

D AASHO Road Test, PSI, and ESAL Concepts

(資料來源：

1. Carey, W.N., Jr., and P.E. Irick, "The Pavement Serviceability-Performance Concept," Highway Research Board, Bulletin No. 250, 1960.
2. Highway Research Board, "The AASHO Road Test," Report 5, Pavement Research, Special Report 61E, Publication No, 954, National Academy of Sciences - National Research Council, Washington, D.C., 1962.
3. Huang, Y. H., Pavement Analysis and Design, Prentice Hall Inc., 1993.)

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Acceptable?

Yes

No

Undecided

5 Very Good

4 Good

3 Fair

2 Poor

1 Very Poor

0

Section Identification _____ Rating _____

Rater _____ Date _____ Time _____ Vehicle _____

Figure 1. Individual present serviceability rating form.

Measurements for Selected Pavements

Following the acceptability opinion, Tables 1 and 2 give summary values for measurements made on the selected pavements. Measurements are shown in three categories—those that describe longitudinal and transverse roughness, those that summarize surface cracking and, finally, a measurement of the patched area found in the section.

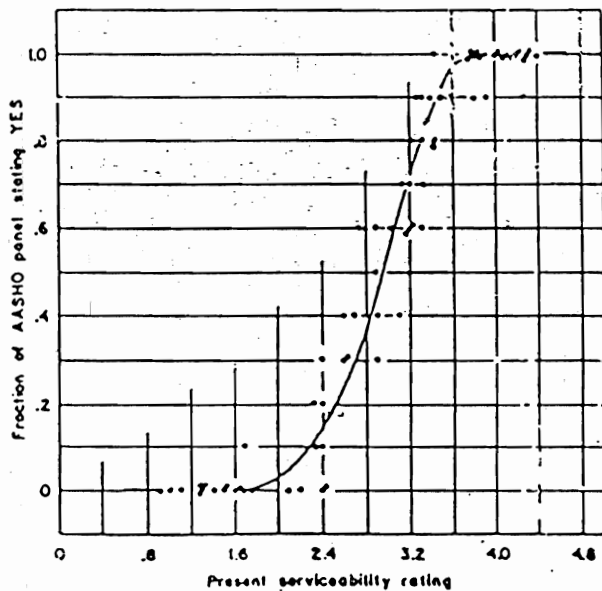


Figure 2. Acceptability vs present serviceability rating; 74 flexible pavements.

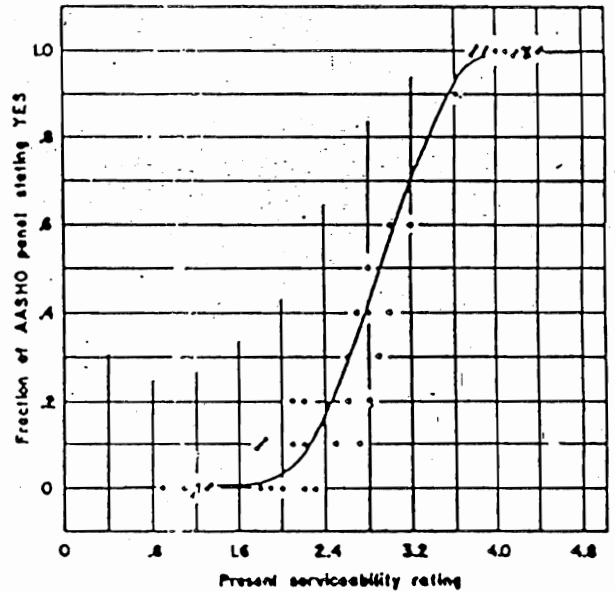


Figure 3. Acceptability vs present serviceability rating; 49 rigid pavements.

GENERAL INFORMATION

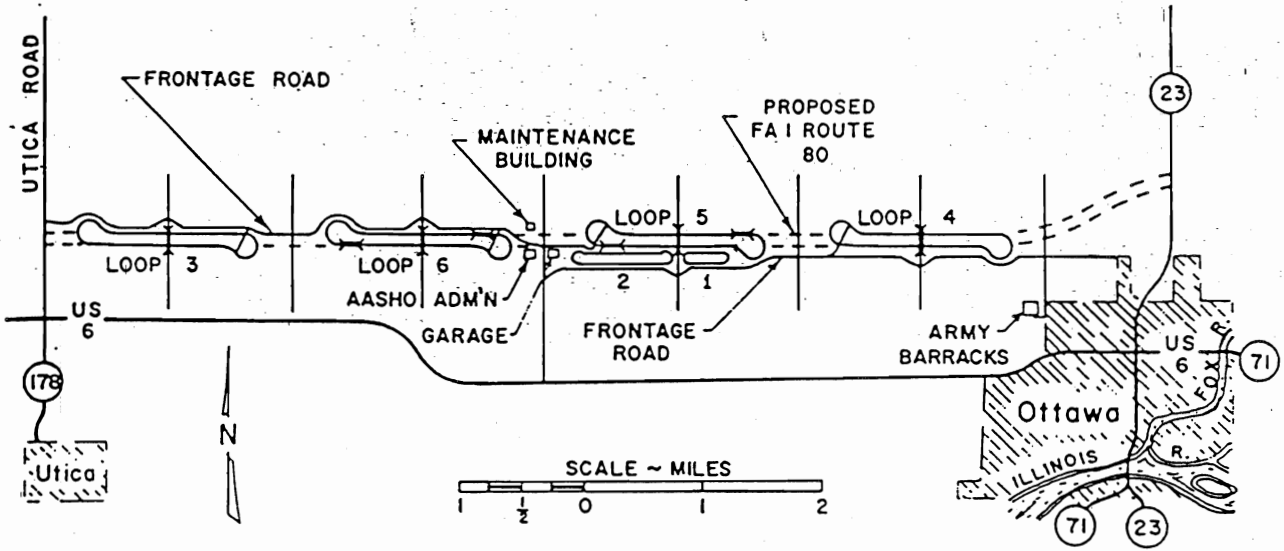


Figure 2. Layout of AASHO Road Test.

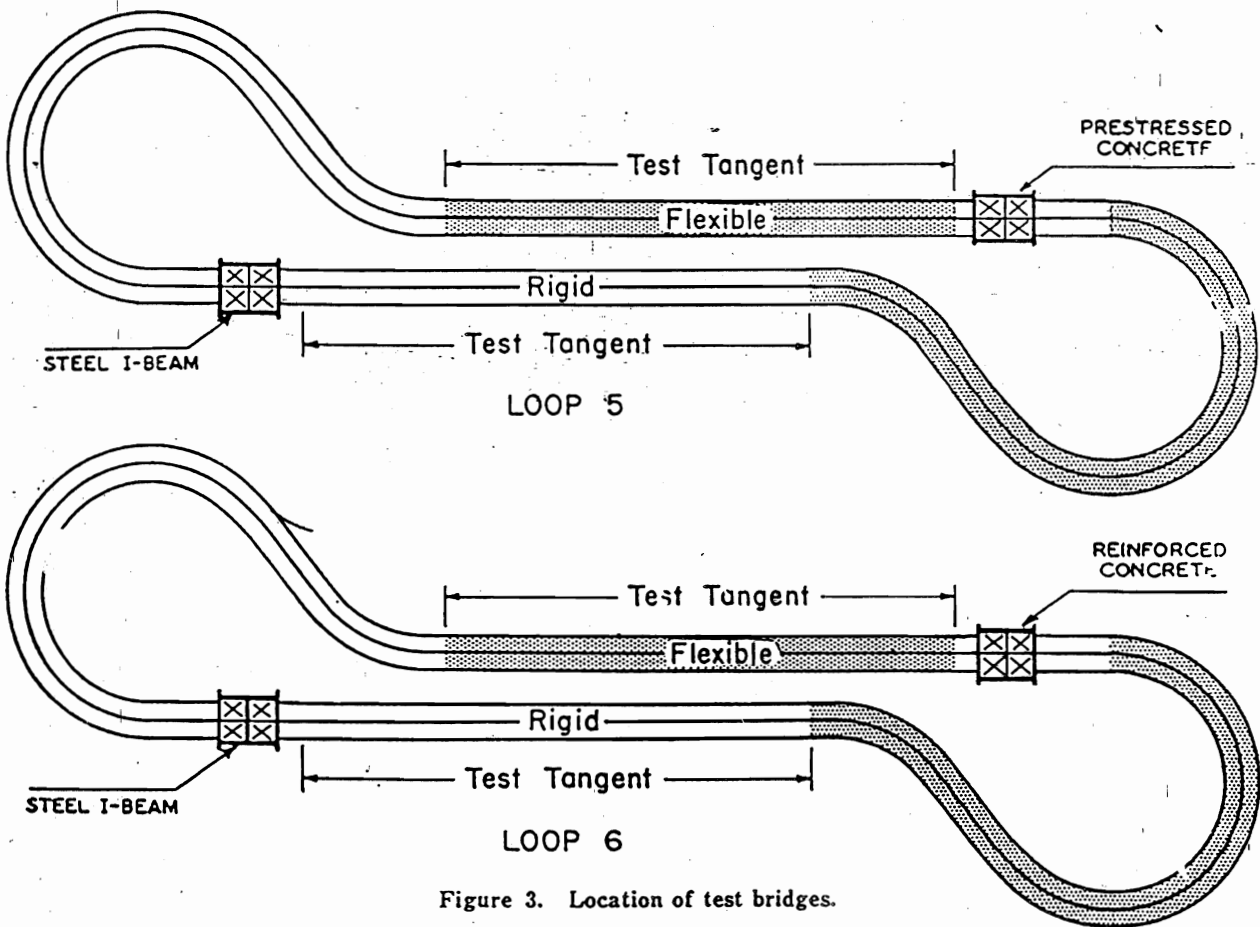


Figure 3. Location of test bridges.

Loop 4						
Axle Load						
Lane 1			Lane 2			
18,000-S			32,000-T			
Main Factorial Design						
Design 1						
Surface Thickness	Base Thickness	Subbase Thickness	Factorial Block	Test Section No.		
				Lane 1	Lane 2	
3	0	4	1	633	634	
		8	2	607	608	
		12	3	571	572	
	3	3	4	2	599	600
			8	3	573	574
			12	1	617	618
	6	6	4	3	585	586
			8	1	623	624
			12	2	601	602
4	0	4	3	583	584	
		8	1	619	620	
		12	2	603	604	
	3	3	4	1	627	628
			8	2	589	590
			12	2	597	598
	6	6	4	3	575	576
			8	2	595	596
			12	3	577	578
5	0	4	1	625	626	
		8	2	605	606	
		12	3	587	588	
	3	3	4	1	621	622
			8	3	579	580
			12	1	631	632
	6	6	4	2	593	594
			8	1	629	630
			12	1	615	616
6	6	4	2	591	592	
		8	3	581	582	
		12	3	581	582	

Figure 1-2.1. Pavement Sections Constructed on Loop 4 of the AASHO Road Test.

Table 3-2.1 Axle Weights and Distributions Used on Various Loops of the AASHO Road Test (5).

LOOP LANE

WEIGHT IN KIPS

		FRONT AXLE	LOAD AXLE	GROSS WEIGHT
②	①	2	2	4
	②	2	6	8
③	①	4	12	28
	②	6	24	54
④	①	6	18	42
	②	9	32	73
⑤	①	6	22.4	51
	②	9	40	89
⑥	①	9	30	69
	②	12	48	108

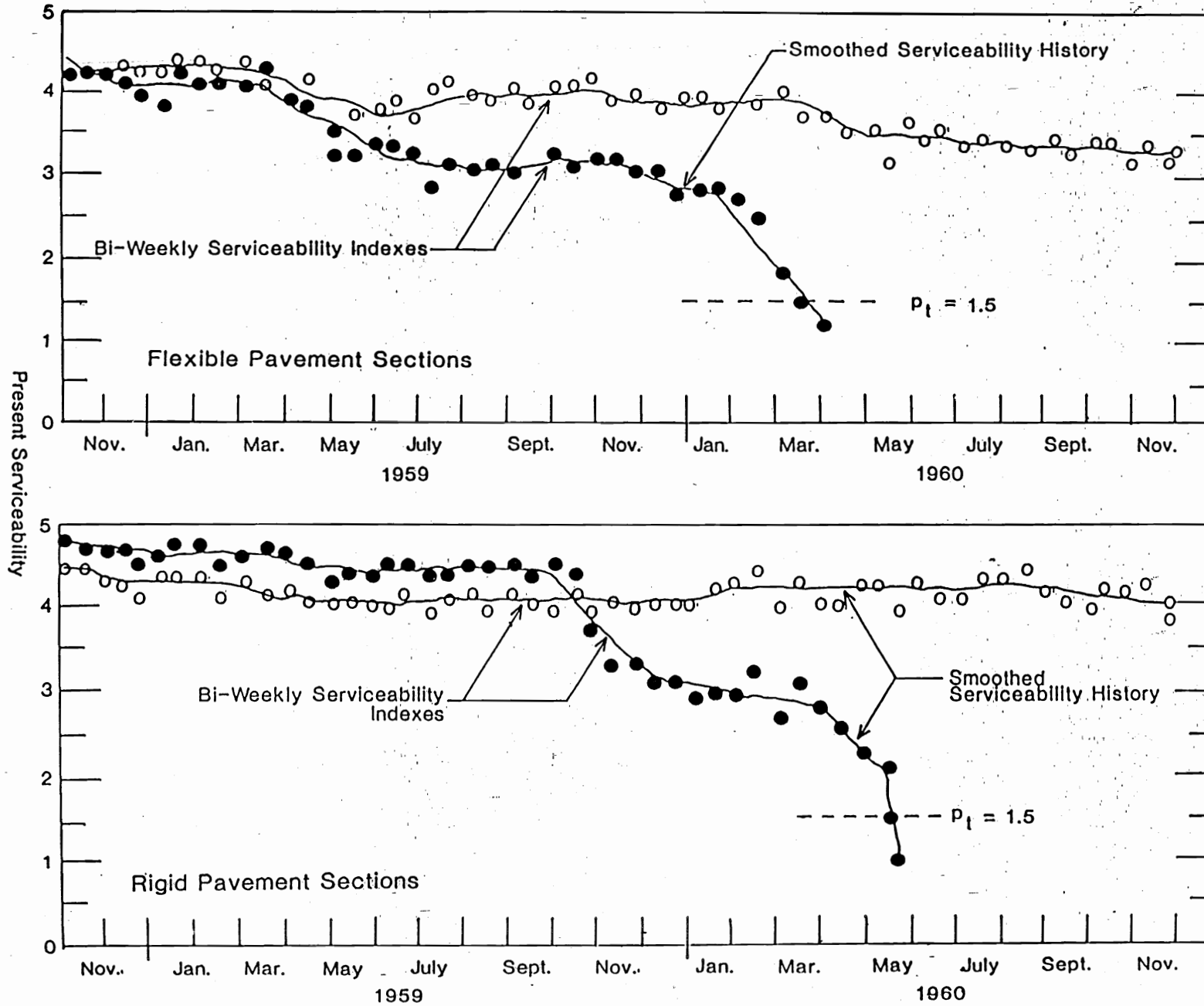


Figure 1-2.2. Typical Serviceability Histories from the AASHO Road Test.

TYPICAL EXAMPLES OF PREDICTION MODELS

1. AASHO ROAD TEST:

$$g = \frac{P_i - P}{P_i - P_t} = \left(\frac{W}{\rho} \right)^\beta$$

Where:

g = "damage" index;

P_i, P_t, P = initial, terminal, and present serviceability indices (0-5), respectively;

W = number of standard loads, and;

ρ, β = functions of pavement thickness, strength, and axle load configurations.

2. NCHRP 1-19 PROJECT (COPES):

$$\begin{aligned} \text{DISTRESS} = & (\text{TRAFFIC OR AGE})^a * \\ & (b * \text{DESIGN}^c + d * \text{SUBGRADE}^e \\ & + f * \text{CLIMATE}^g + h * \text{MATERIALS}^i) \end{aligned}$$

WEIGHTED FLEXIBLE PAVEMENT EQUATIONS

FROM THE AASHO ROAD TEST:

$$\log_{10} W = \log_{10} \rho + \frac{\log_{10} \left(\frac{4.2 - P}{2.7} \right)}{\beta}$$

$$\beta = 0.4 + \frac{0.081(L_1 + L_2)^{3.23}}{(D + 1)^{5.19} L_2^{3.23}}$$

$$\rho = \frac{10^{5.93} (D + 1)^{9.36} L_2^{4.33}}{(L_1 + L_2)^{4.79}}$$

$$D = 0.44D_1 + 0.14D_2 + 0.11D_3$$

Statistics:

For Predicting $\log_{10} W$: $R^2 = 0.70$, $\text{SEE} = 0.31$, $N = 1171$

(Mean Replicate Difference of $\log_{10} W = 0.17$, $n = 126$)

For Predicting W : $R^2 = 0.61$, $\text{SEE} = 155.3$, $N = 1171$

For Predicting PSI : $R^2 = 0.21$, $\text{SEE} = 0.62$, $N = 1083$

表10.1 軸重換算常數表 (單軸) $P_t = 2.5$

軸重 (千磅)	路面結構數值 (SN)					
	1	2	3	4	5	6
2	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002
4	0.003	0.004	0.004	0.003	0.003	0.002
6	0.01	0.02	0.02	0.01	0.01	0.01
8	0.03	0.05	0.05	0.04	0.03	0.03
10	0.08	0.10	0.12	0.10	0.09	0.08
12	0.17	0.20	0.23	0.21	0.19	0.18
14	0.33	0.36	0.40	0.39	0.36	0.34
16	0.59	0.61	0.65	0.65	0.62	0.61
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98
30	10.31	9.55	7.94	6.83	6.97	7.79
32	13.90	12.82	10.52	8.85	8.88	9.95
34	18.41	16.94	13.74	11.34	11.18	12.51
36	24.02	22.04	17.73	14.38	13.93	15.50
38	30.90	28.30	22.61	18.06	17.20	18.98
40	39.26	35.89	28.51	22.50	21.08	23.04

表10.2 軸重換算常數表 (複軸) $P_t = 2.5$

軸重 (千磅)	路面結構數值 (SN)					
	1	2	3	4	5	6
10	0.01	0.01	0.01	0.01	0.01	0.01
12	0.02	0.02	0.02	0.02	0.01	0.01
14	0.03	0.04	0.04	0.03	0.03	0.02
16	0.04	0.07	0.07	0.06	0.05	0.04
18	0.07	0.10	0.11	0.09	0.08	0.07
20	0.11	0.14	0.16	0.14	0.12	0.11
22	0.16	0.20	0.23	0.21	0.18	0.17
24	0.23	0.27	0.31	0.29	0.26	0.24
26	0.33	0.37	0.42	0.40	0.36	0.34
28	0.45	0.49	0.55	0.53	0.50	0.47
30	0.61	0.65	0.70	0.70	0.66	0.63
32	0.81	0.84	0.89	0.89	0.86	0.83
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.07	4.80	4.25	3.98	4.17	4.49

Axle Load	Traffic Equivalency Factor		Number of Axles		A18 Kip EAL's	
Single Axles						
	P = 2.5, SN = 5					
Under 3,000	0.0002	X	0	=	0.000	
3,000 - 6,999	0.0050	X	1	=	0.005	
7,000 - 7,999	0.0320	X	6	=	0.192	
8,000 - 11,999	0.0870	X	144	=	12.528	
12,000 - 15,999	0.3600	X	16	=	5.760	
26,000 - 29,999	5.3890	X	1	=	5.3890	
Tandem Axle Groups						
Under 6,000	0.0100	X	0	=	0.000	
6,000 - 11,993	0.0100	X	14	=	0.140	
12,000 - 17,999	0.0440	X	21	=	0.924	
18,000 - 23,999	0.1480	X	44	=	6.512	
24,000 - 29,999	0.4260	X	42	=	17.892	
30,000 - 32,000	0.7530	X	44	=	33.132	
32,001 - 32,500	0.8850	X	21	=	18.585	
32,501 - 33,999	1.0020	X	101	=	101.202	
34,000 - 35,999	1.2300	X	43	=	52.890	
18 Kip EAL's for all trucks weighed					=	255.151
$\text{Truck Load Factor} = \frac{18 \text{ Kip EAL's for all trucks weighed}}{\text{Number of trucks weighed } 1654} = \frac{255.151}{1654} = 1.5454$						

Figure 10. Computation of the Truck Load Factor for 5-Axle or Greater Trucks on Flexible Pavement (2).

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R \cdot S_O + 0.36 \cdot \log_{10} (SN + 1) - 0.20 + \frac{\log_{10} \left[\frac{\Delta \text{ PSI}}{4.2 - 1.5} \right]}{0.40 + \frac{1094}{(SN+1)^{0.18}}} + 2.32 \cdot \log_{10} M_R - 8.07$$

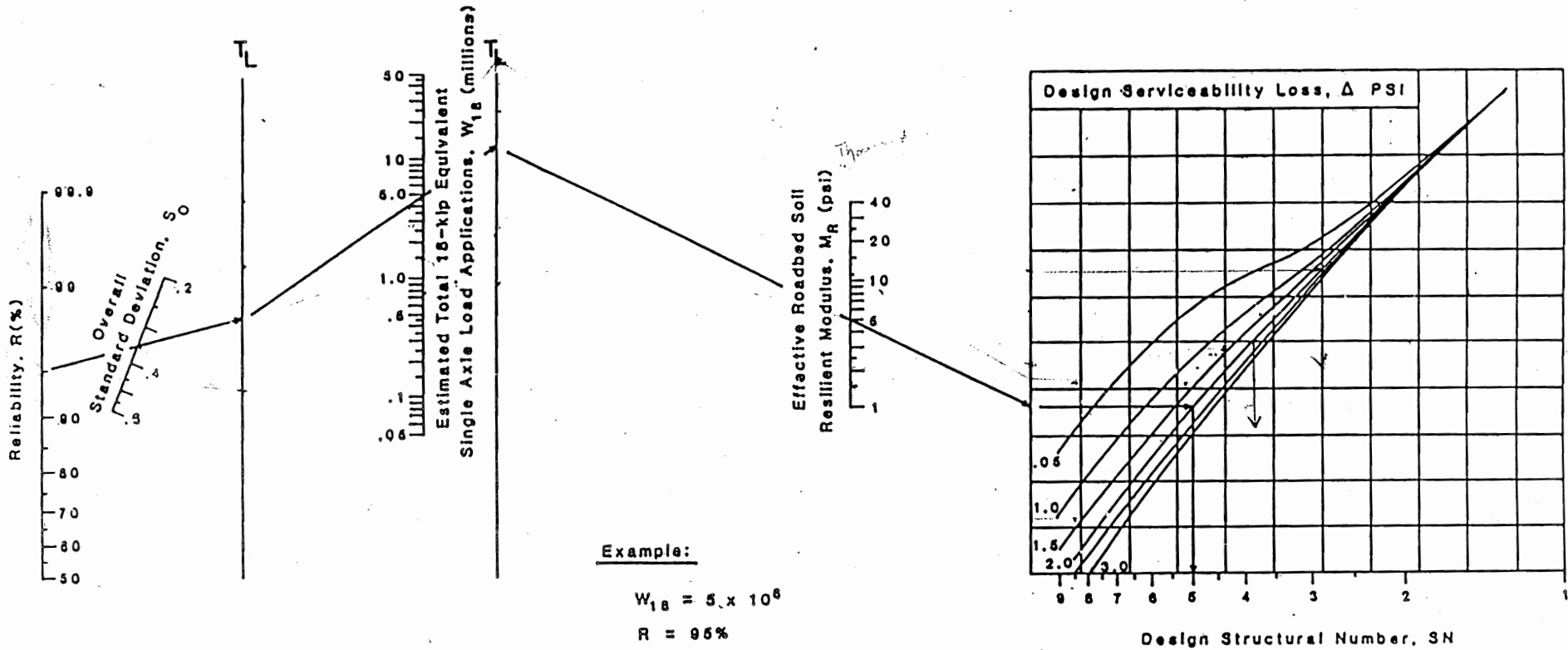
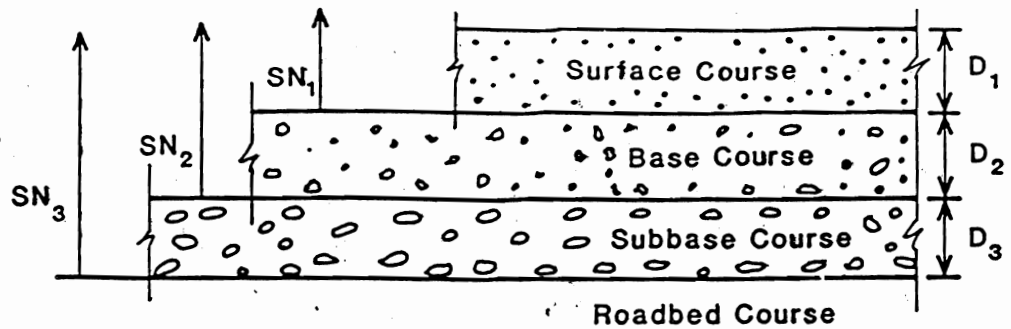


Figure 3-2.11 AASHTO Flexible Pavement Thickness Design Nomograph (4).



$$D^*_1 \geq \frac{SN_1}{a_1}$$

$$SN^*_1 = a_1 D^*_1 \geq SN_1$$

$$D^*_2 \geq \frac{SN_2 - SN^*_1}{a_2 m_2}$$

$$SN^*_1 + SN^*_2 \geq SN_2$$

$$D^*_3 \geq \frac{SN_3 - (SN^*_1 + SN^*_2)}{a_3 m_3}$$

1) a, D, m, and SN are as defined in the text and are minimum required values.

2) An asterisk with D or SN indicates that it represents the value actually used, which must be equal to or greater than the required value.

Figure 3-2.12 Design of Flexible Pavement Layer Thicknesses Using Layer Analysis Concepts.

6.3 EQUIVALENT AXLE LOAD FACTOR

An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, usually the 18-kip (80-kN) single-axle load. The design is based on the total number of passes of the standard axle load during the design period, defined as the equivalent single-axle load (ESAL) and computed by

$$ESAL = \sum_{i=1}^m F_i n_i \quad (6.19)$$

in which m is the number of axle load groups, F_i is the EALF for the i th-axle load group, and n_i is the number of passes of the i th-axle load group during the design period.

The EALF depends on the type of pavements, thickness or structural capacity, and the terminal conditions at which the pavement is considered failed. Most of the EALFs in use today are based on experience. One of the most widely used methods is based on the empirical equations developed from the AASHTO Road Test (AASHTO, 1972). The EALF can also be determined theoretically based on the critical stresses and strains in the pavement and the failure criteria. In this section, the equivalent factors for flexible and rigid pavements are discussed separately.

6.3.1 Flexible Pavements

The AASHTO equations for computing EALF are described first, followed by a discussion of equivalent factor based on the results obtained from KENLAYER.

AASHTO Equivalent Factors

The following regression equations based on the results of road tests can be used for determining EALF:

$$\log\left(\frac{W_{rx}}{W_{r18}}\right) = 4.79 \log(18 + 1) - 4.79 \log(L_x + L_2) + 4.33 \log L_2 + \frac{G_x}{\beta_x} - \frac{G_{18}}{\beta_{18}} \quad (6.20a)$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \quad (6.20b)$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN + 1)^{5.19}L_2^{3.23}} \quad (6.20c)$$

in which W_{tx} is the number of x -axle load applications at the end of time t ; W_{t18} is the number of 18-kip (80-kN) single-axle load applications to time t ; L_x is the load in kip on one single axle, one set of tandem axles, or one set of tridem axles; L_2 is the axle code, 1 for single axle, 2 for tandem axles, and 3 for tridem axles; SN is the structural number, which is a function of the thickness and modulus of each layer and the drainage conditions of base and subbase; p_t is the terminal serviceability, which indicates the pavement conditions to be considered as failures; G_t is a function of P_t ; and β_{18} is the value of β_x when L_x is equal to 18 and L_2 is equal to one. The method for determining SN is presented in Section 11.3.4. Note that

$$\text{EALF} = \frac{W_{t18}}{W_{tx}} \quad (6.21)$$

Equation 6.20 can be used to solve EALF. The effect of p_t and SN on EALF is erratic and is not completely consistent with theory. However, under heavy axle loads with an equivalent factor much greater than unity, the EALF increases as p_t or SN decreases. This is as expected because heavy axle loads are more destructive to poor and weaker pavements than to good and stronger ones. A disadvantage of using the above equations is that the EALF varies with the structural number, which is a function of layer thicknesses. Theoretically, a method of successive approximations should be used because the EALF depends on the structural number and the structural number depends on the EALF. Practically, EALF is not very sensitive to pavement thickness and a SN of 5 may be used for most cases. Unless the design thickness is significantly different, no iterations will be needed. The AASHTO equivalent factors with $p_t = 2.5$ and SN = 5 are used by the Asphalt Institute, as shown in Table 6.4. The original table has single and tandem axles only but the tridem axles are added based on the AASHTO design guide (AASHTO, 1986). Tables of equivalent factors for SN values of 1, 2, 3, 4, 5, and 6 and p_t values of 2, 2.5, and 3 can be found in the AASHTO design guide.

Example 6.7:

- Given $p_t = 2.5$ and SN = 5, determine the EALF for a 32-kip (151-kN) tandem-axle load and a 48-kip (214-kN) tridem-axle load.

Solution: For the tandem axles, $L_x = 32$ and $L_2 = 2$, from Eq. 6.20, $G_t = \log(1.7/2.7) = -0.201$, $\beta_x = 0.4 + 0.081(32 + 2)^{3.23}/[(5 + 1)^{5.19}(2)^{3.23}] = 0.470$, $\beta_{18} = 0.4 + 0.081(18 + 1)^{3.23}/(5 + 1)^{5.19} = 0.5$, and $\log(W_{tx}/W_{t18}) = 4.79 \log 19 - 4.79 \log(32 + 2) + 4.33 \log 2 - 0.201/0.47 + 0.201/0.5 = 0.067$, or $W_{tx}/W_{t18} = 1.167$. From Eq. 6.21, EALF = 0.857, which is exactly the same as that shown in Table 6.4.

For the tridem axles, $L_x = 48$, $L_2 = 3$, from Eq. 6.20, $\beta_x = 0.4 + 0.081(48 + 3)^{3.23}/[(5 + 1)^{5.19}(3)^{3.23}] = 0.470$, and $\log(W_{tx}/W_{t18}) = 4.79 \log 19 - 4.79 \log(48 + 3) + 4.33 \log 3 - 0.201/0.47 + 0.201/0.5 = -0.0139$, or $W_{tx}/W_{t18} = 0.968$. From Eq. 6.21, EALF = 1.033, as shown in Table 6.4.