2.6.1.3.1 Design of thickness layers based on AASHTO 1993

There are several accepted flexible pavement design procedures, including the Asphalt Institute method, the National Stone Association procedure, and the Shell procedure. Most of the procedures have been field verified and used by highway agencies for several years. The selection of one procedure over another is usually based on a highway agency's experience and satisfaction with design results.

A widely accepted flexible pavement design procedure is presented in the AASHTO Guide for design of pavement structures, which is published by the American Association of State Highway and Transportation Officials. This design method is based on AASHO test results conducted in Illinois, USA. The procedure was first published in 1972, with latest revision in 1993. The factors considered in this design methods are as follows:

- *Pavement performance*
- *Traffic*
- *Roadbed/Subgrade soils*
- *Construction materials*
- *Environmental factors*
- *Drainage*
- *Reliability*

Pavement performance

There are two factors considered under the performance of the pavement structure, these are

- ✓ Structural performance: this is related to the physical factors that affect load-carrying capacity.

- ✓ Functional performance: this is related to factors that affect the riding quality.

A serviceability performance concept was used for pavement performance quantification. Under this concept, a present serviceability index (PSI) was developed which range from 1 to 5 (typical condition after pavement construction)

For the purpose of pavement design procedure, two serviceability indices are used:

- ❖ Initial serviceability index (pi): serviceability index immediately after pavement construction.
- ❖ Final serviceability index (pt): serviceability index at which pavement needs maintenance.

pi: 4.2 for flexible pavement

pt:

- 2.5 – 3 for major highways
- 2 for lower classification
- 1.5 for extreme economic conditions (limited fund)

ΔPSI = pi - pt

<u>Subgrade soils condition</u>

In AASHTO 1993 procedure, the resilient modulus (Mr) is used to represent subgrade property. However, due to the availability and cheapness of the CBR test as compared with resilient modulus test, the following formula are used

Mr = 1500 x CBR

Materials of construction

These can be classified into:

1. Materials for subbase course.

2. Materials for base course.

3. Materials for surface/wearing course

- ***Materials for subbase course***

Layer coefficient is used in pavement design procedure to reflect the layer quality and used to convert the layer thickness to the structural number (SN). Figure 2.11 is used for granular subbase to convert different material properties to equivalent layer coefficient (a3).

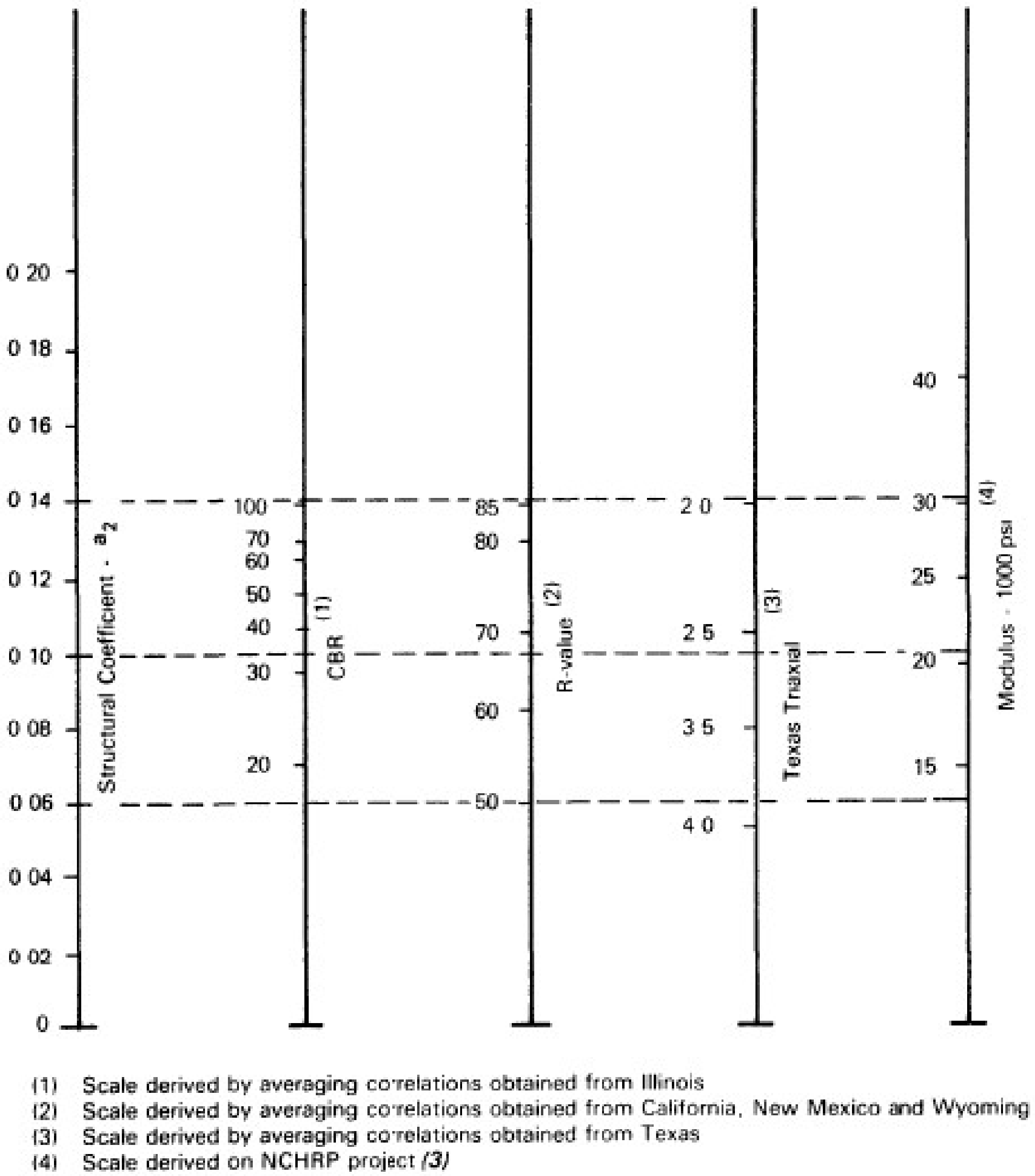
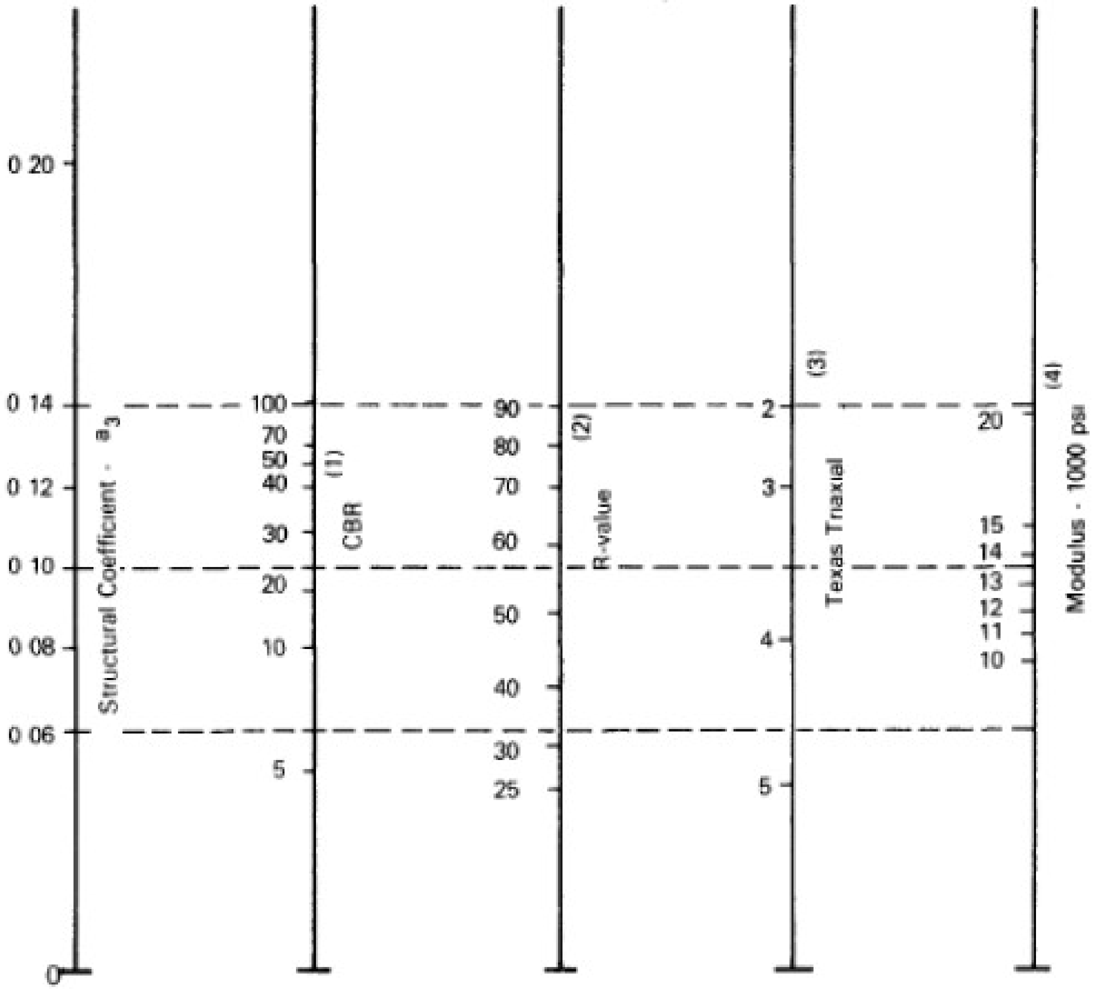


Figure 2.12: Estimation of base layer coefficient a2

- ***Materials for base course***

Materials used for base course should satisfy the general requirements such as gradation and other requirements. Figures 2.12, 2.13 and 2.14 are used for granular, cement-treated and bituminous treated base layers, respectively, to convert layer properties to the structural layer coefficient (a2).



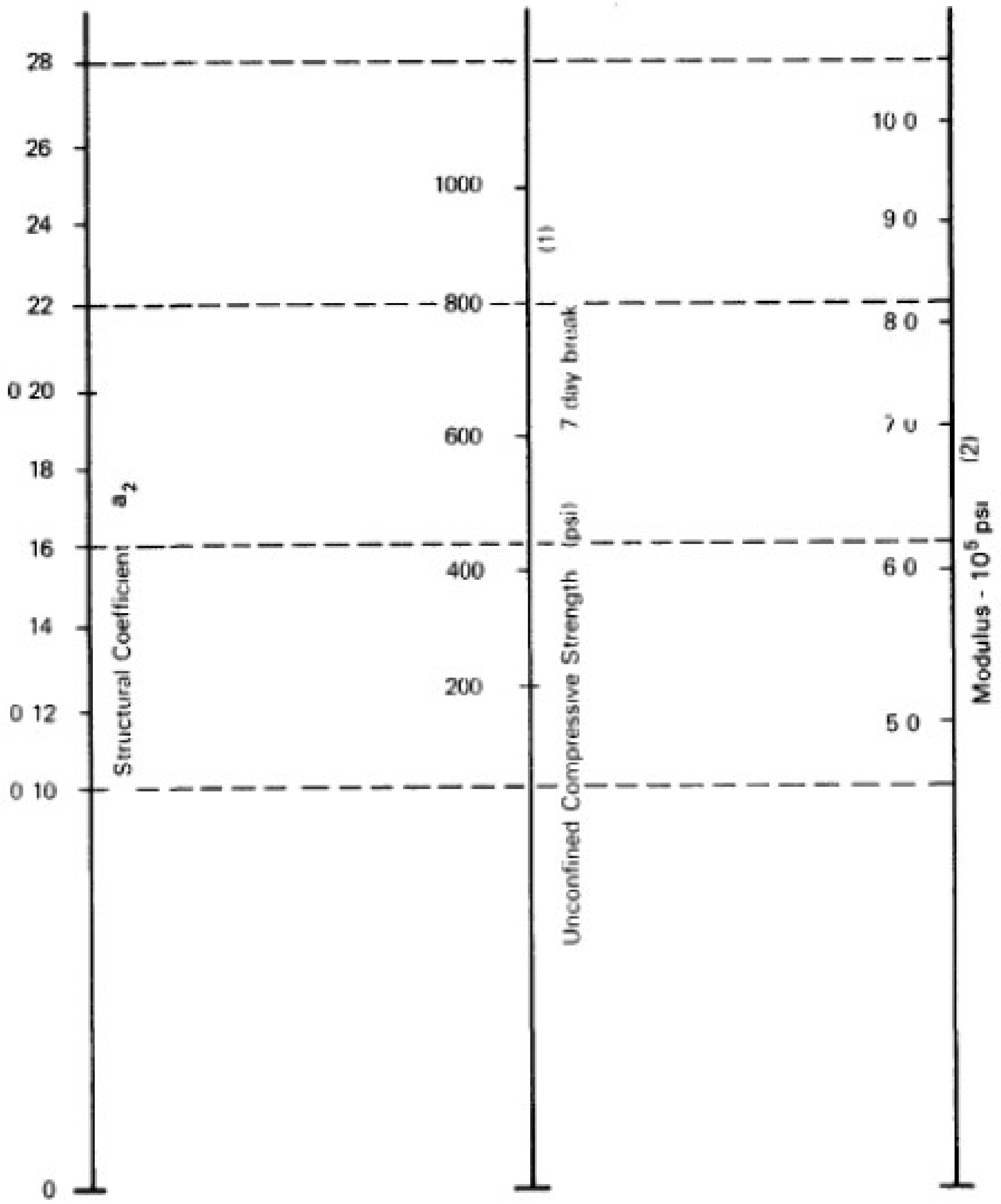
(1) Scale derived from correlations from Illinois

(2) Scale derived from correlations obtained from The Asphalt Institute, California, New Mexico and Wyoming

(3) Scale derived from correlations obtained from Texas

(4) Scale derived on NCHRP project *(3)*

Figure 2.11: Estimation of subbase layer coefficient a3



(1) Scale derived by averaging correlations from Illinois Louisiana and Texas
(2) Scale derived on NCHRP project (3)

Figure 2.13: Estimation of base layer coefficient a2- cement treated base course

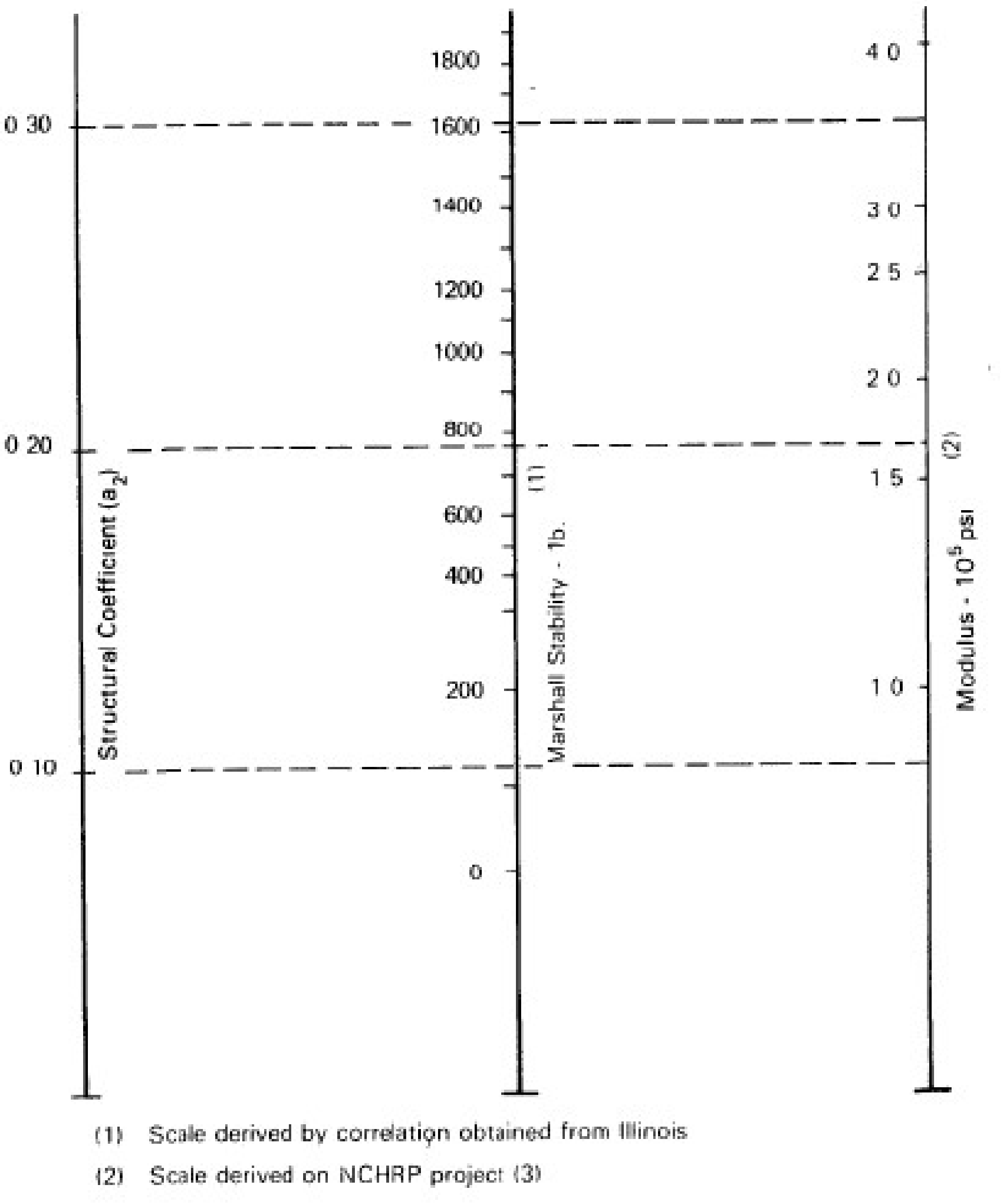


Figure 2.14: Estimation of base layer coefficient a2-bitumenous treated base course

- ***Materials for surface course***

Hot Mix Asphalt (HMA) mixtures are frequently used for surface course construction. Dense-graded mixtures are normally used for such purposes. Figure 2.15 was suggested to estimate layer coefficient (a1) for HMA.

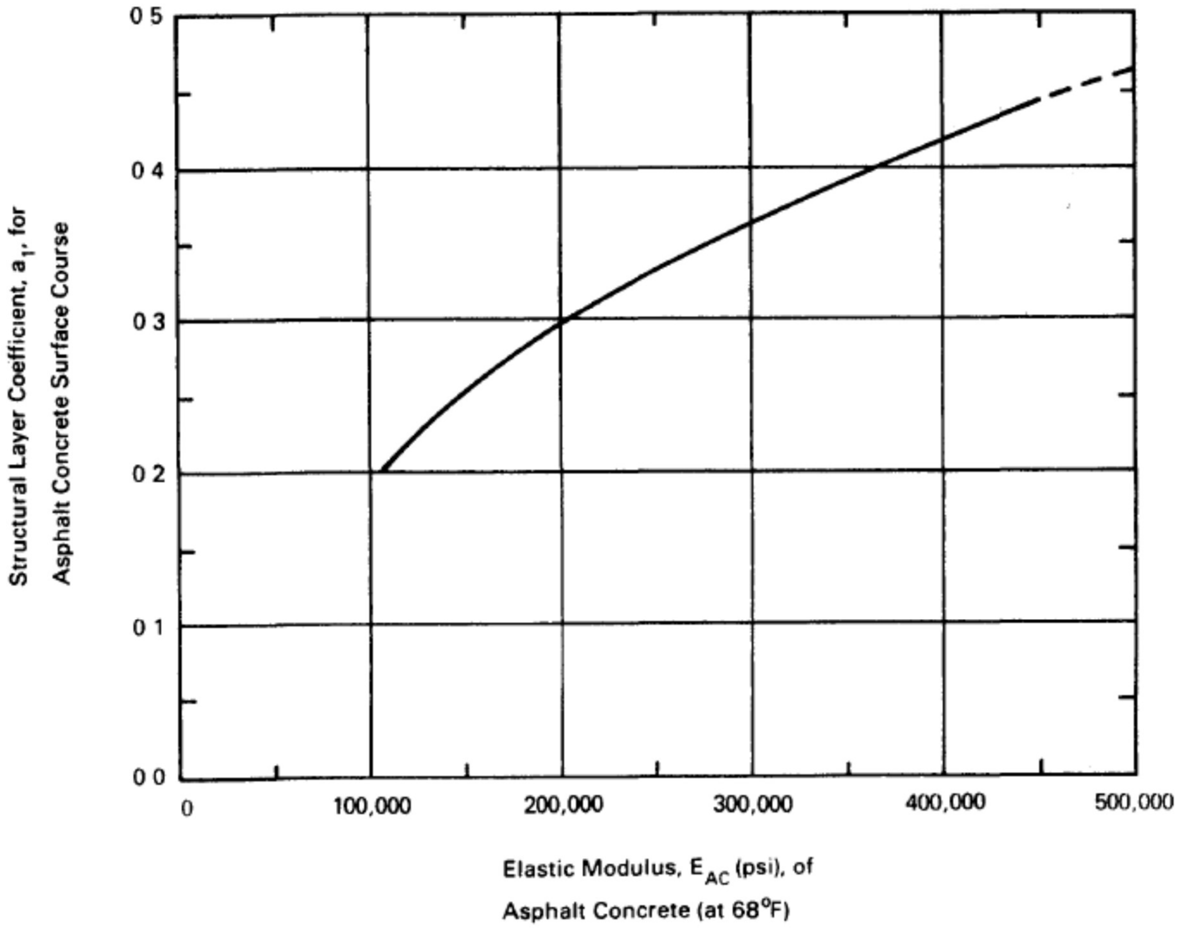


Figure 2.15: Estimation of surface layer coefficient a1

Environmental factors

As discussed previously the main two environmental factors taken onto consideration are temperature and rainfall Figure 2.16 shows pavement performance trends. Temperature affects the thermal properties of pavement materials and also freeze-thaw of the subgrade soil. Rainfall also affects the performance of the pavement and roadbed soil especially when it penetrates into

the underlying layers. The results found that the subgrade soil properties are changing during the year due to increase the temperature and thaw period.

AASHTO procedure takes these seasonal variations during the year into consideration through determination of the effective subgrade resilient modulus (Mr effective.) using the following procedure:

- The whole year is divided into 12 periods and the resilient modulus should be measured for each of these periods.
- The relative damage should be estimated for each period from the following formula

  $uf = 1.18 \times 10^8 \times Mr^{-2.32}$

- The average relative damage is calculated then; the effective resilient modulus can be determined using the same formula above

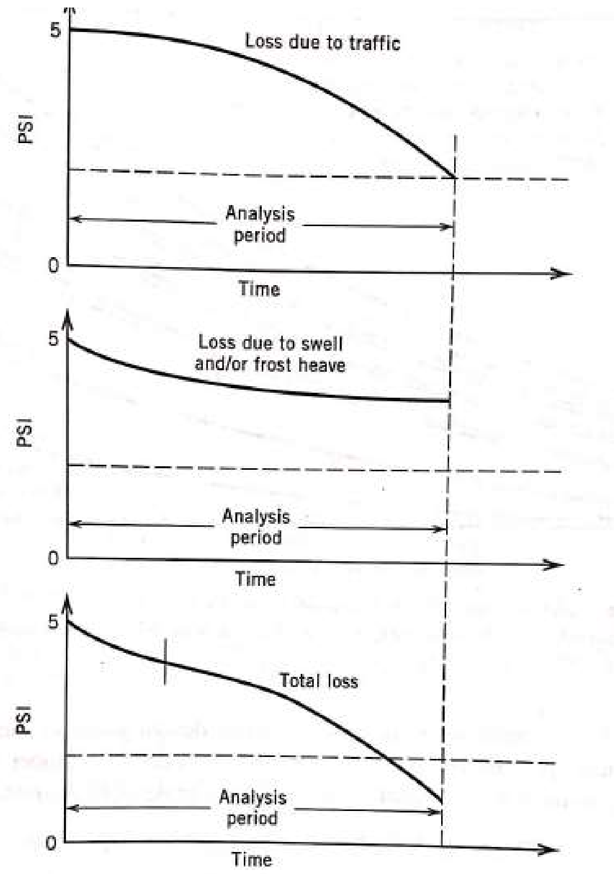


Figure 2.16: Pavement performance trend

Example 2.2: Table below (column 1 and column 2) shows the results of laboratory testing for the resilient modulus of subgrade soil during 12 months. Estimate the effective resilient modulus for this subgrade for pavement design?

$uf = 1.18 * 10^8 * Mr^{-2.32}$

Month	*Subgrade resilient modulus (psi)*	*Damage (uf)*
Jan.	*22000*	*0.01*
Feb.	*22000*	*0.01*
Mar.	*5500*	*0.25*
Apr.	*5000*	*0.3*
May	*5000*	*0.3*
Jun.	*8000*	*0.1*
Jul.	*8000*	*0.1*
Aug.	*8000*	*0.1*
Sep.	*8500*	*0.09*
Oct	*8500*	*0.09*
Nov.	*6000*	*0.2*
Dec.	*22000*	*0.01*
Summation uf		*1.59*

Average uf =0.133 then *Mr eff. = 7250 psi*

Drainage

AASHTO 1993 guide considers the presence of water within granular base or subbase courses affect their strength. Consequently, they suggested a drainage coefficient to modify the structural performance of the mentioned layers. This can be conducted by incorporating drainage factors (mi) for base and subbase layers. These factors depend both on quality of drainage and the percentages of time during which the pavements structure is saturated. The quality of drainage is measured in terms of the time required to reduce the degree of saturation to

50%. Tables 2.4 is used to estimate the quality of drainage while Table 2.5 is for drainage factors estimation.

Table 2.4: Estimation of drainage quality

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	(water will not drain)

Table 2.5: Drainage coefficient for modifying structural coefficients for untreated bases and subbases

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation: Less Than 1%	1–5%	5–25%	Greater Than 25%
Excellent	1 40–1 35	1 35–1 30	1 30–1 20	1 20
Good	1 35–1 25	1 25–1 15	1 15–1 00	1 00
Fair	1 25–1 15	1 15–1 05	1 00–0 80	0 80
Poor	1 15–1 05	1 05–0 80	0 80–0 60	0 60
Very poor	1 05–0 95	0 95–0 75	0 75–0 40	0 40

Reliability

Due the importance that the traffic loads estimation has on the pavement design process, reliability issue was introduced to take into consideration the uncertainty of the traffic loads estimation. This was done by incorporating reliability factors (F_R) which depends on two factors. One of these is the reliability design level (R) which is the level of assurance that the pavement section designed will survive for the whole design period. Table 2.6 shows suggested reliability levels for different highway types. The other factor is the overall variation S_o^2 which account for the variation in the traffic forecasts and actual pavement performance. Reliability level is computed based on the following expression

Z_R = standard normal variation for a given reliability level.

S_o = overall standard deviation.

Table 2.7 presents the Z_R values for various reliability levels while Table 2.8 shows the overall standard deviation S_o for both flexible and rigid pavements.

Table 2.6: Suggested level of Reliability for various functional classifications

	Recommended Level of Reliability	
Functional Classification	*Urban*	*Rural*
Interstate and other freeways	85–99.9	80–99.9
Other principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

Note: Results based on a survey of the AASHTO Pavement Design Task Force.
SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures,* American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Table 2.7: Standard normal deviation (Z_R) values corresponding to select level of Reliability

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures,* American

Table 2.8: S_o values for different pavements

	Standard Deviation, S_o
Flexible pavements	0.40–0.50
Rigid pavements	0.30–0.40

Structural design

The objective of the AASHTO 1993 pavement design method is to determine the Structural Number (SN) adequate to withstand the design traffic loads (in terms of ESAL) for design period. It should be noted that the current design procedure is used for ESAL value above 50,000. Roads those carrying less than this values are classified as low volume roads. Structural number can be computed from the following equation

$SN = a_1 . D_1 + a_2 . m_2 . D_2 + a_3 . m_3 . D_3$

where

a_1, a_2, a_3 = structural layer coefficients

m_2, m_3 = drainage factors.

D_1, D_2, D_3 = surface, base and subbase thicknesses

AASHTO 1993 use the following design equation to perform the structural design

$$\log_{10} W_{18} = Z_R S_o + 9.36 \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}[\Delta PSI/(4.2 - 1.5)]}{0.40 + [1094/(SN + 1)^{5.19}]} + 2.32 \log_{10} M_r - 8.07$$

Where:

W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications
Z_R = standard normal deviation for a given reliability
S_o = overall standard deviation
SN = structural number indicative of the total pavement thickness
$\Delta PSI = p_i - p_t$

p_i = initial serviceability index
p_t = terminal serviceability index
M_r = resilient modulus (lb/in^2)

Figure 2.17 is a solution of equation above and used for SN estimation.

Minimum layers' thicknesses

In terms of practicality and economics considerations, AASHTO suggest that the layer thickness should not be less than the values presented in Table 2.9.

Table 2.9: AASHTO-Recommended minimum thicknesses for highway layers

	Minimum Thickness (in.)	
Traffic, ESALs	*Asphalt Concrete*	*Aggregate Base*
Less than 50,000	1.0 (or surface treatment)	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

SOURCE: Adapted with permission from *AASTHO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

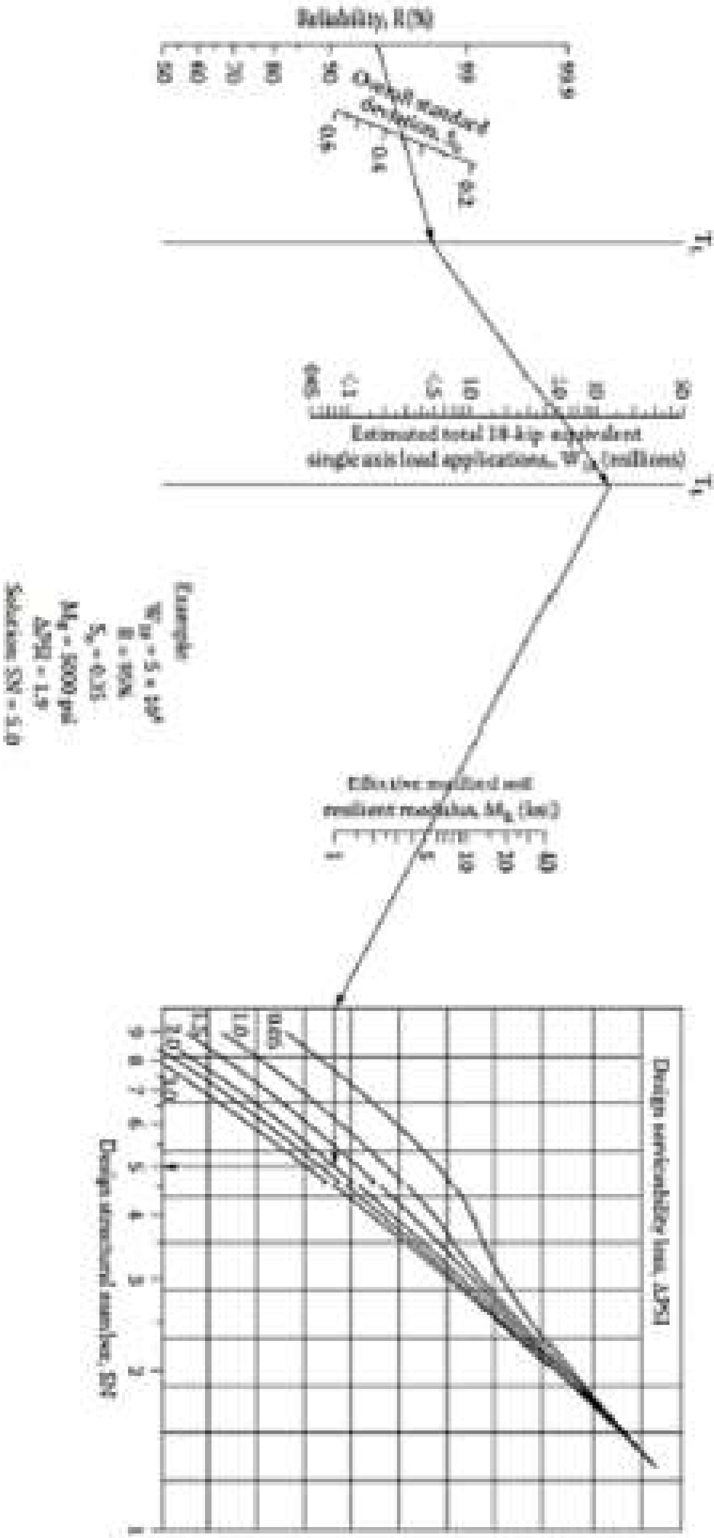


Figure 2.17: Nomograph for thickness design estimation

Example 2.3: A flexible pavement is to be designed to carry ESAL of 2×10^6 applied on an urban interstate highway. It is required about a week to drain the water from within the pavement structures. It is estimated that the pavement structure will be saturated for 30% of the time. The other information as resulted from experimental design is as follows

Resilient modulus of the asphalt concrete at 68° F = 450,000 psi

CBR value of base course = 100, Mr = 31,000 psi

CBR value of subbase course = 22, Mr = 13,500 psi

CBR value of subgrade materials = 6

Initial serviceability index Pi=4.5

Terminal serviceability index pt=2.5

Design a suitable pavement structure in accordance with AASHTO 1993 method?

Sol.

Reliability Level R = 99% (Table 2.6)

Standard deviation S_o = 0.49 (Table 2.8)

Use the nomograph illustrated in Figure 2.17 to design the pavement as follows:

Step 1: Draw a line joining the reliability level of 99% and the overall standard deviation S_o of 0.49, and extend this line to intersect the first T_L line at point A.

Step 2: Draw a line joining point A to the ESAL of 2×10^6, and extend this line to intersect the second T_L line at point B.

Step 3: Draw a line joining point B and resilient modulus (M_r) of the roadbed soil, and extend this line to intersect the design serviceability loss chart at point C

Step 4: Draw a horizontal line from point C to intersect the design serviceability loss (**ΔPSI)** curve at point D. In this example, **ΔPSI = 4.5-2.5 =2**

Step 5: Draw a vertical line to intersect the design SN, and this value SN= 4.4

Step 6: Determine the appropriate structure layer coefficient for construction materials

1- Resilient value of asphalt = 450000 Ib/in^2. From Figure 2.15, a_1 = 0.44
2- CBR of base course material = 100. From Figure 2.12, a_2= 0.14
3- CBR of subbase course material = 22. From Figure 2.11, a_3= 0.1

Step 7: Determine appropriate drainage coefficient mi. since only one set of conditions is given for both the base and subbase layers, the same value will be used for m_1 and m_2. The time required for water to drain from within pavement = 1 week and from Table 2.4, drainage quality is fair. The percentage of time pavement structure will be exposed to moisture levels approaching saturation = 30 and from Table 2.5, m_i = 0.8

Step 8: Determine appropriate layer thickness from the following equation

$= a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$

Taking into consideration that a flexible pavement structure is a layered system, the determination of the different thickness should be carried out as indicated in Figure 2.18. The required SN above the subgrade is first determined, and then the required SN above the base and subbase layers are determined using the appropriate strength of each layer. The minimum allowable thickness of each layer can then be determine using the differences of the computed SNs as shown in Figure 2.18

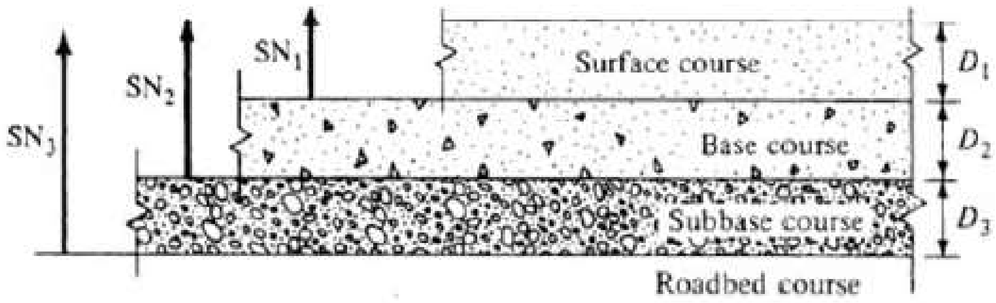


Figure 2.18: Procedure for determining thickness of layers using a layered analysis

Using the appropriate values for Mr in figure 2.18, we obtain $SN_3 = 4.4$ and $SN_2 = 3.8$. Note that when SN is assumed to compute ESAL, the assumed and computed SN_3 must be approximately equal. If these are significantly different, the computation must be repeated with a new assumed SN.

Mr for base course = 31000 Ib/in^2

Using this value in Figure 2.17, we obtain

$SN_1 = 2.6$

Giving

$D_1 = \frac{2.6}{0.44} = 5.9$ in

Using 6 in for the thickness of surface course,

$D^*_1 = 6$ in

$SN^*_1 = a_1 D^*_1 = 0.44 * 6 = 2.64$

$D^*_2 \geq \frac{SN_2 - SN_1^*}{a_2 m_2} \geq \frac{3.8-2.64}{0.14*0.8} \geq 10.36$ in (use 12 in)

$SN^*_2 = 0.14 * 0.8 * 12 + 2.64 = 1.34 + 2.64$

$D^*_3 \geq \frac{SN_3 - SN_2^*}{a_3 m_3} \geq \frac{4.4-(1.34+2.64)}{0.1*0.8} \geq 5.25$ in (use 6 in)

$SN^*_3 = 2.64 + 1.34 + 0.1*0.8*6 = 4.46$

The pavement will therefore consist of 6 in asphalt concrete surface, 12 in granular base, and 6 in subbase.

- * with D or SN indicates that it represents the value actually used which must be equal to or greater than the required value

2.6.2 Rigid Pavement

This type of pavement consists of concrete slab and base course (when used in rigid pavement it is called subbase course). These two layers are resting on subgrade soil.

2.6.2.1 Rigid Pavement Types

1. Jointed plain concrete pavement (JPCP)

2. Jointed reinforced concrete pavement (JRCP)

3. Continuous reinforced concrete pavement (CRCP)

4. Prestressed concrete pavements

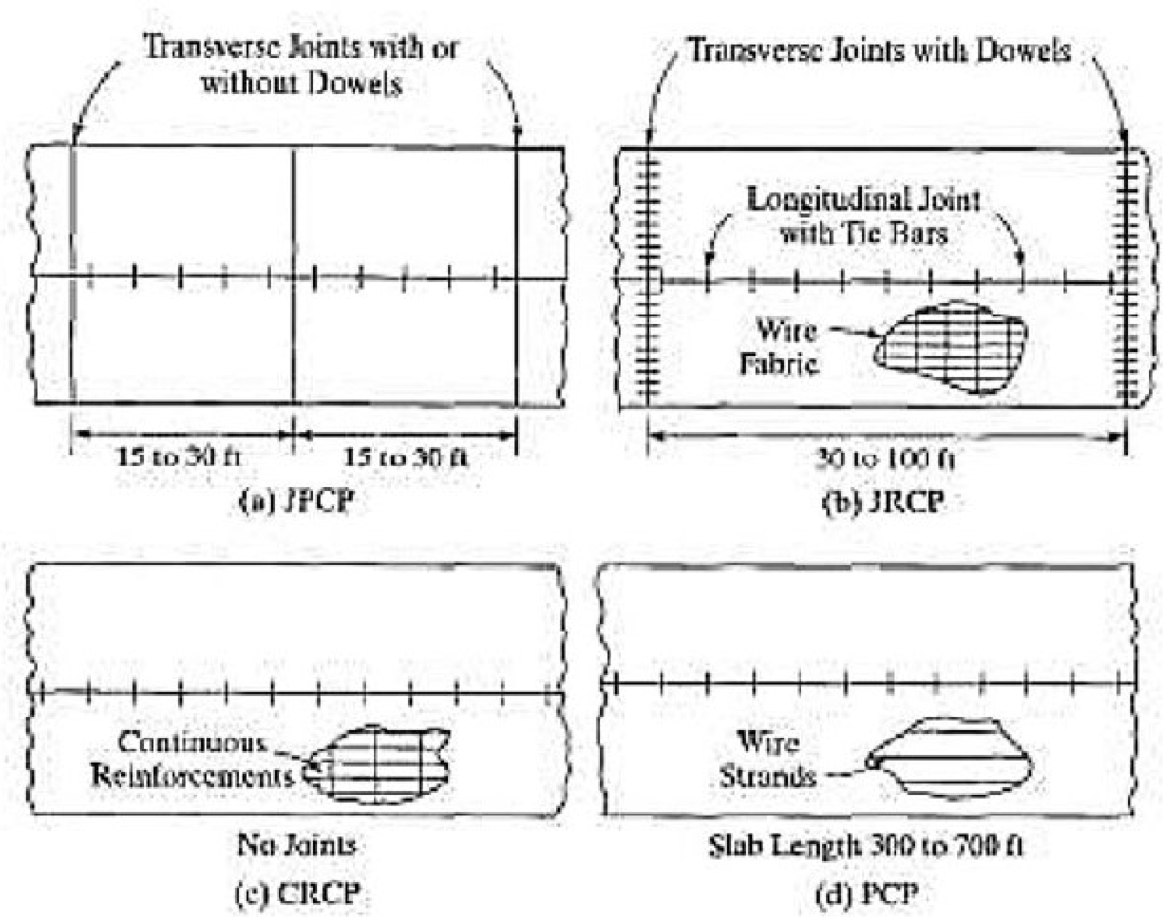


Figure 2.18: Different concrete pavement types (plan views)