AASHTO Flexible Pavement Design Method

Design considerations for the AASHTO Flexible Pavement Design

The following factors are considered in the pavement thickness design.

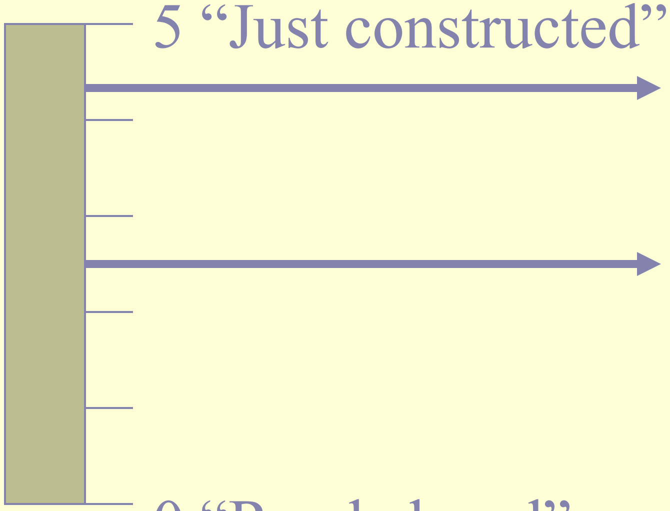
- Pavement performance
- Traffic
- Roadbed soils (subgrade material)
- Materials of construction
- Environment
- Drainage
- Reliability

Pavement performance

Structural ➔ Cracking, faulting, raveling, etc.

Functional ➔ Riding comfort (measured in terms of roughness of pavement.)

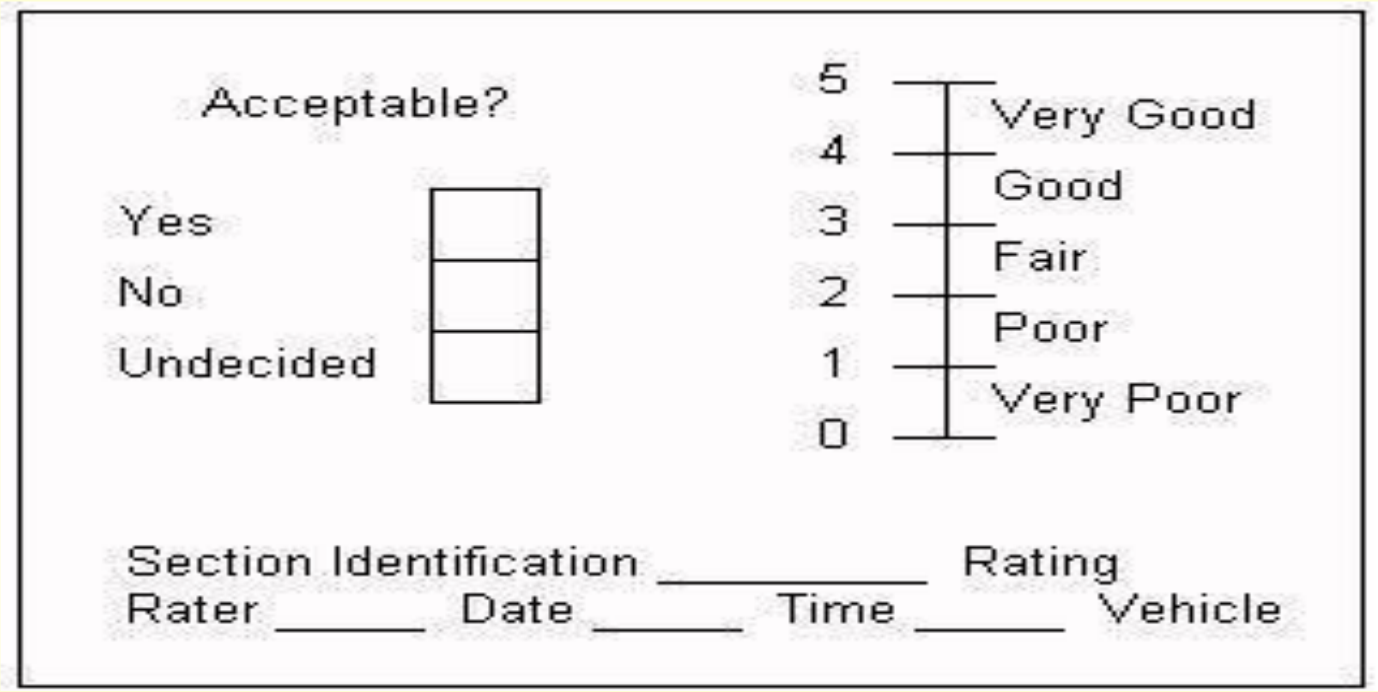
Serviceability Performance: Measured by PSI ➔ Present Serviceability Index with scale 0 to 5.



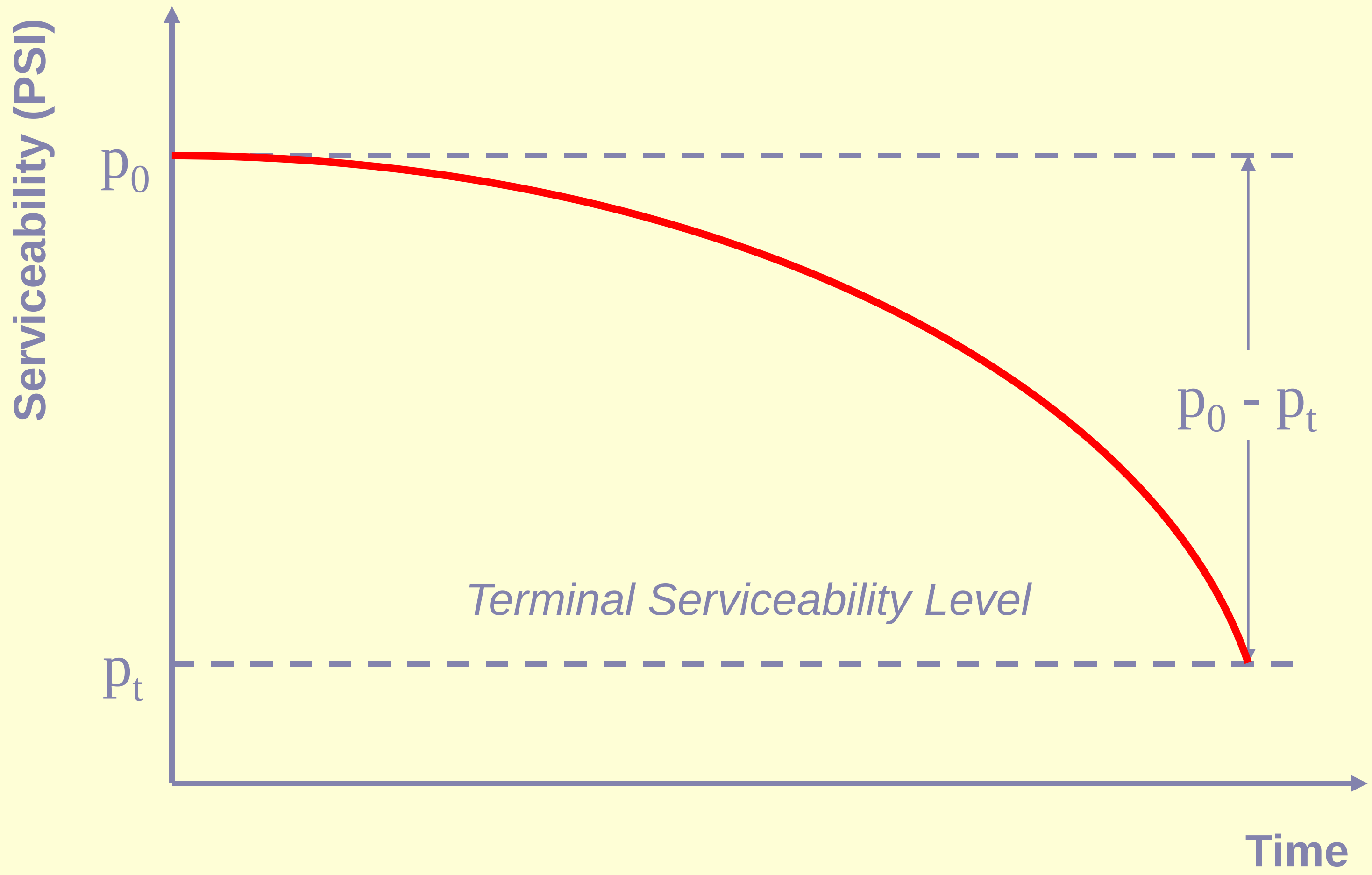
- 2.5 to 3.0 for major highways
- 2.0 for lower class highways
- 1.5 for very special cases

Pavement Condition

From the AASHO Road Test
(1956 – 1961)



Typical PSI vs. Time



Traffic

❖ In the AASHTO flexible pavement design, traffic is considered in terms of ESAL for the terminal PSI (Table 20.13 for $p_t = 2.5$.)

❖ We must assume the structural number of the pavement. So, we must check if the final SN_3 is similar to the assumed SN. ***Higher SN means stronger pavement, thus the impact of traffic on pavement deteriorations is less.***

Table 20.13a
Axle Load Equivalency Factors for Flexible Pavements, Single Axles, and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 20.13b
Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles, and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002

Roadbed soils (Subgrade material)

- CBR (California Bearing Ratio), R-value (Resistance), and M_r (Resilient modulus) are used to describe the property of the subgrade material.
- During the structural design, only M_r values are used. The following conversion formulas are used if either CBR or R-values are given.

M_r (lb/in^2) = 1500 x CBR for fine-grained soils with soaked CBR of 10 or less.

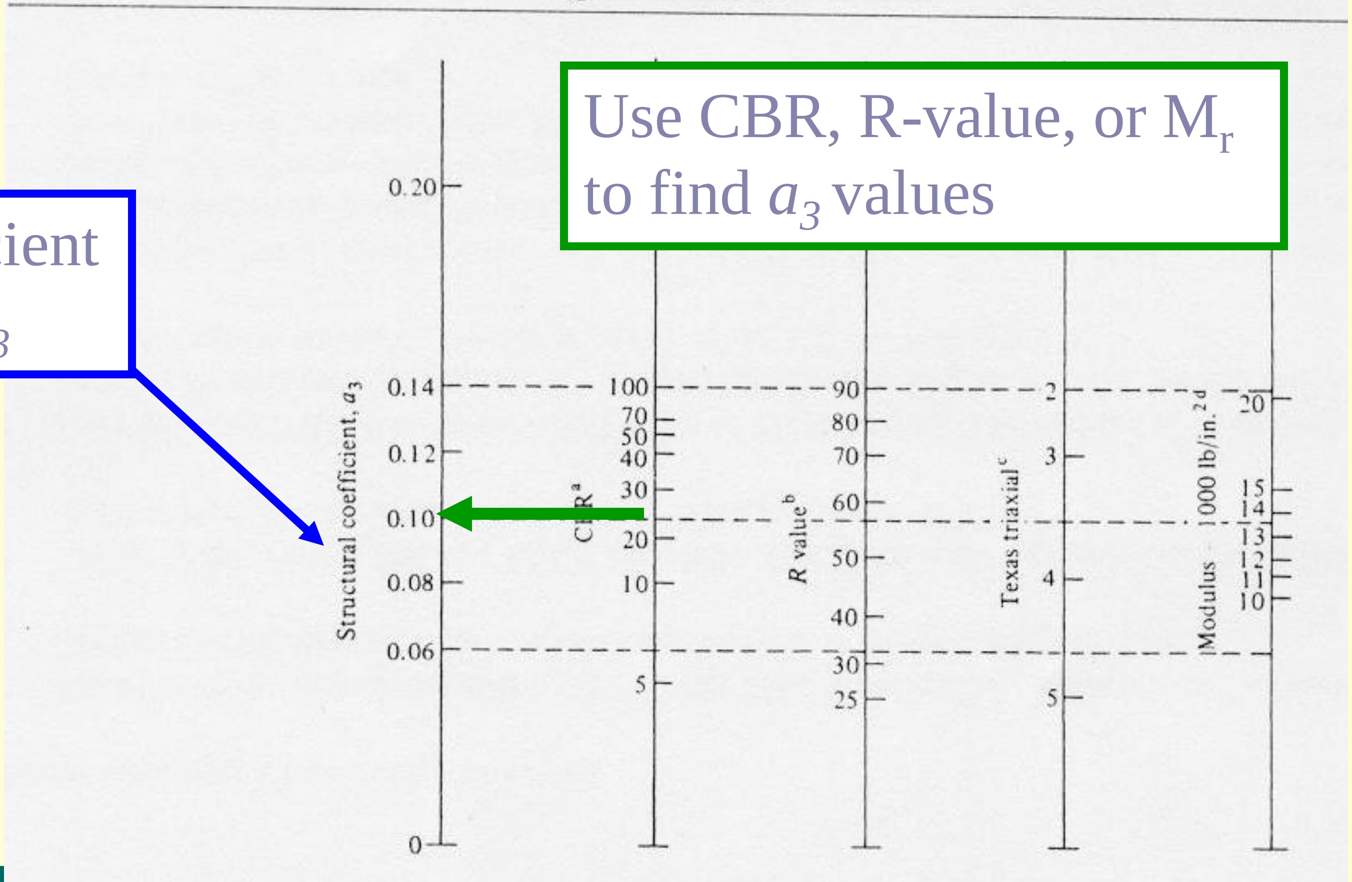
M_r (lb/in^2) = 1000 + 555 x (R-value)   for R <= 20

Materials of construction (Subbase), a_3

- Charts are available to convert the properties of pavement construction materials to structural coefficients: a_3, a_2, and a_1

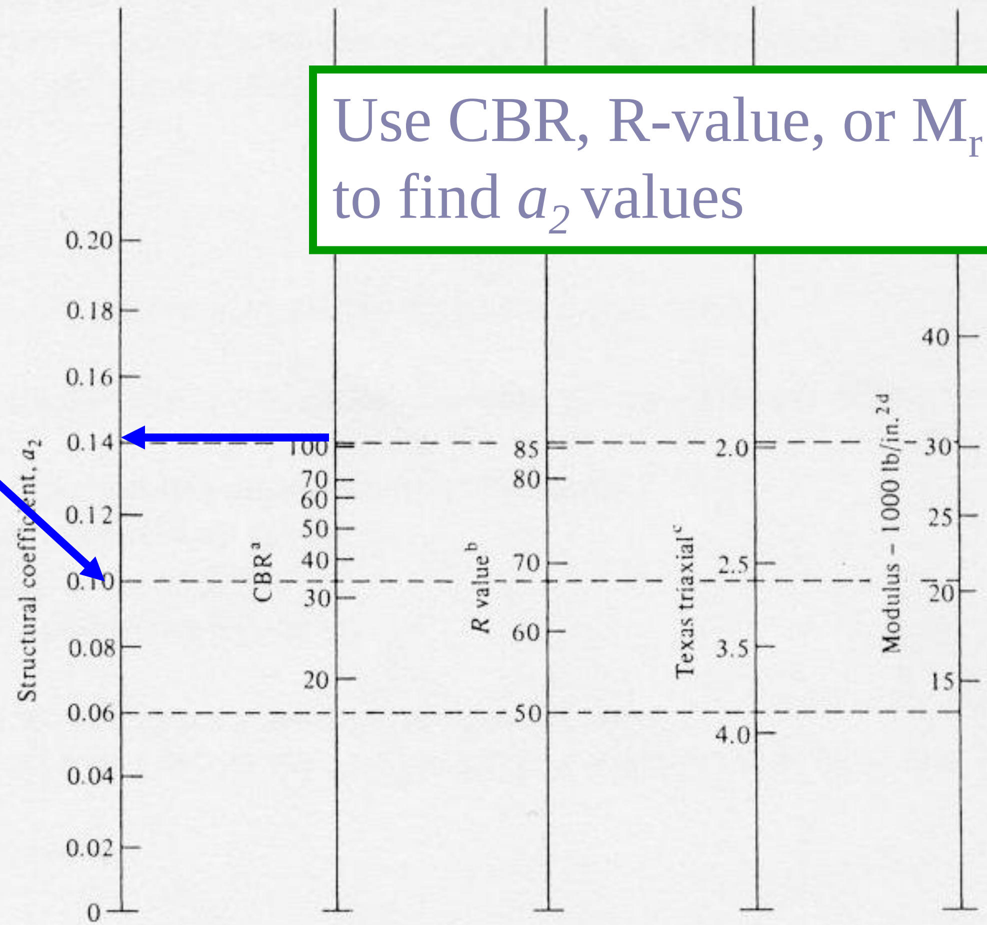
Structural coefficient of the subbase, a_3

Figure 20.15 ■ Variation in Granular Subbase Layer Coefficient, a_3, with Various Subbase Strength Parameters



Materials of construction (Base course), a_2

Figure 20.16 ■ Variation in Granular Base Layer Coefficient a_2, with Various base Strength Parameters

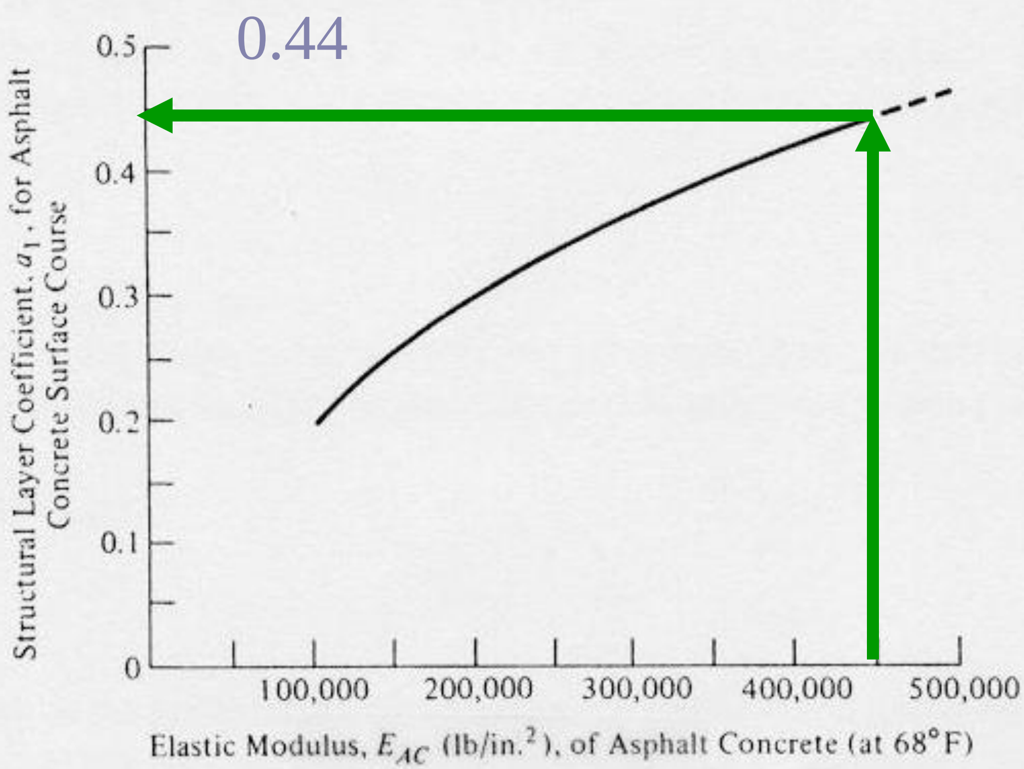


Structural coefficient of the base course, a_2

Use CBR, R-value, or M_r to find a_2 values

Materials of construction (AC surface), a_1

Figure 20.17 ■ Chart for Estimating Structural Layer Coefficient of Dense-Graded/Asphalt Concrete Based on the Elastic (Resilient) Modulus



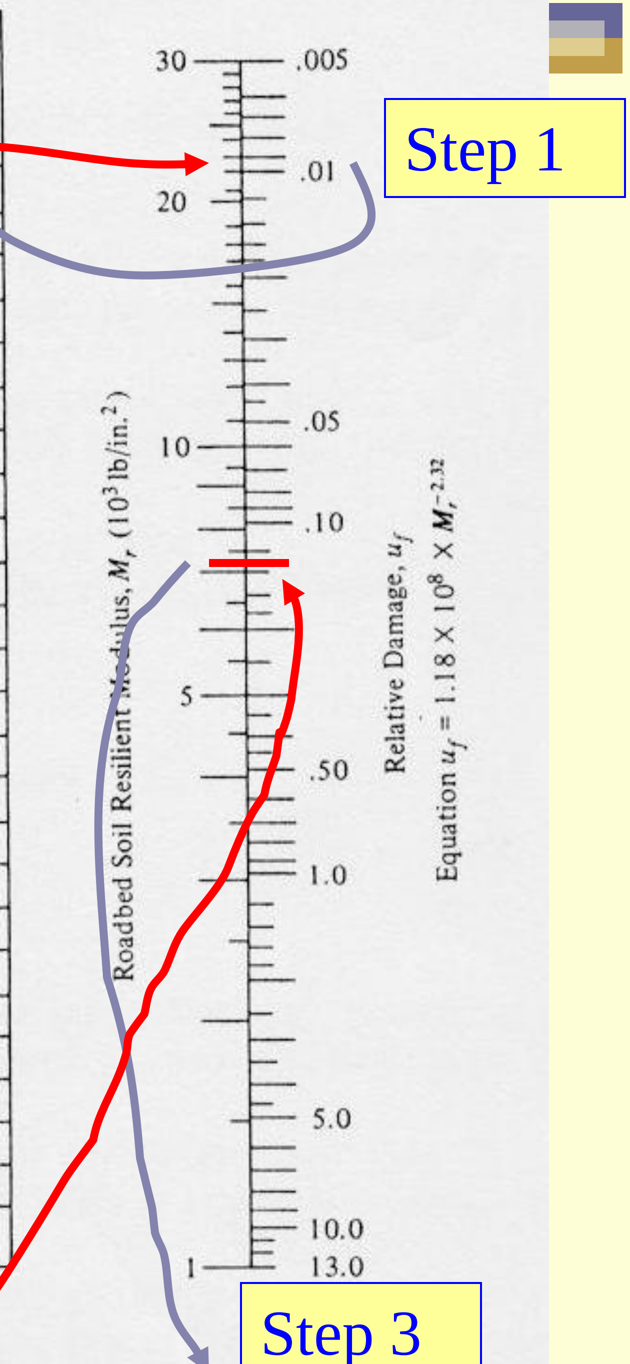
Structural coefficient of the AC surface, a_1

= Resilient modulus, M_r

Month	Roadbed Soil Modulus M_r (lb/in.²)	Relative Damage u_f
Jan.	22000	0.01
Feb.	22000	0.01
Mar.	5500	0.25
Apr.	5000	0.30
May	5000	0.30
June	8000	0.11
July	8000	0.11
Aug.	8000	0.11
Sept.	8500	0.09
Oct.	8500	0.09
Nov.	6000	0.20
Dec.	22000	0.01
Summation:	$\Sigma u_f =$	1.59

Average $\bar{u}_f = \frac{\Sigma u_f}{n} = \frac{1.59}{12} = 0.133$

Effective Roadbed Soil Resilient Modulus, M_r (lb/in.²) = 7250 (corresponds to $\bar{u}_f$)



Environment

- Temperature and rainfall affect the level of strength of the subgrade, reflected on the value of resilient modulus. AASHTO developed a chart that helps us to estimate the effective roadbed soil resilient modulus using the serviceability criteria (in terms of "relative damage, u_f.")
- Determine the average u_f. value and obtain M_r from the chart or the equation of u_f. .

❖ The bar on the right is used twice: Once to read u_f value for each month's sample M_r, then to read annual average M_r using the average u_f value.

Drainage

- The effect of drainage on the performance of flexible pavements is considered with respect to the effect of water on the strength of the base material and roadbed soil.
- This effect is expressed by the drainage coefficient, m_i. This value is dependent on the drainage quality and the percent of time i.e., the time to which a pavement structure is exposed to moisture levels approaching saturation.

Definition of drainage quality and finding recommended m_i values

Table 20.14
Definition 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)

Time required to drain the base/subbase layer to 50% saturation.

Step 1

Table 20.15
Recommended m_i Values

Quality of Drainage	Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation: Less Than 1 Percent	1–5 Percent	5–25 Percent	Greater Than 25 Percent
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

If "Fair" and 30% exposure, then m_i is 0.80.

Step 2

Reliability

The reliability factor (F_R) is computed using:

- The Reliability design level ($R\%$), which determines assurance levels that the pavement section designed using the procedure will survive for its design period (it is a z-score from the standard normal distribution)
- The standard deviation (S_o) that accounts for the chance variation in the traffic forecast and the chance variation in actual pavement performance for a given design period traffic, W_{18}.

$$\log_{10} F_R = -Z_R S_o$$

	SD, S_o
Flexible pavements	0.40-0.5
Rigid pavements	0.30-0.40

Reliability (R%)	Standard Normal Deviation, Z_R
50	−0.000
60	−0.253
70	−0.524
95	−1.645
96	−1.751
97	−1.881

Functional Classification	**Recommended Level of Reliability**	
	Urban	**Rural**
Interstate and other freeways	**85-99.9**	**80-99.9**
Principal arterial	**80-99**	**75-95**
Collectors	**80-95**	**75-95**
Local	**50-80**	**50-80**

Structural design

- The object of the design using the AASHTO method is to determine a flexible pavement SN adequate to carry the projected design ESAL.
- The method discussed in the text applies to ESALs greater than 50,000 for the performance period. The design for ESALs less than this is usually considered under low-volume roads.

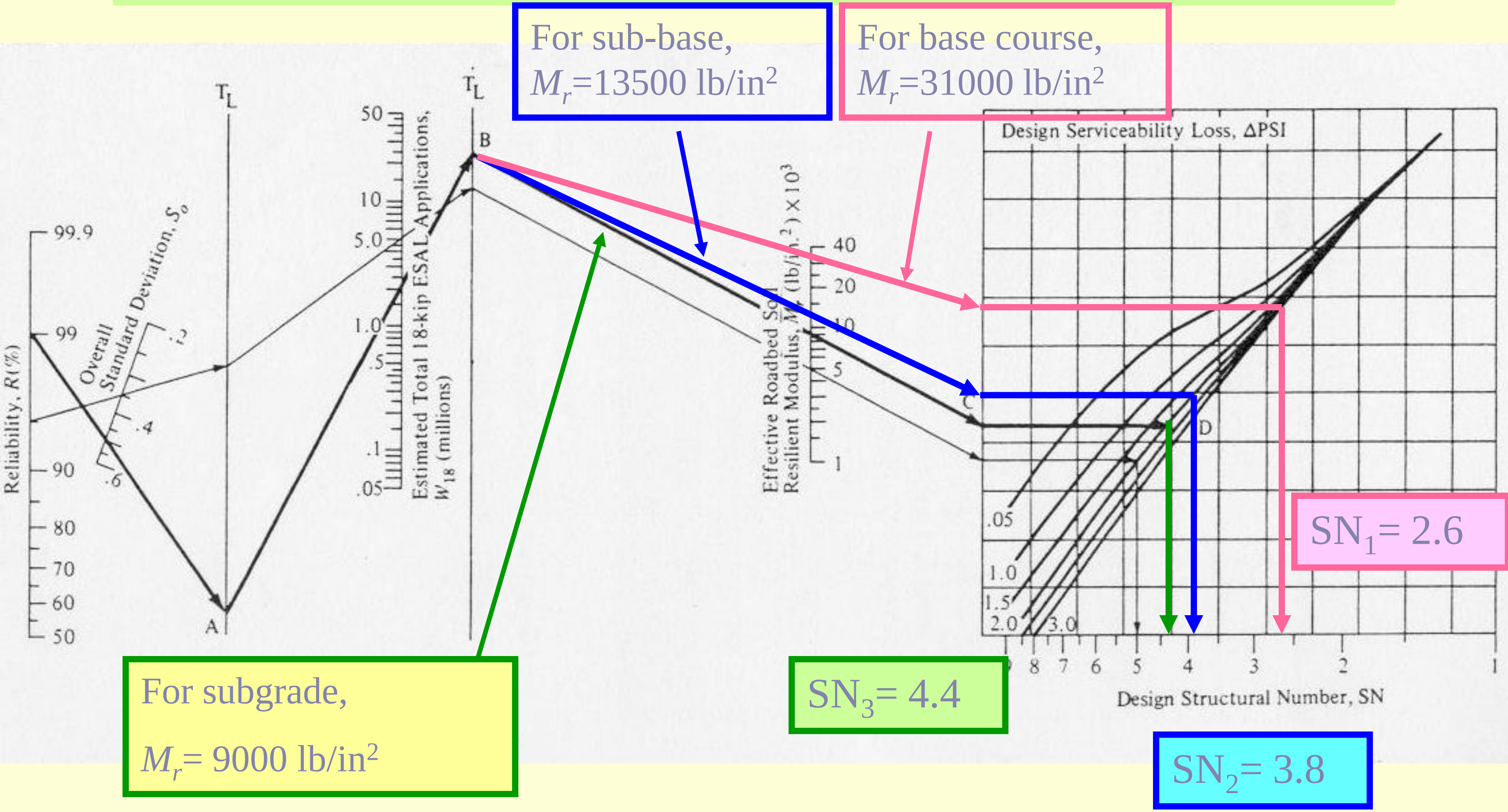
$$\log_{10} W_{18} = Z_R S_o + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}[\Delta PSI/(4.2-1.5)]}{0.40 + [1094/(SN+1)^{5.19}]} + 2.32 \log_{10} M_r - 8.07$$

Where

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

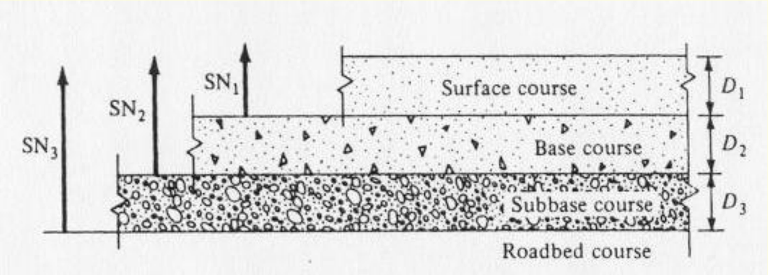
Simplify this as $f(W_{18}) = f(Z_R S_o) + f(SN)$

How to use Fig. 20.20 to get structural numbers based on Eq. 20.13



Once SN value is set, thickness design begins…

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



Proceed in this direction

$$SN_1 = a_1 D_1$$

$$SN_2 = a_1 D_1 + a_2 D_2 m_2$$

$$SN_3 = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

Use Fig.20.15 for a_3, Fig.20.16 for a_2, Fig.20.17 for a_1, and Tab. 20.14 and 20.15 m_2 and m_3. Find the depth that results in a SN value close to the SN value obtained from Fig. 20.20.

Table 20.18
AASHTO-Recommended Minimum Thicknesses of Highway Layers

Traffic, ESALs	Minimum Thickness (in.) 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

Table 20.13 a Axle Load Equivalency Factors for Flexible Pavements, Single Axles and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
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	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	25.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68.8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.	102.	79.	60.	53.	55.

Table 20.13 b Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
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	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2

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

Equivalent Axle Load Factors, Single axles

Axle Load (kips)	$p_t = 2.0$ SN				$p_t = 2.5$ SN				$p_t = 3.0$ SN			
	3	4	5	6	3	4	5	6	3	4	5	6
2	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0006	0.0003	0.0002	0.0002
4	0.003	0.002	0.002	0.002	0.004	0.003	0.002	0.002	0.006	0.004	0.002	0.002
6	0.011	0.010	0.009	0.009	0.017	0.013	0.010	0.009	0.028	0.018	0.012	0.010
8	0.036	0.033	0.031	0.029	0.051	0.041	0.034	0.031	0.080	0.055	0.040	0.034
10	0.090	0.085	0.079	0.076	0.118	0.102	0.088	0.080	0.168	0.132	0.101	0.086
12	0.189	0.183	0.174	0.168	0.229	0.213	0.189	0.176	0.296	0.260	0.212	0.187
14	0.354	0.350	0.338	0.331	0.399	0.388	0.360	0.342	0.468	0.447	0.391	0.058
16	0.613	0.612	0.603	0.596	0.646	0.645	0.623	0.606	0.695	0.693	0.651	0.622
18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.56	1.55	1.57	1.59	1.49	1.47	1.51	1.55	1.41	1.38	1.44	1.51
22	2.35	2.31	2.35	2.41	2.17	2.09	2.18	2.30	1.96	1.83	1.97	2.16
24	3.43	3.33	3.40	3.51	3.09	2.89	3.03	3.27	2.69	2.39	2.60	2.96
26	4.88	4.68	4.77	4.96	4.31	3.91	4.09	4.48	3.65	3.08	3.33	3.91
28	6.78	6.42	6.52	6.83	5.90	5.21	5.69	5.98	4.88	3.93	4.17	5.00
30	9.2	8.6	8.7	9.2	7.9	6.8	7.0	7.8	6.5	5.0	5.1	6.3
32	12.4	11.5	11.5	12.1	10.5	8.8	8.9	10.0	8.4	6.2	6.3	7.7
34	16.3	15.0	14.9	15.6	13.7	11.3	11.2	12.5	10.9	7.8	7.6	9.3
36	21.2	19.3	19.0	19.9	17.7	14.4	13.9	15.5	14.0	9.7	9.1	11.0
38	27.1	24.6	24.0	25.1	22.6	18.1	17.2	19.0	17.7	1.9	11.0	13.0
40	34.3	30.9	30.0	31.2	28.5	22.5	21.1	23.0	22.2	14.6	13.1	15.3

Equivalent Axle Load Factors, tandem axles

Axle Load (kips)	$p_t = 2.0$				$p_t = 2.5$				$p_t = 3.0$			
	SN				SN				SN			
	3	4	5	6	3	4	5	6	3	4	5	6
10	0.008	0.007	0.006	0.006	0.011	0.009	0.007	0.006	0.020	0.012	0.008	0.007
12	0.016	0.014	0.013	0.012	0.023	0.018	0.014	0.013	0.039	0.024	0.017	0.014
14	0.029	0.026	0.024	0.023	0.042	0.033	0.027	0.024	0.068	0.045	0.032	0.026
16	0.050	0.046	0.042	0.040	0.070	0.057	0.047	0.043	0.109	0.076	0.055	0.046
18	0.081	0.075	0.069	0.066	0.109	0.092	0.077	0.070	0.164	0.121	0.090	0.076
20	0.124	0.117	0.109	0.105	0.162	0.141	0.121	0.110	0.232	0.182	0.139	0.119
22	0.183	0.174	0.164	0.158	0.229	0.207	0.180	0.166	0.313	0.260	0.205	0.178
24	0.260	0.252	0.239	0.231	0.315	0.292	0.260	0.242	0.407	0.358	0.292	0.257
26	0.360	0.353	0.338	0.329	0.420	0.401	0.364	0.342	0.517	0.476	0.402	0.360
28	0.487	0.481	0.466	0.455	0.548	0.534	0.495	0.470	0.643	0.614	0.538	0.492
30	0.646	0.643	0.627	0.617	0.703	0.695	0.658	0.633	0.788	0.773	0.702	0.656
32	0.843	0.842	0.829	0.819	0.889	0.887	0.857	0.834	0.956	0.953	0.896	0.855
34	1.08	1.08	1.08	1.07	1.11	1.11	1.09	1.08	1.15	1.15	1.12	1.09
36	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
38	1.73	1.72	1.73	1.74	1.69	1.68	1.70	1.73	1.64	1.62	1.66	1.70
40	2.15	2.13	2.16	2.18	2.06	2.03	2.08	2.14	1.94	1.89	1.98	2.08
42	2.64	2.62	2.66	2.70	2.49	2.43	2.51	2.61	2.29	2.19	2.33	2.50
44	3.23	3.18	3.24	2.31	2.99	2.88	3.00	3.16	2.70	2.52	2.71	2.97
46	3.92	3.83	3.91	4.02	3.58	3.40	3.55	3.79	3.16	2.89	3.13	3.50
48	4.72	4.58	4.68	4.83	4.25	3.98	4.17	4.49	3.70	3.29	3.57	4.07

Equivalent Axle Load Factors, triple axles

Axle Load (kips)	$p_t = 2.0$				$p_t = 2.5$				$p_t = 3.0$			
	SN				SN				SN			
	3	4	5	6	3	4	5	6	3	4	5	6
20	0.029	0.026	0.024	0.023	0.042	0.032	0.027	0.024	0.069	0.044	0.031	0.026
22	0.042	0.038	0.035	0.034	0.060	0.048	0.040	0.036	0.097	0.065	0.046	0.039
24	0.060	0.055	0.051	0.048	0.084	0.068	0.057	0.051	0.132	0.092	0.066	0.056
26	0.083	0.077	0.071	0.068	0.114	0.095	0.080	0.072	0.174	0.126	0.092	0.078
28	0.113	0.105	0.098	0.094	0.151	0.128	0.109	0.099	0.223	0.168	0.126	0.107
30	0.149	0.140	0.131	0.126	0.195	0.170	0.145	0.133	0.279	0.219	0.167	0.143
32	0.194	0.184	0.173	0.167	0.247	0.220	0.191	0.175	0.342	0.279	0.218	0.188
34	0.248	0.238	0.225	0.217	0.308	0.281	0.246	0.228	0.413	0.350	0.279	0.243
36	0.313	0.303	0.288	0.279	0.379	0.352	0.313	0.292	0.491	0.432	0.352	0.310
38	0.390	0.381	0.364	0.353	0.461	0.436	0.393	0.368	0.577	0.524	0.437	0.389
40	0.481	0.473	0.454	0.443	0.554	0.533	0.487	0.459	0.671	0.626	0.536	0.483
42	0.57	0.580	0.561	0.548	0.661	0.644	0.597	0.567	0.775	0.740	0.649	0.593
44	0.710	0.705	0.686	0.673	0.781	0.769	0.723	0.692	0.889	0.865	0.777	0.720
46	0.852	0.849	0.831	0.818	0.918	0.911	0.868	0.838	1.01	1.00	0.920	0.865
48	1.02	1.01	0.999	0.987	1.07	1.07	1.03	1.01	1.13	1.15	1.08	1.03
50	1.20	1.20	1.19	1.18	1.24	1.25	1.22	1.20	1.30	1.31	1.26	1.22
52	1.42	1.42	1.41	1.40	1.44	1.44	1.43	1.41	1.47	1.48	1.45	1.43
54	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
56	1.93	1.93	1.94	1.94	1.90	1.90	1.91	1.93	1.86	1.85	1.88	1.91
58	2.42	2.23	2.25	2.27	2.17	2.16	2.20	2.24	2.09	2.06	2.13	2.20

Figure 20.20 ■ Design Chart for Flexible Pavements Based on Using Mean Values for Each Input