Pavement Analysis and Design

TE-503A/ TE-503

Lecture-12
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KENPAVE SOFTWARE
2nd Session

AASHTO Method

The design guide for rigid pavements was developed at the same time as that for flexible pavements and was published in the same manual. The design is based on the empirical equations obtained from the AASHO Road Test, with further modifications based on theory and experience.

Here, only the thickness design will be discussed. The design of steel reinforcements and tie-bars is similar to that discussed in Section 4.3.2.

AASHTO Method-Modulus of Subgrade Reaction

The property of roadbed soil to be used for rigid pavement design is the modulus of subgrade reaction *k*, rather than the resilient modulus. It is therefore necessary to convert M_R to *k*. As with M_R, the values of *k* also vary with the season of the year, and the relative damage caused by the change of *k* needs to be evaluated.

AASHTO Method-Modulus of Subgrade Reaction

Correlation with Resilient Modulus-Without Subbase

$$k = \frac{M_R}{19.4}$$

$$k = \frac{M_R}{18.8}$$

M_R in psi and k in pci

AASHTO Method-Modulus of Subgrade Reaction

Correlation with Resilient Modulus-With Subbase

If a subbase exists between the slab and the subgrade, the composite modulus of subgrade reaction can be determined from figugre. This modulus is based on a subgrade of infinite depth and is denoted by k_{∞}.

The chart was developed by using the same method as for a homogeneous half-space, except that the 30-in. plate is applied on a two-layer system. Therefore, the *k* values obtained from the chart are too large and do not represent what actually occurs in the field.

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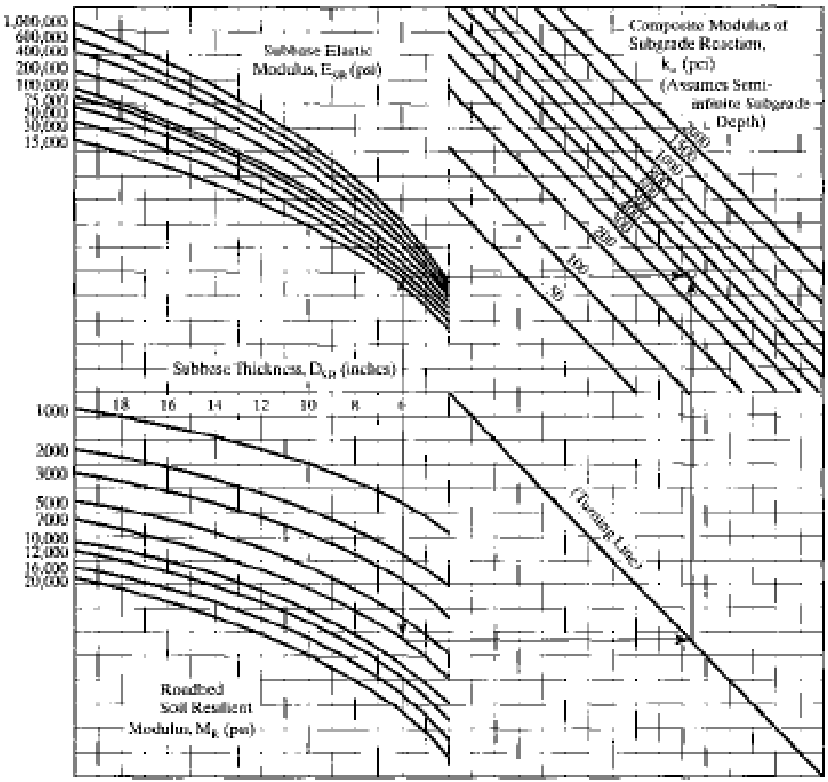
AASHTO Method-Modulus of Subgrade Reaction

Correlation with Resilient Modulus-With Subbase



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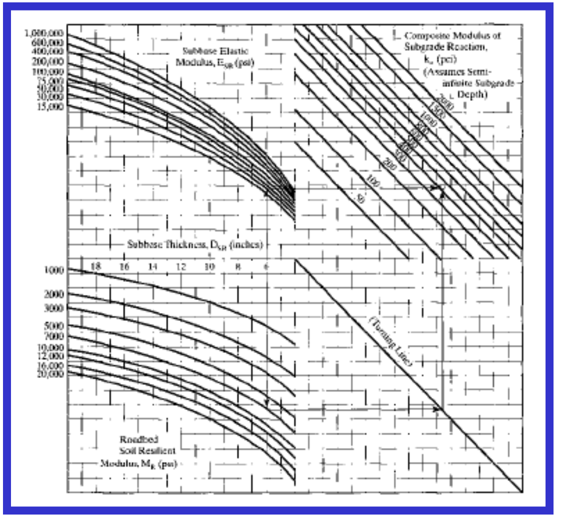
AASHTO Method-Modulus of Subgrade Reaction-Numerical problem

Given a subbase thickness D_{sB} of 6 in., a subbase resilient modulus E_{sB} of 20,000 psi and a roadbed soil resilient modulus M_R of 7000 psi, determine the composite modulus of subgrade reaction k_c.

Solution: The composite modulus of subgrade reaction can be determined as follows:

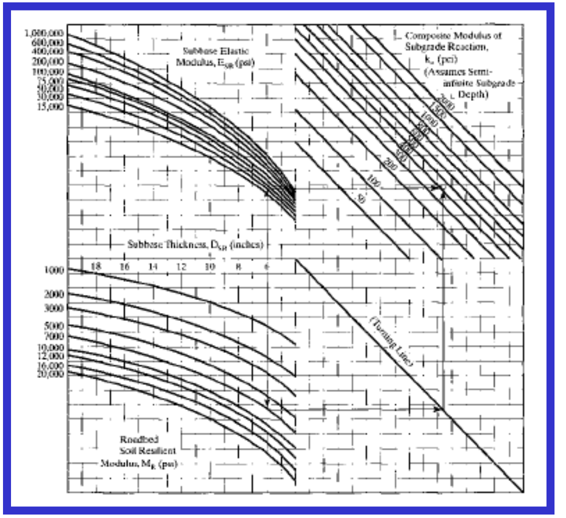
1. In Figure 12.18, a vertical line is drawn upward from the horizontal scale with a subbase thickness of 6 in. until it reaches a point with a subbase modulus of 20,000 psi.



AASHTO Method-Modulus of Subgrade Reaction-Numerical problem

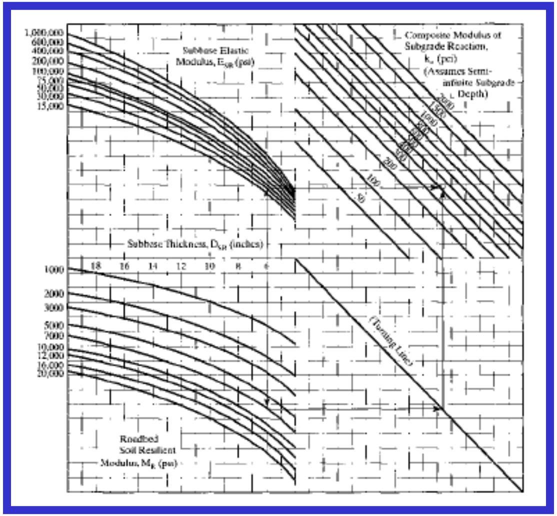
Given a subbase thickness D_{sB} of 6 in., a subbase resilient modulus E_{sB} of 20,000 psi and a roadbed soil resilient modulus M_R of 7000 psi, determine the composite modulus of subgrade reaction k_c.

2. The same line is drawn downward until it intersects the curve with a roadbed soil resilient modulus of 7000 psi and then the line is turned horizontally until it intersects the turning line.



AASHTO Method-Modulus of Subgrade Reaction-Numerical problem

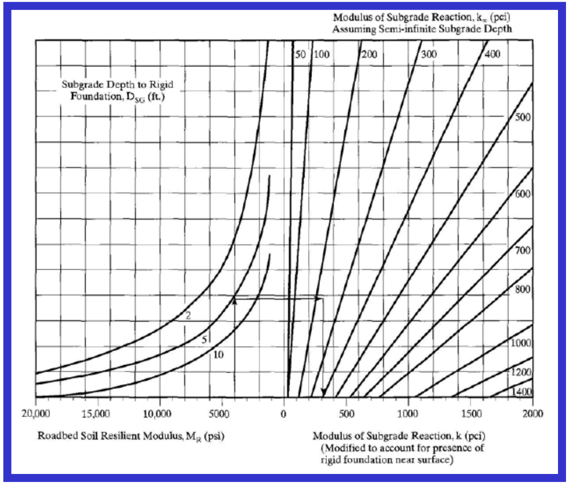
3. A horizontal line is drawn from the point in Step 1, a vertical line from the point on the turning line in Step 2. The intersection of these two lines gives a k_∞ of 400 pci.



Rigid Pavement Design

AASHTO Method-Modulus of Subgrade Reaction-Rigid Foundation at Shallow Depth

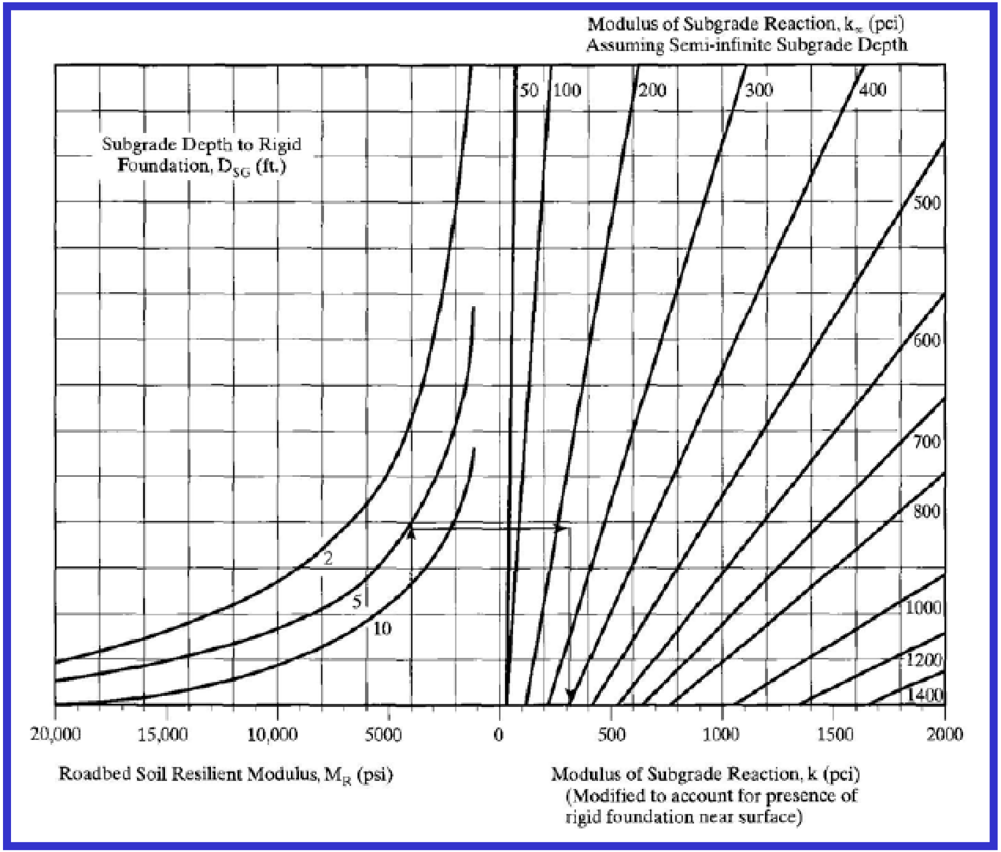
The given equation and Figure are based on a subgrade of infinite depth. If a rigid foundation lies below the subgrade and the subgrade depth to rigid foundation D_{sG} is smaller than 10 ft, then the modulus of subgrade reaction must be modified by the chart shown in Figure. The chart can be applied to slabs either with or without a subbase.



$$k = \frac{M_R}{19.4}$$

Rigid Pavement Design

AASHTO Method-Modulus of Subgrade Reaction-Rigid Foundation at Shallow Depth



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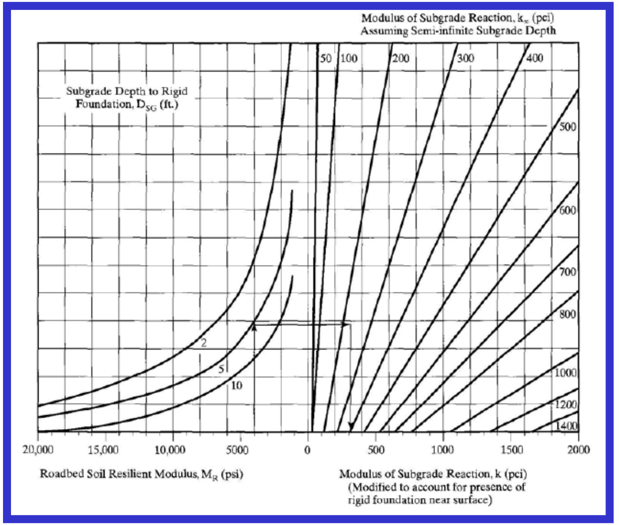
AASHTO Method-Modulus of Subgrade Reaction-Rigid Foundation at Shallow Depth-Numerical problem

Given M_R= 4000 psi, D_{sG} = 5 ft and k_∞ = 230 pci, determine k.

Solution: In Figure, a vertical line is drawn from the horizontal scale with a M_R= 4000 psi until it intersects the curve with a D_{sG} = 5 ft. The line is turned horizontally until it reaches a point with a k_∞ of 230 pci and then vertically until a k of 300 pci is obtained.



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AASHTO Method-Effective Modulus of Subgrade Reaction

D=9 in

$$u_r = (D^{0.75} - 0.39k^{0.25})^{3.42}$$

$$k = \frac{M_R}{19.4}$$

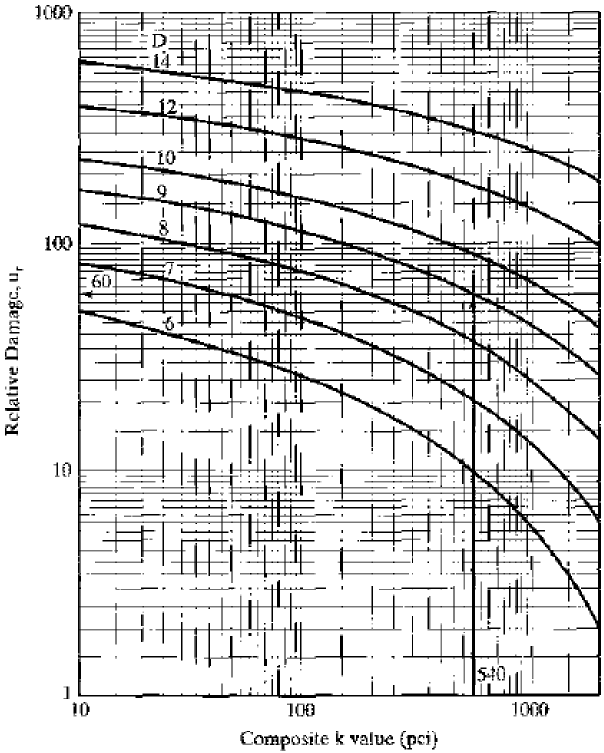

TABLE 12.17 Computation of Effective Modulus of Subgrade Reaction

Month (1)	Roadbed modulus M_R (psi) (2)	k Value (pci) (3)	Relative damage u_r (%) (4)
Jan	4500	232	85.7
Feb	27,300	1407	34.2
Mar	50,000	2577	20.5
Apr	1350	70	121.4
May	2140	110	108.1
Jun	2930	151	98.7
Jul	3710	191	91.6
Aug	4500	232	85.7
Sep	4500	232	85.7
Oct	4500	232	85.7
Nov	4500	232	85.7
Dec	4500	232	85.7

Average $\bar{u}_r = \frac{\Sigma u_r}{n} = 82.4$ $\Sigma u_r = 988.7$

Effective modulus of subgrade reaction, k = 263 pci

Note. 1 psi = 6.9 kPa, 1 pci = 271.3 kN/m³.

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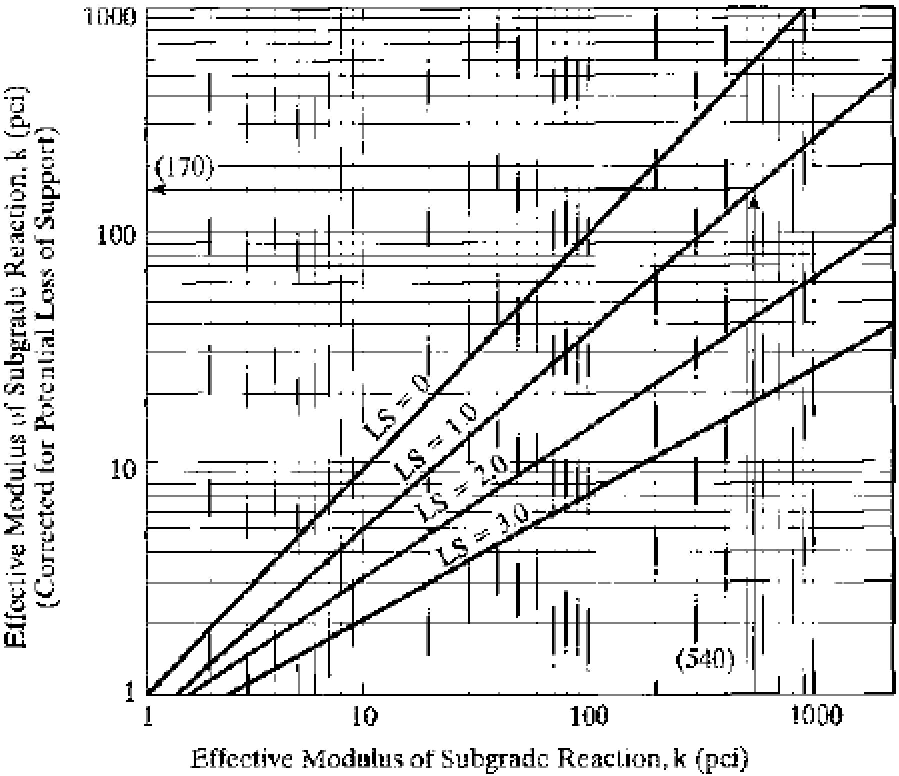
AASHTO Method-Loss of Subgrade Support



To account for the potential loss of support by foundation erosion or differential vertical soil movements, the effective modulus of subgrade reaction must be reduced by a factor, *LS*.

Rigid Pavement Design

AASHTO Method-Loss of Subgrade Support

TABLE 12.18 Typical Ranges of LS Factors for Various Types of Materials

Type of material	Loss of support (LS)
Cement-treated granular base ($E = 1 \times 10^6$ to 2×10^6 psi)	0.0 to 1.0
Cement aggregate mixtures ($E = 500{,}000$ to 1×10^6 psi)	0.0 to 1.0
Asphalt-treated bases ($E = 350{,}000$ to 1×10^6 psi)	0.0 to 1.0
Bituminous-stabilized mixture ($E = 40{,}000$ to $300{,}000$ psi)	0.0 to 1.0
Lime-stabilized materials ($E = 20{,}000$ to $70{,}000$ psi)	1.0 to 3.0
Unbound granular materials ($E = 15{,}000$ to $45{,}000$ psi)	1.0 to 3.0
Fine-grained or natural subgrade materials ($E = 3000$ to $40{,}000$ psi)	2.0 to 3.0

Note. E in this table refers to the general symbol of the resilient modulus.
Source. After AASHTO (1986).

AASHTO Method-Design Variables-Elastic modulus of concrete

The elastic modulus of concrete can be determined according to the procedure described in ASTM C469 or correlated with the compressive strength. The following is a correlation recommended by the American Concrete Institute:

$$E_c = 57{,}000(f'_c)^{0.5}$$

in which E_c is the concrete elastic modulus in psi and f'_c is the concrete compressive strength in psi as determined by AASHTO T22, T140 or ASTM C39.

AASHTO Method-Design Variables-Concrete modulus of rupture

The modulus of rupture required by the design procedure is the mean value determined after 28 days by using third-point loading, as specified in AASHTO T97 or ASTM C78. If center-point loading is used, a correlation should be made between the two tests.

AASHTO Method-Design Variables-Load Transfer Coefficient

The load transfer coefficient *J* is a factor used in rigid pavement design to account for the ability of a concrete pavement structure to transfer a load across joints and cracks. The use of load transfer devices and tied concrete shoulders increases the amount of load transfer and decreases the load-transfer coefficient.

Table 12.19 shows the recommended load transfer coefficients for various pavement types and design conditions. The AASHO Road Test conditions represent a J value of 3.2, because all joints were doweled and there were no tied concrete shoulders.

TABLE 12.19 Recommended Load Transfer Coefficient for Various Pavement Types and Design Conditions

Type of shoulder	Asphalt		Tied PCC	
Load transfer devices	Yes	No	Yes	No
JPCP and JRCP	3.2	3.8–4.4	2.5–3.1	3.6–4.2
CRCP	2.9–3.2	N/A	2.3–2.9	N/A

Source. After AASHTO (1986).

AASHTO Method-Design Variables-Drainage Coefficient

The drainage coefficient C_d has the same effect as the load transfer coefficient J. As indicated by Eq. 12.21, an increase in C_d is equivalent to a decrease in J, both causing an increase in W_{18}.

$$\log W_{18} = Z_R S_o + 7.35 \log(D + 1) - 0.06 + \frac{\log[\Delta PSI/(4.5 - 1.5)]}{1 + 1.624 \times 10^7/(D + 1)^{8.46}}$$
$$+ (4.22 - 0.32 p_t) \log\left\{\frac{S_c C_d (D^{0.75} - 1.132)}{215.63\, J[D^{0.75} - 18.42/(E_c/k)^{0.25}]}\right\} \qquad (12.21)$$

AASHTO Method-Design Variables-Drainage Coefficient

Table 12.20 provides the recommended C_d values based on the quality of drainage and the percentage of time during which the pavement structure would normally be exposed to moisture levels approaching saturation. As with flexible pavements, the percentage of time is dependent on the average yearly rainfall and the prevailing drainage conditions.

TABLE 12.20 Recommended Values of Drainage Coefficients C_d for Rigid Pavements

Quality of drainage		Percentage of time pavement structure is exposed to moisture levels approaching saturation			
Rating	Water removed within	Less than 1%	1–5%	5–25%	Greater than 25%
Excellent	2 hours	1.25–1.20	1.20–1.15	1.15–1.10	1.10
Good	1 day	1.20–1.15	1.15–1.10	1.10–1.00	1.00
Fair	1 week	1.15–1.10	1.10–1.00	1.00–0.90	0.90
Poor	1 month	1.10–1.00	1.00–0.90	0.90–0.80	0.80
Very poor	Never drain	1.00–0.90	0.90–0.80	0.80–0.70	0.70

Source. After AASHTO (1986).

AASHTO Method-Design equations

$$\log W_{18} = Z_R S_o + 7.35 \log(D+1) - 0.06 + \frac{\log[\Delta PSI/(4.5-1.5)]}{1 + 1.624 \times 10^7/(D+1)^{8.46}}$$

$$+ (4.22 - 0.32 p_t) \log\left\{\frac{S_c C_d (D^{0.75} - 1.132)}{215.63\, J[D^{0.75} - 18.42/(E_c/k)^{0.25}]}\right\} \qquad (12.21)$$

D: Thickness of slab

E_c: Modulus of elasticity of concrete

S_c: Modulus of rupter of concrete

k: Modulus of subgrade reaction

C_d:Drainage coefficient

J:Load transfer coefficient

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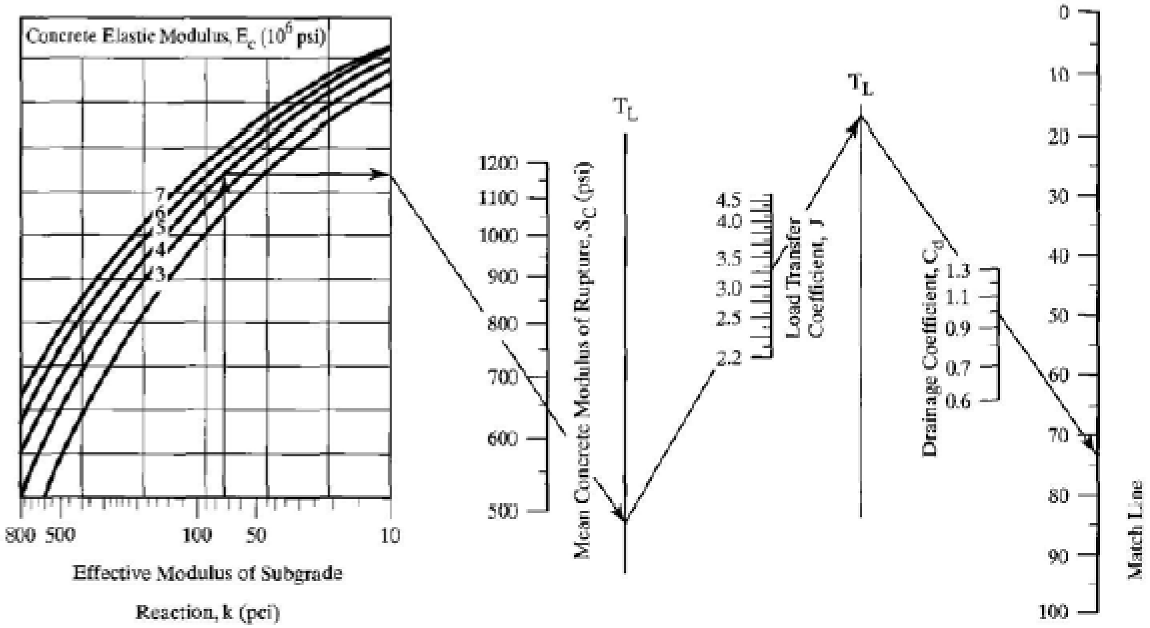
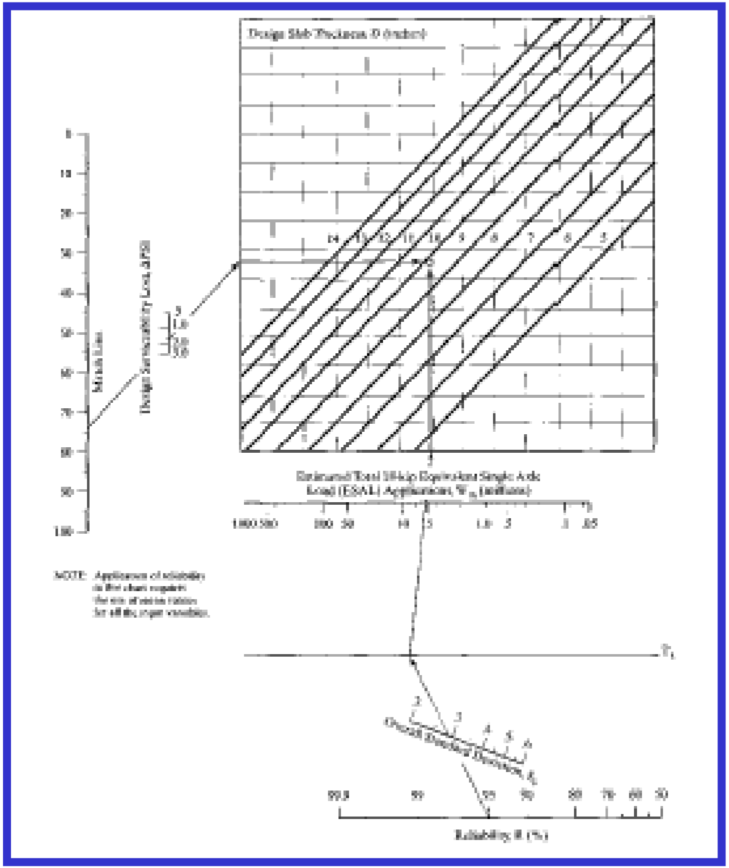
AASHTO Method-Design equations



AASHTO Method-Design equations



AASHTO Method-Numerical problem

Given k = 72 pci, E_c = 5x10^6 psi, S_c = 650 psi, J = 3.2, C_d=1.0, ΔPSI = 4.2-2.5 = 1.7, R = 95%, S_o = 0.29 and W_t = 5.1x10^6, determine thickness D.

The required thickness D can be determined by the following steps :

1. Starting from nomograph-a with k = 72 pci, a series of lines, as indicated by the arrows, are drawn through E_c = 5x10^6 psi, S_c = 650 psi, J = 3.2, C_d = 1.0 until a scale of 74 is obtained at the match line.

2. Starting at 74 on the match line in nomograph-b, a line is drawn through ΔPSI=1.7 until it intersects the vertical axis.

AASHTO Method-Numerical problem

Given k = 72 pci, E_c = 5x10^6 psi, S_c = 650 psi, J = 3.2, C_d=1.0, ΔPSI = 4.2-2.5 = 1.7, R = 95%, S_o = 0.29 and W_t = 5.1x10^6, determine thickness D.

The required thickness D can be determined by the following steps:

3. From the scale with R=95%, a line is drawn through S_o = 0.29 and then through W_{18}= 5.1x10^6 until it intersects the horizontal axis.

4. A horizontal line is drawn from the last point in Step 2, a vertical line from that in Step 3. The intersection of these two lines gives a D of 9.75 in., which is rounded to 10 in.

AASHTO Method-Numerical problem

Given k = 72 pci, E_c = 5x10^6 psi, S_c = 650 psi, J = 3.2, C_d=1.0, ΔPSI = 4.2-2.5 = 1.7, R = 95%, S_o = 0.29 and slab thickness D=9.75 in., determine W_{18} using the following equation.

$$\log W_{18} = Z_R S_o + 7.35 \log(D+1) - 0.06 + \frac{\log[\Delta PSI/(4.5-1.5)]}{1 + 1.624 \times 10^7/(D+1)^{8.46}} + (4.22 - 0.32 p_t) \log\left\{\frac{S_c C_d (D^{0.75} - 1.132)}{215.63\, J[D^{0.75} - 18.42/(E_c/k)^{0.25}]}\right\} \quad (12.21)$$

For R=95%, Z_R = -1.645

W_{18} = 5.2x10^6