IOWA STATE HIGHWAY COMMISSION

Study of
ALTERNATE PAVEMENT DESIGNS

MAY 1968

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CONSULTING ENGINEERS
HNTB

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May 1, 1968

Mr. J. R. Coupal, Jr.
Director of Highways
Iowa State Highway Commission
Ames, Iowa

Dear Mr. Coupal:

We present in the attached report the results of our review of current Iowa Highway Commission pavement design procedures, for determination of pavement section and selection of rigid or flexible pavement type and also, our recommended pavement designs for the Cedar Valley Freeway and U.S.-518 from I-80 to U.S. 30.

The report compares the practices being used by the State of Iowa with those of four other States, with the criteria recommended by the American Association of State Highway Officials and with the methods used by private agencies representing production of the two pavement types. We have found that the methods utilized by the Commission, in the design of pavement and selection of pavement type are highly acceptable and are in conformance with those used by the surrounding states.

Grateful acknowledgement is made to the engineering staff of the Commission for cooperation and assistance in the development of this study.

Respectfully submitted,

HOWARD, NEEDLES, TAMMEN & BERGENDOFF

Rex M. Whitton
P. E. Iowa Reg. No. 5744

R. N. Bergendoff
P. E. Iowa Reg. No. 3304

I hereby certify that this plan, specification or report was prepared by me or under my direct personal supervision and that I am a duly registered Professional Engineer under the laws of the State of Iowa.

3304

Signed .... Date May 1, 1968

R. N. Bergendoff, P. E. Iowa Reg. No. 3304

CONTENTS

IOWA STATE HIGHWAY COMMISSION

Alternate Pavement Designs for Iowa Highway Projects
Cedar Valley Freeway
and
US 518 from Interstate 80 to US 30

CHAPTER I

SCOPE OF REPORT

This report is submitted pursuant to a contract dated August 30, 1967, between the Iowa State Highway Commission and Howard, Needles, Tammen & Bergendoff, Consulting Engineers, in connection with studies determining (II,A) alternate pavement designs, and (II,B) criteria for geometric design studies. Included herein is that portion of the report covering Paragraph II,A, comprising preparation of alternate type pavement designs (Portland Cement and Asphaltic Concrete) for the Cedar Valley Freeway and proposed US–518 from I–80 to US–30. These alternate pavement designs consider quality and availability of aggregates, soil conditions and traffic information, to determine details and dimensions of pavement design. Comparative cost studies were prepared from alternate design data and recommendations as to pavement type are presented for Commission review.

OUTLINE OF PROCEDURE

The studies undertaken for the purpose of this report have been pursued in accordance with the following outline.

1. Review of Iowa pavement design procedures.

    a. For the given set of basic data (traffic, subgrade characteristics, pavement and base materials,) roadway sections were designed for both flexible and rigid types using Iowa procedures. For these analyses, basic traffic data was furnished for US 518 from I-80 to US 30.

b. Sections were designed in accordance with procedures recommended by AASHO, the Portland Cement Association and the Asphalt Institute, and procedures used in adjoining States, using the same basic data.

2. Design results obtained in Item 1 were compared and recommendations are made for changes in Iowa procedures as were indicated by this comparison.

3. Comparative cost analyses of flexible and rigid designs were made according to Iowa procedures. These analyses were reviewed in comparison with procedures employed by other States.

PAVEMENT DESIGN

There are three basic elements of the pavement design determination. They are (1) Traffic analysis for determination of design load, (2) Selection of the components of the pavement section for both rigid and flexible types and (3) Economic evaluation of alternate pavement types, and selection of type for the project plans. These elements are not separate considerations, but are interdependent and must be considered in their entirety in the final determination of the pavement structure. Design loads differ for rigid and flexible types. Components of the pavement section may vary according to availability of materials and according to variable costs. The results of the composite analysis including all three elements may be also be affected by variation in supporting strength of the subgrade and variation in regional (climatological) factor. The results of economic evaluation vary according to differences in service life, interest rate, thickness and life of resurfacing and method of economic analysis.

In the comparative analyses developed in this report, the designs made using procedures employed by other States or agencies are based on the same subgrade strength and the same regional factors as used in the Iowa analyses. The pavement sections developed in the course of this study are applicable to Primary and Interstate highways, for which the service expectancy (Present Serviceability Index) is the same for all States and agencies, and a value of 2.5 is used.

The following factors have been used in the designs developed in this report.

For Rigid Pavement:

Modulus of Subgrade Reaction (k)	100
Modulus of Subgrade Resistance (R)*	10
Modulus of Rupture (Design)	500
Load Safety Factor	1.2
California Bearing Ratio (CBR)**	3

* Where used in determination of k.
** Where used in design of rigid pavement.

For Flexible Pavement:

Soil Support Value (S)	3
Regional Factor (R)	3
Present Serviceability Index (P+)	2.5
California Bearing Ratio (CBR)	3
Modulus of Subgrade Resistance (R)	10

In the event final soils surveys indicate a soil support value or K-value other than the values herein assumed, revision of the pavement design and selection of pavement type may be required.

SUMMARY OF TRAFFIC AND SECTION STUDIES

The results of studies of Traffic and Pavement Sections for Iowa and other States are summarized in the following table. All of the States use a 20-year design period, and all except Iowa use the traffic for the year representing half the design period.

SUMMARY OF PAVEMENT DESIGNS

	Iowa	State 2	State 3	State 4	State 5
Rigid Pavement					
Traffic	Design Period	10th Year	10th Year	10th Year	10th Year
Method	Heaviest 13 Axles	Min. Std.	Formula	AASHO	P C A
% Design Lane	100%		90%	86%	100%
Section					
Slab	10" Plain 9" Reinf. 8" Cont.	9" Reinf. 8" Cont.	10" Reinf. 7" Cont.	9" Reinf.	.70' Reinf. .45' Cem. Tr. Base
Subbase	4" Gran.	5.25" Gran.	4" Stab. Gran.	4" Gran.	.50 Gran.
Method	P C A & Formula	Min. Std.	State 3 Chart	AASHO Chart	State 5 Charts & P C A
Flexible Pavement					
Traffic	Design Period	10th Year	10th Year	10th Year	10th Year
Method	AASHO	Min. Std.	Formula	AASHO	5k. EWL
% Design Lane	100%		90%	86%	100%
Section					
Surface	4.5" A C	3.5" A C	4.5" A C	1.5" A C	.45' A C
Base	12" Asph. Tr.	4.5" Bituminous 4" Bit. Treated	12" Stab.	10.5" A C (45% Rock)	.90' Cem. Treated
Subbase	6" Soil Agg.	14" Sand--Gr.	8" Gran.	6" Soil Agg.	1.00' Cl. 2 Agg.
Method	AASHO SN	Min. Std.	State 3 SN (D+)	Modified AASHO 1.15 SN	State 5 Formula
Strength Coefficients	Iowa & AASHO	State 2 Gravel Equivalents	State 3	State 4 & AASHO	State 5 Gravel Equivalents
Reference: See Page	16	18	21	23	26

Pavement sections determined by the various State methods for rigid pavement show some consistency in slab thickness required. Consideration of differences in subbase characteristics leads to the conclusion that, for the traffic volumes assigned to the subject project, an 8-inch continuously reinforced concrete slab with a 4-inch granular subbase is appropriate for the rural portion of the project. For the Cedar Valley Freeway, where widening and ramps would complicate the construction of a continuously reinforced slab, the rigid type pavement design should be either 9-inch conventionally reinforced concrete or 10-inch plain concrete, on a 4-inch granular subbase.

Comparison of the flexible pavement sections developed from the several methods used by the various States indicates considerable variation in results. Based on Iowa's design methods which we find completely acceptable, the flexible pavement section would consist of a 4-1/2 inch asphaltic concrete on a 12 inch asphalt treated base on a 6 inch soil aggregate subbase. States 2, 3 and 5 require a heavier section than Iowa. The State 4 section is lighter, even though that state applies an additional factor to the required structural number. However, if State 4 used strength coefficients equivalent to those used by Iowa, the State 4 section would be similar to the Iowa Section. An appropriate flexible pavement section for the subject project, to be comparable to States 2, 3 and 5 should have a substantial crushed stone or gravel subbase over the full width of the roadbed.

SUMMARY OF COST COMPARISONS

It is the practice of all of the States studied to determine the type of pavement to be used for a project on the basis of the economic analysis. A separate study is made for each contract segment of the project, rather than a "systems" analysis, whereby a pavement type may be determined by the type generally existing on the route in which the project is included.

The cost comparisons of the five methods studied are summarized in the following table. This table shows the comparison between rigid and flexible types as determined by each State's method of computation. *The amounts in the table apply to one mile of 4-lane divided highway, using the construction, resurfacing and maintenance cost figures for the Iowa design.*

SUMMARY OF COST COMPARISONS

	Iowa	State 2	State 3	State 4	State 5
Method	Shaw	Breed	Baldock		
Analysis Period	30 Yrs.	35 Yrs.	40 Yrs.	40 Yrs.	25 Yrs.
Interest Rate	5%	2.5%	6%	None	5%
Present Worth, Rigid	$291,573				$290,875
Present Worth, Flexible	$309,797				$310,892
Annual Cost, Rigid		$10,356	$20,614	$8,530	
Annual Cost, Flexible		$12,006	$20,148	$9,275	
Ratio $\frac{\text{Rigid}}{\text{Flexible}}$	.95	.86	1.02	.92	.94
Resurfacing, Rigid	30 Yrs.	35 Yrs.	20.4 Yrs*	24 & 36 Yrs.	25 Yrs.
Resurfacing, Flexible	15 Yrs.	17.5 Yrs.	20 Yrs.	16 & 28 Yrs.	14 Yrs.
Reference: See Page	34	35	39	40	42

* Time for resurfacing State 3 Rigid depends on Ratio of selected design to required design.

CONCLUSIONS

As may be observed by examination of the foregoing summary, the difference in cost between the two types is not very great and therefore it is necessary that all factors influencing the unit prices be carefully considered.

The procedures being followed by the Traffic, Design, Materials and Contracts Departments of the Iowa Highway Commission conform to the practices of the other States studied. There are, however, appreciable differences in details of pavement sections, particularly for the flexible type, resulting from application of the same traffic and soils criteria. The development of the art of pavement design is still far from an exact science, and considerable reliance upon performance experience with previous pavement structures is necessary.

UPON THE BASIS OF THE FOREGOING SUMMARIES OF TRAFFIC AND SECTION STUDIES AND ECONOMIC ANALYSES, AN 8 INCH CONTINUOUSLY REINFORCED CONCRETE PAVEMENT ON A 4 INCH GRANULAR SUBBASE IS RECOMMENDED FOR THE F-518 PROJECT FROM INTERSTATE 80 TO US 30 AND EITHER A 9 INCH CONVENTIONALLY REINFORCED OR A 10 INCH PLAIN CONCRETE PAVEMENT ON A 4 INCH GRANULAR SUBBASE IS RECOMMENDED FOR THE CEDAR VALLEY FREEWAY IN CEDAR RAPIDS.

As a result of our studies, it is suggested that consideration be given to modifying present practices so that:

1. Both rigid and flexible pavement be constructed on a granular subbase extending the full width of the roadbed, regardless of whether or not a subbase is required by the mathematical analysis. The practice in most of the States studied is to provide a subbase under rigid pavement for protection against pumping, and a subbase under flexible pavement to provide a substantial working platform for construction of the asphaltic concrete courses.

2. Design of continuously reinforced concrete pavement considers near edge loading as well as interior loading in order to conform to the conservative practice of other States.

3. Maintenance and resurfacing cost data for use in economic evaluations for the multilane divided type of highways be assembled from records applicable only to this type of highway.

CHAPTER II

PAVEMENT DESIGN

IOWA PAVEMENT DESIGN

Traffic volume to be used for pavement design is determined by the Traffic Department. The data includes present average daily traffic, with passenger cars, pick-up and panel trucks grouped, and commercial trucks and buses shown separately. Total estimated average daily traffic 20 years hence is also furnished. From this data the estimated passenger car, pick-up and panel truck traffic (20th year) and estimated commercial truck traffic volumes are determined, using the same ratios to total traffic as are furnished for present day traffic.

Traffic distribution, that is, assignments of number of vehicles of each type, for each section of road included in the project, is obtained from the traffic book, which tabulates traffic assignments for each section of Primary and Interstate highway in the State. For this project the data was obtained from the appropriate sections listed on Page 279 of the 1965 traffic book.

The traffic data thus obtained is entered on the calculation form TAPD2 (applicable to Interstate Routes) and computations are made which will determine, for rigid pavement, the anticipated load of the heaviest thirteen axles, and for flexible pavement, the number of 18-Kip single axle applications for each of the assumed Structural Numbers 3, 4, 5 and 6. (Structural Number is an index number which may be converted to pavement thickness through the use of coefficients related to the type of material used in the pavement structure).

The traffic analysis is summarized on form TAPD1, shown opposite. together with computation form TAPD2 and traffic book Page 279. This data was furnished by the Iowa State Highway Commission.

TRAFFIC APPENDIX
(Pavement Determinations)

PROJECT January 24, 1967

County Linn Road No. Proposed Reloc. US 218 Program Year 1968

Location From I-80 in Johnson Co. to Jct. U.S. 30 in Cedar Rapids

Present Average Daily Traffic, 1968		
(a) Cars, Pickups & Panels	7130	vpd
(b) Commercial Trucks & Buses	1370	vpd
(c) Total	8500	vpd

Estimated Average Daily Traffic (20 year) 1988		
(a) Cars, Pickups & Panels	12580	vpd
(b) Commercial Trucks & Buses	2420	vpd
(c) Total	15000	vpd

Estimated Load Distribution (20 year) 1988

Flexible Pavement ($P_t = 2.5$)

SN	18k Equivalent Single Axle Loads Per Day
3	1387
4	1353
5	1301
6	1277

Rigid Pavement

Single Axle Weight Group	No. of Axles Per Day Each Direction	Total Weight Group Per Group	Repetitions 20 Years
26,000-28,000	.22	6160	1606
24,000-26,000	1.36	35360	9928
22,000-24,000	4.66	111840	34018
20,000-22,000	6.76	148720	49348

TAPD1 (Revised) Design Wheel Load $\frac{302080 \times 1.2}{13 \times 2} = 13.9$ Kips

Form TAPD 2
Interstate
1963 - 1965 Data

Proposed U.S. 218 From I-80 in Johnson Co. to Jct. U.S. 30 in Cedar Rapids

(PROJECT LOCATION)

SECTION DESCRIPTION	SECTION LENGTH	SU 2AX 4T		SU 2AX 6T		SU 3AX		TTST 3AX		TTST 4AX		TTST 5AX		TRUCK COMB. AND BUSES		TOTAL	
		TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES	TRAFFIC	VEHICLE MILES
(A) From I-80 Interchange N 1/4 Cor Sec 36 - 80 - 7 to Beg 24 Ft Section	.23	17	3.91	294	67.62	57	13.11	72	16.56	164	37.72	396	91.08	54	12.42	1054	242.42
Cent Sec 12 80 7W	3.30	17	56.10	294	970.20	57	188.10	72	237.60	164	541.20	396	1306.80	54	178.20	1054	3478.20
Beg: Divided Section	.36	13	4.68	222	79.92	43	15.48	71	25.56	162	58.32	392	141.12	47	16.92	950	342.00
Jct. 218 and 153	.16	13	2.08	222	35.52	43	6.88	71	11.36	162	25.92	392	62.72	47	7.52	950	152.00
Jct. Old 218	3.17	17	53.89	280	887.60	54	171.18	66	209.22	151	478.67	365	1157.05	51	161.67	984	3119.28
Co Trk In NW 1/4 Sec. 21 81 - 7W	1.78	17	30.26	285	507.30	55	97.90	68	121.04	153	272.34	371	660.38	51	90.78	1000	1780.00
NW Cor Sec 9 81 7W	2.43	15	36.45	253	614.79	49	119.07	67	162.81	151	366.93	367	891.81	48	116.64	950	2308.50
S Line Linn County	.96	16	15.36	264	253.44	51	48.96	66	63.36	150	144.00	364	349.44	49	47.04	960	921.60
Jct. 218 and 84	2.00	16	32.00	264	528.00	51	102.00	66	132.00	150	300.00	364	728.00	49	98.00	960	1920.00
S. Lts. Cedar Rapids	1.01	19	19.19	315	318.15	61	61.61	65	65.65	146	147.46	354	357.54	53	53.53	1013	1023.13
Beg. 36 Ft Taper Sec.	1.41	24	33.84	422	595.02	82	115.62	65	91.65	147	207.27	356	501.96	64	90.24	1160	1635.60
S. Jct. 218 and 30	.08	24	1.92	422	33.76	82	6.56	65	5.20	147	11.76	356	28.48	64	5.12	1160	92.80
(B) TOTAL	16.89		289.68		4891.32		946.47		1142.01		2591.59		6276.38		878.08		17015.53
(C) AVERAGE TRAFFIC		17		290		56		68		153		371		52		1007	
(D) ADJ. EST (20 YR) ADT		40		696		136		164		368		892		124		2420	
(E) DIREC. TRAFFIC		20		348		68		82		184		446		62		1210	
(F) DIREC. NO AXLES		40		696		204		246		736		2230		186			
(G) WEIGHT GROUPS		Factor	No. Ax	Factor	No. Ax	Factor	No. Ax	Factor	No. Ax	Factor	No. Ax	Factor	No. Ax	Factor	No. Ax	Total	
32,000 - 34,000																	
30,000 - 32,000																	
28,000 - 30,000																	
26,000 - 28,000												.0001	.2230			.2230	.22
24,000 - 26,000								.0007	.1722	.0007	.5152	.0003	.6690			1.3564	1.36
22,000 - 24,000										.0027	1.9872	.0009	2.0070	.0036	.6696	4.6638	4.66
20,000 - 22,000								.0094	2.3124	.0079	5.8144	.0054	12.0420	.0018	.3348	20.5036	6.76
18,000 - 20,000				.0045	3/1320	.0074	1.5096	.0243	5.9778	.0373	27.4528	.0367	81.8410	.0072	1.3392	121.2524	

18K Single Axle Location (H)		SU 2AX 4T	SU 2AX 6T	SU 3AX	TTST 3AX	TTST 4AX	TTST 5AX	TK-TR	PC & PU	TOTAL
SN-3	Rate/Vehicle	0.00919	0.17344	0.60820	0.89776	1.30629	2.08970	0.57699	0.00030	
	Applications	0.18380	60.35712	41.35760	73.61632	240.35736	932.00620	35.77338	3.77400	1387.43
SN-4	Rate/Vehicle	0.00722	0.16186	0.58499	0.86826	1.26302	2.04136	0.55113	0.00070	
	Applications	0.14440	56.32738	39.77932	71.19732	232.39568	910.44656	34.17006	8.80600	1353.27
SN-5	Rate/Vehicle	0.00599	0.14992	0.55069	0.83721	1.22367	1.97756	0.52749	0.00020	
	Applications	0.11980	52.17216	37.44692	68.65122	225.15528	881.99176	32.70438	2.51600	1300.76
SN-6	Rate/Vehicle	0.00546	0.14353	0.53034	0.82220	1.20721	1.94340	0.51692	0.00020	
	Applications	0.10920	49.94844	36.06312	67.42040	222.12664	866.75640	32.04904	2.51600	1276.99

AVERAGE ANNUAL DAILY (24 HOUR) TRAFFIC

ON

THE PRIMARY ROAD SYSTEM OF IOWA

DURING

1965

ROUTE	COUNTY	SECTION DESCRIPTION (TERMINAL)	P-PAV B-BIT G-GRAV / R-RURAL M-MUN / I-DUP ROUTE	SECTION LENGTH	SUFFICIENCY RATING	AVERAGE DAILY TRAFFIC	AVERAGE DAILY VEHICLE MILES: ALL VEHICLES	AVERAGE DAILY VEHICLE MILES: TRUCKS AND BUSSES	PASSENGER CARS	PICK-UPS AND PANELS	TOTAL PASS-CARS PICK-UPS AND PANELS	SINGLE UNIT TRUCKS: 2-AXLE 4-TIRE	SINGLE UNIT TRUCKS: 2-AXLE 6-TIRE	SINGLE UNIT TRUCKS: 3-AXLE	TRUCK TRACTOR SEMI-TRAILER COMBINATIONS: 3-AXLE	TRUCK TRACTOR SEMI-TRAILER COMBINATIONS: 4-AXLE	TRUCK TRACTOR SEMI-TRAILER COMBINATIONS: 5 OR MORE AXLES	TK-TR	BUSSES	TOTAL TRUCKS AND BUSSES
218	52	S 1/4 COR NW 1/4 SEC 6 79 6W	PR1	.77	88	7770	5,983	605	6488	496	6984	19	248	58	49	107	269	14	22	786
218	52	W JCT 218 & 6	PR1	.97	92*	8180	7,935	915	6723	514	7237	26	344	80	52	113	283	15	30	943
218	52	W JCT 218&6-I-80 INTERCHANGE	PR	.20	100	6340	1,268	149	5200	397	5597	15	251	48	44	101	244	15	25	743
218	52	I80 INT NS TANGENT S PART	PR	.16	100	4830	773	149	3622	277	3899	16	278	54	62	138	335	21	27	931
218	52	I80 INT NS TANGENT S CENT PART	PR	.04	100	4830	193	37	3622	277	3899	16	278	54	62	138	335	21	27	931
218	52	I80 INT NS TANGENT N CENT PART	PR	.04	100	4830	193	37	3622	277	3899	16	278	54	62	138	335	21	27	931
218	52	I80 INT NS TANGENT N PART	PR	.16	100	4830	773	149	3622	277	3899	16	278	54	62	138	335	21	27	931
218	52	I 80 INTERCHANGE-N1/4 COR 36- 80 7	PR	.30	100	8250	2,475	323	6663	509	7172	21	355	69	65	149	361	23	35	1078
218	52	BEG 24FT SECTION	PR	.23	100	6300	1,449	242	4874	372	5246	17	294	57	72	164	396	25	29	1054
218	52	CENT SEC 12 80 7W	PR	3.30	35	6300	20,790	3,478	4874	372	5246	17	294	57	72	164	396	25	29	1054
218	52	BEG DIVIDED SECTION	PR	.36	35	5440	1,958	342	4171	319	4490	13	222	43	71	162	392	25	22	950
218	52	JCT 218 & 153	PR	.16	100	5440	870	152	4171	319	4490	13	222	43	71	162	392	25	22	950
218	52	JCT OLD 218	PR	3.17	41	5960	18,893	3,119	4623	353	4976	17	280	54	66	151	365	23	28	984
218	52	CO TRK IN NW 1/4 SEC 21 81 7W	PR	1.78	41	5960	10,609	1,780	4608	352	4960	17	285	55	68	153	371	23	28	1000
218	52	NW COR SEC 9 81 7W	PR	2.43	41	5880	14,288	2,309	4580	350	4930	15	253	49	67	151	367	23	25	950
218	52	S LINE LINN COUNTY	PR	.96	41	6090	5,846	922	4766	364	5130	16	264	51	66	150	364	23	26	960
218	57	JCT 218 & 84	PR	2.00	35	6090	12,180	1,920	4766	364	5130	16	264	51	66	150	364	23	26	960
218	57	S LIMITS OF CEDAR RAPIDS	PR	1.01	28	8400	8,484	1,023	6863	524	7387	19	315	61	65	146	354	22	31	1013
218	57	BEG 36FT TAPER SECTION	PM	1.41	55	10960	15,454	1,636	9104	696	9800	24	422	82	65	147	356	22	42	1160
218	57	S JCT 218 & 30	PM	.08	76*	10960	877	93	9104	696	9800	24	422	82	65	147	356	22	42	1160
218	57	INT 6TH ST & WILSON AVE	PM1	1.99	68	16820	33,472	3,803	13552	1357	14909	51	656	130	45	292	654	30	53	1911
218	57	INT 6TH ST & 18TH AVE	PM1	.34	64	19610	6,667	782	15736	1575	17311	58	750	149	57	366	821	37	61	2299
218	57	JCT 218 30 & 16TH AVE S W	PM1	.06	77	19610	1,177	138	15736	1575	17311	58	750	149	57	366	821	37	61	2299
218	57	INT 16TH AVE & 12TH ST	PM1	.47	51*	13480	6,336	690	10919	1093	12012	33	421	83	39	257	575	26	34	1468
218	57	BEG 40FT SECTION	PM1	.34	61	13480	4,583	442	11072	1108	12180	31	398	79	33	218	487	22	32	1300
218	57	INT 16TH AVE & 18TH ST	PM1	.05	81	13480	674	65	11072	1108	12180	31	398	79	33	218	487	22	32	1300
218	57	BEG 48FT SECTION	PM1	.64	77	11900	7,616	800	9681	969	10650	30	374	74	32	212	476	22	30	1250
218	57	JCT 218,30,64,149 & 151	PM1	.14	95	11900	1,666	175	9681	969	10650	30	374	74	32	212	476	22	30	1250
218	57	W LTS OF CEDAR RAPIDS	PM1	1.12	87*	9440	10,573	1,098	7690	770	8460	22	291	58	25	168	375	17	24	980
218	57	N 1/4 COR NE 1/4 SEC 35 83 8W	PR1	.54	30	6230	3,364	544	4748	475	5223	25	322	64	25	163	365	17	26	1007
218	57	NW COR SEC 34 83 8W	PR1	1.72	30	5680	9,770	1,809	4207	421	4628	21	279	55	29	193	432	20	23	1052
218	57	NW COR SEC 32 83 8W	PR1	2.01	30	4960	9,970	1,956	3624	363	3987	20	260	52	27	178	397	18	21	973
218	57	E LINE BENTON CO	PR1	1.03	30	4630	4,769	943	3376	338	3714	18	231	46	26	173	386	17	19	916
218	6	JCT 218,30,64 & 279	PR1	1.02	34	4630	4,723	934	3376	338	3714	18	231	46	26	173	386	17	19	916

IOWA PAVEMENT DESIGN - Cont'd.

For rigid pavement the design procedure is an adaptation of the method recommended by the Portland Cement Association's "Thickness Design for Concrete Pavements." The single-axle weight groups found in the traffic analysis to comprise the heaviest thirteen axles are tabulated on the calculation form. The weight groups are increased by a load safety factor. A trial thickness is assumed and for each weight group the flexural stress is determined from the Portland Cement Association chart. The ratio of the flexural stress to the allowable stress is then applied to PCA Table 3* to determine the allowable number of load repetitions. The ratios of the expected load repetitions to allowable load repetitions are summarized as the Fatigue Resistance Used. This total should not exceed 125 per cent.

For continuously reinforced concrete pavement the design chart is not used; the flexural stress is computed from a formula for stresses due to an interior loading using 100% of the repetitions, and checked by a formula for loading 1 foot inside the pavement edge, using 5 per cent of the expected repetitions. Other procedures are the same as above. Rigid pavement designs for several assumed depths, k-values and with subbases are shown on the following form XP6515. These designs indicate that the rural portion of the project should have 8-inch continuously reinforced concrete pavement. For the urban portion, where numerous ramp and widening situations will occur the rigid design should be 9-inch mesh reinforced pavement or 10-inch plain concrete, using standard load transfer joints.

The trial depths shown on form XP6515 are the governing cases, and are satisfactory thicknesses for either k-100 or k-150. Additional trial designs are shown in the Appendix.

*PCA Table 3 is shown as Table 7-605.4 on Appendix page A-21.

CALCULATION OF CONCRETE PAVEMENT THICKNESS XP6515

Project Proposed US 518 From I-80 to US 30

Type Class I **No. of Lanes** 4

Subgrade k 150 100 **pci., Subbase** 4" Granular

Combined k 180 130 **pci., Load Safety Factor** 1.2 **(L.S.F.)**

PROCEDURE

1	2	3	4	5	6	7
Axle Loads kips	Axle Loads X L.S.F. kips	Stress psi	Stress Ratios M.R. 500	Allowable Repetitions No.	Expected Repetitions No.	Fatigue Resistance Used percent

Trial Depths

SINGLE AXLES

K = 180

9" Mesh Reinforced

28	33.6	300	.60	32,000	1,606	5
26	31.2	285	.57	75,000	9,928	13
24	28.8	265	.53	240,000	34,018	14
22	26.4	250	.50	Unlimited	49,348	0
					Total	32

K = 180

8" Continuously Reinforced Edge Loading 5% Repetitions Ce = 1.38

28	33.6	363	.73	850	80	9.4
26	31.2	337	.67	4,500	496	11.0
24	28.8	311	.62	18,000	1,701	9.5
22	26.4	285	.57	75,000	2,467	3.3
					Total	33.2

K = 130

9" Mesh Reinforced

28	33.6	325	.65	8,000	1 1,606	20
26	31.2	310	.62	18,000	9,928	55
24	28.8	285	.57	75,000	34,018	45
22	26.4	265	.53	240,000	49,348	21
					Total	141

K = 130

8" Continuously Reinforced Edge Loading 5% Repetitions Ce = 1.46

28	33.6	384	.77	270	80	29
26	31.2	357	.71	1,500	496	33
24	28.8	329	.66	6,000	1,701	28
22	26.4	301	.60	32,000	2,467	8
					Total	98

For Complete List of Trials, See Appendix

For flexible pavement the design procedure is essentially the method of the AASHO Recommended Guide for the Design of Flexible Pavement Structures. Thickness coefficients of the Guide have been supplemented with coefficients applicable to the various Standard Specification items used in Iowa. Design Chart 400-2 (a nomograph) is entered with the known soil support values and equivalent daily 18-Kip single-axle load applications, determining structural number which is corrected for the assigned regional factor to arrive at a weighted structural number.

SN	18k Equivalent Single Axle Loads Per Day
3	1387
4	1353
5	1301
6	1277

S	18^kS.A.L.	$\overline{SN}$	R	Weighted SN
3	1387	5.7	3	6.3
3	1353	5.6	3	6.2
3	1301	5.5	3	6.1
3	1277	5.4	3	6.0

Selection of a combination of Surface Course, Base Course and Subbase Course and summation of the products of thickness and coefficients is made so as to equal the weighted structural number. The selection is narrowed to two or three combinations by reference to limiting factors governed by the class of highway and actual experience with previous flexible pavement designs.

Calculations of the required thicknesses of flexible pavement courses are shown below.

1.	Type A Asphaltic Concrete	4.5"	x .44 =	1.98
	Asphalt Treated Base Class I	12"	x .34 =	4.08
	Soil Agg. Subbase	6"	x .05 =	.30
		22.5"		6.36
2.	Type A Asphaltic Concrete	4.5"	x .44 =	1.98
	Type B Asphaltic Concrete Base	10"	x .40 =	4.00
	Soil Agg. Subbase	16"	x .05 =	.30
		20.5"		6.28
3.	Type Asphaltic Concrete	3"	x .44 =	1.32
	Asphalt Treated Base Class I	12"	x .34 =	4.08
	Soil Agg. Subbase	6"	x .05 =	.30
		21"		5.70

The third combination shown is the same as the first combination, except that the top 1.5" thickness of surface asphalt is not included. This combination represents the initial section for stage construction. Checking back through the nomograph shows this section is adequate for only 600 equivalent 18-Kip axles per day, corresponding to 1,140 commercial vehicles per day. Since this is less than the initial design traffic, stage construction is not advisable.

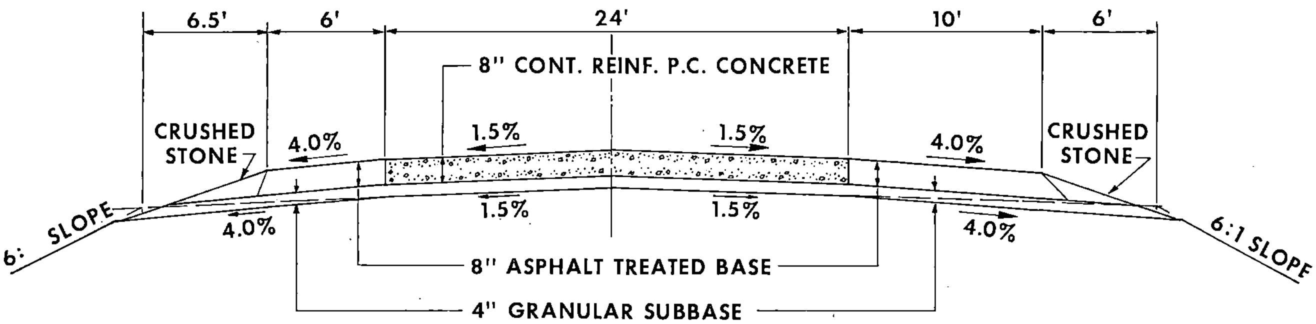
Typical sections of the alternate rigid and flexible pavement designs are shown on the following page and ARE CONSIDERED COMPARABLE FOR THE PREVAILING TRAFFIC VOLUMES AND SOIL CONDITIONS ON THIS SECTION. Estimates of cost per mile of four-lane divided roadway have been made on the basis of these sections and used in the economic analyses.

IOWA

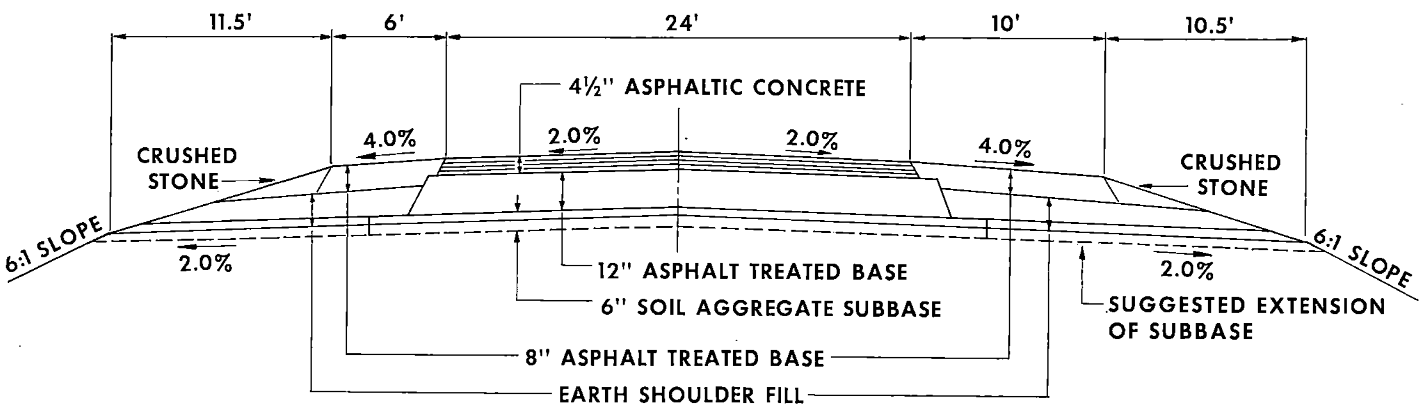
COMPARABLE TYPICAL PAVEMENT SECTIONS

U.S. 518

I-80 to U.S.-30



RIGID PAVEMENT



FLEXIBLE PAVEMENT

STATE 2 PAVEMENT DESIGN

State 2 did not make available for this study a detailed procedure for analyzing traffic. This State did furnish standards showing pavement sections for various groupings of heavy commercial average daily traffic. The average daily commercial traffic for the Iowa project for the 10th year of the 20-year design period is approximately 1900 vehicles per day.

For rigid pavement, State 2 would use either a 9-inch reinforced concrete pavement or an 8-inch continuously reinforced pavement. Both sections would have a gravel base 2.25 inches thick at centerline and 3 inches thick at pavement edges, on a 3-inch sand-gravel subbase.

The flexible pavement section is determined by State 2 from a standard section for the applicable traffic group, based on a subgrade soil in AASHO Soil Class A-6. Thickness of subbase is adjusted to other soil classes by use of a formula which relates the gravel equivalent to the soil factors designated for other soil classes. The State 2 procedure for flexible pavement design is shown in the Appendix.

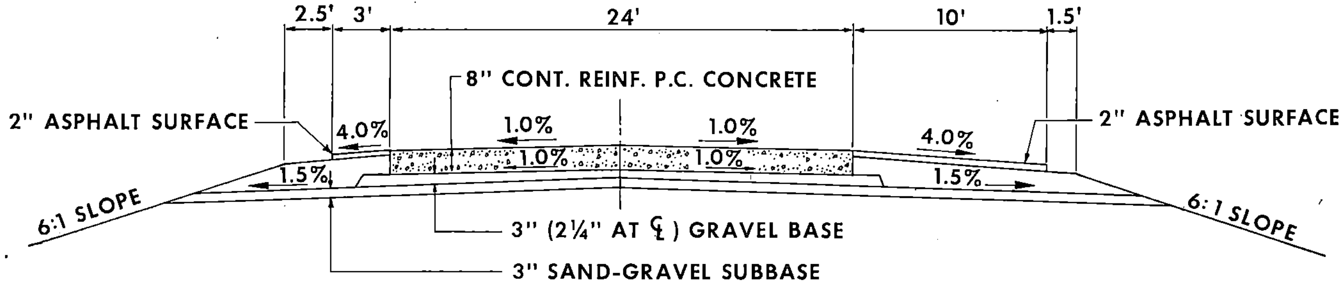
The flexible pavement section suitable to the Iowa project would consist of the following:

Asphaltic Concrete Surface		3.5 Inches
Bituminous Base		4.5 Inches
Bituminous Treated Base		4 Inches
Sand-Gravel Subbase		14 Inches
	Total	26 Inches

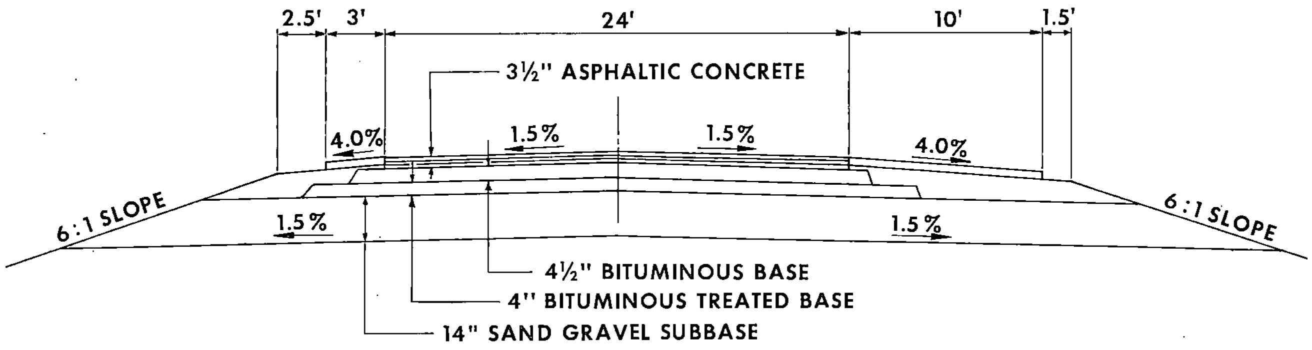
Typical sections of both rigid and flexible designs are shown on the following exhibit.

STATE 2

PAVEMENT SECTIONS



RIGID PAVEMENT



FLEXIBLE PAVEMENT

STATE 3 PAVEMENT DESIGN

State 3 bases its design analysis on estimated average daily traffic for the year representing one half of the structural design period (20 years). This State has developed formulas for converting mixed traffic axle loads into a Traffic Factor. The Traffic Factor (TF) is the total number of equivalent 18-Kip single axle load applications, expressed in millions, that a given pavement may be expected to carry throughout its entire service life. The formulas include separate coefficients for passenger cars (PC), single unit trucks (SU) and multiple unit trucks (MU), and percentages of each type of vehicle in the design lane. For a four-lane highway these percentages are Passenger Cars 32%, Single Units 45% and Multiple Units 45%, of the total 2-way traffic of each type.

The formula for Rigid Pavement is:

$$TF = \frac{20 \text{ (Years)}}{1,000,000} \left(.146 \times .32 \text{ PC} + 44.895 \times .45 \text{ SU} + 421.575 \times .45 \text{ MU} \right)$$

An application of this formula to the Iowa project traffic requires grouping of the vehicle classifications into the three types above and determining the estimated number of vehicles at the middle year of the design period. The Iowa project traffic at the 10th year would be 9,900 passenger cars, 700 single unit trucks and 1,200 multiple unit trucks. Use of these values in the formula results in a Traffic Factor of 4.86. State 3 uses California Bearing Ratio for subgrade support. The CBR value corresponding to a K-value of 100 is 3. From the State 3 nomograph the required concrete section is either a 10-inch standard reinforced or a 7-inch continuously reinforced concrete pavement. Standards of State 3 for a four-lane highway require use of the continuously reinforced concrete section and a 4-inch bituminous stabilized granular subbase.

A similar formula is used for design of flexible pavements, the difference being in the coefficients for single and multiple unit trucks:

$$TF = \frac{20\ (\text{Years})}{1{,}000{,}000}\ (.146 \times .32\ PC + 42.705 \times .45\ SU + 345.655 \times .45\ MU)$$

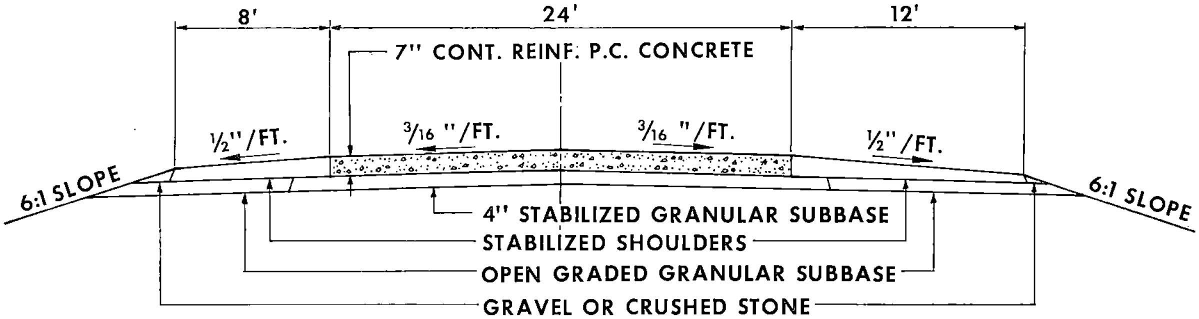
Applying this formula to the Iowa project traffic gives a traffic factor of 4.01. From the nomograph for State 3 Flexible Design, a structural number of 5.18 is found, using a CBR value of 3. A selection of surface course, base course and subbase course is made, using State 3 Standard Design requirements as a guide, which specify a minimum structural number of 5.5 for this class of highway.

The nomographs for State 3 rigid and flexible design are included in the Appendix.

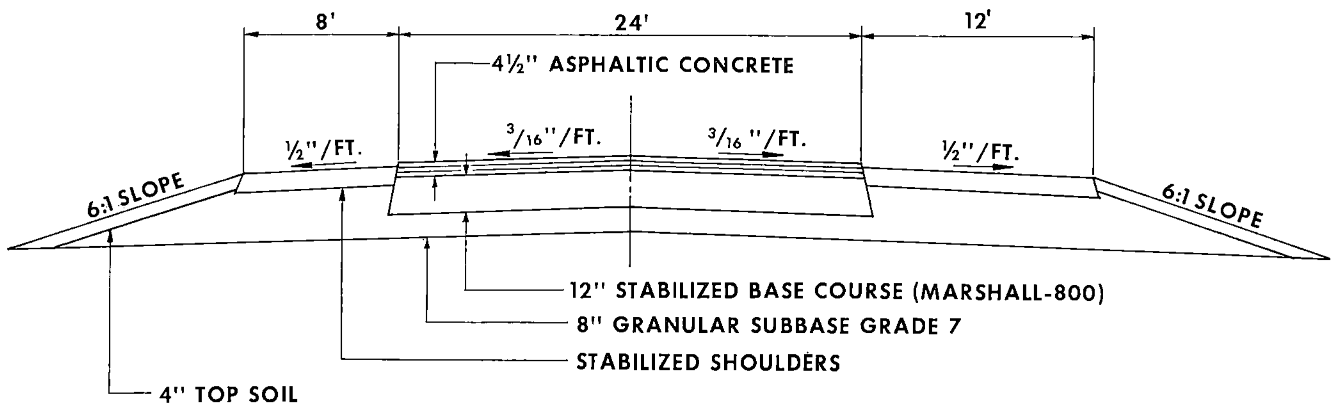
Typical sections of rigid and flexible designs determined as above described are shown in the following. These sections represent the pavement structures which would be applicable in State 3 for the estimated traffic volumes of the Iowa project.

STATE 3

PAVEMENT SECTIONS



RIGID PAVEMENT



FLEXIBLE PAVEMENT

STATE 4 PAVEMENT DESIGN

Traffic analyses for both rigid and flexible pavements are made in accordance with the "Interim Guide of the Design of (Rigid) (Flexible) Pavement Structures" recommended by the AASHO Committee on Design. Distribution of commercial axle loads and number of axle loads per commercial vehicle are determined from that State's "Truck Weight Studies," for both single axle and tandem axle groups. Design is based on one way volume of cars and trucks for the middle year of the 20 year design period. Assignment to the design lane by State 4 is 86 per cent of the commercial traffic and 62 per cent of the passenger car traffic.

Applying the Iowa project traffic to this method results in 515 equivalent 18-kip loads for rigid pavement and 354 equivalent 18-kip loads for flexible pavement.

The AASHO Design Charts 400-2 are used by State 4, and for the above loads the rigid design is 9-inch reinforced concrete. For the flexible design the chart determines a structural number of 5.25. State 4 applys a factor of 1.15 to the chart value, on the premise that AASHO road test results are not adequate for State 4 highways. The required structural number then becomes 6.03.

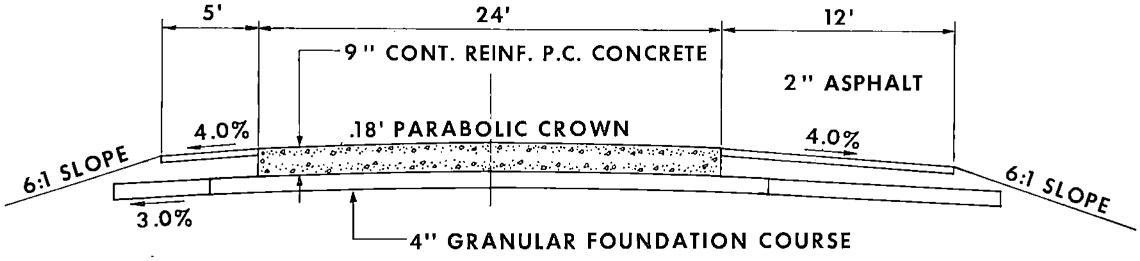
Asphaltic Concrete Type A*	12" x .44 = 5.28
Soil Aggregate Base Course (45% Rock)	6" x .14 = .84
*(45% Rock Lower 10.5")	SN = 6.12

AASHO Design Charts 400-2(Rigid) and 400-2(Flexible) are included in the Appendix.

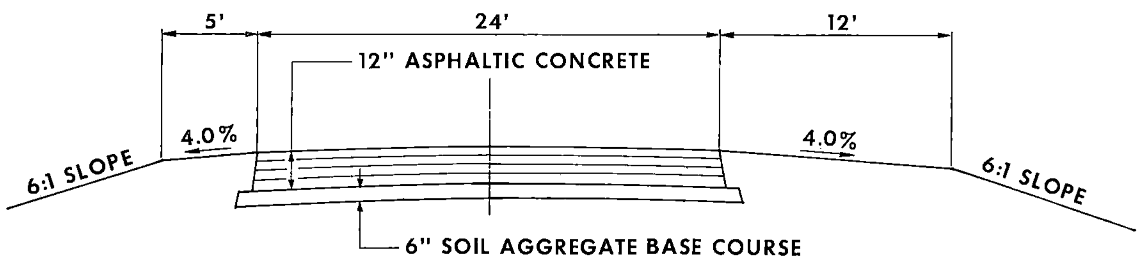
Following are typical sections of rigid and flexible designs determined by the above methods. The section shown for flexible pavement is incomplete because State 4 did not furnish shoulder standards for the flexible type.

STATE 4

PAVEMENT SECTIONS



RIGID PAVEMENT



FLEXIBLE PAVEMENT

(INCOMPLETE SECTION)

STATE 5 PAVEMENT DESIGN

Design traffic is the estimated average daily traffic for the 10th year of a 20-year design period. The method used for obtaining total repetitions of load for rigid pavement design is essentially the Portland Cement Association method, but with constants derived from the State's own study of truck traffic. Both single and tandem axle loads are considered. For flexible pavement design, the number of equivalent 5,000-pound wheel loads (EWL) are determined from constants established by truck traffic studies, and converted to a Traffic Index (TI) by use of a formula, or more conveniently, from a table. For both rigid and flexible designs the axle loads and equivalent wheel loads are values for traffic in one direction. The design lanes of a four-lane highway are assumed to carry 100 per cent of the one-direction traffic.

Application of the Iowa project traffic to the State 5 procedures requires, for rigid pavement design, computation of load repetitions for each axle weight group and these repetitions become a part of the thickness determination. The Iowa project traffic, applied to the State 5 procedures for flexible pavement design results in a Traffic Index of 11.0.

State 5 design of rigid pavement section requires a cement-treated base 0.35 foot* thick on a 6-inch subbase. Graphs are used to convert the resistance value of the soil (R) to a k-value on the soil, to convert k-value on the soil to k-value on the subbase, and then to convert k-value on the subbase to k-value on the cement-treated base. For a soil resistance value of 10, these conversions result in a k-value of 195 for thickness design of the concrete slab. A thickness is assumed and stresses are obtained from the Portland Cement Association chart for all axle load increments. Stress ratios, allowable repetitions and per cent of fatigue resistance used are computed, and the results indicate that a 0.70 foot thick slab uses 95 per cent of the fatigue resistance. An 8.4" concrete pavement is required, based on a soil R-value of 10. A check analysis for a soil R-value of 20 permits reduction to an 8-inch thickness.

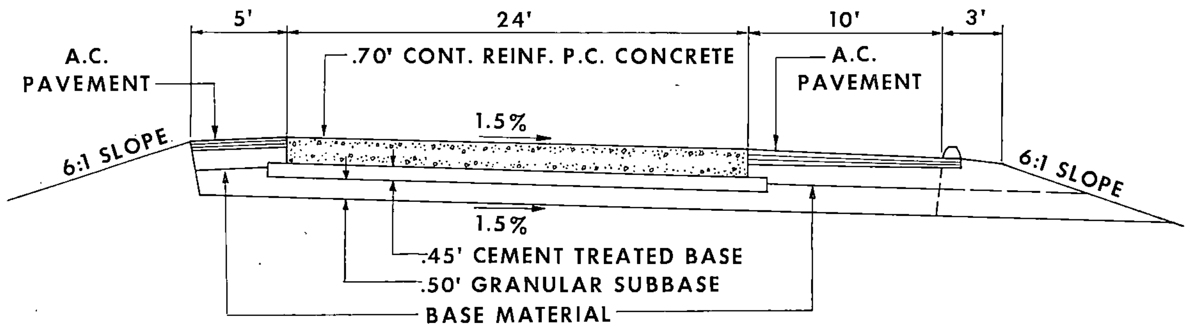
*Design thickness, constructed 0.45 foot thick.

Flexible pavement section is determined in the term of total gravel equivalent required (GE) by the formula GE = 0.0032 (TI) (100-R). For a traffic index of 11.0 and R-value of 10, the total gravel equivalent is 3.17 feet. For an R-value of 20, the total gravel equivalent is 2.82 feet. Assumption of type of base R-value in the formula determines thickness of asphaltic concrete, and assumption of type of subbase R-value determines the thickness of base. Several alternate flexible pavement selections are possible, but controlled by established State standards.

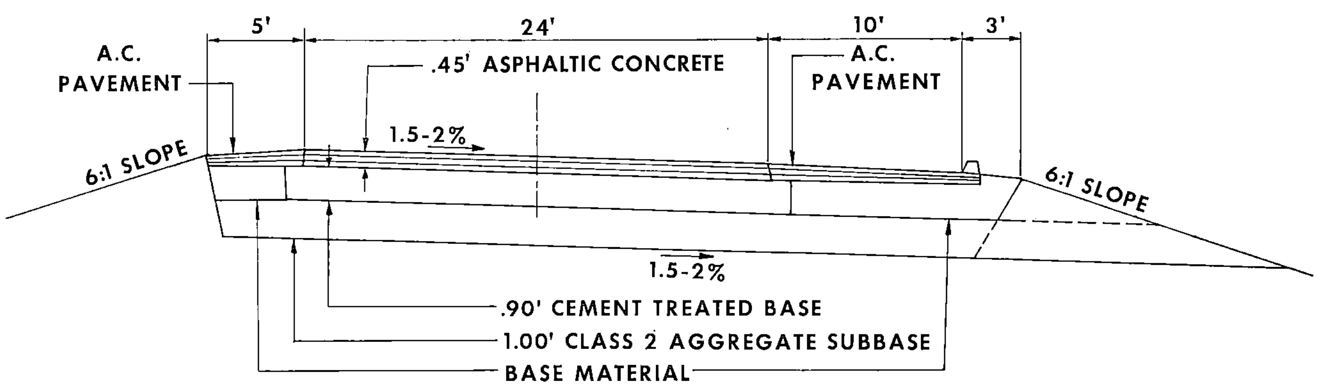
The following typical rigid and flexible designs, based on a R-value of 10, show the sections suitable to State 5 for the Iowa project traffic.

STATE 5

PAVEMENT SECTIONS



RIGID PAVEMENT



FLEXIBLE PAVEMENT

PAVEMENT DESIGN - OTHER AGENCIES

Pavement design procedures by agencies other than State Highway Departments include the Guides recommended by the American Association of State Highway Officials and Thickness Design Manuals of the Portland Cement Association and the Asphalt Institute. The method of the AASHO Guide for rigid pavement has been demonstrated in the design of rigid pavement for State 4. The AASHO Guide Method for flexible pavement is employed by Iowa and State 4. The Portland Cement Association method for rigid pavement is used by Iowa in modified form and by State 5 in its entirety.

The method recommended by the Asphalt Institute for design of flexible pavement consists of determination of a Design Traffic Number from a chart or from computation of Load Equivalency Factor and then by use of a chart for CBR or R-value, finding the total asphaltic concrete thickness required. Various combinations of asphalt concrete, base thickness and subbase thickness are found by use of the same charts and substitution ratios. The ratios recommended by the Institute are: 2 inches of granular base having CBR 100 for 1 inch of asphaltic concrete and 2.7 inches of subbase having CBR 20 for 1 inch of asphaltic concrete.

Following are typical Institute Sections suitable to the Iowa Design Traffic:

	All Asphalt	Asphalt & Base	Asphalt & Subbase	Asphalt, Base and Subbase
Asphaltic Concrete	13.5"	6"	9.5"	6"
Base CBR 100	----	15"	---	7"
Subbase CBR 20	----	---	11"	11"
Total Thickness	13.5"	21"	20.5"	24"

These sections are based on Initial Traffic of 8500 v.p.d., Design Traffic Number of 900 and CBR of 3.

The sections assume compaction of the upper 18 to 24 inches of the subgrade to 95 per cent (Cohesive Soils) or 100 per cent (Cohesionless Soils) of AASHO T 180, Method D, density.

SUMMARY

The previously described studies of Traffic and Pavement Sections are summarized in Chapter I.

CHAPTER III

ECONOMIC EVALUATION

Evaluation of costs of alternate pavement types requires consideration of the initial construction cost, annual maintenance cost, resurfacing cost, resurfacing frequency, economic life and assumption of an interest rate to determine the present worth, ultimate cost or equivalent uniform annual cost. In some instances where available data is not considered applicable, maintenance costs are not considered. Also, some analyses do not make application of an interest rate.

Initial costs are determined from estimates of quantities included in the pavement section applied to appropriate unit prices. In general the unit prices are obtained from a compilation of previous contract prices. For those quantities which contain mineral aggregates, inquiries are made of the producers to determine availability and probable material cost.

Maintenance costs are determined from records and may or may not include maintenance of shoulder surfacing. Effort is made to exclude from the economic analysis such items as snow removal, ice control, repair of accident damage or shoulder washouts; these are maintenance items common to both types of pavement.

Resurfacing costs usually include the cost of additional shoulder construction to meet the new pavement edge, and prices include probable upward price trend to the year the resurfacing is programmed. Cost of resurfacing is of course, dependent upon thickness used.

Resurfacing frequency varies considerably among the States studied and has an appreciable effect on the cost comparisons of the two types of pavement. There is also considerable variation in number of years of economic life and rate of interest.

IOWA COST ANALYSIS

In Iowa, development of the cost estimate and determination of pavement type is done by the Contracts Department, after the required pavement sections have been designed by the Design Department. A list of probable materials sources is obtained for the Materials Department Geology Section. Inquiries are sent to producers in the area of the project for quotations and hauling costs. Replies from the producers are examined for acceptability of the sources, hauling distances and quantity available.

The procedure used for preparing the cost estimate is as follows:

(A) Review bids received on similar work in the same general area.

(B) Compare conditions on subject project with other projects. This includes size of project, continuity, haul roads, probable plant sites and other pertinent factors.

(C) Portland cement pavement cost estimate is based on:

1. Cost of the concrete per sq. yd. from Plant.
2. Base price includes equipment, overhead, labor costs, etc.
3. Steel reinforcing, bar chairs, doweled joints, curing, etc.
4. Haul (batch trucks, etc.).
5. Profit.
6. Deductions for slip form use if applicable.

(D) The cost estimate for flexible pavement is based on:

1. Cost of asphalt treated base and Type "A" Asphaltic Conc. Base and Surface Course mix.
2. Move in cost.
3. Lay cost.
4. Plant cost (cost of mixing material at Plant)
5. Haul cost of mixed material
6. Profit.

(E) Quantities per typical mile for each type of pavement are obtained from the Design Department Road Design Manual.

(F) Estimated unit prices are applied to quantities per mile.

(G) Calculate present worth of Maintenance and Resurfacing costs.

Cost of resurfacing the flexible pavement is estimated as follows, for a 3-inch thickness.

Cleaning and Preparation of Old Base	2 miles	@	$400.00 =	$ 800
Sand Cover	83 tons	@	4.00 =	332
Prime and Tack	1,660 gals	@	.20 =	332
A C Surface	5,100 tons	@	10.00 =	51,000
Granular Surfacing	600 tons	@	3.00 =	1,800
	Total			$54,264

Unit prices used in this estimate reflect upward price trend.

Average annual maintenance costs for the preceding five years have been furnished as follows:

Rigid Pavement	$273 per 2-lane mile
Flexible Pavement	$671 per 2-lane mile

Following is an estimate of cost of both rigid and flexible types corresponding to the pavement sections previously determined for the Iowa design described in this report.

Engineer's Preliminary Estimate of Cost
of
Interstate Pavement Per Mile

County Johnson - Linn   Road No. 518   Date March 1, 1968

Location:

PORTLAND CEMENT PAVEMENT			Typical Section		4" Gran. Subbase 8" Cont. PCC Pavt.
Granular Subbase	: 14,250 tons	@ $	3.00 :	$ 42,750	
PCC Pavement, 8"	: 28,160 sq. yds.	@ $	6.30 :	177,408	
Asphalt Treated Base	: 8,525 tons	@ $	6.00 :	51,150	
Prime & Tack & Fog Coat	: 10,000 gals.	@ $	.17 :	1,700	
Binder Bitumen	: 3,760 gals.	@ $	.18 :	677	
Cover Aggregate	: 93 tons	@ $	5.00 :	465	
Gran. Surf. of Shldr.	: 3,010 tons	@ $	3.00 :	9,030	
		TOTAL		$283,180	

ASPHALTIC CONCRETE PAVEMENT			Typical Section	6" Soil Aggregate 12" Asph. Tr. 4.5" A.C.	
Const. Soil Agg. Subbase	: 2 miles	@ $	2,000.00 :	$ 4,000	
Sealer Bitumen	: 6,750 gals.	@ $	0.20 :	1,350	
Asph. Treated Base	: 29,400 tons	@ $	6.00 :	176,400	
A.C. Binder	: 2,358 tons	@ $	7.80 :	18,392	
A.C. Surface	: 2,334 tons	@ $	7.80 :	18,205	
Prime and Tack	: 18,400 gals.	@ $	.17 :	3,128	
Gran. Surf. of Shldr.	: 3,010 tons	@ $	3.00 :	9,030	
Shoulder Excav.	: 9,504 cu. yds.	@ $	1.00 :	9,504	$240,009
Clean & Prep. Old Base	: 2 miles	@ $	300.00 :	600	
Sand Cover	: 83 tons	@ $	4.00 :	332	
Binder Bitumen	: 5,515 gals.	@ $	.18 :	993	
Cover Aggregate	: 93 tons	@ $	5.00 :	465	
A.C. Surface	: 2,542 tons	@ $	8.00 :	20,336	
Prime and Tack	: 1,657 gals.	@ $	.20 :	331	$ 23,057
		TOTAL		$263,066	

IOWA COST ANALYSIS - Cont'd.

Iowa uses a present worth method for its economic evaluation of alternate pavement types. The formula is suggested by Mr. Emery L. Shaw. Generally stated the present worth of a pavement is the sum of the following:

Present value of the initial construction cost.

Present value of the resurfacing cost.

Present value of annual maintenance cost.

The present value of the initial construction cost is of course the estimated construction cost previously determined. The present value of the resurfacing cost is the product of the estimated resurfacing cost and a "single payment present worth factor." This product is an amount which, if invested at the given interest rate at the time the pavement is constructed, would accrue the funds required to resurface the pavement. The equation is:

$$\text{Present worth of resurfacing} = \frac{R}{(1+i)^n}$$

R = the cost of resurfacing.
i = the annual interest rate. (Iowa uses 5%)
n = the resurfacing interval (years).

Assuming that the annual maintenance cost will be constant for the life of the pavement, the present value of annual maintenance cost is the product of the annual cost and an "equal payment present worth factor." This product is an amount which, if invested at the given interest rate, will provide funds for annual maintenance in equal annual payments for the economic life of the pavement. The equation is:

$$\text{Present value of annual maintenance costs} = M\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

M = the annual maintenance cost.
n = the number of years in the analysis period.

Where a rigid pavement is resurfaced at the middle year of the analyses period the present value of annual maintenance is

$$M_1 \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] + M_2 \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \left[\frac{1}{(1+i)^n}\right]$$

M_1 = the annual maintenance cost of rigid pavement.
M_2 = the annual maintenance cost of flexible pavement.
n = the number of years to resurfacing date.

Iowa uses an economic analysis period of 30 years, approximately the historical life of its better quality concrete pavements, and assumes no resurfacing of rigid pavements in the 30-year period. The State assumes one resurfacing of flexible pavement at 15 years after initial construction.

The economic analysis is summarized as follows:

	Rigid Pavement	Flexible Pavement
Initial Construction Cost	\$283,180	\$263,066
Present Worth of Resurfacing (Rigid)	0	
Present Worth Maintenance (Rigid) $\$546 \times \frac{(1.05)^{30} - 1}{.05(1.05)^{30}} = 546 \times 15.37245 =$	8,393	
Present Worth of Resurfacing (Flexible) $\$54,264 \times \frac{1}{(1.05)^{15}} = 54,264 \times .48102 =$		26,102
Present Worth of Maintenance (Flexible) $\$1,342 \times \frac{(1.05)^{30} - 1}{.05(1.05)^{30}} = 1,342 \times 15.37245 =$		20,629
Total Present Worth of Paving	\$291,573	\$309,797

STATE 2 COST ANALYSIS

State 2 uses a modification of a method developed by the Committee on Highway Transportation of the Highway Research Board. The modification was suggested by Professor C. B. Breed of the Massachusetts Institute of Technology. The formula is as follows:

$$C = \frac{A-S}{n} + \frac{(A+S)r}{2} + B + \frac{E}{n}$$

C = Annual Road Cost. A = Original Cost. n = Life expectancy in years.
r = rate of interest. S = Salvage value of highway at the end of n years.
B = Annual routine maintenance costs. E = Cost of special maintenance.

State 2 uses a life expectancy of 35 years, a salvage value of 40 per cent and a 2.5 per cent interest rate. Resurfacing of traffic lanes and shoulders of flexible pavement is done at 17.5 years. No resurfacing of rigid pavement is considered in the 35-year period.

The annual road costs, determined from the above formula, are as follows:

			Rigid Pavement	Flexible Pavement
1.	First Cost (A)		$283,180	$263,066
2.	Salvage (40%) (S)		113,272	105,226
3.	Depreciation (A-S)		$169,908	$157,840
4.	Annual Depreciation (A-S)/35		$ 4,854	$ 4,510
5.	Annual Interest (A+S) x 2.5%/2		4,956	4,604
6.	Routine Surface Maintenance		546	1,342
7.	Special Surface Maintenance 54,264/35			1,550
	Total Annual Road Costs, per mile		$ 10,356	$ 12,006
	For interest rate of 5%, add		4,956	4,604
		Annual Cost	$ 15,312	$ 16,610
	For interest rate of 6%, add		1,982	1,841
		Annual Cost	$ 17,294	$ 18,451

STATE 3 COST ANALYSIS

The method used by State 3 in determining the annual road cost is the procedure suggested by R. H. Baldock. ("Determination of the Annual Cost of Highways," Highway Research Board Record 12, 1963). The formula and definitions of its terms are as follows:

ANNUAL COST FORMULA

$$C = CRF_n \left[A + E_1 (PWF_{n1}) + E_2 (PWF_{n2}) - (1 - \frac{Y}{x}) (E_1 \text{ or } E_2) PWF_n \right] + M$$

where:

C	=	total annual cost, per mile
CRF_n	=	$\frac{r(1+r)^n}{(1+r)^n - 1}$
PWF_n	=	present worth factor, for a single payment, defined as $\frac{1}{(1+r)^n}$ which includes all cost of building, maintaining, operating, and administering the highway.
r	=	interest rate.
n	=	analysis period.
A	=	total construction cost, per mile.
E_1	=	first resurfacing cost, per mile.
E_2	=	second resurfacing cost, per mile
n_1	=	number of years after construction that future work is performed.
n_2	=	the number of years after construction that future work is performed.
Y	=	number of years between time of last resurfacing and the end of the analysis period.
x	=	estimated life of last resurfacing, in years.
M	=	total annual maintenance cost, per mile.

State 3 uses an analysis period of 40 years and an interest rate of 6 per cent. Preliminary to the use of this formula the effect of the difference between "nomograph thickness" and "construction thickness" on the service life of a rigid pavement must be considered. For example, when a thickness of 7.7 inches is indicated on the design nomograph an 8 inch thick pavement will be constructed and hence the service life will be greater than 20 years; conversely, when a thickness of 7.3 inches is indicated on the design nomograph a 7-inch thick pavement will be constructed and the service life will be less than 20 years.

For the pavement design by State 3 methods previously determined in this report, a 7-inch thick slab is slightly in excess of the thickness required and the service life is slightly in excess of 20 years:

$$\text{Traffic Factor } (TF_{R1}) = \frac{\text{Design Period} \times \text{Traffic Volume}}{1{,}000{,}000} = 4.86$$

Required Thickness (nomograph) = 6.98"

Traffic Factor for 7-inch thickness (nomograph) $TF_{R2} = 4.95$

$$\text{Design Period to first resurfacing} = \frac{4.95 \times 1{,}000{,}000}{\text{Traffic Volume}} = 20.4 \text{ years}$$

From this calculation, only one resurfacing is required in the 40-year analysis period, at 20 years, and therefore the terms of the formula pertaining to second resurfacing are excluded.

Original surfacing and resurfacing of flexible pavement are considered to have a life of 20 years. State 3 has developed a table of structural coefficients of materials for original construction and for subsequent resurfacings. Pertinent values from this table are shown on the following page.

	New Pavement	First Resurfacing
Standard Reinforced PCC 2500 (7 days)	0.50	0.40
Continuously Reinforced PCC 2500 (7 days)	0.71	0.57
Bituminous Surface Course - Marshall 1700	0.40	0.30
Stabilized Granular Base - Marshall 1500	0.30	0.23
Stabilized Granular Base - Marshall 800	0.23	0.17
Gravel Subbase - CBR 50	0.12	0.10

From these values the thickness of resurfacing is determined as follows:

Resurfacing over rigid pavement:

Required Structural Value	6.98" x .71	= 4.96
Existing Pavement Structural Value	7" x .57	= 3.99
Required Structural Value of Resurfacing		0.97

Required Thickness = 0.97/0.40 = 2.43 Use 2.5 inches.

Resurfacing over flexible pavement:

Required Structural Value		= 5.50
Existing Pavement Structural Value	4.5x.30+12x.17+8x.10	= 4.19
Required Structural Value of Resurfacing		1.31

Required Thickness = 1.31/0.40 = 3.28 Use 3.5 inches.

Estimates of resurfacing costs are based on the thicknesses determined in the above manner.

2.5" Resurfacing over rigid pavement	$45,120
3.5" Resurfacing over flexible pavement	$63,308

Application of the Iowa project costs to the State 3 procedure using the Baldock formula produces the following comparison:

STATE 3

RIGID PAVEMENT

A = \$283,180	CRF_n = .0665	Y = 20 Yrs.	n = 40 Yrs.
E_1 = \$ 45,120	PWF_n = .0972	x = 20 Yrs.	n_1 = 20 Yrs.
E_2 = --	PWF_{n1} = .3118	r = 6%	n_2 = --

	$n_1 = 20$		$n_1 = 28$	Y = 12
A	\$283,180		\$283,180	
$E_1 PWF_{n1}$ = \$45,120 x .3118	14,068	.1956	8,825	
$E_2 PWF_{n2}$ =	0		\$292,005	
$(1-Y/x)E_1$ or E_2) PWF_n	0	.0972	- 1,854	
Total	\$297,248		\$290,151	
CRF_n x Total = .0665 x 297,248	19,670		19,295	
$M = \frac{546 + 1342}{2}$	944		785	
Annual Cost, Rigid	\$ 20,614		\$ 20,080	

FLEXIBLE PAVEMENT

A = \$262,066	CRF_n = .0665	Y = 20 Yrs.	n = 40 Yrs.
E_1 = \$ 63,308	PWF_{n1} = .3118	x = 20 Yrs.	n_1 = 20 Yrs.

A	\$263,066
$E_1 PWF_{n1}$ = \$63,308 x .3118	19,739
Total	\$282,805
CRF_n x Total = .0665 x 282,805	18,806
M	1,342
Annual Cost, Flexible	\$ 20,148

STATE 4 COST ANALYSIS

State 4 uses an analysis period of 40 years in its cost comparison and does not consider interest or maintenance. Prior to 1965 this State assumed resurfacing the rigid pavement at 24 and 32 years, and the flexible pavement at 8, 16, 24 and 32 years. Maintenance was also included in the cost comparison.

Since 1965 this State assumes resurfacing rigid pavement at 24 and 36 years, and flexible pavement at 16 and 28 years and considers the salvage of the 36 year resurfacing of rigid pavement at two-thirds of the resurfacing cost. No salvage value is assigned to the flexible pavement. Interest is not considered on the premise that since the State operates on a cash basis, interest is not applicable. Maintenance is excluded because the State considers its maintenance records not appropriate for the newer Interstate and other high traffic volume roads.

Summary of the State 4 Cost Analysis is as follows:

	Rigid Pavement	Flexible Pavement
Initial Cost	$283,160	$263,066
Resurfacing Rigid: 1.5" at 24 years	27,132	
1.5" at 36 years	27,132	
Resurfacing Flexible: 1.5" at 16 years		27,132
1.5" at 28 years		27,132
	$337,424	$317,330
Salvage Value of 36-year Resurfacing (2/3)	- 18,088	0
Ultimate Cost Per Mile	$319,336	$317,330
Annual Cost over 40 years	$ 7,984	$ 7,933
If maintenance is included	546	1,342
	$ 8,530	$ 9,275

STATE 5 COST ANALYSIS

Economic comparison of rigid and flexible pavement types is made by State 5 on a present worth cost basis. The approach is similar to the method used by Iowa, but several additional factors are considered, such as engineering and supplemental work incidental to resurfacing and salvage value of the resurfacing.

The economic analysis period is chosen for each project based on the average life to first resurfacing of rigid pavements in the area of studied project that served under comparable conditions, usually 25 years. Flexible pavement is assumed to require resurfacing at 14 years. No resurfacing of rigid pavement is contemplated within the analysis period. Estimated costs of resurfacing include a price trend factor of 2 per cent compound interest. For both analysis periods a 5 per cent interest rate is used.

The equation used by State 5 is:

$$PWC = IC + (RC \times PTF + EC + SC + DC)\ PWF_1 + MC \times PWF_2 - SV \times PWF_3$$

IC	=	Initial Cost
RC	=	Resurfacing Cost (at present)
PTF	=	Price Trend Factor (2% Compound Interest)
EC	=	Engineering Cost (in connection with resurfacing)
SC	=	Supplemental Work (in connection with resurfacing - traffic handling, striping, guardrail protection, drainage adjustments, etc.)
DC	=	Delay Cost (Presumably theoretical public inconvenience)
PWF_1	=	Present Worth Factor (of resurfacing 14 years after construction)
MC	=	Maintenance Cost (annual)
PWF_2	=	Present Worth Factor (for 20 or 25 years of annual maintenance)
SV	=	Salvage Value (of resurfacing)
PWF_3	=	Present Worth Factor (of salvage for 20 or 25 years)

The economic comparison by the State 5 method is shown on the following page.

STATE 5

25 Year Comparison Period		5% Compound Interest
Rigid:		
Initial Cost		$283,180
Maintenance for 25 Years 546(14.094)		7,695
Present Worth Cost		$290,875
Flexible:		
Initial Cost		$263,066
Resurfacing at 14 Years	$54,264	
Engineering 54,264 x 11.33%	6,148	
Supplemental Work 54,264 x 8.71%	4,726	
Traffic Delay	300	
	$65,438	
Present Worth of Resurfacing 65,438(.5051)		33,053
Maintenance for 25 Years 1,342(14.094)		18,914
		$315,033
*Less Salvage (3/14) 65,438 (.2953)		- 4,141
Present Worth Cost		$310,892

*Remaining Life of Resurfacing at the end of the 25-year period is 3 years.

ESTIMATES OF COST

Iowa and State 2 employ procedures designed to arrive at unit prices for estimating purposes whereby inquiry is made as to the cost of aggregate materials to be incorporated in the construction. The aggregate materials comprise about 15 per cent of the unit price for concrete pavement, and from 30 to 40 per cent of the unit prices for asphaltic pavement and base courses.

State 4 bases its cost estimates on average unit prices with consideration as to whether the project is urban or rural work. States 3 and 5 do not indicate the source of prices used and in the absence of any treatise on the subject of breakdown costs of each item, it is assumed that these States are also using average unit prices.

The estimate of cost of the Iowa Design is shown on page 32.

SUMMARY OF COST COMPARISONS

The cost comparisons of the five methods studied are summarized in Chapter I.

STAGE CONSTRUCTION OF FLEXIBLE PAVEMENTS

Stage construction of flexible pavement means original construction with base and subbase courses as required by design traffic, and sufficient thickness of the surface course to meet traffic loads anticipated at the beginning of highway use. The remainder of the surface course is constructed at a later date.

The Iowa cost analysis procedure includes consideration of stage construction by use of higher unit prices for the items covering the final course of the asphalt surfacing. Information made available by State 2 did indicate use of stage construction.

State 3 defines Planned State Construction as a procedure whereby the highway is initially constructed with the design required thicknesses of subbase and base courses and a temporary bituminous surface course. Subsequently, the design required thickness of bituminous mat is constructed, within a period not to exceed 3 years after original construction. State 3 permits use of stage construction where the required structural number is less than 2.5. Since the minimum structural number for the type of highway considered in the study is 5.5, State 3 would not use stage construction.

States 4 and 5 do not consider stage construction in their procedures.

The Asphalt Institute considers planned stage construction advantageous in improved pavement performance, more accurate analysis of traffic and possibly more effective use of funds. Two methods are suggested:

(1) Reduce the required thickness of asphaltic concrete an arbitrary amount (such as the thickness of the final life of surfacing) and compute the design period from ratio of traffic numbers; and (2) select an arbitrary design period for the initial stage (such as 3 to 5 years) and compute the required Traffic Number from the ratio of the first stage period to the 20 year period.

The practice of stage construction does not appear to be in use by the States studied, for high traffic volume roads. Any consideration of stage construction should include the cost of re-administration, advertising and awarding a new contract, re-staffing the State's inspection and supervisory personnel and re-assignment of laboratory time, personnel and equipment.

RESURFACING

Resurfacing practices among the States studied show considerable variation, as shown in the following table. Resurfacing time for original rigid pavement varies from 20 to 35 years. For flexible pavement time of first resurfacing varies from 14 to 20 years. Except for State 4, thicknesses of resurfacing are fairly consistent, usually about 3 inches.

Resurfacing:	Iowa	State 2	State 3	State 4	State 5
Rigid Pavement					
Time - Years	30	35	20	24 & 36	25
Thickness	0	0	2.5"	1.5" Ea.	0
Flexible Pavement					
Time - Years	15	17.5	20	16 & 28	14
Thickness	3"	3"	3.5"	1.5" Ea.	3"

In most instances the thickness and resurfacing interval is based on past experience. State 3 employs a method based on re-evaluation, or rating of the original rigid pavement at the time of resurfacing. The reason that the resurfacing time for State 3 is so early is that the actual thickness selected is practically the same as the thickness required by Traffic Factor calculations. State 3 assumes a 7" continuously reinforced slab adequate for any required thickness between 6.4 inches and 7.3 inches. If the traffic factor for resurfacing was determined for 7.3 inches instead of 7 inches, the calculated resurfacing time would be 28 years. State 3 has no comparable method of calculating the resurfacing time for flexible pavement, but assumes a life of 20 years for both original asphalt surface and asphalt resurfacing.

APPENDIX

IOWA

CALCULATION OF CONCRETE PAVEMENT THICKNESS

Project: Proposed US 518 From I-80 to US 30

Type: Class I No. of Lanes: 4

Subgrade k: See pci., Subbase: 4" Granular Except Trials 1 and 3

Combined k: Below pci., Load Safety Factor: 1.2 (L.S.F.)

PROCEDURE

1	2	3	4	5	6	7
Axle Loads kips	Axle Loads X L.S.F. kips	Stress psi	Stress Ratios M.R. 500	Allowable Repetition No.	Expected Repetitions No.	Fatigue Resistance Used percent
Trial Depths			SINGLE AXLES			
1. 8" Mesh Reinforced	No Subbase K = 150		PCA Chart			
28	33.6	375	.75	490	1,606	328 N.G.
2. 8" Mesh Reinforced	4" Subbase K = 180		PCA Chart			
28	33.6	355	.71	1,500	1,606	107
26	31.2	335	.67	4,500	9,928	220 N.G.
3. 9" Mesh Reinforced	No Subbase K = 150		PCA Chart			
28	33.6	315	.63	14,000	1,606	11
26	31.2	295	.59	42,000	9,928	24
24	28.8	275	.55	130,000	34,018	26
22	26.4	260	.52	300,000	49,348	17 /78
4. 7" Cont. Reinforced	4" Subbase	K = 180	Interior Formula	Ci = .91		
28	33.6	312	.62	18,000	1,606	9
26	31.2	290	.58	57,000	9,928	17
24	28.8	268	.53	240,000	34,018	14
22	26.4	245	.49	Unlimited	49,348	0 /40
5. 8" Cont. Reinforced	4" Subbase	K = 180	Edge Formula	5% Rep.	Ce = 1.38	
28	33.6	363	.73	850	80	9.4
26	31.2	337	.67	4,500	496	11.0
24	28.8	311	.62	18,000	1,701	9.5
22	26.4	285	.57	75,000	2,467	3.3/33.2

IOWA

CALCULATION OF CONCRETE PAVEMENT THICKNESS

Project: Proposed US 518 From I-80 to US 30

Type: Class I No. of Lanes: 4

Subgrade k: See pci., Subbase: 4" Granular

Combined k: Below pci., Load Safety Factor: 1.2 (L.S.F.)

PROCEDURE

1 Axle Loads kips	2 Axle Loads X L.S.F. kips	3 Stress psi	4 Stress Ratios M.R. 500	5 Allowable Repetition No.	6 Expected Repetitions No.	7 Fatigue Resistance Used percent
Trial Depths		SINGLE AXLES				
6. 9" Mesh Reinforced 4" Subbase K = 180 PCA Chart						
28	33.6	300	.60	32,000	1,606	5
26	31.2	285	.57	75,000	9,928	13
24	28.8	265	.53	240,000	34,018	14
22	26.4	250	.50	Unlimited	49,348	0 / 32
7. 7" Cont. Reinforced 4" Subbase K = 180 Edge Formula 5% Rep. Ce = 1.27						
28	33.6	439	.88	0	80	∞ N.G.
8. 9" Mesh Reinforced 4" Subbase K = 130 PCA Chart						
28	33.6	325	.65	8,000	1,606	20
26	31.2	310	.62	18,000	9,928	55
24	28.8	285	.57	75,000	34,018	45
22	26.4	265	.53	240,000	49,348	21 /141
9. 9-1/4" Mesh Reinforced 4" Subbase K = 130 PCA Chart						
28	33.6	310	.62	18,000	1,606	9
26	31.2	295	.59	42,000	9,928	24
24	28.8	275	.55	130,000	34,018	26
22	26.4	260	.52	300,000	49,348	16 / 75
10. 9-1/2" Mesh Reinforced 4" Subbase K = 130 PCA Chart						
28	33.6	305	.61	24,000	1,606	7
26	31.2	285	.57	75,000	9,928	13
24	28.8	265	.53	240,000	34,018	14
22	26.4	250	.50	Unlimited	49,348	0 / 34

IOWA

CALCULATION OF CONCRETE PAVEMENT THICKNESS

Project: Proposed US 518 From I-80 to US 30

Type: Class I — No. of Lanes: 4

Subgrade k: 100 pci., Subbase: 4" Granular

Combined k: 130 pci., Load Safety Factor: 1.2 (L.S.F.)

PROCEDURE

1 Axle Loads kips	2 Axle Loads X L.S.F. kips	3 Stress psi	4 Stress Ratios M.R. 500	5 Allowable Repetition No.	6 Expected Repetitions No.	7 Fatigue Resistance Used percent
Trial Depths			SINGLE AXLES			
11. 7" Cont. Reinforced 4" Subbase K = 130 Edge Formula 5% Rep. Ce = 1.32						
28	33.6	453	.90	0	80	∞ N.G.
12. 7" Cont. Reinforced 4" Subbase K = 130 Interior Formula Ci = .95						
28	33.6	328	.66	6,000	1,606	27
26	31.2	302	.60	32,000	9,928	31
24	28.8	279	.56	100,000	34,018	34
22	26.4	256	.51	400,000	49,348	12 /104
13. 8" Cont. Reinforced 4" Subbase K = 130 Edge Formula 5% Rep. Ce = 1.46						
28	33.6	384	.77	270	80	29
26	31.2	357	.71	1,500	496	33
24	28.8	329	.66	6,000	1,701	28
22	26.4	301	.60	32,000	2,467	8 / 98
14. 8" Cont. Reinforced 4" Subbase K = 130 Interior Formula Ci = 1.01						
28	33.6	265	.53	240,000	1,606	.007
26	31.2	246	.49	Unlimited		
24	28.8	227	.45			
22	26.4	208	.41			

IOWA

DESIGN CHART

RIGID PAVEMENT

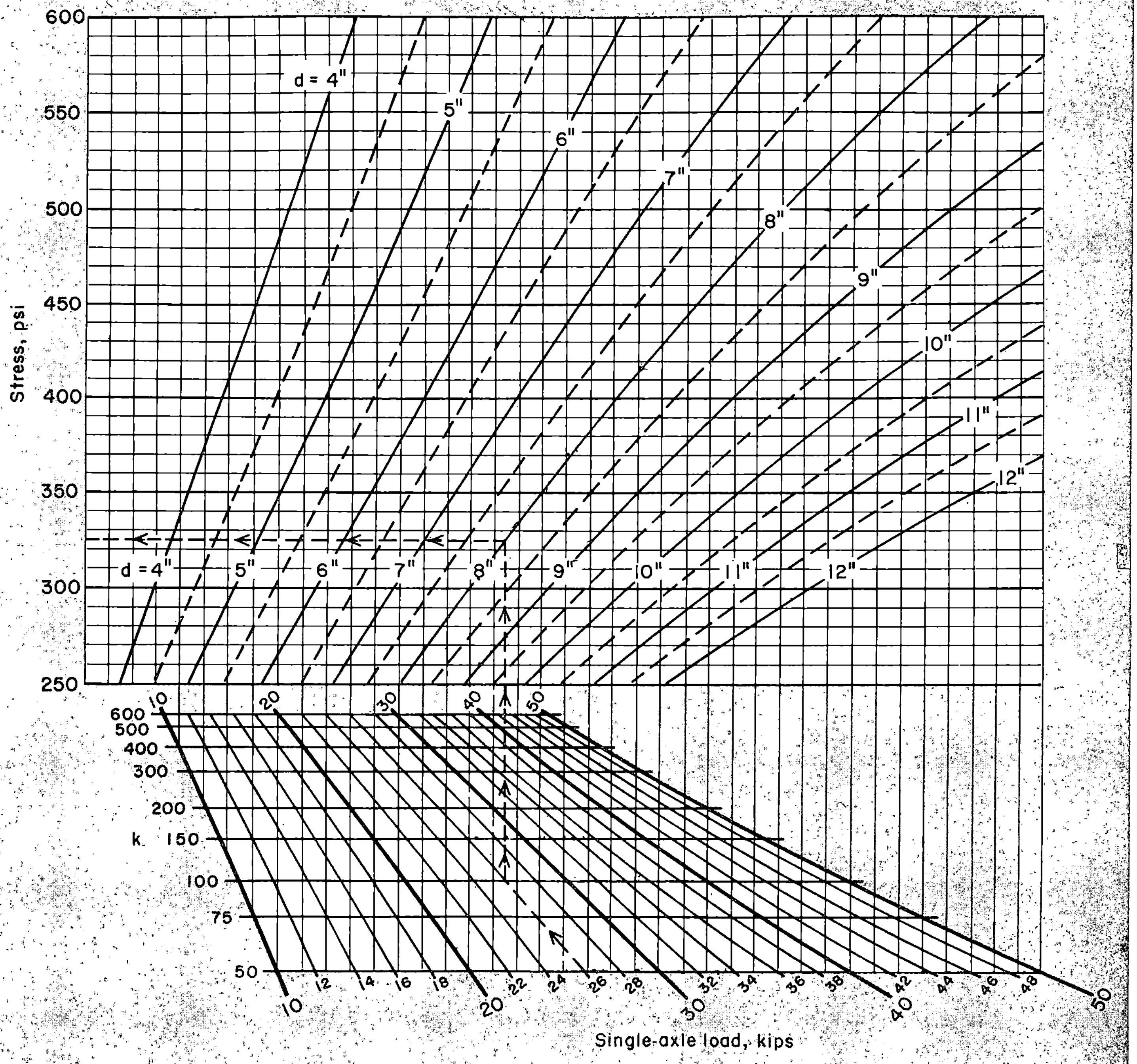
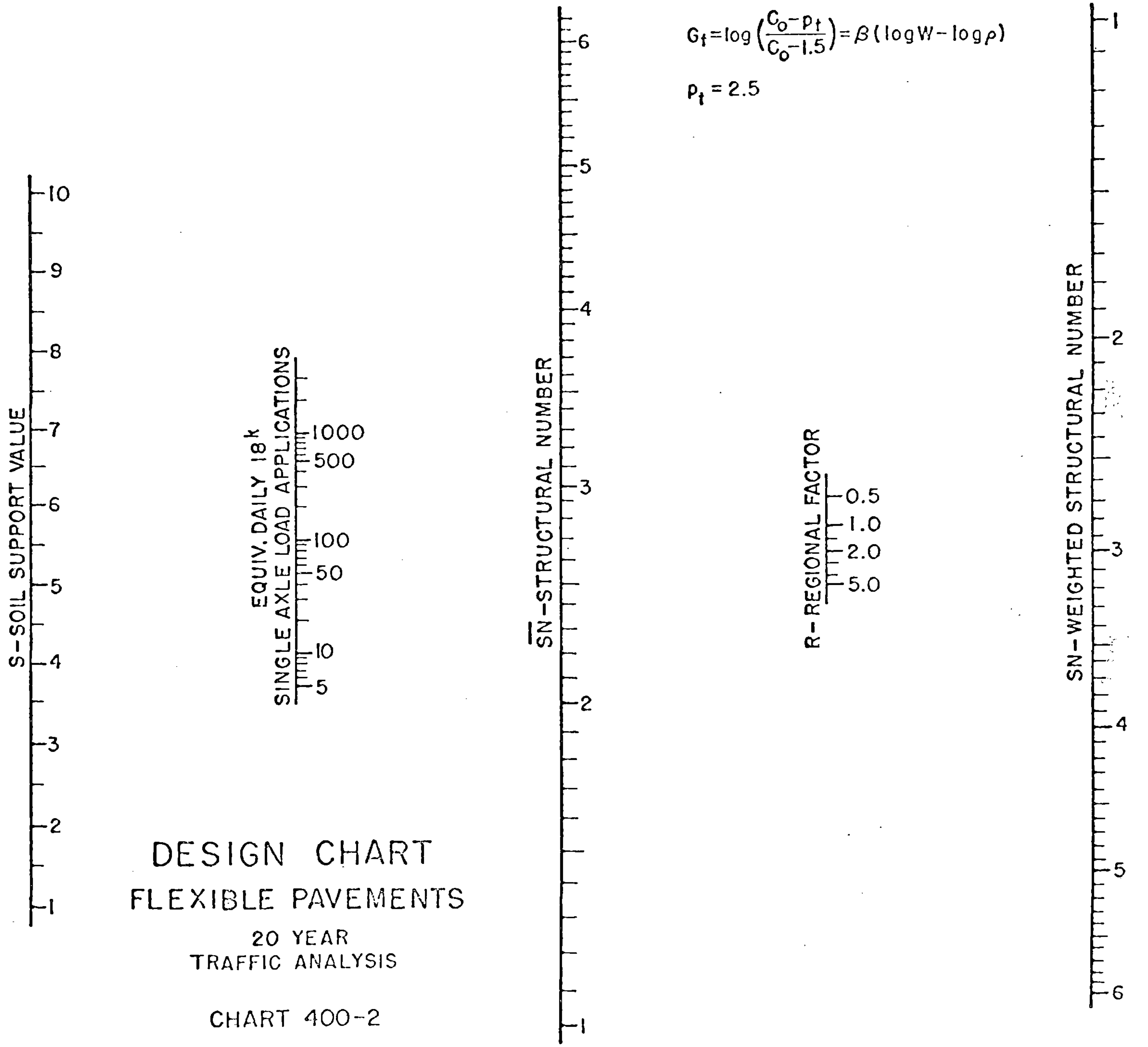


Fig. 6. Design chart for single-axle loads for Case I (based on Ref. 8, Influence Chart 6).



DESIGN CHART
FLEXIBLE PAVEMENTS
20 YEAR
TRAFFIC ANALYSIS

CHART 400-2

IOWA (AASHO)

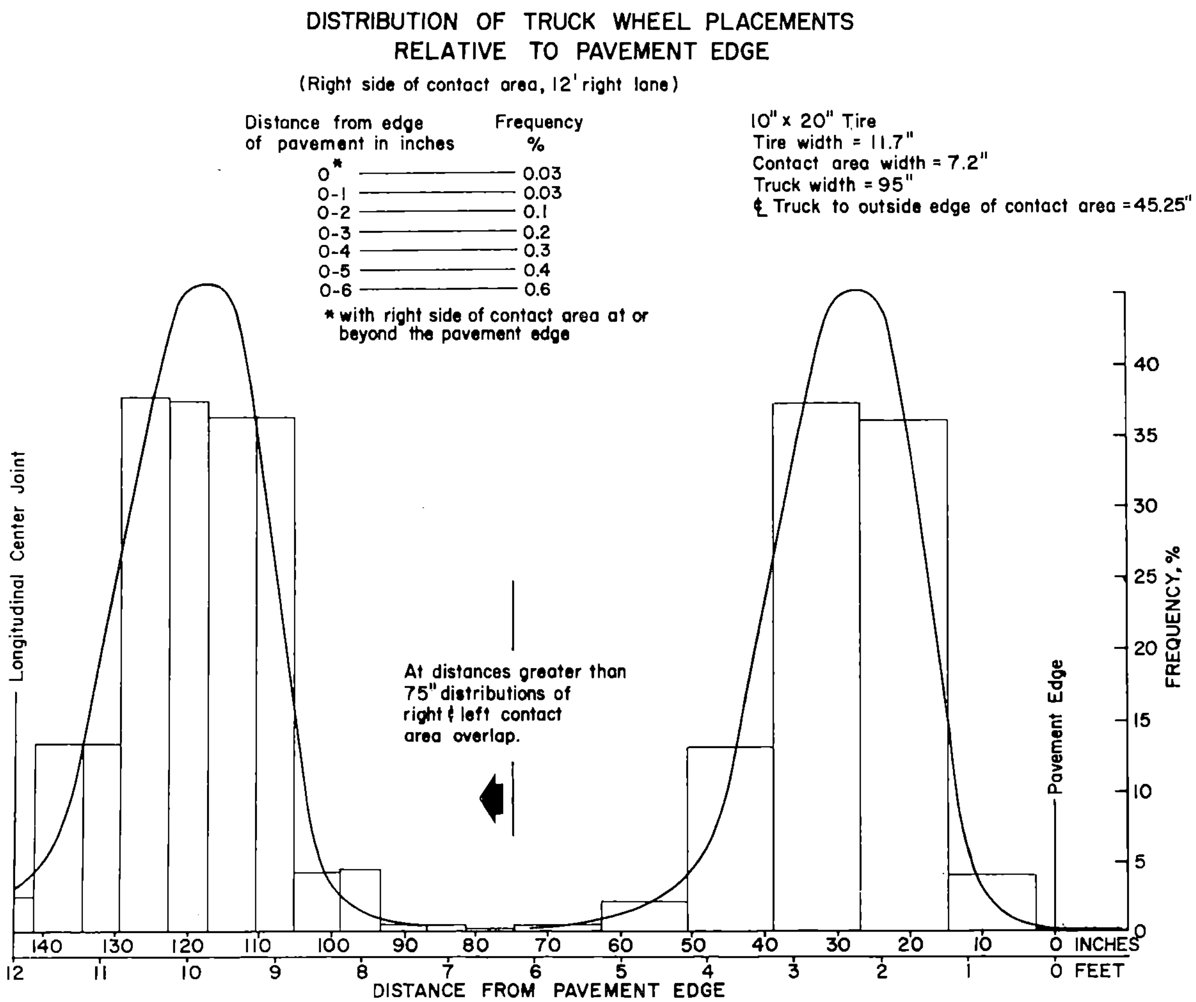
IOWA

TABLE I

Component	Coefficient	Minimum Thickness Permitted
Surface Course		
Type A Asphaltic Concrete	0.44*	3 (>300 tpd)
Type B Asphaltic Concrete	0.44*	2 (<300 tpd)
Inverted Penetration	0.20	--
Base Course		
Type B Asphaltic Concrete Base	0.40	2
Asphalt Treated Base Class I	0.34*	4
Bituminous Treated Aggregate Base	0.23	6
Asphalt Treated Base Class II	0.23	4
Cold Laid Bituminous Concrete Base	0.20	6
Cement Treated Aggregate Base	0.20*	6
Soil-Cement Base	0.15	6
Graded Stone Base	0.14*	6
Rolled Stone Base	0.12	6
New Portland Cement Concrete	0.50	
Old Portland Cement Concrete	0.40	
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 AASHO Interim Guide for the Design of Flexible Pavement structures.

IOWA



Revised July, 1965

Pavement Thickness	Soils Class A-4,5,6,7 (Subgrade K-150)		Soils Class A-1,2,3 (Subgrade K-300)	
	① HCADT	② TST HCADT	HCADT	TST HCADT
6" Non Reinf.	20	0	50	2
$6\frac{1}{2}$" Non Reinf.	50	2	200	10
7" Non Reinf.	200	10	400	60
$7\frac{1}{2}$" Non Reinf.	400	60	600	180
8" Non Reinf.	600	180	1000	300
8" Reinf.	1000	300	5000	1000
9" Reinf.	15000	3000	Unlimited	Unlimited

RIGID PAVEMENT THICKNESS BASED ON 20 YEAR PROJECTED AVERAGE DAILY TRAFFIC

NOTE: The above values are based on Minnesota Traffic Studies. A change in normal traffic loads or increase in legal load values will require new values to be determined.

Passenger cars and 4 tire trucks volume does not affect the design thickness of pavement.

SHOULDER WIDTHS

20 Year Projected ADT Volume or DHV Volume	SHOULDER WIDTH	
	Desirable	Min.
Over 2000 ADT or Over 400 DHV	* $11\frac{1}{2}$	10'
1000-2000 ADT or 200-400 DHV	10'	8'
Less 1000 ADT or Less 200 DHV	8'	6'

*Includes 10' Bit. Surfaced Shoulders

NOTE: Minimum widths need the approval of the Office of the Chief Engineer.

① HEAVY COMMERCIAL AVERAGE DAILY TRAFFIC

VEHICLE TYPE CODE

1 Single Unit - 2 Axle 6 Tire Trucks
2 Single Unit - 3 Axle Trucks
② { 3 Tractor - Truck or Semi-Trailer - 3 Axles
② { 4 Tractor - Truck or Semi-Trailer - 4 Axles
② { 5 Tractor - Truck or Semi-Trailer - 5 Axles
6 Buses & Trucks with Trailers

STATE 2

AXLE LOAD	DAILY HVY. COM. (HCADT)	TOTAL DAILY VEH. (ADT)	SURFACE		BIT. BASE		BIT. TREAT. BASE		GRAVEL BASE SPEC. NO. 3138		SAND-GRAVEL SUBBASE SPEC. 3138		TOTAL BASE THICKNESS INCHES OF G.E.	TOTAL PAVE. THICKNESS INCHES OF G.E.
			THICK. (IN.)	(SPEC)	THICK. (IN.)	(SPEC)	THICK. (IN.)	(SPEC)	THICK. (IN.)	CLASS	THICK. (IN.)	CLASS		
5 TON		Less Than 400	1½	2321					3	5	5	4	7	9
7 TON		Less Than 400	1½	2331					4	5	6	4	8½	11½
5T-ULT.7T		400-1000	1½	2331	1	2208			3	5	6	4	9	12
7 TON		400-1000	2	2331	1	2208			3	5	8	4	10½	14½
7T-ULT.9T	Less Than 150	Less Than 1000	2	2208					4	5	9	4	11	14
7T-ULT.9T	150-300	1000-2000	2	2331	1	2208			5	5	9	4	13½	17½
9 TON	Less Than 150	Less Than 1000	2	2331	1	2208			5	5	9	4	13½	17½
9 TON	150-300	1000-2000	3	2341	1	2208			5	5B	10	4	14	21
9 TON	300-600	2000-5000	3	2341	1½	2331	4 Rich	2204			6 6	4A 4	18	25
9 TON	600-1100	5000-10,000	3½	2351	3½	2331	4 Lean	2204			6 6	4A 4	21	29
9 TON	More Than 1100	More Than 10,000	3½	2351	4½	2331	4 Lean	2204			6 8	4A 4	24½	32½
COMPOSITE PAVEMENT DESIGN - BIT. SURF AND RIGID BASE (FOR URBAN SECTION ONLY)														
9 TON	More Than 1100	More Than 10,000	3	2351	8 Concrete				3	5	3	4		

NOTE: These designs are for use on A-6 subgrade soils. For use on other soils, thicknesses should be adjusted as described in "Flexible Pavement Design Standards - Method of Application."

STATE 2

TAB C 5-291.523(1) FLEXIBLE PAVEMENT DESIGN STANDARDS - METHOD OF APPLICATION

1. Design thicknesses for the 5, 5 ult. 7, and 7 ton roads are based on total average daily traffic (ADT); the 7-ult. 9 and 9 ton roads are based on heavy commercial average daily traffic (HCADT) which includes all except 4-tired vehicles.

2. Design thicknesses shown in the table apply only for A-6 subgrade soils. Use the following method to adjust the design thickness for other classes of subgrade soils:

A. Bituminous base, bituminous treated base, gravel base and sand-gravel subbase thicknesses are converted to an equivalent thickness of gravel base (denoted as gravel equivalent = G.E.) using the gravel equivalent factors listed below. The sum of these quantities for each design is listed under the column headed "Total Base Thickness-Inches of G.E."

B. Select the appropriate soil factor corresponding to the AASHO soil classification of the subgrade soils. The soil factor is to be applied to the "Total Base Thickness-In. G.E." in adjusting to the gravel equivalent base thickness required for subgrade soils other than A-6 soils. Apply this adjustment to the thickness of the subbase only.

C. This adjustment is made algebraically using the following formula:

$$\text{Adjusted Subbase Thickness} = \text{Subbase Thickness} + \left[\frac{\text{Total Base G.E.} \times \frac{\text{Soil Factor}}{100} - \text{Total Base G.E.}}{0.75}\right]$$

MATERIAL	GRAVEL EQUIVALENT FACTORS	
Plant-Mix Surface	(PMS) 2341-51	2.25
Plant-Mix Surface	(PMS) 2331	2.00
Plant-Mix Base	(PMB) 2331-41-51	2.00
Road-Mix Surface	(RMS) 2321	1.50
Road-Mix Base	(RMB) 2208	1.50
Bit. Treat. Base	(Rich) 2204	1.50
Bit. Treat. Base	(Lean) 2204	1.25
Gravel Base	(Cl. 5,Cl. 5B) 3138	1.00
Gravel Base	(Cl. 5A) 3138	0.90
Crushed Rock Base	(Cl. 3) 3138	1.00
Sand-Gravel Subbase	(Cl. 4 & 4A) 3138	0.75

AASHO SOIL CLASS	SOIL FACTOR (S.F.) - %
A-1	50-75
A-2	50-75
A-3	50
A-4	100-130
A-5	130+
A-6	100
A-7-5	120
A-7-6	130

D. When the subbase adjustment eliminates the subbase where the subgrade consists of A-1, A-2 or A-3 soils, design the upper 12" of the embankment with selected granular material. Treat the upper portion of the selected granular material with 1" or 2" of class 5 gravel (7-15 % passing the No. 200 sieve) or treat the upper 3 inches with 0.2 Gal./Sq.Yd./inch of Asphalt Emulsion, SS-1.

3. 5T - ult. 7T and 7T-ult 9T. Designs: Increase to 7 and 9 tons respectively by adding a 2-in. plant mix wearing course.

4. The following substitutions may be used:

A. 7 ton less than 150 HCADT: 1½ in. of 2331 PM surface for 2 inches of 2208 RM base.

B. 9 ton 300-600 HCADT: 6 in. of class 5B gravel base for 4 inches of "Rich" 2204 Bit. treated base.

C. 9 ton 600-1100 HCADT: 5 in. of class 5B gravel base for 4 inches of "Lean" 2204 Bit. treated base.

5. Example Design Problems

A. Design for a 9-Ton, more than 1100 H.C.A.D.T., for an A-3 soil (S.F. = 50%)

1. Design for A-6 soil (from table):

3½" Surface + 4½" Bit. Base + 4" (Lean) Bit. Treat. Base + 14" Subbase.

2. Adjusted subbase thickness (for A-3 soil) = Subbase thickness + $\left[\frac{\left(\text{Total Base G.E.} \times \frac{\text{S.F.}}{100}\right) - \text{Total Base G.E.}}{0.75}\right]$

$$= 14" + \frac{\left(24½" \times \frac{50}{100} - 24½"\right)}{0.75} = 14" - 16.3"$$

The adjustment is more than the standard thickness, therefore the subbase is eliminated and the upper portion of the embankment shall be designed according to Item 2D above.

B. Design for a 9-Ton, 300-600 H.C.A.D.T., for an A-7 soil (S.F. = 130%)

1. Design for an A-6 soil (from table):

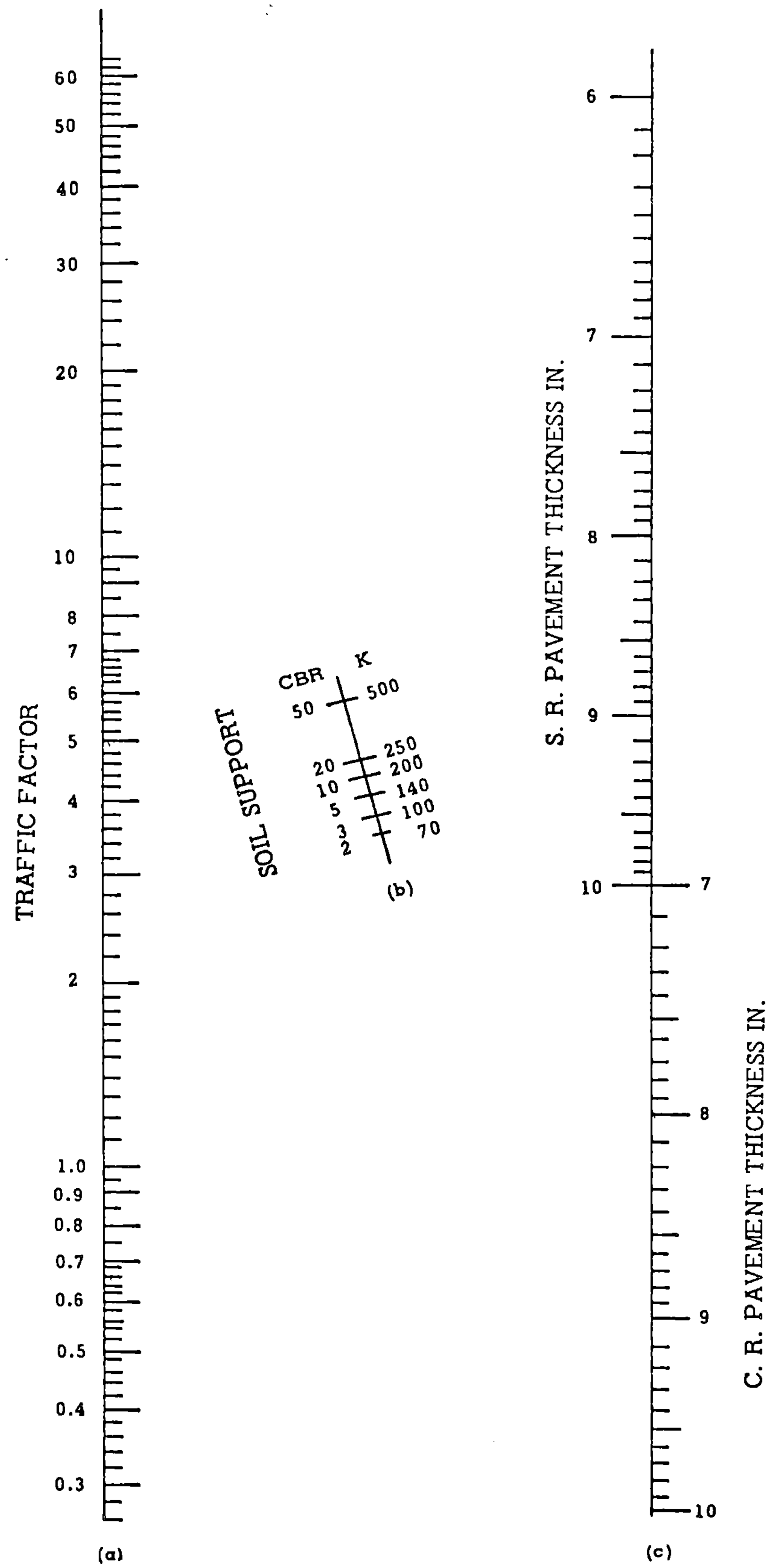
3" surface + 1½" Bit. Base + 4" (Rich) Bit. Treat. Base + 12" Subbase.

2. Adjusted Subbase thickness (for A-7 soil) = Subbase Thickness + $\left[\frac{\left(\text{Total Base G.E.} \times \frac{\text{S.F.}}{100}\right) - \text{Total Base G.E.}}{0.75}\right]$

$$= 12 + \frac{\left(18 \times \frac{130}{100} - 18\right)}{0.75} = 12 + 7.2 = 19". \text{ Use } 19" \text{ of Subbase.}$$

STATE 3
PORTLAND CEMENT CONCRETE PAVEMENTS

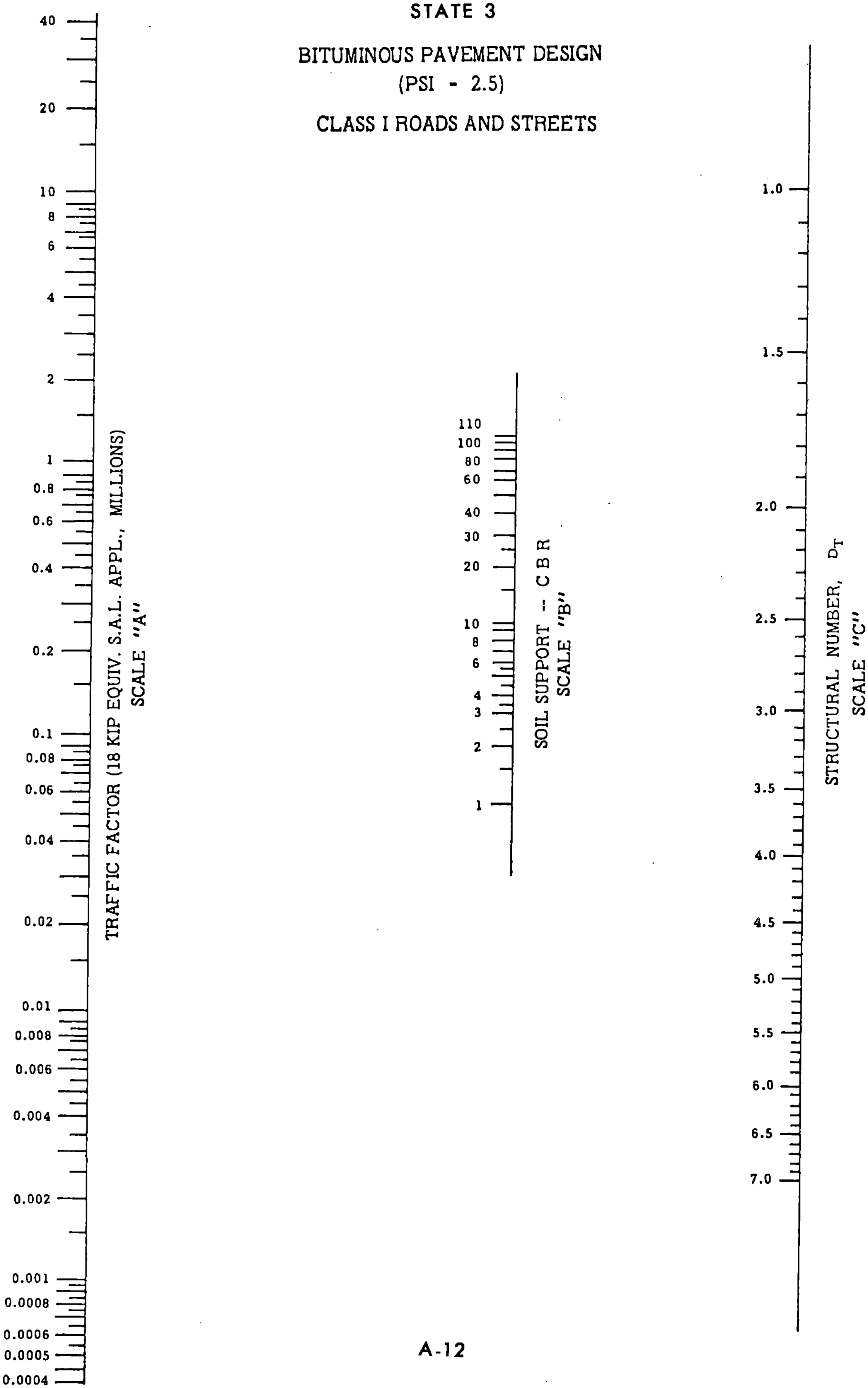
CLASS I ROADS & STREETS



STATE 3

BITUMINOUS PAVEMENT DESIGN
(PSI - 2.5)

CLASS I ROADS AND STREETS



STATE 3

STRUCTURAL COEFFICIENTS FOR PAVEMENT MATERIALS

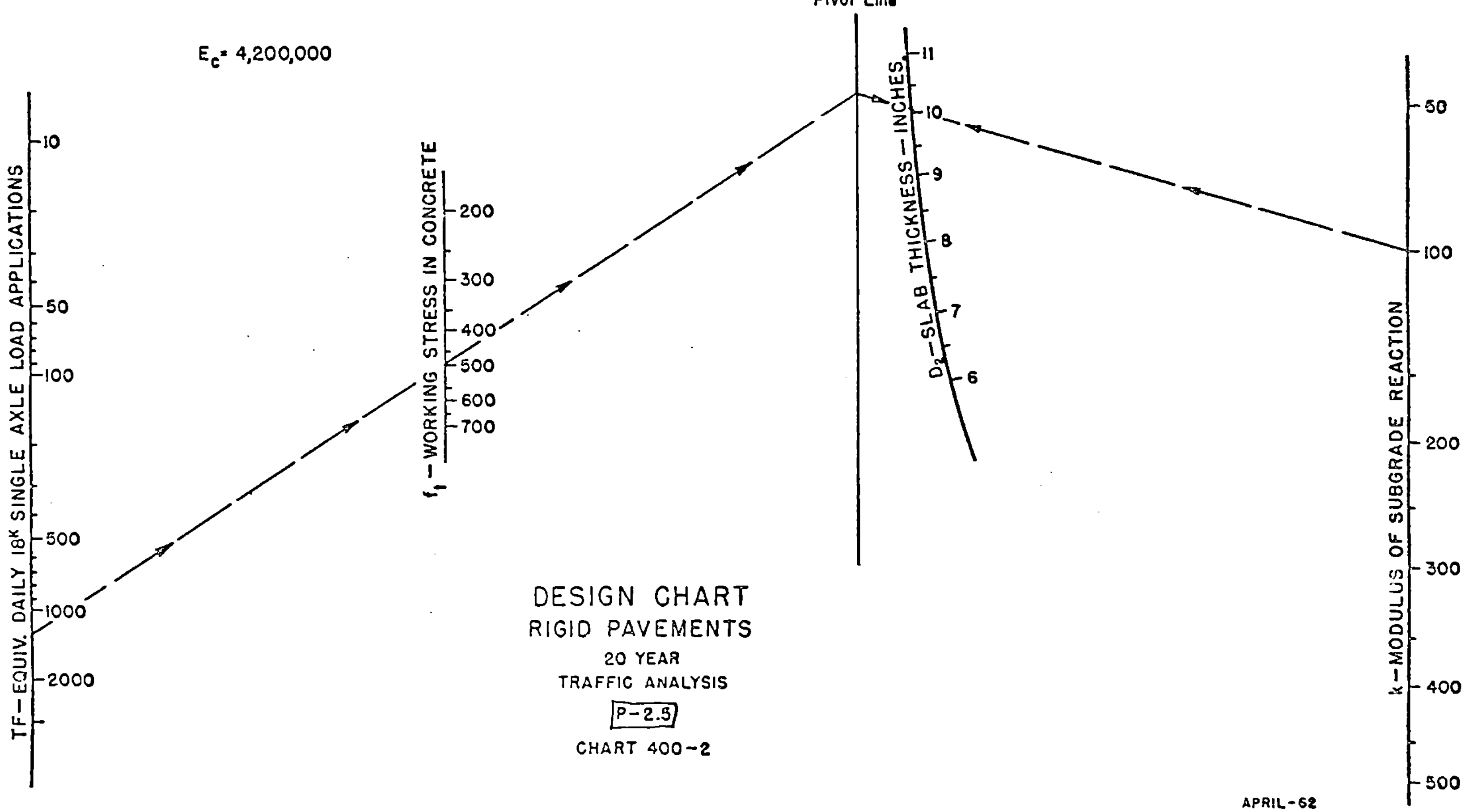
MATERIAL TYPE	MINIMUM STRENGTH REQUIREMENTS MS 1/	CBR	PSI	COEFFICIENT VALUES New Pav't.	1st Resurf	2nd Resurf	3rd Resurf
		- Surface Course, a_1 -					
Concrete Surface Course Type:				a_1	a_1'	a_1''	a_1'''
Standard Reinforced PCC			2500 2/	0.50	0.40	0.30	0.20
Continously Reinforced PCC			2500 2/	0.71	0.57	0.43	0.29
Bituminous Surface Course Type:							
B-1, B-2, B-3, B-4	300			0.20	0.15	0.11	0.11
B-5, J-1	900			0.30	0.23	0.17	0.17
I-11 (1954 and before)				—	0.23	0.17	0.17
I-11 (1955 and later)	1700			0.40	0.30	0.23	0.23
		Base Course					
Gravel or Crushed Stone, Type B				a_2	a_2'	a_2''	a_2'''
Grade 7 Gravel		50		0.10	0.08	0.06	0.06
Grade 9 Gravel		70		0.12	0.09	0.07	0.07
Grade 8 Crushed Stone		90		0.13	0.10	0.08	0.08
Gravel or Crushed Stone, Type A.				0.13	0.10	0.08	0.08
Waterbound Macadam		110		0.14	0.11	0.09	0.09
Soil Cement			300 2/	0.15	0.12	0.09	0.09
Granular Material Stabilized With:							
Paving Asphalt	450			0.19	0.15	0.11	0.11
	800			0.23	0.17	0.13	0.13
	1500			0.30	0.23	0.17	0.17
B5 Base Course	900			0.24	0.19	0.14	0.14
I-11 Binder Course	1700			0.33	0.25	0.20	0.20
PCC Base Course				0.50	0.40	0.30	0.20
Existing PCC				--	0.40	0.30	0.20
		Subbase Course, a_3					
Gravel or Crushed Stone, Type B				a_3	a_3'	a_3''	a_3'''
Grade 11 Gravel		30		0.11	0.09	0.07	0.07
Grade 7 Gravel		50		0.12	0.10	0.08	0.08
Grade 9 Gravel		70		0.13	0.11	0.08	0.08
Grade 8 Crushed Stone		90		0.14	0.11	0.08	0.08

1/ Marshall Stability or equivalent

2/ 7-day compressive strength (value that can be reasonably expected under field conditions)

$$\log W_t' = \log(7300\,TF) + 7.35\log(D_2+1) - 0.06 - \left[\frac{0.176}{1+\frac{1.624\times10^{7}}{(D_2+1)^{8.46}}}\right] + 3.42\log\left[\frac{f_t}{690}\left(\frac{D_2^{0.75}-1.132}{D_2^{0.75}-0.407\,k^{0.25}}\right)\right]$$

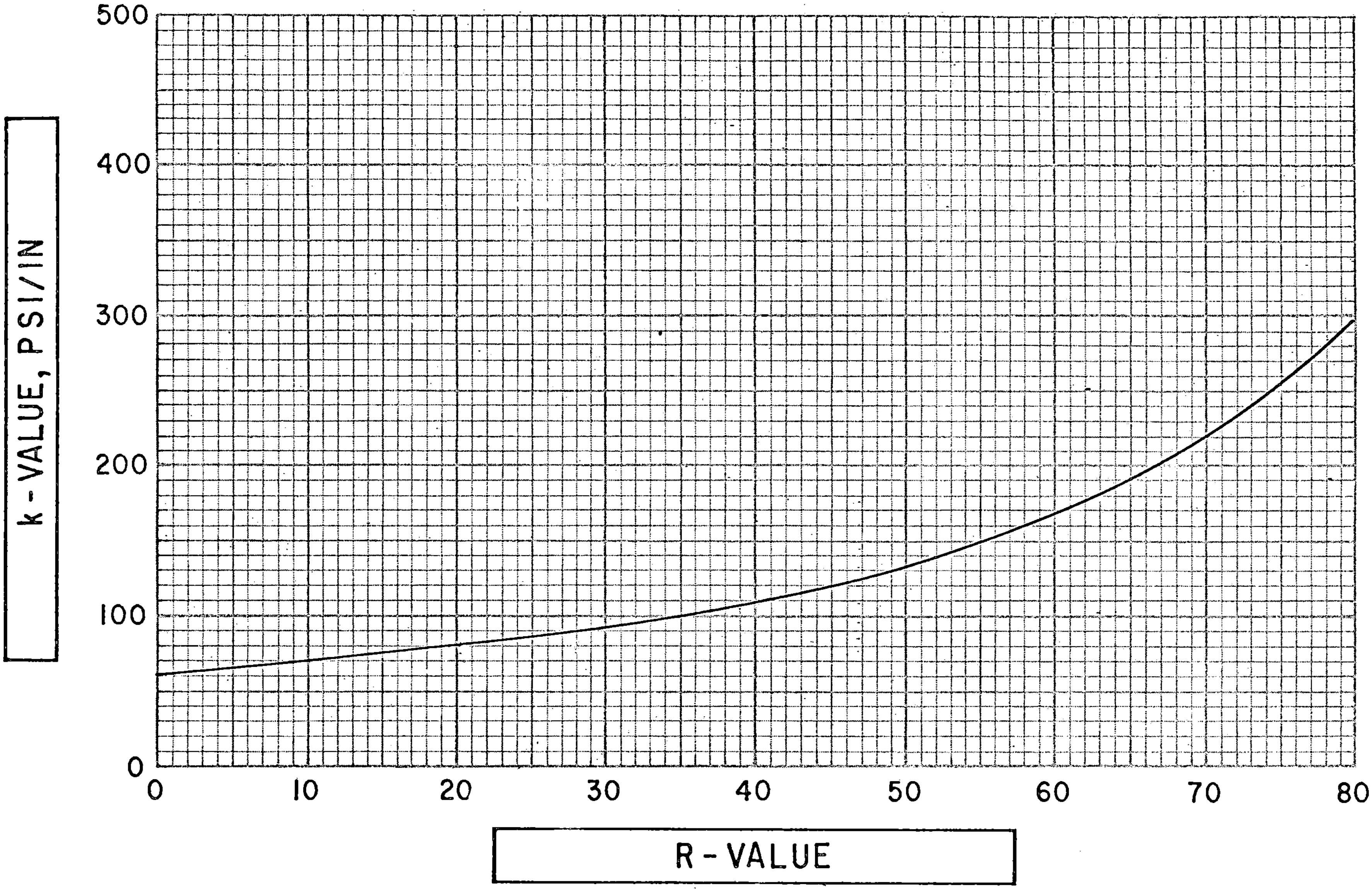
$E_c = 4{,}200{,}000$



DESIGN CHART
RIGID PAVEMENTS
20 YEAR
TRAFFIC ANALYSIS
P-2.5
CHART 400-2

APRIL-62

STATE 4 (AASHO)

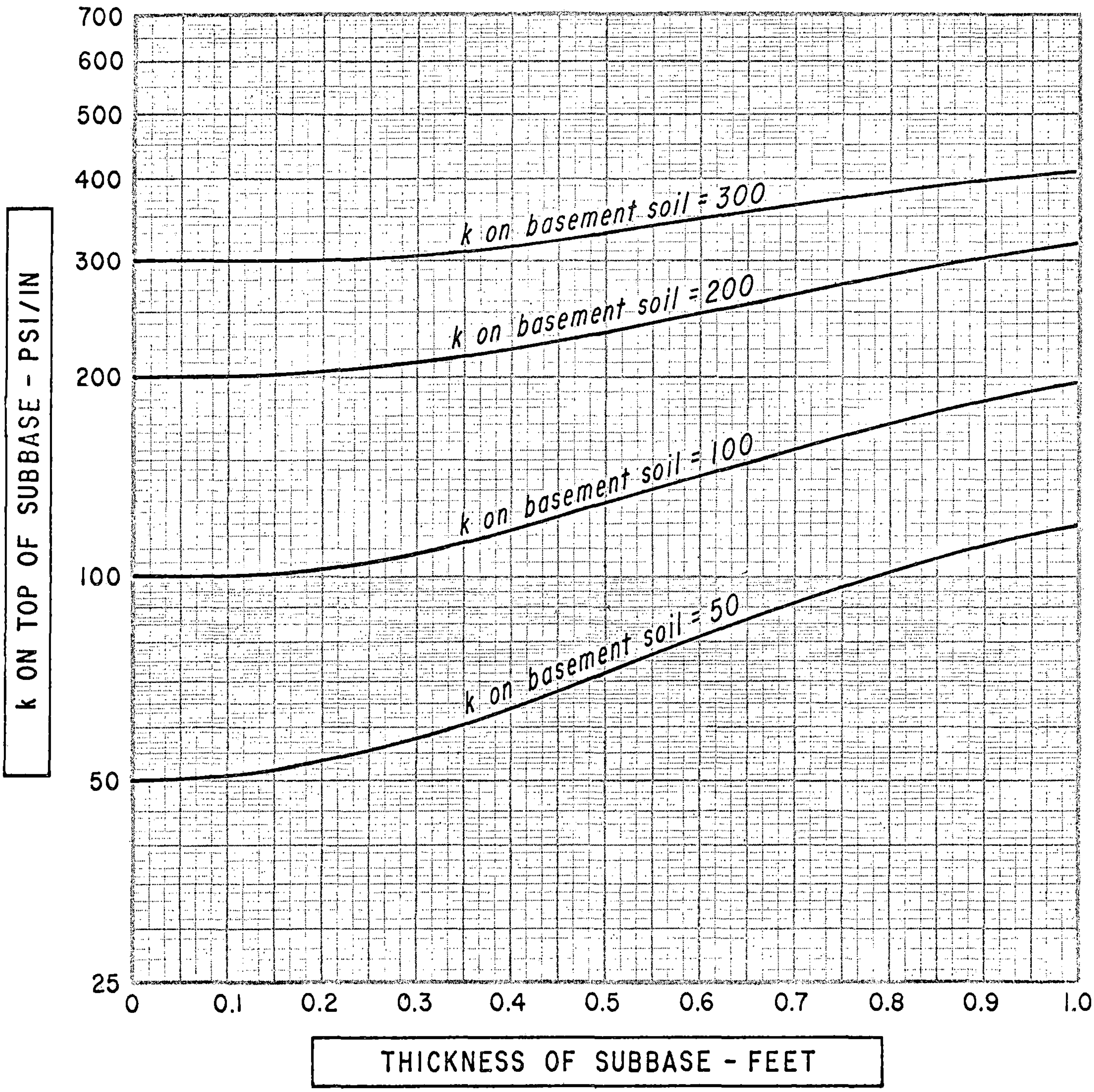


k VALUE VS R VALUE

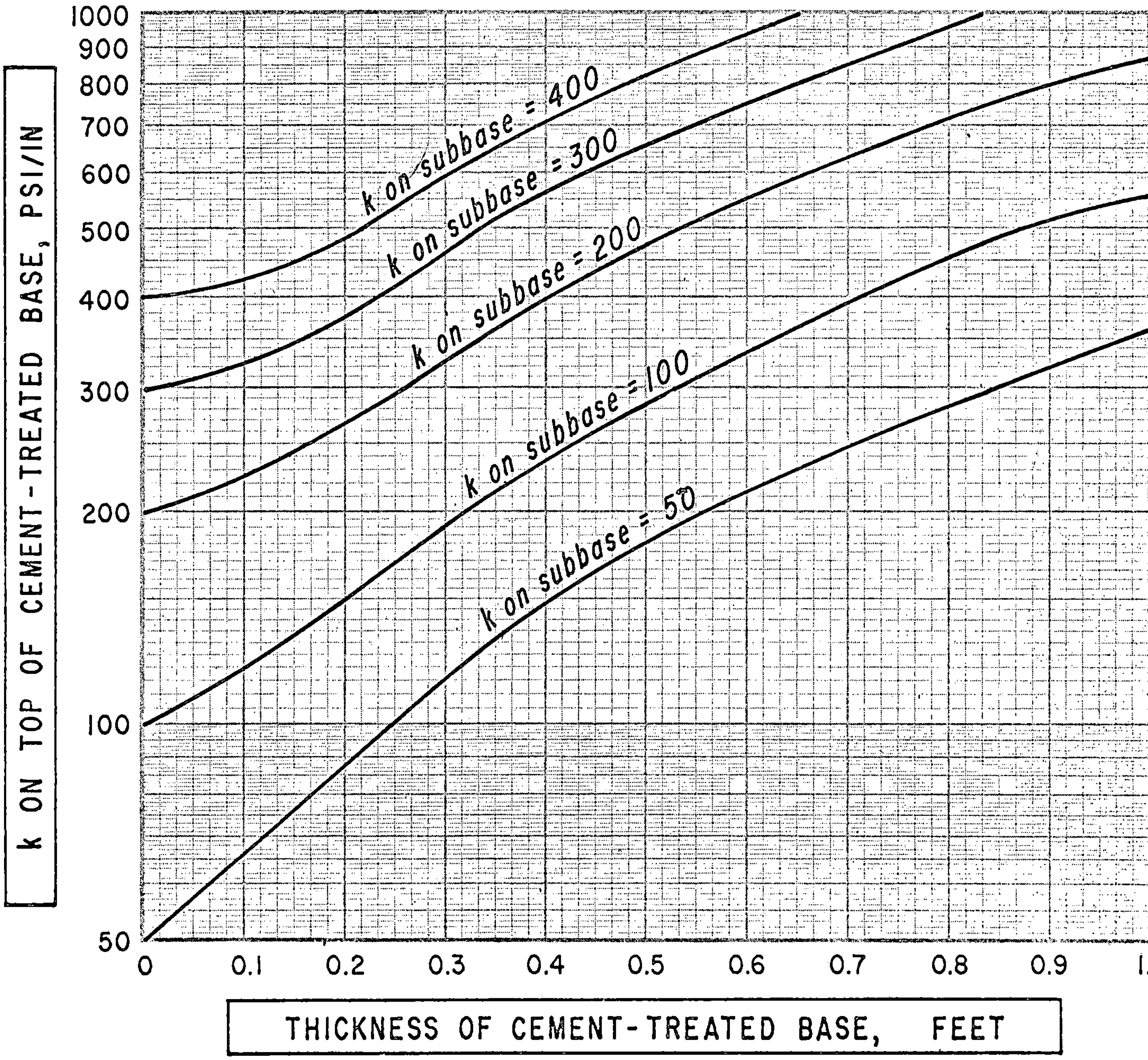
STATE 5

STATE 5

EFFECT OF VARIOUS THICKNESSES OF GRANULAR SUBBASES ON k VALUES

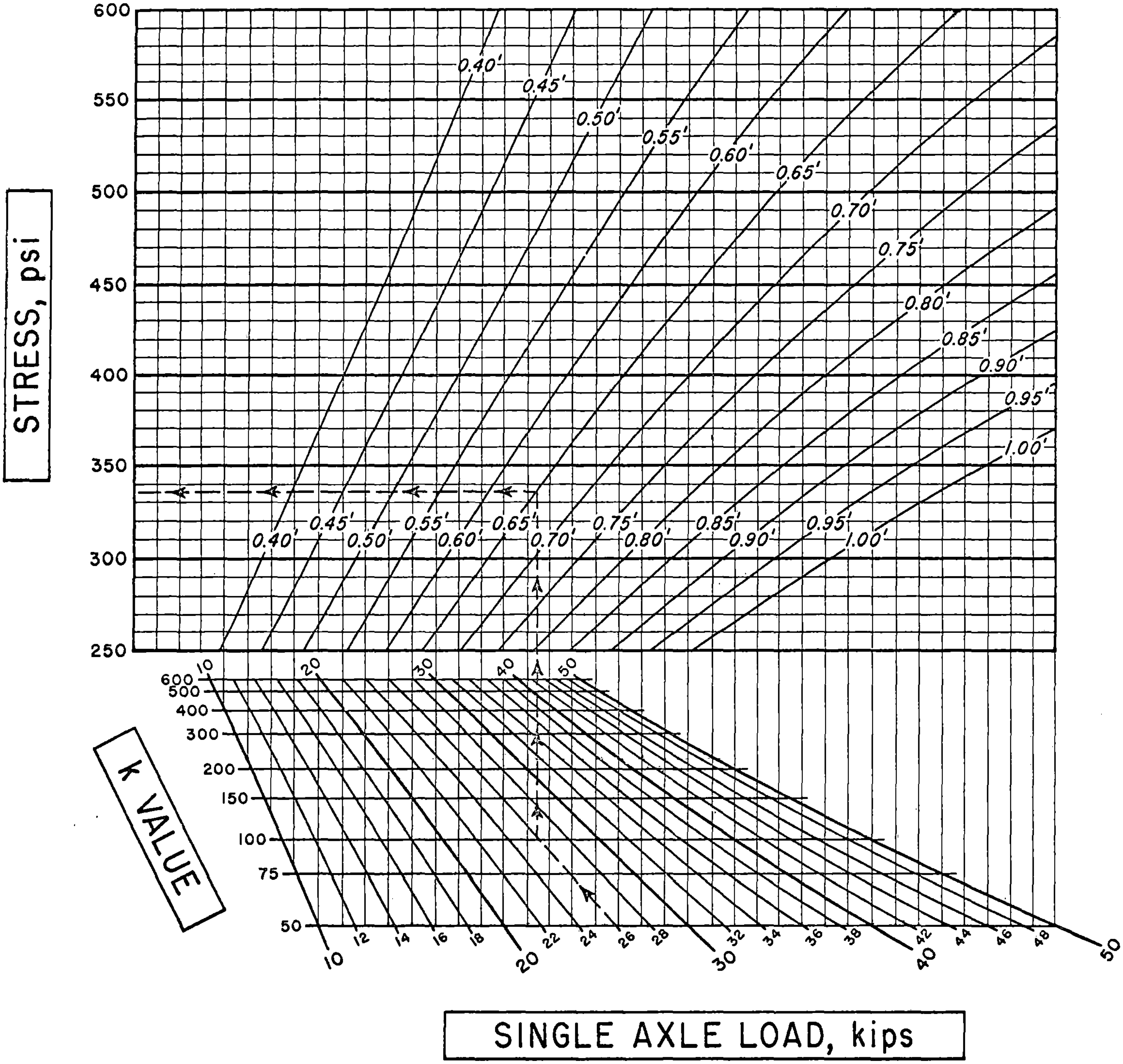


EFFECT OF VARIOUS THICKNESSES OF CEMENT-TREATED BASES ON k VALUES



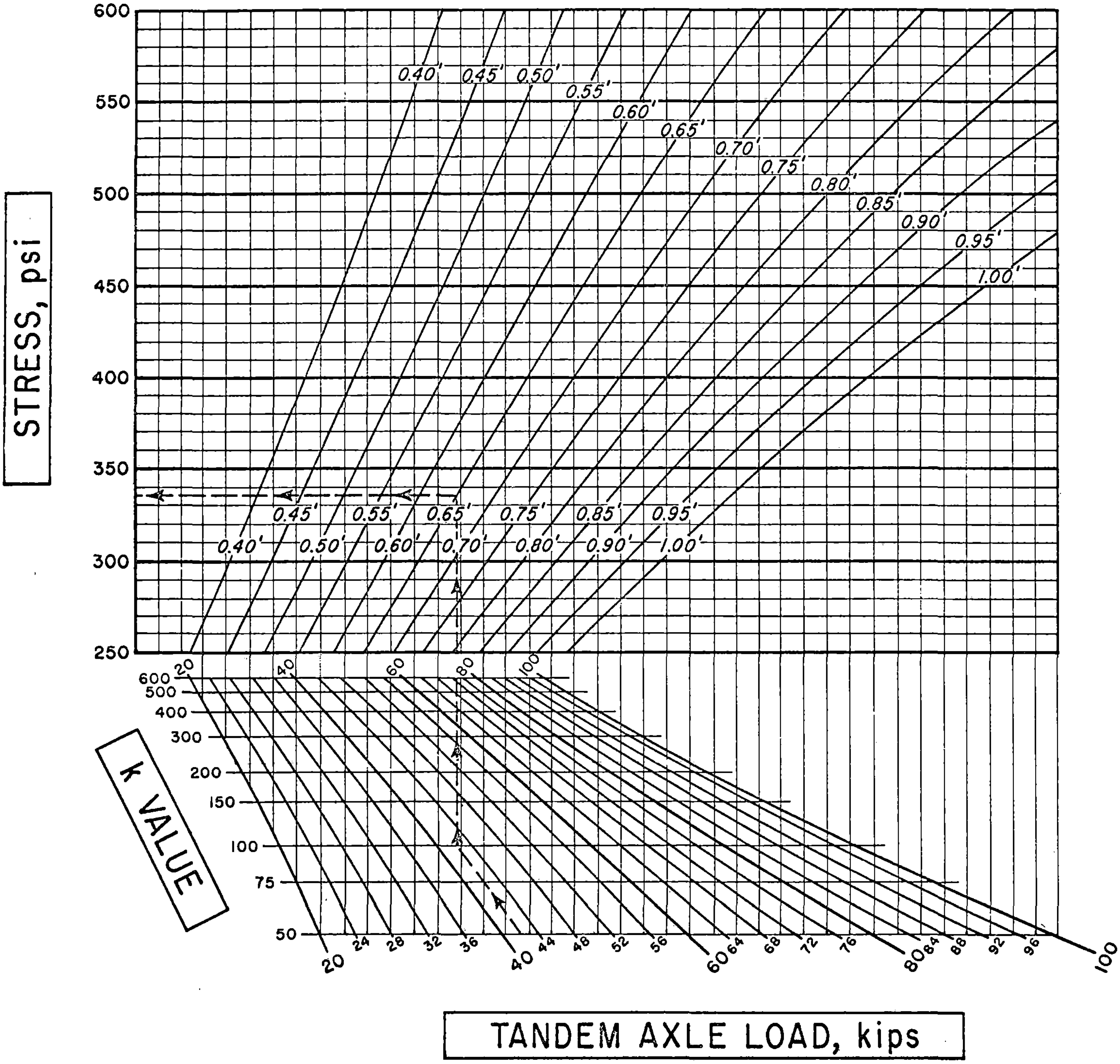
STATE 5

STRESS CHART FOR SINGLE AXLE LOADS



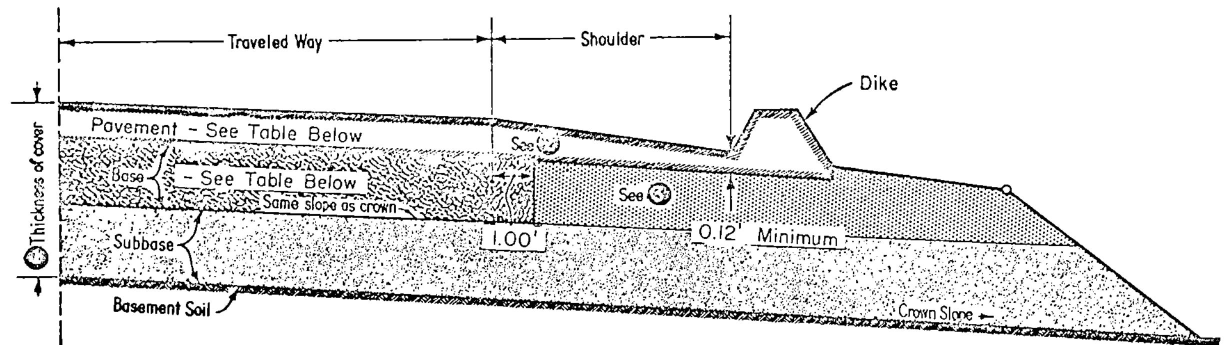
STATE 5

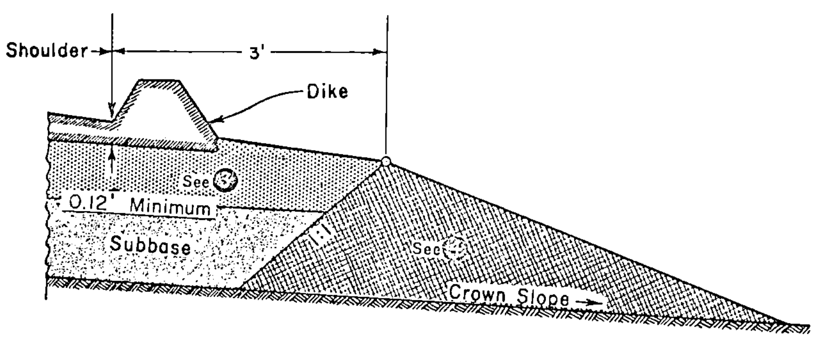
STRESS CHART FOR TANDEM AXLE LOADS



STATE 5

STRUCTURAL ELEMENTS OF FLEXIBLE PAVEMENTS





① THICKNESS OF COVER

Use design formula for thickness of total cover.

② SHOULDER DESIGN

Except for all-paved 2-lane roads and median shoulders on 4-lane and 6-lane divided highways, shoulder design is based on 1% of EWL but not less than a TI of 5.0

Median shoulders on 4-lane and 6-lane divided highways shall be paved 5'-wide with a uniform thickness of 0.20'

③ SHOULDER BASE

Use base material or high quality subbase.

④ FLAT FILL SLOPE DESIGN

Use embankment material in this area when slopes are flatter than 4:1 and subsurface drainage problems are not anticipated.

TABLE 7-603.1
Typical Depths of Pavement and Base Related to TI

Type of base material	Pavement or base layer	Depth of layer (feet)									
		TI 5.0 and below	TI 5.5 and 6.0	TI 6.5 and 7.0	TI 7.5 and 8.0	TI 8.5 and 9.0	TI 9.5 and 10.0	TI 10.5 and 11.0	TI 11.5 and 12.0	TI 12.5 and 13.0	TI 13.5 and 14.0
Class A CTB	Pavement	--------	--------	--------	0.25	0.30	0.35	0.40	0.45	0.50	0.55
	Base	--------	--------	--------	0.60	0.65	0.75	0.80	0.85	0.90	1.00
Class B CTB	Pavement	--------	--------	0.25	0.30	0.35	0.40	0.45	0.50	0.55	*
	Base	--------	--------	0.55	0.60	0.70	0.75	0.85	0.90	1.00	*
Class C CTB	Pavement	--------	0.25	0.30	0.35	0.40	--------	--------	--------	--------	--------
	Base	--------	0.50	0.60	0.65	0.75	--------	--------	--------	--------	--------
Class 1 AB	Pavement	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.65	
(80 R Value)	Base	0.45	0.50	0.65	0.70	0.80	0.90	1.00	1.05	1.15	*
Class 2 AB	Pavement	0.20	0.25	0.35	0.40	0.45	0.50	0.55	0.65	*	*
(78 R Value)	Base	0.45	0.50	0.60	0.65	0.75	0.85	0.90	1.00	*	*

TES: The above table was made as a guide with the thicknesses based on the higher TI in each column and the assumption made that subbase with an R Value of 50 would be used. Extra thickness was added for a safety factor as stated in 7-604.4.

Asphalt concrete base course 0.25 foot thick would normally be specified where the total thickness of asphalt concrete exceeds 0.34 foot.

* Designs in these categories require special justification.

CTB is cement-treated base. AB is aggregate base.

STATE 5

(1) Vehicle Type	(2) Present average daily trucks in both directions	(3) Expansion factor to 10 years after construction	(4) Expanded average daily trucks (Col. 2 × Col. 3)	(5) EWL Constants	(6) Average annual EWL (Col. 4 × Col. 5)
2-axle trucks	400	1.70	680	280	190,400
3-axle trucks	150	2.70	405	930	376,650
4-axle trucks	100	1.55	155	1320	204,600
5-axle trucks	230	1.45	335	3190	1,068,650
6-axle trucks	60	1.00	60	1950	117,000
Total average annual design EWL					1,957,300

TABLE 7-602.3C
Lane Distribution Factors on Multilane Roads

Number of lanes in both directions	Factors to be applied to EWL percent			
	*Lane 1	Lane 2	Lane 3	Lane 4
2	100	--	--	--
4	100	100	--	--
6	20	80	80	--
8	20	20	80	80

* Lane 1 is next to the centerline or median on the driver's left.

TABLE 7-605.4
Allowable Load Repetitions for Various Stress Ratios

Stress ratio	Allowable repetitions	Stress ratio	Allowable repetitions
0.51	400,000	0.71	1,500
0.52	300,000	0.72	1,100
0.53	240,000	0.73	850
0.54	180,000	0.74	650
0.55	130,000	0.75	490
0.56	100,000	0.76	360
0.57	75,000	0.77	270
0.58	57,000	0.78	210
0.59	42,000	0.79	160
0.60	32,000	0.80	120
0.61	24,000	0.81	90
0.62	18,000	0.82	70
0.63	14,000	0.83	50
0.64	11,000	0.84	40
0.65	8,000	0.85	30
0.66	6,000	0.86	23
0.67	4,500	0.87	17
0.68	3,500	0.88	13
0.69	2,500	0.89	10
0.70	2,000	0.90	8

TABLE 7-602.3A
Conversion of EWL to Traffic Index

EWL	*TI	EWL	*TI
104		15,000,000	
	2.5		9.5
562		23,400,000	
	3.0		10.0
2,290		35,600,000	
	3.5		10.5
7,620		53,100,000	
	4.0		11.0
21,800		77,900,000	
	4.5		11.5
55,600		112,000,000	
	5.0		12.0
129,000		159,000,000	
	5.5		12.5
277,000		223,000,000	
	6.0		13.0
558,000		308,000,000	
	6.5		13.5
1,060,000		420,000,000	
	7.0		14.0
1,940,000		568,000,000	
	7.5		14.5
3,400,000		759,000,000	
	8.0		15.0
5,750,000		1,000,000,000	
	8.5		15.5
9,420,000		1,320,000,000	
	9.0		
15,000,000			

$$\text{* Traffic Index} = 6.7\left(\frac{\text{EWL}}{10^6}\right)^{0.119}$$

TABLE 7-602.3B
EWL Constants for Dual-tired Commercial Vehicles

Type of vehicle	Annual design EWL per vehicle per day	
	State highways	City streets, and county roads
2-Axle truck	280	200
3-Axle truck	930	690
4-Axle truck	1320	1070
5-Axle truck	3190	1700
6-Axle truck	1950	1050

TABLE 7-604.3

Gravel Equivalents of Structural Layers in Feet

Actual thickness of layer feet	ASPHALT CONCRETE										BTB and LTB	Cement-treated Base			Aggregate base	Aggregate subbase
	Traffic Index (TI)											Class				
	5 and below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0		A	B	C		
	Gravel Equivalent Factor (G_f)										G_f	G_f			G_f	G_f
	2.50	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.2	1.7	1.5	1.2	1.1	1.0
0.10	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.12					
0.15	0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.18					
0.20	0.50	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.24					
0.25	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.30					
0.30	0.75	0.70	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.46	0.36					
0.35	0.88	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.42				0.39	0.35
0.40	1.00	0.93	0.86	0.80	0.76	0.72	0.68	0.66	0.63	0.61	0.48				0.44	0.40
0.45		1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.54	0.77	0.68	0.54	0.50	0.45
0.50		1.16	1.07	1.01	0.95	0.90	0.86	0.82	0.79	0.76	0.60	0.85	0.75	0.60	0.55	0.50
0.55			1.18	1.11	1.04	0.98	0.94	0.90	0.86	0.84	0.66	0.94	0.83	0.66	0.61	0.55
0.60				1.21	1.13	1.07	1.03	0.98	0.94	0.91	0.72	1.02	0.90	0.72	0.66	0.60
0.65				1.31	1.23	1.16	1.11	1.07	1.02	0.99	0.78	1.11	0.98	0.78	0.72	0.65
0.70					1.32	1.25	1.20	1.15	1.10	1.06	0.84	1.19	1.05	0.84	0.77	0.70
0.75						1.34	1.28	1.23	1.18	1.14	0.90	1.28	1.13	0.90	0.83	0.75
0.80						1.43	1.37	1.31	1.26	1.22	0.96	1.36	1.20	0.96	0.88	0.80
0.85						1.52	1.45	1.39	1.33	1.29	1.02	1.45	1.28	1.02	0.94	0.85
0.90							1.54	1.48	1.41	1.37	1.08	1.53	1.35	1.08	0.99	0.90
0.95								1.56	1.49	1.44	1.14	1.62	1.43	1.14	1.05	0.95
1.00								1.64	1.57	1.52	1.20	1.70	1.50	1.20	1.10	1.00
1.05									1.65	1.60	1.26	1.79	1.58	1.26	1.16	1.05

NOTES: BTB is bituminous-treated base.
LTB is lime-treated base.
For the design of road-mixed asphalt surfacing, use 0.8 of the gravel equivalent factors (G_f) shown above for asphalt concrete.

7-604.4 Summary

The completed design is 0.30 foot of asphalt concrete over 0.65 foot of Class 2 aggregate base over 1.00 foot of Class 2 subbase.

Other alternate designs for the assumed basic data could be as follows:

Actual Thickness (in feet)	Material in Layer	Gravel Equivalent (in feet)
0.30	Asphalt concrete	0.60
0.45	Class "B" cement-treated base	0.68
1.00	Class 2 subbase	1.00
1.75		2.28
0.25	Asphalt concrete	0.50
0.45	Class "A" cement-treated base	0.77
1.05	Class 2 subbase	1.05
1.75		2.32

The above designs based on the formula do not provide an adequate factor of safety. It is necessary to add thickness to the theoretical designs to provide this safety factor and it is accomplished by providing an increase in required gravel equivalent for the layer to which it is to be applied. In designs using Class "A" or Class "B" cement-treated base, the increased thickness should be applied to the base layer. In untreated aggregate base and Class "C" cement-treated base designs, the factor of safety should be provided by increased thickness of the asphalt surfacing. The increased thickness of surfacing or base will result in a decrease in the thickness of subbase because the safety factor is not applied to the over-all gravel equivalent requirement. The gravel equivalent increases to be provided are as follows:

Base Type	Gravel Equivalent Increase (Feet)	Layer Applied To
Class "A" cement-treated base	0.24	Cement-treated base
Class "B" cement-treated base	0.22	Cement-treated base
Class "C" cement-treated base	0.18	Asphalt concrete
Aggregate base	0.16	Asphalt concrete

Values of $\dfrac{i(1+i)^n}{(1+i)^n-1}$ Annuity Factor, Capital Recovery Factor

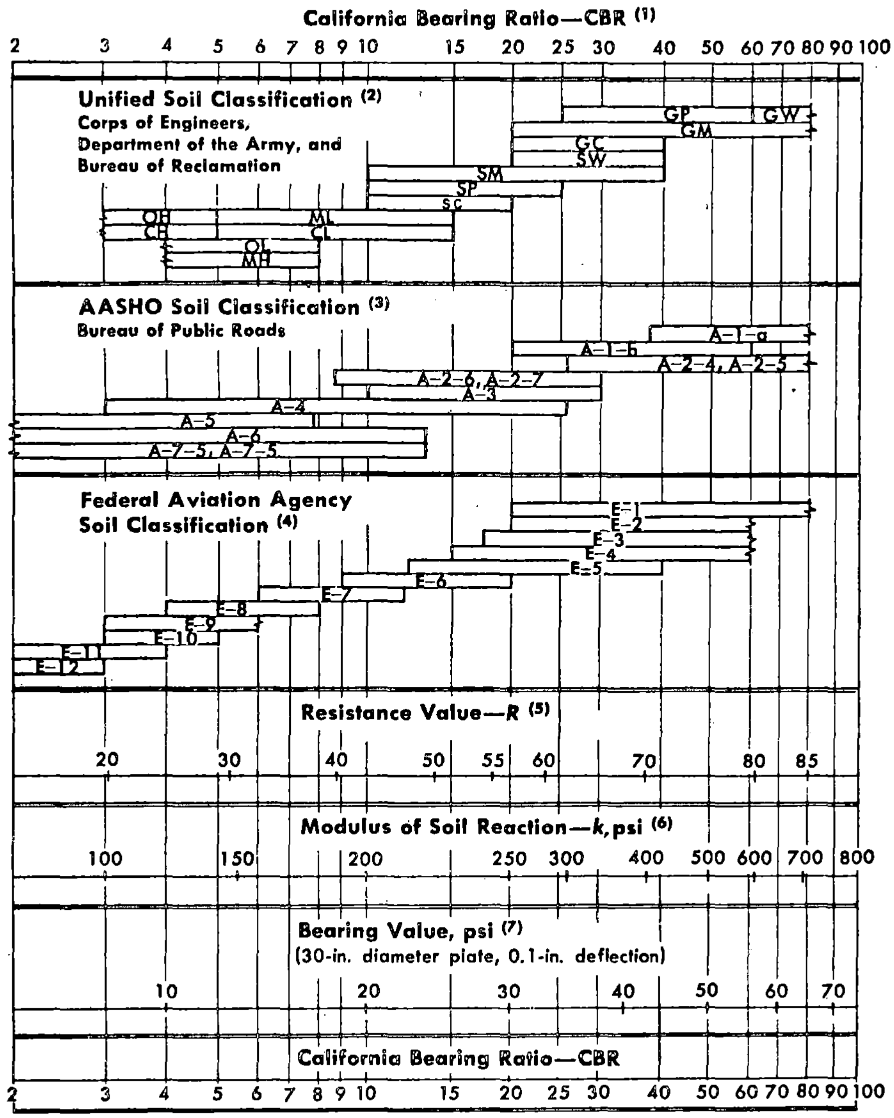
$$D = R\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

n	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	10%
1	1.0200	1.0250	1.0300	1.0350	1.0400	1.0450	1.0500	1.0600	1.0700	1.0300	1.1000
2	0.5150	0.5188	0.5226	0.5264	0.5302	0.5340	0.5378	0.5454	0.5531	0.5608	0.5762
3	0.3468	0.3501	0.3535	0.3569	0.3603	0.3638	0.3672	0.3741	0.3811	0.3880	0.4021
4	0.2626	0.2658	0.2690	0.2723	0.2755	0.2787	0.2820	0.2886	0.2952	0.3019	0.3155
5	0.2122	0.2152	0.2184	0.2215	0.2246	0.2278	0.2310	0.2374	0.2439	0.2505	0.2638
6	0.1785	0.1815	0.1846	0.1877	0.1908	0.1939	0.1970	0.2034	0.2098	0.2163	0.2296
7	0.1545	0.1575	0.1605	0.1635	0.1666	0.1697	0.1728	0.1791	0.1856	0.1921	0.2054
8	0.1365	0.1395	0.1425	0.1455	0.1485	0.1516	0.1547	0.1610	0.1675	0.1740	0.1874
9	0.1225	0.1255	0.1284	0.1314	0.1345	0.1376	0.1407	0.1470	0.1535	0.1601	0.1736
10	0.1113	0.1143	0.1172	0.1202	0.1233	0.1264	0.1295	0.1359	0.1424	0.1490	0.1628
11	0.1022	0.1051	0.1081	0.1111	0.1141	0.1172	0.1204	0.1268	0.1334	0.1401	0.1540
12	0.0946	0.0975	0.1005	0.1035	0.1066	0.1097	0.1128	0.1193	0.1259	0.1327	0.1468
13	0.0881	0.0910	0.0940	0.0971	0.1001	0.1033	0.1065	0.1130	0.1197	0.1265	0.1408
14	0.0826	0.0855	0.0385	0.0916	0.0947	0.0978	0.1010	0.1076	0.1143	0.1213	0.1358
15	0.0778	0.0808	0.0838	0.0868	0.0899	0.0931	0.0963	0.1030	0.1098	0.1168	0.1315
16	0.0737	0.0766	0.0796	0.0827	0.0858	0.0890	0.0923	0.0990	0.1059	0.1130	0.1278
17	0.0700	0.0729	0.0760	0.0790	0.0822	0.0854	0.0887	0.0954	0.1024	0.1096	0.1247
18	0.0667	0.0697	0.0727	0.0758	0.0790	0.0822	0.0855	0.0924	0.0994	0.1067	0.1219
19	0.0638	0.0668	0.0698	0.0729	0.0761	0.0794	0.0827	0.0896	0.0968	0.1041	0.1196
20	0.0612	0.0641	0.0672	0.0704	0.0736	0.0769	0.0802	0.0872	0.0944	0.1019	0.1175
21	0.0588	0.0618	0.0649	0.0680	0.0713	0.0746	0.0780	0.0850	0.0923	0.0998	0.1156
22	0.0566	0.0596	0.0627	0.0659	0.0692	0.0725	0.0760	0.0830	0.0904	0.0980	0.1140
23	0.0547	0.0577	0.0608	0.0640	0.0673	0.0707	0.0741	0.0813	0.0887	0.0964	0.1126
24	0.0529	0.0559	0.0590	0.0623	0.0656	0.0690	0.0725	0.0797	0.0872	0.0950	0.1113
25	0.0512	0.0543	0.0574	0.0607	0.0640	0.0674	0.0710	0.0782	0.0858	0.0937	0.1102
26	0.0497	0.0528	0.0559	0.0592	0.0626	0.0660	0.0696	0.0769	0.0846	0.0925	0.1092
27	0.0483	0.0514	0.0546	0.0579	0.0612	0.0647	0.0683	0.0757	0.0834	0.0914	0.1083
28	0.0470	0.0501	0.0533	0.0566	0.0600	0.0635	0.0671	0.0746	0.0824	0.0905	0.1075
29	0.0458	0.0489	0.0521	0.0554	0.0589	0.0624	0.0660	0.0736	0.0814	0.0896	0.1067
30	0.0446	0.0478	0.0510	0.0544	0.0578	0.0614	0.0651	0.0726	0.0806	0.0888	0.1061
31	0.0436	0.0467	0.0500	0.0534	0.0569	0.0604	0.0641	0.0718	0.0798	0.0881	0.1055
32	0.0426	0.0458	0.0490	0.0524	0.0559	0.0596	0.0633	0.0710	0.0791	0.0875	0.1050
33	0.0417	0.0449	0.0482	0.0516	0.0551	0.0587	0.0625	0.0703	0.0784	0.0869	0.1045
34	0.0408	0.0440	0.0473	0.0508	0.0543	0.0580	0.0618	0.0696	0.0777	0.0863	0.1041
35	0.0400	0.0432	0.0465	0.0500	0.0536	0.0573	0.0611	0.0690	0.0772	0.0858	0.1037
40	0.0366	0.0398	0.0433	0.0468	0.0505	0.0543	0.0583	0.0665	0.0750	0.0839	0.1023
45	0.0339	0.0373	0.0408	0.0445	0.0483	0.0522	0.0563	0.0647	0.0735	0.0826	0.1014
50	0.0318	0.0353	0.0389	0.0426	0.0466	0.0506	0.0548	0.0634	0.0725	0.0817	0.1009
55	0.0301	0.0337	0.0373	0.0412	0.0452	0.0494	0.0537	0.0625	0.0717	0.0812	0.1005
60	0.0288	0.0324	0.0361	0.0401	0.0442	0.0485	0.0528	0.0619	0.0712	0.0808	0.1003
65	0.0276	0.0313	0.0351	0.0392	0.0434	0.0477	0.0522	0.0614	0.0709	0.0805	0.1002
70	0.0276	0.0304	0.0343	0.0385	0.0427	0.0472	0.0517	0.0610	0.0706	0.0804	0.1001
75	0.0259	0.0297	0.0337	0.0379	0.0422	0.0467	0.0513	0.0608	0.0704	0.0802	0.1001
80	0.0252	0.0290	0.0331	0.0374	0.0418	0.0464	0.0510	0.0606	0.0703	0.0802	0.1000
85	0.0246	0.0285	0.0326	0.0370	0.0415	0.0461	0.0508	0.0604	0.0702	0.0801	0.1000
90	0.0240	0.0280	0.0323	0.0367	0.0412	0.0459	0.0506	0.0603	0.0702	0.0801	0.1000
95	0.0236	0.0276	0.0319	0.0364	0.0410	0.0457	0.0505	0.0602	0.0701	0.0800	0.1000
100	0.0232	0.0273	0.0316	0.0362	0.0408	0.0456	0.0504	0.0602	0.0701	0.0800	0.1000

Values of $\dfrac{1}{(1+i)^n}$ Present-worth Factor (p^n)

$$P = \frac{A}{(1+i)^n}$$

n	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	10%
1	0.9804	0.9756	0.9709	0.9662	0.9615	0.9569	0.9524	0.9434	0.9346	0.9259	0.9091
2	0.9612	0.9518	0.9426	0.9335	0.9246	0.9157	0.9070	0.8900	0.8734	0.8573	0.8264
3	0.9423	0.9286	0.9151	0.9019	0.8890	0.8763	0.8638	0.8396	0.8163	0.7938	0.7513
4	0.9238	0.9060	0.8884	0.8714	0.8548	0.8386	0.8227	0.7921	0.7629	0.7350	0.6830
5	0.9057	0.8839	0.8626	0.8420	0.8219	0.8025	0.7835	0.7473	0.7130	0.6806	0.6209
6	0.8880	0.8623	0.8375	0.8135	0.7903	0.7679	0.7462	0.7050	0.6663	0.6302	0.5645
7	0.8706	0.8413	0.8131	0.7860	0.7599	0.7348	0.7107	0.6651	0.6227	0.5835	0.5132
8	0.8535	0.8207	0.7894	0.7594	0.7307	0.7032	0.6768	0.6274	0.5820	0.5403	0.4665
9	0.8638	0.8007	0.7664	0.7337	0.7026	0.6729	0.6446	0.5919	0.5439	0.5002	0.4241
10	0.8203	0.7812	0.7441	0.7089	0.6756	0.6439	0.6139	0.5584	0.5083	0.4632	0.3855
11	0.8043	0.7621	0.7224	0.6849	0.6496	0.6162	0.5847	0.5268	0.4751	0.4289	0.3505
12	0.7885	0.7436	0.7014	0.6618	0.6246	0.5897	0.5568	0.4970	0.4440	0.3971	0.3186
13	0.7730	0.7254	0.6810	0.6394	0.6006	0.5643	0.5303	0.4688	0.4150	0.3677	0.2897
14	0.7579	0.7077	0.6611	0.6178	0.5775	0.5400	0.5051	0.4423	0.3878	0.3405	0.2633
15	0.7430	0.6905	0.6419	0.5969	0.5553	0.5167	0.4810	0.4173	0.3624	0.3152	0.2394
16	0.7284	0.6736	0.6232	0.5767	0.5339	0.4945	0.4581	0.3936	0.3387	0.2919	0.2176
17	0.7142	0.6572	0.6050	0.5572	0.5134	0.4732	0.4363	0.3714	0.3166	0.2703	0.1978
18	0.7002	0.6412	0.5874	0.5384	0.4936	0.4528	0.4155	0.3503	0.2959	0.2502	0.1799
19	0.6864	0.6255	0.5703	0.5202	0.4746	0.4333	0.3957	0.3305	0.2765	0.2317	0.1635
20	0.6730	0.6103	0.5537	0.5026	0.4564	0.4146	0.3769	0.3118	0.2584	0.2145	0.1486
21	0.6598	0.5954	0.5375	0.4856	0.4388	0.3968	0.3589	0.2942	0.2415	0.1987	0.1351
22	0.6468	0.5809	0.5219	0.4692	0.4220	0.3797	0.3418	0.2775	0.2257	0.1839	0.1228
23	0.6342	0.5667	0.5067	0.4533	0.4057	0.3634	0.3256	0.2618	0.2109	0.1703	0.1117
24	0.6217	0.5529	0.4919	0.4380	0.3901	0.3477	0.3101	0.2470	0.1971	0.1577	0.1015
25	0.6095	0.5394	0.4776	0.4231	0.3751	0.3327	0.2953	0.2330	0.1842	0.1460	0.0923
26	0.5976	0.5262	0.4637	0.4088	0.3607	0.3184	0.2812	0.2198	0.1722	0.1352	0.0839
27	0.5859	0.5134	0.4502	0.3950	0.3468	0.3047	0.2678	0.2074	0.1609	0.1252	0.0763
28	0.5744	0.5009	0.4371	0.3817	0.3335	0.2916	0.2551	0.1956	0.1504	0.1159	0.0693
29	0.5631	0.4887	0.4243	0.3687	0.3207	0.2790	0.2429	0.1846	0.1406	0.1073	0.0630
30	0.5521	0.4767	0.4120	0.3563	0.3083	0.2670	0.2314	0.1741	0.1314	0.0994	0.0573
31	0.5412	0.4615	0.4000	0.3442	0.2965	0.2555	0.2204	0.1643	0.1228	0.0920	0.0521
32	0.5306	0.4538	0.3883	0.3326	0.2851	0.2445	0.2099	0.1550	0.1147	0.0852	0.0474
33	0.5202	0.4427	0.3770	0.3213	0.2741	0.2340	0.1999	0.1462	0.1072	0.0789	0.0431
34	0.5100	0.4319	0.3660	0.3105	0.2636	0.2239	0.1904	0.1379	0.1002	0.0730	0.0391
35	0.5000	0.4214	0.3554	0.3000	0.2534	0.2143	0.1813	0.1301	0.0937	0.0676	0.0356
40	0.4529	0.3724	0.3066	0.2526	0.2083	0.1719	0.1420	0.0972	0.0668	0.0460	0.0221
45	0.4102	0.3292	0.2644	0.2127	0.1712	0.1380	0.1113	0.0727	0.0476	0.0313	0.0137
50	0.3715	0.2909	0.2281	0.1791	0.1407	0.1107	0.0872	0.0543	0.0339	0.0213	0.0085
55	0.3365	0.2572	0.1968	0.1508	0.1157	0.0888	0.0683	0.0406	0.0242	0.0145	0.0053
60	0.3048	0.2273	0.1697	0.1269	0.0951	0.0713	0.0535	0.0303	0.0173	0.0099	0.0033
65	0.2761	0.2009	0.1464	0.1069	0.0781	0.0572	0.0419	0.0227	0.0123	0.0067	0.0020
70	0.2500	0.1776	0.1263	0.0900	0.0642	0.0459	0.0329	0.0169	0.0088	0.0046	0.0013
75	0.2265	0.1569	0.1089	0.0758	0.0528	0.0368	0.0258	0.0127	0.0063	0.0031	0.0008
80	0.2051	0.1387	0.0940	0.0638	0.0434	0.0296	0.0202	0.0095	0.0045	0.0021	0.0005
85	0.1858	0.1226	0.0811	0.0537	0.0357	0.0237	0.0158	0.0071	0.0032	0.0014	0.0003
90	0.1683	0.1084	0.0699	0.0452	0.0293	0.0190	0.0124	0.0053	0.0023	0.0010	0.0002
95	0.1524	0.0958	0.0603	0.0381	0.0241	0.0153	0.0097	0.0039	0.0016	0.0007	0.0001
100	0.1380	0.0846	0.0520	0.0321	0.0198	0.0123	0.0076	0.0029	0.0012	0.0005	0.0001



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.

(2) "Characteristics of Soil Groups Pertaining to Roads and Airfields," Appendix B, *The Unified Soil Classification System*, U.S. Army Corps of Engineers, Technical Memorandum 3-357, 1953.

(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.

(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*.

(5) F. N. Hveem, "A New Approach for Pavement Design," *Engineering News-Record*, Vol. 141, No. 2, July 8, 1948, pages 134-139. R is factor used in California Stabilometer Method of Design.

(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152. k is factor used in Westergaard's analysis for design of concrete pavement.

(7) See reference (6), page 184.

***Fig. 9.* Approximate interrelationships of soil classifications and bearing values.**