Material Properties

AASHTO Design Equation

$$\log_{10} W_{18} = 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2-p}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10}(M_R) - 8.07$$

Constructed Pavement

Subgrade

1986

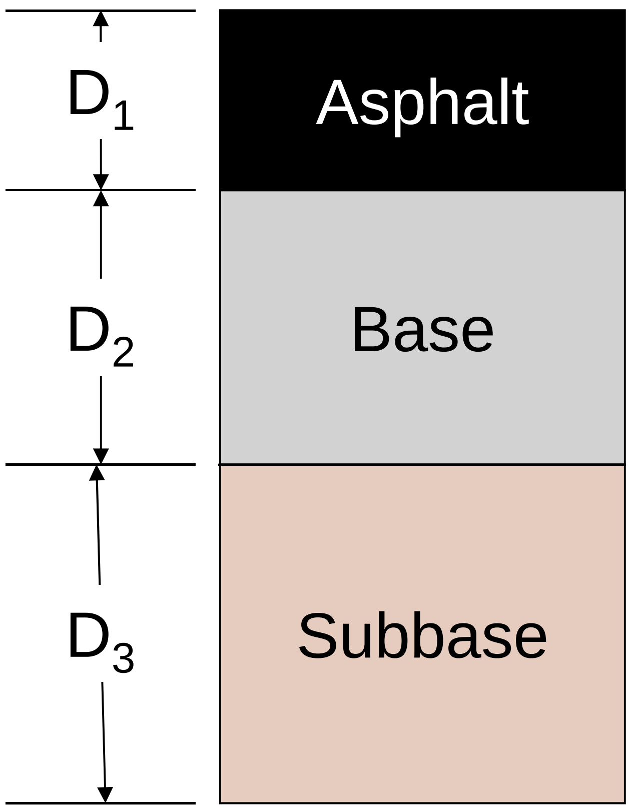
Structural Number

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3$$

asphalt base subbase

$$a_1, a_2, a_3 = f(M_R)$$

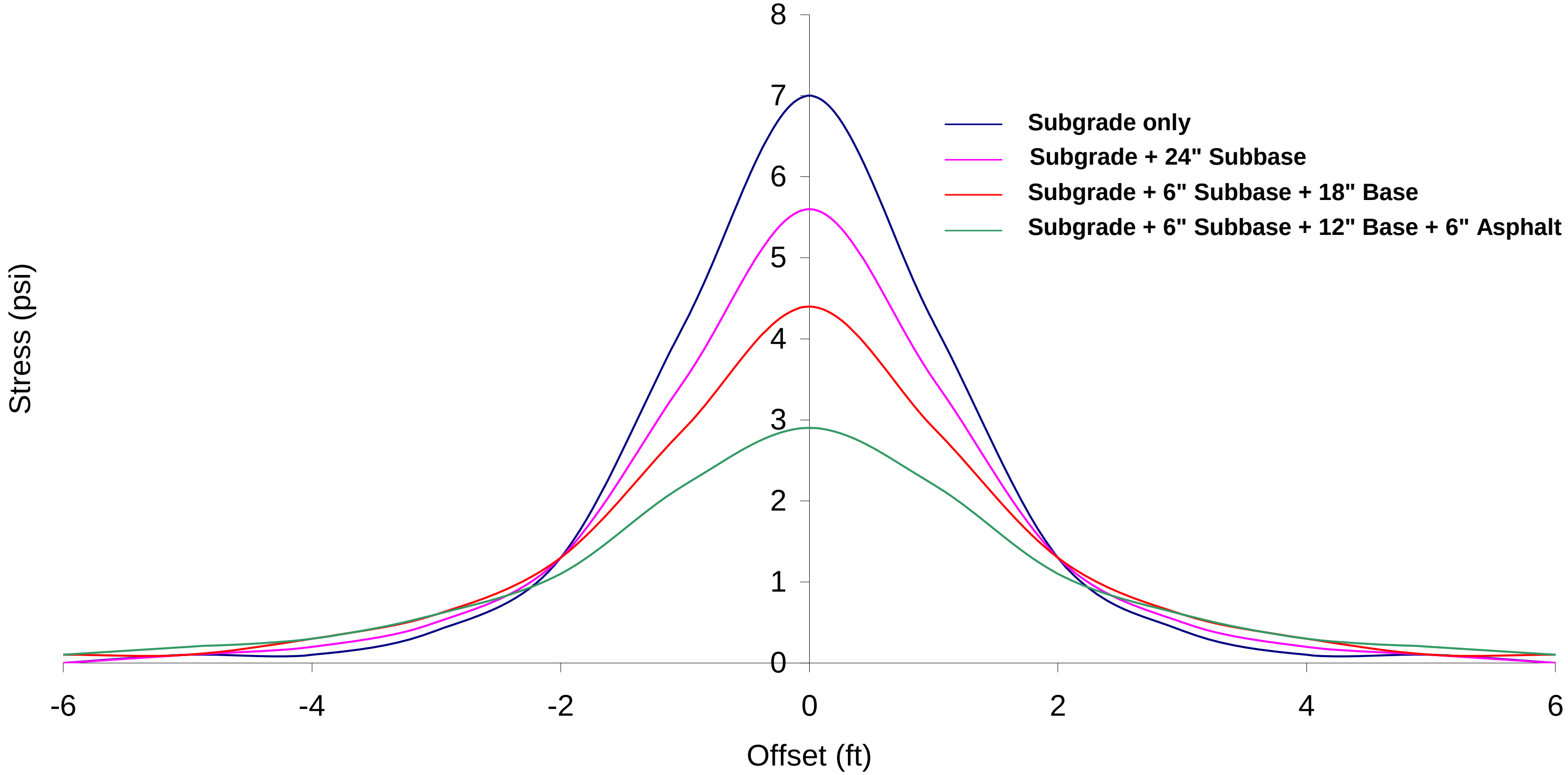
Typical Layer Coefficients



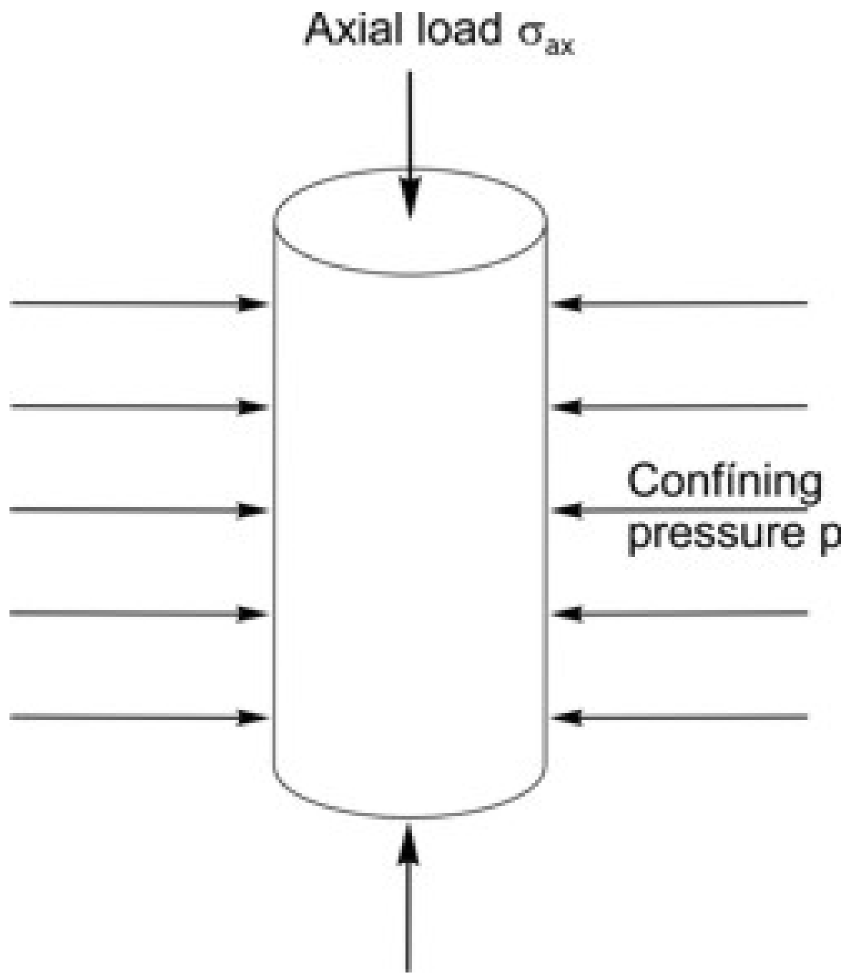
Typical Layer Coefficients

Dense-graded asphalt	0.44
Sand asphalt	0.40
Crushed stone base	0.14
Sandy gravel base	0.07
Cement-treated base	0.20
Asphalt-treated base	0.30
Lime-treated base	0.20
Sandy gravel subbase	0.11
Sand subbase	0.08

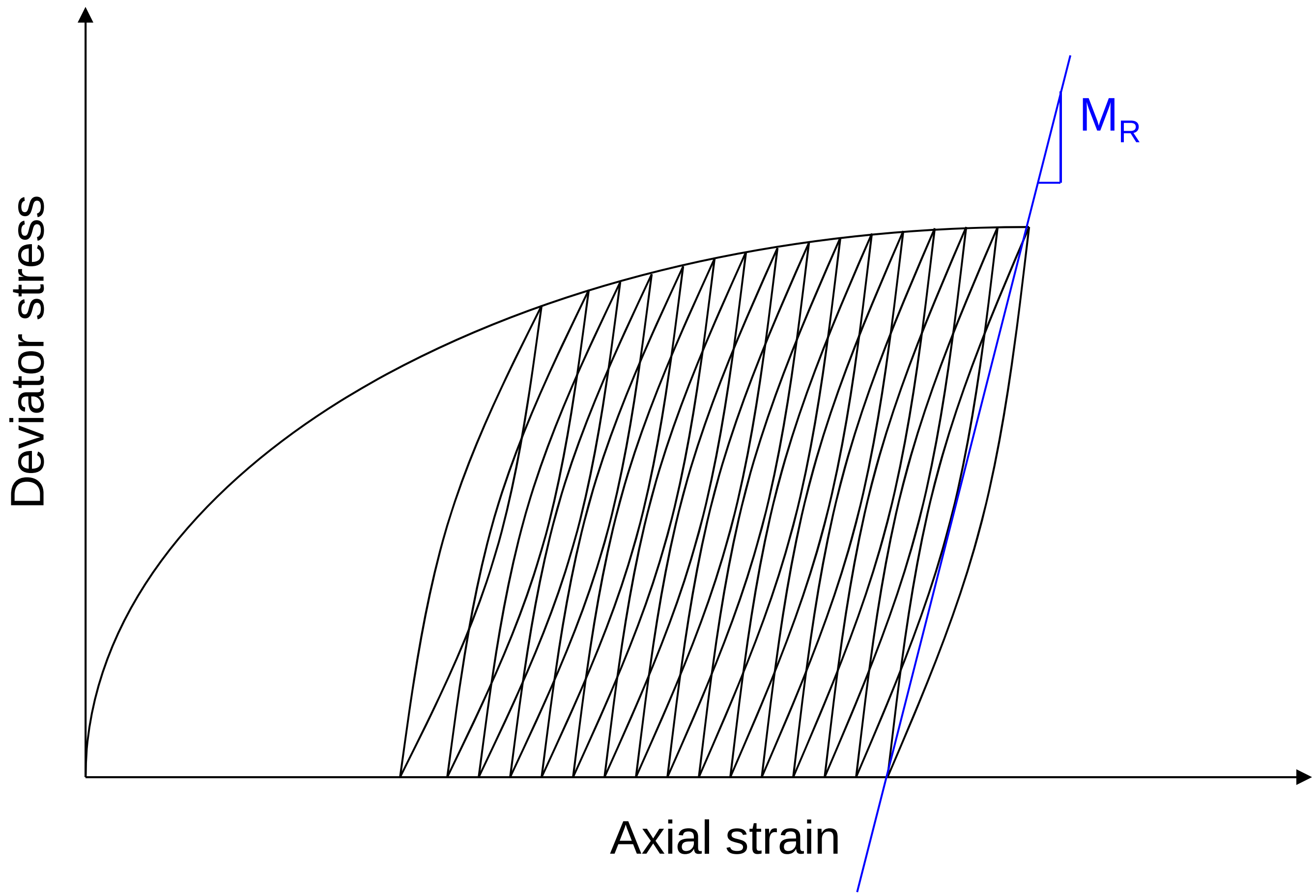
Pavement Stresses @ 24"



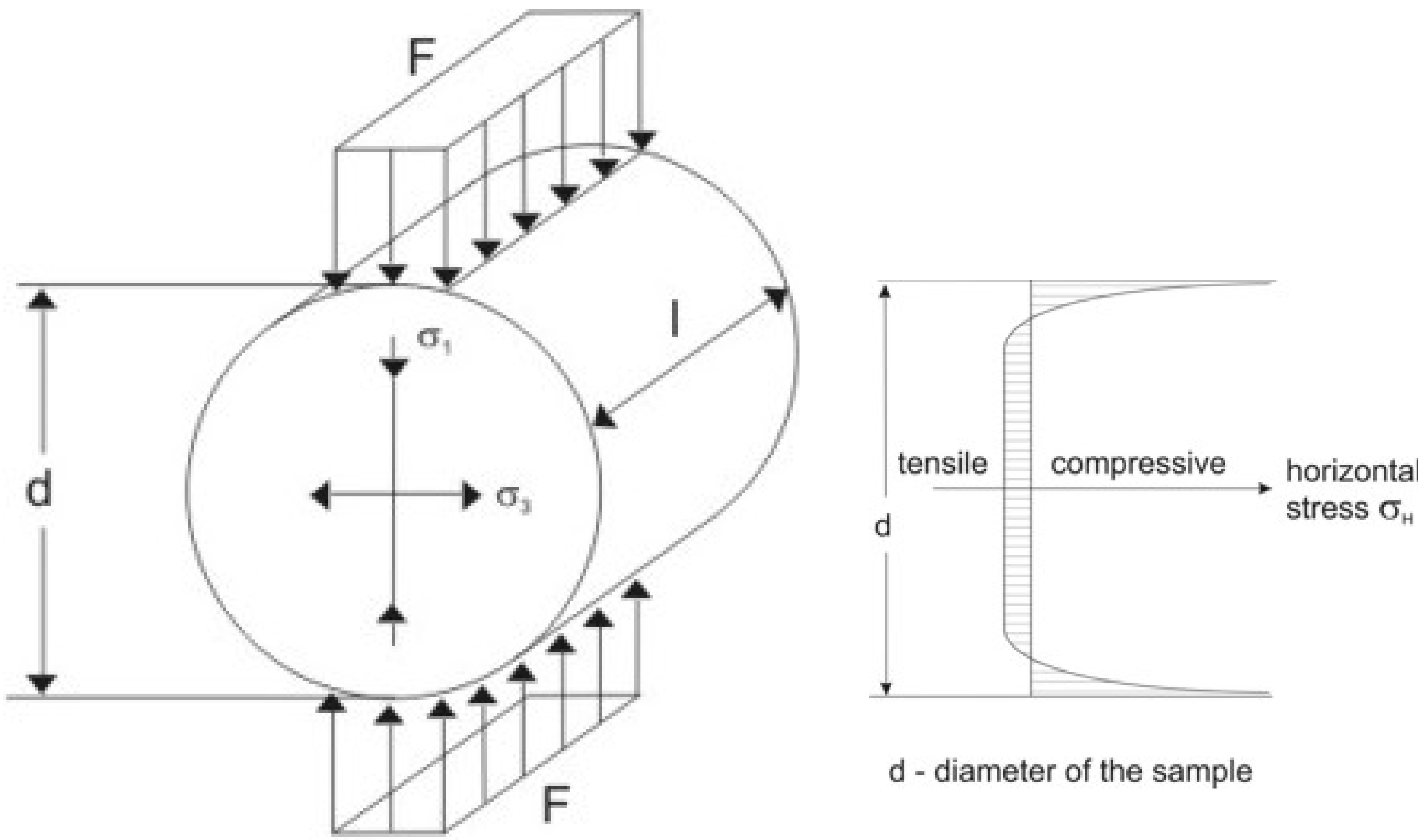
Resilient Modulus



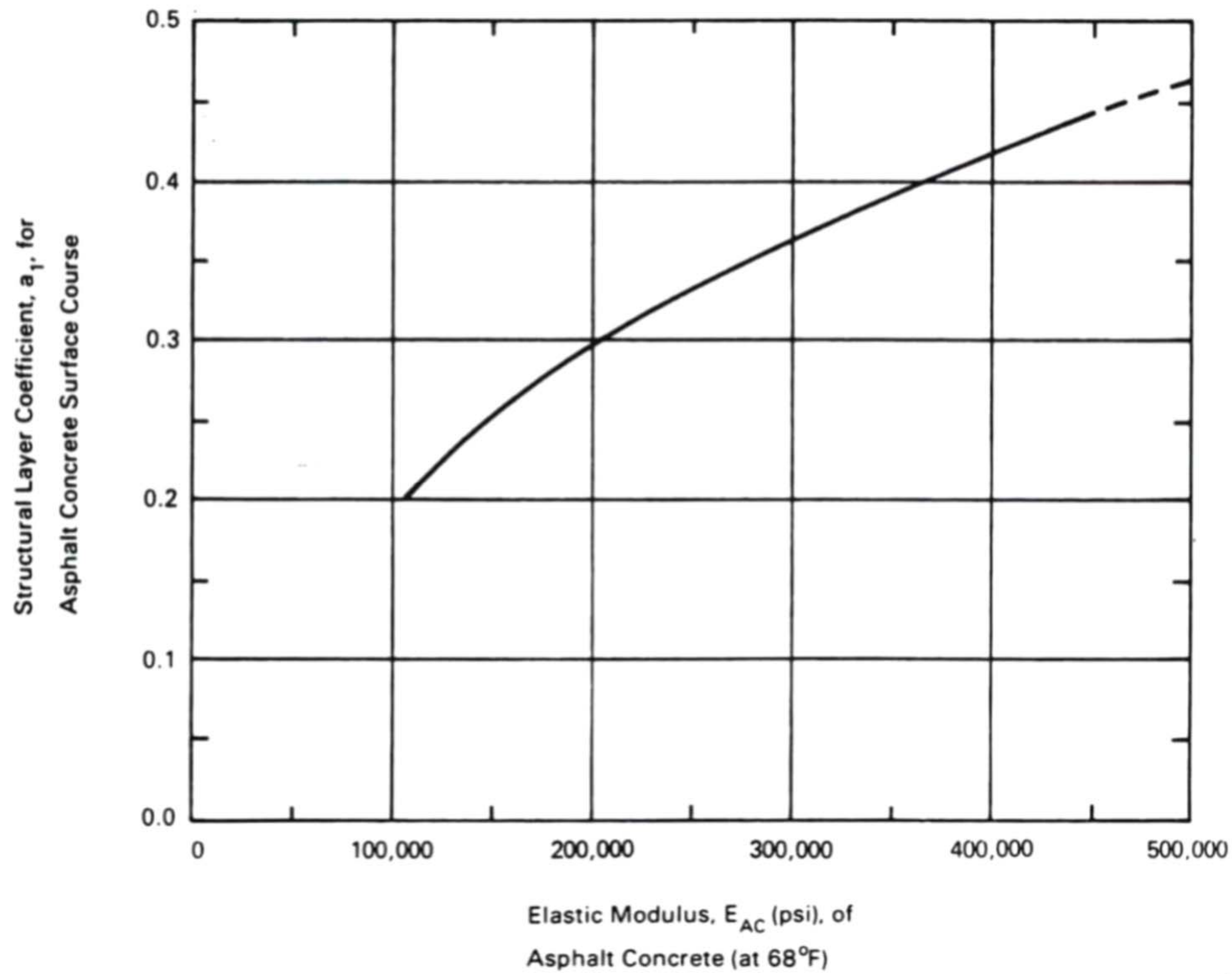
Resilient Modulus



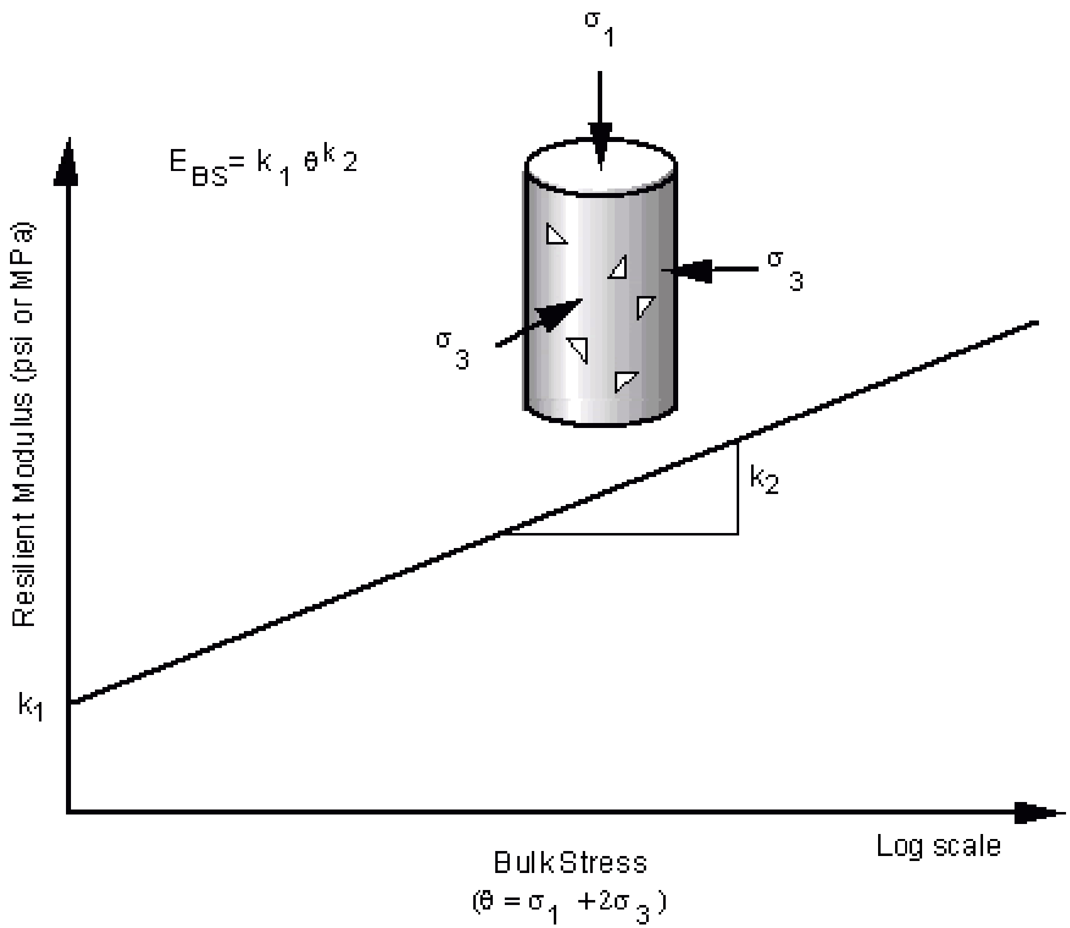
Diametral Resilient Modulus



Asphalt Layer Coefficient



Granular Soils



Source: WSDOT Pavement Guide Interactive CD-ROM

Base Layer

$$a_2 = 0.249\log_{10}\left(E_{BS}\right) - 0.977$$

$$E_{BS} = k_1\theta^{k_2}$$

AASHO Road Test

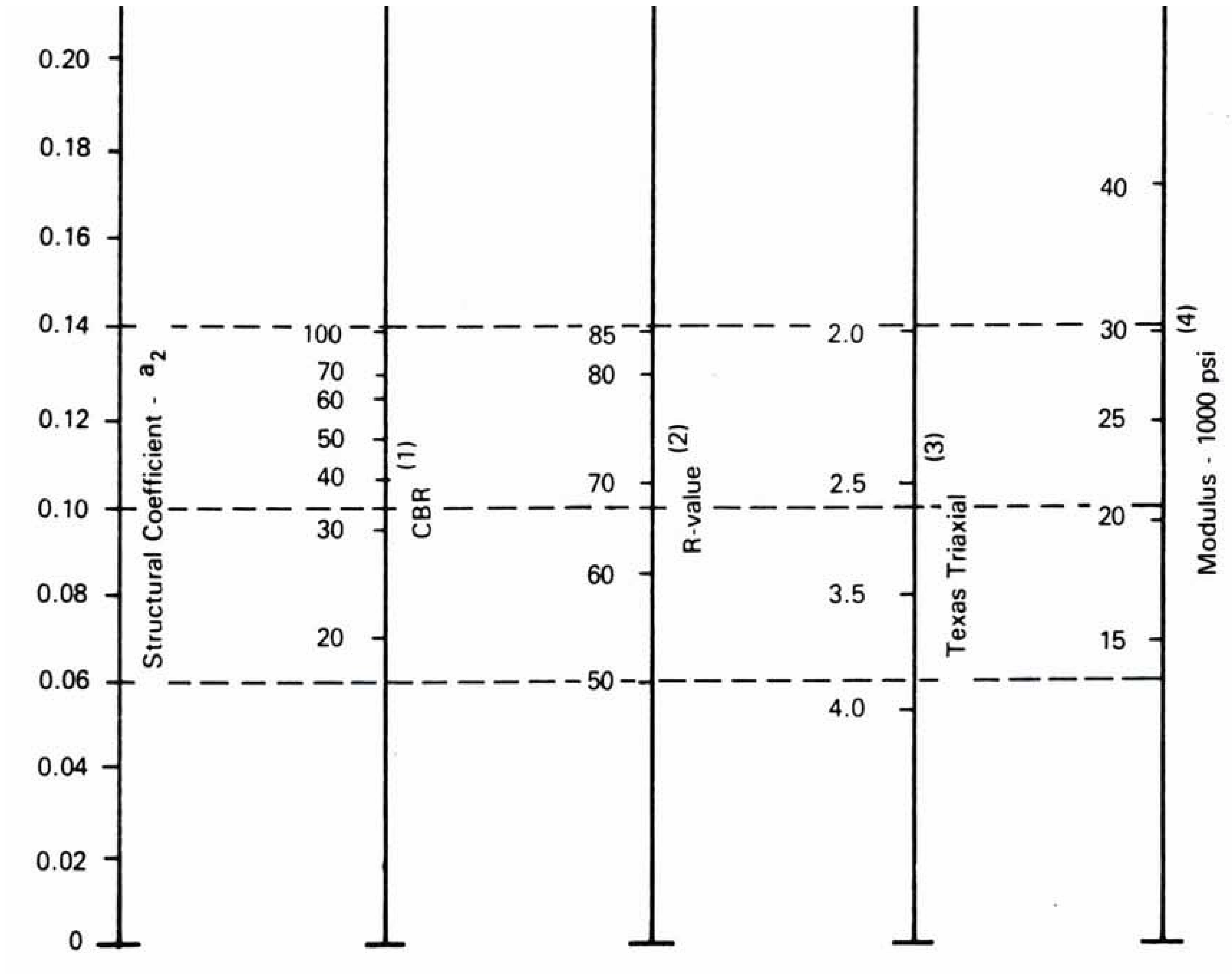
Moisture State	**k_1 (psi)**	**k_2 (-)**
Dry	8000	0.6
Damp	4000	0.6
Wet	3200	0.6

WARNING: We don't actually use different values for different moisture states. This just illustrates the effects of moisture on base layer resilient modulus.

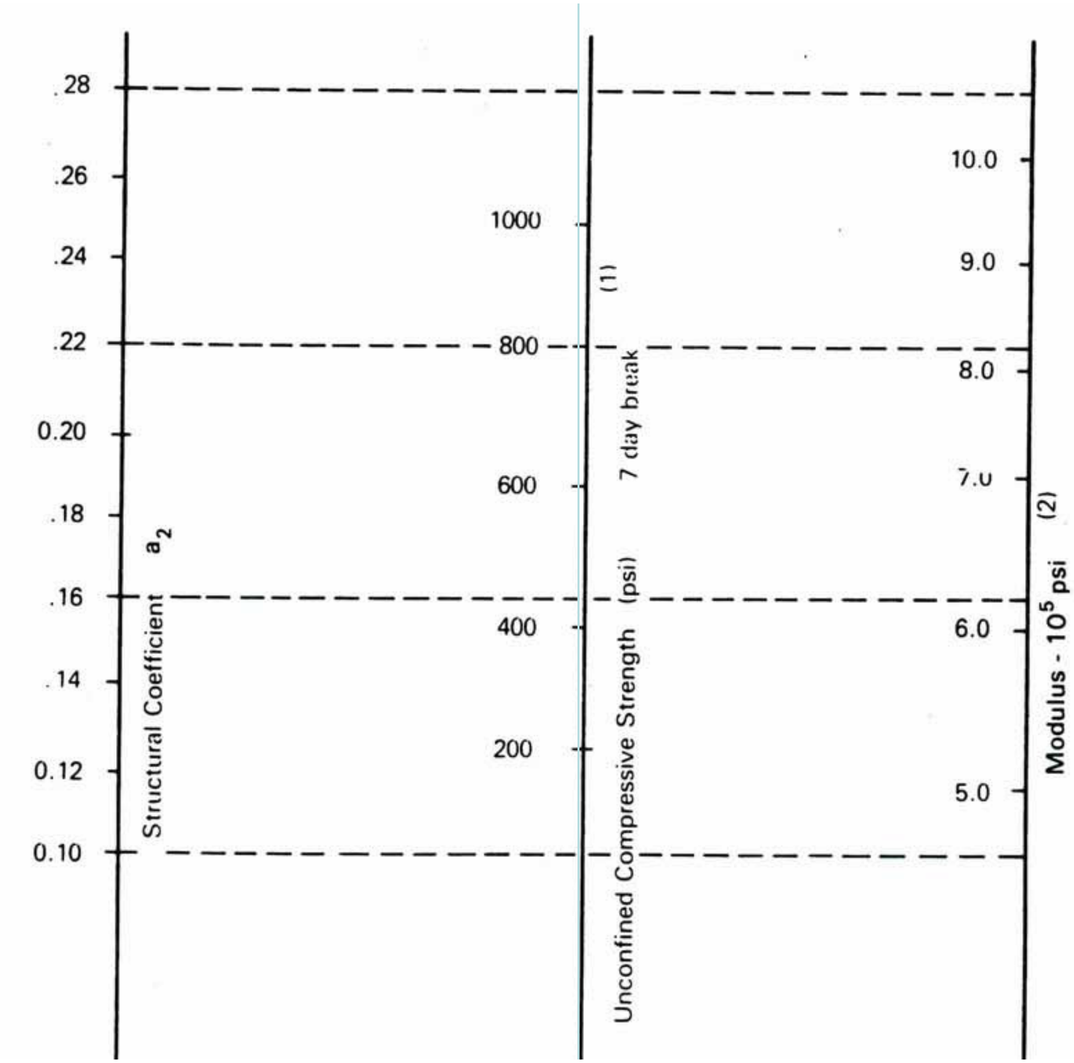
Estimating Base θ

Asphalt Thickness (in)	Subgrade Resilient Modulus (psi)		
	3000	**7500**	**15,000**
< 2	20	25	30
2 – 4	10	15	20
4 – 6	5	10	15
> 6	5	5	5

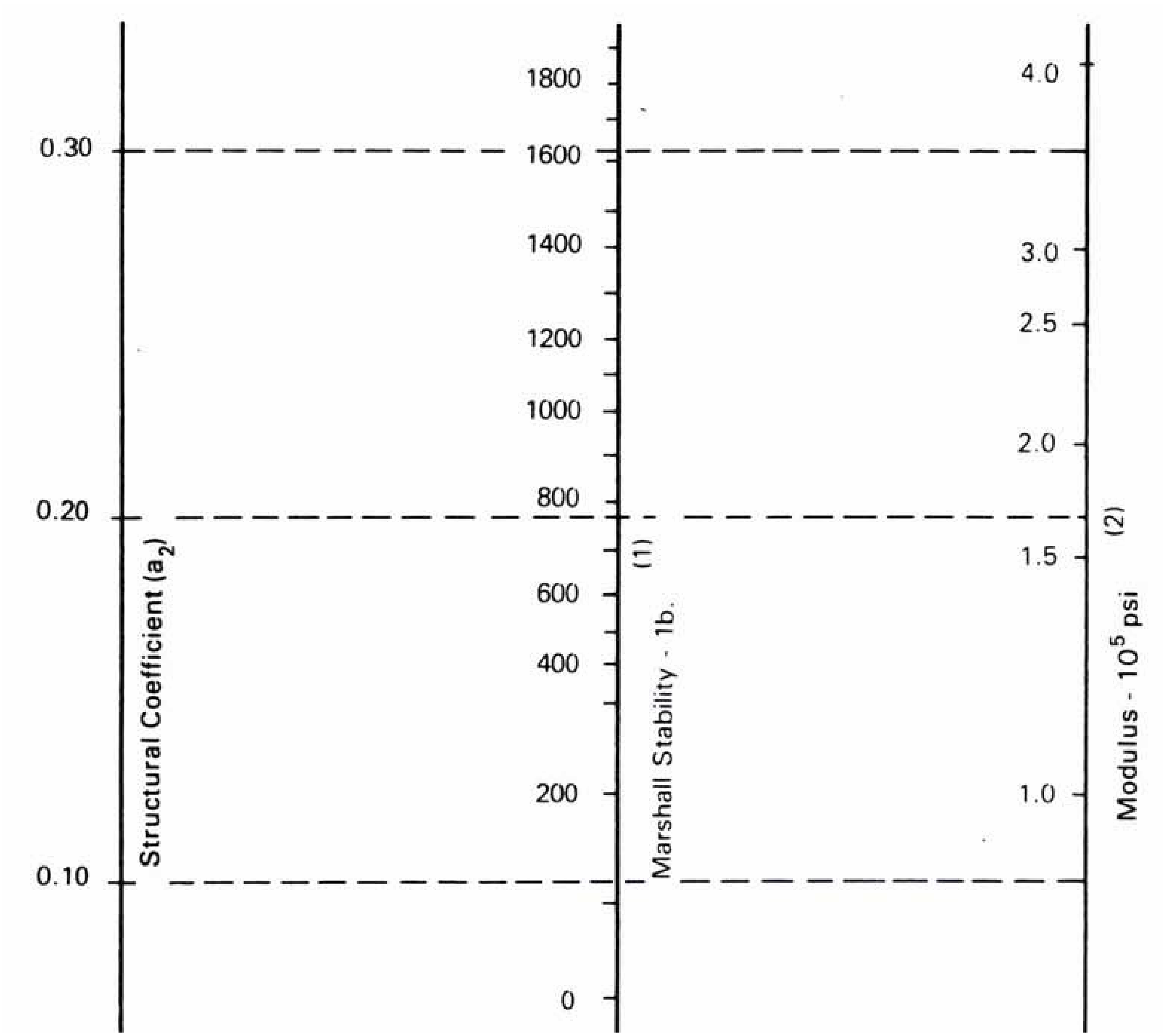
Base Layer Coefficient



CTB Layer Coefficients



ATB Layer Coefficients



Subbase Layer

$$a_3 = 0.227\log_{10}\left(E_{SB}\right) - 0.839$$

$$E_{SB} = k_1\theta^{k_2}$$

AASHO Road Test

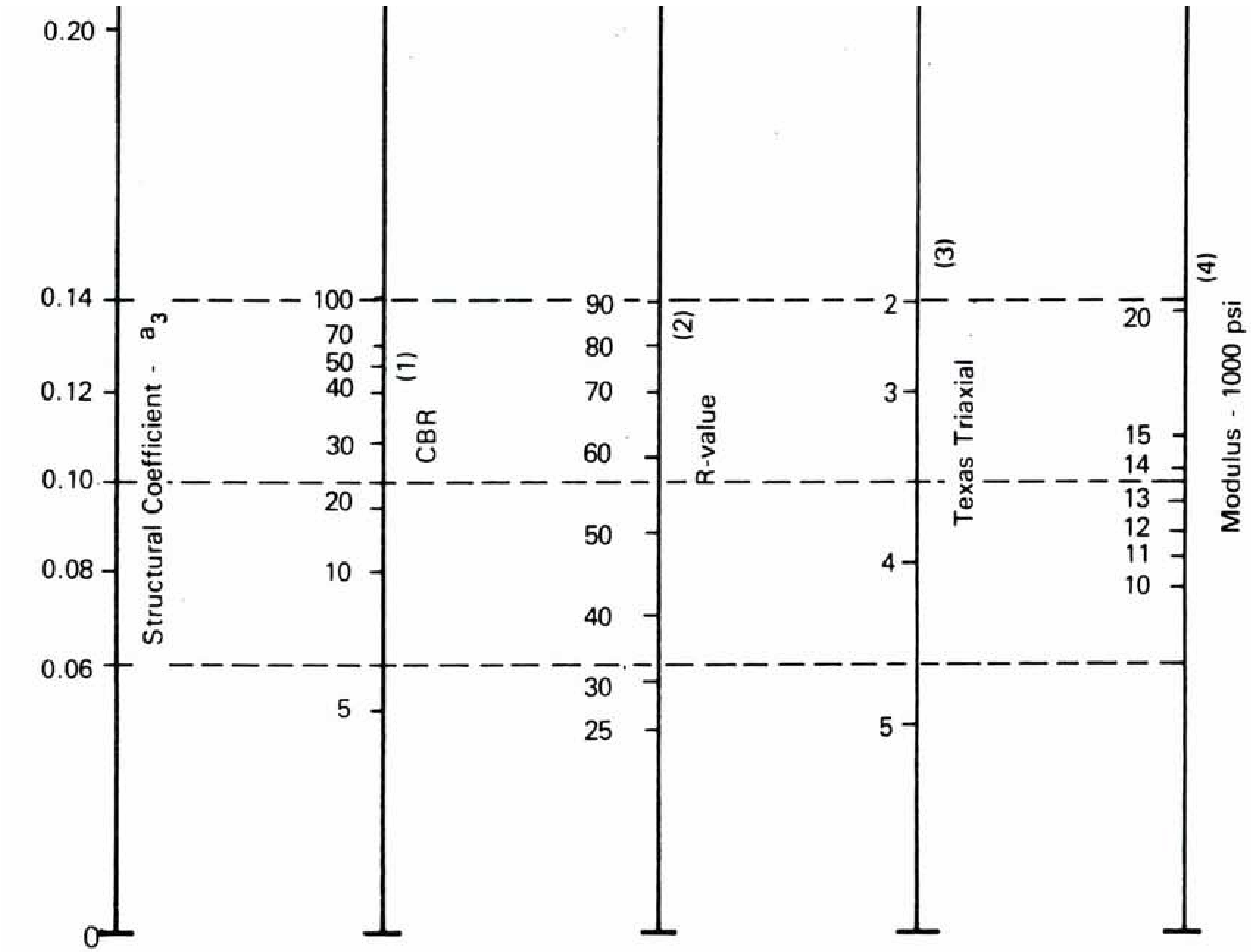
Moisture State	k_1 (psi)	k_2 (-)
Damp	5400	0.6
Wet	4600	0.6

WARNING: We don't actually use different values for different moisture states.
This just illustrates the effects of moisture on base layer resilient modulus.

Estimating Subbase θ

Asphalt Thickness (in)	Stress State (psi)
< 2	10
2 – 4	7.5
> 4	5

Subbase Layer Coefficients



Drainage Coefficients

$$\log_{10} W_{18} = 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}}$$

1966

$$\log_{10} W_{18} = 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + \log \frac{1}{R} + 0.372(S_i - 3.0)$$

1972

$$\log_{10} W_{18} = 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log_{10}(M_R) - 8.07$$

1986

Drainage Coefficients

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

asphalt base subbase

$$m_2, m_3 = f\left(drainage\right)$$

Drainage Quality

Quality	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very Poor	No drainage

Drainage Coefficients

	Percentage of Time Material Approaches Saturation			
Quality	**< 1%**	**1-5%**	**5-25%**	**> 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

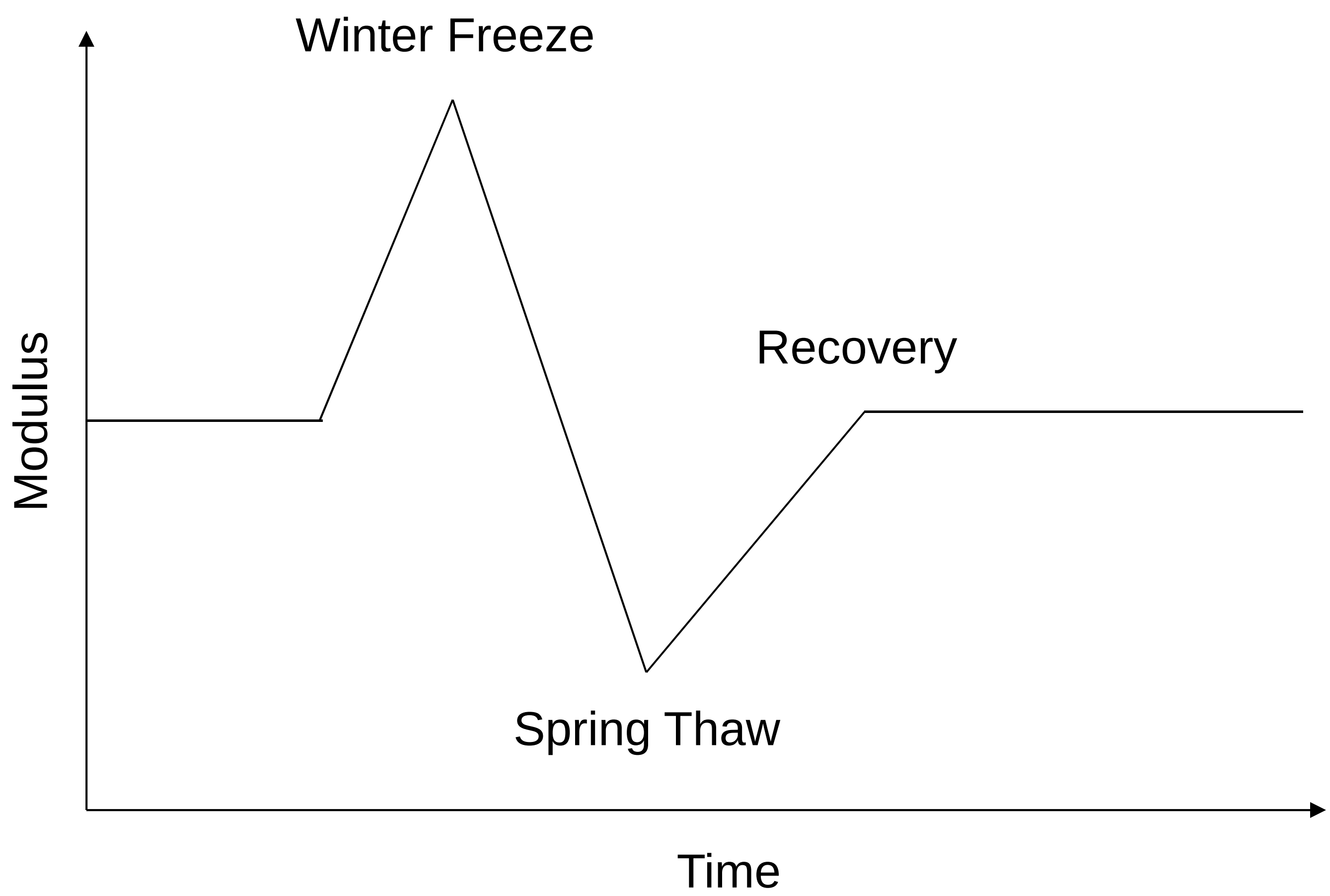
AASHTO Design Equation

$$\log_{10} W_{18} = 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2-p}{4.2-1.5}\right)}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10}(M_R) - 8.07$$

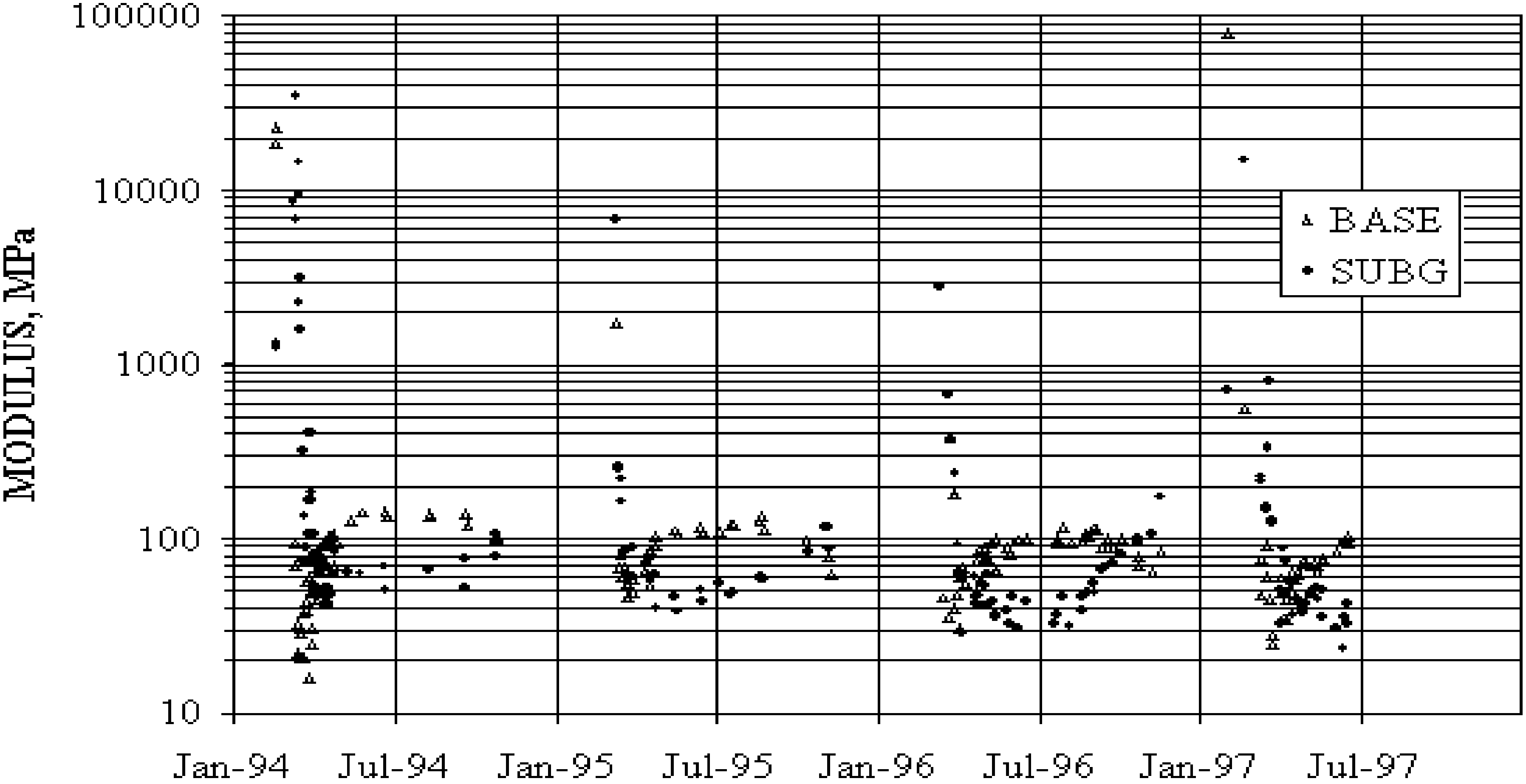
Constructed Pavement — Subgrade

1986

Seasonal Moisture Effects



Seasonal Moisture Effects



WSDOT

Condition		Moduli Ratio
Western Washington		
	Winter (Dec, Jan, Feb)	0.85
	Spring (Mar, Apr, May)	0.90
	Summer (Jun, Jul, Aug, Sep)	1.00
	Fall (Oct, Nov)	0.90
Eastern Washington		
	Winter (Jan)	1.00 - 1.10
	Winter/Spring (Feb, Mar, Apr, May)	0.85
	Summer (Jun, Jul, Aug, Sep)	1.00
	Fall (Oct, Nov, Dec)	0.90

Minnesota DOT

	Season I Winter	Season II Early Spring	Season III Late Spring	Season IV Summer	Season V Fall
Description	All Layers Are Frozen	Base Thaws, SG Frozen	Base Recovers, SG Thaws	HMA Low, SG Recovers	All Layers Are Standard
Pavement Layer Moduli Relative to Fall Values					
HMA	High	High	Standard	Low	Standard
Base	High	Low	Low	Standard	Standard
SG	High	High	Low	Low	Standard

Minnesota DOT

	Season I Winter	Season II Early Spring	Season III Late Spring	Season IV Summer	Season V Fall
Description	All Layers Are Frozen	Base Thaws, SG Frozen	Base Recovers, SG Thaws	HMA Low, SG Recovers	All Layers Are Standard
Seasonal Modulus Factors					
HMA	2.6	2.1	1.4	0.4	1.0
Base					
SG	22	2.4	0.73	0.75	1.0

AASHTO Design Equation

$$\log_{10} W_{18} = 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2-p}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10}(M_R) - 8.07$$

Constructed Pavement

Subgrade

1986

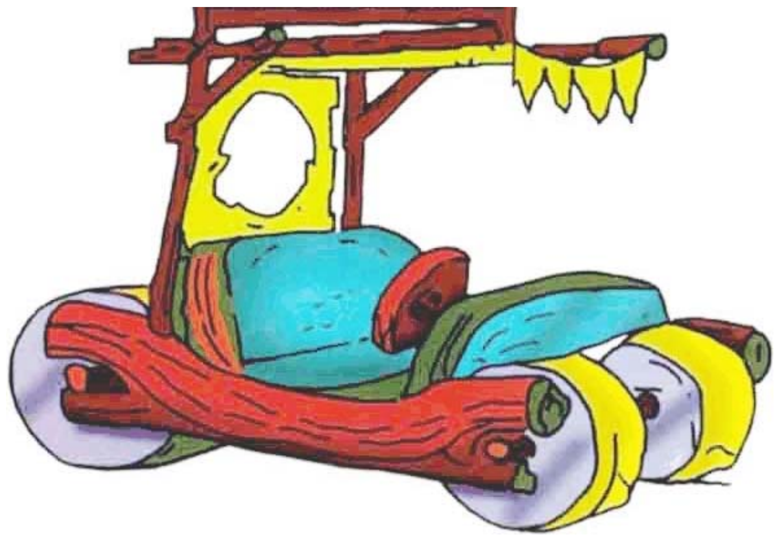
AASHTO Design Equation

$$\log_{10} W_{18} = \underbrace{9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{4.2-p}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}}}_{Q} + \underbrace{2.32\log_{10}(M_R) - 8.07}_{T_i}$$

$$\log_{10}(W_{18})_i = Q + T_i \quad \Rightarrow \quad (W_{18})_i = 10^Q 10^{T_i}$$

"i" represents a block of time with constant M_R
It could be a month, a week, a season, etc.

“Standard” Vehicle



$$d_S = \frac{1}{N_S}\left(\text{consumption per passage}\right)$$

Seasonal Damage per ESAL

$$\text{Let} \quad u_i = \frac{1}{10^{T_i}} = \frac{1.18 \times 10^8}{(M_R)_i^{2.32}}$$

$$\Downarrow$$

$$d_i = \frac{1}{(W_{18})_i} = \frac{1}{10^Q 10^{T_i}} = \frac{u_i}{10^Q}$$

d_i = damage per ESAL in Season i

Average Damage per ESAL

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} f_i d_i = \frac{1}{n}\left(\frac{1}{10^Q}\sum_{i=1}^{n} f_i u_i\right) = \frac{1}{10^Q}\left(\frac{1}{n}\sum_{i=1}^{n} f_i u_i\right) = \frac{\bar{u}_f}{10^Q}$$

f_i = fraction of annual ESALs applied during Season i

Effective Modulus

$$\bar{u}_f = \frac{1.18 \times 10^8}{\left(M_R\right)_{eff}^{2.32}}$$

$$\Downarrow$$

$$\left(M_R\right)_{eff} = \frac{3005}{\bar{u}^{0.431}}$$

Example

Period	M_R	u_i	N	$u_i \times N$
Dec-Feb	20,000		3	
Mar	2500		1	
Apr-May	4000		2	
Jun-Nov	7000		6	