5F-1 Pavement Thickness Design Parameters

A. General

Pavement thickness for flexible or rigid pavement can be determined either by using AASHTO equations or nomographs. This section will explain the parameters required for either the equations or nomographs. The same parameters can be used for input data in computer programs on pavement determinations. The program that may be used must be based on AASHTO design methods.

The items contained in Table 1 and corresponding reference discussions for each item, as described in Parts 5C and 5F, were developed from the AASHTO Guide for Design of Pavement Structures. Various referenced documents from the American Concrete Paving Associations, Asphalt Institutes and Iowa DOT were also used.

B. Pavement thickness design parameters

Since Part 5F addresses the design requirements for two types of pavement structures (flexible and rigid) only certain sets of inputs are required for a given structural design combination. Table 1 identifies all possible design input requirements.

Table 1: Summary of design parameters for pavement thickness

Section	Description	Flexible HMA	Rigid JCP/JRCP	CRCP
5F-1, B, 1	Performance Criteria			
	a. Initial Serviceability Index	X	X	X
	b. Terminal Serviceability Index	X	X	X
5F-1, B, 2	Design Variables			
	a. Analysis Period	X	X	X
	b. Design Traffic	X	X	X
	c. Reliability	X	X	X
	d. Overall Standard Deviation	X	X	X
5F-1, B, 3	Material Properties for Structural Design			
	a. Roadbed Soil Resilient Modulus	X		
	b. Modulus of Subgrade Reaction		X	X
	c. Concrete Properties		X	X
	d. Layer Coefficients	X		
5F-1, B, 4	Pavement Structural Characteristics			
	a. Coefficient of Drainage	X	X	X
	b. Load Transfer Coefficients for Jointed and Continuous Reinforced Pavements		X	X
	c. Loss of Support		X	X
5F-1, B, 5	Pavement Reinforcement			
	a. General			
	b. Jointed Reinforced Concrete Pavements (JRCP)			
	1) Slab Length		X	
	2) Steel Working Stress		X	
	3) Friction Factor		X	

HMA – Hot Mix Asphalt Pavement
JCP – Jointed Concrete Pavement (Non-reinforced)
JRCP – Jointed Reinforced Concrete Pavement
CRCP – Continuously Reinforced Concrete Pavement

The following considerations should be used when designing pavement thickness for flexible and rigid pavements.

1. **Performance criteria (serviceability indexes).** Condition of pavements are rated with a present serviceability index (PSI) ranging from 5 (perfect condition) to 0 (impossible to travel).

   a. **Initial serviceability index (P_o).** The initial serviceability index (P_o) is considered to be that PSI immediately after the pavement is open. According to AASHTO road tests, this value is 4.5 for rigid pavement and 4.2 for flexible pavement.

   b. **Terminal serviceability index (P_t).** The terminal serviceability index (P_t) is considered to be that PSI that represents the lowest acceptable level before resurfacing or reconstruction becomes necessary.

   The following values are used for terminal serviceability index.

   Table 2: Terminal serviceability indexes (P_t) for street classifications

P_t	Classifications
2.00	Secondary Roads, Local Residential Streets
2.25	Minor Collectors, Industrial and Commercial Streets
2.50	Major Collectors and all Arterials

   c. **Serviceability loss.** The predicted loss or drop in serviceability (ΔPSI) is the difference between initial and terminal serviceability (P_o - P_t). The ΔPSI is the basis for the pavement design.

2. **Design variables**

   a. **Analysis period.** This refers to the period of time for which the analysis is to be conducted. Normal analysis period is 50 years for concrete and 30 years for asphalt.

   b. **Design traffic.** An estimate of the number of Equivalent 18,000-pound Single Axle Loads (ESALs) during the analysis period is required. This value can be estimated based on:

   - the Average Annual Daily Traffic (AADT) in the base year,
   - the average percentage of trucks expected to use the facility,
   - the average annual traffic growth rate, and
   - the analysis period.

   To estimate the design ESALs, the following procedure may be used or a more thorough analysis may be performed using the procedures found in Appendix D of the *1993 AASHTO Guide for the Design of Pavement Structures* or computer programs based on that procedure.

   1) Obtain an estimate of the design AADT for the beginning, or base year of the analysis period.

   2) Obtain an estimate of the average percentage of the AADT that will be trucks.

   3) Select the Base Year Design Lane ESALs from Tables 3 through 6, depending upon whether the facility is 2-lane, 4-lane, rigid or flexible.

4) Select the Growth Factor from Table 7 based on the average annual traffic growth rate and the analysis period.

5) Multiply the Base Year Design Lane ESALs, by the growth factor to obtain the total ESALs for the analysis period.

Table 3: Base year design lane ESALs

Rigid Pavement
2-Lane Pavement
Assumes the following trucks (fully loaded standard AASHTO design vehicle):
1/3 Single axle light trucks
1/3 Tandem axle trucks
1/3 Tractor trailer trucks
50% directional split of 2-way, Base Year AADT
100% of one-way traffic in design lane
Assumes Rigid Pavement, D=9", Pt=2.50
ESAL's computed using WinPAS Pavement Analysis Software v 1.0.0, 2000

	2-way, Base Year AADT					
% Trucks	5,000	10,000	15,000	20,000	25,000	30,000
1	31,000	59,000	89,000	119,000	147,000	177,000
2	58,000	118,000	176,000	234,000	294,000	352,000
3	86,000	177,000	263,000	349,000	440,000	526,000
4	114,000	237,000	351,000	464,000	587,000	701,000
5	142,000	296,000	438,000	579,000	733,000	875,000
6	170,000	355,000	525,000	695,000	880,000	1,050,000
7	198,000	415,000	612,000	810,000	1,026,000	1,224,000
8	226,000	474,000	699,000	925,000	1,173,000	1,398,000
9	254,000	533,000	787,000	1,040,000	1,320,000	1,573,000
10	282,000	593,000	874,000	1,155,000	1,466,000	1,747,000
11	310,000	652,000	961,000	1,270,000	1,613,000	1,922,000
12	338,000	711,000	1,048,000	1,385,000	1,759,000	2,096,000
13	365,000	771,000	1,136,000	1,500,000	1,906,000	2,271,000
14	393,000	830,000	1,223,000	1,616,000	2,052,000	2,445,000
15	421,000	889,000	1,310,000	1,731,000	2,199,000	2,620,000
16	449,000	949,000	1,397,000	1,846,000	2,345,000	2,794,000
17	477,000	1,008,000	1,485,000	1,961,000	2,492,000	2,969,000
18	505,000	1,067,000	1,572,000	2,076,000	2,639,000	3,143,000
19	533,000	1,127,000	1,659,000	2,191,000	2,785,000	3,318,000
20	561,000	1,186,000	1,746,000	2,306,000	2,932,000	3,492,000
21	589,000	1,245,000	1,834,000	2,422,000	3,078,000	3,667,000
22	617,000	1,305,000	1,921,000	2,537,000	3,225,000	3,841,000
23	645,000	1,364,000	2,008,000	2,652,000	3,371,000	4,015,000
24	673,000	1,423,000	2,095,000	2,767,000	3,518,000	4,190,000
25	700,000	1,482,000	2,182,000	2,882,000	3,664,000	4,364,000
26	728,000	1,542,000	2,270,000	2,997,000	3,811,000	4,539,000
27	756,000	1,601,000	2,357,000	3,112,000	3,958,000	4,713,000
28	784,000	1,660,000	2,444,000	3,228,000	4,104,000	4,888,000
29	812,000	1,720,000	2,531,000	3,343,000	4,251,000	5,062,000
30	840,000	1,779,000	2,619,000	3,458,000	4,397,000	5,237,000

Table 4: Base year design lane ESALs

Flexible Pavement
2-Lane Pavement
Assumes the following trucks (fully loaded standard AASHTO design vehicle):
- 1/3 Single axle light trucks
- 1/3 Tandem axle trucks
- 1/3 Tractor trailer trucks

50% directional split of 2-way, Base Year AADT
100% of one-way traffic in design lane
Assumes Flexible Pavement, Sn=5, Pt=2.50
ESAL's computed using WinPAS Pavement Analysis Software v 1.0.0, 2000

	2-way, Base Year AADT					
% Trucks	5,000	10,000	15,000	20,000	25,000	30,000
1	22,000	42,000	63,000	85,000	105,000	126,000
2	42,000	84,000	125,000	167,000	209,000	250,000
3	62,000	126,000	187,000	248,000	313,000	374,000
4	81,000	168,000	249,000	330,000	417,000	498,000
5	101,000	210,000	311,000	412,000	521,000	622,000
6	121,000	253,000	373,000	493,000	625,000	745,000
7	141,000	295,000	435,000	575,000	729,000	869,000
8	161,000	337,000	497,000	657,000	833,000	993,000
9	180,000	379,000	559,000	739,000	937,000	1,117,000
10	200,000	421,000	621,000	820,000	1,041,000	1,241,000
11	220,000	463,000	683,000	902,000	1,145,000	1,365,000
12	240,000	505,000	745,000	984,000	1,249,000	1,488,000
13	260,000	547,000	806,000	1,065,000	1,353,000	1,612,000
14	279,000	589,000	868,000	1,147,000	1,457,000	1,736,000
15	299,000	631,000	930,000	1,229,000	1,561,000	1,860,000
16	319,000	674,000	992,000	1,311,000	1,665,000	1,984,000
17	339,000	716,000	1,054,000	1,392,000	1,769,000	2,108,000
18	359,000	758,000	1,116,000	1,474,000	1,873,000	2,231,000
19	379,000	800,000	1,178,000	1,556,000	1,977,000	2,355,000
20	398,000	842,000	1,240,000	1,637,000	2,081,000	2,479,000
21	418,000	884,000	1,302,000	1,719,000	2,185,000	2,603,000
22	438,000	926,000	1,364,000	1,801,000	2,289,000	2,727,000
23	458,000	968,000	1,426,000	1,883,000	2,393,000	2,851,000
24	478,000	1,010,000	1,488,000	1,964,000	2,497,000	2,974,000
25	497,000	1,053,000	1,549,000	2,046,000	2,601,000	3,098,000
26	517,000	1,095,000	1,611,000	2,128,000	2,705,000	3,222,000
27	537,000	1,137,000	1,673,000	2,209,000	2,809,000	3,346,000
28	557,000	1,179,000	1,735,000	2,291,000	2,913,000	3,470,000
29	577,000	1,221,000	1,797,000	2,373,000	3,018,000	3,594,000
30	596,000	1,263,000	1,859,000	2,455,000	3,122,000	3,717,000

Table 5: Base year design lane ESALs

Rigid Pavement
4-Lane Pavement
Assumes the following trucks (fully loaded standard AASHTO design vehicle):

- 1/3 Single axle light trucks
- 1/3 Tandem axle trucks
- 1/3 Tractor trailer trucks

50% directional split of 2-way, Base Year AADT
80% of one-way traffic in design lane
Assumes Rigid Pavement, D=9", Pt=2.50
ESAL's computed using WinPAS Pavement Analysis Software v 1.0.0, 2000

	2-way, Base Year AADT					
% Trucks	10,000	15,000	20,000	25,000	30,000	35,000
1	47,000	71,000	95,000	118,000	142,000	166,000
2	95,000	141,000	187,000	235,000	281,000	328,000
3	142,000	211,000	279,000	352,000	421,000	490,000
4	190,000	281,000	372,000	470,000	561,000	652,000
5	237,000	350,000	464,000	587,000	700,000	813,000
6	284,000	420,000	556,000	704,000	840,000	975,000
7	332,000	490,000	648,000	821,000	979,000	1,137,000
8	379,000	560,000	740,000	939,000	1,119,000	1,299,000
9	427,000	629,000	832,000	1,056,000	1,258,000	1,461,000
10	474,000	699,000	924,000	1,173,000	1,398,000	1,623,000
11	522,000	769,000	1,016,000	1,290,000	1,538,000	1,785,000
12	569,000	839,000	1,109,000	1,407,000	1,677,000	1,947,000
13	617,000	909,000	1,201,000	1,525,000	1,817,000	2,109,000
14	664,000	978,000	1,293,000	1,642,000	1,956,000	2,271,000
15	712,000	1,048,000	1,385,000	1,759,000	2,096,000	2,433,000
16	759,000	1,118,000	1,477,000	1,876,000	2,235,000	2,594,000
17	806,000	1,188,000	1,569,000	1,994,000	2,375,000	2,756,000
18	854,000	1,258,000	1,661,000	2,111,000	2,515,000	2,918,000
19	901,000	1,327,000	1,753,000	2,228,000	2,654,000	3,080,000
20	949,000	1,397,000	1,845,000	2,345,000	2,794,000	3,242,000
21	996,000	1,467,000	1,938,000	2,463,000	2,933,000	3,404,000
22	1,044,000	1,537,000	2,030,000	2,580,000	3,073,000	3,566,000
23	1,091,000	1,606,000	2,122,000	2,697,000	3,212,000	3,728,000
24	1,139,000	1,676,000	2,214,000	2,814,000	3,352,000	3,890,000
25	1,186,000	1,746,000	2,306,000	2,932,000	3,492,000	4,052,000
26	1,234,000	1,816,000	2,398,000	3,049,000	3,631,000	4,213,000
27	1,281,000	1,886,000	2,490,000	3,166,000	3,771,000	4,375,000
28	1,328,000	1,955,000	2,582,000	3,283,000	3,910,000	4,537,000
29	1,376,000	2,025,000	2,675,000	3,401,000	4,050,000	4,699,000
30	1,423,000	2,095,000	2,767,000	3,518,000	4,189,000	4,861,000

Table 6: Base year design lane ESALs

Flexible Pavement
4-Lane Pavement
Assumes the following trucks (fully loaded standard AASHTO design vehicle):
- 1/3 Single axle light trucks
- 1/3 Tandem axle trucks
- 1/3 Tractor trailer trucks

50% directional split of 2-way, Base Year AADT
80% of one-way traffic in design lane
Assumes Flexible Pavement, Sn=5, Pt=2.50
ESAL's computed using WinPAS Pavement Analysis Software v 1.0.0, 2000

	2-way, Base Year AADT					
% Trucks	10,000	15,000	20,000	25,000	30,000	35,000
1	34,000	51,000	68,000	84,000	101,000	118,000
2	67,000	100,000	133,000	167,000	200,000	233,000
3	101,000	150,000	199,000	250,000	299,000	348,000
4	135,000	199,000	264,000	334,000	398,000	463,000
5	168,000	249,000	329,000	417,000	497,000	578,000
6	202,000	299,000	395,000	500,000	596,000	693,000
7	236,000	348,000	460,000	583,000	696,000	808,000
8	270,000	398,000	526,000	667,000	795,000	923,000
9	303,000	447,000	591,000	750,000	894,000	1,038,000
10	337,000	497,000	656,000	833,000	993,000	1,153,000
11	371,000	546,000	722,000	916,000	1,092,000	1,267,000
12	404,000	596,000	787,000	999,000	1,191,000	1,382,000
13	438,000	645,000	853,000	1,083,000	1,290,000	1,497,000
14	472,000	695,000	918,000	1,166,000	1,389,000	1,612,000
15	505,000	744,000	983,000	1,249,000	1,488,000	1,727,000
16	539,000	794,000	1,049,000	1,332,000	1,587,000	1,842,000
17	573,000	843,000	1,114,000	1,416,000	1,686,000	1,957,000
18	606,000	893,000	1,179,000	1,499,000	1,785,000	2,072,000
19	640,000	942,000	1,245,000	1,582,000	1,884,000	2,187,000
20	674,000	992,000	1,310,000	1,665,000	1,983,000	2,302,000
21	707,000	1,042,000	1,376,000	1,748,000	2,082,000	2,417,000
22	741,000	1,091,000	1,441,000	1,832,000	2,182,000	2,532,000
23	775,000	1,141,000	1,506,000	1,915,000	2,281,000	2,646,000
24	808,000	1,190,000	1,572,000	1,998,000	2,380,000	2,761,000
25	842,000	1,240,000	1,637,000	2,081,000	2,479,000	2,876,000
26	876,000	1,289,000	1,703,000	2,164,000	2,578,000	2,991,000
27	909,000	1,339,000	1,768,000	2,248,000	2,677,000	3,106,000
28	943,000	1,388,000	1,833,000	2,331,000	2,776,000	3,221,000
29	977,000	1,438,000	1,899,000	2,414,000	2,875,000	3,336,000
30	1,011,000	1,487,000	1,964,000	2,497,000	2,974,000	3,451,000

Table 7: Growth factor

Design Period, Years (n)	Average Annual Traffic Growth Rate, Percent (r) No Growth	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.1
3	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3
4	4.0	4.1	4.1	4.2	4.2	4.3	4.4	4.4	4.5	4.6	4.6
5	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.8	5.9	6.0	6.1
6	6.0	6.2	6.3	6.5	6.6	6.8	7.0	7.2	7.3	7.5	7.7
7	7.0	7.2	7.4	7.7	7.9	8.1	8.4	8.7	8.9	9.2	9.5
8	8.0	8.3	8.6	8.9	9.2	9.5	9.9	10.3	10.6	11.0	11.4
9	9.0	9.4	9.8	10.2	10.6	11.0	11.5	12.0	12.5	13.0	13.6
10	10.0	10.5	10.9	11.5	12.0	12.6	13.2	13.8	14.5	15.2	15.9
11	11.0	11.6	12.2	12.8	13.5	14.2	15.0	15.8	16.6	17.6	18.5
12	12.0	12.7	13.4	14.2	15.0	15.9	16.9	17.9	19.0	20.1	21.4
13	13.0	13.8	14.7	15.6	16.6	17.7	18.9	20.1	21.5	23.0	24.5
14	14.0	14.9	16.0	17.1	18.3	19.6	21.0	22.6	24.2	26.0	28.0
15	15.0	16.1	17.3	18.6	20.0	21.6	23.3	25.1	27.2	29.4	31.8
16	16.0	17.3	18.6	20.2	21.8	23.7	25.7	27.9	30.3	33.0	35.9
17	17.0	18.4	20.0	21.8	23.7	25.8	28.2	30.8	33.8	37.0	40.5
18	18.0	19.6	21.4	23.4	25.6	28.1	30.9	34.0	37.5	41.3	45.6
19	19.0	20.8	22.8	25.1	27.7	30.5	33.8	37.4	41.4	46.0	51.2
20	20.0	22.0	24.3	26.9	29.8	33.1	36.8	41.0	45.8	51.2	57.3
21	21.0	23.2	25.8	28.7	32.0	35.7	40.0	44.9	50.4	56.8	64.0
22	22.0	24.5	27.3	30.5	34.2	38.5	43.4	49.0	55.5	62.9	71.4
23	23.0	25.7	28.8	32.5	36.6	41.4	47.0	53.4	60.9	69.5	79.5
24	24.0	27.0	30.4	34.4	39.1	44.5	50.8	58.2	66.8	76.8	88.5
25	25.0	28.2	32.0	36.5	41.6	47.7	54.9	63.2	73.1	84.7	98.3
26	26.0	29.5	33.7	38.6	44.3	51.1	59.2	68.7	80.0	93.3	109.2
27	27.0	30.8	35.3	40.7	47.1	54.7	63.7	74.5	87.4	102.7	121.1
28	28.0	32.1	37.1	42.9	50.0	58.4	68.5	80.7	95.3	113.0	134.2
29	29.0	33.5	38.8	45.2	53.0	62.3	73.6	87.3	104.0	124.1	148.6
30	30.0	34.8	40.6	47.6	56.1	66.4	79.1	94.5	113.3	136.3	164.5
31	31.0	36.1	42.4	50.0	59.3	70.8	84.8	102.1	123.3	149.6	181.9
32	32.0	37.5	44.2	52.5	62.7	75.3	90.9	110.2	134.2	164.0	201.1
33	33.0	38.9	46.1	55.1	66.2	80.1	97.3	118.9	146.0	179.8	222.3
34	34.0	40.3	48.0	57.7	69.9	85.1	104.2	128.3	158.6	197.0	245.5
35	35.0	41.7	50.0	60.5	73.7	90.3	111.4	138.2	172.3	215.7	271.0
36	36.0	43.1	52.0	63.3	77.6	95.8	119.1	148.9	187.1	236.1	299.1
37	37.0	44.5	54.0	66.2	81.7	101.6	127.3	160.3	203.1	258.4	330.0
38	38.0	46.0	56.1	69.2	86.0	107.7	135.9	172.6	220.3	282.6	364.0
39	39.0	47.4	58.2	72.2	90.4	114.1	145.1	185.6	238.9	309.1	401.4
40	40.0	48.9	60.4	75.4	95.0	120.8	154.8	199.6	259.1	337.9	442.6
41	41.0	50.4	62.6	78.7	99.8	127.8	165.0	214.6	280.8	369.3	487.9
42	42.0	51.9	64.9	82.0	104.8	135.2	176.0	230.6	304.2	403.5	537.6
43	43.0	53.4	67.2	85.5	110.0	143.0	187.5	247.8	329.6	440.8	592.4
44	44.0	54.9	69.5	89.0	115.4	151.1	199.8	266.1	356.9	481.5	652.6
45	45.0	56.5	71.9	92.7	121.0	159.7	212.7	285.7	386.5	525.9	718.9
46	46.0	58.0	74.3	96.5	126.9	168.7	226.5	306.8	418.4	574.2	791.8
47	47.0	59.6	76.8	100.4	132.9	178.1	241.1	329.2	452.9	626.9	872.0
48	48.0	61.2	79.4	104.4	139.3	188.0	256.6	353.3	490.1	684.3	960.2
49	49.0	62.8	81.9	108.5	145.8	198.4	273.0	379.0	530.3	746.9	1,057.2
50	50.0	64.5	84.6	112.8	152.7	209.3	290.3	406.5	573.8	815.1	1,163.9

Growth Factor = $\frac{[(1 + r)^{n}] - 1}{r}$ for values of n > 0

c. **Reliability [R (%), Z_R].** Reliability is the probability that the design will succeed for the life of the pavement. The following reliability and normal deviation values will be used.

	Reliability
Local Streets	80%
Collector Streets	88%
Arterial Streets	95%

Table 8: Reliability and deviation values for flexible and rigid pavement design

	Reliability	Normal Deviation, Z_R
Local Streets	80%	-0.841
Collector Streets	88%	-1.270
Arterial Streets	95%	-1.645

d. **Overall standard deviation (S_o).** (Use for flexible and rigid pavement). The Overall Deviation, or Standard Deviation as it is commonly called, is a coefficient which describes how well the AASHTO Road Test data fits the AASHTO Design Equations. The lower the overall deviation, the better the equations models the data. The following ranges are recommended by AASHTO.

For Rigid Pavements: 0.30 to 0.40

For Flexible Pavements: 0.40 to 0.50

3. **Material properties for structural design**

a. **Roadbed soil resilient modulus (M_R).** The important variable in describing the foundation for flexible pavement design is the Roadbed Soil Resilient Modulus (M_R).

M_R - Roadbed Soil Resilient Modulus, a property of the soil which indicates the stiffness or elasticity of the soil under dynamic loading.

The resilient modulus is a slightly different measurement of somewhat similar properties of the soil or subbase. It measures the amount of recoverable deformation at any stress level for a dynamically loaded test specimen. Both measurements are indications of the stiffness of the layer immediately under the pavement.

The environment can affect pavement performance in several ways. Temperature and moisture changes can have an effect on the strength, durability and load-carrying of the pavement and roadbed materials. Another major environmental impact is the direct effect roadbed swelling, pavement blowups, frost heave, disintegration, etc. can have on loss of riding quality and serviceability. If any of these environmental effects have a significant loss in serviceability or ride quality during the analysis period, the roadbed soil resilient modulus (M_R) takes the environmental effects into account if seasonal conditions are considered.

The purpose of using seasonal modulus is to qualify the relative damage a pavement is subject to during each season of the year and treat it as part of the overall design. An effective road bed soil modulus is then established for the entire year which is equivalent to the combined effects of all monthly seasonal modulus values. AASHTO provides different methodology to obtain the effective resilient modulus (M_R) for flexible pavement only. The method that was selected for use in this manual was based on the determination of M_R values for six different climatic regions in the United States that considered the quality of subgrade soils.

The final M_R values in Table 4 were taken, in part, from Climatic Region 3. Also considered in these selected values were M_R values from the Asphalt Paving Association, American Concrete Pavement Association, Special Studies from the State of Ohio, and Iowa DOT. It should be noted that Iowa DOT uses a M_R value of 3,000 psi above a CBR value of 5 for flexible pavement.

Table 9: Relationships between soil types and bearing values

Type of Soil	Subgrade Strength	k Value Range (pci) (Rigid Pavement)	Resilient Modulus[1] M_R, (psi) (Flexible Pavement)	CBR[4]
Silts and clays of high compressibility[2] natural density (not recommended for subgrades without treatment)	Very Low	50 – 100	1000 – 2700	3 or less
Fine grain soils in which silt and clay size particles predominate (low compressibility)[3]	Low	100 – 150	2700 – 4000	3 to 5.5
Poorly graded sands and soils that are predominately sandy with moderate amounts of silts and clays (well drained)	Medium	150 – 220	4000 – 5700	5.5 to 12
Gravely soils, well graded sands, and sand gravel mixtures relatively free of plastic fines	High	220 – 250+	Greater than 5700	> 12

[1] Resilient Modulus, AASHTO T-274, "Standard Method of Test for Resilient Modulus of Subgrade Soils." (For flexible pavement only)
[2] High Compressibility - Liquid limit equal to or greater than 50.
[3] Low Compressibility - Liquid limit less than 50
[4] CBR - California Bearing Ratio
(NOTE: Liquid limit by ASTM-D-423, "Standard Method of Test for Liquid of Soils")

b. **Modulus of subgrade reaction (k, k_c).** Several variables are important in describing the foundation upon which the pavement rests:

k - The modulus of subgrade reaction for the soil,
k_c - A composite k which includes consideration of subbase materials under the new pavement.
M_R - Roadbed Soil Resilient Modulus (See Section 5F-1, 3, a)

1) *Modulus of subgrade reaction, k.* For concrete pavements, the primary requirement of the subgrade is that it be uniform. This is the fundamental reason for specifications on subgrade compaction. In concrete pavement design the strength of the soil is characterized by the modulus of subgrade reaction or, as it is more commonly referred to "k".

   An approximate relationship between k and M_R published by AASHTO is fairly straightforward:

   $$k = M_R/19.4$$

   where

   k = modulus of subgrade reaction (pci)
   M_R = roadbed soil resilient modulus of the soil as determined by AASHTO Test Method T274.

2) *Composite modulus of subgrade reaction, k_c.* In many highway applications the pavement is not placed directly on the subgrade. Instead, some type of subbase material is used. When this is done, the k value actually used for design is a "composite k" (k_c) which represents the strength of the subgrade corrected for the additional support provided by the subbase. Table 9 and 10 lists k and k_c values for typical soils along with some other common measures of subgrade strength.

Table 10: Approximate composite modulus of subgrade reaction (k_c) values for various pavement conditions

Subgrade k Value	Untreated Subbase Depth vs. k_c Value, pci, (LS*=1)			
	4 in	6 in	8 in	10 in
50	27	31	34	37
100	43	47	51	56
150	57	62	66	71
200	70	74	78	85

For crushed stone subbase, use subgrade value of k=100, and for 6 to 12 in of subbase use k_c = 150.

Subgrade k Value	Bituminous Subbase Depth vs. k_c Value, pci (LS*=0)			
	4 in	6 in	8 in	10 in
50	84	112	141	170
100	144	198	243	288
150	221	277	334	392
200	284	351	419	487

Subgrade k Value	Cement Treated Subbase Depth vs. k_c Value, pci (LS*=0)			
	4 in	6 in	8 in	10 in
50	101	145	193	245
100	185	258	334	414
150	265	360	460	563
200	341	457	577	700

Subgrade k Value	Econocrete (Lean Concrete) Subbase Depth vs. k_c Value, pci (LS*=0)			
	4 in	6 in	8 in	10 in
50	104	156	205	262
100	192	271	354	443
150	274	378	488	603
200	353	480	612	750

Source: Derived from Chapter II “AASHTO Guide for the Design of Pavement Structures”
* Loss of Support (See Section 5F-1, 4, c)

c. **Concrete properties.** PCC - Modulus of Elasticity (E_c) and Modulus of Rupture (S'_c). The concrete strength used in the design of concrete pavements is based on AASHTO Test Method T-97 or ASTM C 78, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). The performance equations predict pavement performance based on the <u>average</u> 28-day flexural strength of the concrete.

Although the modulus of elasticity (E_c) can be evaluated (ASTM Test Method C469), in practice this is rarely done. The range of values for E_c which are reasonable depend largely on the strength of the concrete. Typical values are from 2 to 6 million psi. The following equation will give you an approximate value for E_c:

$E_c = 5700\ (S'_c)$

where:

S'_c = modulus of rupture (28-day flexural strength of the concrete using third-point loading (psi))

The approximately relation between flexural modulus of rupture (S'_c) and compressive strength (f_c) is:

$S'_c = 2.3\ f_c^{0.667}$(psi)

The following table shows typical values for layer coefficients.

d. **Layer coefficients.** Structural layer coefficients (a_i values) are required for flexible pavement structural design. A value for these coefficients are assigned to each layer material in the pavement structure in order to convert actual layer thickness into the structural number (SN).

The following table shows typical values for layer coefficients.

Table 11: Layer coefficients

Component	Coefficient	Minimum Thickness Permitted
Surface / Intermediate Course		
Hot Mix Asphalt with Type A Aggregate	0.44*	2
Hot Mix Asphalt with Type B Aggregate	0.40	2
Base Course		
Type B Hot Mix Asphalt	0.40	2
Asphalt Treated Base Class I	0.34*	4
Bituminous Treated Aggregate Base	0.23	6
Asphalt Treated Base Class II	0.26	4
Cold-Laid Bituminous Concrete Base	0.23	6
Cement Treated Granular (Aggregate) Base	0.20*	6
Soil-Cement Base	0.15	6
Crushed (Graded) Stone Base	0.14*	6
Macadam Stone Base	0.12	6
Portland Cement Concrete Base (New)	0.50	
Old Portland Cement Concrete	0.40**	
Crack and Seated PCC	0.25 – 0.30	
Rubblized PCC	0.20	
Cold in Place Recycled	0.22 – 0.27	
Subbase Course		
Soil-Cement Subbase	0.10	6
Soil-Lime Subbase	0.10	6
Granular Subbase	0.10*	4
Soil-Aggregate Subbase	0.05*	4

* Indicates coefficients taken from AASHTO Interim Guide for the Design of Flexible Pavement Structures.

**This value is for reasonably sound existing concrete. Actual value used may be lower, depending on the amount of deterioration that has occurred.

Source: American Association of State Highway & Transportation Officials (AASHTO)
Iowa Department of Transportation (IDOT)

4. **Pavement structural characteristics**

a. **Coefficient of drainage.** Water under the pavement is one of the primary causes of pavement failure. Water, either from precipitation or groundwater, can cause the subgrade to become saturated and weaken. This will contribute to pavement pumping under large numbers of heavy loads.

C_d - The coefficient of drainage for rigid pavement design used to account for improved or decreased quality of drainage.

M_i - The coefficient of drainage for flexible pavement design used to modify layer coefficients.

At the road test the pavements were not well drained as evidenced by the heavy pumping which occurred on some of the test sections. The cross-sections were elevated and drainage ditches were provided. However, edge drains which are used frequently in today's highway construction were not evaluated at the AASHTO road test. Edge drains are an effective deterrent to premature pumping and associated pavement distress.

In selecting the proper C_d or M_i value, consideration must be given to two factors: how effective is the drainage and how much of the time is the subgrade and subbase in a saturated condition? For example, pavements in dry areas with poor drainage may perform as well as pavements built in wet areas with excellent drainage.

The following definitions are offered as a guide.

Excellent drainage - Material drained to 50% of saturation in 2 hours.

Good drainage - Material drained to 50% of saturation in 1 day.

Fair drainage - Material drained to 50% of saturation in 7 days.

Poor drainage - Material drained to 50% of saturation in 1 month.

Very poor drainage - Material does not drain.

Based on these definitions the C_d or M_i value for the road test conditions would be 1.00. A value of 1.00 would have no impact on pavement thickness or the number of W-18's a section would carry. Lower values increase the required pavement thickness; higher values decrease the required pavement thickness.

Table 12: Recommended values of the drainage coefficient (C_d) for rigid pavement design

Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation				
Quality of Drainage	**< 1%**	**1 – 5%**	**5 – 25%**	**> 25%**
Excellent	1.25 – 1.20	1.20 – 1.15	1.15 – 1.10	1.10
Good	1.20 – 1.15	1.15 – 1.10	1.10 – 1.00	1.00
Fair	1.15 – 1.10	1.10 – 1.00	1.00 – 0.90	0.90
Poor	1.10 – 1.00	1.00 – 0.90	0.90 – 0.80	0.80
Very Poor	1.00 – 0.90	0.90 – 0.80	0.80 – 0.70	0.70

Table 13: Recommended M_i values for modifying structural layer coefficients of untreated base and subbase materials in flexible pavements

Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation				
Quality of Drainage	**< 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

b. **Load transfer coefficients for jointed and continuous reinforced pavements.** The one item which distinguishes pavement is the type of joint used to control cracking and whether or not steel dowels are used in the joint for load transfer. Each of these designs provides a different level of transfer of load from one side of a pavement joint to the other. To adjust projected pavement performance for these various designs the load transfer coefficient or "J" factor is used.

Table 14: Load transfer coefficients (J) for typical designs

	Doweled & Mesh Reinforced[1]		Aggregate Interlock[1]		Continuously Reinforced[2]		
E-18's			Edge Support[3]		Pavement		
Millions	No	Yes	No	Yes	No	Yes	Class
Up to 0.3	3.2	2.7	3.2	2.8	--	--	Local streets & roads
0.3 to 1	3.2	2.7	3.4	3.0	--	--	
1 to 3	3.2	2.7	3.6	3.1	--	--	
3 to 10	3.2	2.7	3.8	3.2	2.9	2.5	Arterials and highways
10 to 30	3.2	2.7	4.1	3.4	3.0	2.6	
Over 30	3.2	2.7	4.3	3.6	3.1	2.6	

1 "Comments on the Proposed 'AASHTO Guide for Design of Pavement Structures' March, 1985, "Portland Cement Association, Presented at May 14, 1985 Public Hearings, Washington, D.C.

2 Volume 2, Appendix KK, "Proposed AASHTO Guide for Design of Pavement Structures," May 15, 1985.

3 Edge support includes lanes widths greater than 13 feet, tied concrete shoulders, and integral or tied concrete curb and gutter.

Note from Table 14 that J is the same whether or not the pavement is reinforced with mesh or if the pavement contains no reinforcement. Both types of pavements were evaluated at the AASHTO road test and produced roughly equivalent performance, therefore J is the same for both types of pavements.

c. **Loss of Support.** The loss of support factor is included in the design of rigid pavements to account for the potential loss of support arising from subbase erosion and/or differential vertical soil movement.

Table 15: Typical ranges of loss of support (LS) factors for various types of materials

Type of Material	Loss of Support (LS)
Cement Treated Granular Base (E=1,000,000 to 2,000,000 psi)	0.0 to 1.0
Cement Aggregate Mixtures (E=500,000 to 1,000,000 psi)	0.0 to 1.0
Asphalt Treated Base (E=350,000 to 1,000,000 psi)	0.0 to 1.0
Bituminous Stabilized Mixtures (E=40,000 to 300,000 psi)	0.0 to 1.0
Lime Stabilized (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=3,000 to 40,000 psi)	2.0 to 3.0

Note: E in this table refers to the general symbol for elastic or resilient modulus of the material.

5. Pavement Reinforcement

a. **General.** There are two types of reinforced rigid pavements. These are Jointed Reinforced Concrete Pavement (JRCP) and Continuously Reinforced Concrete Pavement (CRCP). The major difference between the two is that JRCP has joints and CRCP does not. A summary of reinforcement variable design requirements are outlined in Table 1 with additional explanation following this introduction.

The purpose of distributed steel reinforcement in reinforced concrete pavement is not to prevent cracking, but to hold tightly closed any cracks that may form, thus maintaining the pavement as an integral structural unit. The physical mechanism through which cracks develop is affected by (1) temperature and/or moisture-related slab contractions, and (2) frictional resistance from the underlying material. As temperature drops or moisture content decreases, the slab tends to contract. This contraction is resisted by the underlying material through friction and shear between it and the slab. The restraint of slab contraction results in tensile stresses which reach a maximum at midslab. If these tensile stresses exceed the tensile strength of the concrete, a crack will develop and all the stresses are transferred to the steel reinforcement. Thus, the reinforcement must be designed to carry these stresses without any appreciable elongation that would result in excessive crack width.

Because the longitudinal steel reinforcement requirements between jointed reinforced (JRCP) and continuously reinforced concrete pavement (CRCP) are significantly different, the reinforcement designs are treated separately. It should be recognized, however, that the design for transverse steel in CRCP is exactly the same as the design for longitudinal and transverse steel reinforcement in JRCP. In all cases, the amount of reinforcement required is specified as a percentage of the concrete cross-sectional area.

In the Des Moines Metropolitan area and the State of Iowa, only JRCP is used, therefore, no future discussion will be made regarding CRCP. The "AASHTO Guide for Design of Pavement Structures, Chapter 2 and 3 can be used if CRCP is desired.

b. **Jointed reinforced concrete pavement (JRCP).** Jointed Reinforced Concrete Pavement (JRCP) is a rigid pavement designed to have mat reinforcement in terms of either steel bars or welded steel mats. The steel reinforcement is added if the probability of transverse cracking during pavement life is high due to such factors as soil movement and/or temperature/moisture change stresses.

Following are the criteria needed for the design of jointed pavements which are steel reinforced (JRCP). These criteria apply to the design of both longitudinal and transverse steel reinforcement.

1) *Slab length* - This refers to the joint spacing or distance, L (feet), between free (i.e., untied) transverse joints. It is an important design consideration since it has a large impact on the maximum concrete tensile stresses and, consequently, the amount of steel reinforcement required. Because of this effect, slab length (joint spacing) is an important factor that must be considered in the design of any reinforced or non-reinforced jointed concrete pavement. (For this manual, a 15 foot or 20 foot joint spacing needs to be used.)

2) *Steel working stress* - This refers to the allowable working stress, f_s (psi), in the steel reinforcement. Typically, a value equivalent to 75% of the steel yield strength is used for working stress. For Grade 40 and Grade 60 steel, the allowable working stresses are 30,000 and 45,000 psi, respectively. For Welded Wire Fabric (WWF) and Deformed Wire Fabric (DWF), the steel yield strength is 65,000 psi and the allowable working stress is 48,750 psi. The minimum wire size should be adequate so that potential corrosion does not have a significant impact on the cross sectional area. (For this manual a Grade 40 shall be used for plain and smooth dowel bars and deformed bars.)

3) *Friction factor* - This factor, F, represents the frictional resistance between the bottom of the slab and the top of the underlying subbase or subgrade layer and is basically equivalent to a coefficient of friction. Recommended values for natural subgrade and a variety of subbase materials are presented in Table 16.

Table 16: Recommended friction factors

Type of Material Beneath Slab	Friction Factor (F)
Surface treatment	2.2
Lime stabilization	1.8
Asphalt stabilization	1.8
Cement stabilization	1.8
River gravel	1.5
Crushed stone	1.5
Sandstone	1.2
Natural subgrade	0.9