1 Embankments

This module documents the Department's standard of practice for the investigation, design, and construction of embankments. Highway embankments, bridge approaches, embankment widening, and storm damage issues are addressed. Primary references for this module are:

- NHI Soil Slope and Embankment Design, September 2005.
- Washington State Dept. of Transportation Geotechnical Design Manual, M 46-03.09, December 2013, Chapter 9 Embankments.
- Standard Specifications, State of California, Department of Transportation

The Geoprofessional's role is to provide geotechnical recommendations for the design, construction, and maintenance of embankments. Our client is primarily the district to which we provide both planning and design recommendations. District design units submit work requests to GS that should include the following information:

- Plan sheets with embankment area(s)
- Cross-sections (typically at 50-foot to 100-foot intervals, depending upon topography, etc.)
- Profiles of the planned alignment

For planning phase requests may not be well defined but should include planned embankment locations and heights. Design phase requests should be more thoroughly developed. Communicate with the client to assure a common understanding of work to be addressed and project constraints.

For the purposes of this module, embankments include the following:

- Rock embankments, defined as fills in which the material in all or any part of an embankment contains 25 percent or more, by volume, cobbles and/or boulders.
- Structure approach embankments, defined as fill extending from a bridge abutment for 150 feet.
- Embankments are fills that are not classified as rock or structure approach embankments, but that are constructed with soil.
- Lightweight fills contain lightweight fill or recycled materials as a significant portion of the embankment volume, and the embankment construction is usually controlled by special provision. Lightweight fills are most often used as a portion of the structure approach embankment to mitigate settlement and/or stability issues, or in landslide repairs to reestablish roadways.

2 Investigation

Refer to the *Geotechnical Investigations* module for general instructions on performing the planning-phase site investigation (e.g., literature review, site visit) and the design-phase site investigation (e.g., site visit, selection of investigative methods, locations, and depths).

Considerations for design and construction of embankments are stability and settlement of the foundation soil, the impact of the stability and settlement on the construction staging and time requirements, and impacts to nearby structures, such as buildings, bridge foundations, and utilities. The investigation should include a site review outside the proposed embankment footprint in addition to within the embankment footprint. The investigation should extend at least two to three times the width of the embankment on either side and to the top or bottom of slopes adjacent to the embankment.

2.1 Planning the Field Exploration and Laboratory Testing

Assess project requirements and anticipated subsurface conditions to determine the type and quantity of information to obtain during the geotechnical investigation.

- Identify performance criteria (e.g., allowable settlement, time available for construction, seismic design requirements, etc.).
- Identify potential geologic hazards, areas of concern (e.g., soft soil), and potential variability of local geology.
- Identify engineering analyses to be performed (e.g., limit equilibrium slope stability analyses, settlement evaluations, liquefaction susceptibility, lateral spreading, seismic slope deformations,).
- Identify engineering properties required for these analyses.
- Determine methods to obtain parameters and assess the validity of such methods for the material type.
- Estimate the number of tests/samples needed and appropriate locations for them.

The investigative goal for embankment design and construction is to develop the subsurface profile and soil property information needed for stability and settlement analyses. Soil parameters generally required for embankment design include:

- Total stress and effective stress strength parameters (friction angle, cohesion)
- Unit weight
- Compression indexes (primary, secondary and recompression)
- Coefficient of consolidation

Table 1 provides a summary of site characterization needs, and field and laboratory testing considerations for embankment design.

Table 1: Information Needs and Testing Considerations for Embankments (Adapted From Sabatini, Et. Al., 2002)

Engineering Evaluations	Required Information for Analyses	Field Testing and Sampling	Laboratory Testing
• settlement (magnitude & rate) • bearing capacity • slope stability • lateral pressure • internal stability • borrow source evaluation (available quantity and quality of borrow soil) • geosynthetic reinforcement • liquefaction • delineation of soft soil deposits • potential for subsidence (karst, mining, etc.) • constructability	• subsurface profile (soil, ground water, rock) • compressibility parameters • shear strength parameters • unit weights • time-rate consolidation parameters • horizontal earth pressure coefficients • interface friction parameters • pullout resistance • geologic mapping including orientation and characteristics of rock discontinuities • shrink/swell/ degradation of soil and rock fill	• CPT (w/ pore pressure measurement) • SPT • piezometers (GWT and pore pressures during construction) • vane shear • geophysical testing • rock coring (RQD) • plate load test • test fill • settlement plates • slope inclinometers • Undisturbed Sampling	• Consolidation Testing (1-D Oedometer) • triaxial tests • unconfined compression • direct shear tests • grain size distribution • Atterberg Limits • specific gravity • organic content • moisture-density relationship • hydraulic conductivity • geosynthetic/soil testing • shrink/swell • slake durability • unit weight • relative density

The size, complexity and extent of the sampling program will depend primarily on the type, height, and size of the embankment(s) as well as the anticipated soil conditions.

Generally, embankments 10 feet or less in height, constructed over average to good soil conditions (e.g., medium dense to very dense sand, silt or gravel, stiff or overconsolidated clays with low expansion potential, with no signs of previous instability, non-liquefiable) will require only a basic level of site investigation. A geologic site reconnaissance, combined with a few shallow borings, hand holes or possibly a few test pits to verify field observations and the anticipated site geology should be sufficient, especially if the geology of the area is well known, or if there is some prior experience in the area.

For larger embankments, or for any embankment to be placed over soft or potentially unstable ground, geotechnical explorations should be spaced no more than 500 feet apart for uniform conditions. In non-uniform soil conditions, spacing should be decreased to intervals to achieve at least one boring in each major landform or geologic unit or enough borings to adequately define subsurface conditions. A key to the establishment of exploration frequency for embankments is the potential for the subsurface conditions to impact the construction of the embankment and the long-term performance of the finished project.

Embankments over 10 feet in height, embankments over soft soil, or those embankments that could impact adjacent structures (e.g., bridge abutments, buildings etc.) require geotechnical borings (existing borings that provide the needed information will suffice) for their design. The more critical areas for stability of a large embankment are between the hinge point and toe of the slope. This is where base stability is of most concern and where a majority of the borings should be located, particularly if the near-surface soil is expected to consist of soft fine-grained deposits. At critical locations, (e.g., maximum embankment heights, maximum depths and/or thicknesses of soft strata), a minimum of two borings in the transverse direction to define the subsurface conditions for stability analyses should be obtained. Additional borings to define the stratigraphy, including the conditions within and below existing fill, may be necessary for very large fills or erratic site conditions.

Embankment widening projects may need borings near the toe of the existing fill to evaluate the present condition of the underlying soil, particularly if the soil is fine-grained.

In addition, borings through the existing fill into the underlying soft soil, or, if over-excavation of the soft soil had been done during the initial fill construction, borings to define the extent of removal, should be obtained to define conditions below the existing fill.

In some cases, the stability and/or durability of the existing embankment fill may be questionable because the fill materials are suspect or because slope instability in the form of raveling, down-slope lobes, or slope failures are present. In these cases, consider additional borings through the core of the embankment to sample and test the condition of the fill. If the distress is surficial, consider obtaining hand borings or grab samples for determining compaction and strength characteristics. The depth of borings, test pits, and hand holes will generally be determined by the expected soil conditions and the depth of influence of the new embankment. Explorations must penetrate through problem soil such as loose sand, soft silt and clay and organic materials, and at least 10 feet into competent soil. As a rule of thumb, borings should be drilled to a minimum depth of twice the planned embankment height. In some cases, the width of the embankment may have a greater influence on the stress distribution and/or magnitude of settlement than the height and therefore will require that borings be drilled to depths greater than twice the embankment height. In mountainous areas this minimum depth recommendation may not necessarily apply because rock and or competent soil may exist at shallower depths. To ensure that the material under the proposed embankment is adequately studied, consider the following:

- local and/or site-specific geologic conditions,
- the height and width of the new embankment to be built,
- the pressure influence or stress distribution that the new embankment will impart on the supporting soil.

Cone penetration test (CPT) probes should, if practicable, be used to supplement conventional borings. Besides being significantly less expensive, CPT probes allow the nearly continuous evaluation of soil properties with depth. They can detect thin layers of soil, such as a sand lens in clay that would greatly reduce consolidation time that would otherwise be missed in a conventional boring. To utilize the sand lenses, they must be continuous and extend beyond the loaded area to provide drainage. In addition, CPT probes can measure pore pressure dissipation responses to evaluate relative soil permeability and consolidation rates. Because there are no samples obtained, CPT probes should be used in conjunction with a standard boring program.

Consider geophysical testing for void detection, water infiltration and seepage, and evaluation of subsurface variability. Geophysical testing can also provide nearly continuous coverage along the length of an embankment and may be used both to plan the drilling investigation and to extrapolate information beyond test boring and piezometer locations. Geophysical investigations should be considered where supplementation of the drilling investigation is needed.

2.2 Groundwater

At least one piezometer should be installed in borings drilled in each fill zone where stability analysis will be required, and groundwater is anticipated. Water levels measured during drilling are often not adequate for performing stability analysis. This is particularly true where drilling is in fine-grained soil that can take many days or more for the water level to equalize after drilling. Even in more permeable coarse-grained soil, the drilling fluid can obscure detection of the groundwater level. When encountered, groundwater must be measured after each boring is drilled. Information regarding the time and date of the reading and any fluctuations (such as loss of drilling fluid) that might be seen during drilling should be included on the field logs.

For embankment widening projects, piezometers are generally more useful in borings located at or near the toe of an existing embankment, rather than in the fill itself. Exceptions are when the existing fill is along a hillside or if seepage is present on the face of the embankment slope.

The groundwater levels should be monitored periodically to provide useful information regarding variation in levels over time. This can be important when evaluating base stability, consolidation settlement or liquefaction. As a minimum, the monitoring should be accomplished several times during the wet season (October through April) to assess the likely highest groundwater levels that could affect engineering analyses. If practical, a series of year-round readings taken at 1 to 2-month intervals should be accomplished in all piezometers.

The location of the groundwater table is particularly important for stability and settlement analyses. High groundwater tables result in lower effective stress in the soil affecting both the shear strength characteristics or the soil and its consolidation behavior under loading. Identify the location of the groundwater table and determine the range in seasonal fluctuation.

If there is a potential for a significant groundwater gradient beneath an embankment or surface water levels are significantly higher on one side of the embankment than the other, the effect of reduced soil strength caused by water seepage should be evaluated. In this case, more than one piezometer should be installed to estimate the gradient. Geophysical methods may be employed to evaluate locations and the extent of seepage within an embankment. Also, seepage effects must be considered when an embankment is placed on or near the top of a slope that has known or potential for seepage through it. A flow net or a computer model may be used to estimate seepage velocity and forces in the soil. This information may then be used in the stability analysis to model pore pressures.

3 Analysis and Design

3.1 Typical Embankment Materials and Compaction

General instructions for embankment construction are discussed in the specific construction specifications provided in Section 6, Control of Materials, and Section 19, Earthwork, of the Standard Specifications. Compaction requirements for approach embankments are defined by Highway Design Manual (HDM), topic 208.11 and Figure 208.11A. Compaction requirements for embankments outside of approach embankments are defined by Standard Specifications Sections 19-5, Compaction, 19-6 Embankment Construction, and 19-7 Borrow Material. Determine if any of the material from planned earthwork will be suitable for embankment. Consideration should be given to whether the material is moisture sensitive and difficult to compact during wet weather.

Landscape Architecture may request reduced compaction requirements from 90-95% relative compaction to 85-88% relative compaction to promote the growth of vegetation on embankment slopes. Careful consideration of this type of request should be made as well as discussion with all project stakeholders should be held to determine what will be acceptable slope performance.

3.1.1 Rock Embankments

Standard Specifications Section 19-6.03C, Placing and Compacting, discusses compaction and construction requirements of rock embankments.

Special consideration should be given to the type of material that will be used in rock embankments. In some areas of the state, moderately weathered to decomposed, and moderately soft to very soft rock (i.e. poorly indurated) may be encountered in cuts and used as embankment fill. Degradable fine-grained sandstone and siltstone are often encountered in the cuts. The use of this material in embankments can result in significant long-term settlement and stability problems as the rock degrades, unless properly compacted with heavy tamping foot rollers (Machan, et al., 1989). The type, size, durability, and layer thickness of the rocky material will need to be considered. Also, compaction of rocky fill is generally not measured with standard compaction equipment and therefore a method specification will be required.

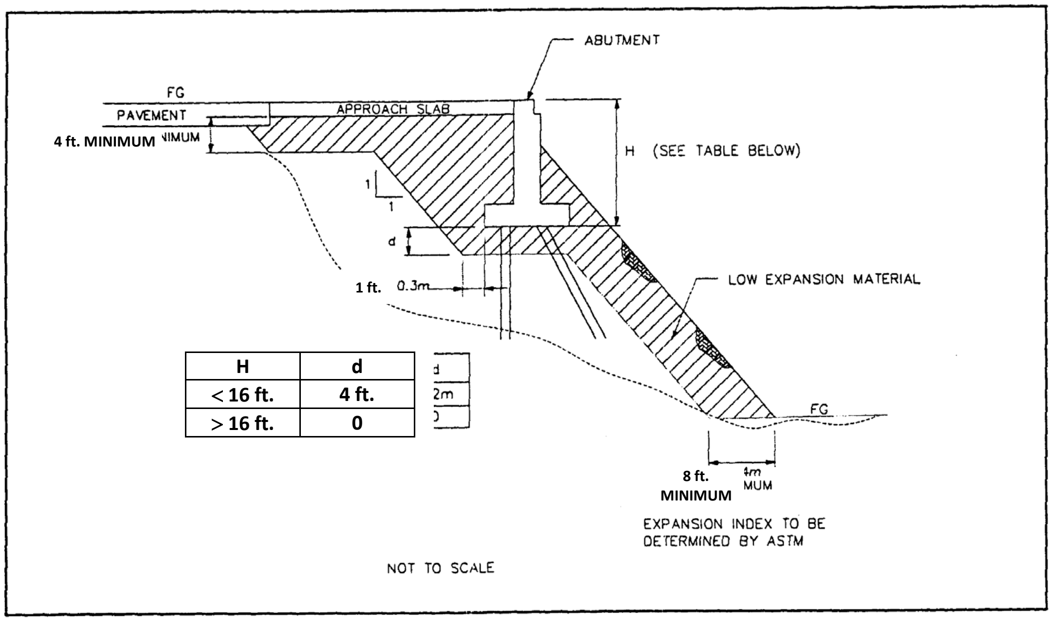
3.1.2 Earth Embankments and Bridge Approach Embankments

Two types of materials are commonly used in earth embankments: embankment fill (such as import borrow, local borrow, excavated material, lightweight imported borrow) and structure backfill.

Specifications for embankment fill and structure backfill are in Section 19 of the Standard Specifications. Specifications for compaction of embankment fill and structure backfill are in Section 6, Control of Materials, and Section 19, Earthwork, and California Test Methods 216, 226, and 231.

Do not place expansive soil as part of the embankment within the limits of a bridge abutment as shown in Figure 1 for the full width of the embankment. Expansive soil materials for this requirement are defined as having either an Expansion Index (EI) (ASTM D 4829) greater than 50, or a Sand Equivalent (SE) (California Test Method 217) less than 20. This requirement is exclusive of the structure backfill and pervious backfill material requirements as shown on the plans and set forth in the Standard Specifications under Sections 19-3.02B and 19-3.03E, Structure Backfill, and 19-3.02C and 19-3.03G, Pervious Backfill Material, respectively. If you suspect that expansive soil might be available for use either locally or by import, include Figure 1 and appropriate discussion in the Foundation Report.

Figure 1: Expansive Soil Exclusion Zone



3.2 Fill Placement Below Water

If material will be placed below the water table, specify material that does not require compaction such as gravel or cobbles or boulders. Above the water surface, transition to standard embankment materials, using geosynthetics to prevent migration of the finer materials into the void spaces of the coarser underlying material.

3.3 Stability Assessment

In general, embankments 10 feet or less in height with 2H:1V or flatter side slopes, may be designed based on past precedence and engineering judgment provided there are no known problem soil conditions such as organic soil, soft/loose soil, potentially unstable soil, such as Bay Mud or peat, or liquefiable sands. Embankments over 10 feet in height or any embankment on soft soil, in unstable areas, or those comprised of lightweight fill require more in-depth stability analyses, as do any embankments with side slope inclinations steeper than 2H:1V. Moreover, any fill placed near or against a bridge abutment or foundation, or that can impact a nearby buried or above-ground structure, will likewise require stability analyses.

Prior to the start of the stability analysis, determine key issues that need to be addressed, such as:

- Is the site underlain by soft silt, clay, or peat? If so, a staged stability analysis may be required.
- Are site constraints such that slopes steeper than 2H:1V are required (1.5H:1V embankments are common in mountainous areas)? If so, a slope stability assessment is required to evaluate the various alternatives.
- Is the embankment temporary or permanent? Factors of safety for temporary embankments may be lower than for permanent ones, depending on the site conditions and the potential for variability.
- Will the new embankment impact nearby structures or bridge abutments? If so, more elaborate sampling, testing and analysis are required.
- Is there potentially liquefiable soil at the site? If so, seismic analysis to evaluate this may be warranted and ground improvement may be needed. For a structure approach embankment or if seismic distress to the embankment would impact a bridge or building, then liquefaction (including settlement, lateral spreading, and deformation) must be evaluated, and the embankment should be designed to remain stable during seismic events. It is not common perform liquefaction mitigation for highway embankments due to the high cost of applying such a policy uniformly to all highway embankments statewide. In the latter case, if liquefaction is identified, a risk discussion must be held with the Project Development Team (PDT).

3.3.1 Safety Factors

The minimum Factor of Safety (FoS) to be used in stability analyses for an embankment depends on many factors such as:

1. The degree of uncertainty in the stability analysis inputs
2. The extent of investigation and data collection
3. Costs of constructing a more stable slope
4. The risks and consequences of slope failure, including impacts on the traveling public and the roadway
5. Whether the slope is temporary or permanent

Use the static FoS values below; however, higher or lower values may be appropriate, depending on the specifics of the project and considerations listed above.

- Highway embankments (embankments that neither support nor potentially impact structures) should have a minimum FoS of 1.25. When repairing an embankment slide or slip out, and the FoS for the embankment can be reliably calculated, a minimum FoS of 1.15 may be used.
- Highway embankments supporting or potentially impacting structures should have a minimum FoS of 1.3.
- Bridge Approach Embankments and embankments supporting important (see MTD 20-1) structures should have a minimum FoS of 1.5.

- Temporary embankments (i.e., short-term conditions during construction) can have a lower FoS than long-term embankments, typically about 1.1 to 1.2, but not lower than 1.1.
- Refer to considerations above.

Evaluate seismic overall slope stability in accordance with the *Seismic Overall Slope Stability* module.

3.3.2 Strength Parameters

Strength parameters are required for both stability and settlement analyses. Use FHWA Geotechnical Engineering Circular No. 5 (Sabatini, et al., 2002), the *Soil Correlations* Module, or other appropriate references for guidance on the selection of strength parameters. Obtain the parameters by a combination of laboratory testing and in-situ testing. For low-risk situations, soil correlations may be appropriate.

Tables 2 and 3 present the typical field and laboratory tests used to determine soil strength parameters. These tables are not exhaustive but do cover the most common tests.

Consider the applicable operating ranges of these tests, and that the values that these tests yield are dependent upon various rates and types of loading, boundary conditions, and stress history, etc.

Table 2: Strength Parameters from Field Testing

Field Test	Parameter	Remarks
Standard Penetration Test (SPT)	Friction Angle	Values indirectly obtained by correlation (see Correlation Module). Only good for cohesionless soil. Discrete testing.
Cone Penetration Test (CPT)	Friction Angle, Undrained Shear Strength	Values indirectly obtained by correlation. Good for both cohesive and cohesionless soil. Continuous testing. No samples retrieved for lab testing.
Pocket Penetrometer (PP)	Undrained Shear Strength	Applicable for cohesive soil. Good for estimating shear strength ranges. PP values may be confirmed with lab tests.
Torvane (TV)	Undrained Shear Strength	Only good for cohesive soil. Good for estimating shear strength ranges. TV values may be confirmed with lab tests.
Vane Shear Test	Undrained Shear Strength, Residual Undrained Shear Strength	Limited to soft and stiff clays.

Table 3: Strength Parameters and Stress History from Laboratory Testing

Laboratory Test	Parameter	Remarks
Unconfined Compressive Strength	Undrained Shear Strength, (S_u)	Applicable for Clays and Silty soil; $S_u = C_u = q_u/2$
Triaxial	Undrained Shear Strength, (S_u), Effective Stress Parameters (c' and ϕ')	Good for both cohesive and cohesionless soil. Requires careful field sampling techniques. Most commonly, UU and/or CUe.
Direct Shear	Effective Stress Parameters (c' and ϕ')	Good for both cohesive and cohesionless soil. Requires careful field sampling/handling techniques. Shearing occurs over a pre-defined plane.
One-dimensional Consolidation	Overconsolidation Ratio (OCR), Preconsolidation Stress(σ_p'), Compression and Recompression Indices (C_c & C_r), Swelling Index (C_s), secondary compression (C_α), and Time-rate settlement values	Requires engineering judgment/experience to determine parameters.

If the critical stability is under drained conditions, such as in sand or gravel, then effective stress analysis using a peak friction angle is appropriate and should be used for stability assessment. In the case of over-consolidated fine-grained soil, the residual strength based on down-hole vane shear or lab tests, may be appropriate. This is especially true for soil that exhibits strain softening or are particularly sensitive to shear strain.

If the critical stability is under undrained conditions, such as in most clays and silts, a total stress analysis using the undrained cohesion value, based on a combination of field and laboratory tests, with no friction, should be used for stability assessment.

For staged construction, both short (undrained) and long term (drained) stability need to be assessed. At the start of a stage the input strength parameter is the undrained cohesion. The total shear strength of the fine-grained soil increases with time as the excessive pore water dissipates.

3.4 Embankment Settlement Assessment

New embankments, as is true of almost any new construction, will add load to the underlying soil and cause settlement. The total settlement has up to three potential components: 1) immediate settlement, 2) consolidation settlement, and 3) secondary compression.

Settlement must be assessed for all embankments. Even if the embankment has an adequate overall stability FoS, the performance of a highway embankment can be adversely affected by excessive differential settlement at the road surface.

Settlement analyses for embankments over soft soil require the compression index parameters as an input parameter. These parameters are typically obtained from standard one-dimensional oedometer tests of the fine-grained soil. For granular soil, settlement is estimated empirically.

3.4.1 Settlement Impacts

Because primary consolidation and secondary compression can continue to occur long after the embankment is constructed, they represent the major settlement concerns for embankment design and construction. Post construction settlement can damage structures and utilities located within the embankment, especially if those facilities are also supported by adjacent soil or foundations that do not settle appreciably, leading to differential settlements. Embankment settlement near an abutment could create an unwanted dip in the roadway surface, or downdrag and lateral squeeze on the foundations.

If the primary consolidation is allowed to occur prior to placing utilities or building structures that would otherwise be impacted by the settlement, the impact is essentially mitigated. However, it can take weeks to years for primary settlement to be essentially complete, and significant secondary compression of organic soil can continue for decades. Many construction projects cannot absorb the scheduling impacts associated with waiting for primary consolidation and/or secondary compression to occur. Therefore, estimating the time rate of settlement is often as important as estimating the magnitude of settlement.

To establish the target settlement criteria, the tolerance of potentially affected structures or utilities to differential settlement that will be impacted by the embankment settlement must be determined. Lateral movement of soil (i.e., lateral squeeze) caused by the embankment settlement and its effect on adjacent structures, including light, overhead sign, and signal foundations, must also be considered. If structures or utilities are not impacted by the embankment settlement, settlement criteria are likely governed by the long-term maintenance needs of the roadway surfacing. In that case, the target settlement criteria must be established with consideration of the effect differential settlement will have on the pavement life and surface smoothness.

The amount of total and differential settlement that can be tolerated during and following embankment construction should be evaluated. The PDT will determine the applicable design criteria for the project.

3.4.2 Settlement Analysis

Perform settlement analysis according to the NHI Soil, Slopes, and Embankment design Manual, Chapter 4.

3.5 Stability Mitigation

A variety of techniques are available to mitigate inadequate slope stability for new embankments or embankment widenings. These techniques include staged construction to allow for the underlying soil to gain strength, base reinforcement, ground improvement, use of lightweight fill, and construction of toe berms and shear keys.

3.5.1 Staged Construction

Where soft compressible soil is present below a new embankment and it is not economical to remove and replace the soil with compacted fill, the embankment can be constructed in stages to allow the strength of the compressible soil to increase under the weight of the new fill. For stability analysis for staged construction, refer to the NHI manual, Chapter 8.6, Embankments on Soft Ground and WSDOT Geotechnical Design Manual, 9.3.1 Staged Construction and its example in Appendix 9-A.

3.5.2 Base Reinforcement

Base reinforcement may be used to increase the FoS against slope failure. Base reinforcement typically consists of placing a geotextile or geogrid at the base of an embankment prior to constructing the embankment. Base reinforcement is particularly effective where soft/weak soil is present below a planned embankment. The base reinforcement can be designed for either temporary or permanent applications. Most base reinforcement applications are temporary, in that the reinforcement is needed only until the underlying soil's shear strength has increased sufficiently from consolidation under the weight of the embankment. Temporary reinforcement does not need to meet the same creep and durability requirements as permanent reinforcement. Use the creep reduction factors outlined in the WSDOT Geotechnical Design Manual, 9.3.2, Base Reinforcement and WSDOT Standard Practice T925.

The design of base reinforcement is similar to the design of a reinforced slope in that limit equilibrium slope stability methods are used to determine the strength required to obtain the desired safety factor. The design procedures by Holtz, et al. (1995) should be used for embankments utilizing base reinforcement.

Base reinforcement materials should be placed in continuous longitudinal strips in the direction of main reinforcement. Joints between pieces of geotextile or geogrid in the strength direction (perpendicular to the slope) should be avoided. All seams in the geotextiles should be sewn and not lapped. Likewise, geogrids should be linked with mechanical fasteners or pins and not simply overlapped. Where base reinforcement is used, the use of gravel, from imported or local borrow sources, may also be appropriate to increase the embankment shear strength.

3.5.3 Ground Modification

Ground modification can be used to mitigate inadequate slope stability for both new and existing embankments, as well as reduce settlement. The primary ground improvement techniques to mitigate slope stability fall into two general categories, namely densification and altering the soil composition. The *Ground Modification* module should be reviewed for a more detailed discussion and key references regarding the advantages and disadvantages of these techniques, applicability for the prevailing subsurface conditions, construction considerations, and costs. In addition to the two general categories of ground improvement identified above, Prefabricated Vertical Drains (PVD) (also known as “wick” drains) may be used in combination with staged embankment construction to accelerate strength gain and improve stability, in addition to accelerating primary consolidation. PVD reduce the drainage path length, thereby accelerating the rate of strength gain. Other ground improvement techniques such as stone columns can function to accelerate strength gain in the same way as PVD, though the stone columns also redistribute how the stress is applied to the soil, thereby reducing the total strength gain obtained. See the *Ground Modification* module for additional guidance and references to use if these techniques are to be implemented.

3.5.4 Lightweight Fills

Lightweight fill is another method to improve embankment stability. Lightweight fills are generally used for two conditions: the reduction of the driving forces contributing to instability, and the reduction of potential settlement resulting from consolidation of compressible foundation soil. Situations where lightweight fill may be appropriate include conditions where the construction schedule does not allow the use of staged construction, where existing utilities or adjacent structures are present that cannot tolerate the magnitude of settlement induced by placement of typical fill, and at locations where post-construction settlements may be excessive under conventional fills.

Lightweight fill consists of a variety of materials including polystyrene blocks (geofoam), lightweight aggregates (rhyolite, expanded shale, blast furnace slag, fly ash), wood fiber, tire derived aggregate (TDA), and other materials. Lightweight fills are infrequently used due to either high costs or other disadvantages with using these materials. Refer to the *Ground Modification* module for more information.

3.5.5 Toe Berms, Shear keys, and Stabilization Trenches

Toe berms and shear keys improve the stability of an embankment by increasing the resistance along potential failure surfaces. As implied by the name, toe berms are constructed near the toe of the embankment slopes where stability is a concern. The toe berms are often inclined flatter than the fill embankment side slopes, but the berm itself should be checked for stability. The use of berms may increase the magnitude of settlements because of the increased size of the loaded area. Toe berms may be constructed using compacted earth embankment or from granular materials that can be placed quickly, do not require much compaction, but have relatively high shear strength. Use of compacted earth embankment may be warranted due to cost savings from using local borrow as compared to importing granular materials.

Toe berms increase the shearing resistance by:

- Adding weight, and thus increasing the shear resistance of granular soil below the toe area of the embankment.
- Adding high strength materials for additional resistance along potential failure surfaces that pass through the toe berm; and creating a longer failure surface, thus more shear resistance, as the failure surface now must pass below the toe berm if it does not pass through the berm.

Shear keys function in a manner similar to toe berms, except instead of being adjacent to and incorporating the toe of the fill embankment, the shear key is placed under the fill embankment—frequently below the toe of the embankment. Shear keys are best suited to conditions where they key can be embedded into a stronger underlying formation. Shear keys typically range from 5 to 15 feet in width and extend 4 to 10 feet below the ground surface. They are typically backfilled with quarry spalls or similar materials that are relatively easy to place below the groundwater level, require minimal compaction, and have high internal shear strength. Like toe berms, shear keys improve the stability of the embankment by forcing the potential failure surface through the strong shear key material or along a much longer path below the shear key.

Stabilization trenches function to key an embankment into competent foundation material and facilitate drainage within an embankment foundation. The specified trenches significantly reduce the amount of excavation of poor foundation materials that might otherwise be required. See Section 8.B.8, Slope Stability and Foundation Investigation, 1973 for more stabilization trench details.

3.6 Settlement Mitigation

3.6.1 Over-excavation

Over-excavation simply refers to excavating the soft compressible soil from below the embankment footprint and replacing these materials with higher quality, less compressible soil. Over-excavation (remove and replace) should be assessed prior to consideration of other mitigation strategies, such as PVD, surcharges and lightweight fills. Because of the high costs associated with excavating and disposing of unsuitable soil as well as the difficulties associated with excavating below the water table, over-excavation and replacement typically only makes economic sense under certain conditions. Some of these conditions include:

- The area requiring overexcavation is limited.
- The unsuitable soil is near the ground surface and does not extend very deep. Over-excavation depths greater than about 10 feet are generally not economical, even under favorable conditions.
- Temporary shoring and dewatering are not required to support or facilitate the excavation.
- The unsuitable soil can be wasted on site.
- Suitable excess fill materials are readily available to replace the over-excavated unsuitable soil.

3.6.2 Acceleration Using Prefabricated Vertical Drains, Surcharges, or Lightweight FIlls

Refer to the *Ground Modification* module.

4 Instrumentation

Common instrumentation methods for designing and constructing embankments include:

- Piezometers – standpipe, vibrating wire
- Time Domain Reflectometry
- Slope Inclinometers
- Survey Hubs
- Settlement Platforms

Place as many instruments as needed to ensure that foundation soil provide adequate bearing for the embankment prism. Likewise, the embankment prism should be sufficiently instrumented to ensure settlement is complete during construction.

A more comprehensive discussion of these and other monitoring techniques is available in the Geotechnical Instrumentation for Monitoring Field Performance (Dunnicliff, 1993) and Geotechnical Instrumentation Reference Manual, NHI Course No. 13241 FHWA-HI-98-034 (Dunnicliff, 1998).

5 Reporting

Present planning phase embankment recommendations for highways and approach embankments in the District Preliminary Geotechnical Report (DPGR).

Planning phase recommendations for approach embankments should be presented in the Structure Preliminary Geotechnical Report so the bridge designer is made aware of potential or anticipated settlement/stability considerations, waiting periods, planned ground modification, etc. (see *Foundation Reports for Bridges* module).

Include the following in the *Analyses and Design* section of the Preliminary Geotechnical Design Report and Geotechnical Design Report.

1. Describe the representative cross-sectional geometry, ground line condition, and external loads. Reference the plan sheets when possible.
2. Design groundwater elevation.
3. Effects of embankment construction on adjacent ground and/or existing structures, utilities, both above and below ground. Present related recommendations in the *Recommendations* section.

Include the following in the *Recommendations* section of the Preliminary Geotechnical Design Report or Geotechnical Design Report:

1. Seismic hazard recommendations required in the following modules, as applicable:
    a. Surface Fault Rupture
    b. Liquefaction Evaluation
    c. Lateral Spreading
2. If requested by the district, provide mitigation recommendations for specific seismic hazards identified in #1.
3. Statement verifying that the global stability meets minimum requirements.
4. Specifics required in Section 5.1 below.
5. Optional - provide tables and/or figures such as plan views, elevations, and cross-sections, to detail the limits of specific recommendations.
6. Optional – include a statement to request the opportunity to review the draft final PS&E.

5.1 Information to Provide for each Type of Recommendation

5.1.1 Loading rates

- Allowable height of fill for each stage and maximum rate of construction.
- Geotechnical instrumentation to monitor field performance and provide information relevant to decisions regarding the rate of construction.
- If instrumentation is required to control the rate of fill placement, explain how this will be done and how the readings will be used to control the contractor's

operation. This information is typically presented in a non-standard special provision (NSSP) produced by the GP.

5.1.2 Preloading, Surcharges (heights and periods)

- Geometry (size and limits of surcharge).
- Rate(s) of loading (1-ft per week, etc.).
- When the surcharge will be removed.

5.1.3 Settlement

- Settlement waiting period (duration).
- Whether construction of adjacent structures be delayed during embankment settlement period.
- Need for monitoring of adjacent structures.
- Provide magnitude and time of settlement with and without recommended measures.
- State whether settlement will mostly be completed during construction and estimate amount of settlement that is expected to continue after embankment construction, post construction total and differential settlements.
- Provide locations that have significant differential settlement that can affect the performance of highway embankment.
- Discuss post construction settlement and potential effect to structures and utilities located within the embankment, especially if those facilities are also supported by adjacent soil or foundations that do not settle appreciably.
- Discuss potential settlement of existing structure foundations as the new embankment is placed.
- Discuss time periods that the settlement should be monitored and the frequency of observations.
- List types of monitoring such as survey hubs, monuments, and settlement plates for vertical and lateral movement.
- List type of piezometers for pore pressure monitoring.

5.1.4 Over-excavation

- Location and geometry (depths, limits of removal).
- Backfill materials.
- Geosynthetic materials used for separation and/or reinforcement.

5.1.5 Lightweight Fill

- Refer to the *Ground Modification* module.

5.1.6 Stabilization trenches

- Trench configuration and geometry, depth to and description of competent material.

- Backfill material and whether excavated material can be used as backfill.
- Location and dimension of drainage blanket, drainage material, pipe.
- Geosynthetic materials.

5.1.7 Buttresses/Berms

- Geometry (limits, height, width, slopes, cross-sections).
- Backfill materials.
- Drainage materials and details.
- Geosynthetic materials.

5.1.8 Surface Drainage

- Geometry (slopes, plans and cross-sections).
- Surface drainage design may include sheet flow, swales, ditches, catchment areas, and erosion control/slope protection.

5.1.9 Subdrainage

<u>Trenches</u>

- Geometry, size, type of geotextile, drainage pipe, type of trench back fill materials.

<u>Horizontal Drains</u>

- Location, length, vertical and horizontal angle, spacing, type of pipe and geotextile.

<u>Drainage Blanket</u>

- Slope, thickness, type of geotextile, size and type of drainage pipes.

<u>Relief Wells and Drainage Galleries</u>

- Location, spacing, diameter, depth, bottom bell out.
- Backfill material.
- Methods of water disposal i.e., pumping and discharge channels, or horizontal drains.

6 References

1. Soil Slope and Embankment Design, September 2005.
2. Washington State Dept. of Transportation Geotechnical Design Manual, M 46-03.09, December 2013, Chapter 9 Embankments.
3. Geotechnical Instrumentation Reference Manual, NHI Course No. 13241 FHWA-NHI-98-034 (Dunnicliff, 1998).
4. Geotechnical Instrumentation for Monitoring Field Performance (Dunnicliff, 1993)
5. Subsurface Investigations – Geotechnical Site Characterization Reference Manual, NHI Course No. 132031 FHWA-NHI-01-031 (Mayne, Christopher, and De Long).
6. Caltrans' Construction Manual, Construction Details, Earthwork (Section 4-19), June 2012.
7. Slope Stability and Foundation Investigation, California Division of Highways, September 1973 (Forsyth and McCauley).
8. WSDOT Standard Practice T925, January 2009
9. ASTM D2435/D2435M-11; Standard Test Methods for One-Dimensional Consolidation Properties of Incremental Loading; American Society for Testing and Materials International (2011.05.01)