends and serve as a counterweight to offset buoyant or uplift forces.

(4) *Rounded Lip.* This treatment costs little, smoothes flow contraction, increases culvert capacity, and reduces the level of ponding at the entrance. The box culvert and pipe headwall standard plans include a rounded lip. The rounded lip is omitted for culverts less than 48 inches in diameter; however, the beveled groove end of concrete pipe at the entrance produces an effect similar to that of a rounded lip.

(5) *Mitered End.* A mitered culvert end is formed when the culvert barrel is cut to conform with the plane of the embankment slope. Mitered entrances are not to be used. They are hydraulically less efficient than either flared end sections or headwalls, and they are structurally unstable.

(6) *Entrance Risers.* At a location where the culvert would be subject to plugging, a vertical pipe riser should be considered. Refer to Index 822.2 for discussion on debris-control structures.

826.4 Improved Inlet Designs

Entrance geometry refinements can be used to reduce the flow contraction at the inlet and increase the capacity of culverts operating under inlet control without increasing the headwater depth. The following entrance types improve culvert inlet performance and can be provided at reasonable cost.

(1) *Expanded Entrances.* Headwalls with straight flared wingwalls or warped wingwalls offer a more highly developed entrance appropriate for large culverts, regardless of type or shape of barrel. The effect of such entrances can be approximated more economically by a shaped entrance using air blown mortar, concreted riprap, sacked concrete or slope paving.

Straight flared wingwalls and warped wingwalls aid in maintaining the approach velocity, align and guide drift, and funnel the flow into the culvert entrance. To insure enough velocity to carry drift and debris through the culvert or increase the velocity and thereby increase the entrance capacity, a sloping drop down apron at the entrance may be used. To minimize snagging drift, the standard plans require wingwalls to be flush with the culvert barrel. The flare angle may range from 30 to 75 degrees; the exact angle is based on the alignment of the approach channel banks and not the axis of the culvert. Greater efficiency is obtained when the top of the wingwall is the same elevation as the headwall.

Whether warped or straight flared wingwalls are used depends on the shape of the approach channel. Straight flared wingwalls are appropriate for well defined channels with steep banks. Warped wingwalls are more suited to shallow trapezoidal approach channels.

Usually it is more economical to transition between the stream section and the culvert by means of straight flared wingwalls or warped wingwalls than to expand the culvert barrel at entrance. For a very wide channel, this transition may be combined with riprap, dikes, or channel lining extending upstream to complete the transition.

(2) *Transitions.* Elaborate transitions and throated openings for culverts may be warranted in special cases. Generally a highly developed

entrance is unnecessary if the shape of the culvert fits the approach channel. In wide flat channels where ponding at entrance must be restricted, a wide shallow structure or multiple conduit should be used if drift and debris are not a problem.

Throated or tapered barrels at entrance are more vulnerable to clogging by debris. They are not economical unless they are used for corrective measures; for example, where there is a severe restriction in right of way width and it is necessary to increase the capacity of an existing culvert structure.

For further information refer to HEC-9, "Debris-Control Structures" and HDS 5, "Hydraulic Design of Highway Culverts"

Topic 827 - Outlet Design

827.1 General

The outlet velocity of highway culverts is usually higher than the maximum natural stream velocity. This higher velocity can cause streambed scour and bank erosion for a limited distance downstream from the culvert outlet.

The slope and roughness of the culvert barrel are the principle factors affecting outlet velocity. The shape and size of a culvert seldom have a significant effect on the outlet velocity. When the outlet velocity is believed to be excessive and it cannot be satisfactorily reduced by adjusting the slope or barrel roughness, it may be necessary to use some type of outlet protection or energy dissipator. A method of predicting and analyzing scour conditions is given in the FHWA publication "Scour at Culvert Outlets in Mixed Bed Materials", FHWA/RD - 82/011.

When dealing with erosive velocities at the outlet, the effect on downstream property should be evaluated.

827.2 Embankment Protection

Improved culvert outlets are designed to restore natural flow conditions downstream. Where erosion is to be expected, corrective measures such as bank protection, vertical flared wingwalls, warped wingwalls, transitions, and energy dissipators may be considered. See Chapter 870, "Channel and Shore Protection-Erosion Control", FHWA Hydraulic Engineering Circulars No. 11, "Design of Riprap Revetment", No. 14, "Hydraulic Design of Energy Dissipators for Culverts and Channels", and No. 15, "Design of Roadway Channels with Flexible Linings", and "Hydraulic Design of Stilling Basins and Energy Dissipators", Engineering Monograph No. 25 by the U. S. Department of Interior, Bureau of Reclamation, 1964 (revised 1978). HY-8, within the Hydrain Integrated Computer Program System, provides designs for energy dissipators and follows the HEC-14 method for design.

Culvert outlet design should provide a transition for the 100-year flood or design event from the culvert outlet to a section in the natural channel where natural stage, width, and velocity will be restored, or nearly so, with consideration of stability and security of the natural channel bed and banks against scour.

If an outfall structure is required for transition, typically it will not have the same design as the entrance.

Wingwalls, if intended for an outlet transition (expansion), generally should not flare at an angle (in degrees) greater than 150 divided by the outlet velocity in feet per second. However, transition designs fall into two general categories: those applicable to culverts in outlet control (subcritical flow) or those applicable to culverts in inlet control (supercritical). The procedure outlined in HEC-14 for subcritical flow expansion design should also be used for supercritical flow expansion design if the culvert exit Froude number (Fr) is less than 3, if the location where the flow conditions desired is within 3 culvert diameters of the outlet, and if the slope is less than 10 percent. For supercritical flow expansions outside these limits, the energy equation can be used to determine flow conditions leaving the transition.

Warped endwalls can be designed to fit trapezoidal or U-shaped channels, as transitions for moderate-to-high velocity (10 feet per second – 18 feet per second).

For extreme velocity (exceeding 18 feet per second) the transition can be shortened by using an energy-dissipating structure.

Topic 828 - Diameter and Length

828.1 Introduction

From a maintenance point of view the minimum diameter of pipe and the distance between convenient cleanout access points are important considerations.

The following instructions apply to minimum pipe diameter and the length of pipe culvert.

828.2 Minimum Diameter

The minimum diameter for cross culverts under the roadway is 18 inches. For other than cross pipes, the minimum diameter is 12 inches. For maintenance purposes, where the slope of longitudinal side drains is not sufficient to produce self-cleaning velocities, pipe sizes of 18 inches or more in diameter should be considered.

The minimum diameter of pipe to be used is further determined by the length of pipe between convenient cleanout access points. If pipe runs exceed 100 feet between inlet and outlet, or intermediate cleanout access, the minimum diameter of pipe to be used is 24 inches. When practicable, intermediate cleanout points should be provided for runs of pipe 24 inches in diameter that exceed 300 feet in length.

If a choice is to be made between using 18-inch diameter pipe with an intermediate cleanout in the highway median or using 24-inch diameter pipe without the median access, the larger diameter pipe without the median access is preferred.

828.3 Length

The length of pipe culvert to be installed is determined as follows:

(a) Establish a theoretical length based on slope stake requirements making allowance for end treatment.

(b) Adjust the theoretical length for height of fill by applying these rules:

- For fills 12 feet or less, no adjustment is required.
- For fills higher than 12 feet, add 1 foot of length at each end for each 10 foot increment of fill height or portion thereof. The additional length should not exceed 6 feet on each end.
- In cases of high fills with benches, the additional length is based on the height of the lowest bench.

(c) Use the nearest combination of commercial lengths which equal or exceed the length obtained in (b) above.

Topic 829 - Special Considerations

829.1 Introduction

In addition to the hydraulic design, other factors must be considered to assure the integrity of culvert installations and the highway.

829.2 Bedding and Backfill

The height of overfill a culvert will safely sustain depends upon foundation conditions, method of installation, and its structural strength and rigidity.

Uniform settlement under both the culvert and the adjoining fill will not overstress flexible and segmental rigid culverts. Unequal settlement, however, can result in distortion and shearing action in the culvert. For rigid pipes this could result in distress and disjointing of the pipe. A flexible culvert accommodates itself to moderate unequal settlements but is also subject to shearing action. Monolithic culverts can tolerate only a minimal amount of unequal settlement, and require favorable foundation conditions. Any unequal settlement would subject a monolithic culvert to severe shear stresses.

(1) Foundation Conditions. A slightly yielding foundation under both the culvert and adjoining fill is the foundation condition generally encountered. The maximum height of cover tables given in Chapter 850 are based on this foundation condition.

Unyielding foundation conditions can produce high stresses in the culverts. Such stresses may be counteracted by subexcavation and backfill.

The Standard Plans show details for shaped, sand, and soil cement bedding treatments.

Foundation materials capable of supporting pressures between 1.0 tons per square foot and 8.0 tons per square foot are required for culverts with cast-in-place footing or inverts, such as reinforced concrete boxes, arches, and structural plate arches. When culvert footing pressures exceed 1.5 tons per square foot or the diameter or span exceeds 10 feet, a geology report providing a log of test boring is required.

Adverse foundation and backfill conditions may require a specially designed structure. The allowable overfill heights for concrete arches, structural plate arches, and structural plate vehicular undercrossings are based on existing soil withstanding the soil pressures indicated on the Standard Plans. A foundation investigation should be made to insure that the supporting soils withstand the design soil pressures for those types of structures.

(2) *Method of Installation.* Under ordinary conditions, the methods of installation described in the Standard Specifications and shown on the Standard Plans should be used. For any predictable settlement, provisions for camber should be made.

Excavation and backfill details for circular concrete pipe, reinforced box and arch culverts, and corrugated metal pipe and arch culverts are shown on Standard Plans A62-D, A62DA, A62-E, and A62-F respectively.

(3) *Height of Cover.* There are several alternative materials from which acceptable culverts may be made. Tables of maximum height of cover recommended for the more frequently used culvert shapes, sizes, corrugation configurations, and types of materials are given in Chapter 850. Not included, but covered in the Standard Plans, are maximum earth cover for reinforced concrete box culverts, reinforced concrete arches, and structural plate vehicular undercrossing.

For culverts where overfill requirements exceed the limits shown on the tables a special design must be prepared. Special designs are to be submitted to the Division of Structures for review, or the Division of Structures may be directly requested to prepare the design.

Under any of the following conditions, the Division of Structures is to prepare the special design:

- Where foundation material will not support footing pressure shown on the Standard Plans for concrete arch and structural plate vehicular undercrossings.
- Where foundation material will not support footing pressures shown in the Highway Design Manual for structural plate pipe arches or corrugated metal pipe arches.
- Where a culvert will be subjected to unequal lateral pressures, such as at the toe of a fill or adjacent to a retaining wall.

Special designs usually require that a detailed foundation investigation be made.

(4) *Minimum Cover.* When feasible, culverts should be buried at least 1 foot. For construction purposes, a minimum cover of 6 inches greater than the thickness of the structural cross section is desirable for all types of pipe. The minimum thickness of cover for various type culverts under rigid or flexible pavements is given in Table 856.5.

829.3 Piping

Piping is a phenomenon caused by seepage along a culvert barrel which removes fill material, forming a hollow similar to a pipe. Fine soil particles are washed out freely along the hollow and the erosion inside the fill may ultimately cause failure of the culvert or the embankment.

The possibility of piping can be reduced by decreasing the velocity of the seepage flow. This can be reduced by providing for watertight joints. Therefore, if piping through joints could become a problem, consideration should be given to providing for watertight joints.

Piping may be anticipated along the entire length of the culvert when ponding above the culvert is expected for an extended length of time, such as when the highway fill is used as a detention dam or to form a reservoir. Headwalls, impervious materials at the upstream end of the culvert, and anti-seep or cutoff collars increase the length of the flow path, decrease the hydraulic gradient and the velocity of flow and thus decreases the probability of piping developing. Anti-seep collars usually consist of bulkhead type plate or blocks around the entire perimeter of the culvert. They may be of metal or concrete, and, if practical, should be keyed into impervious material.

Piping could occur where a culvert must be placed in a live stream, and the flow cannot be diverted. Under these conditions watertight joints should be specified.

829.4 Joints

The possibility of piping being caused by open joints in the culvert barrel may be reduced through special attention to the type of pipe joint specified. For a more complete discussion of pipe joint requirements see Index 854.1.

The two pipe joint types specified for culvert installations are identified as "standard" and "positive". The "standard" joint is adequate for ordinary installations and "positive" joints should be specified where there is a need to withstand soil movements or resist disjointing forces. Corrugated metal pipe coupling band details are shown on Standard Plan sheets D97A through D97G and concrete pipe joint details on sheet D97H.

If it is necessary for "standard" or "positive" joints to be watertight they must be specifically specified as such. Rubber "O" rings or other resilient joint material provides the watertight seal. Corrugated metal pipe joints identified as "downdrain" are watertight joint systems with a tensile strength specification for the coupler.

829.5 Anchorage

Refer to Index 834.4(5) for discussion on anchorage for overside drains.

Reinforced concrete pipe should be anchored and have positive joints specified if either of the following conditions is present:

(a) Where the pipe diameter is 60 inches or less, the pipe slope is 33 percent or greater, and the fill over the top of the pipe less than 1.5 times the outside diameter of the pipe measured perpendicular to the slope.

(b) Where the pipe diameter is greater than 60 inches and the pipe slope is 33 percent or greater, regardless of the fill over the top of the pipe.

Where the slopes have been determined by the geotechnical engineer to be potentially unstable, regardless of the slope of the pipe, as a minimum, the pipes shall have positive joints. Alternative pipes/anchorage systems shall be investigated when there is a potential for substantial movement of the soil.

Where anchorage is required, there should be a minimum of 18 inches cover measured perpendicular to the slope.

Typically buried flexible pipe with corrugations on the exterior surface will not require anchorage, however, a special detail will be required for plastic pipe without corrugations on the exterior surface.

829.6 Irregular Treatment

(1) Junctions. (Text Later)

(2) Bends. (Text Later)

829.7 Siphons and Sag Culverts

(1) General Notes. There are two kinds of conduits called siphons: the true siphon and the inverted siphon or sag culvert. The true siphon is a closed conduit, a portion of which lies above the hydraulic grade line. This results in less than atmospheric pressure in that portion. The sag culvert lies entirely below the hydraulic grade line; it operates under pressure without siphonic action.

Under the proper conditions, there are hydraulic and economic advantages to be obtained by using the siphon principle in culvert design.

(2) Sag Culverts. This type is most often used to carry an irrigation canal under a highway when the available headroom is insufficient for a normal culvert. The top of a sag culvert should be at least 4.5 feet below the finished grade where possible, to ensure against damage from heavy construction equipment. The culvert should be on a straight grade and sumps provided at each end to facilitate maintenance. Sag culverts should not be used:

(a) When the flow carries trash and debris in sufficient quantity to cause heavy deposits,

(b) For intermittent flows where the effects of standing water are objectionable, or

(c) When any other alternative is possible at reasonable cost.

(3) *Types of Conduit.* Following are two kinds of pipes used for siphons and sag culverts to prevent leakage:

(a) Reinforced Concrete Pipe - Reinforced concrete pipe with joint seals is generally satisfactory. For heads over 20 feet, special consideration should be given to hydrostatic pressure.

(b) Corrugated Metal Pipe - corrugated metal pipe must be of the thickness and have the protective coatings required to provide the design service life. Field joints must be watertight. The following additional treatment is recommended.

- When the head is more than 10 feet and the flow is continuous or is intermittent and of long duration, pipe fabricated by riveting, spot welding or continuous helical lockseam should be soldered.

  Pipe fabricated by a continuous helical welded seam need not be soldered.

- If the head is 10 feet or less and the flow is intermittent and lasts only a few days, as in storm flows, unsoldered seams are permissible.

829.8 – Currently Not In Use

829.9 Dams

Typically, proposed construction which is capable of impounding water to the extent that it meets the legal definition of a dam must be approved by the Department of Water Resource (DWR), Division of Safety of Dams. The legal definition is described in Sections 6002 and 6003 of the State Water Code. Generally, any facility 25 feet or more in height or capable of impounding 50 acre-feet or more would be considered a dam. However, any facility 6 feet or less in height, regardless of capacity, or with a storage capacity of not more than 15 acre-feet, regardless of height, shall not be considered a dam. Additionally, Section 6004 of the State Water Code states "... and no road or highway fill or structure ... shall be considered a dam." Therefore, except for large retention or detention facilities there will rarely be the need for involvement by the DWR in approval of Caltrans designs.

Although most highway designs will be exempt from DWR approval, caution should always be exercised in the design of high fills that could impound large volumes of water. Even partial plugging of the cross drain could lead to high pressures on the upstream side of the fill, creating seepage through the fill and/or increased potential for piping.

The requirements for submitting information to the FHWA Division Office in Sacramento as described in Index 805.6 are not affected by the regulations mentioned above.

829.10 Reinforced Concrete Box Modifications

(1) *Extensions.* Where an existing box culvert is to be lengthened, it is essential to perform an on-site investigation to verify the structural integrity of the box. If signs of distress are present, the Division of Structures must be contacted prior to proceeding with the design.

(2) *Additional Loading.* When significant additional loading is proposed to be added to an existing reinforced concrete box culvert the Division of Structures must be contacted prior to proceeding with the design. Overlays of less than 6 inches in depth, or widenings that do not increase the per unit loading on the box are not considered to be significant. Designers should also check the extent that previous projects might have increased loading on box culverts, even if the current project is not adding a significant amount of loading.

(3) *Side Gutters.* These are triangular gutters adjoining the shoulder as shown in Figures 307.2 and 307.5. The main purpose of the 3 feet wide side gutter is to prevent runoff from the cut slopes on the high side of superelevation from flowing across the roadbeds. The use of side gutters in tangent alignment should be avoided where possible. Local drainage conditions, such as in snow areas, may require their use on either tangent or curved alignment in cut sections. In snow areas it may be necessary to increase the width of side gutters from 3 feet to 6 feet. The slope from the edge of the shoulder to the bottom of the gutter should be no steeper than 6:1. The structural section for paved side gutters should be adequate to support maintenance equipment loads.

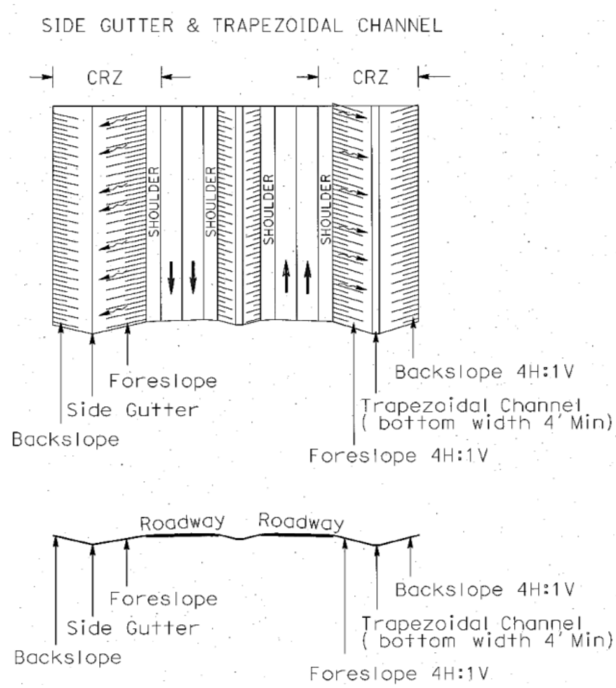
(4) *Side Gutters within the Clear Recovery Zone (CRZ).* Foreslopes parallel to the flow of traffic are considered to be recoverable if the slope is 4:1 or flatter. Side gutter sections located within the CRZ should have a foreslope and backslope combination of either 6:1 and 4:1, or 4:1 and 6:1 (refer to Figures 305.6, 307.2, 307.4A, 307.4B, and 307.5). See Figure 834.3.

When side gutters are included within the CRZ the depth of flow in the gutter section should be determined for the appropriate design storm. The depth of flow for the design storm may be used to design the structural section of the channel capable of supporting errant vehicles. The side gutter cross-section should satisfy hydraulic conveyance as well as support the load of errant vehicles without the wheels sinking into saturated soil in the channel section. Design criteria for concrete lined channels may be referenced from the US Army Corps Publication "Structural Design of Concrete Lined Flood Control Channels, EM 1110-2-2007".

(5) *Dikes.* Dikes placed adjoining the shoulder, as shown in Figures 307.2, 307.4A, 307.4B and 307.5, provide a paved triangular gutter within the shoulder area. For conditions governing their use, see Index 303.3.

(6) *Chart Solutions.* Charts for solutions to triangular channel flow problems are contained in FHWA Hydraulic Engineering Circular No. 22, "Urban Drainage Design Manual".

Figure 834.3
Side Gutter and Trapezoidal Channel



834.4 Overside Drains

The purpose of overside drains, sometimes called slope drains, is to protect slopes against erosion. They convey down the slope drainage which is collected from the roadbed, the tops of cuts, or from benches in cut or fill slopes. They may be pipes, flumes or paved spillways.

(1) *Spacing and Location.* The spacing and location of overside drains depend on the configuration of the ground, the highway profile, the quantity of flow and the limitations on flooding stated in Table 831.3. When possible, overside drains should be positioned at the lower end of cut sections. Diversion from one watershed to another should be avoided. If diversion becomes necessary, care should be used in the manner in which this diverted water is disposed.

Overside drains which would be conspicuous or placed in landscaped areas should be concealed by burial or other means.

(2) *Type and Requirement.* Following are details of various types of overside drains and requirements for their use:

(a) Pipe Downdrains. Metal and plastic pipes are adaptable to any slope. They should be used where side slopes are 4:1 or steeper. Long pipe downdrains should be anchored.

The minimum pipe diameter is 8 inches but large flows, debris, or long pipe installations may dictate a larger diameter.

Watertight joints are necessary to prevent leakage which causes slope erosion. Economy in long, high capacity downdrains is achieved by using a pipe taper in the initial reach. Pipe tapers should insure improved flow characteristics and permit use of a smaller diameter pipe below the taper. See Standard Plan D87-A for details.

(b) Flume Downdrains. These are rectangular corrugated metal flumes with a tapered entrance. See the Standard Plan D87-D for details. They are best adapted to slopes that are 2:1 or flatter but if used on 1.5:1 slopes, lengths over 60 feet are not recommended. Abrupt changes in alignment or grade should be avoided. Flume downdrains should be depressed so that the top of the flume is flush with the fill slope.

(c) Paved Spillways. Permanent paved spillways should only be used when the side slopes are flatter than 4:1. On steeper slopes a more positive type of overside drain such as a pipe downdrain should be used.

Temporary paved spillways are effective in preserving raw fill slopes that are 6:1 or flatter in friable soils during the period when protective growth is being established. Paved spillways should be spaced so that a dike 2 inches high placed at the outer edge of the paved shoulder will effectively confine drainage between spillways. When it is necessary to place a spillway on curved alignment, attention must be given to possible overtopping at the bends. See Index 868.2(3) for discussion of superelevation of the water surface.

(3) *Entrance Standards.* Entrance tapers for pipes and flume downdrains are detailed on the Standard Plans. Pipe entrance tapers should be depressed at least 6 inches.

The local depressions called "paved gutter flares" on the Standard Plans are to be used at all entrance tapers. See Standard Plans D87-A and D87-D for details and Index 837.5 for further discussion on local depressions.

In areas where local depressions would decrease safety the use of flush grate inlets or short sections of slotted drain for entrance structures may be necessary.

(4) *Outlet Treatment.* Where excessive erosion at an overside drain outlet is anticipated, a simple energy dissipater should be employed. Preference should be given to inexpensive expedients such as an apron of broken concrete or rock, a short section of pipe placed with its axis vertical with the lowermost 6 inches filled with coarse gravel or rock, or a horizontal tee section which is usually adequate for downdrain discharges.

(5) *Anchorage*. For slopes flatter than 3:1 overside drains do not need to be anchored. For slopes 3:1 or steeper overside drains should be anchored with 6 foot pipe stakes as shown on the Standard Plans to prevent undue strain on the entrance taper or pipe ends. For drains over 150 feet long, and where the slope is steeper than 2:1, cable anchorage should be considered as shown on the Standard Plans. Where the cable would be buried and in contact with soil, a solid galvanized rod should be used the buried portion and a cable, attached to the rod, used for the exposed portion. Beyond the buried portion, a slip joint must be provided when the installation exceeds 60 feet in length. Regard-less of pipe length or steepness of slope, where there is a potential for hillside movement cable anchorage should be considered.

When cable anchorage is used as shown on the Standard Plans, the maximum allowable downdrain lengths shall be 200 feet for a slope of 1.5:1 and 250 feet for a slope of 2:1. For pipe diameters greater than 24 inches, or downdrains to be placed on slopes steeper than 1.5:1, special designs are required. Where there is an abrupt change in direction of flow, such as at the elbow or a tee section downstream of the end of the cable anchorage system, specially designed thrust blocks should be considered.

(6) *Drainage on Benches.* Drainage from benches in cut and fill slopes should be removed at intervals ranging from 300 feet to 500 feet.

(7) *Selection of Types.* Pipe and flume downdrains may consist of either corrugated steel, corrugated aluminum, or any other approved material that meets the minimum design service life required under Chapter 850. Refer to Index 855.2 for additional discussion on limitations of abrasive resistance of aluminum pipe culverts.

Topic 835 - Dikes and Berms

835.1 General

Dikes and berms are to be used only as necessary to confine drainage and protect side slopes susceptible to erosion.

835.2 Earth Berms

(Text Later)

835.3 Dikes

Details of dikes are shown on Standard Plan A87. See Topic 303 for a detailed discussion on the types and placement considerations for dikes.

Topic 836 - Curbs and Gutters

836.1 General

The primary reason for constructing curbs and gutters may be for delineation or pedestrian traffic rather than for drainage considerations. Refer to Topic 303 for further discussion and Standard Plan A87 for details on concrete curbs and gutters.

Whatever the justification for constructing curbs and gutters, they will usually have an effect on surface water runoff and result in becoming a roadway drainage design consideration.

836.2 Gutter Design

(1) *Capacity.* Gutters and drainage facilities are to be designed to keep flooding within the limits given in Table 831.3. Easy solutions to gutter flow problems can be obtained by using the charts contained in FHWA Hydraulic Engineering Circular No. 22, "Urban Drainage Design Manual" which applies to triangular channels and other shapes illustrated in the charts. Parked cars reduce gutter capacity and also can cause water to shoot over the curb. The downstream ends of driveway ramps can also cause water to flow over the curb. As a rule of thumb, gutter capacity should be determined on a depth equal to 0.5 the curb height for grades up to 10 percent and 0.4 the curb height for grades over 10 percent in locations where parking is allowed or where driveways are constructed.

(2) *Grade and Cross Slope.* The longitudinal grade of curbs and gutters is controlled by the highway grade line as discussed under Index 831.2.

The cross slope of standard gutters is typically 8.33 percent toward the curb. Pavement slopes on superelevated roadways extend the full width of the gutter, except that gutter slopes on the low side should be not less than 8.33 percent. Because they cut down gutter capacity and severely reduce inlet efficiency, cross slopes flatter than 8.33 percent should be avoided, except where gutters are adjacent to curb ramps where ADA requirements limit the slope to a maximum of 5 percent.

(3) *Curbed Intersections.* If pedestrian traffic is a ruling factor, intersection drainage presents the following alternatives to be weighed as to effectiveness and economy.

(a) Intercept the whole flow upstream of the crosswalk.

(b) Intercept a part of the water and allow the overflow to cross the intersection. The width of flow should be controlled so that pedestrian traffic is not unduly hampered.

(c) If flow is small, pass the entire flow across the intersecting street in a valley gutter.

(4) *Valley Gutters.* Valley gutters across the traveled way of the highway should not be used. Valley gutters may be used across intersecting streets and driveways, however, at intersections with high traffic volumes on all approaches, it is desirable to intercept all gutter flow upstream of the intersection and avoid the use of valley gutters. Valley gutters are also undesirable along streets where speeds are relatively high. In locations of frequent intermittent low flows, the use of valley gutters with slotted drains should be considered. In general, the total width of gutters should not exceed 6 feet and cross slopes should not exceed 3 percent. Two percent is suggested where more than nominal speeds are involved.

Topic 837 - Inlet Design

837.1 General

The basic features of standard storm drain inlets are shown in Figure 837.1. Full details appear on Standard Plan D72 through D75, D98-A and D98-B. The variety of standard designs available is considered sufficient to any drainage situation; hence, the use of nonstandard inlets should be rare.

837.2 Inlet Types

From an operating standpoint, there are five main groups of inlets; these are:

(1) *Curb-Opening.* Curb opening inlets have an opening parallel to the direction of flow in the gutter. This inlet group is adapted to curb and gutter installations. The curb opening is most effective with flows carrying floating debris. As the gutter grade steepens, their interception capacity decreases. Hence, they are commonly used on grades flatter than 3 percent.

When curb opening inlets are used on urban highways other than fenced freeways, a 3/4 inch plain round protection bar is placed horizontally across any curb or wall opening whose height is 7 inches or more. The unsupported length of bar should not exceed 7 feet. Use of the protection bar on streets or roads under other jurisdiction is to be governed by the desires of the responsible authorities.

The Type OS and OL inlets are only used with Type A or B curbs. A checkered steel plate cover is provided for maintenance access.

The Type OS inlet has a curb opening 3.5 feet long. Since a fast flow tends to overshoot such a short opening, it should be used with caution on grades above 3 percent.

The Type OL inlet is a high capacity unit in which the length of curb opening ranges from 7 feet to 21 feet.

(2) *Grate.* Grate inlets provide a grate opening in the gutter or waterway. As a class, grate inlets perform satisfactorily over a wide range of gutter grades. Their main disadvantage is that they are easily clogged by floating trash and should not be used without a curb opening where total interception of flow is required. They merit preference over the curb opening type on grades of 3 percent or more. Gutter depressions, discussed under Index 837.5, increase the capacity of grate inlets. Grate inlets may also be used at locations where a gutter depression is not desirable. See the Standard Plans for grate details.

Locate grate inlets away from areas where bicycles or pedestrians are anticipated whenever possible. Grate designs that are allowed where bicycle and pedestrian traffic occurs have smaller openings and are more easily clogged by trash and debris and are less efficient at intercepting flow. Additional measures may be necessary to mitigate the increased potential for clogging.

The grate types depicted on Standard Plan D77B must be used if bicycle traffic can be expected. Many highways do not prohibit bicycle traffic, but have inlets where bicycle traffic would not be expected to occur (e.g., freeway median). In such instances, the designer may consider use of grates from Standard Plan D77A. The table of final pay weights on Standard Plan D77B indicates the acceptable grate types to be used for each listed type of inlet.

If grate inlets must be placed within a pedestrian path of travel, the grate must be compliant with the Americans with Disabilities Act (ADA) regulations which limit the maximum opening in the direction of pedestrian travel to no more than 0.5 inch. Presently, the only standard grating which meets such restrictive spacing criterion is the slotted corrugated steel pipe with heel guard, as shown in the Standard Plans. Because small openings have an increased potential for clogging, a minimum clogging factor of 50 percent should be assumed; however, that factor should be increased in areas prone to significant debris. Other options which may be considered are grated line drains with specialty grates (see the Standard Plans for grated line drain details, and refer to manufacturers catalogs for special application grates) or specially designed grates for standard inlets. The use of specially designed grates is a nonstandard design that must be approved by the Office of State Highway Drainage Design prior to submittal of PS&E.

(3) *Combination.* Combination inlets provide both a curb opening and a grate. These are high capacity inlets which make use of the advantages offered by both kinds of openings.

(a) Type GO and GDO. These types of inlets have a curb opening directly opposite the grate. The GDO inlet has two grates placed side by side and is designed for intercepting a wide flow. A typical use of these inlets would be in a sag location either in a curb and gutter installation or within a shoulder fringed by a dike. When used as the surface inlet for a pumping installation, the trash rack shownontheStandardPlanD74Bisprovided.

(b) Type GOL. This is called a sweeper inlet because the curb opening precedes the grate. It is particularly useful as a trash interceptor during the initial phases of a storm. When used in a grade sag, the sweeper inlet can be modified by providing a curb opening on both sides of the grate.

(4) *Pipe.* Pipe drop inlets are made of a commercial pipe section of concrete or corrugated metal. As a class, they develop a high capacity and are generally the most economical type. This type of inlet is intended for uses outside the roadbed at locations that will not be subjected to normal highway wheel loads.

Two kinds of inlets are provided; a wall opening and a grate top. The wall opening inlet should only be used at protected locations where it is unlikely to be hit by an out of control vehicle.

(a) Wall Opening Intake. This opening is placed normal to the direction of surface flow. It develops a high capacity unaffected by the grade of the approach waterway. The inlet capacity is increased by depressing the opening; also by providing additional openings oriented to intercept flows from different directions. When used as the surface intake to a pumping installation, a trash rack across the opening is required. See Standard Plans for pipe inlet details. Because this type of inlet projects above grade, its use should be avoided in areas subject to traffic leaving the roadway.

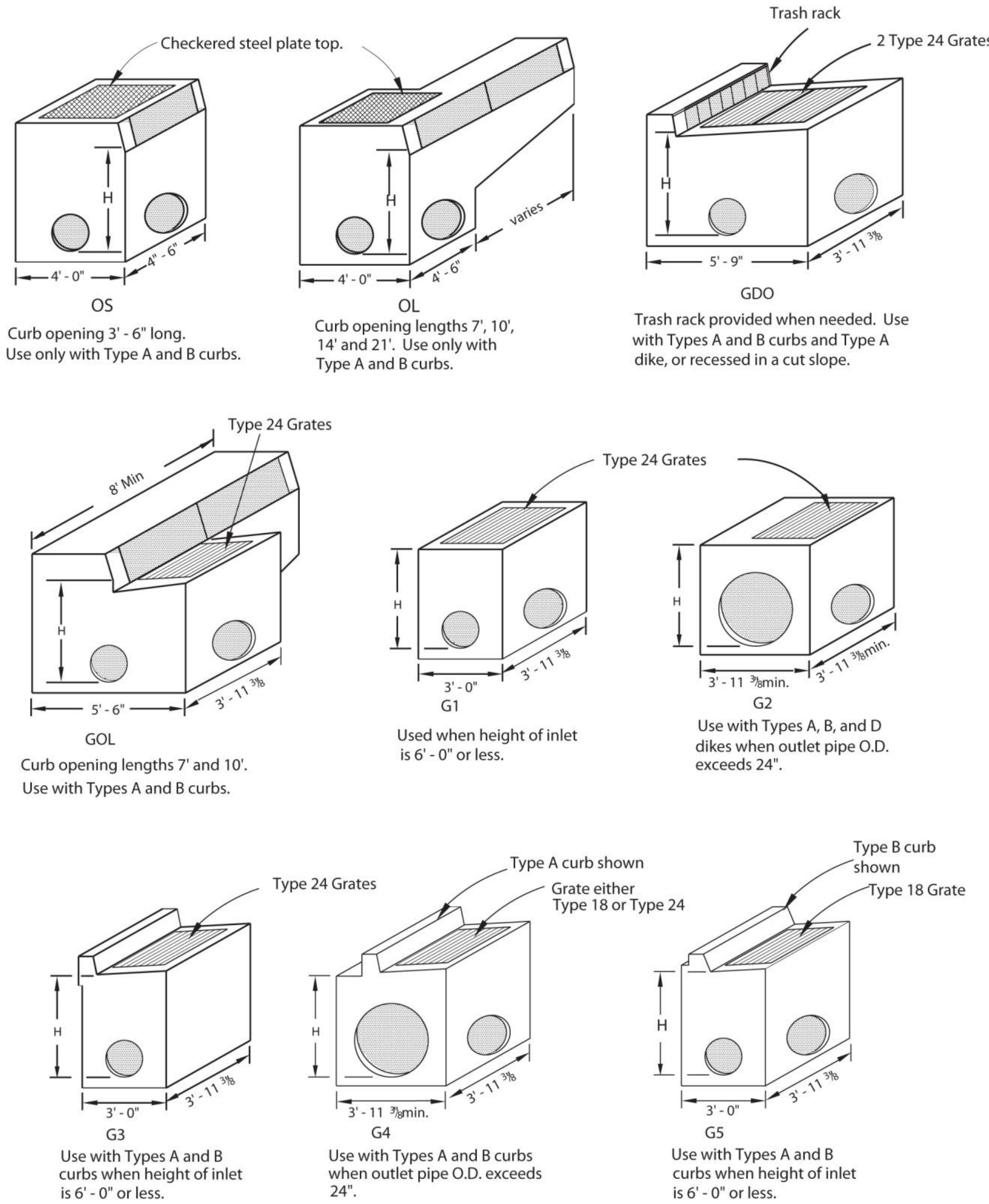
(b) Grate Intake. The grate intake intercepts water from any direction. For maximum efficiency, however, the grate bars must be in the direction of greatest surface flow. Being round, it is most effective for flows that are deepest at the center, as in a valley median.

(5) *Slotted Drains.* This type of inlet is made of corrugated metal or polyethylene pipe with a continuous slot on top. This type of inlet can be used in flush, all paved medians with superelevated sections to prevent sheet flow from crossing the centerline of the highway. Short sections of slotted drain may be used as an alternate solution to a grate catch basin in the median or edge of shoulder.

Drop inlets or other type of cleanout should be provided at intervals of about 100 feet.

(6) *Grated Line Drains.* This type of inlet is made of monolithic polymer concrete with a ductile iron frame and grate on top. This type of inlet can be used as an alternative at the locations described under slotted drains, preferably in shoulder areas away from traffic loading. However, additional locations may include localized flat areas of pavement at private and

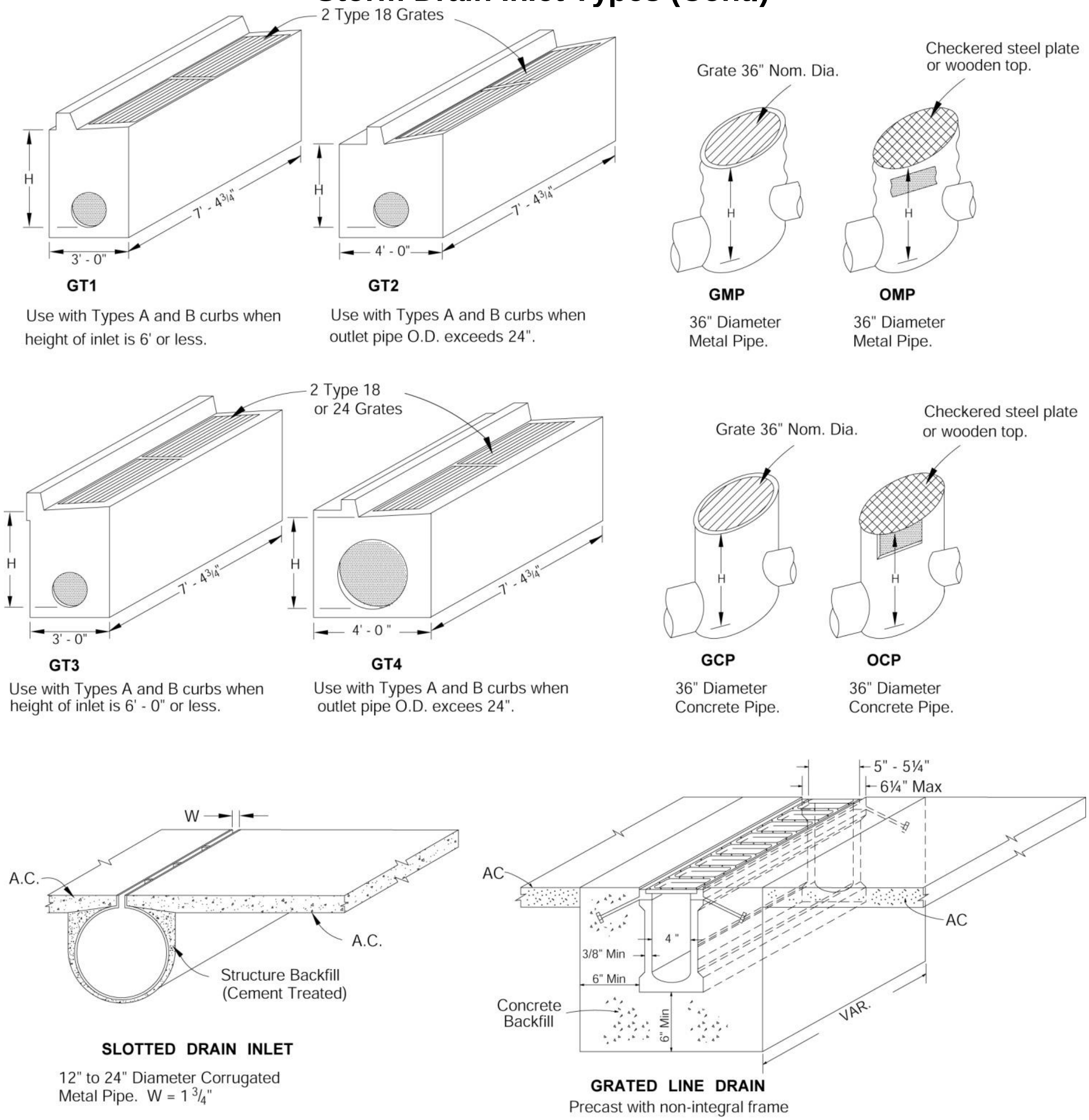
Figure 837.1
Storm Drain Inlet Types



NOTES:
1. All dimensions are outside dimensions based on 6" wall thickness.
2. For full details on uses according to type, see Index 837.2.
3. H = height of inlet.
4. See Standard Plans for Details.
5. Grates shown are not bicycle proof nor ADA compliant.

Figure 837.1

Storm Drain Inlet Types (Cont.)



NOTES:
1. All dimensions are outside dimensions based on 6" wall thickness.
2. For full details on uses according to type, see Index 837.2.
3. H = height of inlet.
4. See Standard Plans for Details.

public intersections, superelevation transitions, along shoulders where widening causes a decrease to allowable water spread, tollbooth approaches, ramp termini, parking lots and on the high side of superelevation in snow and ice country to minimize black ice and sheet flow from snow melt. Removable grates should not be placed where subject to traffic.

Short sections of grated line drain may be used in conjunction with an existing drainage inlet as a supplement in sag locations. However, based on the depth of the water, the flow condition will be either weir or orifice. The transition between weir and orifice occurs at approximately 7 inches depth of flow. The HEC-22 method of design for slotted pipe is recommended as the basis for grated line drain design. It should be noted that this is inlet interception/capacity design, not the carrying capacity of the product as a conduit.

Furthermore, the grated line drain has a smaller cross sectional area than slotted pipe, and therefore typically less carrying capacity.

Grated line drains are recommended as an alternative to slotted pipe at locations susceptible to pipe clogging from sediments and debris. Self-cleaning velocities can usually be generated from their smooth interior surface, or if necessary by specifying the optional pre-sloped sections.

Grated line drains may also be useful where there is a potential for utility conflicts with slotted drains, which are generally installed at a greater depth.

At locations where clean out access is needed, removable grates can be specified. In areas with pedestrian traffic, special grates which meet the Americans with Disabilities Act (ADA) requirements are mandatory. This type of grate is susceptible to clogging, therefore removable grates are recommended at these locations, and they should only be specified when placement directly within the pedestrian path of travel is unavoidable.

(7) *Scuppers.* This type of inlet consists of a low, rectangular slot cut through the base of a barrier. Similar to but smaller than curb opening inlets (See Index 837.2(1)), scuppers are prone to clogging by sediment and debris and require enhanced maintenance attention. Scupper interception efficiency decreases with increased longitudinal gradient and scupper design is not typically compatible with construction of an inlet depression. Scuppers are typically considered only when other inlet options are infeasible.

837.3 Location and Spacing

(1) *Governing Factors.* The location and spacing of inlets depend mainly on these factors:

(a) The amount of runoff,

(b) The longitudinal grade and cross slope,

(c) The location and geometrics of interchanges and at-grade intersections,

(d) Tolerable water spread, see Table 831.3,

(e) The inlet capacity,

(f) Accessibility for maintenance and inspection,

(g) Volume and movements of motor vehicles, bicycles and pedestrians,

(h) Amount of debris, and

(i) The locations of public transit stops.

(2) *Location.* There are no ready rules by which the spacing of inlets can be fixed; the most effective and economical installation should be the aim.

The following are locations where an inlet is nearly always required:

- Sag points
- Points of superelevation reversal
- Upstream of ramp gores
- Upstream and downstream of bridges – bridge drainage design procedure assumes no flow onto bridge from approach roadway, and flow off bridge to be handled by the district.
- Intersections
- Upstream of pedestrian crosswalks
- Upstream of curbed median openings

In urban areas, the volume and movements of vehicles, bicyclists, and pedestrians constitute an important control. For street or road crossings, the usual inlet location is at the intersection at the upstream end of the curb or pavement return and clear of the pedestrian crosswalk. Where the gutter flow is small and vehicular, bicycle, and pedestrian traffic are not important considerations, the flow may be carried across the intersection in a valley gutter and intercepted by an inlet placed downstream. See Index 836.2(4).

At depressed grade lines under structures, care must be taken to avoid bridge pier footings. See Index 204.6.

Safety of location for maintenance purposes is an important consideration. Wall opening inlets should not be placed where they present an obstacle to maintenance equipment and to vehicles that leave the traveled way. Grate top inlets should be installed in such locations.

Placement of inlets within the traveled way is discouraged. Inlets should typically be relocated when roadways are widened or realigned. Any proposal to leave an existing or construct a new inlet within the traveled way should be discussed with District Maintenance to verify that future access is feasible.

(3) *Spacing.* Arbitrary spacing of inlets should be avoided. The distance between inlets should be determined by a rational analysis of the factors mentioned above. Detailed procedures for determining inlet spacing are given in FHWA Hydraulic Engineering Circular No. 22, "Urban Drainage Design Manual". In a valley median, the designer should consider the effect of inlet spacing on flow velocities where the soil is susceptible to erosion. To economize on disposal facilities, inlets are often located at culverts or near roadway drainage conduits.

(4) *Inlets in Series.* Where conditions dictate the need for a series of inlets, the recommended minimum spacing should be approximately 20 feet to allow the bypass flow to return to the curb face.

837.4 Hydraulic Design

(1) *Factors Governing Inlet Capacity.* Inlet capacity is a variable which depends on:

(a) The size and geometry of the intake opening,

(b) The velocity and depth of flow and the gutter cross slope just upstream from the intake, and

(c) The amount of depression of the intake opening below the flow line of the waterway.

(2) *General Notes.*

(a) Effect of Grade Profile. The grade profile affects both the inlet location and its capacity. The gutter grade line exerts such an influence that it often dictates the choice of inlet types as well as the gutter treatment opposite the opening. See Index 831.2.

Sag vertical curves produce a flattening grade line which increases the width of flow at the bottom. To reduce ponding and possible sedimentation problems, the following measures should be considered:

- Reduce the length of vertical curve.
- Use a multiple installation consisting of one inlet at the low point and one or more inlets upstream on each side. Refer to HEC 22 for further discussion and design procedures for locating multiple inlets.

  Short sections of slotted or grated line drains on either side of the low point may be used to supplement drop inlets.

(b) Cross Slope for Curbed Gutters. Make the cross slope as steep as possible within limits stated under Index 836.2(2). This concentrates the flow against the curb and greatly increases inlet capacity.

(c) Local Depressions. Use the maximum depression consistent with site conditions; for further details see Index 837.5.

(d) Trash. The curb-opening type inlet, when the first in a series of grate inlets, may intercept trash and improve grate efficiency. In a grade sag, one trash interceptor should be used on each side of the sump.

(e) Design Water Surface Within the Inlet. The crown of the outlet pipe should be low enough to allow for pipe entrance losses plus a freeboard of 0.75 feet between the design water surface and the opening at the gutter intake. This allows sufficient margin for turbulence losses, and the effects of floating trash.

(f) Inlet Floor. The inlet floor should generally have a substantial slope toward the outlet. In a shallow drain system where conservation of head is essential, or any system where the preservation of a nonsilting velocity is necessary, the half round floor shown on the Standard Plan D74C should be used when a pipe continues through the inlet.

(g) Partial Interception. Economies may be achieved by designing inlets for partial interception with the last one or two inlets in series intercepting the remaining flow. See Hydraulic Engineering Circular No. 22.

(3) Curb-Opening Inlets. Gutter depressions should be used with curb-opening inlets. The standard gutter depressions for curb-opening inlets, shown on Standard Plan D78 are 0.1 foot and 0.25 foot deep.

Curb-opening inlets are most economical and effective if designed and spaced to intercept only 85 to 90 percent of the flow. This provides for an increased flow depth at the curb face.

Figure 4-11, "Comparison of Inlet Interception Capacity, Slope Variable", and Figure 4-12, "Comparison of Inlet Interception Capacity, Flow Rate Variable" of Hydraulic Engineering Circular No. 22 can be used to obtain interception capacities for various longitudinal grades, cross slopes, and gutter depressions. Charts for determining interception capacities under sump conditions are also available in HEC No. 22.

(4) Grate Inlets. The grate inlet interception capacity is equal to the sum of the frontal flow (flow over the grate) interception and the side flow interception. The frontal flow interception will constitute the major portion of the grate interception. In general, grate inlets will intercept all of the frontal flow until a velocity is reached at which water begins to splash over the grate. Charts provided in HEC 22 can be used to compute grate interception capacities for the various grates contained therein. Grate depressions will greatly increase inlet capacity.

The HEC 22 charts neglect the effects of debris and clogging on inlet capacity. In some localities inlet clogging from debris is extensive, while in other locations clogging is negligible. Local experience should dictate the magnitude of the clogging factor, if any, to be applied. In the absence of local experience, design clogging factors of 33 percent for freeways and 50 percent for city streets may be assumed.

Grate type inlets are most economical and effective if designed and spaced to intercept only 75 to 80 percent of the gutter flow.

(5) Combination Inlets.

(a) Type GO and GDO Inlet. For design purposes, only the capacity of the grates need be considered. The auxiliary curb opening, under normal conditions, offers little or no increase in capacity; but does act as a relief opening should the grate become clogged. Since the grates of Type GDO are side by side, the inlet capacity is the combined capacity of the two grates.

(b) Type GOL Inlet. The interception capacity of this inlet, a curb-opening upstream of a grate, is equal to the sum of the capacities for the two inlets except that the frontal flow and thus interception capacity of the grate is reduced by interception at the curb opening.

(6) Pipe Drop Inlets.

(a) Wall Opening Intake. The standard intake opening 2 feet wide and 8 inches to 12 inches deep provides a capacity of approximately 6.0 CFS when the water surface is 1 foot higher than the lip of the opening. Where the flow is from more than one direction, two or more standard openings may be provided. Higher capacity openings larger than standard may be provided but are of a special design.

(b) Grate Intake. The choice between inlets with a round grate (Types GCP and GMP) and those with a rectangular grate (Type G1) hinges largely on hydraulic efficiency. In a waterway where the greatest depth of flow is at the center, both grates are equally effective. In a waterway where the cross slope concentrates the flow on one side of the grate, the rectangular shape is preferred. For rectangular grates, the charts contained in HEC 22 can be used to compute flow intercept. Round grates (Type 36R) with 0.5 foot of depression develop a capacity of 12 CFS to 15 CFS.

837.5 Local Depressions

(1) Purpose. A local depression is a paved hollow in the waterway shaped to concentrate and direct the flow into the intake opening and increases the capacity of the inlet. In a gutter bordered by a curb, it is called a gutter depression.

(2) Requirements. Local depressions generally consist of a paved apron or transition of a shape which serves the purpose. Local depressions should meet the following requirements:

(a) Valley Medians. In medians on a grade, the depression should extend a minimum of 10 feet upstream, 6 feet downstream and 6 feet laterally, measured from the edge of the opening. In a grade sag, the depression should extend a minimum of 10 feet on all sides. No median local depression, however should be allowed to encroach on the shoulder area.

The normal depth of depression is 4 inches.

(b) Paved Gutter Flares. The local depression which adjoins the outer edge of shoulder at the entrance to overside downdrains and spillways is labeled "paved gutter flare" on Standard Plans D87-A and D87-D. The flow line approaching the inlet is depressed to increase capacity and minimize water spread on the roadbed. Within a flare length of 10 feet the gutter flow line is depressed a minimum of 6 inches at the inlet. Recommended flare lengths for various gutter flow line depression depths are given on the Standard Plans. When conditions warrant, these flare lengths may be exceeded.

Traffic safety should not be compromised for hydraulic efficiency. Any change in the shape of the paved gutter flare that will result in a depression within the shoulder area should not be made. The Type 2 entrance taper and paved gutter flare is intended for use on divided highways where gutter grades exceed 2 percent and flow is in the opposite direction of traffic.

(c) Roadside Gutter and Ditch Locations. Regardless of type of intake, the opening of a drop inlet in a roadside gutter or ditch should be depressed from 4 inches to 6 inches below the flow line of the waterway with 10 feet of paved transition upstream.

(d) Curb and Gutter Depressions. This type of depression is carefully proportioned in length, width, depth, and shape. To best preserve the design shape, construction normally is of concrete. Further requirements for curb and gutter depressions are:

- Length - As shown on Standard Plan D78.
- Width - Normally 4 feet, but for wide flows or a series of closely spaced inlets, 6 feet is authorized.
- Depth - Where traffic considerations govern, the depth commonly used is 0.1 foot. Use the maximum of 0.25 foot wherever feasible at locations where the resulting curb height would not be objectionable.

(e) Type of Pavement. Local depressions outside the roadbed are usually surfaced with asphalt concrete 0.15 foot thick.

(3) *General Notes on Design.* Except for traffic safety reasons, a local depression is to be provided at every inlet even though the waterway is unpaved. Where the size of intake opening is a question, a depression of maximum depth should be considered before deciding on a larger opening. For traffic reasons, the gutter depression should be omitted in driveways and median curb and gutter installations.

It is permissible to omit gutter depressions at sump inlets where the width of flow does not exceed design water spread.

Topic 838 - Storm Drains

838.1 General

The total drainage system which conveys runoff from roadway areas to a positive outlet including gutters, ditches, inlet structures, and pipe is generally referred to as a storm drain system. In urban areas a highway storm drain often augments an existing or proposed local drainage plan and should be compatible with the local storm drain system.

This section covers the hydraulic design of the pipe or enclosed conduit portion of a storm drain system.

838.2 Design Criteria

To adequately estimate design storm discharges for a storm drain system in urban areas involving street flooding it may be necessary to route flows by using hydrograph methods. Hydrographs are discussed under Index 816.5 and further information on hydrograph methods may be found in Chapters 6 and 7 of HDS No.2, Highway Hydrology.

838.3 Hydraulic Design

Closed conduits should be designed for the full flow condition. They may be allowed to operate under pressure, provided the hydraulic gradient is 0.75 foot or more below the intake lip of any inlet that may be affected. The energy gradient should not rise above the lip of the intake. Allowances should be made for energy losses at bends, junctions and transitions.

To determine the lowest outlet elevation for drainage systems which discharge into leveed channels or bodies of water affected by tides, consideration should be given to the possibilities of backwater. The effect of storm surges (e.g., winds and floods) should be considered in addition to the predicted tide elevation.

Normally, special studies will be required to determine the minimum discharge elevation consistent with the design discharge of the facility.

838.4 Standards

(1) *Location and Alignment.* Longitudinal storm drains are not to be placed under the traveled way of highways. Depending upon local agency criteria, storm drains under the traveled way of other streets and roads may be acceptable. A manhole or specially designed junction structure is usually provided at changes in direction or grade and at locations where two or more storm drains are joined. Refer to Index 838.5 for further discussion on manholes and junction structures.

(2) *Pipe Diameter.* The minimum pipe diameter to be used is given in Table 838.4.

(3) *Slope.* The minimum longitudinal slope should be such that when flowing half full, a self cleaning velocity of 3 feet per second is attained.

(4) *Physical Properties.* In general, the considerations which govern the selection of culvert type apply to storm drain conduits. Alternative types of materials, overfill tables and other physical factors to be considered in selecting storm drain conduit are discussed under Chapter 850.

(5) *Storage.* In developing the most economical installation, the designer should not overlook economies obtainable through the use of pipeline storage and, within allowable limits, the ponding of water in gutters, medians and interchange areas. Inlet capacity and spacing largely control surface storage in gutters and medians; inlet capacity governs in sump areas.

Table 838.4
Minimum Pipe Diameter for Storm Drain Systems

Type of Drain	Minimum Diameter (in)
Trunk Drain	18
Trunk Laterals	15(1)
Inlet Laterals	15(1)

NOTE:

(1) 18 minimum if wholly or partly under the roadbed.

Specific subjects for special consideration are:

* Bedding and Backfill. Bedding and backfill consideration are discussed under Index 829.2. Maximum height of cover tables are included in Chapter 850 and minimum thickness of cover is given in Table 856.5.

* Roughness Factor. The roughness factor, Manning's n value, generally assumes greater importance for storm drain design than it does for culverts. Suggested Manning's n values for various types of pipe materials are given in Table 852.1.

(6) Floating Trash. Except at pumping installations, every effort should be made to carry all floating trash through the storm drain system. Curb and wall opening inlets are well suited for this purpose. In special cases where it is necessary to exclude trash, as in pumping installations, a standard trash rack must be provided across all curb and wall openings of tributary inlets. See the Standard Plans for details.

(7) Median Flow. In estimating the quantity of flow in the median, consideration should be given to the effects of trash, weeds, and plantings.

838.5 Appurtenant Structures

(1) Manholes.

(a) General Notes. The purpose of a manhole is to provide access to a storm drain for inspection and maintenance. Manholes are usually constructed out of cast in place concrete, pre-cast concrete, or corrugated metal pipe. They are usually circular and approximately three or four feet in diameter to facilitate the movement of maintenance personnel.

There is no Caltrans Standard Plan for manholes. Relocation and reconstruction of existing storm drain facilities, owned by a city or county agency, is often necessary. Generally the local agency has adopted manhole design standard for use on their facilities. Use of the manhole design preferred by the responsible authority or owner is appropriate.

Commercial precast manhole shafts are effective and usually more economical than cast in place shafts. Brick or block may also be used, but only upon request and justification from the local agency or owner.

(b) Location. Following are common locations for manholes:

- Where two or more drains join,
- At locations and spacing which facilitate maintenance,
- Where the drain changes in size,
- At sharp curves or angle points in excess of 10 degrees,
- Points where an abrupt flattening of the grade occurs, and
- On the smaller drains, at the downstream end of a sharp curve.

Manholes are not required if the conduit is large enough to accommodate a man, unless spacing criteria govern. Manholes should not be placed within the traveled way. Exceptions are frontage roads and city streets, but intersection locations should be avoided.

(c) Spacing. In general, the larger the storm drain, the greater the manhole spacing. For pipe diameter of 48 inches or more, or other shapes of equal cross sectional area, the manhole spacing ranges from 700 feet to 1200 feet. For diameters of less than 48 inches, the spacing may vary from 300 feet to 700 feet. In the case of small drains where self-cleaning velocities are unobtainable, the 300 feet spacing should be used. With self-cleaning velocities and alignments without sharp curves, the distance between manholes should be in the upper range of the above limits.

(d) Access Shaft. For drains less than 48 inches in diameter, the access shaft is to be centered over the drain. When the drain diameter exceeds the shaft diameter, the shaft should be offset and made tangent to one side of the pipe for better location of the manhole steps. For drains 48 inches or more in diameter, where laterals enter from both sides of the manhole, the offset should be toward the side of the smaller lateral. See Standard Plan D93A for riser connection details.

(e) Arrangement of Laterals. To avoid unnecessary head losses, the flow from laterals which discharge opposite each other should converge at an angle in the direction of flow. If conservation of head is critical, a training wall should be provided.

(2) Junction Structures. A junction structure is an underground chamber used to join two or more conduits, but does not provide direct access from the surface. It is designed to prevent turbulence in the flow by providing a smooth transition. This type of structure is usually needed only where the trunk drain is 42 inches or more in diameter. A standard detailsheet of a junction structure is available for pipes ranging from 42 inches to 84 inches in diameter at the following Office Engineer web site address: http://www.dot.ca.gov/hq/esc/structures_cadd/XS_sheets/Metric/dgn/. The XS sheet reference is XS 4-26. Where required by spacing criteria, a manhole should be used.

(3) Flap Drainage gates. When necessary, backflow protection should be provided in the form of flap drainage gates. These gates offer negligible resistance to the release of water from the system and their effect upon the hydraulics of the system may be neglected.

If the outlet is subject to floating debris, a shelter should be provided to prevent the debris from clogging the flap drainage gate. Where the failure of a flap drainage gate to close would cause serious damage, a manually controlled gate in series should be considered for emergencies.

Topic 839 - Pumping Stations

839.1 General

Drainage disposal by pumping should be avoided where gravity drainage is reasonable. Because pumping installations have high initial cost, maintenance expense, power costs, and the possibility of failure during a storm, large expenditures can be justified for gravity drainage. In some cases, this can be accomplished with long runs of pipe or continuing the depressed grade to a natural low area.

Whenever possible, drainage originating outside the depressed areas should be excluded. District and Division of Structures cooperation is essential in the design of pumping stations, tributary storm drains, and outfall facilities. This is particularly true of submerged outlets, outlets operating under pressure, and outlets of unusual length.

839.2 Pump Type

Horizontal pumps in a dry location are generally specified for ease of access, safety, and standardization of replacement parts.

Only in special cases is stand-by power for pumping plants a viable consideration. All proposals for stand-by power are to be reviewed by and coordinated with the Division of Structures.

839.3 Design Responsibilities

When a pumping station is required, responsibility for design between the District and the Division of Structures is as follows:

(1) *Districts.* The District designs the collector and the outfall facilities leading from the chamber into which the pumps discharge. This applies to outfalls operating under gravity and with a free outlet. Refer to Topic 838.

Details of pumping stations supportive information to be submitted by the District to the Division of Structures is covered under Index 805.8 and Chapter 3-3.1(4) of the Drafting and Plans Manual.

(2) *Division of Structures.* The Division of Structures will prepare the design and contract plans for the pumping station, the storage box and appurtenant equipment, considering the data and recommendations submitted by the District.

The Division of Structures will furnish the District a preliminary plan based on data previously submitted by the District. It will show the work to be covered by the Division of Structures plans, including a specific location for the pumping plant and storage box, the average and maximum pumping rates and the power required.

839.4 Trash and Debris Considerations

Storm drain systems leading to pumping plants are to be designed to limit the inflow of trash and debris, as these may cause damage to the pump impellers and create a maintenance removal nuisance. Standard grate designs are effective at ensuring that trash and debris are screened out of the inflow, but where side opening or curb opening inlets are constructed, trash racks must be added to the inlet design. The only Standard Plan detail for curb opening designs is shown on Standard Plan D74B and is used in conjunction with Type GDO inlets. On those occasions where pipe risers with side opening inlets are part of the system, refer to Standard Plan D93C for appropriate trash rack design details.

839.5 Maintenance Consideration

Access to the pumping plant location for both maintenance personnel and maintenance vehicles is generally provided by way of paved access road or city street. One parking space minimum is to be provided in the vicinity of the pumping plant. An area light is generally provided when it is determined that neither the highway lighting nor the street lighting is adequate. Access to the pumping plant for maintenance from the top of the cut slope generally consists of a stairway located adjacent to the pumping plant. The stairway generally extends from the top of cut slope to the toe of cut slope. Access to the pump control room should be through a vertical doorway with the bottom above flood level, and never through a hatch.

839.6 Groundwater Considerations

As the lowest point in the storm drain system, pumping plants are particularly susceptible to problems associated with rises in groundwater tables. Where the foundation of pump houses or associated storage boxes are at an elevation where they would be subjected to existing or future groundwater tables, sealing around the base of the foundation is necessary. The use of bentonite or other impervious material is typically sufficient in keeping groundwater from welling up through the relatively pervious structure backfill.

Sealing requirements will typically be specified by the Division of Structures during the pump plant design. However, the district should provide any information relative to historical groundwater levels or fluctuations which would be of importance, or known plans by local or regional water districts to modify recharge patterns in a manner that could impact the design.

watertight certification test, and is sufficiently watertight for well graded, quality backfill conditions. Where conditions are more sensitive, a lower rate should be specified. Rates below 50 to 100 gallons per inch per mile per day are difficult to achieve and would rarely be necessary. For example, sanitary sewers are rarely required to have leakage rates below 200 gallons per inch per mile per day, even though they have stringent health and environmental restrictions. Field hydrostatic tests are typically conducted over a period of 24 hours or more to establish a valid leakage rate. Designers should also be aware that non-circular pipe shapes (CMP pipe arches, RCP oval shapes, etc.) should not be considered watertight even with the use of rubber gaskets or other sealants due to the lack of uniform compression around the periphery of the joint. Additionally, watertight joints specified for pressure pipe or siphon applications must meet the requirements indicated in Standard Specification Sections 65 and 66. Pipe joints that meet Standard Specification Section 61 water-tightness performance criteria are:

<u>RCP and NRCP</u>	-Flared Bell -Flushed Bell -Steel Joint-Flush Bell -Single or Double Offset Design (Flared or Flushed Bell) -Double Gasket
<u>CMP and SSRP</u>	-Hugger Bands (H-10, 12) w/gasket and double bolt bar -Annular Band w/gasket -Two Piece Integral Flange w/sleeve-type gasket*
<u>PLASTIC</u>	-Bell/Spigot w/gasket

* Acceptable as a watertight pipe only in downdrain applications and in 6, 8 and 10 inch diameters. Factory applied sleeve-type gaskets are to be used instead of O-ring or other sealants.

Table 854.1 provides information to help the designer select the proper joint under most conditions.

Topic 855 - Design Service Life

855.1 Basic Concepts

The prediction of design service life of drainage facilities is difficult because of the large number of variables, continuing changes in materials, wide range of environments, and use of various protective coatings. The design service life of a drainage facility is defined as the expected maintenance-free service period of each installation. After this period, it is anticipated major work will be needed for the facility to perform as originally designed for further periods.

For all metal pipes and arches that are listed in Table 857.2, maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation at any location on the culvert (See Figures 855.3A, 855.3B, and Tables 855.2D and 855.2F). AltPipe can be used to estimate service life of all circular metal pipe. See Index 857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe.

For reinforced concrete pipe (RCP), box (RCB) and arch (RCA) culverts, maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of exposed reinforcement at any point on the culvert. AltPipe can be used to estimate service life of reinforced concrete pipe (RCP), but not RCB, RCA or NRCP. See Index 857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe.

For non-reinforced concrete pipe culverts (NRCP), maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation or major cracking with soil loss at any point on the culvert.

For plastic pipe, maintenance-free service period, with respect to corrosion, abrasion, and long term structural performance, is the number of years from installation until the deterioration reaches the point

Table 854.1
Joint Leakage Selection Criteria

JOINT TYPE ⇒ ⇓ SITE CONDITIONS	"NORMAL" JOINT	"SOIL TIGHT" JOINT	"WATER TIGHT" JOINT
SOIL FACTORS			
Limited potential for soil migration (e.g., gravel, medium to coarse sands, cohesive soil)	X	X	X
Moderate potential for soil migration (e.g., fine sands, silts)	X(1)	X	X
High potential for soil migration (e.g., very fine sands, silts of limited cohesion)		X(1)	X(1)
INFILTRATION / EXFILTRATION			
No concern over either infiltration or exfiltration.	X	X	X
Infiltration or exfiltration not permitted (e.g., potential to contaminate groundwater, contaminated plume could infiltrate)			X(2)
HYDROSTATIC POTENTIAL			
Installation will rarely flow full. No contact with groundwater.	X	X	X
Installation will occasionally flow full. Internal head no more than 10 feet over crown. No potential groundwater contact.		X	X
Installation may or may not flow full. Internal head no more than 10 feet over crown. May contact groundwater.			X
Possible hydrostatic head (internal or external) greater than 10 feet, but less than 25 ft(3).			X(2)

Notes:
"X" indicates that joint type is acceptable in this application. The designer should specify the most cost-effective option.
(1) Designer should specify filter fabric wrap at joint. See Index 831.4.
(2) Designer should consider specifying field watertightness test.
(3) Pipe subjected to hydrostatic heads greater than 25 ft should have joints designed specifically for pressure applications.

On steep slopes, most vegetated flexible linings are limited in the erosive forces they can sustain without damage to the channel and lining unless the vegetative lining is combined with another more erosion-resistant long-term lining below, such as a cellular soil confinement system. See Figure 865.1 and Index 865.3(1). The District Landscape Architect should be contacted to provide viable vegetation alternatives within the District, however all design responsibilities belong to the Project Engineer.

Figure 865.1
Steep-Sloped Channel with Composite Vegetative Lining

Vegetative flexible lining placed on top of cellular soil confinement system on a steep-sloped channel.

865.2 Rigid

A rigid lining can typically provide higher capacity and greater erosion resistance and in some cases may be the only feasible alternative.

Rigid linings are useful in flow zones where high shear stress or non-uniform flow conditions exist, such as at transitions in channel shape or at an energy dissipation structure.

The most commonly used types of rigid lining are hot mixed asphalt and Portland cement concrete. Hot mixed asphalt is used mainly for small ditches, gutters and overside drains (see Standard Plan D87D) because it cannot withstand hydrostatic pressure from the outside.

Table 865.1 provides a guide for Portland cement concrete and air blown mortar roadside channel linings. See photo below Table 865.1 for example.

For the design of concrete lined flood control channels discussed in Index 861.2 (1), see U.S. Army Corps of Engineers publication; "Structural Design of Concrete Lined Flood Control Channels", EM 1110-2-2007:

http://planning.usace.army.mil/toolbox/library/EMs/em1110.2.2007.pdf

Table 865.1
Concrete(2) Channel Linings

Abrasion Level(1)	Thickness of Lining (in)		Minimum Reinforcement
	Sides	Bottom	
1 - 3	5	5	6 x 6-W2.9 x W2.9 welded wire fabric

NOTES:

(1) See Table 855.2A.

(2) Portland Cement Concrete or Air Blown Mortar

Figure 865.2
Concrete Lined Channel

For large flows, consideration should be given to using a minimum bottom width of 12 feet for construction and maintenance purposes, but depths of flow less than one foot are not recommended.

Despite the non-erodible nature of rigid linings, they are susceptible to failure from foundation instability and abrasion. The major cause of failure is undermining that can occur in a number of ways.

Trapezoidal Channel Within the Clear Recovery Zone (CRZ): Foreslopes and backslopes of trapezoidal channel constructed within the CRZ should not be steeper than 4:1. Trapezoidal channel sections located within the CRZ should have foreslopes matching the slopes of the CRZ slopes but should not be steeper than 4:1 (refer to Figures 305.6, 307.2, 307.4A, 307.4B, and 307.5). The backslope should not be steeper than 4:1. The bottom width of the channel should not be less than 4 feet (see Figure 834.3). The trapezoidal channel cross-section should satisfy hydraulic conveyance as well as support the load of errant vehicles without the wheels sinking into saturated soil in the channel section. Design criteria for concrete lined channels may be referenced from the US Army Corps Publication "Structural Design of Concrete Lined Flood Control Channels, EM 1110-2-2007".

865.3 Flexible

Flexible linings can be long-term, transitional or temporary. Long-term flexible linings are used where the channel requires protection against erosion for the design service life of the channel. Per Index 861.12, more complete information on hydraulic principles and engineering techniques of flexible channel lining design may be found in HEC No. 15 and Chapter 5 of HEC No. 22.

Flexible linings act to reduce the shear stress on the underlying soil surface. Therefore, the erodibility of the underlying soil is a key factor in the performance of flexible linings. Erodibility of non-cohesive soils (plasticity index less than 10) is mainly due to particle size, while cohesive soil erodibility is a function of cohesive strength and soil density. Vegetative and rolled erosion control product lining performance relates to how well they protect the underlying soil from shear stress, and so these lining types do not have permissible shear stresses independent of soil type. The soil plasticity index should be included in the Materials or Geotechnical Design Report.

In general, when a lining is needed, the lowest cost lining that affords satisfactory protection should be used. This may include vegetation used alone or in combination with other types of linings. Thus, a channel might be grass-lined on the flatter slopes and lined with more resistant material on the steeper slopes. In cross section, the channel might be lined with a highly resistant material (e.g., cellular soil confinement system – see Index 865.3(1) *Long Term*) within the depth required to carry floods occurring frequently and lined with grass above that depth for protection from the rare floods.

(1) Long Term. Long-term lining materials include vegetation, rock slope protection, gabions (wire-enclosed rock), and turf reinforcement mats with enhanced UV stability. Standard Specification Section 72-4 includes specifications for constructing small-rock slope protection for gutters, ditches or channels and includes excavating and backfilling the footing trench, placing RSP fabric and placing small rocks (cobble, gravel, crushed gravel, crushed rock, or any combination of these) on the slope. Where the channel design includes a requirement for runoff infiltration to address stormwater needs, the designer may need to consider installation of a granular filter in lieu of RSP fabric if it is anticipated that the RSP fabric would become clogged with sediment. See following link to HEC No. 23, Volume 2, Design Guideline 16, Index 16.2.1, for information on designing a granular filter:

http://www.fhwa.dot.gov/engineering/hydraulics/pubs/09112/page16.cfm

Standard Specification Section 72-16 includes specifications for constructing gabion structures. Gabions consist of wire mesh baskets that are placed and then filled with rock. Gabion basket wires are susceptible to corrosion and are most appropriate for use as a channel lining where corrosion potential is minimized, such as desert or other arid locations.

Cellular soil confinement systems may be used as an alternative for steep channels with a variety of infills available including soil and gravel. Soil confinement systems consist of sheet polyethylene spot welded to form a system of individual confinement cells. See Figure 865.3.

Figure 865.3
Long-Term Flexible Lining

Placing a polyethylene cellular soil confinement system on a steep-sloped channel.

Per Index 865.1, these systems may be combined with other vegetated flexible linings, e.g., turf reinforcement mats.

(2) *Transitional.* Transitional flexible linings are used to provide erosion protection until a long-term lining, such as grass, can be established. For mild slopes, these may include jute netting (depending on environmental, i.e., wildlife, parameters) or turf reinforcement. Turf reinforcement can serve either a transitional or long-term function by providing additional structure to the soil/vegetation matrix. Typical turf reinforcement materials include gravel/soil mixes and turf reinforcement mats (TRM's). A TRM is a non-degradable rolled erosion control product (RECP) processed into a three-dimensional matrix. For examples see following link:

http://www.dot.ca.gov/hq/LandArch/ec/recp/trm.htm

The design for transitional products should be based on a flood event with an exceedance probability at least equal to the expected product service life (i.e., 12 to 36 months).

(3) *Temporary.* Temporary channel linings are used without vegetation to line channels that might be part of a construction site or some other short-term channel situation.

Standard Specification Section 21-1 was developed primarily to address slope erosion products, however, it includes specifications for constructing turf reinforcing mats, netting and rolled erosion control products (RECP's – see Index 865.6) which may also be applied to channels as temporary and transitional linings. See Index 865.1for coordinating vegetative recommendation with District Landscape Architecture.

865.4 Composite Lining Design

The procedure for composite lining design is based on the stable channel design procedure presented in Index 864.2 with additional sub-steps to account for the two lining types. Specifically, the modifications are:

Step 1. Determine design discharge and select channel slope and shape. (No change.)

Step 2. Need to select both a low flow and side slope lining. (See Table 866.3A.)

Step 3. Estimate the depth of flow in the channel and compute the hydraulic radius. (No change.)

Step 4. After determining the Manning's n for the low flow and side slope linings, calculate the effective Manning's n:

$$n_e = \left[\frac{P_L}{P} + \left(1 - \frac{P_L}{P}\right)\left(\frac{n_s}{n_L}\right)^{3/2}\right]^{2/3} n_L$$

where:

n_e = Effective Manning's n value for the composite channel

P_L = Low flow lining perimeter, ft

P = Total flow perimeter, ft

n_s = Manning's n value for the side slope lining

n_L = Manning's n value for the low flow lining

Step 5. Compare implied discharge and design discharge. (No change.)

Step 6. Determine the shear stress at maximum depth, τ_d ($\tau_d = \gamma d S$), and the shear stress on the channel side slope, τ_s (see Index 864.2).

Step 7. Compare the shear stresses, τ_d and τ_s, to the permissible shear stress, τ_p, for each of the channel linings. If τ_d or τ_s is greater than the τ_p for the respective lining, a different combination of linings should be evaluated. See Table 865.2.

865.5 Bare Soil Design and Grass Lining

Per Index 865.1, the District Landscape Architect should be contacted to recommend vegetation alternatives (including vegetation for transitional products, if needed) and the same procedure for the stable channel design procedure presented in Index 864.2 should be followed by the Project Engineer. See Figure 865.4 for grass lining example in a median channel. For slope stability when constructing embankment (4:1 and steeper), 85-90% relative compaction is desired. Although not optimal for best plant growth, compaction of up to 90% is not a major constraint for grass establishment. Prior to seeding, scarification to a depth of 1 inch of the compacted soil surface is recommended for improving initial runoff absorption and ensuring the seed is incorporated into the soil. A temporary degradable erosion control blanket (ECB) (e.g., single net straw) can then be installed on top.

The permissible shear stress for the vegetation is based on the design flood (Table 831.3). If the calculated shear for any given vegetation method is inadequate, then an alternative vegetation type with greater shear stress must be selected and/or a different channel shape may be selected that results in a lower depth of flow.

Figure 865.4
Grass-Lined Median Channel

The permissible shear stress for rolled erosion control products should be based on a flood event with an exceedance probability no less than the expected product service life (i.e., 12 to 36 months). The maximum shear stresses for channel applications shown in Erosion Control Technology Council Rolled Erosion Control Products Specification Chart must be lower than the permissible shear stresses indicated in Table 865.2. See: http://www.ectc.org/specifications.asp

The Manning's roughness coefficient for grass linings varies depending on grass properties and shear stress given that the roughness changes as the grass stems bend under flow. The equation describing the n value for grass linings is:

$$n = \alpha C_n \tau_0^{-0.4}$$

where:

τ_0 = Average boundary shear stress, lb/ft^2

α = Unit conversion constant, 0.213

C_n = Grass roughness coefficient (use 0.20 or Tables 4.3 and 4.4 from HEC-15)

The remaining shear at the soil surface is termed the effective shear stress. When the effective shear stress is less than the allowable shear for the soil surface, then erosion of the soil surface will be controlled. The effective shear at the soil surface is given by the following equation.

$$\tau_e = \tau_d (1 - C_f) \left(\frac{n_s}{n}\right)^2$$

where:

τ_e = Effective shear stress on the soil surface, lb/ft^2

τ_d = Design shear stress, lb/ft^2

C_f = Grass cover factor (use 0.6 to 0.8 or Table 4.5 from HEC-15)

n_s = Soil grain roughness

n = Overall lining roughness

The soil grain roughness, n_s, is 0.016 when D_{75} < 0.05 in. For larger grained soils the soil grain roughness is

$$n_s = \alpha (D_{75})^{1/6}$$

where:

n_s = Soil grain roughness (D_{75} > 1.3 (0.05 in))

Table 865.2[2]
Permissible Shear and Velocity for Selected Lining Materials

Boundary Category	Boundary Type	Permissible Shear Stress (lb/ft^2)	Permissible Velocity (ft/s)
Soils[1]	Fine colloidal sand	0.03	1.5
	Sandy loam (noncolloidal)	0.04	1.75
	Clayey sands (cohesive, PI ≥ 10)	0.095	2.6
	Inorganic silts (cohesive, PI ≥ 10)	0.11	2.7
	Silty Sands (cohesive, PI ≥ 10)	0.072	2.4
	Alluvial silt (noncolloidal)	0.05	2
	Silty loam (noncolloidal)	0.05	2.25
	Finer than course sand - D_{75} < 0.05 in. (non-cohesive)	0.02	1.3
	Firm loam	0.075	2.5
	Fine gravels	0.075	2.5
	Fine gravel (non-cohesive, D_{75} = 0.3 in, PI<10)	0.12	2.8
	Gravel (D_{75} = 0.6 in) (non-cohesive, D_{75} = 0.6 in, PI<10)	0.24	3.7
	Inorganic clays (cohesive, PI ≥ 20)	0.14	2.9
	Stiff clay	0.25	4.5
	Alluvial silt (colloidal)	0.25	3.75
	Graded loam to cobbles	0.38	3.75
	Graded silts to cobbles	0.43	4
	Shales and hardpan	0.67	6
Vegetation	Class A turf (Table 4.1, HEC No. 15)	3.7	8
	Class B turf (Table 4.1, HEC No. 15)	2.1	7
	Class C turf (Table 4.1, HEC No. 15)	1.0	3.5
	Long native grasses	1.7	6
	Short native and bunch grass	0.95	4

Table 865.2[2] (con't.)
Permissible Shear and Velocity for Selected Lining Materials

Boundary Category	Boundary Type	Permissible Shear Stress (lb/ft^2)	Permissible Velocity (ft/s)
Rolled Erosion Control Products (RECPs)			
Temporary Degradable Erosion Control Blankets (ECBs)	Single net straw	1.65	3
	Double net coconut/straw blend	1.75	6
	Double net shredded wood	1.75	6
Open Weave Textile (OWT)	Jute	0.45	2.5
	Coconut fiber	2.25	4
	Vegetated coconut fiber	8	9.5
	Straw with net	1.65	3
Non Degradable Turf Reinforcement Mats (TRMs)	Unvegetated	3	7
	Partially established	6.0	12
	Fully vegetated	8.00	12
Rock Slope Protection, Cellular Confinement and Concrete			
Rock Slope Protection	Small-Rock Slope Protection (4-inch Thick Layer)	0.8	6
	Small-Rock Slope Protection (7-inch Thick Layer)	2	8
	No. 2	2.5	10
	Facing	5	12
Gabions	Gabions	6.3	12
Cellular Confinement: Vegetated infill	71 in^2 cell and TRM	11.6	12
Cellular Confinement: Aggregate Infill	1.14 - in. D_{50} (45 in^2 cell)	6.9	12
	3.5" D_{50} (45 in^2 cell)	15.1	11.5
	1.14" D_{50} (71 in^2 cell)	13.2	12
	3.5" D_{50} (71 in^2 cell)	18	11.7
	1.14" D_{50} (187 in^2 cell)	10.92	12
	3.5" D_{50} (187 in^2 cell)	10.55	12
Cellular Confinement: Concrete Infill	(71 in^2 cell)	2	12
Hard Surfacing	Concrete	12.5	12

NOTES:

(1) PI = Plasticity Index (From Materials or Geotechnical Design Report)

(2) Some materials listed in Table 856.2 have been laboratory tested at shear stresses/velocities above those shown. For situations that exceed the values listed for roadside channels, contact the District Hydraulic Engineer.

D_{75} = Soil size where 75 percent of the material is finer, in

α = Unit conversion constant, 0.026

The permissible soil shear stress for fine-grained, non-cohesive soils (D_{75} < 0.05 in. is relatively constant and is conservatively estimated at 0.02 lb/ft^2. For coarse grained, non-cohesive soils (0.05 in. < D_{75} < 2 in.) the following equation applies.

$$\tau_{p,soil} = \alpha D_{75}$$

where:

$\tau_{p,soil}$ = Permissible soil shear stress, lb/ft^2

D_{75} = Soil size where 75 percent of the material is finer, in

α = Unit conversion constant, 0.4

A simplified approach for estimating the permissible shear stress for cohesive soils (based on Equation 4.6 in Chapter 4 of HEC No. 15) is illustrated in Figure 4.1 of Chapter 4 in HEC No. 15. The combined effects of the soil permissible shear stress and the effective shear stress transferred through the vegetative lining results in a permissible shear stress for the given conditions. Table 865.2 provides typical values of permissible shear stress and permissible velocity for cohesive soils and selected lining types. Representative values for different soil, vegetation and lining types are based on the methods found in Chapter 4 of HEC No. 15 while those for gravel, rock gabions and rock slope protection are based on methods found in Chapters 6 and 7 of HEC No. 15. The permissive shear stress values shown for soil confinement systems are based on testing by others, however, the maximum permissive velocity shown in Table 865.2 for all boundary types has been limited to 12 feet per second based on the following assumptions:

- The upper limit of flow rate is 50 cfs
- The longitudinal slope is 10 percent maximum
- The maximum side slope is 2H:1V
- The maximum storm duration is one hour

When the permissible shear stress is greater than or equal to the computed shear stress, the lining is considered acceptable. If the computed velocity exceeds the permissive velocity, or any of the above-listed assumptions are exceeded, contact the District Hydraulic Engineer for support.

865.6 Rolled Erosion Control Products

(1) *General.* Manufacturers have developed a variety of rolled erosion control products (RECPs) for erosion protection of channels.

RECPs consist of materials that are stitched or bound into a fabric. Vegetative and RECP lining performance relates to how well they protect the underlying soil from shear stresses so these linings do not have permissible shear stresses independent of soil types. Chapters 4 (vegetation) and 5 (RECPs) of HEC No. 15 describe the methods for analyzing these linings. Standard Specification Section 21-1 was developed primarily to address slope erosion products, however, the specifications for constructing turf reinforcing mats (TRM’s), open weave textiles and erosion control blankets may also be applied to channels as temporary and transitional linings, and some TRM’s may be used as permanent linings.

(2) *Non-Hydraulic Design Considerations.* The long-term performance of TRMs has traditionally been evaluated using hydraulic testing performance within controlled flume environments, or laboratory testing of specific parameters, usually conforming to ASTM or other industry standards. In recent years additional important design factors have been identified, from damages due to insect infestation to drainage problems or soil conditions resulting in poor vegetative establishment. Table 5.5 within Chapter 5 of HEC No. 15 provides a detailed TRM protocol checklist.

Six broad categories of stressors or potential damages to RECPs are listed below that can cause decrease in performance, considered as a function of specific properties of these lining materials.

(a) Environmental stress – tensile stresses that exceed the mechanical strength of the material accelerated by other stresses in the exposure environment.

Many manufacturer-reported values for maximum velocity or shear stress are based on short duration testing, however, longer duration flows – hours to days – more closely represent field conditions. Erosive properties of soils change with saturation, vegetation becomes stressed or damaged, and properties of some lining materials change with long periods of inundation or hydraulic stress. The result is that maximum reported shear stress and velocity may overestimate actual field performance of the full range of channel lining materials in the event of longer duration flows (Table 865.2). See Index 865.5 for safety factor discussion.

(b) Mechanical damage – localized damage due to externally applied loads such as debris or machinery, often during installation but also due to operation and maintenance activities

(c) Oxidation – due to exposure to air and water, a chemical reaction with a specific chemical group in a constituent polymer that leads to damage at a molecular level and changes in physical properties. Other chemical stresses can include acidity, corrosives, salinity, ozone and other air pollutants.

(d) Photo degradation – change in chemical structure due to exposure to UV wavelengths of sunlight, most often occurring during installation, prior to full vegetation establishment or inadequate vegetation establishment and coverage over time.

UV-Resistance per ASTM D-4355 should conform to the following for the specified type of TRM and design life:

- Temporary or transitional TRM – 90% tensile strength retained at 500 hr for the TRM product to be considered up to a 5-year design life.
- Long-term TRM – 90% tensile strength retained at 5,000 hr for the TRM product to be considered up to a 50-year design life.

(e) Temperature instability – changes in appearance, weight, dimension or other properties as a result of low, high, or cyclic temperature exposure.

As TRM or other materials are degrading, the vegetative component of a project is simultaneously becoming established, presumably leading to an overlap in effectiveness of each component. The engineer must carefully evaluate published performance data for specific materials with anticipated degradation, consider specific performance added by vegetative components, and apply a factor of safety in choosing materials that may provide enough strength initially to bridge the gap. Per Index 865.6(1), the District Landscape Architect should be consulted to provide viable long-term and compatible transitional vegetation recommendations (if required by the designer).

Topic 866 - Hydraulic Design of Roadside Channels

866.1 General

Open channel hydraulic design is of particular importance to highway design because of the interrelationship of channels to most highway drainage facilities.

The hydraulic principles of open channel flow are based on steady state uniform flow conditions, as defined in Index 866.2. Though these conditions are rarely achieved in the field, generally the variation in channel properties is sufficiently small that the use of uniform flow theory will yield sufficiently accurate results for most roadside channels.

866.2 Flow Classifications

(1) Steady vs. Unsteady Flow. The flow in an open channel can be classified as steady or unsteady. The flow is said to be steady if the depth of flow at a section, for a given discharge, is constant with respect to time. The flow is considered unsteady if the depth of flow varies with respect to time.

(2) Uniform Flow. Steady flow can further be classified as uniform or nonuniform. The flow is said to be uniform if the depth of flow and

quantity of water are constant at every section of the channel under consideration. Uniform flow can be maintained only when the shape, size, roughness and slope of the channel are constant. Under uniform flow conditions, the depth and mean velocity of flow is said to be normal. Under these conditions the water surface and flowlines will be parallel to the stream bed and a hydrostatic pressure condition will exist, the pressure at a given section will vary linearly with depth.

As previously mentioned, uniform flow conditions are rarely attained in the field, but the error in assuming uniform flow in a channel of fairly constant slope, roughness and cross section is relatively small when compared to the uncertainties of estimating the design discharge.

(3) *Non-uniform Flow.* There are two types of steady state non-uniform flow:

- Gradually varied flow.

  Gradually varied flow is described as a steady state flow condition where the depth of water varies gradually over the length of the channel. Under this condition, the streamlines of flow are practically parallel and therefore, the assumption of hydrostatic pressure distribution is valid and uniform flow principles can be used to analyze the flow conditions.

- Rapidly varied flow.

  With the rapidly varied flow condition, there is a pronounced curvature of the flow streamlines and the assumption of hydrostatic pressure distribution is no longer valid, even for the continuous flow profile. A number of empirical procedures have been developed to address the various phenomena of rapidly varied flow. For additional discussion on the topic of rapidly varied flow, refer to "Open-Channel Hydraulics" by Chow.

866.3 Open Channel Flow Equations

The equations of open channel flow are based on uniform flow conditions. Some of these equations have been derived using basic conservation laws (e.g. conservation of energy) whereas others have been derived using an empirical approach.

(1) *Continuity Equation.* One of the fundamental concepts which must be satisfied in all flow problems is the continuity of flow. The continuity equation states that the mass of fluid per unit time passing every section in a stream of fluid is constant. The continuity equation may be expressed as follows:

$$Q = A_1V_1 = A_2V_2 = \ldots = A_nV_n$$

Where Q is the discharge, A is the cross-sectional flow area, and V is the mean flow velocity. This equation is not valid for spatially varied flow, i.e., where flow is entering or leaving along the length of channel under consideration.

(2) *Bernoulli Equation.* Water flowing in an open channel possesses two kinds of energy: (1) potential energy and (2) kinetic energy. Potential energy is due to the position of the water surface above some datum. Kinetic energy is due to the energy of the moving water. The total energy at a given section as expressed by the Bernoulli equation is equal to:

$$H = z + d + \frac{V^2}{2g}$$

where:

H = Total head, in feet of water

z = Distance above some datum, in feet

d = Depth of flow, in feet

$\frac{V^2}{2g}$ = Velocity head, in feet

g = Acceleration of gravity

= 32.2 feet per second squared

(3) *Energy Equation.* The basic principle used most often in hydraulic analysis is conservation of energy or the energy equation. For uniform flow conditions, the energy equation states that the energy at one section of a channel is equal to the energy at any downstream section plus the intervening energy losses. The energy equation, expressed in terms of the Bernoulli equation, is:

$$z_1 + d_1 + \frac{V_1^2}{2g} = z_2 + d_2 + \frac{V_2^2}{2g} + h_L$$

where:

h_L = Intervening head losses, in feet

(4) *Manning's Equation.* Several equations have been empirically derived for computing the average flow velocity within an open channel. One such equation is the Manning Equation. Assuming uniform and turbulent flow conditions, the mean flow velocity in an open channel can be computed as:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

where:

V = Mean velocity, in feet per second

n = Manning coefficient of roughness

S = Channel slope, in foot per feet

R = Hydraulic Radius, in feet

= A/WP

where:

A = Cross sectional flow area, in square feet

WP = Wetted perimeter, in feet

Commonly accepted values for Manning's roughness coefficient, n, based on materials and workmanship required in the Standard Specifications, are provided in Table 866.3A. The tabulated values take into account deterioration of the channel lining surface, distortion of the grade line due to unequal settlement, construction joints and normal surface irregularities. These average values should be modified to satisfy any foreseeable abnormal conditions. See Chapters 4 and 6 in HEC No. 15 for Manning's roughness equations for grass linings, RSP, cobble and gravel linings. Refer to Index 861.11 for a discussion of Manning's roughness coefficients for water quality channels.

Direct solutions for Manning's equation for many channels of trapezoidal, rectangular, triangular and circular cross sections can be found within the Channel Analysis subcomponent FHWA's Hydraulic Toolbox software program.

(5) *Conveyance Equation.* Often it is convenient to group the properties peculiar to the cross section into one term called the conveyance factor, K. The conveyance factor, as expressed by the Manning's equation, is equal to:

$$K = \frac{1.486}{n} A R^{2/3}$$

For the non-pressure, full flow condition, the geometric properties and conveyance of a channel section can be computed. Then for a given channel slope the discharge capacity can be easily determined.

(6) *Critical Flow.* A useful concept in hydraulic analysis is that of "specific energy". The specific energy at a given section is defined as the total energy, or total head, of the flowing

Table 866.3A

Average Values for Manning's Roughness Coefficient (n)

Type of Channel	n value
Unlined Channels:	
Clay Loam	0.023
Sand	0.020
Gravel	0.030
Rock	0.040
Lined Channels:	
Portland Cement Concrete	0.014
Air Blown Mortar (troweled)	0.012
Air Blown Mortar (untroweled)	0.016
Air Blown Mortar (roughened)	0.025
Asphalt Concrete	0.016-0.018
Sacked Concrete	0.025
Pavement and Gutters:	
Portland Cement Concrete	0.013-0.015
Hot Mix Asphalt Concrete	0.016-0.018
Depressed Medians:	
Earth (without growth)	0.016 - 0.025
Earth (with growth)	0.050
Gravel (d_{50} = 1 in. flow depth ≤ 6 in.)	0.040
Gravel (d_{50} = 2 in. flow depth ≤ 6 in.)	0.056

NOTES:

For additional values of n, see HEC No. 15, Tables 2.1 and 2.2, and "Introduction to Highway Hydraulics", Hydraulic Design Series No. 4, FHWA Table 14.

water with respect to the channel bottom. For a channel of small slope;

$$E = d + \frac{V^2}{2g}$$

where:

E = Specific energy, in feet

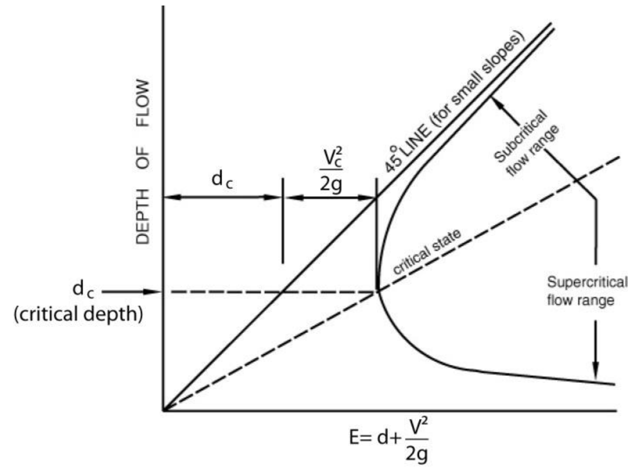
d = Depth of flow, in feet

$\frac{V^2}{2g}$ = Velocity head, in feet

When the depth of flow is plotted against the specific energy, for a given discharge and channel section, the resulting plot is called a specific energy diagram (see Figure 866.3C). The curve shows that for a given specific energy there are two possible depths, a high stage and a low stage. These flow depths are called alternate depths. Starting at the upper right of the curve with a large depth and small velocity, the specific energy decreases with a decrease in depth, reaching a minimum energy content at a depth of flow known as critical depth. A further decrease in flow depth results in a rapid increase in specific energy.

Flow at critical depth is called critical flow. The flow velocity at critical depth is called critical velocity. The channel slope which produces critical depth and critical velocity for a given discharge is the critical slope.

Figure 866.3C
Specific Energy Diagram



Uniform flow within approximately 10 percent of critical depth is unstable and should be avoided in design, if possible. The reason for this can be seen by referring to the specific energy diagram. As the flow approaches critical depth from either limb of the curve, a very small change in energy is required for the depth to abruptly change to the alternate depth

on the opposite limb of the specific energy curve. If the unstable flow region cannot be avoided in design, the least favorable type of flow should be assumed for the design.

When the depth of flow is greater than critical depth, the velocity of flow is less than critical velocity for a given discharge and hence, the flow is subcritical. Conversely, when the depth of flow is less than critical depth, the flow is supercritical.

When velocities are supercritical, air entrainment may occur. This produces a bulking effect which increases the depth of flow. For concrete lined channels, the normal depth of flow with bulking can be computed by using a Manning's "n" value of 0.018 instead of the 0.014 value given in Table 866.3A. Air entrainment also causes a reduction in channel friction with a resulting increase in flow velocity. A Manning's "n" value of about 0.008 is recommended for computing the velocity and specific energy of flow in concrete-lined channels carrying supercritical flow

Critical depth is an important hydraulic parameter because it is always a hydraulic control. Hydraulic controls are points along the channel where the water level or depth of flow is limited to a predetermined level or can be computed directly from the quantity of flow. Flow must pass through critical depth in going from subcritical flow to supercritical flow. Typical locations of critical depth are at:

(a) Abrupt changes in channel slope when a flat (subcritical) slope is sharply increased to a steep (supercritical) slope,

(b) A channel constriction such as a culvert entrance under some conditions,

(c) The unsubmerged outlet of a culvert on subcritical slope, discharging into a wide channel or with a free fall at the outlet, and

(d) The crest of an overflow dam or weir.

Critical depth for a given channel is dependent on the channel geometry and discharge only, and is independent of channel slope and roughness.

When flow occurs at critical depth the following relationship must be satisfied

$$\frac{A^3}{T} = \frac{Q^2}{g}$$

where:

A = Cross sectional area, ft^2

T = Top width of water surface, ft

Q = Discharge, CFS

g = Acceleration of gravity, 32.2 ft/s^2

Critical depth formulas, based on the above equation, for various channel cross-sections include:

- Rectangular sections,

$$d_c = \left(\frac{q^2}{g}\right)^{1/3}$$

Where:

q = Flow per unit width, CFS

- Trapezoidal sections. The tables in King's "Handbook of Hydraulics" provide easy solutions for critical depth for channels of varying side slopes and bottom widths.
- Circular sections. The tables in King's "Handbook of Hydraulics" can be used for obtaining easy solutions for critical depth.

(7) *Froude Number.* The Froude number is a useful parameter which uniquely describes open flow. The Froude number is a dimensionless value:

$$Fr = \frac{V}{(gD)^{1/2}}$$

Where:

D = A/T = Hydraulic depth, in feet

Fr < 1.0 ==> Subcritical flow

Fr = 1.0 ==> Critical flow

Fr > 1.0 ==> Supercritical flow

866.4 Water Surface Profiles

Depending on the site conditions, accuracy required, and risks involved, a single section analysis may be sufficient to adequately describe the channel stage discharge relationship. The basic assumptions to a single section analysis are uniform cross section, slope, and Manning's "n" values which are generally applicable to most roadside and median channels. The condition of uniform flow in a channel at a known discharge is computed using the Manning's equation combined with the continuity equation:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

The depth of uniform flow is solved by rearranging Manning's Equation to the form the given below. This equation is solved by trial and error by varying the depth of flow until the left side of the equation is zero:

$$\frac{Qn}{1.49S^{1/2}} - AR^{2/3} = 0$$

Per Index 866.3 (4), direct solutions for Manning's equation for many channels of trapezoidal, rectangular, triangular and circular cross sections can be found within the Channel Analysis subcomponent FHWA's Hydraulic Toolbox software program.

Where uniform flow conditions do not adequately describe the actual flow conditions (e.g., natural channels) or where additional accuracy is desired, the computation of complete water surface profiles for each discharge value may be necessary using detailed backwater analysis methods. Per Index 802.1(4)(g) contact the District Hydraulic Engineer for support.

Topic 867 - Channel Changes

867.1 General

Chapter 860 primarily addresses the design of small man-made open channels called roadside channels (gutters, ditches, swales etc.) that are constructed as part of a highway drainage system. However, both the terms 'open channel' or 'channel' may be applied to any natural or improved watercourse as well as roadside channels. See Index 861.1.

A channel change is any realignment or change in the hydraulic characteristics of an existing channel. Per Index 802.1(4)(g), contact the District Hydraulic Engineer for support.

The main reasons for channel changes to either natural or improved watercourses (flood control channels, irrigation channels etc.) within the right of way are to:

- Permit better drainage
- Improve flow conditions
- Protect the highway from flood damage
- Reduce right of way requirements

The guidelines in Topic 823 (Culvert Location) generally recommend alignment of the thalweg of the stream with the centerline of the culvert, however, for economic reasons, small skews should be eliminated, moderate skews retained and large skews reduced. Road crossings requiring fish passage are strongly encouraged to retain the natural alignment of the stream, regardless of the skew. Alignment of the culvert centerline with the channel approach angle aids debris passage during storm flows and minimizes hydraulic turbulence which may impede fish passage.

Sometimes a channel change may be to its vertical alignment. For example, inverted siphons or sag culverts may be used to carry irrigation channels crossing the right of way via vertical realignment entirely below the hydraulic grade line. However, maintenance concerns include sediment build-up and potential leakage problems with full-flow barrel(s). See Index 829.7(2) and Index 867.2 below.

867.2 Design Considerations

Channel changes should be designed with extreme caution and coordinated with District Hydraulics. Careful study of the channel characteristics upstream and downstream as well as within the channel change area is required to achieve a safe and effective design.

Channel changes may result in a decreased surface roughness or increased channel slope. As a result the following may occur:

- Higher velocities which result in damage due to scour
- Sedimentation and meandering at downstream end of channel change
- A flattened downstream gradient which progresses upstream undercutting the channel banks or highway fill
- Flattened downstream gradient or channel restrictions may create undesirable backwater conditions.

A channel change perched above the bottom of an old flood stage stream bed may cause the stream to return to its old channel during a subsequent flood. In addition, the designer should consult with Geotechnical Services to ensure that infiltration through the bank would not be problematic.

Topic 868 - Freeboard Considerations

868.1 General

Freeboard is the extra height of bank above the design depth where overflow is predicted to cause damage. Freeboard allowances will vary with each situation.

866.2 Height of Freeboard

(1) *Straight Alignment*. In channels where overflow may cause substantial damage, a

guide for freeboard height for channels on a straight alignment, is provided in Table 868.2

Table 868.2
Guide to Freeboard Height

Shape of Channel	Subcritical Flow	Supercritical Flow
Rectangular	0.1 He	0.20 d
Trapezoidal	0.2 He	0.25 d

where:

He = Energy head, in feet

d = Depth of flow, in feet for a straight alignment

(2) *Critical Flow*. An unstable zone of flow occurs where the flow is near critical state. This is characterized by random waves. An allowance for waves should be added to the normal depth when the slope of the channel is between 0.7 S_c and 1.3 S_c.

$$H_w = 0.25 d_c \left[1 - 11.1 \left(\frac{S}{S_c} - 1\right)^2\right]$$

where:

H_w = height of wave, in feet

d_c = critical depth, in feet

S = slope of channel, in foot per feet

S_c = critical slope, in foot per feet

(3) *Superelevation.* The height of freeboard discussed above does not provide for superelevation of the water surface on curved alignments.

Flow around a curve will result in a rise of the water surface on the outside of the curve and extra lining is necessary to guard against overtopping.

Additional freeboard is necessary in bends and can be calculated use the following equation:

$$\Delta d = \frac{V^2 T}{g R_c}$$

where:

Δd = Additional freeboard required because of superelevation, feet

V = Average channel veloctiy, ft/s

T = Water surface top width, ft

G = Acceleration due to gravity, ft/s^2

R_c = Radius of curvature of the bend to the channel centerline, ft

See HEC No. 15, Chapter 3, for shear stress considerations around bends.

material from the bottom, the ends, or the top.

The bottom should be founded on bedrock or below the depth of possible scour.

If the ends are not tied into rock or other nonerosive material, cutoff returns are to be provided and if the protection is long, cutoff stubs are built at 30-foot intervals, in order to prevent or retard a progressive failure.

Protection should be high enough to preclude overtopping. If the roadway grade is subject to flooding and the shoulder material does not contain sufficient rock to prevent erosion from the top, then pavement should be carried over the top of the slope protection in order to prevent water entering from this direction.

Class 8 RSP fabric as described in Standard Specification Section 96 should be placed behind all sacked concrete revetments. For revetments over 4 feet in height, weep tubes should also be placed, see Figure 873.3E.

For good appearance, it is essential that the sacks be placed in horizontal courses. If the foundation is irregular, corrective work such as placement of entrenched concrete or sacked concrete is necessary to level up the foundation. Refer to HDS No. 6, Section 6.6.5, for further discussion on the use of sacked concrete slope protection.

(5) Bulkheads. A bulkhead is a steep or vertical structure supporting a natural slope or constructed embankment. As bank protection structures, bulkheads serve to secure the bank against erosion as well as retaining it against sliding. As a retaining structure, conventional design methods for retaining walls, cribs and laterally loaded piles are used.

Bulkheads are usually expensive, but may be economically justified in special cases where valuable riparian property or improvements are involved and foundation conditions are not satisfactory for less expensive types of slope protection. They may be used for toe protection in combination with other revetment types of slope protection. Some other considerations that may justify the use of bulkheads include:

- Encroachment on a channel cannot be tolerated.
- Retreat of highway alignment is not viable.
- Right of Way is restricted.
- The force and direction of the stream can best be redirected by a vertical structure.

The foundation for bulkheads must be positive and all terminals secure against erosive forces. The length of the structure should be the minimum necessary, with transitions to other less expensive types of slope protection when possible. Eddy currents can be extremely damaging at the terminals and transitions. If overtopping of the bulkheads is anticipated, suitable protection should be provided.

Along a stream bank, using a bulkhead presumes a channel section so constricted as to prohibit use of a cheaper device on a natural slope. Velocity will be unnaturally high along the face of the bulkhead, which must have a fairly smooth surface to avoid compounding the restriction. The high velocity will increase the threat of scour at the toe and erosion at the downstream end. Allowance must be made for these threats in selecting the type of foundation, grade of footing, penetration of piling, transition, and anchorage at downstream end. Transitions at both ends may appropriately taper the width of channel and slope of the bank. Transition in roughness is desirable if attainable. Refer to HDS No. 6, Section 6.4.8, for further discussion on the use of bulkheads to prevent streambank erosion or failure.

(a) Concrete or Masonry Walls. The expertise and coordination of several engineering disciplines is required to accomplish the development of PS&E for concrete walls serving the dual purpose of slope protection and support. The Division of Structures is responsible for the structural integrity of all retaining walls, including bulkheads.

(b) Crib walls. Timber and concrete cribs can be used for bulkheads in locations where some flexibility is desirable or permissible. Metal cribs are limited to support of embankment and are not recommended for use as protection because of vulnerability to corrosion and abrasion.

The design of crib walls is essentially a determination of line, foundation grade, and height with special attention given to potential scour and possible loss of backfill at the base and along the toe. Concrete crib walls used as bulkheads and exposed to salt water require special provisions specifying the use of coated rebars and special high density concrete. Recommendations from METS Corrosion Technology Branch should be requested for rebar protection and type of concrete. DES Structures Design should be consulted with the physical, structural design of a crib wall.

(c) Sheet Piling. Timber, concrete and steel sheet piling are used for bulkheads that depend on deep penetration of foundation materials for all or part of their stability. High bulkheads are usually counterforted at upper levels with batter piles or tie back systems to deadmen. Any of the three materials is adaptable to sheet piling or a sheathed system of post or column piles.

Excluding structural requirements, design of pile bulkheads is essentially as follows:

- Recognition of foundation conditions suitable to or demanding deep penetration. Penetration of at least 15 feet below scour level, or into soft rock, should be assured.
- Choice of material. Timber is suitable for very dry or very wet climates, for other situations economic comparison of preliminary designs and alternative materials should be made.
- Determination of line and grade. Fairly smooth transitions with protection to high-water level should be provided.

(6) Vegetation. Vegetation is the most natural method for stabilization of embankments and channe bank protection. Vegetation can be relatively easy to maintain, visually attractive and environmentally desirable. The root system forms a binding network that helps hold the soil. Grass and woody plants above ground provide resistance to the near bank water flow causing it to lose some of its erosive energy.

Erosion control and revegetation mats are flexible three-dimensional mats or nets of natural or synthetic material that protect soil and seeds against water erosion prior to establishment of vegetation. They permit vegetation growth through the web of the mat material and have been used as temporary channel linings where ordinary seeding and mulching techniques will not withstand erosive flow velocities. The designer should recognize that flow velocity estimates and a particular soils resistance to erosion are parameters that must be based on specific site conditions. Using arbitrarily selected values for design of vegetative slope protection without consultation with the District Hydraulic Unit and/or the District Landscape Architect Unit is not recommended. However, a suggested starting point of reference is Table 865.2 in which the resistance of various unprotected soil classifications to flow velocities are given. Under near ideal conditions, ordinary seeding and mulching methods cannot reasonably be expected to withstand sustained flow velocities above 4 feet per second. If velocities are in excess of 4 feet per second, a lining maybe needed, see Table 865.2.

Temporary channel liners are used to establish vegetative growth in a drainage way or as slope protection prior to the placement of a permanent armoring. Some typical temporary channel liners presented in Table 865.2 are:

- Single net straw
- Double net coconut/straw blend
- Double net shredded wood

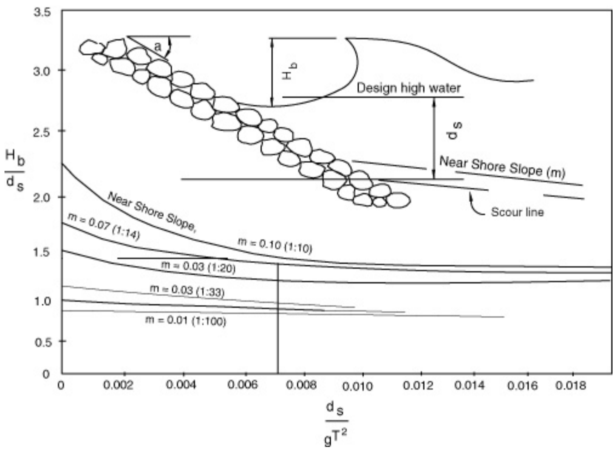
Vegetative and temporary channel liners are suitable for conditions of uniform flow and moderate shear stresses.

Permanent soil reinforcing mats and rock riprap may serve the dual purpose of temporary and permanent channel liner. Some typical permanent channel liners are:

- Small rock slope protection
- Geosynthetic mats
- Polyethelene cells or grids

Figure 883.2C

Design Breaker Wave



Example:

By using hindcast methods, the significant wave height (H_s) has been estimated at 4 feet with a 3 second period. Find the design wave height (H_d) for the slope protection if the depth of water (d) is only 2 feet and the nearshore slope (m) is 1:10.

Solution:

$$\frac{d_s}{gT^2} = \frac{2\ ft}{(32.2\ ft/sec^2) \times (3\ sec)^2} = 0.007$$

From Graph) - $H_b/d_s = 1.4$

$H_b = 2 \times 1.4 = 2.8$ ft

Answer:

Since the maximum breaker wave height, H_b, is smaller than the significant deepwater wave height, H_s, the design wave height H_d is 2.8 feet.

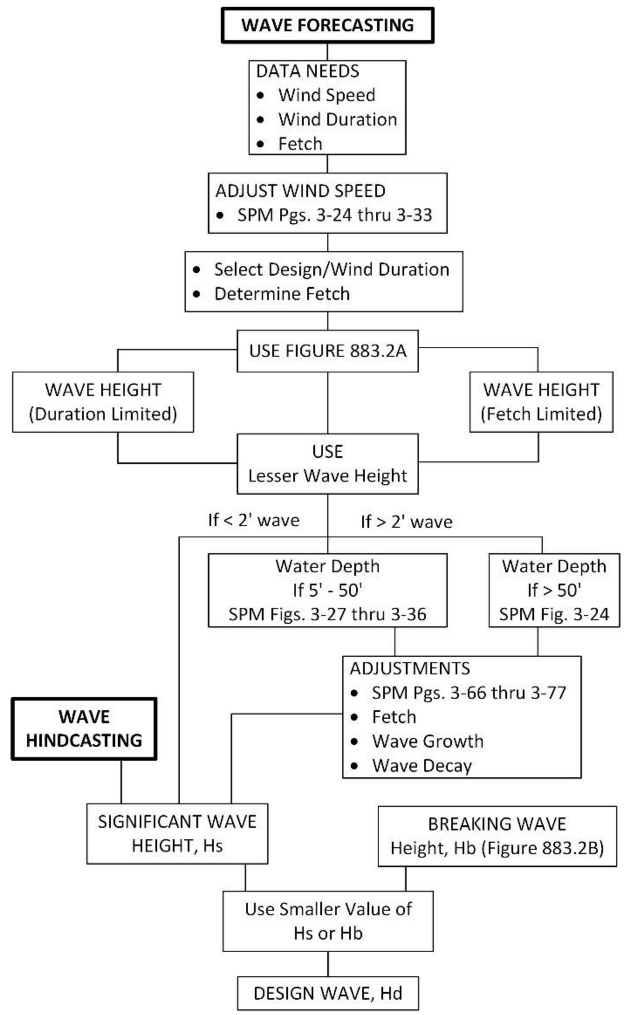
T = Wave Period (SPM)

policy for projects subject to California Coastal Commission (CCC) jurisdiction (see CCC guidance document "Beach Erosion and Response," December 1999). Procedures for estimating wave run-up for rough surfaces (e.g., RSP) are contained in the U.S. Army Corps of Engineers manual, Design of Coastal Revetments, Seawalls, and Bulkheads, (EM 1110-2-1614) published in 1995.

Procedures for estimating wave run-up for smooth surfaces (e.g., concrete paved slopes) and for vertical and curved face walls are contained in the U.S. Army Corps of Engineers, Shore Protection Manual, 1984. See Figure 873.2D for estimating wave run-up on smooth slopes for wave heights of 2 feet or less.

In protected bays and estuaries, waves generated by recreational or commercial boat traffic and other watercraft may dominate the design over wind generated waves. Direct observation and measurements during high tidal cycles may provide the designer the most useful tool for establishing wave run-up for these situations.

Determining Design Wave



(g) Littoral Processes. See Index 882.3(2). Littoral processes result from the interaction of winds, waves, currents, tides, and the availability of sediment. The rates at which sediment is supplied to and removed from the shore may cause excessive accretion or erosion that can affect the structural integrity of shore protection structures or functional usefulness of a beach. The aim of good shore protection design is to maintain a stable shoreline where the volume of sediment supplied to the shore balances that which is removed.

Designers interested in a more complete discussion on littoral processes should consult the U.S. Army Corps of Engineers' Coastal Engineering Manual (CEM) – Part III.

(3) *Sea Level Rise.* The California Ocean Protection Council (OPC) has developed sea-level rise guidance for use by state and local governments to assess the associated risks with sea-level rise and incorporate sea-level rise into planning, permitting and investment decisions. The "State of California Sea-Level Rise Guidance 2018" provides estimates of sea-level rise based upon the best available science. A step-by step approach to selecting a value for sea-level rise based on OPC 2018 Guidance is provided in the steps below. This method of evaluating sea-level rise could be revised and updated in the future based on the most current guidance provided by OPC or other responsible agencies.

Step 1: Identify the nearest tide gauge. The rates of sea-level rise along the California coast is dependent on land elevations resulting from tectonic activity as well as land subsidence. There are 12 active tide gauges along the California coast and sea-level rise projections vary across the tide gauges based on trends in tectonic activity and land subsidence.

Identify the tide gauge nearest to the project site. If the project is located equidistant between two tide gauges it would be appropriate to interpolate between the two gauges or average the two gauges. The 12 tide gauges along the California coast are identified in Figure 883.2 D.

Step2. Evaluate the project lifespan: Determine the project lifespan for selection of appropriate year for associated sea-level rise. The California Transportation Commission has adopted asset classes associated with the State Highway System and the Primary Asset Classes are defined as: (a) Pavement, (b) Bridges, (c) Culverts, and (d) Transportation Management Systems. In the absence of a designated project lifespan, the design life associated with an asset class may be used to determine the year associated with the projected sea-level rise. Design lives of pavement projects are referenced in Section 612, and maintenance free service life of culverts (typically 50-years) referenced in chapter 850 of this manual. Bridge Design Life (per AASHTO LRFD Bridge Design Specifications 8th Edition Sec. 1.3.2.2) is 75 years.

Figure 883.2D

California 12 Tide Gauges

Emissions Scenarios: Prior to 2050 the differences in sea-level rise projected values across multiple emissions scenarios are not significant since sea-level rise till 2050 is locked-in by past greenhouse gas emissions. After 2050 sea-level rise is dependent on the severity of greenhouse gas emissions, low emissions represented by Representative Concentration Pathway (RCP) 2.6 and the high emissions scenario represented by RCP 8.5. Sea-level rise is evaluated for both high and low emissions scenarios associated with multiple risk aversions. A

H++ scenario is also included and is considered to be an extreme scenario not associated with any probability. The H++ scenario may be considered for projects and its impact on potential projects may be documented but may not necessarily be used for design purposes. Feasibility and costs associated with the H++ scenario should be evaluated and included in the justification for the acceptance/rejection of the H++ scenario for design purposes.

Jurisdictional agencies (such as the California Coastal Commission) may require an evaluation of sea-level rise under the RCP 8.5 as well as the H++ scenarios. However, project design may not necessarily include incorporation of the highest value of sea-level rise selected. Factors such as project costs and feasibility, may require a negotiated agreement with the agencies to develop a modular approach to design using a value associated with a shorter time frame than the selected design life of the project with the understanding that successive projects over time would build upon the proposed design to ultimately provide a resilient infrastructure.

Step 3. Identify range of Sea-Level Rise Projections: Vulnerability of people, communities, natural resources, infrastructure and properties should be considered for developing a range of sea-level rise projections. Sea-level rise projections for various risk aversions including a low risk aversion (66% probability sea-level rise lies within this range), a medium risk aversion (1 in 20 chance), a medium high-risk aversion (1 in 200 chance), an extreme risk aversion (H++ scenario) should be studied against impacts of potential sea-level rise on people, communities, natural resources, infrastructure, and properties.

Low risk aversion represents a condition where an asset has a 17% chance of being adversely impacted by sea-level rise. Examples of a low risk aversion may include a parking lot within the coastal area, or a constructed trail leading down towards a beach. Should such assets be damaged or destroyed, they may be relatively easy to repair or replace.

Medium risk aversion represents a condition where an asset has a 5% chance of being adversely impacted by sea-level rise. Such risk may be exercised for a segment of roadway that if inaccessible would not jeopardize public safety or public health. Additionally, such a risk may be adopted if an asset would be cost effective to repair/replace as opposed to major resiliency redesign, and whose inaccessibility would not negatively impact natural resources or properties. Another example may be culvert outfalls that may tend to be inundated by sea-level rise on a coastal highway. Medium risk aversion may be assumed if a contingency plan exists to retrofit the culvert outfalls with tidal flap gates to prevent backflow.

Medium-high risk aversion represents a condition where an asset has a 0.5% chance of being inundated and is expected to be needed for public health/safety. The likelihood that sea-level rise may meet or exceed this value is low. A highway expected to be used as an emergency evacuation route for people/communities, as access to and from hospitals, as a major route for support of local/regional economies, may be evaluated for sea-level rise under the medium-high risk aversion scenarios.

Extreme risk scenario represented by H++ may be used for projects that have little to no adaptive capacity, that are essential for public safety and health, that is cost prohibitive to replace or repair, and with a design life well beyond 2050. An example would be a major bridge connecting communities with access to hospitals and economic interests and spanning a water body directly impacted by sea-level rise, and where freeboard requirements are necessary for passage of ships, boats or other crafts. Such situations with project design lives extending into the 22nd century where a minimum freeboard is required for passage of watercraft may require consideration of the H++ scenario.

Sea-level rise projections for each tide gauge are provided in the 'State of California Sea Level Rise Guidance 2018 Update" Appendix 3 and may be accessed at: http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.

Step 4. Evaluate potential impacts and adaptive capacity across a range of sea-level rise projections and emissions scenarios: Evaluate the potential impacts of sea-level rise on the project in terms of vulnerable communities, critical infrastructure, and economic burden.

Step 5. Select sea-level rise projections based on risk tolerance and incorporate appropriate resiliency into design. Contingency plans may be included in case sea-level rise exceeds design projections. Evaluate impacts of sea-level rise by using sea-level rise mapping tools (sea-level rise) viewer available at: https://coast.noaa.gov/slr/#/layer/slr/0/-13566681.667176013/4585243.78640795/9/satellite/none/0.8/2050/interHigh/midAccretion.

NOAA's sea-level rise viewer evaluates the impacts of sea-level rise at water surface elevations derived from adding the selected value of sea-level rise to the mean higher high water (MHHW) elevation of the sea in the vicinity of the project. MHHW values for various stations may be obtained from https://tidesandcurrents.noaa.gov/stations.html?type=Datums. Select appropriate station and datum from website. Add selected value of sea-level rise to MHHW to obtain water surface elevation for design. An example for selection of sea-level rise for a hypothetical project near Crescent City, Del Norte County is provided below.

Project Scope: A segment of SR 101 is to be reconstructed south of Crescent City. A parking lot for access to the beach is also included in the scope of the project as shown in Figure 883.2E.

Figure 883.2E
Crescent City Example

Assumed project scope includes reconstruction of segment of SR-101 south of Crescent City. A parking lot is to be constructed for beach access for recreational purposes. Consideration of sea-level rise for proposed project is as follows:
The nearest tide gauge is Crescent City. The data for sea-level rise at Crescent City is provided in Table 883.1B. Per HDM Index 612.2, pavement design life of parking lots is 20 years; reconstruction projects is 40 years. Applicable sea-level rise for the parking lot will be for year 2040. Applicable sea-level rise for roadway reconstruction will be for year 2060.

Consider range of sea-level rise for varying risk and emissions conditions. For the parking lot, sea-level rise for projects prior to 2050 reflect only a high emissions scenario. Refer to Table 883.1B for information:

- Sea-level rise associated with a low risk aversion for year 2040 ranges from 0.1 to 0.4 feet. Select the higher value in the range, i.e. 0.4-foot.
- Sea-level rise associated with a medium risk aversion (5% probability sea level rise meets or exceeds) for the year 2040 is 0.6 feet.
- Sea-level rise associated with the medium-high risk aversion (0.5% probability sea-level rise meets or exceeds) for the year 2040 is 0.9 feet.

Now evaluate the impact of the potential loss of the parking lot.

- The loss of the parking lot is not expected to have a significant impact on public health and safety. The loss would be expected to have an insignificant economical impact on any community.
- When there is no significant economical loss, no threat to public safety, public health or transportation resulting from the loss of the parking lot, an evaluation of the costs of construction, repair and replacement should determine the risk factor to be adopted for selection of an appropriate value for sea-level rise.
- Although sea-level rise associated with a low risk aversion may be justified, however, costs of construction, future

repair or replacement should be examined. For the parking lot the differences between sea-level rise values associated with the low risk, medium risk and the medium-high risk is very small (ranges from 5 inches to 11 inches) and based on costs an appropriate risk aversion may be selected.

For highway reconstruction, sea-level rise projections for projects with design life extending beyond 2050 are provided for low emissions as well as high emissions scenarios. With a 40-year design life for pavement reconstruction projects sea-level rise for year 2060 may be considered. Refer to Table 883.1B for information. Review sea-level rise projection for both low as well as high emissions scenarios for low risk, medium risk as well as medium-high risk aversions. The comparisons for year 2060 are provided Table 883.1A.

Table 883.1A

Crescent City Example Comparison for 2060

Emissions	Low Risk Aversion	Medium Risk Aversion	Medium-High Risk Aversion
Low (RCP 2.6)	0.1 to 0.7-foot	1.0-foot	1.8-foot
High (RCP 8.5)	0.2 to 0.9-foot	1.3-foot	2.1-foot

Determine impact of potential loss of this segment of highway on communities:

- Will the loss of this segment impact transport of patients to and from a hospital?
- Will the loss of this segment impact response times for emergency vehicle?
- Will the loss of this segment impact freight and deliveries resulting in economic losses?
- Can traffic be detoured easily around this segment?

The value of sea-level rise for designing the roadway may be selected after evaluating relevant issues such as mentioned above. The difference between the low and high emissions scenarios is less than 4-inches. Based on the small difference between the emissions scenarios, the high emissions scenario RCP 8.5 may be appropriate. If the highway segment is important for public safety/health and local economy, the medium-high risk value of 2.1 feet may be selected. The design would not only incorporate a higher elevation of the roadway but would also include measures for protecting the roadway (Armoring sea approach to roadway embankment).

Although the project does not have to be designed for the H++ scenario, it may be considered. Sea-level rise associated with the H++ scenario is 3.3 feet. A plan for future modular adaptation may be included should it become apparent at some time in future that sea levels are heading towards the H++ projections. The plan may include raising the profile of the highway and associated protection measures against the 3.3 feet projected sea-level rise.

Determine MHHW elevation from:

https://tidesandcurrents.noaa.gov/datums.html?id=9419750. Figure 883.2F shows the results.

Add MHHW to projected sea-level rise:

For the roadway project add 2.1 feet to 6.49 feet. Elevation of water surface including seal level rise associated with high emissions and medium-high risk aversion is 8.59 feet. Evaluate impact of sea-level rise on project by using NOAA sea-level rise viewer at: https://coast.noaa.gov/slr/.

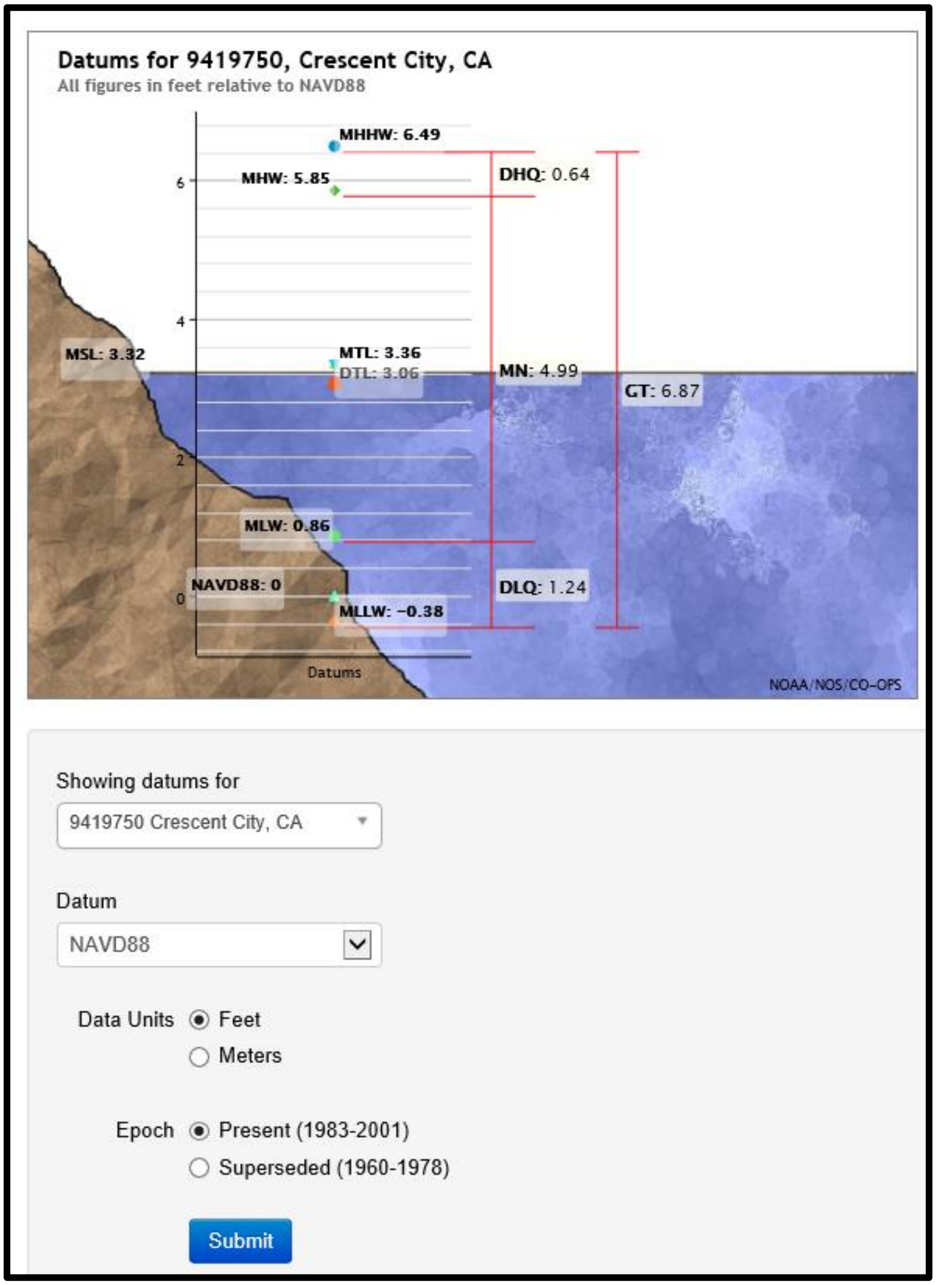
(4) *Assessing Extreme Events and Climate Change.* Chapter 4 of HEC 25, Volume 2 presents guidance on specific methodologies for assessing exposure of coastal transportation infrastructure to extreme events and climate change. For all projects, as a minimum, the use of existing data and resources should be utilized through the use of existing inundation (FEMA) or tsunami hazard maps to determine the exposure of infrastructure under selected sea (lake) level change scenarios, and sensitivity to depth-limited wave or wave runup processes. See HEC 25, Volume 2, Indexes 4.1.1 and 4.5.1 Level of Effort 1: Pacific Coast – Storms.

Table 883.1B
Projected Sea-Level Rise (feet) at Crescent City

Emissions Scenario	Year	Median	Likely Range	1 – In – 20 Chance	1 – In – 200 Chance	H++ Scenario
		50% probability sea-level rise meets or exceeds	66% probability sea-level rise is between	5% probability sea-level rise meets or exceeds	0.5% probability sea-level rise meets or exceed	Not associated with any probability
			Low Risk Aversion	**Medium Risk Aversion**	**Medium – High Risk Aversion**	**Extreme Risk Aversion**
High Emissions	**2030**	**0.1**	**0.0 – 0.3**	**0.4**	**0.5**	**0.8**
High Emissions	**2040**	**0.3**	**0.1 – 0.4**	**0.6**	**0.9**	**1.4**
High Emissions	**2050**	**0.4**	**0.2 – 0.7**	**0.9**	**1.5**	**2.3**
Low Emissions	**2060**	**0.4**	**0.1 – 0.7**	**1.0**	**1.8**	
High Emissions	**2060**	**0.6**	**0.2 – 0.9**	**1.3**	**2.1**	**3.3**
Low Emissions	**2070**	**0.5**	**0.1 – 0.9**	**1.3**	**2.4**	
High Emissions	**2070**	**0.8**	**0.4 – 1.2**	**1.7**	**2.8**	**4.5**
Low Emissions	**2080**	**0.6**	**0.1 – 1.1**	**1.6**	**3.1**	
High Emissions	**2080**	**1.0**	**0.5 – 1.6**	**2.2**	**3.7**	**5.9**
Low Emissions	**2090**	**0.7**	**0.1 – 1.3**	**1.9**	**3.9**	
High Emissions	**2090**	**1.2**	**0.6 – 2.0**	**2.8**	**4.7**	**7.4**
Low Emissions	**2100**	**0.7**	**0.1 – 1.5**	**2.3**	**4.8**	
High Emissions	**2100**	**1.5**	**0.7 – 2.5**	**3.4**	**5.9**	**9.3**
Low Emissions	**2110**	**0.8**	**0.2 – 1.5**	**2.4**	**5.3**	
High Emissions	**2110**	**1.5**	**0.9 – 2.5**	**3.4**	**6.2**	**11.0**
Low Emissions	**2120**	**0.8**	**0.1 – 1.7**	**2.8**	**6.3**	
High Emissions	**2120**	**1.8**	**1.0 – 3.0**	**4.1**	**7.4**	**13.1**
Low Emissions	**2130**	**0.9**	**0.1 – 1.9**	**3.2**	**7.3**	
High Emissions	**2130**	**2.1**	**1.1 – 3.4**	**4.8**	**8.7**	**15.3**
Low Emissions	**2140**	**1.0**	**0.1 – 2.2**	**3.6**	**8.4**	
High Emissions	**2140**	**2.3**	**1.2 – 3.9**	**5.5**	**10.1**	**17.8**
Low Emissions	**2150**	**1.0**	**0.0 – 2.4**	**4.2**	**9.6**	
High Emissions	**2150**	**2.6**	**1.3 – 4.4**	**6.2**	**11.6**	**20.6**

Figure 883.2F

Crescent City MHHW



883.3 Armor Protection

(1) General. Armor is the artificial surfacing of shore or embankment to resist erosion or scour. Armor devices can be flexible (self-adjusting) or rigid. The distinction between revetments (layers of rock or concrete), seawalls, and bulkheads is one of functional purpose. Revetments usually consist of rock slope protection on the top of a sloped surface to protect the underlying soil. Seawalls are walls designed to protect against large wave forces. Bulkheads are designed primarily to retain the soil behind a vertical wall in locations with less wave action. Design issues such as tie-backs, depth of sheets are primarily controlled by geotechnical issues. The use of each one of the three types of coastal protection depends on the relationship between wave height and fetch (distance across the water body). Bulkheads are most common where fetches and wave heights are small. Seawalls are most common where fetches and wave heights are large. Revetments are often common in intermediate situations such as on bay or lake shorelines.

(2) Revetments.

(a) Rock Slope Protection (RSP). Hard armoring of shorelines, primarily with RSP, has been the most common means of providing long-term protection for transportation facilities, and most importantly, the traveling public. With many years of use, dozens of formal studies and thousands of constructed sites, RSP is the armor type for which there exists the most quantifiable data on performance, constructability, maintainability and durability, and for which there exist several nationally recognized design methods.

Due to the above factors, RSP is the general standard against which other forms of armoring are compared.

The results of internal research led to the publication of Report No. FHWA-CA-TL-95-10, "California Bank and Shore Rock Slope Protection Design". Within that report, the methodology for RSP design adopted as the Departmental standard for many years, was the California Bank and Shore, (CABS), layered design. The CABS layered design methodology and its associated gradations are now obsolete. For reference only, the full report is available at the following website:

http://www.dot.ca.gov/hq/oppd/hydrology/hydroidx.htm.

For RSP designs along coastal and lake shores, for wave heights five feet or less, the methodology presented in HEC 23, Volume 2, Design Guideline 17- Riprap Design for Wave Attack has been formally adopted by the Caltrans Bank and Shore Protection Committee. Section 72 of the Standard Specifications provides all construction and material specifications.

Rock is usually the most economical type of revetment where stones of sufficient size and quality are available. It also has the following advantages:

- Wave run-up is less than with smooth types (See Figure 883.2G).
- It is salvageable, may be stockpiled and reused if necessary.

Figure 883.2G

Wave Run-up on Smooth Impermeable Slope

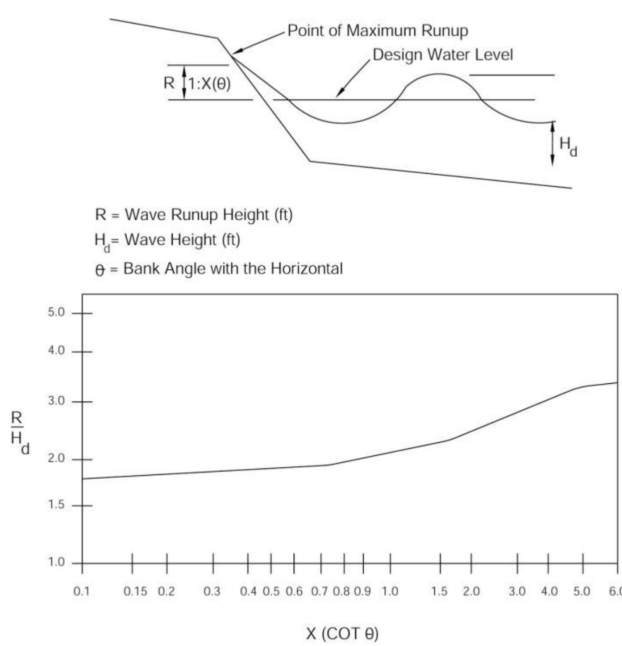


Figure 883.2H
RSP Lined Ocean Shore

In designing the rock slope protection for a shore location, the following determinations are to be made for the typical section.

- Depth at which the stones are founded (bottom of toe trench. See Figure 883.2I and Figure 17.2 in HEC 23, Volume 2, Design Guideline 17).
- Elevation at the top of protection.
- Rock size, specific gravity and section thickness.
- Need for geotextile or rock filter material.
- Face slope.

Well designed coastal rock slope protection should:

- Assure stability and compatibility of the protected shore as an integral part of the shoreline as a whole.
- Not be placed on a slope steeper than 1.5H:1V.
- Use stone of adequate weight to resist erosion, derived from Index 883.3(2)(a)(2)(1).
- Prevent loss of bank materials through interstitial spaces of the revetment. Rock slope protection fabric or a filter layer should be used.
- Rest on a good foundation on bedrock or extend below the depth of probable scour. If questionable, use heavy bed stones and provide a wide base section with a reserve of material to slough into local scour holes (i.e., mounded toe).
- Be constructed of rock of such shape as to form a stable protection structure of the required section. See Index 873.3(3)(a)(2)(a).

(1) General Features -- See Index 873.3(3)(a)(1)(a) through (e) for discussions on methods of placement, foundation treatment, rock slope protection fabrics and gravel filters.

(2) Stone Size -- Two methods for determining riprap size for stability under wave action are presented in HEC 23, Volume 2, Design Guideline 17: (1) the Hudson method, and (2) the Pilarczyk method.

(a) The Hudson Method. Applications of Hudson's equation in situations with a design significant wave height of H=5 feet or less have performed well. This range of design wave heights encompasses many coastal revetments along highway embankments. When design wave heights get large and the design water depths get large, problems with the performance of rubble-mound structures can occur. A more conservative design approach should use a more conservative H statistic. The proper input wave height statistic is required and discussed in Section 6.3 of HEC 25, Volume 1. RSP with design wave heights much greater than H=5 feet require more judgment and more experience and input from a trained, experienced coastal engineer. Therefore, when design wave heights are much greater than H=5 feet, contact the District Hydraulic Engineer. The Hudson method considers wave height, riprap density, and slope of the bank or shoreline to compute a required weight of a median-size riprap particle.

$$W_{50} = \frac{\gamma_r H^3 (\tan\theta)}{K_d (S_r - S_w)^3}$$

Where:

W_{50} = weight of median riprap particle size, (lb)

γ_r = unit weight of riprap, (lb/ft^3)

H = design wave height, (ft) (Note: Minimum recognized value for use with the Hudson equation is the 10 percent wave, $H_{0.10} = 1.27H_s$)

K_d = empirical coefficient equal to 2.2 for riprap

S_r = specific gravity for riprap

S_w = specific gravity for water (1.0 for fresh water, 1.3 for sea water)

θ = angle of slope inclination

The median weight W_{50} can be converted to an equivalent particle size d_{50} by the following relationship:

$$d_{50} = \sqrt[3]{\frac{W_{50}}{0.85\gamma_r}}$$

(b) The Pilarczyk Method. Compared to the Hudson method, the Pilarczyk method considers additional variables associated with particle stability in different wave environments, and therefore should more thoroughly characterize the rock stability threshold. The hydraulic processes that influence rock revetment stability are directly related to the type of wave that impacts the slope, as characterized by the breaker parameter. The breaker parameter is a dimensionless quantity that relates the bank slope, wave period, wave height, and wave length to distinguish between the types of breaking waves. This parameter is defined as:

$$\xi = \frac{\tan\theta}{\sqrt{H_s/L_o}} = \tan\theta\,\frac{K_u T}{\sqrt{H_s}}$$

Where:

ξ = dimensionless breaker parameter

θ = angle of slope inclination

L_o = wave height, (ft)

H_s = significant wave height, (ft)

T = wave period, (sec)

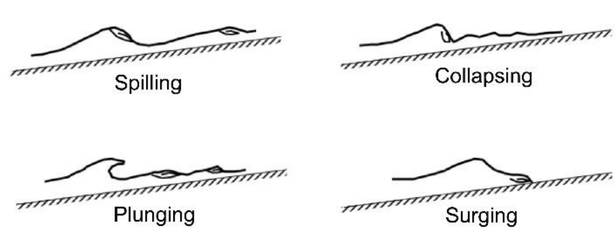
K_u = coefficient equal to 2.25 for wave height, (ft)

The wave types corresponding to the breaker parameter are listed in Table 883.2 and illustrated schematically below.

Table 883.2

Dimensionless Breaker Parameter and Wave Types

Value of the Dimensionless Breaker Parameter ξ	Type of Wave
ξ < 0.5	Spilling
0.5 < ξ < 2.5	Plunging
2.5 < ξ < 3.5	Collapsing
ξ < 3.5	Surging



The Pilarczyk method, like the Hudson method, uses a general empirical relationship for particle stability under wave action. When design wave heights are much greater than H=5 feet, contact the District Hydraulic Engineer. The Pilarczyk equation is:

$$\frac{H_s}{\Delta D} \leq \psi_u \phi \frac{\cos\theta}{\xi^b}$$

Where:

H_s = significant wave height, (ft)

Δ = relative unit weight of riprap, $\Delta = (\gamma_r - \gamma_w)/\gamma_w$

D = armor size thickness, (ft)

ψ_u = stability upgrade factor (1.0 for good riprap)

ϕ = stability factor (1.5 for good quality, angular riprap)

θ = angle of slope inclination

ξ = dimensionless breaker parameter

b = exponent (0.5 for riprap)

Rearranging the Pilarczyk equation to solve for the required stone size, and inserting the recommended values for riprap with a specific gravity of 2.65 and a fresh water specific gravity of 1.0 yields the following equation for sizing rock riprap for wave attack:

$$d_{50} \geq \frac{2}{3}\left(\frac{H_s \xi^{0.5}}{1.64\cos\theta}\right)$$

For salt water locations (specific gravity = 1.03), substitute 1.57 for 1.64 into the denominator of the above equation.

Using standard sizes the appropriate gradation can be achieved by selecting the next larger size class, thereby creating a slightly over-designed structure, but economically a less expensive one. For example, if a riprap sizing calculation results in a required d_{50} of 16.8 inches, Class V riprap should be specified because it has a nominal d_{50} of 18 inches. See Table 873.3A.

Worked examples of the Pilarczyk and the Hudson method are presented in HEC 23, Design Guideline 17. Compared with the Hudson method, the Pilarczyk method is more complicated and includes the consideration of wave period, storm duration, clearly-defined damage level and permeability of structure. The choice of the appropriate formula is dependent on the design purpose (i.e. preliminary design or detailed design).

(3) Design Height -- The recommended vertical extent of riprap for wave attack includes consideration of high tide elevation, storm surge, wind setup, wave height, and wave runup. Details

can be found in HEC 25, Volume 1, and HEC 23, Volume 2, Index 17.3.2.

(3) Bulkheads. The bulkhead types are steep or vertical structures, like retaining walls, that support natural slopes or constructed embankments which include the following:

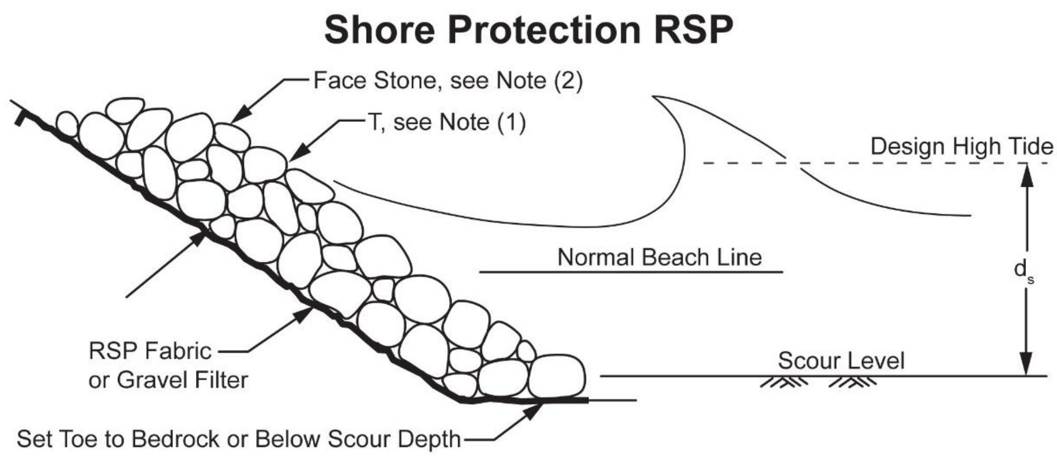
- Gravity or pile supported concrete or masonry walls.
- Crib walls
- Sheet piling

(a) Concrete or Masonry Walls. The expertise and coordination of several engineering disciplines is required to accomplish the development of PS&E for concrete walls serving the dual purpose of slope protection and support. The Division of Structures is responsible for the structural integrity of all retaining walls, including bulkheads.

(b) Crib walls. Timber and concrete cribs can be used for bulkheads in locations where some flexibility is desirable or permissible.

Figure 883.2I

Rock Slope Protection



NOTES:

(1) Thickness "T" = 1.5 d_{50}

(2) Face stone size is determined from Index 883.3(2)(b).

(3) RSP fabric not to extend more than 20 percent of the base width of the Mounded Toe past the Theoretical Toe.

Metal cribs are limited to support of embankment and are not recommended for use as protection because of vulnerability to corrosion and abrasion.

The design of crib walls is essentially a determination of line, foundation grade, and height with special attention given to potential scour and possible loss of backfill at the base and along the toe. Concrete crib walls used as bulkheads and exposed to salt water require special provisions specifying the use of coated rebars and special high density concrete. Recommendations from METS Corrosion Technology Branch should be requested for rebar protection and type of concrete. DES Structures Design should be consulted with the physical, structural design of a crib wall.

(c) Sheet Piling. Timber, concrete and steel sheet piling are used for bulkheads that depend on deep penetration of foundation materials for all or part of their stability. High bulkheads are usually counterforted at upper levels with batter piles or tie back systems to deadmen. Any of the three materials is adaptable to sheet piling or a sheathed system of post or column piles

Excluding structural requirements, design of pile bulkheads is essentially as follows:

- Recognition of foundation conditions suitable to or demanding deep penetration. Penetration of at least 15 feet below scour level, or into soft rock, should be assured.
- Choice of material. Timber is suitable for very dry or very wet climates, for other situations economic comparison of preliminary designs and alternative materials should be made.
- Determination of line and grade. Fairly smooth transitions with protection to high-water level should be provided.

(4) Sea Walls. Sea walls are structures, often concrete or stone, built along a portion of a coast to prevent erosion and other damage by wave action. Seawalls can be rigid structures or rubble-mound structures specifically designed to withstand large waves. Often they retain earth against the shoreward face. A seawall is typically more massive and capable of resisting greater wave forces than a bulkhead. Index 6.1 of HEC 25, Volume 1 provides several examples of seawall designs.

(5) Groins. A groin is a relatively slender barrier structure usually aligned to the primary motion of water designed to trap littoral drift, retard bank or shore erosion, or control movement of bed load.

These devices are usually solid; however, upon occasion to control the elevation of sediments they may be constructed with openings. Groins typically take the following forms of construction:

- Rock mound.
- Concreted-rock dike.
- Sand filled plastic coated nylon bags.
- Single or double lines of sheet piling.

The primary use of groins is for ocean shore protection. When used as stream channel protection to retard bank erosion and to control the movement of streambed material they are

normally of lighter construction than that required for shore installation.

In its simplest or basic form, a groin is a spur structure extending outward from the shore over beach and shoal. A typical layout of a shore protection groin installation is shown in Figure 883.2J.

Assistance from the U.S. Army Corp of Engineers is necessary to adequately design a slope protection groin installation. For a more complete discussion on groins, designers should consult Volume II, Chapter 6, Section VI, of the Corps' Shore

Protection Manual until Part VI of the Coastal Engineering Manual is published. Preliminary studies can be made by using basic information and data available from USGS quadrangle sheets, USC & GS navigation charts, hydrographic charts on currents for the Northeast Pacific Ocean and aerial photos of the area.

Factors pertinent to design include:

(a) Alignment. Factors which influence alignment are effectiveness in detaining littoral drift, and self-protection of the groin against damage by wave action.

A field of groins acts as a series of headlands, with beaches between each pair aligned in echelon, that is, extending from outer end of the downdrift groin to an intermediate point on the updrift groin, see Figure 883.2K. The offset in beach line at each groin is a function of spacing of groins, volume of littoral drift, slope of sea bed and strength of the sea, varying measurably with the season. Length and spacing must be complementary to assure continuity of beach in front of a highway embankment.

A series of parallel spurs normal to the beach extending seaward would be correct for a littoral drift alternating upcoast and downcoast in equal measure. However, if drift is predominantly in one direction the median attack by waves contributes materially to the longshore current because of oblique approach. In that case the groin should be more effective if built oblique to the same degree. Such an alignment will warrant shortening of the groin in proportion to the cosine of the obliquity, see Figure 883.2K.

Conformity of groin to direction of approach of the median sea provides an optimum ratio of groin length to spacing, and the groin is least vulnerable to storm damage. Attack on the groin will be longitudinal during a median sea and oblique on either side in other seas.

(b) Grade. The top of groins should be parallel to the existing beach grade. Sand may pass over a low barrier. The top of the groin should be established higher than the existing beach, say 2 feet as a minimum for moderate exposure combined with an abundance of littoral drift, to 5 feet for severe exposure and deficiency of littoral drift.

The shore end should be tapered upward to prevent attack of highway embankment by rip currents, and the seaward end should be tapered downward to match the side slope of the groin in order to diffuse the direct attack of the sea on the end of the groin.

(c) Length and Spacing. The length of groin should equal or exceed the sum of the offset in shoreline at each groin plus the width of the beach from low water (LW) to high water (HW) line, see Figure 883.2I. The offset is approximately the product of the groin spacing and the obliquity (in radians) of the entrapped beach. The width of beach is the product of the slope factor and the range in stage. The relation can be formulated:

$$L = ab + rh$$

Where:

L = Length of groin, feet

a = obliquity of entrapped beach in radians

b = beach width between groins, feet

r = reciprocal of beach slope

h = range in stage, feet

For example, with groins 400 feet apart, obliquity up to 20 degrees, on a beach sloping 10:1 with a tidal range of 11 feet,

$$L = 0.35 \times 400 + 10 \times 11 = 250\ feet$$

The same formula would have required L = 390 feet for 800-foot spacing, reducing the aggregate length of groins but increasing the depth of water at the outer ends and the average cost per foot. For some combination of length and spacing the total cost will be a minimum, which should be sought for economical design.

If groins are too short, the attack of the sea will still reach the highway embankment with only some reduction of energy. Some sites may justify a combination of short groins with light revetment to accommodate this remaining energy.

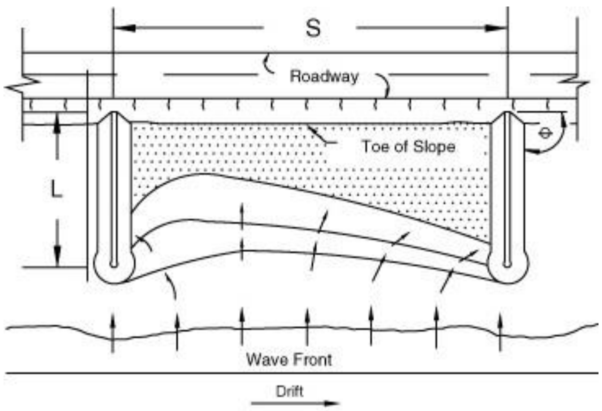
(d) Section. The typical section of a groin is shown in Figure 883.2L. The stone may be specified as a single class, or by designating classes to be used as bed, core, face and cap stones.

Face stone may be chosen one class below the requirement for revetment. Full mass stone should be specified for bed stones, for the front face at the outer end of the groin, and for cap stones exposed to overrun. Core stones in wide groins may be smaller.

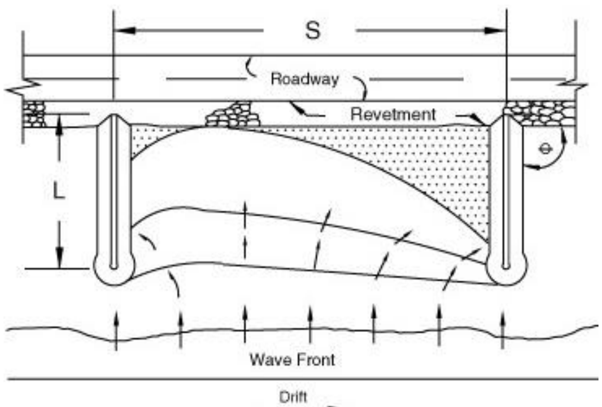
Width of groin at top should be at least 1.5 times the diameter of cap stones, or wider if necessary for operation of equipment. Side slopes should be 1.5:1 for optimum economy and ordinary stability. If this slope demands heavier stone than is available, side slope can be flattened or the cap and face stones bound together with concrete as shown in Figure 883.2L.

Figure 883.2J

Typical Groin Layout with Resultant Beach Configuration



Long Groins Without Revetment



Short Groins With Light Stone Revetment

NOTES:

"S", "L" and "θ" are determined by conditions at site.

Figure 883.2K

Alignment of Groins to an Oblique Sea Warrants Shortening Proportional to Cosine of Obliquity

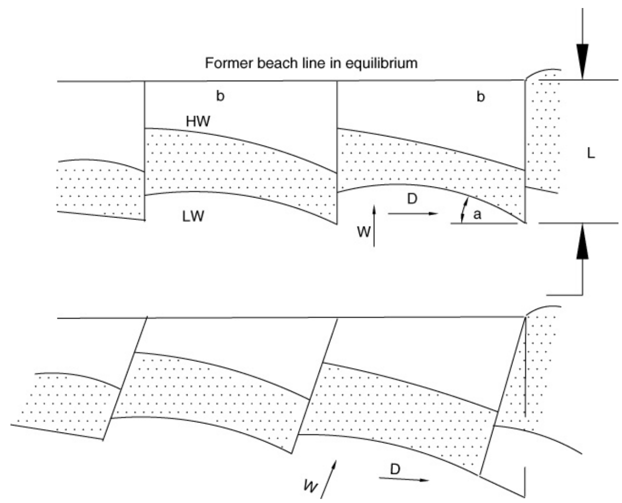
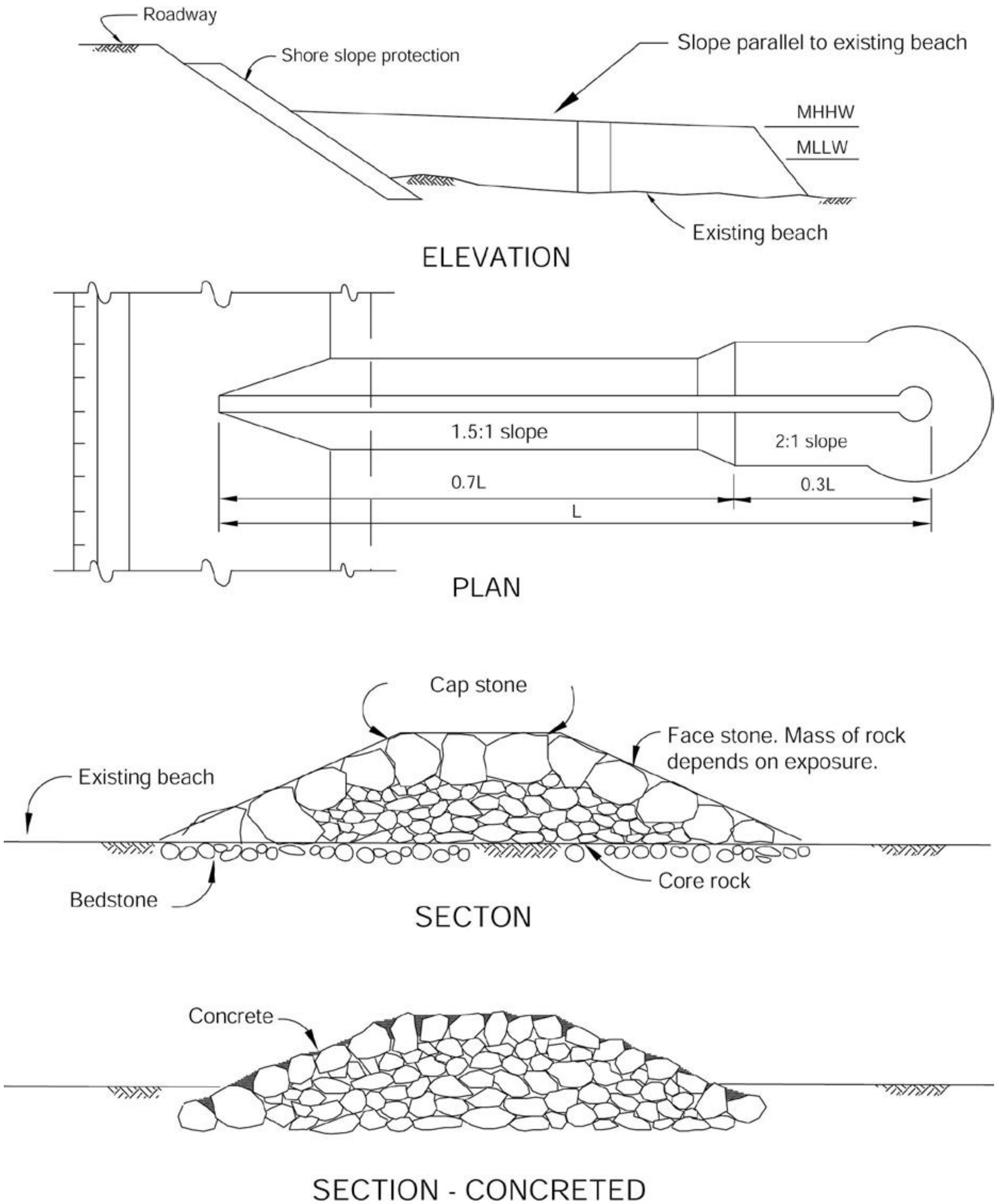


Figure 883.2L

Typical Stone Dike Groin Details



NOTES:

(1) This is not a standard design.

(2) Dimensions and details should be modified as required.

CHAPTER 900 LANDSCAPE ARCHITECTURE - ROADSIDES

Topic 901 – Landscape Architecture General

Index 901.1 - Landscape Architecture Program

The Landscape Architecture Program is responsible for the development of policies, programs, procedures, standards, and guidance for all aspects of the California Highway System Roadside Program including planting, irrigation, permanent erosion control, mainstreet livability, structure aesthetics, roadside safety features, and landform grading.

The Landscape Architecture Program also serves as the coordinator for Safety Roadside Rest Areas, Vista Points, Park & Ride facilities, Scenic Highways, Classified Landscaped Freeways, Blue Star Memorial Highways and Landscape Administration Facilities such as Transportation Art, Gateway Monuments, and Community Identification.

Guidance in the Chapter 900 series is the responsibility of the Landscape Architecture Program and represents minimum standards.

901.2 Landscape Architecture Design Standards

Design roadsides to maximize sustainability and livability benefits through context-sensitive design solutions. Sustainable design solutions are those that consider balanced and long-term benefits to social, economic, and ecological well-being.

Sustainable landscape architecture designs:

- improve safety for workers and travelers
- improve the quality of the public realm
- conserve water and natural resources
- sequester carbon and improve ecosystem resiliency
- address fire safety
- preserve or improve visual quality and aesthetics
- reduce unnecessary maintenance activities
- employ cost-effective solutions
- consider life-cycle costs and benefits.

Attention should be given to the following considerations:

(1) *Worker Safety.* Design roadsides for the safety of highway workers and the public by considering the following:

- Site new roadside features outside of the clear recovery zone and away from gore areas and driver decision points.
- Provide access for workers including maintenance vehicle pullouts, maintenance access roads and gates.
- Design solutions that facilitate the use of mechanical equipment to reduce worker activities on foot including the use of new technology.
- Select design solutions that eliminate maintenance activities.
- Relocate existing roadside elements to accessible areas outside the clear recovery zone or to protected locations.

Incorporate the above design considerations when designing roadsides. For example, provide access gates from local streets and frontage roads for maintenance personnel; coordinate with District Maintenance managers for preferred access points. Provide paved maintenance vehicle pullout areas away from traffic on high-volume highways where access cannot be made from local streets and roads. Consider providing maintenance access roads to the center of loop areas or other open, flat areas. Pave narrow areas and areas beyond freeway gore entrances and exits to reduce the need for maintenance. See Index 504.2(2) for contrasting surface treatment guidance.

(2) *Maintainability.* Field observations with maintenance personnel should be performed

during project development, Pre-PID through PS&E. Ongoing communication between designers, landscape specialists, landscape maintenance personnel, and construction inspectors will ensure that maintenance concerns are addressed.

Design roadsides to minimize routine and ongoing roadside maintenance and to accommodate:

- graffiti control and removal.
- homeless encampment removal.
- mowing and weeding.
- litter, debris, and/or dead vegetation removal.
- exotic or "volunteer" vegetation control.
- pesticide and/or fertilizer application.
- pruning or removal of vegetation.
- irrigation and waterline break repair.
- irrigation scheduling for water budgeting.
- replacement of plants and repairs to inert materials.
- maintenance requirements of permanent stormwater pollution prevention treatment BMPs.

(3) *Livability.* Livability describes the degree to which the built environment improves human quality of life. Designs that improve livability are those that consider how the public realm and roadside can support travel and local community goals. Livable transportation systems connect people to opportunity and promote public health and safety, ecological quality, economic development, community vitality, social equity and interaction, multimodal travel, sense of place, and human health.

Create a state highway public realm through designs that improve community visual quality, provide inviting public spaces, and encourage active transportation. Encourage and support Landscape Architecture Administered Facilities such as Transportation Art, Gateway Monuments, and Community Identification to enhance livability. Livable roadside facilities often include:

- connectivity of active transportation and complete streets facilities.
- site furnishings such as benches, bicycle racks, and trash and recycling receptacles.
- Street trees and other vegetation that provide shade and a separation for vehicles and pedestrians

(4) *Visual Quality and Aesthetics.* Design roadsides to integrate the facility with the adjacent community or natural surroundings. Buffer objectionable views of the highway facility from adjacent homes, schools, and parks. Soften visual impacts of large structures and graded slopes. Screen objectionable or distracting views. Frame or enhance good views. Provide visually attractive roadsides, entrances to communities, and mainstreets.

(5) *Ecological Function.* Design roadsides to incorporate native and climate appropriate vegetation, with attention to supporting pollinators, and facilitating stormwater infiltration on-site. Improve soil with compost to build healthy soils, sequester carbon and mitigate greenhouse gas emissions.

(6) *Water and Resource Conservation.* Roadsides must comply with State water conservation requirements including the Model Water Efficient Landscape Ordinance (MWELO). Comply with local water ordinances. In addition, design landscapes to conserve water by designing efficient irrigation systems and appropriate planting designs that:

- use non-potable or recycled water.
- use soil amendments to build healthy soils and increase water holding capacity.
- use drought tolerant, climate appropriate plants.

- use large groupings of spreading plants.
- use topical mulches to reduce evapotranspiration.
- use automated "smart" irrigation controllers.
- use moisture, wind, and rain sensors.
- use point source irrigation and tree well assemblies.
- minimize use of overhead irrigation.

(7) *Fire Safety.* Consider the risk of fire when designing landscape architecture projects. Consider the following in high fire risk areas:

- Create fire-resistant zones and defensible spaces to minimize the spread of wildfire
- Remove dead and dying vegetation
- Minimize or eliminate vegetative fire ladders
- Select plants with low sap or resin content and high moisture content
- Select plants with prostrate growth and minimal fuel volume
- Select nonflammable or low fuel inert materials for ground surface cover

(8) Cost-effectiveness. The design should maximize short and long-term benefits for the costs involved by:

- Optimizing scheduling, performance, constructability, maintainability, and material life cycle costs.
- Specify commercial/industrial quality materials and methods to improve cost-effectiveness.
- Utilize long-lived plant species.

901.3 Landscape Architecture Administered Facilities

Landscape Architecture administers local projects related to Transportation Art, Gateway Monuments, Community Identification, and Blue Star Memorial Highways. These projects are typically installed through an encroachment permit project.

When a project will impact an existing Landscape Architecture Administration Facility, coordinate with the local agency charged with maintaining the facility to move it if the facility cannot be preserved and protected. Refer to the LAP website and the PDPM for additional information.

Topic 902 – Sight Distance and Clear Recovery Zone Standards

902.1 Landscape Sight Distance and Clear Recovery Zone Standards

Three considerations affect the placement of new landscape features:

(1) Sight Distance. To keep the continuous length of highway ahead visible to the driver. Sight distances for safety surpass aesthetic considerations. Applicable minimum sight distance standards are set forth in Topic 201 - Sight Distance, and Topic 405 - Intersection Design Standards.

(2) Clear Recovery Zone (CRZ). To keep the CRZ free of discretionary fixed objects. Refer to Index 309.1(2).

(3) *Maintenance Access.* To provide worker access without the need for lane or shoulder closure to perform routine maintenance.

Topic 903 – Landscape Site Design

Landscape site design for roadsides involves landform grading and the placement of landscape elements, such as boulders, or other site furnishings for aesthetic or functional purposes.

903.1 Landscape Site Analysis

Landscape site analysis is the study of the site's ability to address Department, corridor, and project goals. Landscape site analysis identifies opportunities and constraints on the site that may have physical, social, fiscal or environmental impacts. Landscape site analysis helps evaluate competing needs and to determine which design decisions will bring the greatest return of investment. Emphasis should be given to design solutions which provide benefits in multiple areas, within a reasonable project schedule and life cycle cost.

Areas typically evaluated include:

- built features, such as existing infrastructure and adjacent land uses
- natural features, such as land form, slopes, soil type, erosion
- community characteristics that may influence design decisions, such as the presence of underserved communities, scenic highways, or other aspects
- travel conditions, such as multimodal access to connections and opportunities to include complete streets features
- existing visual quality and aesthetic conditions
- opportunities to improve livability on mainstreets

903.2 Landscape Site Layout

Landscape site design involves the layout of landscape architectural areas such as planting/irrigation areas, erosion control areas, inert landscape groundcovers and main street elements such as, pedestrian pathways, bicycle paths, tree grates, ornamental pedestrian paving, bus shelters, bollards, benches, tables, trash/recycling receptacles, and bicycle racks.

Landscape site design should start with site analysis that evaluates the optimum location for landscape areas. Consider natural drainage, natural landform, existing vegetation, slope, pedestrian and bicycle circulation patterns (existing and planned), microclimate and any other element that may affect the landscape site layout.

Layout landscape architectural elements to optimize existing site conditions and respond to site constraints.

903.3 Roadside Amenities

Inert landscape features or facilities, that are not necessary for the safety, maintenance, or operation of the highway may be considered discretionary fixed objects. See Index 309.1 for more information. Examples of these objects include but are not limited to boulders placed for decorative purposes, gateway monuments, and transportation art.

903.4 Additional Roadside Site Design Considerations

Consider site features and elements that minimize impacts to natural resources.

(1) *Low Impact Development.* Consider including low impact development features. Low Impact Development mimics natural processes to capture and infiltrate stormwater runoff.

(2) *Landscape Grading.* Integrate highway improvements into the existing environment using contour grading to preserve existing natural topographic features and plant material. Refer to Index 304.4 and 304.5.

Topic 904 – Planting Design

904.1 Planting Design General

Planting provides vegetation for aesthetic, environmental, mitigation, stormwater pollution prevention, and erosion control purposes. Successful planting requires soil that will provide an appropriate growing medium. Protection of existing vegetation, selection and location of the appropriate plant material, and an appropriate plant establishment period must be considered.

Planting contributes to climate resiliency with:

- carbon sequestration
- air quality benefits
- reduced fire risk
- heat island reduction
- habitat restoration
- revegetation
- stormwater treatment
- mitigation
- windbreak protection

Planting provides improvements to visual quality by:

- Integrating the highway into the local community
- graffiti reduction

- screening
- aesthetics

Ensure work within any existing Classified Landscape Freeway maintains the status of the Landscaped Freeway. Refer to the Business and Professions Code Sections 5216 and 5440.

In areas subject to illegal activities, provide open visibility to the roadside. In many areas, this may mean limiting landscape to planting trees and groundcover only.

Review the entire planting design with the District Coordinator, District Landscape Specialist, and Maintenance Landscape Supervisor.

904.2 Site Preparation

(1) *Preserve Existing Vegetation.* Preserving existing vegetation minimizes the disturbance of existing vegetation and soil. Preserving existing site vegetation is more effective at erosion control than removing and planting new vegetation. Where possible, minimize disturbed areas within areas impacted by construction. Consider temporary exclusionary fencing during construction to demarcate and retain significant existing vegetation.

(2) *Soil Health.* Healthy topsoil is needed to ensure successful vegetation establishment. The preservation of existing topsoil or amending poor topsoil is necessary to provide favorable growing conditions. Agronomic soil tests may be necessary to verify soil texture, pH, percent organic content, electrical conductivity, sodium content, the availability of Nitrogen, Phosphorus and Potassium, and other local soil deficiencies.

(a) *Preserve Existing Topsoil and Duff.* The best approach to soil health is to preserve the existing topsoil and duff.

Excavate existing soil and store, on-site during construction, and then replace it at select locations prior to seeding or planting. Care must be taken to ensure that topsoil stockpiles are protected and kept in an aerobic and de-compacted state. Stockpiles in shallow windrows planted with temporary hydroseed will preserve the native seed bank and beneficial microorganisms. Consider the use of exclusionary fencing and signage to identify topsoil stockpiles.

Duff is partly decayed organic matter such as leaves, bark, pine needles, and twigs which have fallen to the ground. Duff is removed along with existing plants and shrubs from an identified area during clearing and grubbing or roadside clearing operations. Duff is then chipped or ground, stockpiled, and reapplied after completion of final grading. Duff may be reapplied within one year of stockpiling. Consider using duff in natural areas where existing organic material is plentiful and preferred for revegetation success.

Mix preserved existing topsoil and duff to maximize natural and organic matter in the soil.

Coordinate with the Design Project Engineer, Environmental, Right of Way, and Construction for acceptable stockpile locations.

(c) *Amending Soil.* Soil amendments are necessary to improve water holding capacity, soil nutrient availability, microbial activity, and texture.

- *Compost.* Compost is manufactured through the controlled aerobic biological decomposition of biodegradable materials. Compost is used to improve soil health by increasing organic content, water holding capacity, and adding nutrients. When feasible, use compost in lieu of fertilizer.
- *Organic Mulch.* Typically, mulch is comprised of tree bark, wood chips, pine needles, shredded bark, or a combination of these.

(d) *Imported Topsoil.* When there is insufficient topsoil, preserving topsoil is infeasible, or the existing topsoil is not able to support vegetation establishment, imported topsoil may be considered. Imported topsoil is obtained from outside the project limits.

(e) *Soil Texture Rehabilitation.* Improve soil texture when compaction restricts air or water movement and inhibits vegetation growth.

- *Cultivation.* Soil can be cultivated or ripped to de-compact the soil.
- *Incorporate Materials.* Incorporate materials is the process of tilling topsoil with amendments. It improves soil health by providing nutrients and biotic activity for vegetation growth and establishment. Use incorporate materials to increase infiltration or when existing soils are compacted or low in nutrients.

904.3 Plant Selection

Plants should be well suited to local environmental conditions such as sun exposure, aspect, climate, annual precipitation, temperature extremes, wind, soil type, and recycled water quality.

Plants should be selected for their anticipated ability to adapt to changing climatic conditions such as extreme temperature, wind or other weather events.

Select plants with a growth rate, longevity, size, and appearance appropriate for their intended use. Select plants that minimize ongoing maintenance requirements.

Select drought tolerant plants that will survive if supplemental water is discontinued. To minimize the risk of pest and disease infestation, select a diverse mix of plant species. Consider using no more than 33 percent of one species.

Whenever possible, select native plant species. Include species with a wide range of bloom times to enhance pollinator habitat.

Consider carbon sequestration rates of species selected.

In fire prone areas select plants that will minimize fire risks. Refer to local fuel modification plans for recommended plants for the specific area.

When selecting plants also consider species availability.

Landscaping projects with federal funding shall include California native wildflowers and grasses in the planting design. Refer to Chapter 29 of the Project Development Procedures Manual for wildflower requirements.

To ensure maintainability of plant selections, consult with your District Landscape Specialist, and Maintenance Landscape Supervisor.

(1) *Tree Selection.* When proposing large trees, the mature size, form, and growth characteristics of the species should be considered. Select tree species that will not require regular pruning at maturity to maintain clearances. Review species selections with the District Landscape Specialist and Tree Crew Supervisor.

(2) *Other Considerations.* Consider avoiding:

- short lived plant species
- restricted plants listed as noxious or invasive on the Federal or California Noxious Weed List managed by the U.S. Department of Agriculture (USDA) or the California Invasive Plant Inventory Database managed by the California Department of Fish and Wildlife (CDFW).
- restricted plants by the State or local County Agriculture agencies for agricultural purposes.
- plants with edible or attractive fruits, berries or nuts.
- plants with thorns or stiff branches that may capture litter.
- plants that are known to be poisonous to humans and animals.
- trees that may be brittle, susceptible to disease, or that increase in size by suckering.

904.4 Locating Plants

Locate plants as appropriate for the adjacent existing or planned environment. Arrange plants to be visually and culturally compatible with local indigenous plant communities.

Place plants according to the perspective of the viewer and their traveling speed. For example, compositions viewed by freeway motorists should be simplified and large scale. Compositions primarily viewed by pedestrians may be designed with greater detail.

Plants with similar water requirements are to be grouped together to conserve water.

Wherever feasible, trees should be used to create the main structure of the planting composition.

Median planting should not be installed on freeways. See Index 305.1(2) for median guidance on conventional highways.

Planting must not interfere with the function of safety devices (e.g., barriers, guardrail), traffic control devices (e.g., signals and signs), shoulders, utilities and facilities.

In areas subject to frost and snow, plantings should not be located where they will cast shade and create patches of ice on vehicle and pedestrian thoroughfares.

Without exception, locate plants to maintain visibility to legal off-premise and on-premise outdoor advertising displays. Typical visibility viewsheds are as shown in the Encroachment Permits Manual 509.4.

(1) Maintenance Considerations. Consider the safety of maintenance workers and the traveling public when locating plants. Evaluate the mature size, form, and characteristics of the species, and long-term maintenance requirements.

Locate plants so that pruning will not be required.

Groundcover should be located so it will not extend onto shoulder backing, into drainage channels, or through fencing.

Minimize worker exposure to traffic and reduce the need for shoulder or lane closures. Locate vegetation away from shoulder, gore, and narrow island areas between ramps and the traveled way to reduce the need for shoulder or lane closures to perform pruning or other maintenance operations.

Refer to the Maintenance Manual and Roadside Vegetation Management Handbook for additional considerations.

904.5 Locating Trees

Trees must be located to not visually restrict existing roadside signs and signals.

Locate trees to maintain a minimum vertical clearance of 17 feet from the pavement to the lower foliage of overhanging branches over the traveled way and shoulder. Locate trees to maintain a minimum vertical clearance of 8 feet from sidewalks or walkways to the lower foliage of overhanging branches for pedestrian passage.

For sidewalks and pedestrian plazas, design tree wells with a minimum of 2 feet from the tree trunk to the edge of the tree well to protect pavement from tree root displacement. Include root barriers to protect the pavement surrounding the tree well. Allow for an appropriate soil volume when designing tree wells.

Without exception, do not plant large trees over gas lines or under overhead utilities and/or structures. Coordinate with local utility provider or District Utility Engineering for guidance.

(1) Large Trees. Large trees are defined as plants which at maturity have trunks 4 inches or greater in diameter, measured 4 feet above the ground. Examples of large tree species are Coast Redwood (*Sequoia sempervirens*), Coast Live Oak (*Quercus agrifolia*), and Deodar Cedar (*Cedrus deodara*).

(2) Small trees. Small trees are defined as smaller trees or plants usually considered shrubs but trained in tree form that will develop up to a 4-inch diameter trunk at maturity. Examples of small trees are Crape Myrtle (*Lagerstroemia indica*), and Bottlebrush (*Callistemon sp.*) trained in standard form.

(3) Clear Recovery Zone (CRZ). Locate trees to be outside the CRZ. The CRZ provides an area for errant vehicles the opportunity to regain control. Refer to Index 309.1(2) for additional information and requirements of the CRZ.

Setbacks are measured from the edge of traveled way to the face of tree trunk. Situate trees to accommodate the anticipated mature tree size.

(a) Freeways and Expressways. On freeways and expressways, including interchange

areas, there should be 40 feet or more of clearance between the edge of traveled way and large trees; but, a minimum clearance of 30 feet must be provided where trees may become a fixed object to errant vehicles. However, large trees may be planted within the 30-foot limit if they cannot be reached by an errant vehicle. For example, on cut slopes above a retaining wall, in areas shielded behind concrete barriers, metal beam guardrail, thrie beam, etc. which has been placed for reasons other than tree planting. Additionally, exceptions to the 30-foot setback may also be considered on cut slopes which are 2:1 or steeper The minimum tree setback in these cases should be 25 feet from the edge of traveled way.

Special considerations should be given to providing additional clearance in potential recovery areas. Setback distances greater than 30 feet should be provided at locations such as on the outside of horizontal curves and near ramp gores.

Large trees should not be planted in unprotected areas of freeway medians or expressway medians except for separated roadways with medians of sufficient width to meet the plant setback requirements for tree planting.

(b) *Conventional Highways.* When locating large trees on conventional highways comply with the requirements in Table 904.5.

904.6 Locating Plants in Conformance with Sight Distances

Sight distance requirements restrict the height of plants or the horizontal distance of plants from the traveled way. Low growing plants may be planted if the requirements for sight distance are met as discussed in Topic 201 – Sight Distance. Locate plants to maintain sight distance.

When locating plants, preserve views of pedestrians and bicyclists at intersections and other conflict points.

Sight distance limits are measured from the edge of traveled way to the outside edge of the mature growth. Locate plants to meet sight distance requirements when the plant reaches mature size.

Refer to Index 405.1(2) for corner sight distance requirements at intersections and driveways.

Proposed mature planting should maintain sight distance required by the design speed of the facility. In cases where, due to geometric restrictions, the existing freeway facility does not provide optimum sight distance, no further reduction should be caused by planting.

When locating plantings at interchanges, provide ramp and collector-distributor road sight distance equal to or greater than that required by the design speed criteria. A minimum provision of sight distance of 40 miles per hour should always be maintained. At points within an interchange area where ramp connections or channelization are provided, keep plantings clear of the shoulders and sight line shown in Figure 504.3I, Location of Ramp Intersections on the Crossroads.

Ensure clear recovery and sight distances are retained for vehicles, bicycles and pedestrians on the inside of curves in interchange loops, in median areas, on the ends of ramps, and on cut slopes. Generally, in interchange areas, a 50-foot horizontal clearance from the edge of traveled way, within the loops, is considered the sight distance plant setback for plants that grow above a 2-foot height.

904.7 Vine Planting

(1) *Vine Planting on Barriers.* Vine planting should be considered with all noise barriers to reduce the potential for graffiti and to soften the appearance of the barrier. If retaining walls or noise barriers are located within the clear recovery zone (see Index 309.1(2)), plants may be placed behind the walls and be allowed to grow over (or through) the barrier, plants placed in front of a noise barrier must be behind a safety shaped barrier. Plants are not permitted on concrete safety shaped barriers unless an exception is granted from the Division of Traffic Operations and all the following requirements are met:

- Only vines which have a natural tendency to cling to noise barriers or retaining walls may be planted on barriers. Support structures on barriers

Table 904.5

Large Tree Setback Requirements on Conventional Highways

ROADSIDE[2]		
Condition	Posted Speed (mph)	
	≤ 35	≥ 40
With curb	18" min. from curb face, without exception	30'min. from ETW, and 18" min. from curb face, without exception
With barrier	Min. deflection distance from barrier face (barrier type specific), and 18" min. from face of barrier, without exception	
Without curb or barrier	30' min. from ETW	
MEDIAN[1], [2]		
Condition	Posted Speed (mph)	
	≤ 35	≥ 40
With curb	5'min. from curb face, and 18" min. from curb face, without exception	30' min. from ETW, and 18" min. from curb face, without exception
With barrier	Min. deflection distance from barrier face (barrier type specific), and 18" min. from face of barrier, without exception	
Without curb or barrier	30' min. from ETW, without exception	

Notes:

(1) Trees in the median should be located at least 20 feet from manholes.

(2) Place trees in accordance with sight distance criteria.

are prohibited. Vine species selected must readily adhere to the barriers. Do not select vines with a habit of peeling off hard surfaces at maturity.

- Each plant should be individually irrigated.
- Plants should not encroach onto the shoulder or create sight distance problems.

Consult with the District Landscape Specialist and Maintenance Landscape Supervisor when considering planting vines on barriers. See Index 1102.7 for maintenance considerations in noise barrier design.

(2) *Planting of Vines on Bridge Structures.* Vines should not be planted where they might grow over any portion of the bridge structure. When the regular inspection of bridge structures is required and where rapid visual inspection of these structures is required in areas of high seismic activity, the planting of vines on bridge structures or columns is prohibited, without exception. There are certain conditions such as low average daily traffic, high redundancy in the substructure, etc. where exceptions from Structure Maintenance may be granted to plant vines.

904.8 Planting in the Vicinity of Airports and Heliports

All plants selected must comply with the height restriction standards contained in Topic 207 – Airway-Highway Clearances. Mature plant height must be used to determine if there is an obstruction to navigable airspace.

904.9 Plant Establishment

Plant Establishment is the period of time necessary that allows newly installed plant material to reach a state of maturity and ensures the operability of the irrigation system, to minimize future maintenance. The plant establishment period typically includes the following:

- replacement of dead or damaged plant material
- weed, rodent, and pest control
- litter removal
- irrigation operation and repair
- activities required to ensure the long-term survival of plant material

Depending on the type of project, there may be different requirements for plant establishment.

For Highway Planting within the right-of-way of all federally funded highways, plant establishment periods must be of a sufficient duration for establishment within the highway environment. This period is used for identification and resolution of problems, and to minimize long-term maintenance requirements.

Provide a three-year plant establishment period, if planting is installed with a highway construction project, otherwise provide a one-year plant establishment period.

<u>Projects with less than 5,000 square feet of planting or irrigation should have a plant establishment period of at least six months.</u>

Mitigation planting may require longer plant establishment periods. Refer to specific permit requirements.

Topic 905 – Irrigation Design

905.1 Irrigation Design General

Irrigation systems should be designed to conserve water, minimize maintenance, minimize worker exposure to traffic, and sustain the planting. The design should be simple and efficient.

Irrigation systems that use recycled, non-potable, or untreated water must comply with State and local regulations.

Permanent irrigation systems are to be designed for automatic operation.

Review the entire irrigation design with the District Water Manager, District Landscape Specialist, and Maintenance Landscape Supervisor.

905.2 Water Supply

Use recycled or non-potable water for permanent irrigation systems. Designers should be familiar with the provisions of the California Streets and Highways Code, Section 92.3.

When the irrigation system is being installed as part of a separate contract install the water supply connection with the parent highway construction project.

Temporary irrigation systems may use potable water.

Coordinate water connections with the local water purveyor, follow water purveyor requirements for MWELO requirements, water meters, and cross contamination requirements.

905.3 Irrigation Conduit

Irrigation Conduits should be provided on Highway Construction Projects under new roadways and ramps, and on new Bridge Structures when future irrigated planting is anticipated. Extend existing conduits, as needed, on highway construction projects when widening or modifying roadways and ramps or modifying Bridge Structures.

Irrigation conduit consists of a conduit with a water supply line and sprinkler control conduit with a pull tape.

Coordinate with the District Landscape Architect to determine irrigation conduit needs, sizes, and locations.

(1) *Conventional Highways, Freeways, and Expressways.* Consider the following when sizing and locating irrigation conduits under roadways or ramps:

- Irrigation conduit consists of a minimum size of 8-inch DN conduit, with a 3-inch water supply line and a 2-inch DN sprinkler control conduit with pull tape. Consider sizing conduits and water supply lines larger when using nonpotable water.
- Irrigation conduits are typically spaced 1,000 feet apart on freeways. Consider using undercrossings for alternative crossing opportunities.
- Keep drainage facilities and irrigation conduit separate.

(2) *Bridge Structures*

Coordinate with Structures for location and placement of irrigation conduit in new bridge structures.

Consider the following when designing irrigation conduits for Bridge Structures:

- Generally, locate the irrigation conduit on the side of the bridge closest to the water source.
- Consider the maximum water demand and number or irrigation controller stations. The water supply line should be a minimum 3-inch DN and conduit for the sprinkler control conduit should be a minimum 2-inch DN and contain a pull wire.
- Ductile iron pipe is required for potable water supply line for pipes 4-inch DN or larger because of its superior strength and flexible joints.

905.4 Irrigation System Equipment

Use standard, commercially available irrigation components. Nonstandard features may be used to address unique site conditions.

Select "smart" irrigation equipment and controllers to minimize worker exposure and conserve water.

Consider security measures, such as locking cabinets, enclosures and valve boxes.

When selecting irrigation components, consider water quality, such as sediment, salinity, and increased particulate content often found in recycled, and non-potable water sources. Include an appropriate filtration system when the recycled water quality contains undesirable suspended particles.

Place irrigation components that require regular maintenance as far from traffic as possible, outside the clear recovery zone, or behind safety devices. Place irrigation components in areas easily accessible by maintenance forces.

Consider potential damage from pedestrians or vehicles when locating irrigation equipment. Minimize exposure to traffic and reduce the need for shoulder or lane closures, irrigation equipment must be located far away from shoulder areas, gore areas, driver decision points, and narrow island areas between ramps and the traveled way.

Review the proposed location of backflow preventers and irrigation controllers in the field with the District Maintenance Supervisor and the District Water Manager.

(1) *Backflow Preventer Assembly.* The use of a reduced pressure principle backflow device is required for permanent irrigation systems using potable water. Include an enclosure with backflow preventer assemblies.

Use master remote control valves directly downstream of the backflow preventer assembly.

(2) *Booster Pump System*. When water pressure is insufficient, a Variable Frequency Drive (VFD) booster pump may be required in the irrigation design. Determine booster pump specifications by conducting calculations to determine the horsepower and electrical power input requirements. Coordinate with Division of Engineering Services Office of Electrical, Mechanical, Water and Wastewater Engineering. If necessary, consult with an irrigation pump manufacturer for assistance.

Coordinate with the District Electrical Design and Maintenance field personnel to coordinate power supply specifications and location.

(3) *Irrigation Controller.* Use the district specific "smart" irrigation controller that automatically adjusts water application rates based upon weather conditions. Include a vandal resistant cabinet. Coordinate with the District Maintenance Water Manager for irrigation controller information.

Locate irrigation controllers where they are easily accessible, protected from vehicular traffic, and in an area away from shoulders. Locate the irrigation controller cabinet so maintenance personnel will be able to see oncoming traffic in the nearest traffic lane when accessing the controller. Locate controllers away from dense shrubbery, in an area with good lighting, and out of the spray from sprinklers.

(4) *Sprinklers.* Select sprinklers appropriate for local wind and soil conditions. Include swing joints with sprinklers. Consider check valves, flow shutoff devices and other water conservation measures when selecting sprinklers. Install sprinklers on fixed risers only in areas away from the roadway.

Overhead irrigation systems should be limited to irrigating low shrub masses, ground cover or establishing native grasses.

Individually water trees and shrubs spaced farther apart than 10 feet on center. Trees in overhead irrigated ground cover areas should receive basin water with a separate irrigation valve using tree well assemblies.

When possible, locate sprinkler heads outside the clear recovery zone. Design irrigation to spray towards the roadway, but not on the pavement. Protect sprinklers by locating them away from areas where damage from vehicles, bicyclists, or pedestrians may take place.

(5) *Flow Sensor.* Select a flow sensor that can be used in conjunction with the irrigation controller and has capability to monitor low flow, excess flow, and communicate learned flow to the irrigation controller.

(6) *Valves.* Select industrial grade plastic valves to deter theft.

Remote control valves, including master valves should be normally closed to minimize water loss if a break occurs.

Cluster remote control valves and consolidate manifolds whenever possible. Install a ball valve or gate valve up stream of the manifold.

Locate valves adjacent to access paths or in locations accessible from outside the right of way via access gates.

Install gate valves on each side of irrigation conduits. To minimize the risk of water hammer do not use ball valves at irrigation conduits.

(7) *Sprinkler Protectors.* Use sprinkler protectors around pop-up sprinklers and quick coupling valves adjacent to the roadway, bicycle paths, or walkways and sidewalks.

905.5 Temporary Irrigation

Native and drought tolerant plants may require temporary irrigation for successful establishment. Consider using a temporary irrigation system if establishment of non-irrigated vegetation will be difficult.

Manual, battery, or solar operated valves and controllers may be used when systems are temporary.

The use of drip irrigation systems or on grade irrigation system may be considered with a temporary irrigation system.

Temporary irrigation systems should be removed once they are no longer needed.

Topic 906 – Erosion Control

906.1 Erosion Control General

Permanent erosion and sediment control are required when surface soils are disturbed by construction activities. Erosion control prevents erosion by water, wind, or gravity from moving soil particles away from their original location.

Establishing non-irrigated vegetation is the preferred permanent erosion control measure. Permanent erosion control is accomplished with a combination of soil surface protection (mulches and blankets) and planting techniques.

Steep slope applications and stormwater treatment biofiltration areas may require the application of specialized techniques to ensure the establishment of permanent erosion control.

Sediment control is the interception of eroded soil particles from moving offsite when they become dislodged. Sediment control is accomplished by installing interruption devices on slopes and at concentrated flow locations. Examples include fiber rolls and check dams.

Refer to the LAP website Erosion Control Toolbox and the California Stormwater Quality Handbook: Project Planning and Design Guide (PPDG).

906.2 Soil Surface Protection

Soil surface protection is a necessary component of the erosion control strategy to ensure that soil is protected.

Soil surface protection includes application of the following measures:

(1) *Organic Material:* Locally obtained or imported organic material applied to the soil surface. Duff, wood chips, and mulch applied topically.

(2) *Inorganic Material:* Inert mulches such as rock gravel can be applied to protect soil surface erosion.

(3) *Straw:* Natural fiber stalks from wheat, rice, or native grasses applied to the soil surface. Straw may be stabilized mechanically (punched straw) or with hydromulch and tackifiers.

(4) *Hydraulic Erosion Control Products (HECPs):* Temporary, degradable, pre-packaged fibrous mulch materials which are mixed with water into a slurry and hydraulically applied to the soil surface. HECPs include hydromulch, and bonded fiber matrix (BFM), and other hydraulically applied materials.

(5) *Rolled Erosion Control Products (RECPs):* RECPs are a blanket that is typically an open weave, degradable material composed of processed natural (jute mesh) or polymer yarns woven into a matrix. RECPs may be applied to the soil surface where vegetation alone will not sustain expected flow conditions and/or provide sufficient erosion protection. RECPs include netting, blanket, and turf reinforcement mat (TRM).

Short term cover measures are intended as transitional soil protection until establishment of vegetation is achieved. Short term cover includes organic material, straw, hydromulch, RECP (Blanket), and RECP (Jute Mesh). Short term cover generally lasts between 1 and 18 months.

Long term cover measures provide immediate and long-term erosion protection where establishing vegetation may be difficult. Long term cover includes RECP (Netting), RECP (Blanket), and RECP (Turf Reinforcing Mat). Long term cover generally lasts 24 months.

906.3 Planting

Planting for erosion control purposes is typically accomplished with seeding, liner plants, seedling plants, and/or native grass sod. Coordinate with the District Biologist to determine specific permit requirements. Contract growing of site specific and genetically appropriate plant materials may be required.

Seeding. Do not specify seeds that have a short shelf life. Seeds may be applied as hydraulically applied seed, drill seed, or dry seed.

(1) *Hydraulically applied seed*. This method uses hydroseed equipment to mix seed, fiber, tackifiers, and/or other materials with water into a slurry which is hydraulically applied to the soil surface. Hydromulch and bonded fiber matrix are HECPs used to hydraulically apply seed. Consider hydraulically applied seed for slopes 2:1 or flatter and larger than half an acre.

(2) *Drill Seed*. This method involves sowing seed into the soil using a drill seeder. Consider this method in areas 3:1 or flatter due to drill seeding equipment limitations. This method should not be used to provide temporary cover.

(3) *Dry Seed*. This method applies seed and amendments by hand to small areas. Consider this method in areas less than half an acre.

(4) *Liner and Seedling Plants*. Consider using small nursery grown perennial and woody plants for erosion control and mitigation purposes. These are usually native species. Liners are containerized. Seedlings are bare root without a container.

(5) *Native Grass Sod*. Consider using native grass sod whenever immediate and complete plant coverage is required. Consider the use of native grass sod in biofiltration strips and swales or for low impact development water quality control projects. Consider including temporary irrigation with native grass sod.

(6) *Brush Layering.* Consider brush layering when there is adequate soil moisture for the cuttings to grow; use temporary irrigation when brush layering is not installed near a seep, spring or waterway. Locally harvested cuttings from existing cottonwood or willow stands either on site or from an adjacent site are embedded in horizontal layers parallel to the contours of a slope. Consider using in areas 2:1 or flatter. Consult with Geotechnical for slopes steeper than 2:1.

906.4 Sediment Control

Linear sediment controls are utilized to slow and spread runoff, reduce concentrated flow, and limit the movement of sediment. Linear sediment control products are manufactured 3-dimensional tubes of a specified filler material encapsulated within a flexible containment material.

(1) *Fiber Roll*. Consider placing fiber rolls on the contour of the slope. Place along slope faces at regular intervals to minimize sediment loss while permanent vegetation is becoming established.

(2) *Compost Sock*. Consider placing compost socks on the contour of the slope. Place along slope faces at regular intervals to minimize sediment loss while permanent vegetation is becoming established. Compost socks will also provide biofiltration and organic content to the existing soil.

906.5 Permanent Erosion Control Establishment

Permanent Erosion Control Establishment (PECE) extends the contract period beyond the completion of the highway construction phase requiring the Contractor to be available to perform permanent erosion control repairs prior to "Contract Acceptance." This ensures that adequate vegetation cover and slope stabilization is attained prior to construction contract acceptance.

Having the Contractor available during the PECE period will hasten any repair work that may be needed, such as after severe weather events, and will reduce the workload on the Maintenance Division. PECE provides an additional 250 working days after completion of all other construction activity to assess the success of the erosion control work and meet the project's slope stabilization goals.

Include Permanent Erosion Control Establishment when slopes are steeper than 2:1, where poor soil conditions may inhibit vegetation establishment, erosion control elements are expected to need maintenance while vegetation is being established during construction, or there is the potential of direct discharge of sediment into 303D listed receiving waters.

CHAPTER 910
LANDSCAPE ARCHITECTURE – ROADSIDE SITES

Topic 911 - General

Index 911.1 Roadside Sites General

The guidance in this chapter refers directly to roadside sites such as Safety Roadside Rest Areas, Vista Points and Park & Ride facilities. Design requirements for roadside site Planting, Irrigation, and Erosion Control can be found in Chapter 900.

Topic 912 – Roadside Sites Design

Landscape site design for roadside sites involves landform grading, building and structure placement, parking design, and the placement of landscape elements, such as boulders or other site furnishings for aesthetic or functional purposes.

912.1 Roadside Sites Layout

Landscape site features and elements should be designed to minimize impacts to natural resources. Buildings, roads, parking areas, shade structures, amenities, and associated earthwork define the site layout. Building locations, roads and parking areas should be arranged to fit the terrain, views, site constraints, and opportunities. If the site has few physical constraints, roads and parking areas should be designed with generous curves and curvilinear parking. Keep pedestrian and parking circulation separate. If the site is heavily wooded, roads and parking should be designed to retain existing trees and tree groupings.

Design roadside sites with adequate lighting, accessible walking surfaces, and open visibility through the site to provide adequate pedestrian security.

(1) *Low Impact Development* Consider including low impact development features. Refer to Index 903.4(1).

(2) *Site Grading.* Grading designs should integrate the required development with as little disturbance to the site as practical. Grading should be harmonious with natural landforms and follow the direction of existing slopes and drainage patterns. Cuts and fills should be shaped and rounded to blend with existing land forms, and the designed terrain should complement the layout of parking areas and sidewalks.

(3) *Ingress, Egress and Circulation.* Vehicular ingress, egress, and circulation should be simple, direct and obvious to the traveler. See Topic 403 – Principles of Channelization.

Travelers entering a site should be directed to the proper parking area for the type of vehicle driven-automobiles (cars, vans, motorcycles), bicycles, or long-vehicles.

Where practical, provide ample ramps and transitions, good sight distance, and well-placed signs and pavement markings preceding the point where vehicle types separate. Place potential distractions (non-traffic-control signs, plantings, vehicle pullouts, dumpsters, etc.) after this point.

Consider the speed and angle at which the various traffic types (long vehicle traffic, bicycle, and automobile traffic) will merge prior to egress. Avoid configurations where one type of traffic can gain excessive speed preceding a merge with slow moving traffic.

Curvilinear road layout, narrow road width and placement of landscape elements can be used to manage traffic so that merging is done at slow and similar speeds.

The design of roads, aisles, parking spaces and parking lot islands should ensure that commercial truck maneuvers can be accommodated without damage to curbs, sidewalks, pavement edges, or parked vehicles. See Topic 404 – Design Vehicles, for truck and bus turning template guidance.

Maintain clear sight lines for all users when locating planting, signs, and other landscape elements.

Provide paved service roads to allow access for maintenance and service to facilities and to protect vegetation, soil and water quality. Service roads should be 10 feet to 12 feet wide.

(4) *Roadway Connections.* The design of roadway connections to roadside sites should be in accordance with Index 107.1.

Roadside sites designed for freeways shall have standard freeway exit and entrance ramps, in accordance with Chapter 500. Roadside sites on expressways and conventional highways should be designed with standard public road connections and median left-turn lanes, according to Topic 405 – Intersection Design Standards.

Projects to rehabilitate or modify existing ramps, roads, and parking lots should address any requirements to upgrade geometrics to current design standards.

The District Design Liaison should be involved in reviewing the geometric features for the design roadway connections for a roadside site.

Consider including a gate at roadway connections for roadside installations if temporary closures will be required.

(5) *Pedestrian Circulation.* Walkways should be a minimum of 10 feet wide. When possible, make grade changes with ADA accessible slopes and avoid steps. Sidewalks in front of automobile parking spaces should be a minimum of 12 feet wide to compensate for the overhang of automobiles or provide wheel stops. Locate primary walkways that direct users from automobile, bicycle, and long-vehicle parking areas to facilities.

Clearly defined accessible paths of travel to restrooms, picnic shelters, picnic tables, benches, drinking fountains, telephones, vending machines, information kiosks, interpretive displays, and viewing areas are required. The path of travel from designated accessible parking to accessible facilities should be as short and direct as practical, must have an even surface, and must include curb ramps, marked aisles and crosswalks, and other features as required to facilitate circulation of visitors with wheelchairs, walkers and other mobility aids.

See DIB 82 for further information on accessibility requirements.

The Division of Engineering Services, Structures Design – Office of Transportation Architecture should be consulted when proposing aesthetic treatments to pedestrian features.

912.2 Parking Area Design

Parking areas should be designed to encourage orderly traffic movement and parking.

Parking facilities are to be designed accessible to all modes of travel and are to conform to California MUTCD and DIB 82 guidance. See Table 912.2. Designated accessible parking spaces must be provided for automobiles and vans.

Parking areas should be well defined and include the use of concrete curbs and striping, where appropriate.

(1) *Low Impact Development.* Include low impact development features, such as porous pavement, curb cut outs, planted bio-strips, planted bioswales, cisterns, or other types of low impact development, into the parking area design to treat stormwater runoff from paved parking surfaces. Refer to Index 903.4(1).

(2) *Shade Requirements.* Include planting and irrigation for shade trees, when appropriate. Design tree planting areas to shade auto parking areas. Provide 50% shade within 15 years on all impervious driving surfaces (including parking stalls and all driving and maneuvering areas within the parking area.) Trees may receive 25%, 50%, 75% or 100% shade credit based on planted location and the amount of canopy shading paved surfaces. Shade overlap is not counted twice. Follow Planting and Irrigation requirements in Topics 904 - Planting Design and 905 - Irrigation Design.

(3) *Pavement.* Pavement for parking should be designed in accordance with Chapters 600 through 670. Parking lots may be constructed of flexible or rigid pavement. Rigid pavement has the advantage of being resistant to deterioration from dripping fuel and antifreeze. Consider the use of pervious pavement.

Table 912.2
Vehicle Parking Stall Standards

Vehicle Type	Min Stall Width (ft)	Aisle Width (ft)	Aisle Location
1 Auto	9	5	Passenger side
2 Autos	9	5	Between stalls
1 Van	9	8	Passenger side
1 Van/ 1 Auto	9	8	Between stalls
1 long vehicle	12	8	Passenger side
2 long vehicles	12	8	Between stalls

912.3 Site Furnishings

Amenities including trash and recycling facilities, pedestrian signs, pet areas, drinking fountains, shade structures, kiosks, benches, seat walls, bicycle racks, picnic tables, and other site appropriate features should be included. Landscape areas should be provided and may include areas for monuments, artwork, interpretive facilities, and informal exercise and play facilities.

Pedestrian amenities must be designed and constructed to be accessible to persons with disabilities in accordance with all applicable State and Federal law.

(1) *Bicycle Facilities at Roadside Sites.* Where bicycling is allowed, bicycle parking should be considered at roadside sites. Bicycle parking should be in an open area. Consult the District Bicycle Coordinator for information on placement, capacity, and design requirements for bicycle parking.

(2) *Signage.* Non-traffic signs may be of customized design, provided they are easy to maintain or replace should they be damaged or stolen.

(a) *Required Signage.* Place standard reflectorized signs along the roadside to inform and direct travelers as they approach roadside sites.

Directional, regulatory, and warning signs must conform to the California MUTCD.

(b) *Interpretive Areas.* Provide interpretive displays and signage within the pedestrian area of roadside sites. The display or sign should be appropriate to the site in design and content and should be accessible; see DIB 82 for exhibit guidance. Display structures or signs should blend into the site, and be placed at the proper location for viewing the attraction.

Information should pertain to local environmental, ecological, or historical features. It should inform the public while inspiring stewardship in site visitors and strengthen awareness of cultural and natural resources.

Historical plaques, monuments, vicinity maps, and directions to other public facilities are examples of other appropriate interpretive items.

Topic 913 - Safety Roadside Rest Areas

913.1 Safety Roadside Rest Areas General

Safety roadside rest areas typically include restrooms, vehicle parking, bicycle parking, shade shelters, sidewalks, picnic tables, telephones, water, landscape, pet areas, tourist and traveler service information, and vending machines.

Designers should be familiar with the provisions of the California Streets and Highways Code, Article 7 Sections 218 through 226.5.

Comply with State and Federal codes and regulations that address buildings, electrical work, plumbing, lighting, drinking water, wastewater treatment discharge, grading, stormwater discharge, hazardous material containment and disposal, resource conservation, accessibility for persons with disabilities, and environmental protection and mitigation.

Design safety roadside rest areas for cost effective and efficient maintenance. Use high quality, durable and easily cleanable materials to accommodate the heavy use that safety roadside rest areas receive. Select replaceable components, such as mirrors, sinks, signs, and lighting fixtures that will be readily available during the lifetime of the facility.

Safety roadside rest area expansion should not diminish the scenic and environmental qualities of the existing site.

Determine capacity from the current Safety Roadside Rest Area System Master Plan or site-specific traffic and user counts. Safety roadside rest area parking and restroom capacity should be designed to accommodate the anticipated demand in the design year (20 years from construction completion). When feasible, the design may allow the parking area to be expanded by 25 percent beyond the 20-year design period. Consider future expansion needs for the restroom, parking, water, and wastewater facility beyond the design year.

(1) *Wayside stops.* Include parking areas and restrooms provided by or jointly developed and operated by partners (such as existing or new truck stops, or other highway oriented commercial development). These are for longer-duration stops and overnight parking, primarily for commercial vehicle operators. These facilities are located outside of state right of way, within one-half mile of the freeway. The freeway interchange should accommodate, or be improved to accommodate, the volume and geometric movements of anticipated traffic.

913.2 Safety Roadside Rest Area Site Selection

(1) *Need.* Locations for new or replacement safety roadside rest areas and wayside stops should be consistent with the Safety Roadside Rest Area System Master Plan. Proposed locations identified on the Safety Roadside Rest Area System Master Plan are approximate only. Actual sites may be located within several miles in either direction from the location indicated on the Safety Roadside Rest Area System Master Plan. More than one alternate site should be identified and analyzed before selecting a preferred site. When offering potential sites for wayside stop proposals, it is best to allow for as many acceptable alternative sites as possible.

(2) *Access.* Safety roadside rest areas located on a freeway or a highway of four or more lanes, should be planned as a pair of units, each unit serving a separate direction of traffic.

(3) *Right of Way Requirements.* A safety roadside rest area unit may require 10 to 15 acres of right of way. Potential negative impacts to prime agricultural land, native vegetation, natural terrain, water quality, and drainage features should be considered when identifying potential sites for rest areas. Consider sites where natural vegetation has already been disturbed and where rest area development may facilitate restoration.

913.3 Safety Roadside Rest Area Layout

Refer to Topic 912 - Landscape Site Design for additional information.

(1) *Ingress and Egress.* Access (ingress/egress) should be by means of direct on and off ramps from the freeway or highway. See Index 912.1 for additional roadside site ingress/egress and roadway connection information.

When a rest area or wayside stop facility is developed outside the freeway right of way at an interchange location, the interchange ramps, bridges, and geometric design should accommodate the volume of traffic anticipated and the turning movements of commercial trucks.

(2) *Restroom Location.* Locate the restroom building in a prominent location with appropriate access from parking areas. Entrances to restrooms should be visible from the parking area. They should be well lit and clearly identified with signs and/or graphics. Vegetation, walls, recesses and other areas that allow concealment should not be located near restroom entrances. Restroom entrances should not be in areas of dead-end circulation. Facilities intended for public use should not be located near restroom entrances.

(3) *Public Information Displays and Telephones.* Locate public information displays, commercial advertising displays, and telephones in pedestrian areas that are well lit and protected from rain, snow, and wind. Information should be placed near telephones and public information displays indicating local emergency numbers and indicating the rest area name and location.

(4) *Service Facilities.* Service facilities including crew rooms, equipment storage rooms, dumpster enclosures, service yards, and utility equipment, can be distracting and unattractive to safety roadside rest area users. Service facilities should be aesthetically attractive, separated, and oriented away from view of public-use areas (restrooms, pedestrian core, and picnic areas).

(5) *Fencing.* Fences should be provided only for access control, traffic control, or safety purposes. Fencing should be designed to be as unobtrusive as practical.

A minimum 4-foot high fence must be provided between freeways and safety roadside rest areas. Perimeter fencing should be of the minimum height and design necessary. Where adjacent property is developed, more substantial fencing or screening may be required. Fencing in rural or natural areas may be required to control or protect wildlife or livestock. Refer to Topic 701 - Fences.

(6) *Pet Area.* Provide a pet relief area. When placing pet areas, consider location and size, some safety roadside rest areas may require multiple pet relief areas. Consider locating pet relief area near auto parking areas to accommodate pet usage. Consider including fencing, signage, trash receptacles, dog watering fountain, waste bags and dispensers. Remove vegetation with thorns or burrowing seeds and consider replacing with turf, artificial turf, mulch, or decomposed granite.

913.4 Safety Roadside Rest Area Buildings and Structures

Safety roadside rest area structures include restrooms, storage rooms, equipment rooms, crew rooms, CHP drop-in offices, picnic shelters, utility enclosures, dumpster enclosures, kiosks, arbors and other architectural elements. Safety roadside rest area structures should be designed for a service life of at least 20 years. Attention to quality architectural design, construction and maintenance is warranted. Building forms, rooflines, construction materials (stone, timber, steel, etc.), colors and detailing should express the local context including history, cultural influences, climate, topography, geology and vegetation.

Structures must be designed and constructed to be accessible to persons with disabilities in accordance with all applicable State and Federal law. Any building upgrade, even minor projects, must address accessibility and building code deficiencies. Refer to the California Building Code for additional information.

Lockable steel doors should be provided for entrances to rest rooms, storage rooms, crew rooms and CHP drop-in offices.

(1) *Restrooms.* When existing restrooms are replaced as part of rehabilitation projects, it is preferable that the 20-year design need be constructed, even when expansion of parking facilities is deferred.

Two restrooms should be provided for each gender to allow for uninterrupted public access to facilities during janitorial cleaning operations. At least one unisex/family-assisted/all-gender restroom is required; these facilities are not considered part of the total capacity used.

Restroom fixture counts (water closets, urinals for men's rooms, and lavatories) are developed by the Division of Engineering Services-Transportation Architecture and based upon average daily visitor and peak hour visitor data provided by the District. The quantity of fixtures provided for men's restrooms should be divided equally among water closets, urinals and lavatories. The quantity of water closets for women's restrooms should be 1 to 1.5 times the combined quantity of toilets and urinals provided for men.

Each men's, women's, and unisex/family-assisted/all gender restroom must have a baby diaper changing station.

Entrance doors to unisex/family-assisted/all-gender restrooms must be lockable from the inside and outside of the restroom.

Privacy screens at restroom entrances should allow visibility from the ground to a height of 12 inches to 18 inches above the ground.

Maintenance access must be provided to plumbing, sewer, electrical, and equipment to facilitate inspection and repair.

(2) *California Highway Patrol (CHP) Drop-in Office.* Consult with the local CHP to determine need. Drop-in Office consist of a dedicated office and restroom for use by the CHP. The office should be located adjacent to the pedestrian core and near the dedicated CHP parking stall. The CHP office should be designed to allow access by CHP only. The office should be located and designed to provide maximum visibility by officers to, from, and within the facility.

(3) *Maintenance.* Provide crew rooms and storage space for cleaning supplies, tools, and equipment.

(a) *Crew Room.* Provide a maintenance crew room separate from equipment and supply storage at safety roadside rest areas in compliance with the California Occupational Safety and Health Act (Cal-OSHA) requirements. When appropriate, a single crew room may be provided for a pair of safety roadside rest area units. The crew room should be heated and air-conditioned. Conduits or wiring for telephone service, (by others) may be provided.

(b) *Storage Rooms or Buildings.* Storage rooms or buildings should be provided to house maintenance equipment, tools and supplies. Janitorial cleaning supplies and tools should be near the restrooms, and reasonably close to parking for maintenance service vehicles. Provide shelving for paper goods, cleaning supplies and other materials. Grounds-maintenance equipment and supplies should be located outside of public-use areas and views.

913.5 Safety Roadside Rest Area Utilities and Facilities

Utility and facility systems must be designed in conformance with Title 24 Energy Requirements of the California Code of Regulations (State Building Code), and other applicable State and Federal requirements.

(1) *Electrical Service.* Design electrical power systems to accommodate the demands of outdoor lighting (ramps, parking areas, pedestrian walkways and plazas), water supply systems (pumps, pressure tanks, irrigation controllers), restrooms (lighting, hand dryers), pedestrian facilities (lighting, water chillers, telephones, text telephones (TTY), wireless internet, kiosks), crew room (lighting, heating, air conditioning, refrigerator, microwave), CHP drop-in office (lighting, heating, air conditioning), and vending (lighting, vending machines, change machine, storage-room air conditioning).

Primary electrical power sufficient for basic safety needs should be supplied by conventional power providers. Supplemental power may be provided using innovative technologies such as solar panels, wind generation, or conventional means, such as backup generators. Consider security, public safety and environmental protection when determining the type of fuel and fuel storage facilities for electrical generation. Provide vehicular access to fuel storage facilities for refueling; include fencing and gates as necessary to prevent access by the public.

(2) *Lighting*. For functionality and safety, rest areas should be lit for 24-hour-a-day use. Lighting should be automatically controlled and include manual-shutoff capability. Restroom entrances and the interiors of restrooms, utility corridors, CHP drop-in offices, crew rooms, storage rooms or buildings, pedestrian plazas, primary sidewalks, crosswalks, ramps, picnic areas, kiosks, bicycle parking, and interpretive displays should be brightly illuminated. Lighting should illuminate walking surfaces and minimize strong shadows. Peripheral areas of the site should be lighted only where nighttime pedestrian use is anticipated. Non-

pedestrian areas of the site do not require lighting. Comply with local zoning ordinances for lighting restrictions. Refer to the Traffic Manual, Chapter 9 for additional Highway Lighting guidance.

(3) *Water*. Water supply systems should be designed to accommodate the 20-year design need and to handle the peak flow required for restroom fixtures and landscape irrigation. Enclosures should be provided for water supply equipment to discourage vandalism and minimize the appearance of clutter. Water lines beneath parking areas, pedestrian plazas and the highway should be placed in conduits. Maintain appropriate distance between wells and wastewater disposal facilities (applicable laws should be followed). Install a water meter at facilities using a well as a water source to track and report on groundwater usage. Potable water must be provided to sinks, drinking fountains, exterior faucet assemblies and pet-watering stations. Untreated or non-potable water may be used for toilets and landscape irrigation. Irrigation systems should be isolated from the general water system using a backflow prevention device.

(4) *Wastewater Disposal*. Wastewater disposal facilities should be designed to accommodate the 20 year-design need and to handle the peak sewage demand. Waterborne sewage disposal systems should be provided. Division of Engineering Services Structure Design will arrange for soil analysis and percolation tests, and upon completion of testing will obtain approval of the proposed sewage treatment system from the Regional Water Quality Control Board.

Recreational vehicle waste disposal stations may be provided at rest areas where there is a recognized need and commercial disposal stations are not available.

(5) *Telephones*. **Provide public pay telephone(s) and associated conduit and wiring at each safety roadside rest area**. To comply with accessibility laws and regulations, at least one telephone must be wheelchair accessible, at least one telephone must allow for audio amplification, and at least one telephone must include text messaging for the hearing impaired. Whenever possible, all telephones should allow for audio amplification.

Telephones should be wall or pedestal mounted.

Conduits and pull wires should be provided from the telephone service point to the maintenance crew room and to the California Highway Patrol (CHP) drop-in office. Provide telephone service for maintenance contractors and the CHP.

(6) *Call Boxes*. Call Boxes generally are not placed in safety roadside rest areas.

(7) *Wireless Internet Facilities*. Wireless internet facilities may be installed in safety roadside rest areas with funding borne by the provider or others.

(8) *Telecommunications Equipment and Transmission Towers*. Consider future safety roadside rest area expansion, and, when possible, locate facilities outside of areas planned for future development. The Department seeks revenue from placement of wireless telecommunications facilities on State-owned right of way. Transmission towers and associated equipment, structures and fencing should be located outside of pedestrian use areas and views. Telecommunications equipment and transmission towers should be aesthetically integrated into the site.

(9) *Water Holding Tanks for Fire Suppression*. Provide a system for water holding when required for fire suppression.

913.6 Safety Roadside Rest Area Parking

See Index 912.2 for additional parking area design requirements.

(1) *Parking Area Size*. The maximum parking capacity for a safety roadside rest area unit should be 120 total vehicular parking spaces. Site conditions may limit the amount of parking that is practical to build. If construction or enlargement of parking areas to meet anticipated demand will significantly diminish the environmental character of the site, the quantity of parking should be reduced as appropriate.

(2) *Layout.* The maximum walking distance from the most remote parking space to restrooms should be 350 feet.

One accessible parking space for long vehicles may be provided at each rest area unit.

If a California Highway Patrol (CHP) drop-in office is planned, provide one dedicated parking space for use by CHP. The CHP space should be in an area that provides maximum visibility to the public. The CHP space should also be visible from the office location. Provide a sign and pavement markings to designate the CHP space.

913.7 Safety Roadside Rest Area Signage

Freestanding signs should be placed in safety roadside rest areas only to provide traveler direction. This signage should provide clear instructions for travelers as they approach and depart the rest area.

Refer to Index 912.1(3) for additional signage information.

(1) *Roadside Signs.* A roadside sign should be placed one mile in advance of each safety roadside rest area that indicates the distance to that rest area and to the next rest area beyond. In remote areas an additional sign may be placed in advance of a safety roadside rest area indicating the distance to the facility. Additional panels may be included on or near this sign to inform travelers of the availability of vending machines, recreational vehicle waste disposal stations, traveler information, wireless internet or other special services. A directional sign should be placed at the safety roadside rest area ingress ramp. Standard reflectorized traffic control signs should be used within the rest area for all traffic guidance. These signs may be enhanced with aesthetic backing or frames.

A sign advising "Patrolled by Highway Patrol" should be placed on the freeway exit sign preceding each rest area.

(2) *Length of Stay Signage.* Provide length of Stay parking regulation signs for autos and long vehicles per the MUTCD. Provide a "8 Hour Parking" sign at the entrance to the parking area for autos. Provide a "10 Hour Parking Commercial Motor Vehicles" sign at the entrance to the parking area for long vehicles.

(3) *Welcome Signage.* A welcome sign indicating the safety roadside rest area name may be placed within the pedestrian portion of the rest area. Welcome signs must be placed away from traffic decision points and outside the clear recovery zone of the highway or ramps.

(4) *Restroom Signage.* Signs identifying the entrance to each restroom should be clearly visible from the parking area. A sign, in English and Braille, should be placed on the building wall or on the privacy screen at each restroom entrance to identify the gender. Signs may also be provided in other languages as appropriate. A standard sign is required near the entrance to each restroom advising that, a person of the opposite sex may accompany a person with a disability into the restroom. A sign should be installed near the restroom doors advising that State law prohibits smoking in restrooms and the area within 20 feet of the restroom doors. To deter vandalism, signs should be made of metal or other durable material and should be recessed into, or securely mounted on a wall.

(5) *Pet Area Signage:* Provide a sign with the rules of the pet area. Rules may include:

- keep pets leashed
- pick up and dispose of pet waste

913.8 Public Information Display

At least 96 square feet of lighted display space should be provided at each safety roadside rest area for display of public information, such as rest area use regulations, maps, road conditions, rest area closures, safety tips, missing children posters, anti-litter regulations, nonpotable water use, maintenance crew presence/hours, proximity/use of agricultural crops, scenic highways designation, environmental features, etc. Space should consist of wall-mounted cases or freestanding kiosks designed for pedestrian viewing (see DIB 82 for guidance on exhibits).

913.9 Vending Facilities

(1) Vending Machine Facilities. Consider accommodations for vending machines when designing safety roadside rest areas.

Existing vending machine facilities should only be replaced with a project if the existing Vending Machine Facility requires removal.

New vending machine facilities may be installed if initiated, designed, and funded by the California Department of Rehabilitation, Business Enterprise Program (BEP).

When BEP does not install a vending machine facility with a project, provide a vending machine facility location for future vending machine facilities. Provide conduits from the electrical service panel to the planned/future vending machine facility location.

A storage room may be provided by BEP within 150 feet of the vending machines for storage of vended products. The safety roadside rest area project should provide conduits from the electrical service panel to the vending storage room for possible installation of air conditioning by BEP.

(2) Newspaper and Traveler Coupon Booklets. This type of vending machine is owned by others and may be placed in safety roadside rest areas by an encroachment permit.

(3) Coin Operated Binoculars. Coin operated binocular viewing as authorized by law is provided privately through a competitively awarded revenue-generating agreement.

Topic 914 - Vista Points

914.1 Vista Points General

Refer to Topic 912 - Landscape Site Design. A vista point might be a vista point, scenic overlook, wildlife viewing, trailhead access area, or other place specifically for the traveling public to stop and view the local landscape.

Vista points provide a place where motorists and bicyclists can observe the view from outside their vehicles and off their bicycles.

For vista points designed for exiting a vehicle see Index 912.2 for additional parking area design requirements.

Preserve and highlight existing vegetation, rock outcroppings, and other natural features. Removal or pruning of existing plants to frame the view should be minimal. Earth mounding and contour grading may be employed to restore and naturalize the site. Provide planting, including erosion control, to revegetate graded areas. Use plants that thrive without permanent irrigation.

914.2 Vista Point Site Selection

Site selection is based on the following criteria:

(1) Quality. A site should have views and scenery of outstanding merit or beauty. Locations on designated scenic highways or in areas of historical or environmental significance should be given special emphasis. A site should provide the best viewing opportunities compared to other potential locations within the vicinity.

(2) Compatibility. A site should be located on State highway right of way or on right of way secured by easement or agreement with another public agency. A site should be obtainable without condemnation. Select sites away from or adjacent to developed property or property where development is anticipated.

(3) Access. A site should be accessible from a State highway or intersecting road.

(4) Adequate Space. A site should be of adequate size to accommodate the necessary features and facilities. Development of a site shall preserve or improve the scenic quality of the area. Adequate space should be available for earth mounding and planting to minimize the visual impact of larger facilities. Adequate space for future expansion may be desirable.

914.3 Vista Point Amenities

In general, select items that facilitate the viewing of the scenic attraction or blend the vista point into its surroundings.

(1) Maintenance. Coordinate review of the vista point design with the Maintenance Landscape Supervisor to verify all site amenities are appropriately located for maintenance access.

(2) *Barriers*. Railings, bollards, or other appropriate barriers should be used to protect pedestrians and discourage entry into sensitive or hazardous areas. The design of such barriers should be sensitive to pedestrian scale and reflect the scenic character of the site.

(3) *Trash/Recycling Receptacles*. Provide trash and recycling receptacles at each vista point. As a guide, provide one receptacle for every four cars, provide a minimum of two receptacles per vista point. Do not locate dumpsters at a vista point.

(4) *Water*. Potable water may be provided at a reasonable cost. Non-potable water should not be provided in a vista point.

(5) *Other Features*. Optional items include benches, bicycle parking, shade structures, kiosks, interpretive displays, telephones, and coin operated binoculars (See Index 912.3).

Do not include picnic tables at vista points.

(6) *Sanitary Facilities*. Restrooms are usually not provided.

914.4 Vista Point Parking

See Index 912.2 for additional parking area design requirements.

Parking capacity should be based on an analysis of current traffic data. However, at least five vehicle spaces should be provided. The maximum parking capacity should be 0.025 times the DHV or 50 spaces, whichever is less. This number may be exceeded at high use trailheads.

Approximately one-quarter to one-third of the spaces should be allocated to long vehicles (cars with trailers, recreational vehicles, and buses).

Geometrics should be such that all types of vehicles entering the vista point can safely negotiate and exit the facility.

Topic 915 - Park & Ride Facilities

915.1 Park & Ride Facilities General

Park & ride facilities must be considered for inclusion on all major transportation projects that include, but are not limited to, new freeways, interchange modifications, lane additions, transit facilities, and HOV lanes. See Chapter 8, Section 7 of the Project Development Procedures Manual for additional information.

Refer to Topic 912 - Landscape Site Design.

See Index 912.2 for additional parking area design requirements.

Park & ride facilities are to be designed as multi-modal facilities. Provisions for pedestrians, bicyclists, transit, single-occupancy vehicles, and multi-occupancy vehicles are to be provided as appropriate. The local transit provider should be consulted to determine if the facility should provide connections to transit.

The design of a park & ride facility should consider the operations and maintenance of the facility, both in terms of effort as well as safety.

915.2 Site Selection

Park & ride facilities are typically placed to reduce congestion, and to improve air quality, usually associated with other transportation opportunities such as HOV lanes and transit. The specific choice as to location and design should be supported by a detailed analysis of demand and the impact of a park & ride facility based upon these parameters:

- corridor congestion
- community values
- air quality
- transit operations
- overall safety
- multi-modal opportunities

Full involvement of the project development team should be engaged in the evaluation and recommendation of park & ride type, classification, site, and appurtenant facilities.

Refer to the Project Development Procedures Manual and the Park & Ride Program Resource Guide for additional information on site selection.

of Footing line and Retaining Wall height should be shown on the plans.

- The original ground (OG) line and any known utilities should be shown on the Soundwall Plan sheets.

(3) *Pay Quantities.* Soundwalls are to be measured by the square foot between the elevation lines shown on the plans and the length of the wall. Soundwall footings are to be paid as minor concrete and concrete barriers are to be paid for as concrete barrier (modified). Piles are to be paid for separately to facilitate minor changes in the field.

Refer to the Standard Special Provisions for more information on measurement and pay quantities.

When calculating costs for determining "reasonableness," all pay quantities associated with the proposed soundwalls should be included in the analysis. Refer to the California Traffic Noise Analysis Protocol for a discussion on this topic.

(4) *Working Drawings.* Working Drawings are no longer required for state designed masonry block soundwalls in view of the fact that all the information necessary to construct the wall should be shown in the contract plans. The Special Provisions for Alternative Soundwall systems should require the successful bidder to submit four (4) sets of drawings for initial review and between six (6) and twelve (12) additional sets, as requested by the Engineer, for final approval and use during construction. Refer to Bridge Reference Specification 51-561(51SWAL) for more information.

(5) *Preliminary Site Data.* In using the "Top of Soundwall/Bottom of Concrete Barrier" line concept, it is important that the preliminary site data be as complete as possible. To eliminate or minimize construction change orders the following guidance is provided:

- Provide accurate ground line profiles.
- Select only standard or pre-approved design alternative soundwall types.
- Provide adequate information based on foundation investigation.
- Locate overhead and underground utilities.
- Review drainage and show any modifications on the plans.
- Determine and specify architectural treatment.
- Determine the need for special design, and coordinate with the Office of Structures Design during the early stages of design.

1102.6 Noise Barrier Aesthetics

(1) *General.* A landscaped earth berm or a combination wall and berm tend to minimize the apparent noise barrier height and are an aesthetically acceptable alternative among noise barrier options; however, these alternatives are not always suitable for many sites due to limited space.

Some additional cost to enhance the aesthetic quality of the noise barrier is usually warranted. Early community involvement toward proposing asesthetic treatment improvements on noise barriers is recommended to accommodate contextual considerations. However, accountability for designs that significantly increase the cost of the noise barrier should be a topic for discussion early in the design process.

Soundwalls should not be designed with abrupt beginnings or ends. Generally, the ends of the soundwall should be tapered or stepped if the height of the soundwall exceeds 6 feet. See Standard Plans for further details. Consult the District Landscape Architect regarding the design of tapers or stepped ends, aesthetic treatment, highway planting and landscaping adjacent to noise barriers. Refer to DIB 88 for additional information.

(2) *Aesthetic Treatment.* Standard aesthetic treatments have been developed by the DES Office of Structure Design for the various alternative materials.

When treatment that is not a standard aesthetic treatment is proposed for noise barriers, contact the District Landscape Architect for selection of the most appropriate treatment. The District Traffic Engineer or designee should be consulted in these instances to ensure that the treatment of choice satisfies all safety requirements.

(3) *Planting Near Noise Barriers*. The use of plants in conjunction with noise barriers can help to combat graffiti and promote public acceptance of the noise barrier. When landscaping is to be placed adjacent to the soundwall, which will eventually screen a substantial portion of the wall, only minimal aesthetic treatment is justified. Coordinate with District Maintenance when planting near or on noise barriers.

See Index 904.7 and the Project Development Procedures Manual for additional information.

(4) *Transparent Barriers.* Noise barriers may impact viewsheds where consideration of transparent barriers may be warranted. A list of pre-qualified transparent barrier systems is available on the Authorized Materials List at: http://www.dot.ca.gov/aml/.

1102.7 Maintenance Consideration in Noise Barrier Design

(1) *General.* Noise barriers placed within the area between the shoulder and right of way line complicate the ongoing maintenance operations. When there is a substantial distance behind the noise barriers and in front of the right of way line, special consideration is required. If the adjoining land is occupied with streets, roads, parks, or other large parcels, an effort should be made during the right of way negotiations to have the abutting property owners maintain the area. In this case, the chain link fence at the right of way line would not be required. Maintenance by others may not be practical if a number of small individual properties abut the noise barrier.

(2) *Access Requirements.* Access to the back side of the noise barrier must be provided if the area is to be maintained by the Department. In subdivided areas, access can be via local streets, when available. If access is not available via local streets, access gates or openings are essential at intervals along the noise barrier. Access may be provided via offsets in the barrier. Offset barriers must be overlapped a minimum of 2.5 to 3 times the offset distance in order to maintain the integrity of the sound attenuation of the main barrier. Location of the access openings must be coordinated with the District maintenance office.

(3) *Noise Barrier Material.* The alternative materials selected for the noise barrier should be appropriate for the environment in which it is placed. For walls that are located at or near the edge of shoulder, the portion of the noise barrier located above the safety-shape concrete barrier should be capable of withstanding the force of an occasional vehicle which may ride up above the top of the safety barrier.

1102.8 Emergency Access Considerations in Noise Barrier Design

(1) *General.* In addition to access gates being constructed in noise barriers to satisfy the Department's maintenance needs, they may also be constructed to provide a means to access the freeway in the event of a catastrophic event which makes the freeway impassable for emergency vehicles. These gates are not intended to be used as an alternate means of emergency access to adjacent neighborhoods. Access to those areas should be planned and provided from the local street system. Small openings may also be provided in the noise barrier which would allow a fire hose to be passed through it. Local emergency response agencies should be contacted early in the design process to determine the need for emergency access gates and fire hose openings.

(2) *Emergency Access Gate Requirements.* Access gates in noise barriers should be kept to a minimum and should be at least 1,000 feet apart. Locations of access should be coordinated with the District Maintenance office. Only one opening should be provided at locations where there is a need for access openings to serve both the emergency response agency and the Department's maintenance forces. Gates should be designed to comply with the soundwall details developed by the Office of Structures Design.

(3) *Fire Hose Access Openings.* When there is no other means of providing fire protection to the freeway, small openings for fire hoses may be provided. Fire hose access should be located

as close as possible to the fire hydrants on the local street system. Where possible, fire hose access should be combined with emergency or maintenance access openings. The Office of Structures Design should be requested to design fire hose access openings.

1102.9 Drainage Openings in Noise Barrier

Drainage through noise barriers is sometimes required for various site conditions. Depending on the size and spacing, small, unshielded openings at ground level can be provided in the barriers to allow drainage and not adversely impact the noise attenuation of the barrier. The following sizes of unshielded openings at ground level are allowed for this purpose:

(a) Openings of 8" x 8" or smaller, if the openings are spaced at least 10 feet on center.

(b) Openings of 8" x 16" or smaller, if the openings are spaced at least 20 feet on center, and the noise receiver is at least 10 feet from the nearest opening.

The location and size of the drainage openings need to be designed based on the hydraulics of the area. The design should take into consideration possible erosion problems that may occur at the drainage openings.

Where drainage requirements dictate openings that do not conform to the above limitations, shielding of the opening will be necessary to uphold the noise attenuation of the barrier. The shielding designed must consider the hydraulic characteristics of the site. When shielding is determined to be necessary, consultation with the District Hydraulics Unit and the District Traffic Safety Engineer or designee is recommended, as well as the Division of Environmental Analysis.

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