Pavement Analysis and Design

TE-503A/ TE-503

Lecture-9
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Dr. Zia-ur-Rehman
DTEM

Asphalt Institute Method

From 1954 to 1969, eight editions of Manual Series No. 1 (MS-1) were published by the Asphalt Institute for the thickness design of asphalt pavements. The procedures recommended in these manuals were empirical. The seventh and eighth editions of MS-1 were based on data from the AASHO Road Test, the WASHO Road Test and a number of British road tests and on comparisons with the design procedures of the U.S. Army Corps of Engineers and of some state agencies.

In 1981, the ninth edition of MS-1 was published. Unlike previous editions, the ninth edition is based on mechanistic–empirical methodology and uses the mechanistic multilayer theory in conjunction with empirical failure criteria to determine pavement thicknesses.

Asphalt Institute Method

Based on the results from a computer program named DAMA, a series of design charts covering three different temperature regimes were developed. However, only the charts for one regime, which represents a large part of the United States, were included in MS-1.

In 1991, a revision of the ninth edition of MS-1 was made, in which charts for all three temperature regimes were included (AI, 1991).

Asphalt Institute Method-Design Criteria

The horizontal tensile strain at the bottom of the asphalt layer, which causes fatigue cracking and the vertical compressive strain on the surface of the subgrade, which causes permanent deformation or rutting, are used as failure criteria in the Asphalt Institute method.

Asphalt Institute Method-Traffic Analysis

Load repetitions, expressed in terms of an 18-kip (80-kN) single-axle load, are determined from traffic estimates by using AASHTO equivalent factors for a structural number SN of 5 and a terminal serviceability index of 2.5.

Asphalt Institute Method-Traffic Analysis

Simplified procedure for determining design ESAL

TABLE 11.3 Traffic Classification

Traffic class	Type of street or highway	Range of heavy trucks expected in design period	ESAL
I	Parking lots, driveways Light traffic residential streets Light traffic farm roads	Less than 7000	5×10^3
II	Residential streets Rural farm and residential roads	7000 to 15,000	10^4
III	Urban minor collector streets Rural minor collector roads	70,000 to 150,000	10^5
IV	Urban minor arterial and light industrial streets Rural major collector and minor arterial highways	700,000 to 1,500,000	10^6
V	Urban freeways, expressways, and other principal arterial highways Rural interstate and other principal arterial highways	2,000,000 to 4,500,000	3×10^6
VI	Urban interstate highways Some industrial roads	7,000,000 to 15,000,000	10^7

Note. Whenever possible, more rigorous traffic analysis should be used for roads and streets in traffic category IV or higher.

Source. AI (1981b).

Asphalt Institute Method-Material Characterization

Subgrade Soils

To determine a representative resilient modulus, substantial testing of subgrade materials within 2 ft (0.6 m) of the planned subgrade elevation is required. If significant variations are present, random sampling should be done to determine the controlling soil type or the boundaries between different soils.

If the soil types are significantly different and each soil covers a sufficiently large area, consideration should be given to subdividing the project for separate designs. At least six to eight test values are usually used to determine the design subgrade resilient modulus. The design subgrade resilient modulus is defined as the modulus value that is smaller than 60, 75 or 87.5% of all the test values. These percentages are known as percentile values and are related to traffic levels, as shown in Table 11.4.

Asphalt Institute Method-Material Characterization

Subgrade Soils

TABLE 11.4 Design Subgrade Resilient Modulus

Traffic level ESAL	Design resilient modulus percentile value (%)
10^4 or less	60.0
Between 10^4 and 10^6	75.0
10^6 or more	87.5

Source. After AI (1981a).

Asphalt Institute Method-Material Characterization

Subgrade Soils-Numerical problem

The results of eight tests produced the following subgrade resilient modulus values; 6200, 7800, 8800, 9500, 10000, 11300, 11900 and 13500 psi. Determine the design subgrade resilient modulus for ESAL of 10^4, 10^5 and 10^6.

Asphalt Institute Method-Material Characterization

Subgrade Soils-Numerical problem

The percentile values are calculated in Table 11.5. From Table 11.4, the percentile values for ESAL of 10^4, 10^5 and 10^6 are 60, 75 and 87.5%, respectively. It can be estimated from Table 11.5 that the design resilient moduli corresponding to the 60, 75 and 87.5 percentile values are 9600, 8800 and 7800 psi, respectively.

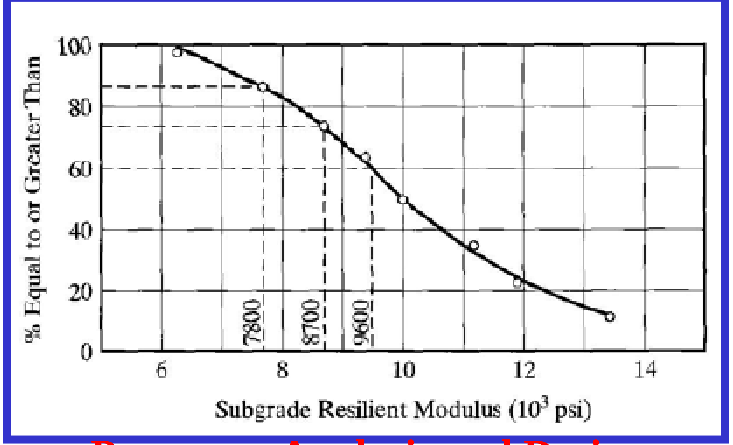
TABLE 11.5 Computation of Percentile Value

Test value (psi)	Number equal to or greater than	Percent equal to or greater than
13,500	1	12.5
11,900	2	25.0
11,300	3	37.5
10,000	4	50.0
9500	5	62.5
8800	6	75.0
7800	7	87.5
6200	8	100.0

Asphalt Institute Method-Material Characterization

Subgrade Soils-Numerical problem

For more accurate results, it is preferable to plot the percentile values versus the subgrade resilient moduli, as shown in Figure and to draw a smooth curve to correct any irregularities. Note that, at 75 percentile, the resilient modulus determined from Figure is 8700 psi, which is slightly different from the original 8800 psi.



Asphalt Institute Method-Material Characterization

Untreated granular materials

When untreated aggregate base and subbase are used, it is recommended that they comply with ASTM Specification D 2940 "Graded Aggregate Material for Bases or Subbases for Highways and Airports," except that the requirements given in Table 11.6 should apply where appropriate.

TABLE 11.6 Quality Requirements for Untreated Aggregate Bases and Subbases

Test	Subbase	Base
CBR, minimum or	20	80
R value, minimum	55	78
Liquid limit, maximum	25	25
Plasticity index, maximum	6	NP
Sand equivalent, minimum	25	35
% passing No. 200, maximum	12	7

Source. After AI (1981a).

Asphalt Institute Method-Material Characterization

Hot mix asphalt

TABLE 11.7 Asphalt Grades and Viscosity for Different Temperature Regimes

Location	Mean annual air temperature (MAAT)	Asphalt grades	Viscosity λ at 70°F (10^6 poise)
New York	45°F (7°C)	AC-5, AC-10	0.6
South Carolina	60°F (15.5°C)	AC-10, AC-20	1.6
Arizona	75°F (24°)	AC-40	5.0

Source. After AI (1982).

Asphalt Institute Method-Material Characterization

Emulsified asphalt mixtures

It is permissible to use emulsified asphalt mixtures for base courses. Depending on aggregate types, three types of mixes are specified :

1. Type I: mixes with processed dense graded aggregates, which should be mixed in a plant and have properties similar to HMA .

2. Type II: mixes with semi-processed, crusher run, pit run, or bank run aggregates.

3. Type III: mixes with sands or silty sands.

Asphalt Institute Method-Material Characterization

Emulsified asphalt mixtures

Representative stiffness moduli at the time of placement and after full curing were used for each of the mix types, based on the results of 32 different mixes tested at 73°F (23°C) and 100°F (38°C). The moduli at other temperatures can be obtained by a straight-line interpolation. The effect of curing time on the stiffness modulus is represented by:

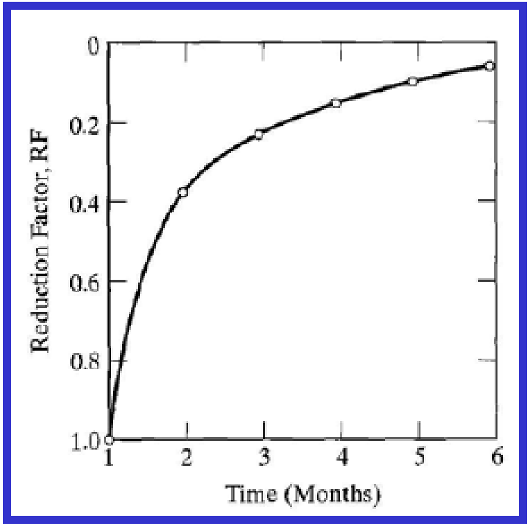
$$E_t = E_f - (E_f - E_i)(RF)$$

in which E_t is the modulus at curing time t, E_f is the modulus in the fully cured state, E_i is the modulus in the uncured or initial state, and RF is the reduction factor representing the amount of cure at time t.

Asphalt Institute Method-Material Characterization

Emulsified asphalt mixtures

A six-month cure period was used to prepare the design charts: longer periods of curing (up to 30 months) do not have a significance influence on the thickness obtained from the design charts. The reduction factor for a six-month cure period is shown in Figure.



Asphalt Institute Method-Material Characterization

Environmental Effects

In addition to the effect of monthly temperature changes throughout the year on the stiffness moduli of HMA and emulsified asphalt mixtures, the design charts also take into consideration the effect of freezing and thawing on the resilient modulus of the subgrade and granular materials. This was accomplished by using an increased modulus to represent the freezing period and a reduced modulus to represent the thaw period.

These adjustments are needed for regions with a MAAT of 45°F (7°C) or 60° F (15.5°C) but not for those of 75°F (24°C).

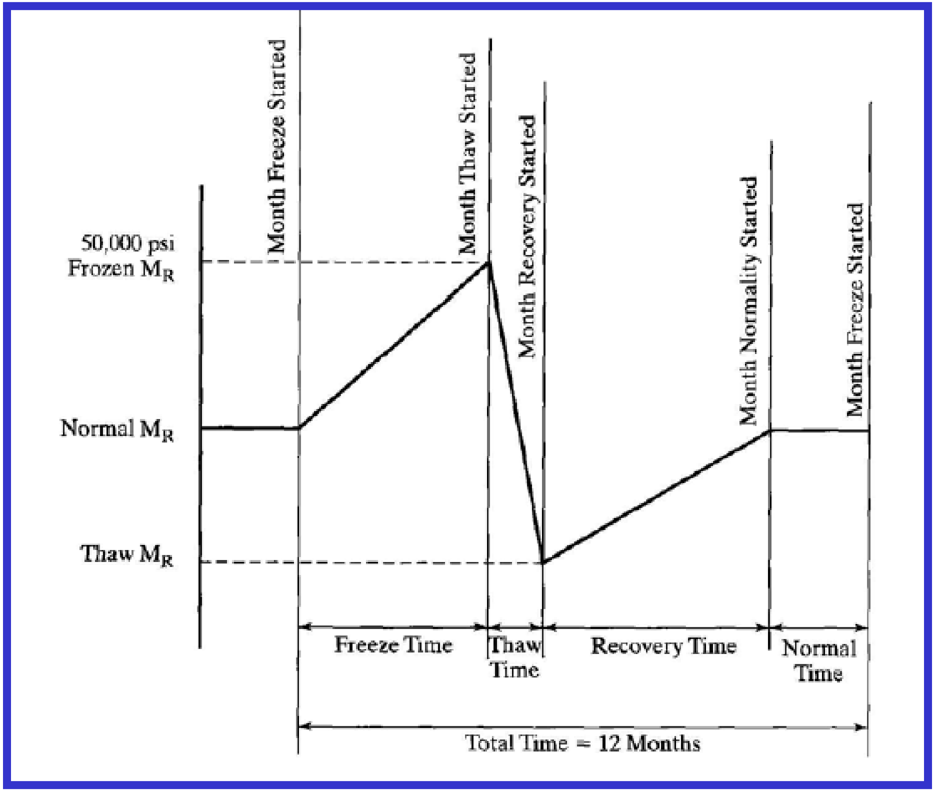
Asphalt Institute Method-Material Characterization

Environmental Effects-Subgrade

Figure shows the variations of a subgrade resilient modulus throughout a year. The diagram represents four distinct periods: freeze, thaw, recovery, and normal. When the subgrade is completely frozen, a frozen modulus of 50,000 psi (345 MPa) is assumed. The modulus is reduced during the thaw period and reaches a minimum thaw modulus, which is a small fraction of the normal modulus. The magnitude of the thaw modulus and the duration of each period are shown in Table 11.9 for the two temperature regimes. When the resilient moduli at the beginning and end of each period are known, those at any month during that period can be interpolated from Figure. Table 11.10 shows the monthly subgrade moduli used in DAMA for developing the design charts.

Asphalt Institute Method-Material Characterization

Environmental Effects-Subgrade



Asphalt Institute Method-Material Characterization

Environmental Effects-Subgrade

TABLE 11.9 Conditions Used to Represent Frost Effects on Subgrade

MAAT	Normal modulus (psi)	Thaw modulus % Normal	Thaw modulus psi	Month freeze started	Duration (month) Freeze	Duration (month) Thaw	Duration (month) Recovery	Duration (month) Normal
45°F	4500	20	900	Dec	4	1	5	2
	12,000	50	6000	Dec	4	1	5	2
(7°C)	22,500	70	15,800	Dec	4	1	5	2
60°F	4500	30	1350	Jan	2	1	4	5
	12,000	60	7200	Jan	2	1	4	5
(15.5°C)	22,500	80	18,000	Jan	2	1	4	5

Note. 1 psi = 6.9 kPa.
Source. After AI (1982).

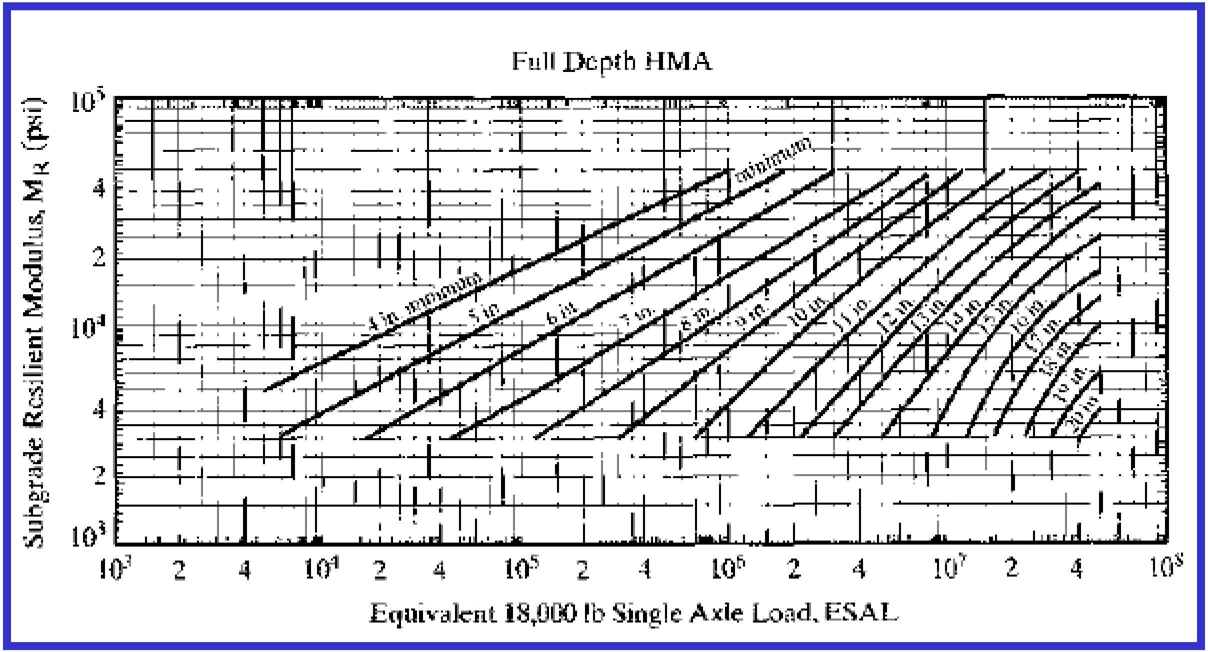
Asphalt Institute Method-Design Procedure

Full depth HMA

Figure is the design chart for full-depth asphalt pavements. Given the subgrade resilient modulus M_R and the equivalent 18-kip single-axle load, ESAL, the total HMA thickness, including both surface and base courses, can be read directly from the chart.

Asphalt Institute Method-Design Procedure

Full depth HMA



Asphalt Institute Method-Design Procedure

Full depth HMA-Numerical problem

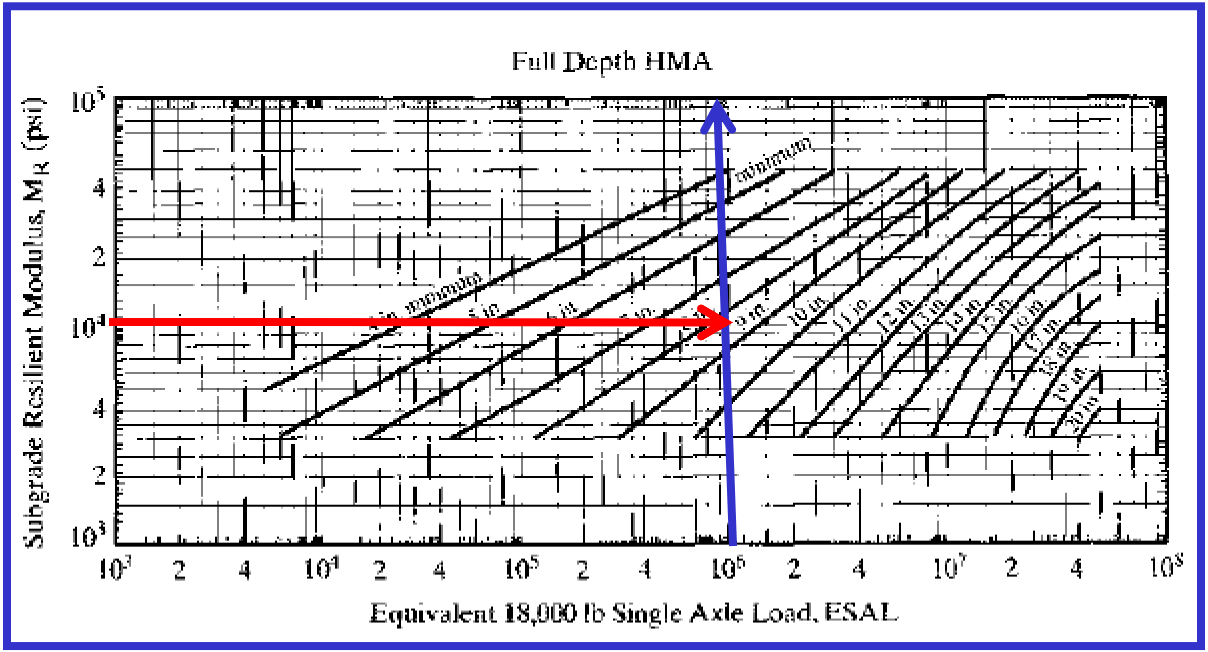
Given M_R= 10,000 psi and ESAL= 10^6, determine the thickness of HMA for a full-depth asphalt pavement.

From chart

HMA thickness=8.5 in.

Asphalt Institute Method-Design Procedure

Full depth HMA



Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base

Figures are the design charts for types I, II and III emulsified asphalt mixes respectively. The chart gives the combined thickness of HMA surface course and emulsified asphalt base course.

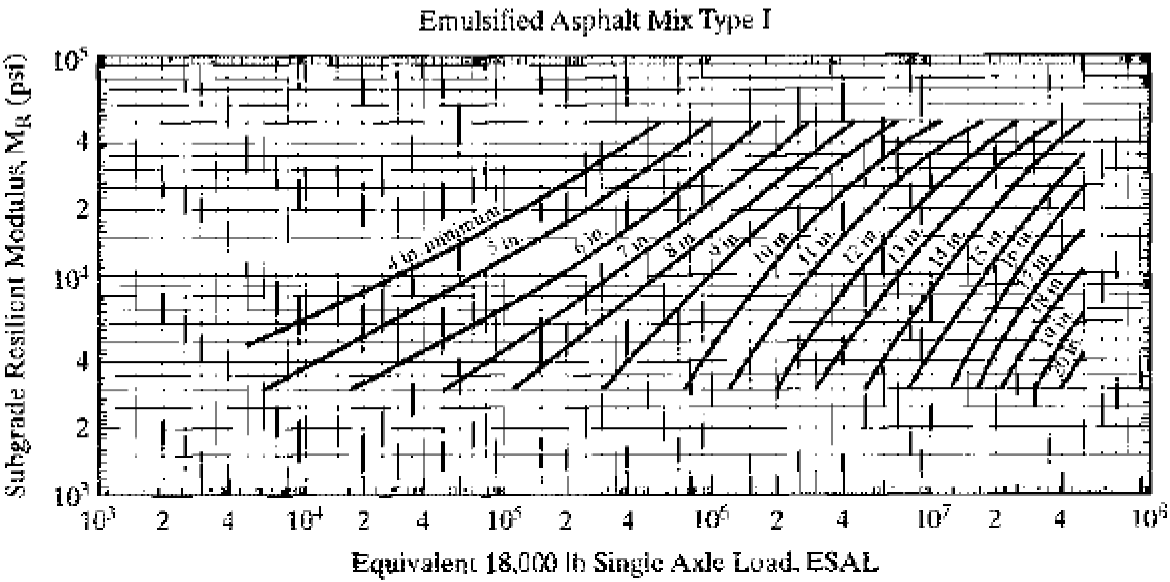
The minimum thickness of HMA over the emulsified asphalt base varies with traffic level as shown in table 11.12.

The difference between the combined thickness and the HMA thickness is the thickness of emulsified asphalt base course required.

Flexible Pavement Design

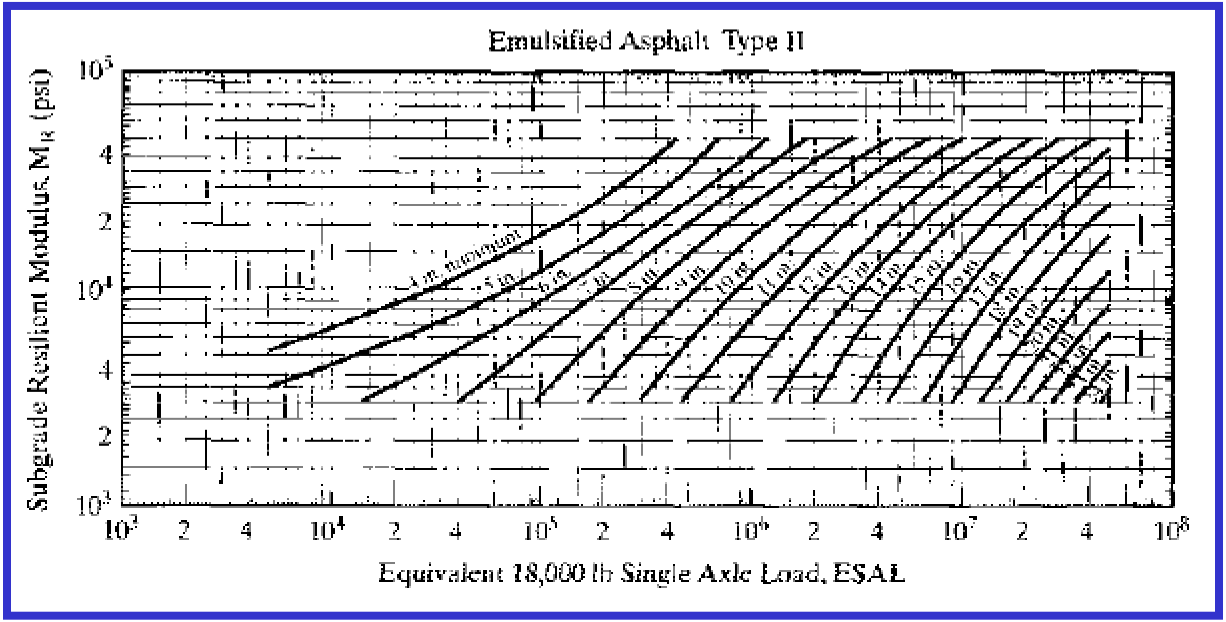
Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base



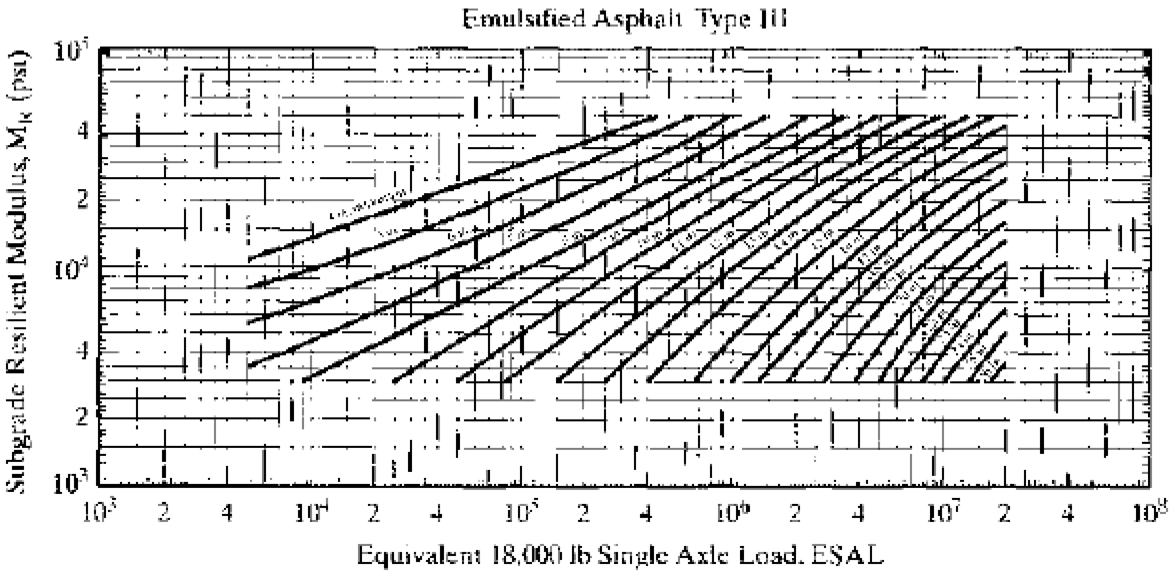
Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base



Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base



Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base

TABLE 11.12 Minimum Thickness of HMA Over Emulsified Asphalt Bases

Traffic level ESAL	HMA thickness for type I mix (in.)	HMA thickness for type II and type III mixes (in.)
10^4	1	2
10^5	1.5	2
10^6	2	3
10^7	2	4
$>10^7$	2	5

Note. 1 in. = 25.4 mm.
Source. After AI (1981a).

Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base-Numerical problem

Given M_R= 10,000 psi and ESAL= 10^6, determine the thickness of a pavement with a HMA surface over a type II emulsified asphalt base.

For ESAL= 10^6, from table 11.12:

Min. HMA thickness= 3in

For M_R= 10,000 psi and ESAL= 10^6, from design chart:

Combined thickness= 10.5 in

Thickness of emulsified asphalt=10.5-3.0=7.5 in

Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base-Numerical problem

TABLE 11.12 Minimum Thickness of HMA Over Emulsified Asphalt Bases

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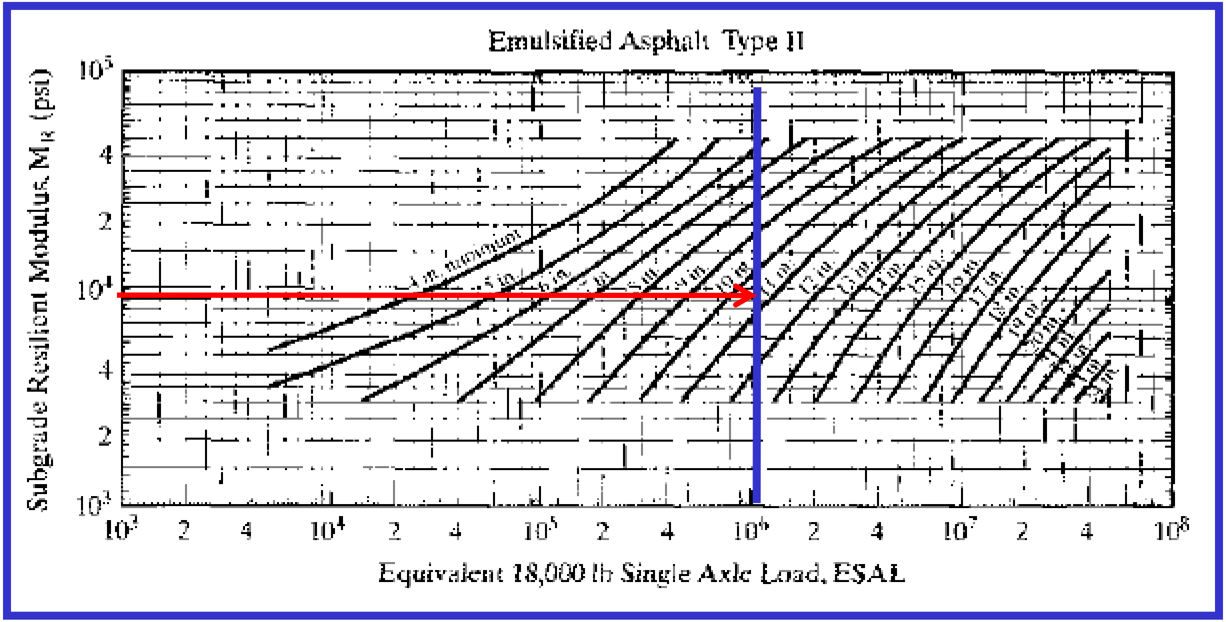
Asphalt Institute Method-Design Procedure

HMA over Emulsified asphalt base-Numerical problem



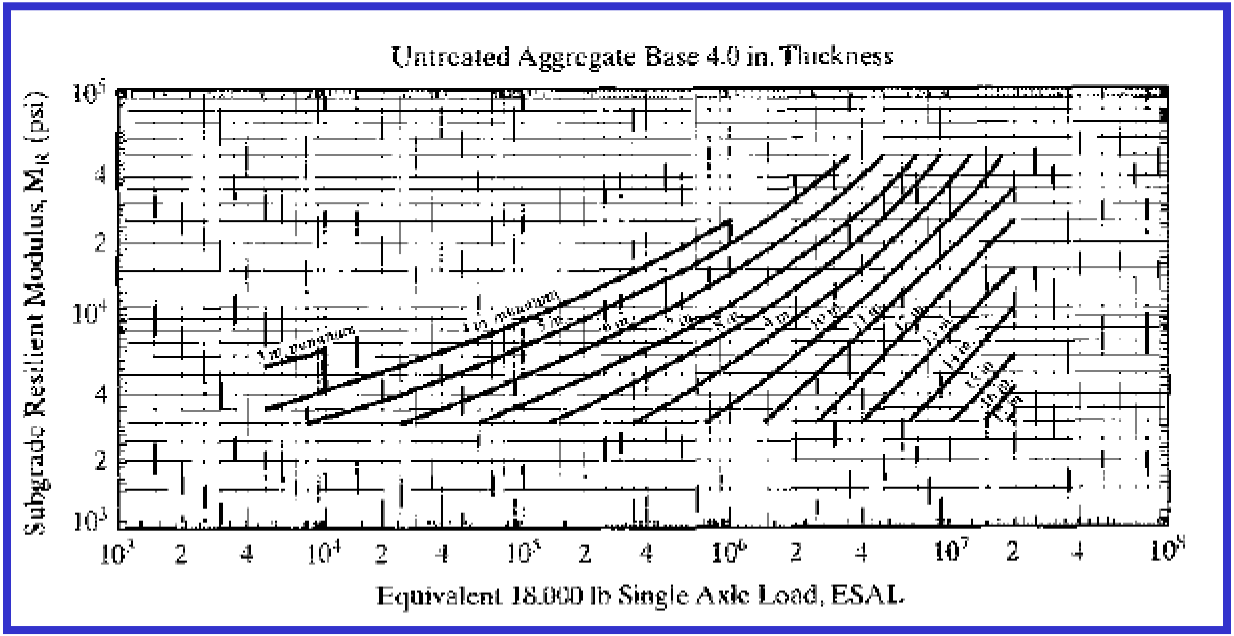
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base

6 design charts are available giving thickness of HMA surface course on untreated base courses of 4, 6, 8, 10, 12, 18 in.

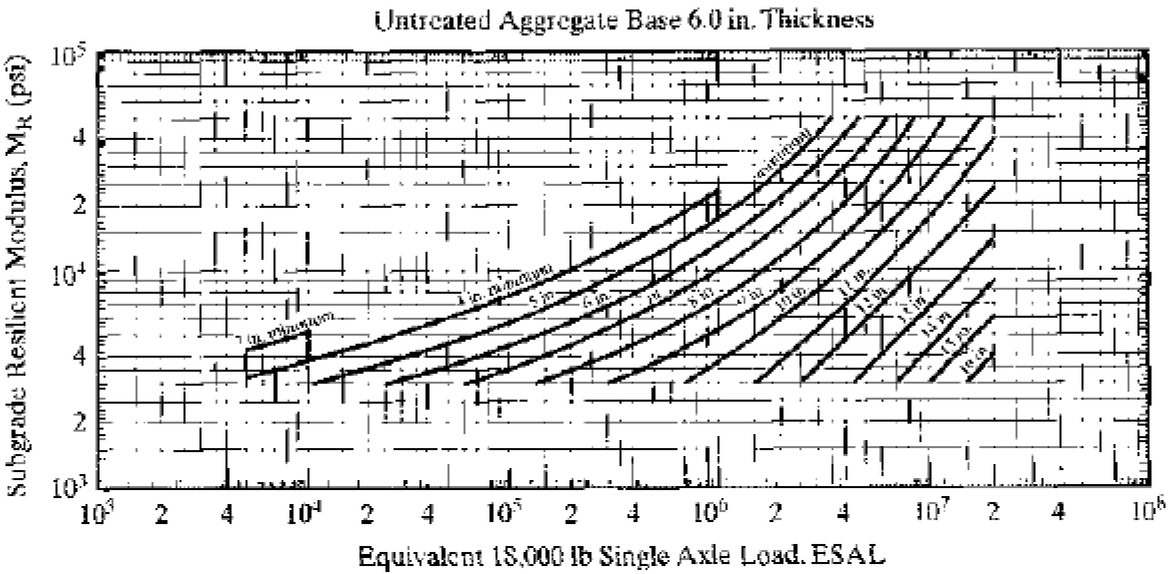
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



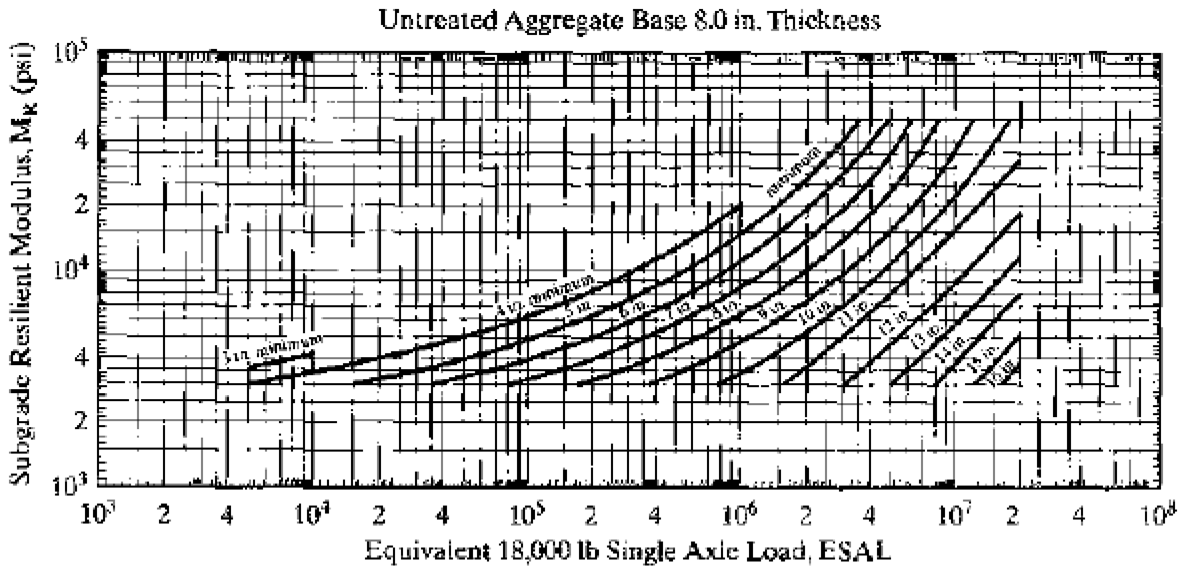
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



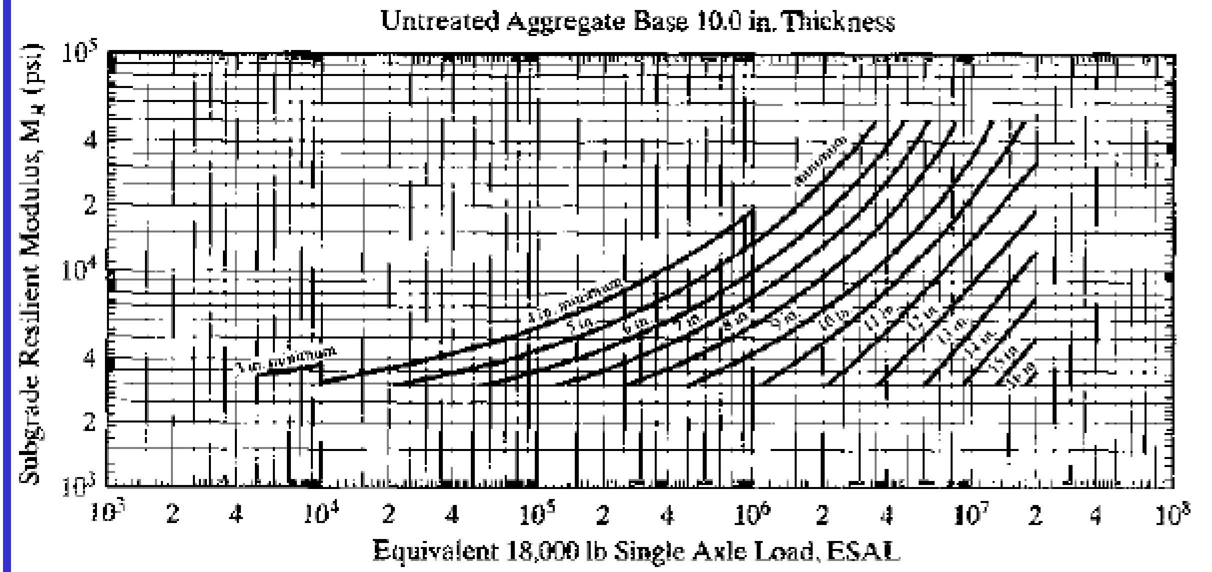
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



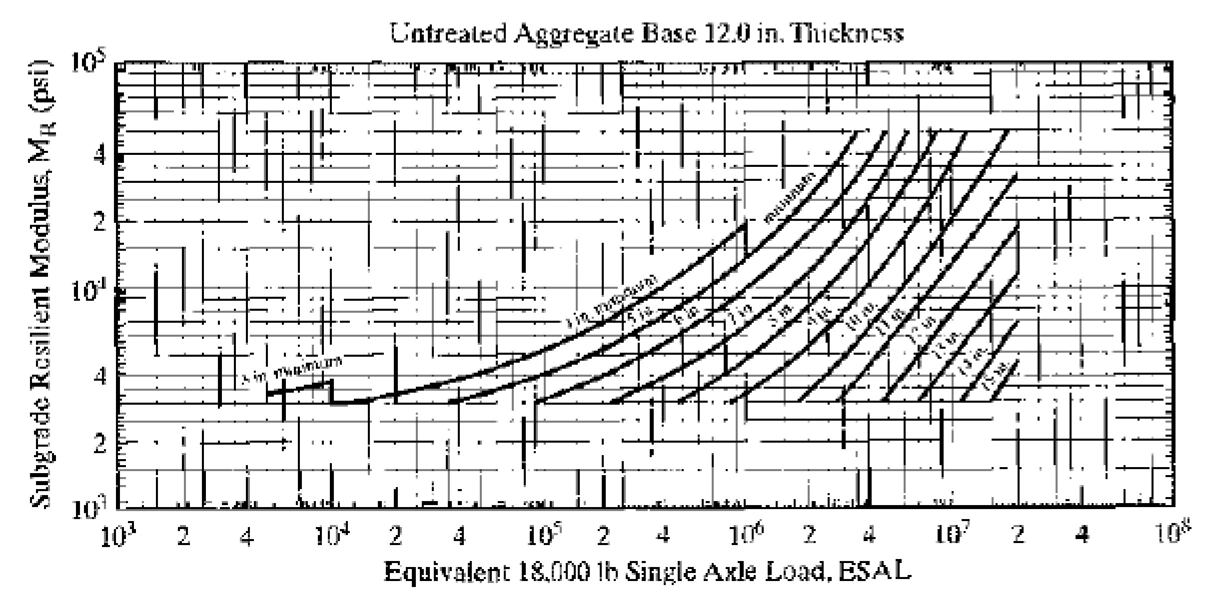
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



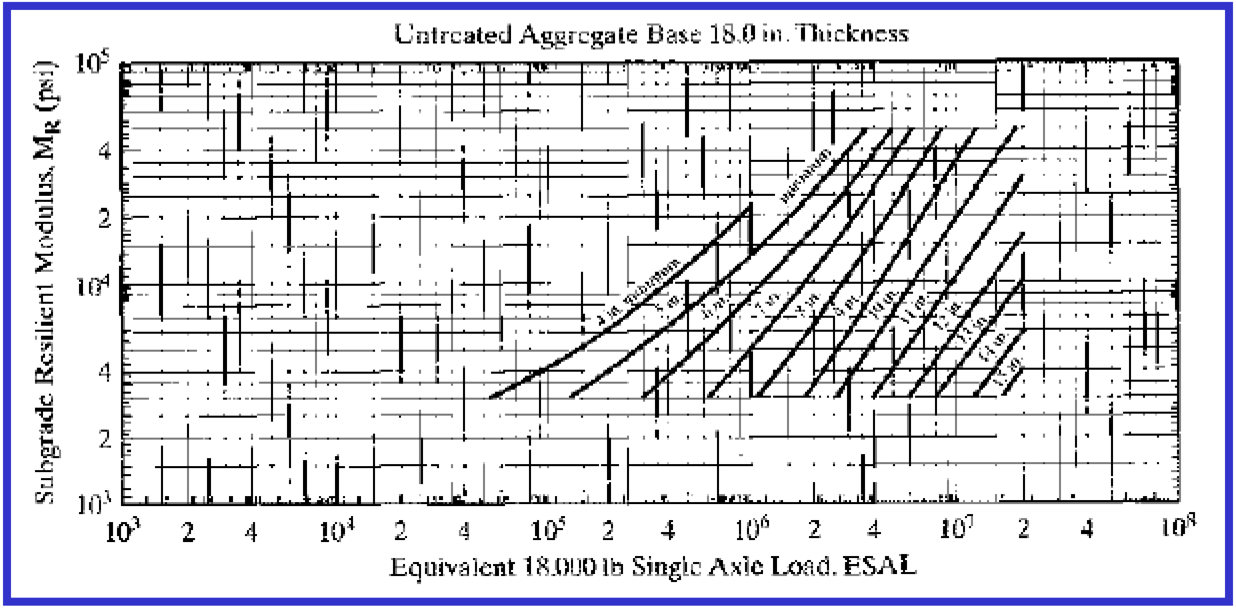
Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base



Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base-Numerical problem

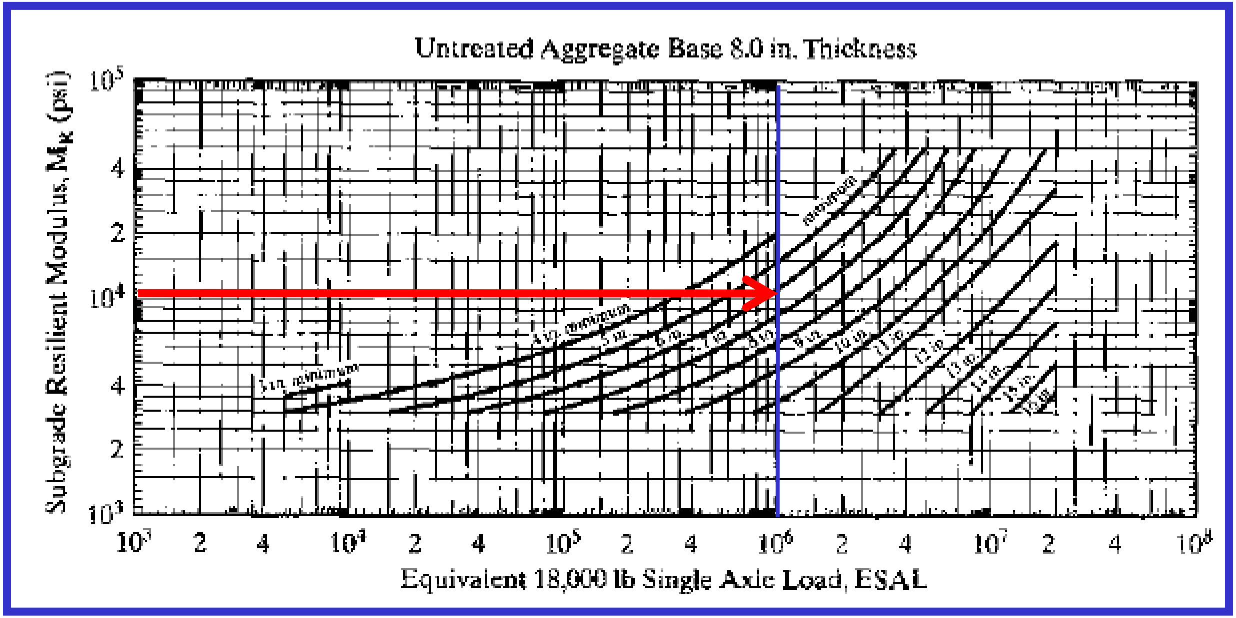
Given M_R= 10,000 psi and ESAL= 10^6 and an untreated aggregate base 8 in. thick, determine the thickness of the HMA required.

For M_R= 10,000 psi and ESAL= 10^6 and an untreated aggregate base 8 in. thick from design chart:

HMA thickness= 6.5 in.

Asphalt Institute Method-Design Procedure

HMA over Untreated aggregate base-Numerical problem



Asphalt Institute Method-Design Procedure

HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base

Design charts for pavements consisting of a HMA surface, an emulsified asphalt base and an untreated base are currently not available.

The best alternative is to use the charts for full depth HMA and emulsified asphalt mix to determine a substitution ratio, which indicates the thickness of emulsified asphalt mix required to substitute for a unit thickness of HMA.

Then the chart for HMA over untreated aggregate base is applied to determine the thickness of HMA, part of which can be replaced by the emulsified asphalt mix according to the substitution ratio.

Asphalt Institute Method-Design Procedure

HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base

The following method has been recommended by the Asphalt Institute:

1. Design a full-depth HMA pavement for the appropriate traffic and subgrade conditions. Assume a 2-in. surface course and calculate the corresponding base thickness.

2. Design a pavement for the same traffic and subgrade conditions, using the selected emulsified mix type. Assume a 2-in. surface course and calculate the corresponding base thickness.

3. Divide the thickness of the emulsified asphalt base in step 2 by the thickness of the HMA base in step 1 to obtain a substitution ratio.

Asphalt Institute Method-Design Procedure

HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base

The following method has been recommended by the Asphalt Institute:

4. Design a pavement for the same traffic and subgrade conditions, using HMA and untreated base.

5. Select a portion of the HMA thickness to be replaced by the emulsified asphalt mix, based on the minimum HMA thickness specified in Table 11.12.

6. Multiply the above thickness by the substitution ratio determined in step 3 to obtain the thickness of emulsified asphalt mix required.

Asphalt Institute Method-Design Procedure

HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base-Numerical problem

Given M_R = 10,000 psi, ESAL = 10^6 and an 8-in. untreated aggregate base, design the thicknesses of HMA surface course and type II emulsified asphalt base course.

Solution:

1 . The thickness for full-depth HMA is 8.5 in. If the HMA surface is 2 in., then the thickness of the HMA base is 6.5 in.

2. The thickness for emulsified asphalt mix to be placed directly on the subgrade is 10.5 in. If the HMA surface is 2 in., then the thickness of the emulsified asphalt base is 8.5 in.

3. The substitution ratio is 8.5/6.5 = 1.31.

Asphalt Institute Method-Design Procedure

HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base-Numerical problem

4. The thickness of HMA over an 8 in. untreated aggregate base is 6.5 in.

5. From Table 11.12, the minimum HMA thickness is 3 in., so 3.5 in. of HMA base must be replaced by the emulsified asphalt base.

6. The thickness of the emulsified asphalt base is:

3.5x1.31= 4.5 in.

The final design consists of 3 in. of HMA, 4.5 in. of emulsified asphalt base and 8 in. of untreated aggregate base, or a total thickness of 15.5 in.

Asphalt Institute Method-Planned Stage Construction

Planned stage construction involves successive applications of HMA layers according to a predetermined time schedule.

The procedure is based on the concept of remaining life, which implies that the second stage will be constructed before the first stage shows serious signs of distress.

Stage construction is beneficial when funds are insufficient for constructing a pavement with a long design life. This approach is also desirable when there is a great amount of uncertainty in estimating traffic.

The pavement can be designed for an initial traffic volume; then the next stage of construction can be designed with traffic projections based on the traffic in service.

Asphalt Institute Method-Planned Stage Construction

Finally, stage construction allows weak spots that develop in the first stage to be detected and repaired in the next stage.

If n_1 is the actual ESAL for stage 1 and N_1 is the allowable ESAL for the initial thickness h_1 selected for stage 1, then the damage ratio D_r at the end of stage 1 is

$$D_r = \frac{n_1}{N_1}$$

Note that D_r must be smaller than 1 because, when $D_r = 1$, the pavement fails. Therefore, the remaining life in the existing pavement at the end of stage 1 is $(1 - D_r)$.

Asphalt Institute Method-Planned Stage Construction

The thickness obtained from the design chart is based on a $D_r = 1$, with no remaining life. To keep some remaining life, the thickness h_1 should be determined from the design chart based on an adjusted design ESAL N_1 , which is somewhat greater than the design ESAL n_1, depending on the D_r specified. If h_1 is based on N_1 and

$$N_1 = \frac{n_1}{D_r}$$

then the damage ratio after N_1 load applications is 1, so N_1 can be considered to be the allowable number of applications.

Asphalt Institute Method-Planned Stage Construction

Since n_1 is smaller than N_1, the damage ratio is smaller than 1; it can be determined from Eq.

$$D_r = \frac{n_1}{N_1}$$

If n_2 is the design ESAL for stage 2 and N_2 is the allowable or adjusted ESAL for stage 2, then the damage incurred in stage 2 should not exceed the remaining life. That is,

$$\frac{n_2}{N_2} = 1 - D_r$$

Or

$$N_2 = \frac{n_2}{1 - D_r}$$

Asphalt Institute Method-Planned Stage Construction

Note that N_2 is an adjusted design ESAL to permit the selection of a thickness h_2 that will carry traffic n_2 and use the remaining life. The difference between h_2 and h_1 is the additional thickness required in stage 2.

Thus, in a stage construction analysis, the designer is required to select a stage time period and the amount of damage D_r to be incurred during this stage. Given D_r and n_1, the adjusted design ESAL N_1 can be computed by Eq.

$$N_1 = \frac{n_1}{D_r}$$

and used for determining h_1.

Asphalt Institute Method-Planned Stage Construction

Given n_2 and D_r, the adjusted design ESAL N_2 can be computed by Eq.

$$N_2 = \frac{n_2}{1 - D_r}$$

and used for determining h_2. The MS-1 manual recommends the use of 5 to 10 years for the first stage, with a damage ratio of 60% at the end of the stage.

Asphalt Institute Method-Planned Stage Construction-Numerical Problem

A full-depth HMA pavement with a subgrade resilient modulus of 10,000 psi will be constructed in two stages. The first stage is 5 years with 150,000 ESAL repetitions, and the second stage is 15 years with 850,000 ESAL repetitions. Limiting the damage ratio to 0.6 at the end of stage 1, determine the thickness of HMA required for the first 5 years and the thickness of overlay required to accommodate the additional traffic expected during the next 15 years.

$$N_1 = \frac{n_1}{D_r}$$

Given n_1 = 150,000, D_r = 0.6, N_1 = 150,000 / 0.6 = 2.5 x 10^5
h_1 = 6.5 in.

$$N_2 = \frac{n_2}{1 - D_r}$$

Given n_2 = 850,000, D_r = 0.6, N_2 = 850,000 / (1 - 0.6) = 2.1 x 10^6
h_2= 10.0 in.

Thickness for first stage = 6.5 in
Overlay for second stage = 10.0 – 6.5 = 3.5 in.

Flexible Pavement Design

Asphalt Institute Method-Planned Stage Construction-Numerical Problem