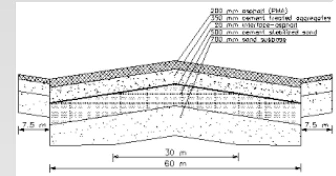
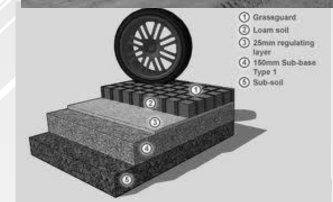
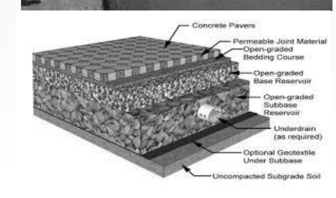
LECTURE 4:
AASHTO design method



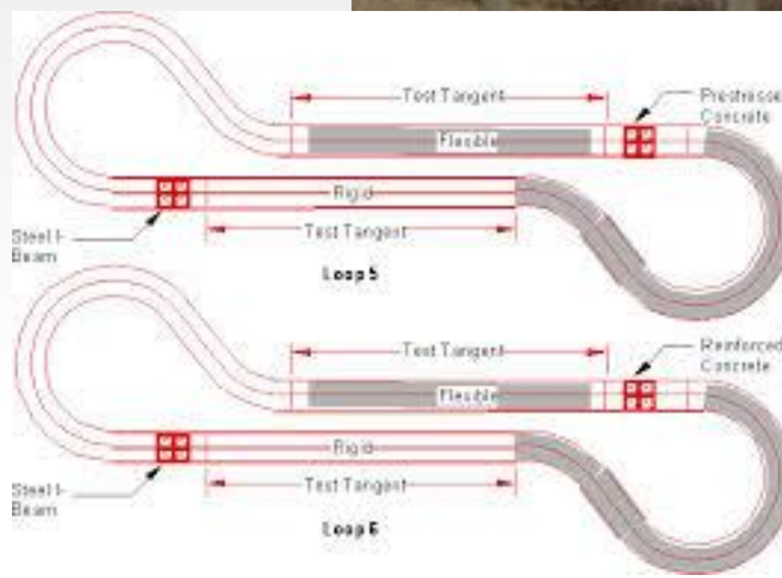




- In the late 1950's, it was understood that, with the rapid increase in number and weight of the vehicles, these simple systems were not good enough anymore for the design of pavements and a strong need for improved methods developed.

- For that reason the American State Highway and Transportation Officials (AASHTO) launched a large research program that had to result in a better understanding of pavement performance in general and in a system that would allow durable and economical feasible pavement structures to be designed.

- For that reason a number of flexible and rigid pavement test sections were built which were subjected to a variety of traffic loads. This test is known as the AASHO Road Test, the results of which, e.g. the load equivalency concept, are still used today.



- One of the most important concepts that was developed during the test was the present serviceability index (PSI).
- This index is a number that reflects the “service” that is given by the pavement to the road user.
- The index was developed by correlating the physical condition of the various test sections in terms of the amount of cracking, rutting and unevenness to the ratings given by a panel of road users to the “service” provided by the pavement to the user.
- This latter rating was a number ranging from 5, being very good, to 0, being very poor.
- For main roads a PSI level of 2.5 was considered to be minimum acceptable level. The PSI is calculated as follows:

$$PSI = 5.03 - 1.91 \log(1 + SV) - 1.38\, RD^2 - 0.01 \sqrt{(C + P)}$$

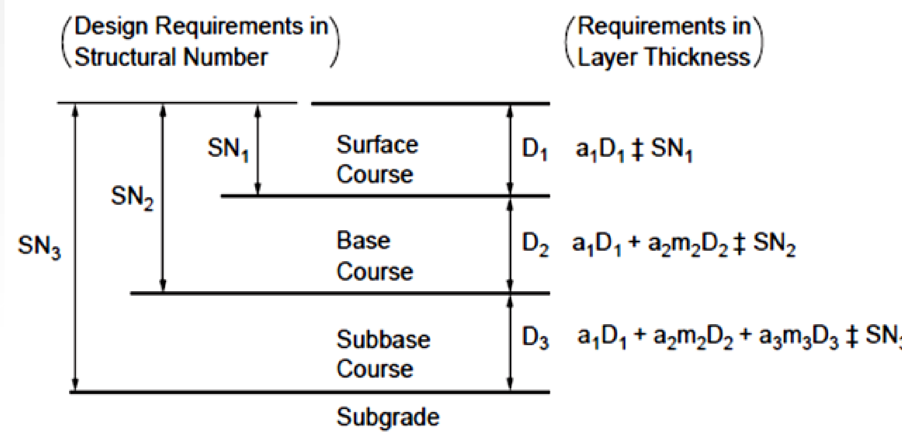
Where:
PSI = serviceability index,
SV = slope variance, a measure of the unevenness of the pavement surface,
C + P = percentage of cracked and patched pavement surface,
RD = rut depth.

- As one could expect, the unevenness of the pavement has a significant effect on the PSI value; it dominates all the other factors. Detailed analyses of the data however showed that the amount of cracking and the slope variance correlate well with each other.

- The pavement design method that was developed using the results of the AASHO Road Test involves the calculation of the so called structural number in relation to the allowable drop in PSI and the number of load repetitions after which this drop in PSI is allowed to occur. The structural number SN is calculated using:

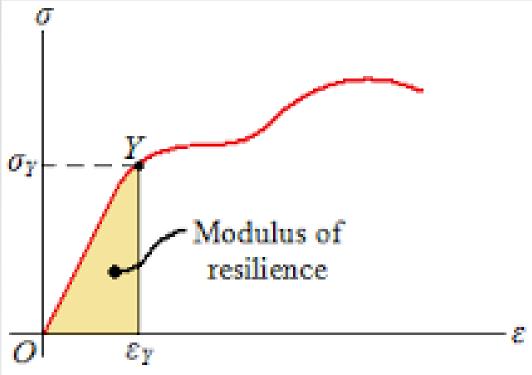
$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

Where:
ai = structural coefficient of layer i [-],
Di = thickness of layer i [inch],
i = 1 is the asphalt layer, 2 = base, 3 = subbase.

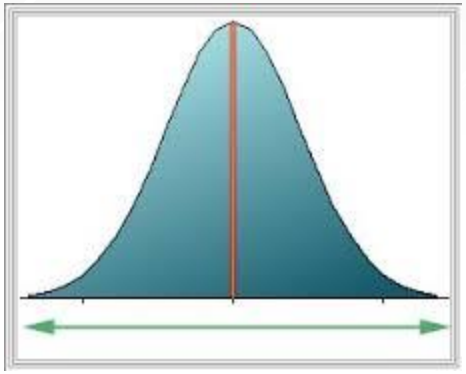


The concept of layer analysis.

- Other factors that are taken into account are the effective resilient modulus of the subgrade.

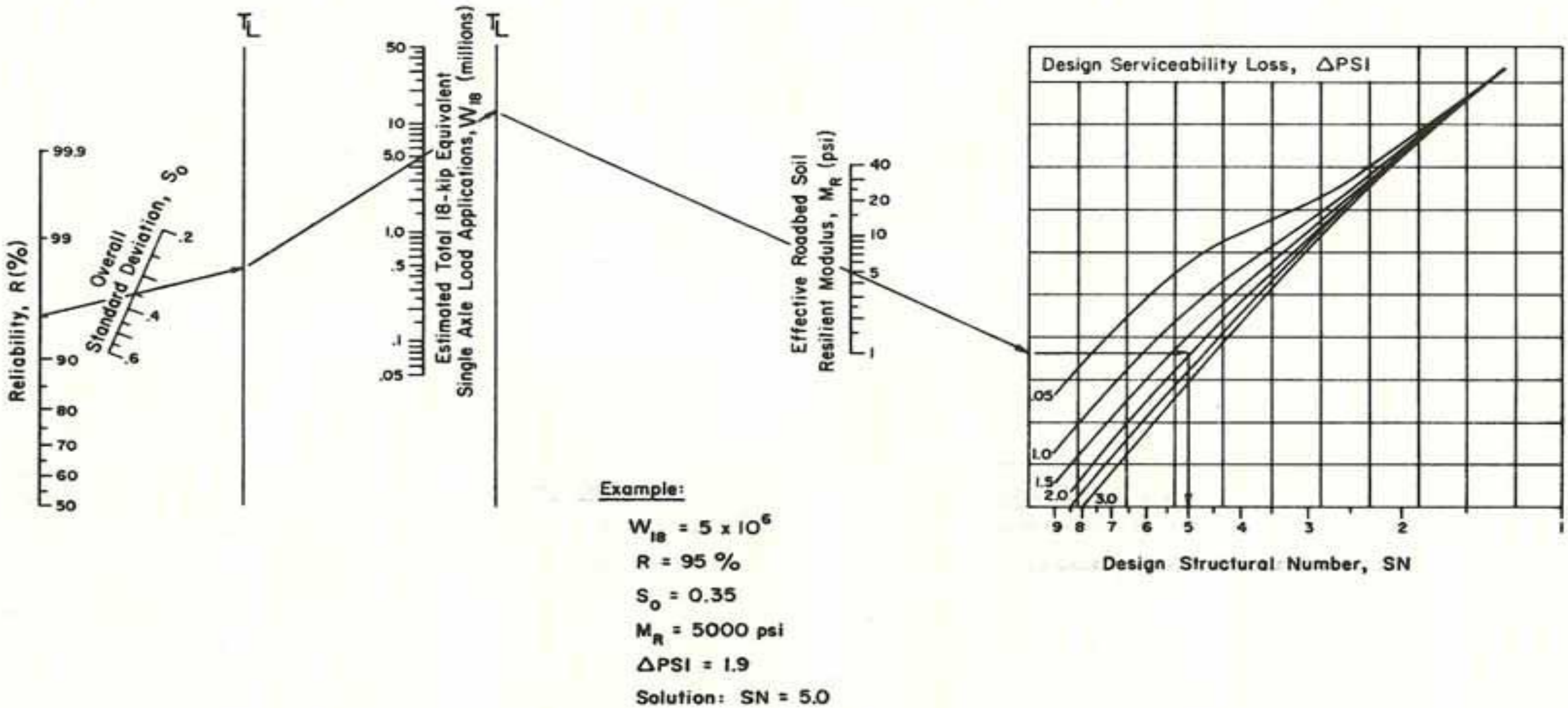


- Furthermore the method allows to design pavements with a certain level of reliability. Also the variation that occurs in the prediction of the occurring number of load repetitions as well as the variation that occurs in the layer thickness, structural layer coefficient and subgrade modulus can be taken into account by means of the overall standard deviation.



NOMOGRAPH SOLVES:

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



AASHTO design chart for flexible pavements based on using mean values for each input.

Advanced Pavement Design: AASHTO design method

- The subgrade modulus might vary during the year due to seasonal variations. One therefore has to determine the effective roadbed resilient modulus which is determined using the chart given in figure. Figure is used as follows.

❖ One first determines the modulus which is to be used in a particular month (please note that it also possible to define the subgrade modulus each half month).

❖ Then the relative damage is determined using the scale at the right hand part of the figure.

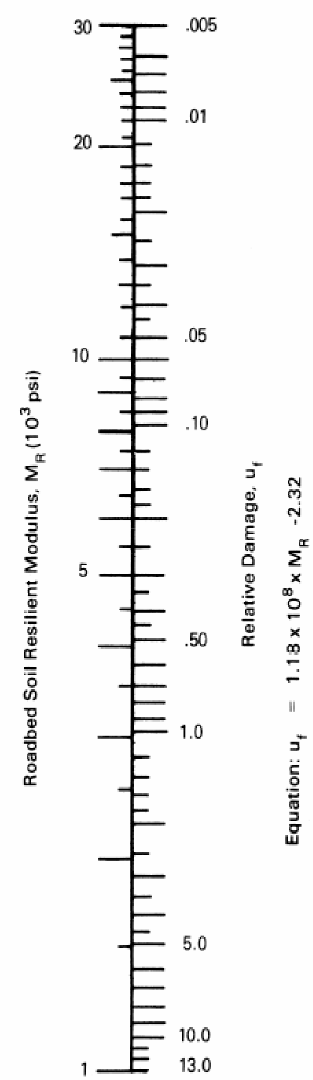
$$u_f = 1.18 \times 10^8 \times M_r^{-2.32}$$

❖ Next to that the sum is determined of the damage factors and divided by 12 (or 24 if the damage factor is defined per half month). This value is then used to determine the effective roadbed or subgrade modulus.

Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage, u_f
Jan.		
Feb.		
Mar.		
Apr.		
May		
June		
July		
Aug.		
Sept.		
Oct.		
Nov.		
Dec.		
Summation: Σu_f =		

Average: $\bar{u}_f = \frac{\Sigma u_f}{n}$ = ______

Effective Roadbed Soil Resilient Modulus, M_R (psi) = ______ (corresponds to $\bar{u}_f$)



- An example of how to use the chart is given in table below.

Month	Roadbed soil modulus [psi]	Relative damage u_f
January	20,000	0.01
February	20,000	0.01
March	2,500	1.51
April	4,000	0.51
May	4,000	0.51
June	7,000	0.13
July	7,000	0.13
August	7,000	0.13
September	7,000	0.13
October	7,000	0.13
November	4,000	0.51
December	20,000	0.01
Average u_f		3.72 / 12 = 0.31

Table 1: Calculation of the mean relative damage factor for the estimation of the effective subgrade modulus.

Since the mean relative damage factor = 0.31, we determine from figure 20 that the mean effective roadbed (or subgrade) modulus is 5,000 psi.

Charts to determine the structural layer coefficients for asphalt concrete.

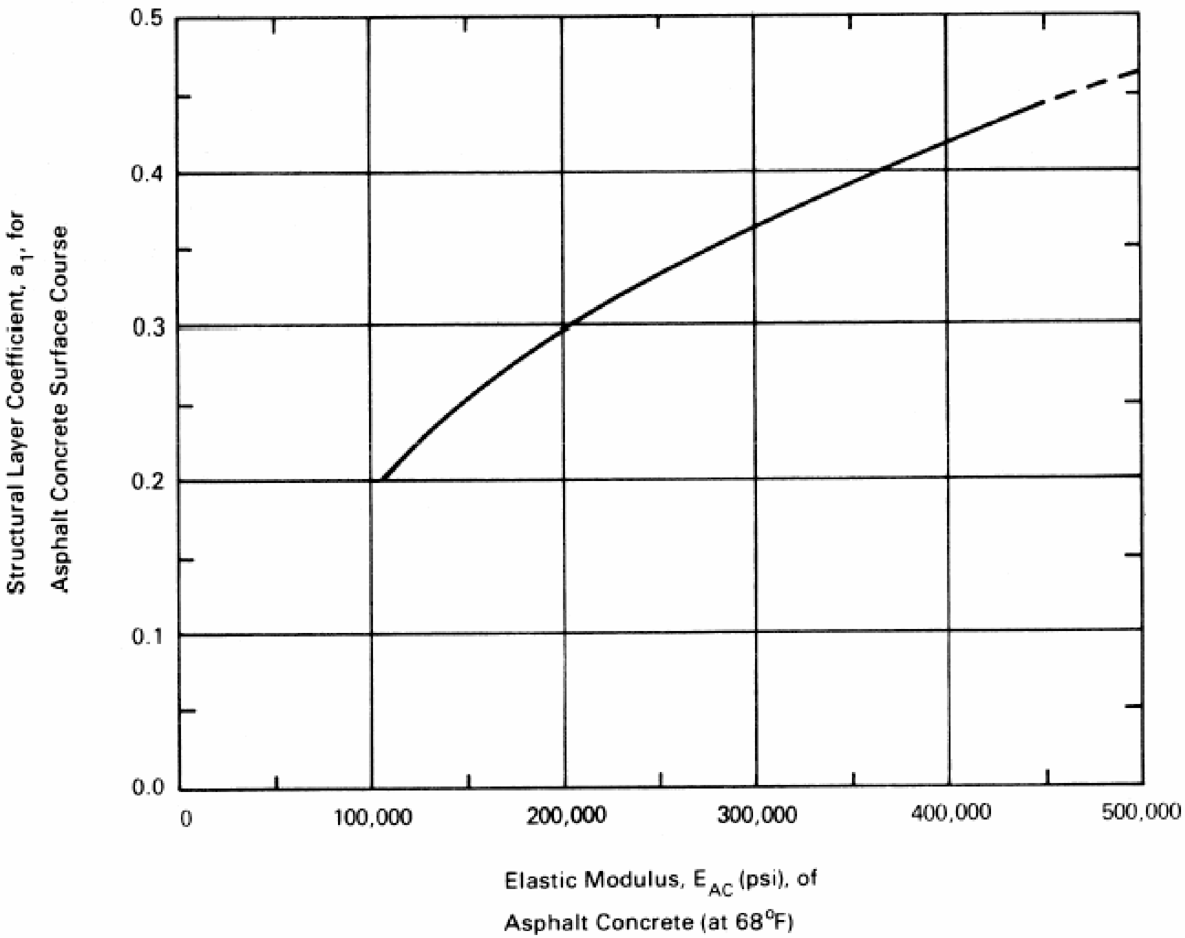


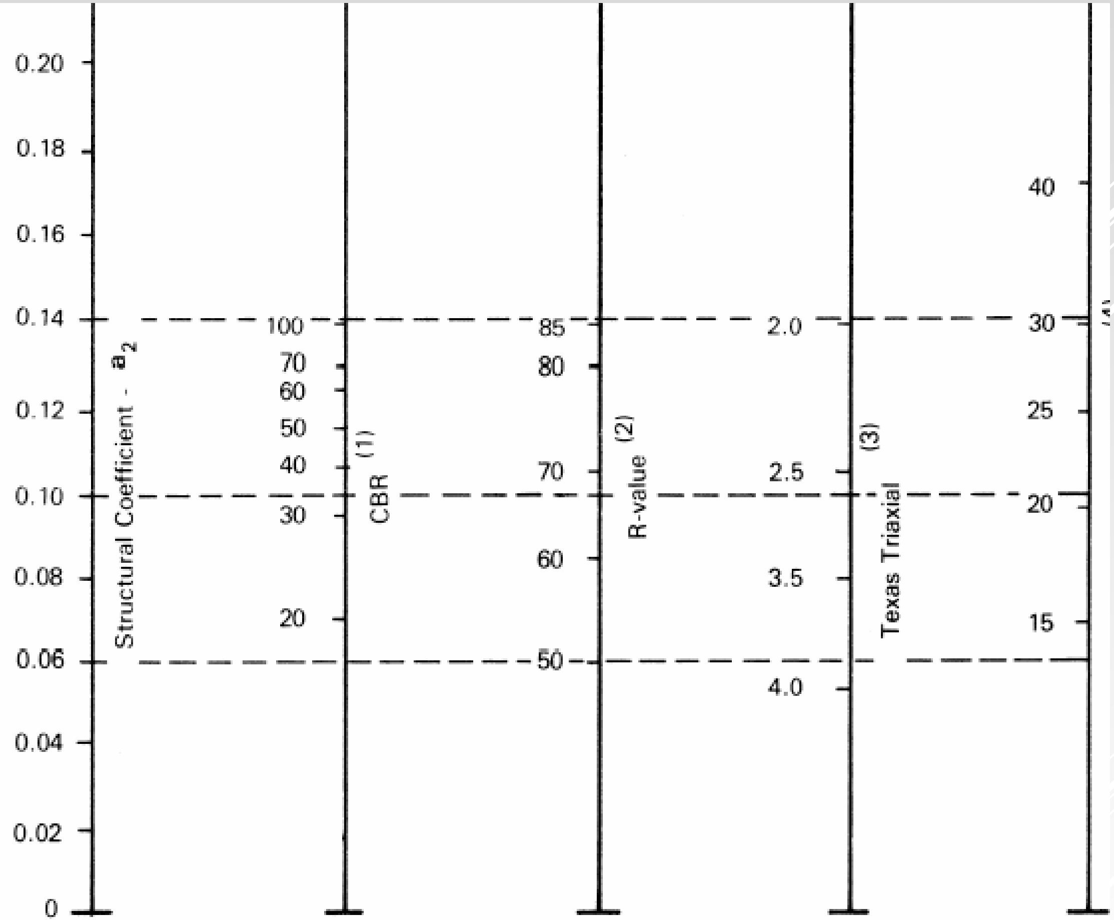
Figure 2.5. Chart for estimating structural layer coefficient of dense-graded asphalt concrete based on the elastic (resilient) modulus (*3*).

Chart for determining the structural layer coefficient for asphalt; please note that the asphalt modulus is at 68 ^{0}F (20 ^{0}C).

Chart to determine the structural layer coefficients for base (granular)

It is based on the following equations:

For the base: $a_2 = 0.249 \log E_{BS} - 0.977$



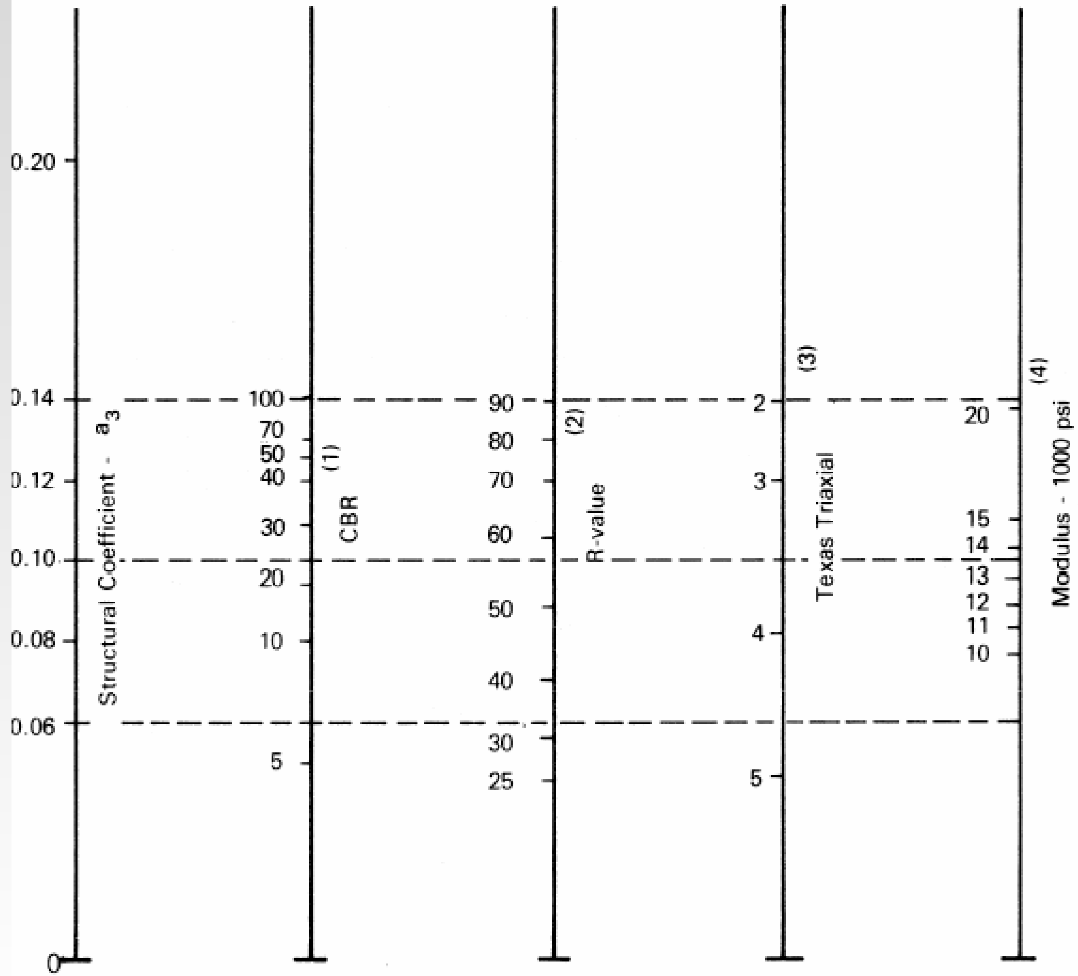
(1) Scale derived by averaging correlations obtained from Illinois.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyor
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived on NCHRP project *(3)*.

Figure 2.6. Variation in granular base layer coefficient (a_2) with various base strength parameters (*3*).

Chart to determine the structural layer coefficients for subbase base

It is based on the following equations:

For the subbase: a3 = 0.227 log ESB – 0.839



(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 2.7. Variation in granular subbase layer coefficient (a_3) with various subbase strength parameters *(3)*.

Both the resilient modulus of the base, E_{BS}, and the subbase, E_{SB}, are stress dependent following

$$E = k_1 \theta^{k2}$$

Where:
E = modulus [psi],
θ = sum of the principal stresses [psi] (see table 2).
k1, k2 = material constants (see table 3).

Asphalt concrete thickness [inch]	Roadbed resilient modulus [psi] 3000	7500	15000
< 2	20	25	30
2 – 4	10	15	20
4 – 6	5	10	15
> 6	5	5	5

Table 2: Estimated values for θ in the base and subbase.

(a) Base

Moisture Condition	k_1*	k_2*
Dry	6,000 - 10,000	0.5 - 0.7
Damp	4,000 - 6,000	0.5 - 0.7
Wet	2,000 - 4,000	0.5 - 0.7

(b) Subbase

Moisture Condition	k_1*	k_2*
Dry	6,000 - 8,000	0.4 - 0.6
Damp	4,000 - 6,000	0.4 - 0.6
Wet	1,500 - 4,000	0.4 - 0.6

Table 3: Values for k_1 and k_2 for base and subbase materials.

- The sum of the principal stresses in the base and subbase depends of course on the thickness and stiffness of the layers placed on top of them as well as on the magnitude of the load. Suggested values for θ are presented in table 2.

- As one will notice from table 3, the material constants k_1 and k_2 are dependent on the moisture condition of the material (dry, damp, wet) as well as the quality of the material (indicated by the range in values).

Chart to estimate the structural layer coefficient of cement treated base layers.

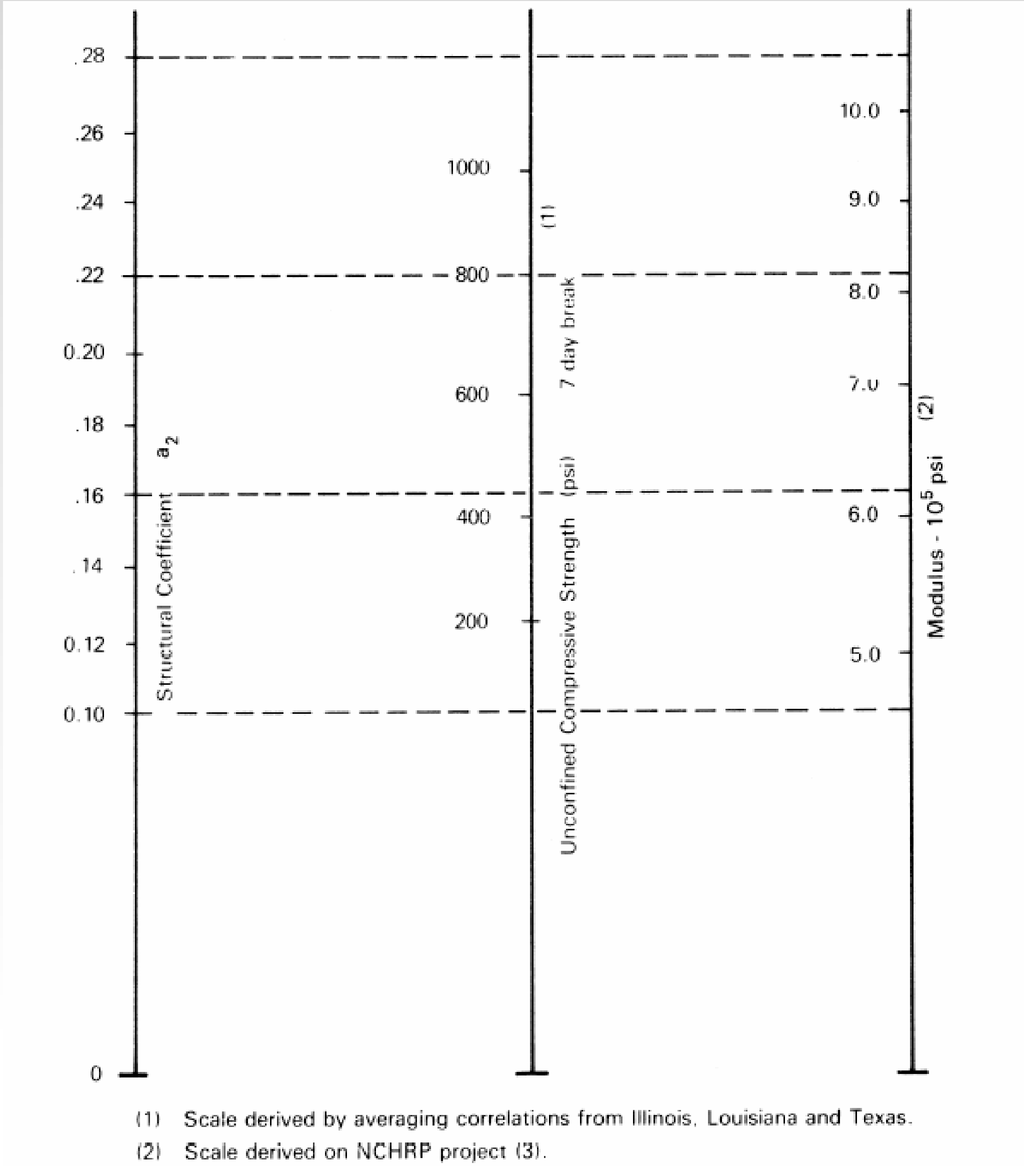
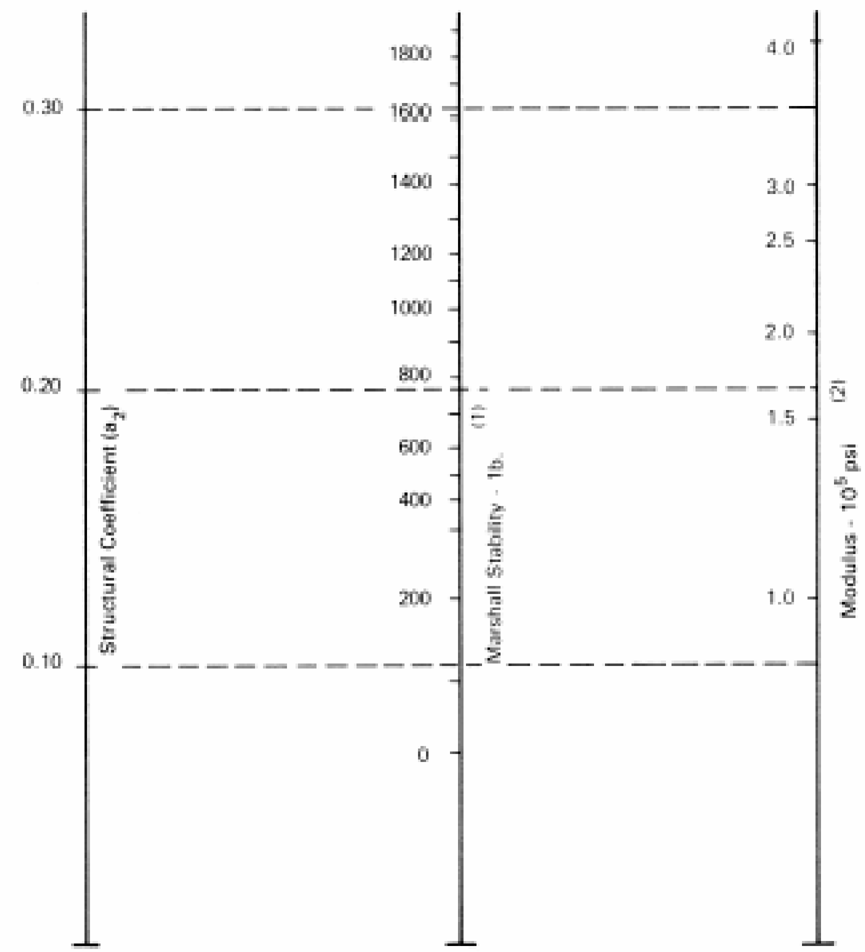


Figure 2.8. Variation in a for cement-treated bases with base strength parameter (3).

Chart to estimate the structural layer coefficient for bituminous treated base courses.



(1) Scale derived by correlation obtained from Illinois.

(2) Scale derived on NCHRP project (3).

Figure 2.9. Variation in a_2 for bituminous-treated bases with base strength parameter *(3)*.

The traffic load is expressed as number of equivalent 18 kip (82 kN) single axles. To get this number the following equation is used.

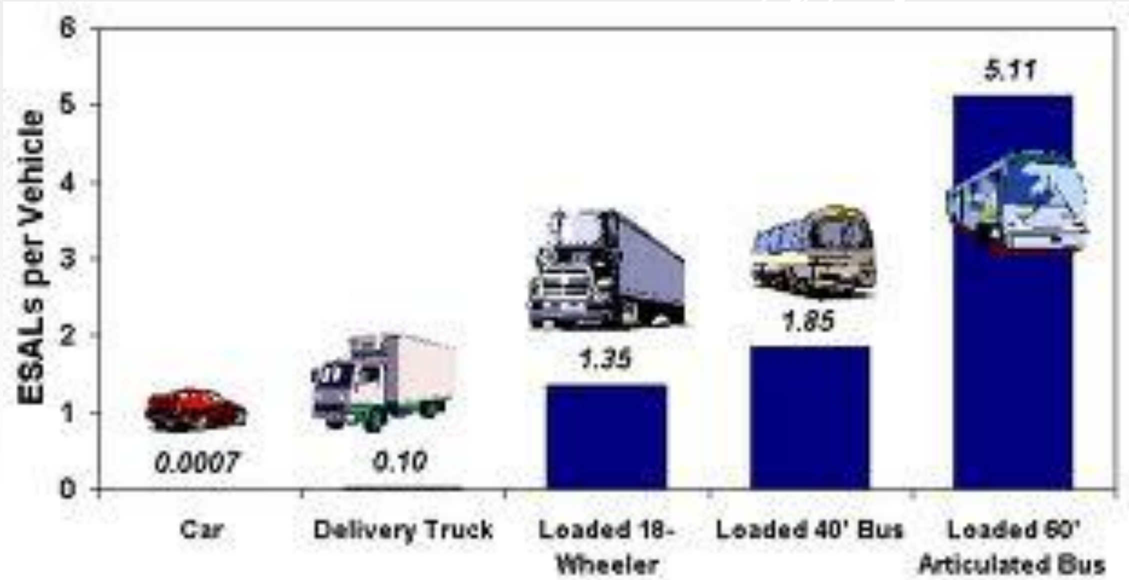
$N_{eq} = \sum_{i=1}^{i=n} (L_i / 82)^4$

Where:

N_{eq} = number of equivalent 18 kip (82 kN) single axles,

n = number of axle load classes,

L_i = axle load of axle load class i.



- The reliability level to be used depends on the importance of the road. Freeways and very important highways are to be designed with a high level of reliability (90% and higher) because of the fact that traffic delays due to maintenance because of premature failure is not considered acceptable. Roads of minor importance can be designed with a much lower reliability level. Low volume roads e.g. can be designed with a reliability level of 60 – 70%.

- The overall standard deviation is much more difficult to estimate. It appeared that this value was 0.45 for the asphalt pavements of the AASHO Road Test. Because production and laying techniques have significantly be improved since then, a lower value could be adopted. Since it is difficult to estimate a proper value, use of the 0.45 value is still suggested.

Drainage is a very important feature of pavement structures. Insufficient drainage might result in moisture conditions close to saturation. As we have seen in table 3, such conditions result in significant lower values for k_1 implying that the modulus of the unbound base and subbase can be 3 times lower in wet conditions than when they are dry. In order to be able to take care for improper drainage, it is suggested to multiply the structural layer coefficients with a drainage factor (m_i) following:

$$SN = a_1D_1 + m_2a_2D_2 + m_3a_3D_3$$

Recommended m values are given in table 4.

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

It should be noted that the selection of the actual layer thicknesses has to follow a certain procedure. First of all one should determine the SN of the entire structure. Following the example in figure 20,

- ❖ we determine that the required SN = 5.
- ❖ Then we determine the required SN_1 on top of the base. Assuming a modulus of 30000 psi for the base ($a_2 = 0.14$) we determine that $SN_1 = 2.6$ and
- ❖ we determine the required asphalt thickness (assuming $a_1 = 0.4$) as $D_1 = SN_1 / a_1 = 2.6 / 0.4 = 6.5$ inch. If we assume that the modulus of the subbase is 15000 psi ($a_3 = 0.11$),
- ❖ we determine in the same way the required thickness on top of the subbase as SN2 = 3.4 The required base thickness is D2 = (SN2 – SN1) / a2 = (3.4 – 2.6) / 0.14 = 5.8 inch.
- ❖ Furthermore we calculate the thickness of the subbase as D3 = (SN3 – SN2) / a3 = (5 – 3.4) / 0.11 = 14.6 inch.