



PAVEMENT TECH NOTES

FLEXIBLE PAVEMENT DESIGN EXAMPLES - NEW CONSTRUCTION

September 28, 2006

Editors Note: The following information was extracted from the July 1, 1995 edition of the Highway Design Manual, Chapter 600 and updated to reflect current practices.

Introduction

Flexible pavement structures are constructed of a flexible pavement (typically asphalt) surface layer that is placed over a treated or untreated base layer and an untreated subbase layer.

Flexible pavement types and procedures are found in Chapter 630 of the Highway Design Manual (HDM). The purpose of this guide is to provide some examples of new flexible pavement designs using the procedures for new construction described in HDM Topic 633. Rehabilitation design procedures and strategies for flexible pavement may be found in HDM Topic 635. Examples of rehabilitation designs may be found on the Department pavement website at:

<http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm>

Flexible pavement design examples included in this guide are:

1. HMA/AB/AS or HMA/CTB-B/AS
2. HMA/CTB-A/AS
3. HMA/ATPB/AB/AS or HMA/HMAB/ATPB/AB/AS
4. HMA/ATPB/AB/AS or full-depth HMA
5. RAC-G/HMA/AB/AS

Where:

HMA – Hot Mixed Asphalt or Asphalt Concrete

CTB-A – Cement Treated Base Class A

AB – Aggregate Base

CTB-B – Cement Treated Base Class B

AS – Aggregate Subbase

ATPB – Asphalt Treated Permeable Base

CTPB – Cement Treated Permeable Base

HMAB – Hot Mixed Asphalt Base (Type A or B)

RAC-G – Rubberized Asphalt Concrete Type G (Gap Graded)



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(1) Design Example 1 - Undrained Pavement structures Designed per California R-values of Underlying Layers (HMA/AB/AS or HMA/CTB-B/AS).

- (a) Determine the total pavement structure GE, over the subgrade, using the standard design formula and the California R-value of the subgrade. For this example, assume a subgrade with a California R-value of 10. A TI of 12.5 is assigned based on the traffic forecasts for trucks. Thus, the total required GE is:

$$GE_{\text{Total}} = 0.0032(\text{TI}) (100 - R_{\text{Subgrade}}); \text{ where } R \text{ is the subgrade California R-value}$$
$$= 0.0032(12.5) (100 - 10) = 3.60 \text{ ft.}$$

- (b) Determine the GE of the HMA surface layer using the standard formula. In this case, R is the California R-value of the Class-2 AB layer (see HDM Table 663.1B of the HDM for California R-values of various materials).

$$GE_{\text{HMA}} = 0.0032(\text{TI}) (100 - R); \text{ where } R \text{ is the Class-2 AB California R-value}$$
$$GE_{\text{HMA}} = 0.0032 (12.5) (100 - 78) = 0.88 \text{ ft.}$$

- (c) Add the required 0.20 ft safety factor to the total GE of HMA:

$$\text{Final } GE_{\text{HMA}} = GE_{\text{HMA}} + \text{Safety Factor} = 0.88 + 0.20 = 1.08 \text{ ft.}$$

- (d) Use HDM Table 633.1 of the HDM to determine the GE and thickness of the HMA surface layer:

With a TI of 12.5, the closest GE from HDM Table 633.1 is 1.09 ft for which the required HMA thickness is 0.65 ft.

- (e) Although the calculated GE for the HMA is 1.09 ft, Table 633.1 of the HDM shows a GE of 1.09 as nearest to the calculated value. The value from Table 633.1 of the HDM will be used in subsequent calculations for the remaining layers.

- (f) Determine the required GE of the combined HMA and AB layers using the standard design formula. In this case, R is the California R-value of the AS layer. For this example, assume a Class 2 AS, which has a specified minimum California R-value of 50 (see Table 663.1B of the HDM).

$$GE_{\text{HMA} + \text{AB}} = 0.0032(\text{TI}) (100 - R) = 0.0032(12.5) (100 - 50) = 2.00 \text{ ft.}$$

where R is the aggregate subbase California R-value

- (g) Add the required 0.20 foot safety factor to this value to determine the GE of the combined HMA and AB.



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$$GE_{HMA + AB} = GE_{HMA} + AB + \text{Safety Factor} = 2.00 + 0.20 = 2.20\text{ft.}$$

- (h) Subtract the GE of the HMA (Step d) from the combined GE of the HMA and AB to determine the required GE of the AB.

$$GE_{AB} = GE_{HMA+AB} - GE_{HMA} = 2.20 - 1.09 = 1.11 \text{ ft.}$$

Table 633.1 of the HDM shows a value of 1.10 as the closest value to the calculated GE of 1.10 ft for the AB layer. The tabular value of 1.11 will be used in subsequent calculations for which the corresponding AB thickness is 1.00 ft.

****Note****

If CTB-B is used in lieu of AB, use HDM Table 633.1 of the HDM to determine actual thickness:

With a GE of 1.11 ft, HDM Table 633.1 shows CTB-B with a GE value of 1.14. This corresponds to a layer thickness of 0.95 foot of CTB-B.

- (i) Subtract the GE of the HMA and AB layers, taken from HDM Table 663.1, from the GE of the total pavement structure (Step a) to determine the GE of the AS:

$$3.60 - 1.09(\text{HMA}) - 1.10(\text{AB}) = 1.41 \text{ ft (Round to 1.40)}$$

****Note****

If CTB-B is used in lieu of AB, the GE of the AS will be:

$$3.60 - 1.09(\text{HMA}) - 1.14(\text{CTB-B}) = 1.37 \text{ ft (Round to 1.35)}$$

Since AS has a G_f of 1.0, the actual thickness and the GE are equal.

- (j) The structural layer thicknesses for the above example are:

****Note**** If CTB-B is used:

Layer	Thickness (ft)
HMA	0.65
AB	0.95
AS	1.35

Layer	Thickness (ft)
HMA	0.65
CTB - B	1.00
AS	1.35



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(2) Design Example 2 - Undrained Pavement Structures with Materials not Subject to California R-value Tests (HMA/CTB-A/AS).

- (a) Determine the total pavement structure GE as described in (1) (a) above. Use the same TI and subgrade California R-value as in Design Example 1.

$$GE_{\text{Total}} = 0.0032(\text{TI}) (100-\text{R}); \text{ Where R is the subgrade California R-value.}$$

$$GE_{\text{Total}} = 0.0032(12.5) (100-10) = 3.60 \text{ ft.}$$

- (b) To determine the GE of the HMA surface layer when placing a material not subject to the California R-value tests (see HDM Table 663.1B for a list of materials not subject to California R-value tests); calculate the GE of the combined HMA and CTB using the standard design formula and the California R-value of the AS. This is needed because 40% of the GE for the combined HMA and CTB will be used to determine the GE of the HMA, which will lead to the HMA surface layer thickness. In cases where the subgrade is of such quality that AS is not necessary, the California R-value of the subgrade is used. For this example, assume a Class 2 AS with a specified California R-value of 50.

Note: When AS is to be replaced with additional base material, use California R-value 50 in this calculation.

$$GE_{\text{HMA} + \text{CTB} - \text{A}} = 0.0032(\text{TI}) (100-\text{R}); \text{ Where R is the AS California R-value.}$$

$$GE_{\text{HMA} + \text{CTB} - \text{A}} = 0.0032(12.5) (100-50) = 2.00 \text{ ft.}$$

- (c) Determine the GE of the HMA layer by multiplying the GE of the combined HMA and CTB layers by 0.4 and adding the safety factor.

$$GE_{\text{HMA}} = GE_{\text{HMA} + \text{CTB} - \text{A}} (0.4) + \text{Safety Factor}$$

$$GE_{\text{HMA}} = (2.00) (0.4) + 0.20 = 1.00 \text{ ft.}$$

- (d) Determine the actual thickness of HMA from Table 633.1 of the HDM.

The closest GE from HDM Table 633.1 is 0.98 ft which corresponds to an HMA layer thickness of 0.60 ft. Subsequent calculations will use 0.98 ft as the GE of the HMA.

- (e) To determine the GE of the CTB -A layer, add the safety factor to the GE of the combined HMA and CTB layers (step b above) and subtract the GE of the HMA surface layer (step d above).

$$GE_{\text{CTB} - \text{A}} = GE_{\text{HMA} + \text{CTB} - \text{A}} + \text{Safety Factor} - GE_{\text{HMA}}$$

$$GE_{\text{CTB} - \text{A}} = 0.0032(\text{TI}) (100-\text{R}) + \text{Safety Factor} - GE_{\text{HMA}}; \text{ Where R is the AS California R-value.}$$

$$GE_{\text{CTB} - \text{A}} = 0.0032(12.5) (100-50) + 0.20 \text{ ft} - 0.98 \text{ ft} \\ = 2.00 + 0.20 - 0.98 = 1.22 \text{ ft.}$$



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- (f) The closest GE from HDM Table 633.1 is 1.19 ft which corresponds to a CTB –A layer thickness of 0.70 ft. Subsequent calculations will use 1.19 ft as the GE of the CTB –A.
- (g) Subtract the GE of the HMA and the CTB –A from the total GE over the subgrade to determine the GE of the AS layer.

$$3.60(\text{total}) - 0.98(\text{HMA}) - 1.19(\text{CTB CL-A}) = 1.43 \text{ ft (Round to 1.45)}$$

- (h) The pavement structural layer thicknesses for the above example are:

Layer	Thickness (ft)
HMA	0.60
CTB (CL - A)	0.70
AS	1.45



I-15 at Baker Grade (1961)



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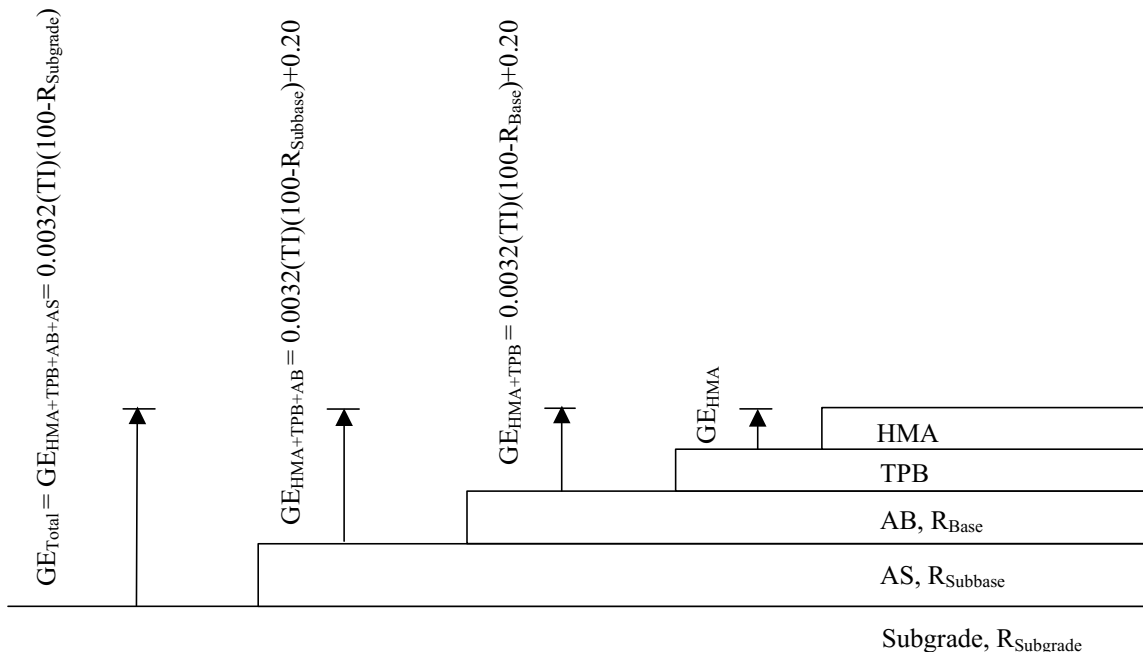
(3) Design Example 3 - Drained Pavement Structures Which Include Treated Permeable Bases. (HMA/ATPB/AB/AS or HMA/HMAB/ATPB/AB/AS):

Note: The efficiency of the drainage layer can be affected by a lack of continuity in the treated permeable base across the width of the traveled way. To help assure adequate drainage on a multilane facility, the flexible pavement and the treated permeable base layers should not be stepped to accommodate differences in TIs of adjacent lanes. Reducing the base and/or subbase layer as appropriate to satisfy the GE requirement over the subgrade can compensate for the resulting overdesign of the flexible pavement in the median lanes.

- (a) Determine the total pavement structure GE as described in Design Example (1) (a) above. Use the same TI and subgrade California R-value as in previous design examples.

$GE_{Total} = 0.0032 (TI) (100-R)$; Where R is the subgrade California R-value.

$GE_{Total} = 0.0032(12.5) (100-10) = 3.60 \text{ ft}$



- (b) Determine the GE of the combined HMA, treated permeable base (TPB), and base using the standard design formula and the California R-value of the AS. This also follows the rule that 40% of the GE above the AS will be used for the HMA surface layer thickness calculations. In this example, Class 2 AS with a specified California R-value of 50 is assumed.

Note: When AS is to be replaced with additional base material, use California R-value of 50 in this calculation.



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$$GE_{HMA + TPB + AB} = 0.0032 (TI) (100 - R_{Subbase})$$

$$GE_{HMA + TPB + AB} = 0.0032(12.5) (100 - 50) = 2.00 \text{ ft.}$$

- (c) Determine the GE of the HMA surface layer by multiplying the required GE of the combined HMA, treated permeable base and base layers by 0.4 and adding the safety factor. On multiple lane roadways, the HMA thickness is constant for all lanes and is based on the TI of the outside lanes.

$$GE_{HMA} = (GE_{HMA + TPB + AB})(0.40) + 0.20 \text{ ft} = (2.00 \text{ ft}) (0.40) + 0.20 \text{ ft} = 1.00 \text{ ft.}$$

- (d) The closest GE from Table 633.1 is 0.98 ft which corresponds to an HMA surface layer thickness of 0.60 ft. Subsequent calculations will use 0.98 ft as the GE of the HMA.

- (e) The GE for Asphalt Treated Permeable Base (ATPB) is 0.35 ft for a corresponding 0.25 ft layer thickness of ATPB. For Cement Treated Permeable Base (CTPB), the GE is 0.60 ft for a corresponding 0.35 ft layer thickness of CTPB. ATPB is used in this example.

$$GE_{ATPB} = 0.35 \text{ ft} = 0.25 \text{ ft thickness for ATPB}$$

- (f) Determine the required GE of the base layer by adding the 0.20 ft safety factor to the GE required over the AS (as shown in 3b above) and then subtracting the GE of the combined HMA and treated permeable base layers.

$$GE_{AB} = GE_{HMA + ATPB + AB} - GE_{HMA} - GE_{ATPB} + 0.20 \text{ ft}$$

$$GE_{AB} = 2.00 \text{ ft} - 0.98 \text{ ft} - 0.35 \text{ ft} + 0.20 \text{ ft} = 0.87 \text{ ft}$$

- (g) The closest GE from HDM Table 633.1 for AB is 0.88 ft, which corresponds to an AB layer thickness of 0.88 ft. Subsequent calculations will use 0.88 as the GE of the AB.

$$GE_{AB} = 0.88 \text{ ft (From Table 633.1 of the HDM)}$$

- (h) Determine the required GE thickness of the AS by subtracting the tabular values from Table 633.1 of the HDM for the GE thickness of the combined HMA, permeable base, and base layers from the total GE required for the pavement structure (as shown in 3a above).

$$GE_{AS} = GE_{Total} - (GE_{HMA} + GE_{ATPB} + GE_{AB})$$

$$GE_{AS} = 3.60 \text{ ft} - (0.98 + 0.35 + 0.88) = 3.60 - 2.21 = 1.39 \text{ ft}$$

$$GE_{AS} = 1.39 \text{ ft (Round up to 1.40 ft)}$$



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****Note**:**

As an alternative, hot mixed asphalt base (HMAB) can be substituted for other HMA types in the pavement structure on an equal basis but is not to be used as the surface course. HMAB is a dense graded HMA material and differs from other HMA in that it includes aggregates with a larger nominal size. Thus, if 0.15 ft were chosen for the HMA surface course then an HMAB layer thickness of 0.45 ft would be used.

Layer	Alternative 1 (ft)	Alternative 2 (ft)
HMA	0.60	0.15
HMAB	-----	0.45
ATPB	0.25	0.25
AB	0.80	0.80
AS	1.40	1.40

(4) Design Example 4 (HMA/ATPB/AB/AS or full-depth HMA):

An additional lane is to be added adjacent to an existing pavement structure, which has a total thickness of 2.75 ft consisting of 0.60 ft HMA, 0.25 ft ATPB, 0.50 ft CTB, and 0.40 ft AS. The new lane has a projected TI of 12.5 and will be constructed over a subgrade with a California R-value of 10. Full-depth HMA provides a viable alternative since it will reduce the number of construction layers and the time required to complete the project. Full depth HMA procedures are found in HDM Index 633.1(2). The GE of the HMA is 3.60 ft. A safety factor of 0.10 ft is added to bring the total GE to 3.70 ft.

$$GE_{HMA} = 0.0032(TI) (100-R) + \text{Safety Factor} = 0.0032(12.5) (100-10) + 0.10 \text{ ft} = 3.70 \text{ ft.}$$

The closest GE from Table 633.1 of the HDM is 3.63 ft with a corresponding HMA thickness of 1.60 ft. This thickness will greatly reduce the total pavement structure thickness compared to example three above and as shown below:



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Layer	Design Example 3 Alternative 1 (ft)	Design Example 6 Full-Depth HMA (ft)
HMA	0.60	1.60
ATPB	0.25	----
AB	0.80	----
AS	1.40	----
Total Thickness (ft)	3.05	1.60

When a minimum 0.35 ft working table of AS is placed below the HMA the GE for the HMA is reduced to 3.35 ft.

When a drainage layer is included with the HMA and AS, the GE of the HMA is further reduced by an amount equal to the GE of the drainage layer. In this example, assume a 0.25 ft layer of ATPB (GE of 0.35) and an AS working table thickness of 0.35 ft (GE of 0.35 ft). Thus, the GE and thickness of the HMA are reduced as follows:

$$GE_{HMA} = GE_{Full-Depth\ HMA} - GE_{ATPB} - GE_{AS}$$

$$GE_{HMA} = 3.70\ \text{ft} - 0.35\ \text{ft} - 0.35\ \text{ft} = 3.00\ \text{ft}.$$

The closest GE from Table 633.1 of the HDM is 3.04 ft with a corresponding HMA thickness of 1.40 ft.

To assure continuity of the drainage layer between the existing and new pavements the ATPB should be placed at the same level as the ATPB in the existing lane. In this example, the ATPB would be placed beneath the top 0.60 ft of HMA. Thus, the pavement structure for the additional lane would be 0.60 ft HMA, 0.25 ft ATPB, 0.80 ft HMA, and 0.35 ft AS.

When full depth HMA is placed, adequate cooling of each compacted layer prior to placing additional lifts is necessary to prevent rutting. The time needed to ensure adequate cooling is achieved, must be considered when developing allowable work hours for lane closure charts.

(5) Design Example 5 (RAC -G/HMA/AB/AS):

Rubberized Asphalt Concrete (RAC) is usually placed on rehabilitation projects as an overlay and in some instances as the surface course for the new construction. For requirements and practices on the use of RAC, see HDM Index 631.1 and the Asphalt Rubber Usage Guide on the Department Pavement website:

<http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm>



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RAC thicknesses are determined by first calculating the HMA thickness and then converting it to RAC. Taking the results from Example 1 of the guide and Index 631.3 of the HDM, up to 0.20 ft of RAC may be substituted for 0.20 ft of HMA (1:1 ratio), resulting in the following modification of the Example 1 Alternative:

Layer	Design Example 1 Dense Graded HMA Alternative (ft)	Design Example 7 RAC Alternative (ft)
RAC	----	0.20
HMA	0.65	0.45
AB	1.00	1.00
AS	1.35	1.35
Total Thickness (ft)	3.00	3.00

Note that the use of RAC-G does not reduce the overall pavement structure thickness in a new construction design. Although typically more expensive, early indications from research and experience with RAC seem to show that the longevity of the pavement will improve with a RAC surface course. So, whereas it may not save on initial construction costs, it may reduce life cycle costs. Studies are currently underway to verify and quantify this benefit.

To determine if RAC is a better solution, a life cycle cost analysis should be done between HMA and RAC during the project development process. The “Life Cycle Cost Procedures Manual” provides procedures and information to complete this analysis and can be found on the Department Pavement web site at:

<http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm>