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. The aggregate can be treated and the binder can be modified. HMA could be made from new or recycled material. Examples of recycled asphalt include, but are not limited to, hot and cold in-place recycling. HMA is classified by type depending on the specified aggregate quality and mix design criteria appropriate for the project conditions. HMA types are found in the Standard Specifications and Standard Special Provisions.

631.2 Open Graded Friction Course (OGFC)

OGFC (formerly known as open graded asphalt concrete (OGAC)) is a non-structural wearing course used primarily on HMA. It is occasionally used with modified binders on rigid pavements. The primary benefit of using OGFC is the improvement of wet weather skid resistance, reduced potential for hydroplaning, reduced water splash and spray, and reduced night time wet pavement glare. Secondary benefits include better wet-night visibility of traffic lane stripes and pavement markers, and better wet weather (day and night) delineation between the traveled way and shoulders.

For 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.

631.3 Rubberized Hot Mix Asphalt (RHMA)

Rubberized asphalt is formulated by mixing granulated (crumb) rubber with hot asphalt to form an elastic binder with less susceptibility to temperature changes. The rubberized asphalt is substituted for the regular asphalt as the binder for the flexible pavement. This is called the wet method. Other methods of using rubber in flexible pavements are available. See Asphalt Rubber Usages Guide (ARUG), available on the Department Pavement website, for further details.

RHMA is generally specified to retard reflection cracking, resist thermal stresses created by wide temperature variations and add flexibility to a structural overlay. At present, the Department uses gap-graded (RHMA-G) and open-graded (RHMA-O) rubberized asphalt. The difference between the two is in the gradation of the aggregate. RHMA-O is used only as a non-structural wearing course. RHMA-G can be used as either a surface course or a non-structural wearing course. RHMA should be considered the strategy of choice when evaluating alternatives for a project. If RHMA is found to be inappropriate due to availability, constructibility, environmental factors, or cost, it shall be documented in the scoping document, Project Initiation Document (PID), or Project Report (PR).

The minimum thickness for RHMA (any type) should be 0.10 foot for new construction and rehabilitation. For pavement preservation, RHMA may be placed as thin as 0.08 foot provided compaction requirements can be met. The maximum thickness for RHMA-G is 0.20 foot. The maximum thickness for RHMA-O is 0.15 foot. If a thicker surface layer or overlay is called for, then a HMA layer should be placed prior to placing the RHMA. RHMA should only be placed over a flexible or rigid surface course and not on a granular layer. RHMA-O may be placed on top of new RHMA-G. Do not place conventional HMA or OGFC over new RHMA pavement.

It is undesirable to place RHMA-G or 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, RHMA-G should be placed over the whole cross section of the road (traveled way and shoulders).

For additional information and applicability of RHMA in new construction and rehabilitation projects refer to Asphalt Rubber Usage Guide available on the Department Pavement website.

631.4 Other Types of Flexible Pavement

There are other types of flexible pavements 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 Department's Maintenance Manual.

631.5 Stress Absorbing Membrane Interlayers (SAMI)

SAMI are used with flexible layer rehabilitation as a means to retard reflective cracks, prevent water intrusion, and (in the case of SAMI-R (rubberized)) enhance pavement structural strength. Two types of SAMI are:

- Rubberized (SAMI-R). SAMI-R is a rubberized chip seal.
- Geosynthetic Pavement Interlayer (GPI), consists of asphalt-imbued geotextile.

Sound engineering judgment is required when considering the use of a SAMI.

- 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 SAMI-R 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 SAMI may be placed between layers of new flexible pavement, such as on a 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. Coarse surfaces may penetrate the 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:

- When placed under rubberized hot mix asphalt (RHMA). This is due to the high placement temperature of the RHMA-G mix, which is close to the melting temperature of the GPI.
- 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.

Topic 632 - Engineering Criteria

632.1 Engineering Properties

(1) *Smoothness.* The smoothness of a pavement impacts its ride quality, overall durability, and performance. Ride quality (which is measured by the smoothness of ride) is also the highest concern listed in public surveys on pavement condition. Smoothness specifications have been improved and incentive/disincentive specifications have been developed to assure designed smoothness values are achieved in construction. Incentive / disincentive specifications can be used where the project meets the warrants for the specification. For up to date and additional information on smoothness and the application of the smoothness specifications see the smoothness page on the Department Pavement website.

(2) *Asphalt Binder Type.* Asphalt binders are most commonly characterized by their physical properties. An asphalt binder's physical properties directly relate to 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 specifically designed to address three specific pavement distress modes: permanent deformation (rutting), fatigue cracking, and low temperature cracking.

In the past, the Department has classified unmodified asphalt binder 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 from January 1, 2007, the Department has graded polymer-modified binders as Performance Graded-Polymer Modified (PG-PM) binder in lieu of PBA.

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 adjustments. 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 must meet 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, in hot mix asphalt (HMA), 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 conventional asphalt in many paving and maintenance applications.

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.

Special conditions are defined as those roadways or portion of roadways that need additional attention due to conditions such as:

- Heavy truck/bus traffic (over 10 million ESALs for 20 years).
- Truck/bus stopping areas (parking area, rest area, loading area, etc.).
- Truck/bus stop and go areas (intersections, metered ramps, ramps to and from Truck Scales etc.).
- Truck/bus climbing and descending lanes.

The final decision as to whether a roadway meets the criteria for special conditions rests with the District. It should be noted that even though special binder grades help meet the flexible pavement requirements for high truck/bus use areas, they should not be considered as the only measure needed to meet these special conditions. The District Materials Engineer should be consulted for additional recommendations for these locations.

For more detailed information on PG binder selection, refer to the Department Pavement website.

632.2 Performance Factors

The procedures and practices found in this chapter are based on research and field experimentation undertaken by the Department 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

Table 632.1

Asphalt Binder Grade

Binder / Climatic Region	Binder Grades for Hot Mixed Asphalt (HMA)[1], [2]				Gap and Open Graded Rubberized Hot Mix Asphalt (RHMA)
	Dense Graded HMA		Open Graded HMA		
			Placement Temperature		
	Typical	Special[3]	> 70°F	≤ 70°F	
South Coast Central Coast Inland Valley	PG 64-10	PG 70-10 or PG 64-28 PM	PG 64-10	PG 58-34 PM	PG 64-16
North Coast	PG 64-16	PG 64-28 PM	PG 64-16	PG 58-34 PM	PG 64-16
Low Mountain South Mountain	PG 64-16	PG 64-28 PM	PG 64-16	PG 58-34 PM	PG 64-16
High Mountain High Desert	PG 64-28	PG 58-34 PM[4]	PG 64-28	PG 58-34 PM	PG 58-22
Desert	PG 70-10	PG 64-28 PM	PG 70-10	PG 58-34 PM or PG 64-28 PM[3]	PG 64-16

NOTES:

(1) PG = Performance Graded

(2) PM = Polmer Modified

(3) PG 76-22 PM may be specified for conventional dense graded hot mix asphalt for special conditions in all climatic regions when specifically requested by the District Materials Engineer.

(4) PG 64-28 may be specified when specifically requested by the District Materials Engineer.

(5) Consult the District Materials Engineer for which binder grade to use.

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.

Topic 633 - Engineering Procedures for New and Reconstruction Projects

633.1 Empirical Method

The data needed to engineer a flexible pavement are California R-value of the subgrade and the TI for the pavement design life. Engineering of the flexible pavement is based on a relationship between the gravel equivalent (GE) of the pavement structural materials, the TI, and the California R-value of the underlying material. The relationship was developed by the Department 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 California Department of Transportation empirical method, commonly referred to as the Hveem 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 sections:

(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 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:

$$GE = 0.0032(TI)(100 - R)$$

Where:

GE = Gravel Equivalent in feet

TI = Traffic Index

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. Gravel factors for HMA decrease as TI increases, and also increase with HMA thickness greater than 0.5 foot; while G_f for base and subbase materials are only dependent on the material type.

The G_f of HMA varies with layer thickness (t) for any given TI as follows:

$t \leq 0.50$ ft:	$G_f = \frac{5.67}{(TI)^{1/2}}$
$t > 0.50$ ft:	$G_f = (7.00)\frac{(t)^{1/3}}{(TI)^{1/2}}$

These equations are valid for TIs ranging from 5 to 15. For TIs greater than 15, use a rigid or composite pavement or contact the Headquarters Division of Maintenance – Pavement Program for experimental options. For TIs less than 5, use a TI=5. 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 633.1B.

(e) The design thickness of each structural layer of flexible pavement is obtained either by dividing the GE by the appropriate gravel factor 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 twice the maximum aggregate size, and the minimum thickness of the 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 Treated Subbase (LTS) should be limited, with 0.65 foot as the minimum and 2 feet as the maximum. A surface layer placed directly on the LTS 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.

(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 initial GE for the entire pavement structure. Increase this 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 mixed 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 mixed asphalt.

A Treated Permeable Base (TPB) layer may be placed below full depth hot mix asphalt on widening projects to perpetuate, or match, an existing treated permeable base 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 table will be used, the GE of the working table is subtracted from the GE of the surface layer as well. A working table is a minimum thickness of material, asphalt, cement, or granular based, used to place construction equipment and achieve compaction requirements when compaction is difficult or impossible to meet.

(3) *Modifications for Pavement Design Life Greater than 20 Years.* The above procedure is based on an empirical method for a twenty-year pavement 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 with a design life greater than twenty years:

- Use the procedures for full depth hot mix asphalt to determine the minimum thickness for flexible pavement. Cement treated base or lean concrete base can be used in lieu of hot mix asphalt but not in lieu of aggregate base, aggregate subbase, or a treated permeable base.
- Place a minimum 0.50 foot of Class 2 Aggregate base underneath the flexible pavement. This aggregate base layer is not considered part of the pavement structural design and cannot be used to reduce the thickness of the full depth hot mix asphalt layer.
- Use a non-structural wearing course (such as OGFC) above the surface layer (minimum 0.10 foot). See Index 602.1(5) for further details.
- Use rubberized hot mix asphalt (maximum 0.20 foot) or a PG-PM binder (minimum 0.20 foot) for the top of the surface layer.

The following enhancements should be incorporated into all flexible pavements with a pavement design life greater than twenty years when recommended by the District Materials Engineer:

(a) Use higher asphalt binder content for bottom of the surface layer (rich-bottom concept) and using higher stiffness asphalt binder.

(b) Utilize subgrade enhancement fabrics at the subgrade for California R-values less than 40.

(c) Use SAMIs within the surface layer.

Table 633.1
Gravel Equivalents (GE) and Thickness of Structural Layers (ft)

Actual Layer Thickness (ft) [5]	HMA [1], [2]											Base and Subbase [3]					
	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	HMAB; 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) [4]											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 663.1B for additional information on Gravel Factors (G_f) and California R-values for base and subbase materials.

(4) These G_f values are for TIs shown and HMA thickness equal to or less than 0.5 foot only. For HMA thickness greater than 0.5 foot, appropriate G_f should be determined using the equation in Index 633.1(1)(c).

(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.

(d) Use a separation fabric above granular layers. Note that the fabric used needs to be able to resist construction loads or construction equipment must be able to keep off of the fabric.

(4) *Alternate Procedures and Materials.* At times, experimental procedures and/or alternative materials are proposed as part of the design or construction. See Topic 606 for further discussion.

633.2 Mechanistic-Empirical Method

For information on Mechanistic-Empirical Design application and requirements, see Index 606.3.

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 required for preventive maintenance projects.

634.2 Capital Preventive Maintenance (CAPM)

The standard design for a flexible pavement CAPM project with an International Roughness Index (IRI) less than 170 inches per mile at PS&E is an overlay of either 0.15 foot of rubberized hot mix asphalt or 0.20 foot of conventional asphalt binder or other approved modified asphalt binder mix. A 0.20-foot overlay of rubberized hot mix asphalt may be appropriate in certain circumstances and may be utilized with the concurrence of the Headquarters Program Advisor in the Headquarters Division of Maintenance – Pavement Program.

For flexible pavement CAPM projects with an IRI greater than 170 inches per mile, the standard design is to place a 0.25-foot hot mix asphalt overlay in two lifts Existing pavement may be milled or cold planed down to the depth of the overlay prior to placing the overlay. 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.

If the necessary ride improvement cannot be adequately addressed with these CAPM treatments, the project should be developed as a roadway rehabilitation project.

A 0.06 foot – 0.10 foot non-structural wearing course (such as an open graded friction course) may be added, but is not to be considered part of the overlay requirements.

Deflection studies are not required for CAPM projects. The roadway rehabilitation requirements for overlays (see Index 635.1(1)) and preparation of existing pavement surface (Index 635.1(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 and Roadway Rehabilitation

635.1 Empirical Method

(1) *General.* The methods presented in this topic are based on studies for a ten-year pavement design life with extrapolations for twenty-year pavement design life. (For pavement design lives greater than twenty years, contact the Headquarters Office of Asphalt Pavement).

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.

Rehabilitation strategies are divided into three categories:

- Overlay
- Mill and Overlay
- Remove and Replace

Rehabilitation designs are governed by one of the following three criteria:

- Structural adequacy
- Reflective crack retardation
- 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 requires collecting background data as well as field data. The Pavement Condition Report (PCR), as-built plans, and traffic information are some of the sources used to prepare 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 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 coring data are used to measure the structural adequacy of the existing pavement. A deflection study is the process of selecting deflection test sections, measuring pavement surface deflection, and calculating statistical deflection values as described in California Test Method 356 for flexible pavement deflection measurements. A copy of the test method can be obtained and/or downloaded from the Department Pavement website.

To provide reliable rehabilitation strategies, deflection studies should be done no more than 18 months prior to the start of construction.

(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:

$$\bar{x} = \frac{\Sigma D_i}{n}$$

Where:

$\bar{x}$ = mean deflection for a test section, in inches

D_i = an individual measured surface deflection in the test section, in inches

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:

$$D_{80} = \bar{x} + 0.84s$$

Where:

D_{80} = 80th percentile of the measured surface deflections for a test section, in inches

s = standard deviation of all test points for a test section, in inches

$$s = \sqrt{\frac{\sum\left(D_i - \bar{x}\right)^2}{n-1}}$$

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 hot mix asphalt 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) Procedures for Rigid Pavement Overlay on Existing Flexible Pavement (Concrete Overlay). For concrete overlay (sometimes referred to as whitetopping) strategies, 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. The overlay should be thick enough to be considered a structural layer. Therefore, thin or ultra thin concrete layers (< 0.65 foot) are not qualified as concrete overlay. To provide a smooth and level grade for the rigid surface layer, place a 0.10 foot to 0.15 foot HMA on top of the existing flexible layer.

(5) Procedures for Flexible Overlay on Existing Flexible Pavement.

(a) Structural Adequacy. Pavement condition, thickness of surface layer, measured deflections, and the projected TI provide the majority of the information used for determining structural adequacy. Structural adequacy is determined using the following procedures and rules:

(b) 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 the planned TI. TDS is obtained from Table 635.1A by knowing the existing thickness of the flexible layer and TI. For existing flexible pavement over a treated

Table 635.1A
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 HMA cover.

Table 635.1B
Gravel Equivalence Needed to Reduce 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.

base, use TI and the TDS values in the row for Treated Base (TB) found in Table 635.1A

The existing base is considered treated if it meets all of the following conditions:

- Its depth is equal to or greater than 0.35 foot.
- The D_{80} is less than 0.015 inch.

(1) It is rigid pavement, Lean Concrete Base (LCB), or Class A Cement Treated Base (CTB-A). For each group compare the TDS to the average D_{80}. The D_{80} is the 80th percentile deflection value. It represents a deflection level at which approximately 80 percent of all deflections of a sample group are less than the calculated value and 20 percent are greater than the value. Therefore, a strategy based on the 80th percentile deflection will provide thicker rehabilitation than using the mean deflection.

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:

$$\text{PRD} = \frac{AverageD_{80} - TDS}{AverageD_{80}}(100)$$

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

(2) Using the calculated PRD and Table 635.1B, determine the GE required to reduce the deflections to less than the tolerable level.

(3) Divide the GE obtained from Table 635.1B by the appropriate G_f for the overlay material to determine the required thickness of the overlay.

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

Commonly used G_f for flexible pavement rehabilitation are presented in Table 635.1C.

Table 635.1C

Commonly Used G_f for Flexible Pavement Rehabilitation

Material	G_f (1)
Hot Mix Asphalt Overlay	1.9
Hot Recycled Asphalt	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 635.1(6)(a).

(c) Reflective Cracking. The goal of these procedures is to keep cracks at the bottom of the surface course layer from propagating to the surface during the pavement design life. Retarding the propagation of cracks is an important factor to consider when engineering flexible pavement overlays. The procedures and rules for engineering for reflective cracking retardation are as follows:

(1) Determine the minimum thickness required for a 10-year pavement

design life. For flexible pavements over untreated bases, the minimum thickness of a HMA overlay with a ten-year design life should be half the thickness of the existing surface course layer but not to exceed 0.35 foot.

For flexible pavements over treated bases (as defined in the previous section on structural adequacy), a minimum HMA overlay of 0.35 foot should be used for a 20-year design life.

Exception: 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 thickness of 0.45 foot should be used.

(2) Adjust thickness if the pavement design life is different than 10 years. For a twenty-year design life, experience has shown that the thickness should be 125 percent of the ten-year thickness for reflective cracking retardation.

(3) 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 equivalencies are tabulated in Table 635.1D.

If a SAMI-R is placed under a non-rubberized hot mix asphalt that is engineered for reflective crack retardation, the equivalence of a SAMI-R depends upon the type of base material under the existing pavement. When the base is a treated material, a SAMI-R placed under HMA or OGFC is considered to be equivalent to 0.10 foot of HMA. When the base is an untreated material SAMI-R is equivalent to 0.15 foot of HMA.

Table 635.1D
Reflective Crack Retardation Equivalencies
(Thickness in feet)

HMA (1)	RHMA-G	RHMA-G over SAMI-R
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 635.1(5)(b) for minimum and maximum HMA thicknesses recommended by the Department for reflective crack retardation on flexible pavements.

A Geosynthetic Pavement Interlay (GPI) placed under HMA that is engineered 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.

Wearing courses are not included in the thickness used to address reflective cracking.

Thicker sections may be warranted. Factors to be considered that might necessitate a thicker overlay are:

- Type, sizes, and amounts of surface cracks.
- Extent of localized failures.
- Existing performance material and age.
- Thickness and performance of previous rehabilitation strategy.
- Environmental factors.
- 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.

(d) Ride Quality. Ride quality is evaluated based on the pavement's smoothness. The Department records smoothness as part of 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.

(e) To improve ride quality, place a hot mix asphalt overlay thick enough (0.25 foot minimum) to be placed in two lifts. RHMA-G may be placed in two 0.10 foot lifts to meet the ride quality requirement. However, if a 0.10 foot layer cools prior to compaction, this strategy is inappropriate. A wearing course may be included in the ride quality thickness. SAMI's do not have any effect on ride quality.

Ride quality will ultimately govern the rehabilitation strategy if the requirements for structural adequacy and reflective crack retardation are less than 0.25 foot.

Note that the Standard Specifications require the Contractor to place a 0.25 foot HMA in one layer. Projects with rehabilitation recommendations based on improving ride quality must specify in the Special Provisions that the overlay needs to be placed in two lifts. Examples of design calculations for flexible overlay thickness on existing flexible pavement are available on the Department Pavement website.

(6) *Mill and Overlay Procedures.* Mill and Overlay is the removal of part of the surface course 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 during the hot or cold in-place recycling. If removal of the entire surface course layer and any portion of the base are required, use the procedures for Remove and Replace in Index 635.1(7).

a) Structural Adequacy. The engineering procedures for determining the structural adequacy for Mill and Overlay are the same as those for overlays found in Index 635.1(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". As defined by the Department, the analytical depth is the least of:

- The milled depth where the Percent Reduction in deflection required at the Milled depth (PRM) reaches 70 percent.
- The milled depth equals 0.50 foot.

- The bottom of the existing HMA layer.

The percent reduction in deflection required at the milled depth is based research that determined deflections increase 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 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, determine the TDS from Table 635.1A. The deflection at the milled depth is found from the equation:

$$\mathrm{DM} = \mathrm{D}_{80} + \left[(12\%) \left(\frac{\mathit{MillDepth}}{\mathit{0.10\ ft}} \right) (\mathrm{D}_{80}) \right]$$

Where

D_{80} = 80th Percentile deflections, in inches.

Mill Depth = the depth of the milling in feet.

DM = the calculated deflection at the Milled depth in inches.

Then:

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

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 635.1B 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.
- 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:

Additional GE = [(1.4)(milled depth below the analytical depth)]

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 635.1B). As stated in Index 633.1(1)(d), the required minimum thickness of the overlay is determined by dividing the total GE by the G_f of the new overlay material.

$$\text{Thickness (t)} = \frac{\text{GE}}{\text{G}_\text{f}}$$

If milled material is to be replaced by Hot Recycled Asphalt (HRA), the overlay thickness is the same as that of HMA since both materials have a G_f of 1.9 (see Table 635.1C).

Since Cold In-Place Recycled Asphalt (CIR) has low resistance to abrasion, if the milled material is to be replaced with CIR, the CIR layer must be covered with a wearing surface shortly after the recycling process. To determine the required thickness of the cap layer, first determine the GE of the CIR layer:

$$\text{GE}_\text{CIR} = (\text{CIR thickness})(\text{G}_\text{f CIR})$$

Where:

GE_{CIR} = Gravel Equivalence of the CIR

$G_{f\ CIR}$ = Gravel Factor of CIR = 1.5 (see Table 635.1C)

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.

If the cap layer is OGFC, its thickness should not be considered in pavement structure design. It is recommended to round up to get the CIR and cap layer thicknesses.

(b) Reflective Cracking. The minimum thickness for reflective cracking is determined using the same procedures used for reflective cracking for overlays found in Index 635.1(5)(b) except that the thickness is determined based on the remaining surface layer rather than the initial surface layer.

(c) Ride Quality. Milling the existing surface and overlaying with new surface course is considered sufficient to smooth a rough pavement.

(7) *Remove and Replace.* The Remove and Replace operation 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.

(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. It should be noted that the greater the depth of removal, the less accurate the determination might be of the calculated deflections.

Also, 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 use 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 procedures are 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 635.1A 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 635.1B 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.

(8) *Preparation of Existing Pavement.* <u>Existing pavement distresses should be repaired before overlaying the pavement.</u> Cracks wider than ¼ inch should be sealed; loose pavement removed/replaced; and potholes and localized failures repaired. 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.

(9) *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 constructibility, maintenance, and the other requirements found in Chapter 610.

635.2 Mechanistic-Empirical Method

For information on Mechanistic-Empirical Design application and requirements, see Index 606.3.

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 should be considered for exit ramp termini where there is a potential for shoving or rutting. At a minimum, rigid pavement should be used for exit ramp termini of flexible pavement ramps where a significant volume of trucks is anticipated (TI > 12.0). 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, the Design Engineer should contact 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.* To engineer a park and ride facility based on the standard traffic projections is not practicable because of the unpredictability of traffic. Therefore, standard structures, based on anticipated typical load, have been adopted. However, if project site-specific traffic information is available, it should be used with the standard engineering procedures.

The layer thicknesses shown in Table 636.4 are 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.

(3) *Bus pads.* Use rigid or composite pavement strategies for bus pads.

Table 636.4
Pavement Structures for Park and Ride Facilities

California R-value for the Subgrade Soil	Thickness of Layers	
	HMA[1] (ft)	AB (ft)
< 40	0.25	0
But < 60	0.15	0.35
≥ 40	0.15	0
≥ 60	Penetration Treatment[2]	

NOTES:

(1) Place in one lift.

(2) Penetration Treatment is the application of a liquid asphalt or dust palliative on compacted roadbed material. See Standard Specifications.

Topic 637 - Engineering Analysis Software

Software programs for engineering flexible pavements using the procedures 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.