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:

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)
	Typical	Special[3]	Placement Temperature > 70°F	Placement Temperature ≤ 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.

- 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 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 theappropriate 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.

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

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.

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.

(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 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 thetime 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:

(a) 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.

(c) 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.

- 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.

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.

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

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

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.

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.

(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:

$$DM = D_{80} + \left[12\% \times \left(\frac{\text{Mill Depth}}{0.10\text{ ft}}\right) \times D_{80}\right]$$

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:

$$PRM = \left(\frac{DM - TDS}{DM}\right) \times 100$$

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.

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

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:

$$GE_{CIR} = (\text{CIR Thickness}) \times G_{f\ CIR}$$

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:

$$\text{Cap Layer Thickness} = \frac{GE_{TOTAL} - GE_{CIR}}{G_f}$$

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} = (FDR Layer Thickness) × $G_{f\ FDR}$

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} = (AB Thickness)× $G_{f\ AB}$

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.

(7) *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 appropriategravel 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.

(8) *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.)

$$\text{Thickness (t)} = \frac{GE}{G_f}$$

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.

(9) 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.

(10) 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.

(11) 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.

(12) 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.

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.

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.