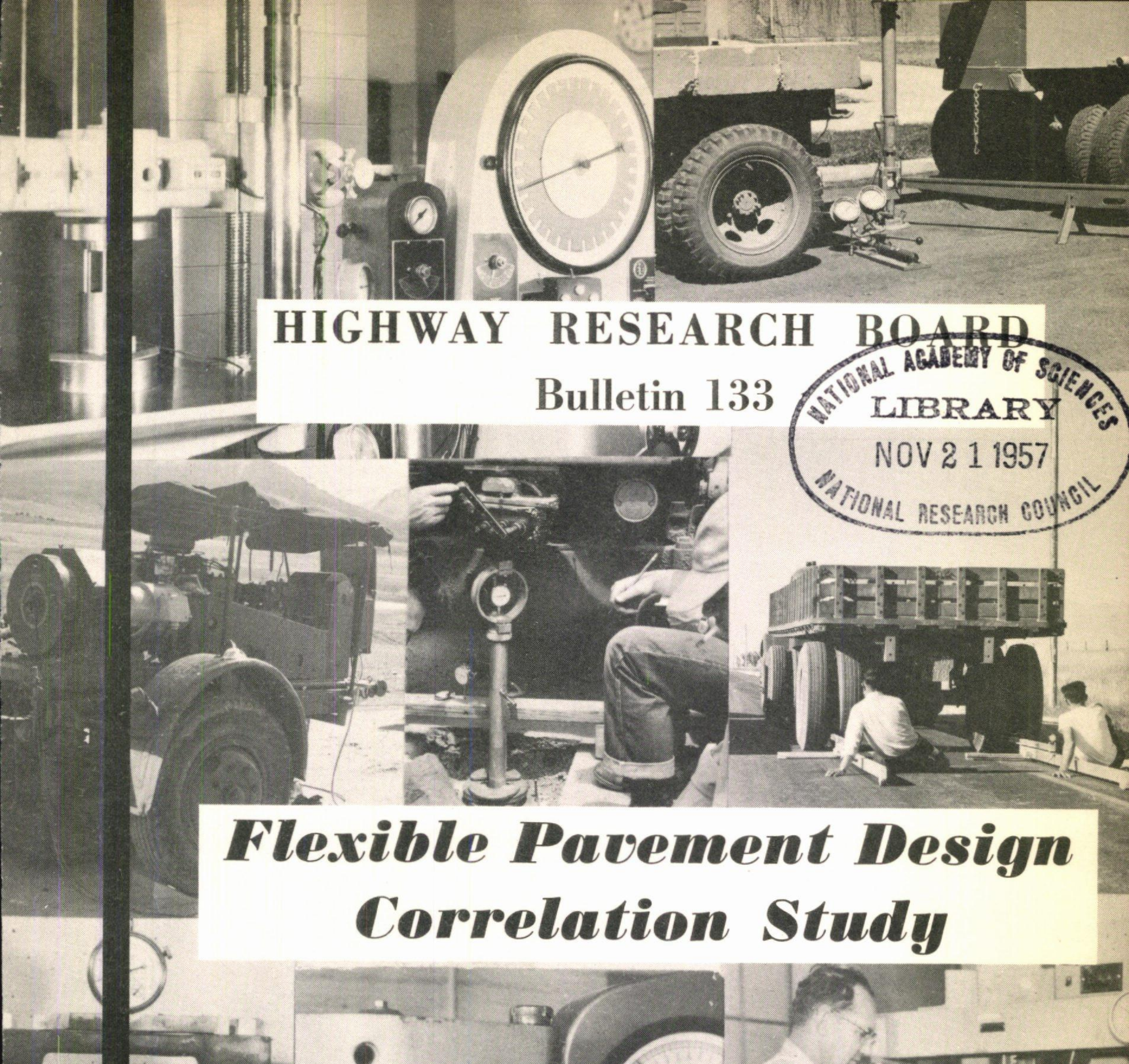

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Flexible Pavement Design Correlation Study

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Foreword

For years the activities of this Committee have been directed primarily to the compilation and dissemination of information on the problem of flexible pavement design and to how this knowledge is being applied in practice. This has been accomplished by the solicitation and sponsorship of papers for the annual meetings of the Highway Research Board. Several of these papers have presented the findings of research and some have described in detail certain design procedures as developed or used by state highway departments and other agencies.

The Board also has published the results of a considerable number of other special activities of this committee. Examples are Current Road Problems 8 and 8R and Bulletin 80. The latter contained information dealing with the essential features of various design methods in use by the states. Recently a survey of cross-sectional design practices has been completed, the results of which will be published as a committee activity circular.

In 1950 the committee initiated a unique study, one in which a number of materials testing laboratories collaborated in the solution of a particular problem of pavement design. The laboratories were furnished samples of the subgrade soil and foundation course materials from a given pavement and were instructed to utilize these materials in designing a pavement that would be capable of carrying a specified weight and volume of traffic. Participation in this project served to enable any one laboratory to compare its method of design with those of the other laboratories.

The conduct of this study proved of great interest to the committee and all of the participants, but the results did not receive the approval of the committee for publication, the principal reason being that sufficient information was not obtained regarding the ultimate load-supporting capacity of the pavement in question.

When the WASHO Road Test was being planned the committee agreed that since adequate factual information would be obtained from this test as to the necessary thickness of pavement to carry a range of single and tandem axle loads a second design correlation study should be undertaken. Nineteen agencies accepted the invitation of the committee to participate in the project. The progress in this work and the spirit of cooperation with which it was carried out were gratifying to the committee.

The results of the study now summarized and discussed in this report quite definitely establish the fact that the different design methods used by the participating agencies gave some rather large variations in the thicknesses of pavement as designed for the specified traffic. Also, that there is great need to develop more factual information on the question of effect of load repetitions and on the question of the relative ability of bituminous surface courses and granular base courses to support traffic loads.

Whether the knowledge acquired from participation in a cooperative project of this type is commensurate with effort expended is still somewhat a matter of conjecture. Nevertheless the subcommittee which gathered the data for this report is of the opinion that the conduct of the study has been worthwhile for a number of reasons: (a) it provides a cross-section of thinking with respect to methods of determination of pavement thickness and of the destructive effect of load repetitions; (b) it affords the opportunity for those engaged in flexible pavement design problem to compare procedures and testing techniques and (c) it focuses attention on those phases of the flexible pavement problem that are in need of additional study.

Cooperative Study of Pavement Thickness

The principal objective of this study sponsored by the Committee on Flexible Pavement Design was to develop information from cooperative testing of materials which would serve to compare the many different methods currently in use for determining the thickness of flexible pavements. In the expectation that definite information would be obtained regarding the necessary thickness of the pavement in the WASHO Road Test to carry certain prescribed loads, the committee decided that the materials composing this pavement should be used as a basis of the study. Samples of the subgrade soil, base and subbase materials were furnished to 19 state highway department laboratories with the request that after studying the materials they submit an estimate of (a) the thicknesses of pavement structure necessary to withstand 200,000 trips of each of the four test vehicles, and (b) the number of trips for each of the four vehicles that would produce failure of the various sections of the test pavement.

For the test sections having 2-in. bituminous surfaces there was good agreement between the average estimated total thicknesses of pavement as reported by the participants and the thicknesses which, by traffic testing, were found to be sufficient for the respective loads. However, for the sections having 4-in. bituminous surfaces the average estimated thicknesses (surface, base and subbase) reported were considerably greater than those found from the road tests to be actually necessary.

With respect to the estimates of the number to trips necessary to fail the various sections of the test road there was a large diversity in the answers, clearly indicating that much more attention and study should be devoted to this phase of pavement design.

●THE WASHO Test Road was built in southeastern Idaho in 1952 and was tested under controlled traffic during 1953 and 1954 (1). The principal objective of the test was to determine the thickness requirements of two designs of flexible pavements for two single and two tandem axle loads.

Sections of the test pavement varied in thickness from 6 to 22-in. in 4-in. increments. Half of the sections were surfaced with 2-in. of asphaltic concrete and the remainder with 4 in. Beneath these two surfaces a granular base course of 4 and 2 in. in thickness was used. The balance of the overall structure thickness was made up of a granular subbase course.

In Part 2 of the WASHO Road Test Report the findings of the investigation (14 in number) are enumerated (2). Insofar as the results of this study are concerned, finding No. 1 is pertinent. It may be stated in part as follows:

> On a basis of engineering analysis the minimum thicknesses of pavement structure with 2-inch surfacing that would have been adequate to carry the four axle loads (238,000 applications of each, or 119,000 vehicle trips) were 16, 19, 17 and 20 inches for the 18,000- and 22,400- pound single axle and 32,000- and 40,000-pound tandem axle loads, respectively. For the 4-inch surfacing the results of the tests showed that the 10-inch thickness sections were undamaged by the first three loads and that the 14-inch section was undamaged by the 40,000-pound tandem axle load.

The principal purpose of the design correlation study was to determine how closely the estimated thicknesses of the two designs of pavement (2- and 4-in. AC) for the four axle loads, reported by those participating in the study, would agree with the thicknesses (listed in the preceding paragraph) that were found to be adequate from the tests.

The conduct of the study was approved by the Advisory Committee of the WASHO Road Test and, through their cooperation, representative samples of the materials were made available to those agencies who expressed a desire to participate. Invitations to do so were extended to all the state highway departments and other agencies interested in the problem. The following 18 states and one territory accepted the invitation: Alabama, Arizona, California, Delaware, Idaho, Kansas, Kentucky, Maryland, Missouri, New

Mexico, New York, North Carolina, Puerto Rico, South Dakota, Texas, Washington, West Virginia, Wyoming and Colorado.

At a meeting of the Flexible Pavement Committee held near the site of the WASHO Test Road in June 1953, a subcommittee was appointed to handle the task of assembling the data obtained from the study, make such analyses as appeared practicable, and prepare the report describing the results. It was made up of the following members:

Robert Horonjeff (Chairman) - Research Engineer, Institute of Transportation and Traffic Engineering, University of California, Berkeley, California.

Raymond C. Herner - Chief, Airport Division, Technical Development and Evaluation Center, Civil Aeronautics Administration.

Chester McDowell - Senior Soils Engineer, Texas Highway Department.

D.J. Olinger - Principal Materials Engineer, Wyoming Highway Department.

Frank R. Olmstead - Chief, Soils Section, Physical Research Branch, Bureau of Public Roads, Washington, D.C.

PROVISIONS OF STUDY

Samples of the subgrade soil, base and subbase materials from the WASHO Test Road were furnished each laboratory taking part in the study. After classifying and testing these materials each participant was to develop answers to two questions designated "Problem A" and "Problem B." It was stipulated that the answers to Problem A should apply for the conditions of climate at the test road and for the as-constructed conditions of the components of the test pavement. In contrast, the answers to Problem B were to apply for the climate and pavement component conditions that each participant considered would obtain in his own area of operation. A detailed description of each of the problems follows:

Problem A

Information Requested

1. Subbase thicknesses for the two WASHO combinations of thickness of surface and base.

	Axle loads (lb.)							
	Single				Tandem			
	18,000		22,400		32,000		40,000	
Surface (in.)[a]	2	4	2	4	2	4	2	4
Base (in.)[a]	4	2	4	2	4	2	4	2
Subbase (in.)	-	-	-	-	-	-	-	-

[a] Thicknesses of the surfacing and base course different from those of the WASHO pavement may be submitted as an alternate design.

2. Number of trips of the four axle loads to produce failure of the WASHO sections:

Surface (in.)	2	2	2	2	2	4	4	4	4	4
Base (in.)	4	4	4	4	4	2	2	2	2	2
Subbase (in.)	0	4	8	12	16	0	4	8	12	16
Total (in.)	6	10	14	18	22	6	10	14	18	22

Information Furnished

1. Condition of materials as constructed in the test road.

	Subgrade Soil[a]	Base Course	Subbase Course[b]
Density (pcf.)	89	133	131
Moisture content (percent dry weight)	23	5	5

[a] Condition uniform to a depth of 2 feet. Underlying material of the same general character to an indefinite depth.

[b] Subbase material same source as processed base material except uncrushed.

2. Traffic

	Trips per day per lane	Total Trips per lane
18,000 single	700	200,000
22,400 single	700	200,000
32,000 tandem	700	200,000
40,000 tandem	700	200,000

Note: Inflation pressure of all tires maintained at 70 psi. All tires to conform to specifications of Tire and Rim Assoc.

3. Thicknesses of surface course and gravel base course.

Surface course - 2 and 4 in. of bituminous concrete with 120-150 penetration asphalt 4.8 percent by weight.

Base course - 4 in. in thickness where surface is 2 in.
2 in. in thickness where surface is 4 in.

4. Climate of the road test area.

Length of record........................23 years
Maximum average temperature..............108° F.
Minimum average temperature..............-25° F.
January average temperature..............21.3° F.
July average temperature.................70.2° F.
Killing frost average date...............Sept. 19 to May 28[1]
Range of depth of frost penetration..........18-36 in.
(Average depth about 24 in.)..............

Average precipitation:

January	1.40 in.	July	1.12 in.
February	1.33 in.	August	.99 in.
March	1.40 in.	September	1.05 in.
April	1.61 in.	October	1.36 in.
May	1.28 in.	November	1.14 in.
June	.91 in.	December	1.27 in.

Average annual........................14.86 in.

Problem B

Information Requested

1. Thicknesses of surface course, base course and subbase course adequate to carry the test loads for the WASHO traffic and for certain stipulated traffic patterns.
2. Design conditions of materials estimated or assumed by participant.

Information Furnished

1. Magnitudes of loads and traffic same as in "Problem A", plus the following traffic patterns:

Passenger Cars	Pattern (a)	Pattern (b)	Pattern (c)	Pattern (d)
No. of vehicles	80	800	3,200	1,000
Commercial Vehicles				
No. of axles 10,000 lb. or less	10[a]	100[a]	400[a]	600[a]
No. of axles 12,000 lb.	4	40	160	800
No. of axles 14,000 lb.	3	30	120	1,000
No. of axles 16,000 lb.	2	20	80	520
No. of axles 18,000 lb.	1	10	40	80

[a] Axle load applications per lane per day.

[1] Average annual number of days without killing frost, 120 days.

TABLE 1

PROBLEM A - SUBBASE THICKNESS

Laboratory	2-inch AC + 4-inch base				4-inch AC + 2-inch base			
	18,000 lb. Single Axle	22,400 lb Single Axle	32,000 lb. Tandem Axle	40,000 lb. Tandem Axle	18,000 lb. Single Axle	22,400 lb. Single Axle	32,000 lb. Tandem Axle	40,000 lb. Tandem Axle
Alabama	10[a]	12	12	14	10	12	12	14
Arizona	8	14	8	14	8	14	8	14
California	12	13.5	13	14.5	11.5	13	12.5	14
Colorado	13	-	13	-	12	-	12	-
Delaware	9	10	12	16	9	10	12	16
Idaho	11	14	11	14	11	14	11	14
Kansas	6	8	6	8	5	7	5	7
Kentucky	12	17	12	17	11	16	11	16
Maryland	18	21	17	19	18	21	17	19
Missouri	3	3	3	3	3	3	3	3
New Mexico	14	16	15	18	4	6	5	8
New York	14	16	15	18	14	16	15	18
North Carolina	21	24	19	23	21	24	19	23
Puerto Rico	9	10	18	18	9	10	18	18
South Dakota	8	12	8	12	6	10	6	10
Texas	9	12	11	14	5.5	7	6	9
Washington	9.5	11	9	10.5	8.5	10	8.5	9.5
West Virginia	9	13	9	13	9	13	9	13
Wyoming	7.5	8.5	7.5	9.5	7.5	8.5	8.5	9.5
Average	10.7	13.1	11.5	14.2	9.6	11.9	10.4	13.1
Test Road	10	13	11	14	4	4	4	8

[a] Values in inches

DATA REPORTED BY PARTICIPANTS

The data reported by the participants are summarized in Tables 1 through 7. Table 1 lists the estimated subbase thicknesses for the four test axle loads along with the thicknesses found to be adequate from th e traffic tests. Tables 2, 3, 4 and 5 present the estimates of the number of trips of each of the loads that would produce failure of the various pavement sections.

Due to the fact that the ability of the WASHO pavement to carry load varied greatly with the seasons, failures were spasmodic in tvpe and little information was obtained from the tests on the question of effect of load repetitions. However, for purposes of comparison there are shown in each Table estimates of the number of trips that would have produced 200 sq. ft. (about 5 per-cent) of distress in each section of the test pavement. These values were extrapolated from data presented in the WASHO report.

Table 6 presents the participants' estimates of necessary thicknesses of surfacing, base, and subbase for the WASHO traffic, assuming that the climatic conditions are those that would normally be encountered by each participant within his own area rather than that at the site of the test road. Table 7 lists similar data for the special traffic patterns referred to under the provisions of Problem B.

ANALYSIS OF DATA

The discussion and analysis of the data reported are divided into four parts. The first deals with a comparison of the thicknesses relating to Problem A; the second with load repetitions necessary to produce failure of the various sections of the test road; the third compares thick-

TABLE 2

PROBLEM A - NUMBER OF TRIPS TO PRODUCE FAILURE - 18,000 lb. SINGLE AXLE LOAD

Laboratory	2-inch AC + 4-inch base, Subbase thickness - inches					4-inch AC + 2-inch base, Subbase thickness - inches				
	0	4	8	12	16	0	4	8	12	16
Alabama	-	Unlim.	Unlim	Unlim.	Unlim	-	Unlim.	Unlim	Unlim	Unlim.
California	15	240	5,300	195,000	14,100,000	22	338	7,500	343,000	28,000,000
Kansas	150	25,000	300,000	40,000,000	500,000,000	300	50,000	5,000,000	60,000,000	600,000,000
Kentucky	15,625	39,050	113,100	469,000	1,875,000	23,450	46,900	156,000	786,500	2,810,000
New Mexico	8,000	10,100	100,000	200,000	200,000	100,000	200,000	200,000	250,000	300,000
Texas	7,750	21,000	61,000	155,000	413,500	13,000	51,000	195,000	759,500	2,044,000
Washington	74	15,000	46,500	1,800,000	48,000,000	102	33,750	87,000	4,350,000	165,500,000
West Virginia	15,000	30,000	60,000	300,000	3,000,000	15,000	30,000	60,000	300,000	3,000,000
WASHO[a]	5,000	8,500	86,000	86,000	119,000+	20,000	119,000+	119,000+	119,000+	119,000+

[a] Extrapolated values.

TABLE 3

PROBLEM A - NUMBER OF TRIPS TO PRODUCE FAILURE - 22,400 LB. SINGLE AXLE LOAD

Laboratory	2-inch AC + 4-inch base					4-inch AC + 2-inch base				
	Subbase thickness - inches					Subbase thickness - inches				
	0	4	8	12	16	0	4	8	12	16
Alabama	-	Unlim.	Unlim	Unlim	Unlim.	Unlim.	Unlim.	Unlim	Unlim	Unlim.
California	11	130	2,000	60,000	2,400,000	15	170	2,800	81,000	4,450,000
Kansas	100	7,000	200,000	9,000,000	16,000,000	150	12,000	750,000	12,000,000	75,000,000
Kentucky	3,905	9,775	28,300	117,500	469,000	5,860	11,750	39,100	195,500	710,000
New Mexico	5,000	8,000	50,000	100,000	200,000	100,000	200,000	225,000	250,000	275,000
Texas	5,750	13,000	31,000	70,000	155,000	10,000	32,500	107,500	340,000	1,100,000
Washington	45	5,000	13,000	400,000	7,000,000	58	10,000	25,000	850,000	22,500,000
West Virginia	4,000	8,000	16,000	80,000	800,000	4,000	8,000	16,000	80,000	800,000
WASHO[a]	8,000	8,500	83,500	119,000+	119,000+	8,500	119,000+	119,000+	119,000+	119,000+

[a] Extrapolated values.

nesses relating to Problem B, and the fourth deals with the thickness requirements for the various test loads.

Comparison of Pavement Thicknesses for the Conditions of Problem A

In Problem A the participants were asked to report the thicknesses of subbase courses that they would have considered adequate (in addition to the surface and base course) to support the four different axle loads used in the WASHO test. The climatic conditions were assumed the same as those at the site of the test and the thicknesses were designed for the specified in-place densities and moisture contents of the subgrade, base, and subbase.

TABLE 4

PROBLEM A - NUMBER OF TRIPS TO PRODUCE FAILURE - 32,000 LB. TANDEM AXLE LOAD

Laboratory	2-inches AC + 4-inch base					4-inch AC + 2-inch base				
	Subbase thickness - inches					Subbase thickness - inches				
	0	4	8	12	16	0	4	8	12	16
Alabama	75,000	175,000	Unlim.	Unlim.	Unlim.	125,000	175,000	Unlim.	Unlim.	Unlim.
California	7	100	2,000	62,500	4,400,000	10	140	2,850	110,000	8,500,000
Kansas	750	25,000	3,000,000	40,000,000	500,000,000	300	50,000	3,000,000	60,000,000	600,000,000
New Mexico	5,000	5,000	50,000	200,000	200,000	100,000	150,000	200,000	200,000	200,000
Texas	6,500	15,500	36,500	87,500	210,000	11,750	43,000	155,000	550,000	1,750,000
Washington	51	14,750	42,500	2,250,000	70,500,000	72	33,500	91,000	5,100,000	281,000,000
West Virginia	15,000	30,000	60,000	300,000	3,000,000	15,000	30,000	60,000	300,000	3,000,000
WASHO[a]	5,000	8,500	119,000+	119,000+	119,000+	11,500	119,000+	119,000+	119,000+	119,000+

[a] Extrapolated values.

Table 1 lists the subbase thicknesses reported. These data are shown in graphical form in Figures 1 and 2. Table 8 was prepared to indicate the differences between the thicknesses submitted by participants and the minimum thicknesses found to be adequate from the road test.

In comparing the thicknesses reported with those found to be adequate from the test, there are several factors which should be borne in mind. It is obvious that the controlled traffic on the test road differed in many respects from that on actual highways, particu-

TABLE 5

PROBLEM A - NUMBER OF TRIPS TO PRODUCE FAILURE - 40,000 LB. TANDEM AXLE LOAD

Laboratory	2-inch AC + 4-inch base					4-inch AC + 2-inch base				
	Subbase thickness - inches					Subbase thickness - inches				
	0	4	8	12	16	0	4	8	12	16
Alabama	50,000	75,000	Unlim.	Unlim.	Unlim.	50,000	75,000	Unlim	Unlim.	Unlim.
California	5	50	760	17,500	700,000	7	70	1,000	26,500	1,250,000
Kansas	100	7,000	200,000	9,000,000	60,000,000	150	12,000	750,000	12,000,000	75,000,000
New Mexico	5,000	5,000	25,000	100,000	200,000	25,000	50,000	200,000	225,000	250,000
Texas	5,250	10,750	22,500	46,000	97,500	7,500	21,000	58,500	155,000	413,500
Washington	29	4,400	11,500	425,000	9,300,000	40	9,150	23,500	1,000,000	31,500,000
West Virginia	4,000	8,000	16,000	80,000	800,000	4,000	8,000	16,000	80,000	800,000
WASHO[a]	4,000	8,500	79,000	81,000	119,000+	8,500	19,000	119,000+	119,000+	119,000+

[a] Extrapolated values.

TABLE 6

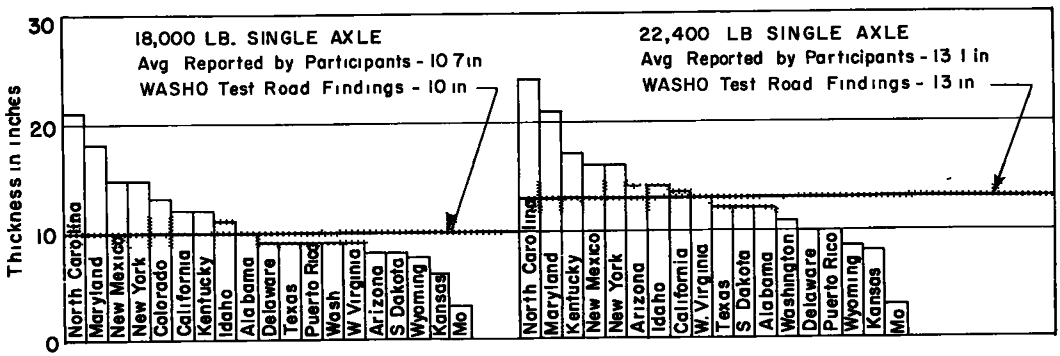
PROBLEM B - THICKNESS OF PAVEMENT COMPONENTS - WASHO TRAFFIC

Laboratory	18,000 lb. Single Axle				22,400 lb. Single Axle				32,000 lb Tandem Axle				40,000 lb. Tandem Axle			
	Surf.	Base	Sub-base	Total	Surf.	Base	Sub-base	Total	Surf.	Base	Sub-base	Total	Surf.	Base	Sub-base	Total
Alabama	1.5[a]	8.0	10.0	19.5	1.5	8.0	10.0	19.5	2.0	10.0	10.0	22.0	2.0	10.0	12.0	24.0
Arizona	2.5	3.0	9.0	14.5	2.5	3.0	15.0	20.5	2.5	3.0	9.0	14.5	2.5	3.0	15.0	20.5
California	3.0	8.0	5.5	16.5	3.0	8.0	7.0	18.0	3.0	8.0	6.5	17.5	3.0	8.0	8.0	19.0
Colorado	2.0	4.0	14.0	20.0	3.0	4.0	11.0	18.0	2.0	4.0	14.0	20.0	3.0	4.0	11.0	18.0
Delaware	3.0	6.0	6.0	15.0	3.0	6.0	7.0	16.0	3.0	8.0	8.0	19.0	3.0	8.0	10.0	21.0
Kansas	2.0	4.0	9.0	15.0	2.0	4.0	11.0	17.0	2.0	4.0	9.0	15.0	2.0	4.0	11.0	17.0
Kentucky	3.0	4.0	11.0	18.0	3.0	6.0	12.0	21.0	3.0	4.0	12.0	19.0	3.0	6.0	13.0	22.0
Maryland	2.0	10.0	12.0	24.0	2.0	12.0	12.0	26.0	2.0	9.0	12.0	23.0	2.0	10.0	12.0	24.0
Missouri	-	-	-	9.0	-	-	-	9.0	-	-	-	9.0	-	-	-	9.0
New Mexico	3.0	3.0	9.0	15.0	3.0	3.0	11.0	17.0	3.0	3.0	10.0	16.0	3.0	3.0	13.0	19.0
No Carolina	2.0	4.0	21.0	27.0	2.0	4.0	24.0	30.0	2.0	4.0	19.0	25.0	2.0	4.0	23.0	29.0
Puerto Rico	3.0	4.0	8.0	15.0	3.0	4.0	9.0	16.0	4.0	6.0	9.0	19.0	4.0	6.0	11.0	21.0
South Dakota	2.0	5.0	8.0	15.0	2.0	5.0	11.0	18.0	2.0	5.0	8.0	15.0	2.0	5.0	11.0	18.0
Texas	1.0	5.0	3.0	9.0	1.0	5.0	4.0	10.0	1.0	5.0	3.0	9.0	1.0	5.0	5.0	11.0
Washington	3.0	2.0	15.0	20.0	3.5	3.5	19.0	26.0	3.0	2.0	15.0	20.0	3.0	3.0	16.0	22.0
West Virginia	2.0	4.0	6.0	12.0	2.5	4.0	9.0	15.0	2.0	4.0	6.0	12.0	2.0	4.0	9.0	15.0
Average	2.3	4.9	9.8	16.5	2.5	5.3	11.5	18.6	2.4	5.3	10.0	17.2	2.5	5.5	12.0	19.3

[a] Values in inches

larly with respect to timing and positioning of load applications. Differences between the figures submitted by the participants and those determined from the road test may also in part be due to the fact that the designs were based on a total of 200,000 trips whereas actually only 119,000 trips were completed.

The pavement sections in the test road were constructed in 4-in. thickness increments and considerable difficulty was apparently experienced in the analysis of the pavement behavior data to determine within narrow or exact limits the thickness capable of supporting a given axle load. For example, the 10-in. sections of pavement having a



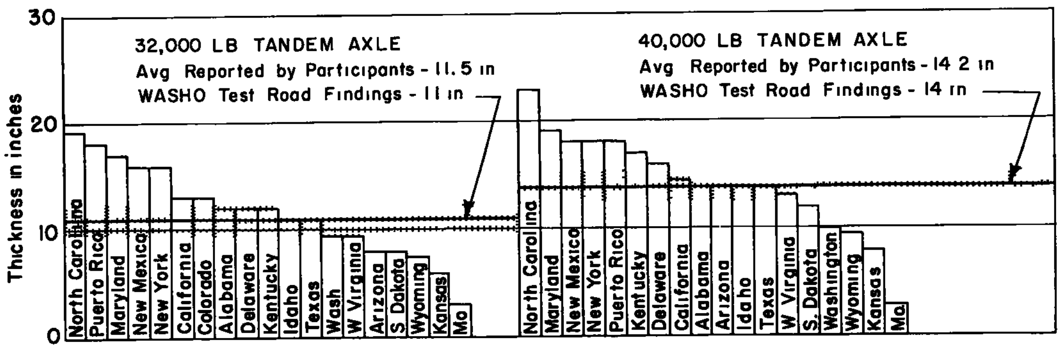


Figure 1. Subbase thickness for stated axle loads (2 in. A.C. + 4 in. base).

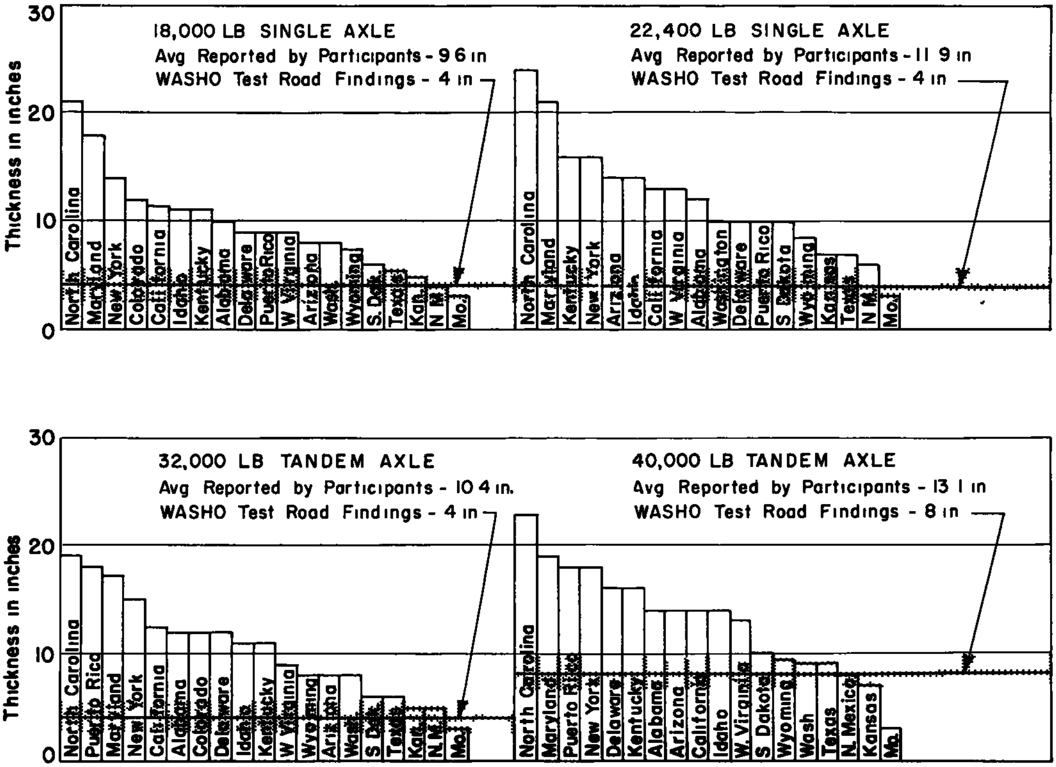


Figure 2. Subbase thickness for stated axle loads (4 in. A.C. + 2 in. base).

4-in. surface, 2-in. base and 4-in. subbase may have carried the 18,000- and 22,400-lb. axle loads. However, both of these loads may have produced distress in the adjoining thinner section (4-in. surface, 2-in. base, no subbase). How would a section having a 2-in. thickness of subbase have performed? It might have been capable of carrying only the lighter of the two loads. Thus, variations of 1½ in. below or above the WASHO thicknesses may not be significant. Accordingly the shaded bands representing 3 in. of thickness of subbase were drawn in Figures 1 and 2.

That a very pronounced range in the thickness of the subbase was reported by the participants for both the 2- and 4-in. AC designs of pavement is clearly evident from the plotted values. For example, for the 18,000-lb. single-axle load, 2-in. AC design (Figure 1), the minimum value is 3 and the maximum 21 in.

Table 9 was prepared to show the extent of variability in the values reported by the participants and to enable comparisons to be drawn between these values and those developed from the WASHO traffic tests. For the 2-in. AC pavement about seven of the

TABLE 7

PROBLEM B - THICKNESS OF PAVEMENT COMPONENTS - SPECIAL TRAFFIC PATTERNS.

Laboratory	Traffic Pattern a				Traffic Pattern b				Traffic Pattern c				Traffic Pattern d			
Laboratory	Surf	Base	Sub-base	Total	Surf.	Base	Sub-base	Total	Surf	Base	Sub-base	Total	Surf	Base	Sub-base	Total
Arizona	2[a]	3	6	11	2	3	9	14	2	3	6	11	2	3	9	14
California	2	4	7	13	2.5	6	6	14.5	3	8	4 5	15 5	3	8	6	17
Colorado	2	4	11	17	2	4	14	20	3	4	11	18	3	4	11	18
Delaware	2	6	6	14	2	6	6	14	3	6	6	15	3	6	6	15
Idaho	2	3 6	8 4	14	2.4	4.8	9 8	17	2.4	4.8	11 6	18.8	3.6	4.8	10.4	18 8
Kansas	2	4	1	7	2	4	5	13	2	4	9	15	2	4	13	19
Kentucky	2	2	5	9	2.5	4	7	13 5	2.8	4	10	16.8	3	6	11	20
Maryland	2	7	12	21.	2	7	12	21.	6.5	12	2	20 5	6.5	12	4	22.5
Missouri	-	-	-	6	-	-	-	7	-	-	-	9	-	-	-	9
New Mexico	2	3	3	8	2	3	9	14	3	3	11	17	4	3	8	15

[a] Values in inches.

TABLE 8

PROBLEM A - DIFFERENCES BETWEEN WASHO AND REPORTED SUBBASE THICKNESSES

	2-inch AC + 4-inch base				4-inch AC + 2-inch base			
Laboratory	18,000 lb	22,400 lb	32,000 lb.	40,000 lb	18,000 lb.	22,400 lb.	32,000 lb.	40,000 lb.
Alabama	0	-1	+1	0	+6	+8	+8	+6
Arizona	-2	+1	-3	0	+4	+10	+4	+6
California	+2	+½	+2	+½	+7½	+9	+8½	+6
Colorado	+3	-	+2	-	+8	-	+8	-
Delaware	-1	-3	+1	+2	+5	+6	+8	+8
Idaho	+1	+1	0	0	+7	+10	+7	+6
Kansas	-4	-5	-5	-6	+1	+3	+1	-1
Kentucky	+2	+4	+1	+3	+7	+12	+7	+8
Maryland	+8	+8	+6	+5	+14	+17	+13	+11
Missouri	-7	-10	-8	-11	-1	-1	-1	-5
New Mexico	+4	+3	+4	+4	0	+2	+1	0
New York	+4	+3	+4	+4	+10	+12	+11	+10
North Carolina	+11	+11	+8	+9	+17	+20	+15	+15
Puerto Rico	-1	-3	+7	+4	+5	+6	+14	+10
South Dakota	-2	-1	-3	-2	+2	+6	+2	+2
Texas	-1	-1	0	0	+1½	+3	+2	+1
Washington	-1	-½	-2	-4	+4	+7½	+4	+1
West Virginia	-1	0	-2	-1	+5	+9	+5	+5
Wyoming	-2½	-4½	-3½	-4½	+3½	+4½	+3½	+1½

Note: Plus sign indicates participant submitted thickness greater than minimum considered to be adequate from the test and minus smaller. Values in inches.

laboratories reported subbase thicknesses that lie within the 3-in. band and about eight out of the 19 reported values greater than the WASHO values and about the same number reported values less than the WASHO values. For the 4-in. AC pavement the values of only abour four of the laboratories fall within the band, practically all of them being greater than the WASHO values. Apparently the majority of the participants in the study did not anticipate that, for the conditions obtaining at the site and during the conduct of the WASHO test, the behavior of the test pavement having the thicker surface would prove superior to that having the thinner surface. However, in the foregoing connection, it should be pointed out that if the 3-in. band (Figure 2) were shifted upward, i.e., 1½ in. above and below the average subbase thickness reported by the participants, the variability of the values from this band as a base would be much the same as indicated in the case of the 2-in. AC pavement.

It was mentioned previously that there was a considerable range in the thicknesses reported. An examination of the data indicates that this may have been due in part to differences in the test constants of the materials obtained by the various laboratories.

TABLE 9

PROBLEM A - COMPARISON OF SUBBASE THICKNESS REPORTED WITH WASHO VALUES

Design	Axle Load	Number of values reported: Same as test road	Within 3-inch band	Greater than test road	Less than test road
2-inch AC +4-inch base	18,000-lb. single	1	7	8	10
	22,400-lb. single	1	7	8	9
	32,000-lb. tandem	2	7	10	7
	40,000-lb. tandem	4	6	8	6
4-inch AC + 2-inch base	18,000-lb. single	1	4	17	1
	22,400-lb. single	0	1	17	1
	32,000-lb. tandem	0	3	18	1
	40,000-lb. tandem	1	5	15	2

Note: 19 answers submitted for 18,000- and 32,000-pound axle loads.
18 answers submitted for 22,400- and 40,000-pound axle loads.

Even in standard identification tests of the subgrade soil, there were ranges of 35 to 40 in liquid limit, 6 to 15 in plasticity index, and 67 to 91 in the percentage of the material passing the No. 200 sieve. Some of these differences may be attributed to variability in the composition of the samples of material tested, but probably most of them were due to variations in testing technique.

Similar differences were found in the results of the strength index tests. Inasmuch as the CBR procedure of design was used by a majority of the participants, this procedure was chosen to illustrate what the thicknesses might have been if the same CBR values had been obtained. For instance, values of the subgrade CBR varied from 2 to 7. The significance of such differences is apparent from a study of Figure 3, which shows the basic relations between subgrade CBR and pavement thickness. In most cases the

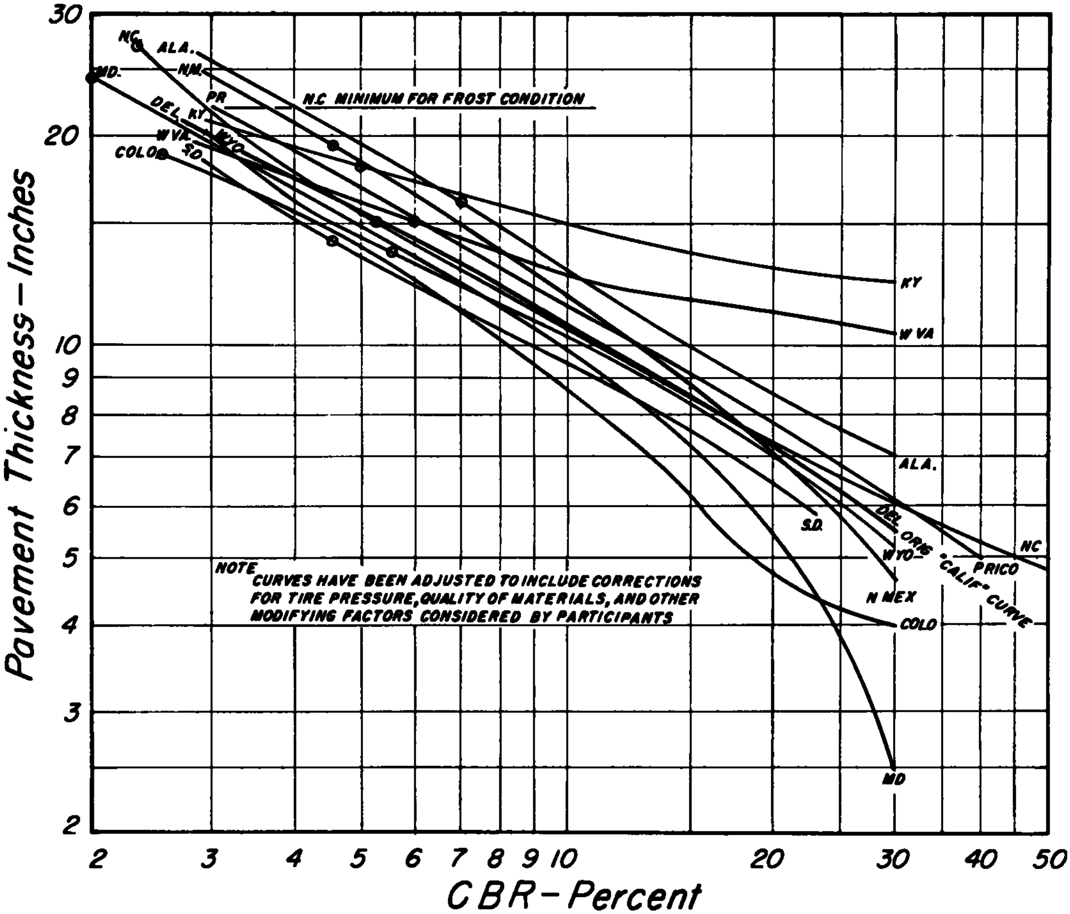


Figure 3. CBR curves for 9,000-lb. wheel load.

drawn curves were developed directly from information furnished by the participants. In some cases, however, the information given was not complete, and it was necessary to use indirect methods of developing the curves. A curve for the 9,000-lb. wheel load interpolated from the original "California" curves given by Porter in the 1942 Proceedings of the Highway Research Board has been included for comparative purposes.

All of the basic curves were adjusted up or down to incorporate any modification used by the participating agencies in adjusting their designs to conditions at the WASHO test road. For instance, Puerto Rico increased the thickness by 10 percent because of the factor of tire pressure; Kentucky increased the subbase thickness 25 percent in the belief that it was of inferior quality; and North Carolina set a minimum thickness of 22 in. because of frost conditions.

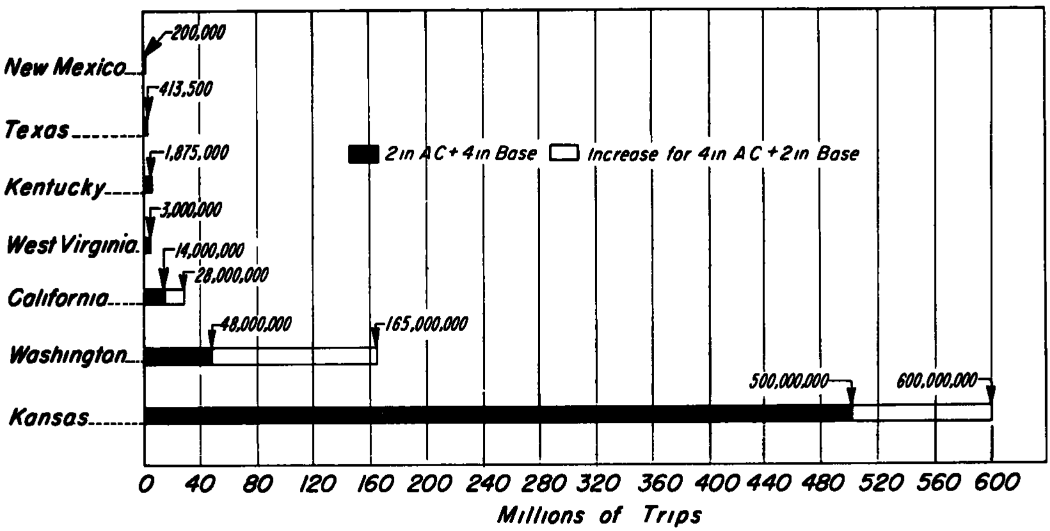


Figure 4. Number of trips to produce failure, 18,000-lb. single axle load, 16-in. subbase.

By virtue of the adjustments which were made, the curves in Figure 3 indicate directly the total thickness reported by each participant for WASHO conditions and for the CBR value found in his tests. They also show clearly the range in thickness for any given CBR value. While some errors may have been introduced in the attempt to interpret incomplete information, the curves are believed to be sufficiently accurate for comparative purposes.

The designs submitted for the first part of Problem A by those agencies using the CBR test actually ranged from $13\frac{1}{2}$ in. to 27 in. in total thickness. The maximum, from North Carolina, was based on a CBR value of 2.3. The second highest (24 in.) was reported by Maryland on the basis of a CBR value of 2. Had all participants used a value of 5 for the subgrade CBR, the range in total thickness would have been narrowed appreciably. North Carolina would still be high, with a thickness of 22 in. It should be pointed out, however, that this thickness was based on frost considerations and not necessarily on the CBR value. The others fall within a comparatively narrow range (13 to 19 in.) with the average reasonably close to the thicknesses determined from the traffic tests.

Another reason for the large spread in the answers reported for Problem A may be due to the fact that many of the participants apparently neglected to give proper consideration to the conditions of subgrade, base, subbase and climate specified.

Comparison of Estimates of the Number of Repetitions to Produce Failure

For this phase of Problem A the participants were asked to estimate the number of trips by each of the four axle loads required to fail the various sections of the test road. Only 8 of the 19 participants attempted to answer this question. The results are presented in Tables 2, 3, 4 and 5.

Figure 4 shows the extreme variations in the estimates of the number of trips of an 18,000-lb. single-axle load necessary to produce failure of the two test road sections having a 16-in. subbase. The data for this chart were taken from Table 2. As stated before, the test road did not yield factual information on the effect of load repetitions which would have permitted direct comparison with the data reported by the participants. However, for comparative purposes data on destructive effects of load repetitions were extrapolated from the WASHO report. Failure was defined as a minimum of 200 sq. ft. of distress in any one pavement section. While such an evaluation appears reasonable, it is realized that the participants differed in their conception of failure; (for example, Alabama defines "failure" as a road with 5 to 10 percent distress; New Mexico as the amount of distress which necessitates maintenance), consequently it is extremely difficult to make direct comparisons of the values shown in the tables.

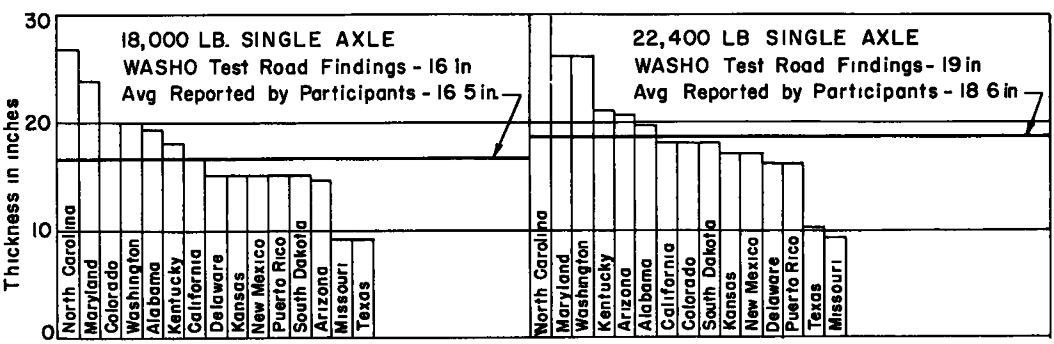
TABLE 10

PROBLEM A AND B - COMPARISON OF TOTAL PAVEMENT THICKNESS

Laboratory	Axle Loads											
	18,000 lb. S			22,400 lb S			32,000 lb T			40,000 lb. T		
	A		B	A		B	A		B	A		B
	2-in AC	4-in AC		2-in AC	4-in AC		4-in AC	4-in. AC		2-in AC	4-in AC	
Alabama	16	16	19 5	18	18	19 5	18	18	22	20	20	24
Arizona	14	14	14 5	20	20	20 5	14	14	14 5	20	20	20.5
California	18	17.5	16.5	19.5	19	18	19	18.5	17 5	20.5	20	19
Colorado	19	18	20	-	-	18	19	18	20	-	-	18
Delaware	15	15	15	16	16	16	18	18	19	22	22	21
Kansas	12	11	15	14	13	17	12	11	15	14	13	17
Kentucky	18	17	18	23	22	21	18	17	19	23	22	22
Maryland	24	24	24	27	27	26	23	23	23	25	25	24
Missouri	9	9	9	9	9	9	9	9	9	9	9	9
New Mexico	20	10	15	22	12	17	21	11	16	24	14	19
North Carolina	27	27	27	30	30	30	25	25	25	29	29	29
Puerto Rico	15	15	15	16	16	16	24	24	19	24	24	21
South Dakota	14	12	15	18	16	18	14	12	15	18	12	18
Texas	15	11.5	9	18	13	10	17	12	9	20	12	11
Washington	15	14	20	18.5	17.5	26	15	14	20	16	14	22

A review of the methods used to evaluate the destructive effects of load repetitions indicates that the majority of those who answered this question used the equivalent 5,000-lb. wheel load relations developed originally by the California State Highway Department. From time to time, however, California has revised its procedure for computing equivalent wheel loads. Each revision gives a different answer. Some of the states used the original procedure; others the EWL_{50} procedure, which is the more recent. Thus, the large variations in the answers may in part be due to the use of different procedures for computing equivalent wheel loads.

That there is a considerable difference of opinion as to what constitutes the proper relation between load repetitions and destructive effect of traffic can hardly be questioned. One participant in this study indicated that where climate and subsurface conditions re-



Note Test road thickness are for 2 in A C + 4 in base Avg thickness of bituminous surfacing submitted by participants is 2 5 in and of base course 5 3 in

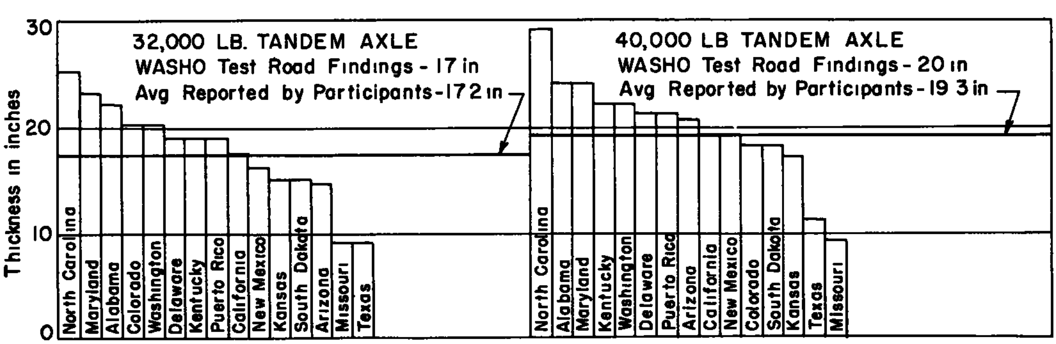


Figure 5. Pavement thicknesses for WASHO traffic (Problem "B").

main constant the destructive effect of traffic is directly proportional to the number of load repetitions; another that it is proportional to the logarithm of the number of load repetitions, and so on.

Comparison of Pavement Thicknesses for the Conditions of Problem B

In Problem B the participants were asked to report the thicknesses of the wearing surface, base course and subbase course that they would have recommended assuming that the test road was to be located in their particular area of operations. The resulting thicknesses are listed in Table 6 and are shown graphically in Figure 5.

A comparison of the thicknesses for Problems A and B are shown in Table 10. Over one-half of the participants reported thicknesses which were different from those submitted for Problem A. For example, Texas would have reduced its thicknesses 6 to 8 in. had the test road been constructed in that state; on the other hand, Washington would have increased its thickness 5 to 8 in.

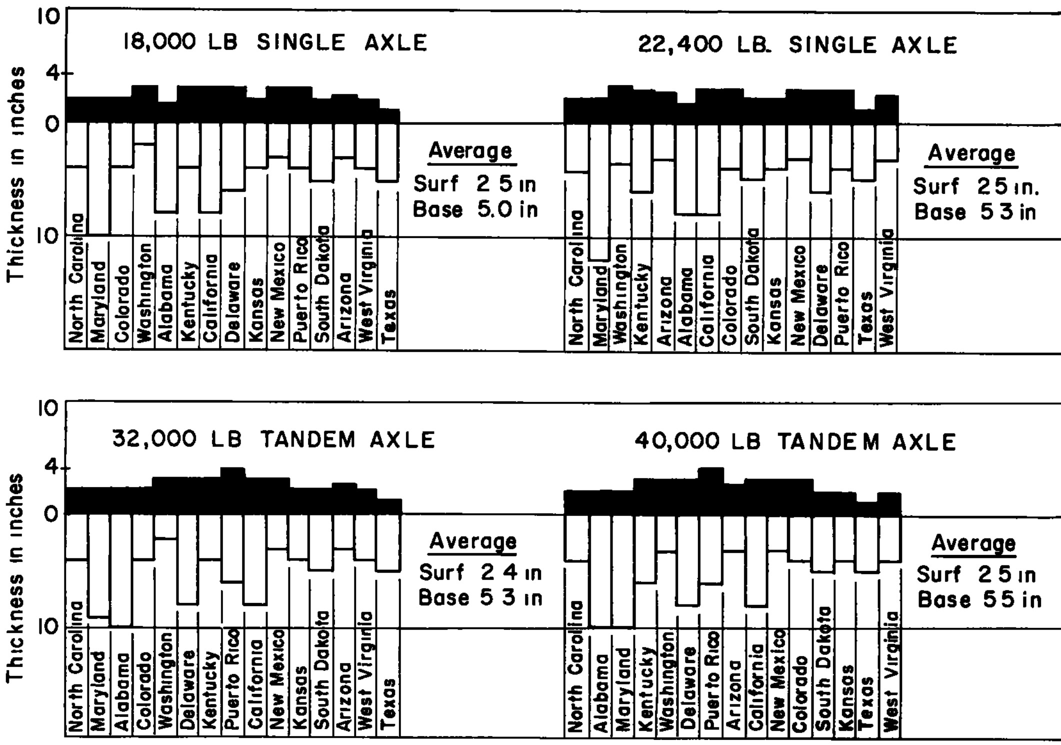


Figure 6. Comparison of bituminous surfacing and base thicknesses (Problem "B").

The answers to Problem B also reflect some of the thinking of the participants with respect to thickness of wearing surface, base, and subbase. These data are summarized in Table 11 and are shown graphically in Figure 6. They show that the average thickness of the wearing surface reported was about 2½ in. regardless of load. The average thickness of the base course was about 5½ in., of the subbase 10 to 12 in.

It is interesting to note from Table 11 that the average thickness of the pavement structure corresponds very closely to the results of the test road for the 2-in. AC + 4-in. base condition, but are considerably at variance with the results of the test road for the 4-in. AC + 2-in. base condition.

Comparison of Pavement Thicknesses for the Specified Traffic Patterns of Problem B

The traffic patterns for which the participants were asked to estimate total pavement thicknesses are listed in the second part of Problem B. Only ten of the agencies sub-

TABLE 11

PROBLEM B - THICKNESS OF PAVEMENT COMPONENTS

	Axle loads			
	18,000 lb. S	22,400 lb. S	32,000 lb. T	40,000 lb. T
Wearing Surface				
Range (In.)	1-3	1-3	1-4	1-4
Average (In.)	2.5	2.5	2.4	2.5
Base Course				
Range (In.)	2-10	3-12	2-10	3-10
Average (In.)	5.0	5.3	5.3	5.5
Subbase Course				
Range (In.)	3-21	4-24	3-19	5-23
Average (In.)	9.0	10.8	9.5	11.3
Average Total				
Thickness	16.5	18.6	17.2	19.3
WASHO Test Road Values				
2-inch AC +				
4-inch base	16	19	17	20
4-inch AC +				
2-inch base	10	10	10	16

mitted answers to this question, the results of whichare listed in Table 7. For any specific traffic pattern, maximum thicknesses were at least double the minimum. The traffic patterns were not in any way related to the traffic on the test road;

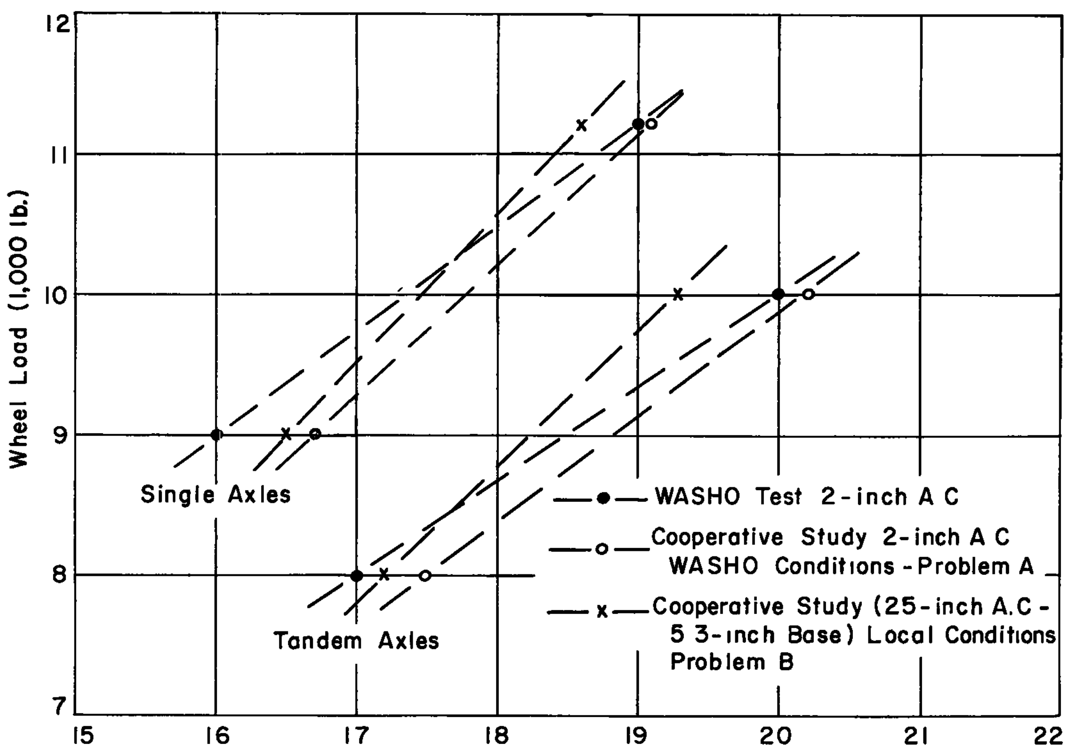


Figure 7. Load-pavement thickness relations.

TABLE 12

TOTAL PAVEMENT THICKNESSES

Load		WASHO Test		Cooperative Study (Average values)		
				WASHO Conditions, Problem A		Local Conditions, Problem B
Axle	Wheel	2-inch AC	4-inch AC	2-inch AC	4-inch AC	2.5-inch AC - 5.3-inch base
(1,000 lbs.)						
18 S	9	16	10	16.7	15.6	16.5
22.4 S	11.2	19	10	19.1	17.9	18.6
32 T	8	17	10	17.5	16.4	17.2
40 T	10	20	14	20.2	19.1	19.3

therefore there was no basis for comparing the answers with test road data.

Pavement Thicknesses to Support the Four Test Axle Loads

Information was developed from the WASHO test regarding the thickness of two designs of flexible pavement necessary to support four axle loads. These thicknesses are listed in Table 12 along with the average of those reported by the participants in the cooperative design study. As shown in Figure 7 the extent to which the thickness of pavement increases with load (both single and tandem axles) is much the same for the WASHO and for the cooperative study values.

SUMMARY COMMENTS

1. The subcommittee is of the opinion that the project has been worthwhile for several reasons: (a) it provides for the profession a cross-section of thinking with respect to methods of determination of pavement thickness and of the destructive effects of load repetitions; (b) it affords the opportunity for those engaged in pavement design work to compare procedures and testing techniques; and (c) it focuses attention on those phases of the flexible pavement design problem that are controversial and need additional study.
2. Although less than one-half of the state highway departments participated in the study, the majority of the current methods of flexible pavement design were represented.
3. There were extreme variations in the thickness of pavement submitted for the different loads and designs of pavement, although the majority of the thicknesses fell within a comparatively narrow range. In some of the more extreme cases of thicknesses reported, differences in the test values of the WASHO materials were major contributing factors. However, the present state of knowledge of the overall problem is such that the many different methods of design being used would not be expected to give the same answers.
4. A number of the participants in the study found it necessary to make major changes in their procedures in the attempt to develop designs for the condition of climate and materials specified. Others found it necessary to use, at least in part, the procedure of some other agency.
5. Average values of the thicknesses of the 2-in. AC design of pavement submitted by the participants were remarkably close to those determined from the WASHO traffic tests to be adequate. However, similar values for the 4-in. AC design were considerably greater than those found adequate from the WASHO test indicating that the superior performance in the WASHO tests and for the WASHO conditions, of this design over that of the 2-in. AC was not anticipated by the majority of the participants.
6. Many of the cooperating agencies experienced difficulty in developing their thicknesses for the type of traffic applied to the test pavement and in considering the fact that the traffic was not uniformly operated on a seasonal basis over the test period.
7. It is believed that information of great interest and value has been developed from this study. It is the recommendation of the subcommittee that has prepared this report

that serious consideration be given to the possibility of conducting a similar study using materials from the AASHO Road Test, a study in which all the state highway departments would be invited and requested to participate.

ACKNOWLEDGMENTS

The subcommittee desires to express its appreciation to all those agencies who cooperated in the study; to A. C. Benkelman, Chairman of the Committee on Flexible Pavement Design, for his assistance in carrying on the project and for his review of the report; and to John R. Sallberg of the Bureau of Public Roads for his assistance in assembling the data on design methods.

References

1. Highway Research Board Special Report 18. "The WASHO Road Test - Part 1, Design, Construction and Testing Procedures."
2. Highway Research Board Special Report 22. "The WASHO Road Test - Part 2, Test Data, Analyses and Findings."

Appendix A

Gradation Test and Other Soil Data

TABLE A

GRADATION TEST DATA - SUBGRADE SOIL, SUBBASE AND BASE COURSE

State	LL	PL	PI	Grading - - Percent Passing $1\frac{1}{2}$"	$\frac{3}{4}$"	No 4	No 40	No. 200	AASHO Opt. % Moist.	MD. TEST Density
					Subgrade					
1. Alabama	36.4	25.9	10.5				99	90	23 3	92.8
2. Arizona	36.	24.	12.				97	79	23.0	92.5
3. California								89		
4 Colorado	36 9	28.	8 9				99	90	25.1	92.1
5. Delaware	37 4	26.7	10 7				99	90		
6. Idaho	37.	27	10.			100	96	84	23.6	94.7
7 Kansas	38.	27.	11.			100	100	89		
8. Kentucky	36.	24.	12.				99	77		
9. Maryland	37 5	27.1	10.4				99	86	23.5	94.4
10. Missouri	37	24.	13			100	98	89	25.7	95.6
11. New Mexico	35.4	24.5	10.9				98	87	23.5	95.0
12 New York	35.5		11.1			99	98	90	24	94.1
13 North Carolina	38	27.	11.							
14. Puerto Rico	35 6	23.2	12.4				99	91	18 8	96 7
15 South Dakota	38.6	25.8	12.8			100	99	89	24.	90.
16. Texas	42.	27	15				100	84	24.5	93.1
17. Washington	40.	25.	15.				99	89		
18. West Virginia	35.	29.	6.				99	67	23.	93.
19 Wyoming	37.	26.	11.			100	98	83	24.4	96.3
					Subbase					
1. Alabama	22 3	20.5	1.8	84		41.	22	14	13.0	118.6
2. Arizona	21	19.	2.	99.	78.	36.	17.	9	7 0	137.5[a]
3. California				96	75.	37.	18.	6		
4. Colorado	NV		NP	97.	76.	36.	18.	8		
5 Delaware	22.0	18	3.0	96.	76.	38.	17.	5		
6 Idaho	NV		NP	97.	75.	39.	17.	8		
7. Kansas	24	20.	4.	97.	76.	36.	14.	5		
8. Kentucky	22.	18.	4	96.	76.	38.	17.	5	10.9	124.0
9. Maryland	23.7	20.8	2.9		76.	38	18.	9.7		
10. Missouri	22.1	20.7	1 4	97	75.	37.	23.	14.		
11. New Mexico	22 3	18.2	4.1	96.	76.	38.	17.	5.		
12. New York	20.6	19.4	1 2		78	38	17.	8.	9.3	129.
13. North Carolina										
14 Puerto Rico	22.8	20.0	2.8	100.	76.	38.	17.	5.		
15. South Dakota	21 1	18.6	2.5	94.	79.	38.	19.	9.		
16. Texas	27.	23.	4.	100.	83.		15.	3.		
17. Washington			NP	96.	78	35.	20.	9.		
18. West Virginia	21.	20.	1.	94.	69.	27.	15.	8.	11.	125.
19 Wyoming	19.	17.	2.		76.	38.	17.	5.		
					Base					
1. Alabama	20.8	17.0	3.8	100	99.2	49.2	24.4	14.5	9.9	125.4
2 Arizona			NP		100	51.	17.	8	7.3	136 8
3. California					100.	53.		4.		
4 Colorado	NV		NP		100.	45.	21.	8		
5. Delaware	21 4		NP		99	48	22.	7.		
6. Idaho	NV		NP		99.	44	19.	8.		
7. Kansas	22.	19.	3.		100.	47	20.	7.		
8. Kentucky	21.	18.	3.		99	48.	22.	7.	9.2	124.9
9. Maryland	19.7	19.7	0.0	100	100.	51.	21	9.5		
10. Missouri	19.7	19.7	0.0		99.	40.	19	9.		
11. New Mexico			NP		99.	48.	22	7.		
12. New York	19.8	18.5	1 3		100.	49.	23.5	9.	9.6	128.2
13. North Carolina										
14. Puerto Rico	18.6	17.0	1.6		100.	48.	21.	7.		
15. South Dakota	19.7	17.7	2	100	99	51.	24	11.		
16 Texas	24.	20.	4.		100.		20.	8.		
17. Washington			NP		100.	52.	20.	9.		
18. West Virginia	NL		NP		99.	47.	23	9.	11	124.0
19. Wyoming	20		NP		99	48.	22.	7.		

[a] Probably tested - $\frac{3}{4}$" sizes

TABLE B

CBR, STABILOMETER, AND TRIAXIAL TEST DATA

State	CBR Values					Stabilometer or Triaxial Specimen Values				
		Moisture Content		Molding Density		Moisture Content		Density pcf		
	CBR	Molding	Testing		Volume Swell	Molding	Testing	Molding	Testing	R Value or strength
	%			pcf	%					
					Subgrade					
1. Alabama	7.0	19.8	28.6	103.1	1.04					
2. Arizona	10.0	17.2		103.8						
3. California							22.3	98		56) Used
							21.0	99		38) 25
							23.6	96		16)
4 Colorado	2 5	25.1	35 1	92.1	1.99		23 9	96		24
5. Delaware	5 to 7	21.2		102 0						
6. Idaho							23 0	95		21) Used
							22.2	101.1		45) 45
							22 1	98.5		55)
7. Kansas										
8. Kentucky	5 5	22 2		97 7						
	5.5	22 4		96.1						
	6.0	23.8		93.7						
9. Maryland	2 0	23.5		94 4	9.3					
10. Missouri										
11. New Mexico	4 5	23 5		95.0						
12. New York										
13. North Carolina	2.3	25.1		93.0						
14. Puerto Rico	6.0									
15. South Dakota est.	4.5									
16 Texas						23 0	30.	88.0	85.5	St. Cl 4.75[a]
						22 0	25.	95.3	95.3	St Cl 3.5[a]
17. Washington						25 4		91 7		18
18. West Virginia est.	.6									
19. Wyoming	5.5	24 4		95.0	1.9					
					Subbase					
1 Alabama	67.3	6 9	6.8	138 8						
2 Arizona	80.0	5.5		145.9						
3 California						7 9		133		82
						8.2		132		81
						7.8		134		82
						8.3		134		19
4 Colorado						5 7		139		83
5. Delaware	140 to 170	8.8		132 0						
6 Idaho						7.1		133.4		78
7. Kansas										
8 Kentucky	124.	4 1		147 6						
	142.									
	126.									
9. Maryland	100.3	6.4		140.0	0.2					
10. Missouri										
11. New Mexico										
12. New York										
13. North Carolina										
14. Puerto Rico										
15 South Dakota										
16. Texas						5.0	6.1	132.0	142.0	St.Cl.3.2[b]
17 Washington										81.0
18 West Virginia est	20									
19 Wyoming est.	60									
					Base					
1. Alabama	109	6 5	7 4	139.0	0.20					
2. Arizona	85	6 0		141.8						
3. California						6 7		132		81
						6 5		132		81
						6 5		132		81
						6 1		134		79
						6 7		132		78
4. Colorado						6 3		139		80
5. Delaware	140 to 173	8.6		132 0						
6. Idaho						6.4		134 6		81
7. Kansas										
8. Kentucky	166.5									
	172.0									
	152.5	4.4		143 8						
9. Maryland	70.0	7.0		138.4	0 19					
10. Missouri										
11. New Mexico										
12. New York										
13. North Carolina										
14 Puerto Rico										
15. South Dakota										
16. Texas						6.8	6.3	137.5	137.5	St.Cl.1[b]
17. Washington										83.0
18. West Virginia est	20									
19. Wyoming										

[a] From triaxial tests strength class is 4 75 for WASHO compaction and would be 3.5 when compacted to Texas methods using 95 pcf as the density desired

[b] By triaxial tests on total material.

Appendix B

Summary of Methods Used by Participating Agencies

TABLE A

SUMMARY OF METHODS USED BY THE PARTICIPATING AGENCIES IN EVALUATING FLEXIBLE PAVEMENT DESIGN FACTORS

State	Design Factors			
	Subgrade Stability	Subbase and base materials[a]	Traffic	Effect of climate on Subgrade stability[d]
Alabama	CBR_A, GI	CBR_A, GI	Max. WL	Specimens soaked before testing
Arizona	Rating based on MA;PI	Rating based on MA;PI	Comparison to Arizona normal heavy traffic	Comparison to similar areas in Arizona
California	R	R	EWL and EWL_{50}	Specimens soaked before testing
Colorado	CBR_O	R	ADT, numerical[b]	Specimens soaked before testing
Delaware	CBR_A	CBR_A	Max. WL	Specimens soaked before testing
Idaho	Soil Formula No.; R	R	EWL	Specimens soaked before testing
Kansas	Triaxial	Triaxial	ADT, numerical[b]	Specimens saturated; numerical[b]
Kentucky	CBR_O	CBR_O comparison to PI	EWL	Specimens soaked before testing
Maryland	CBR_O	CBR_O	Max. WL	Specimens soaked before testing
Missouri	GI	Comparison to LL, PI, gradation limits	Daily bus and truck traffic	-[c]
New Mexico	CBR_O	Comparison to LL, PI, gradation limits	Heaviest axle load, EAL	Specimens soaked before testing
New York	CBR_O, cone bearing unconf. comp.	Comparison to gradation limits	Experience	Specimens tested at different moist. cont.
North Carolina	CBR_O	Comparison to LL, PI, gradation limits	Max. WL	Specimens compacted and tested at equilibrium moist. content
Puerto Rico	CBR_A	CBR_A	Max. WL	Specimens soaked before testing
South Dakota	CBR_O based on LL and GI.	Comparison to physical properties of standard	EWL numerical[b]	Soaked CBR values used; numerical[b]
Texas	Triaxial	Triaxial	Average of 10 heaviest wheel loads	Specimens tested after capillary absorption
Washington	R_W	R_W	EWL_{50}	Specimens soaked before testing
West Virginia	CBR_O based on LL, PI, MA, density	Comparison to limits for gradation plasticity	EWL	Soaked CBR values adjusted for WASHO cond.
Wyoming	CBR_O	CBR_O based on physical tests	EWL, numerical[b]	Specimens soaked numerical[b]

[a] Only reported methods are included in the tabulation; the construction specifications of each participant restricts the gradation and plasticity of materials for base course construction.
[b] A numerical value is assigned this factor according to the range within which it lies, this number is then used in the selection of the thickness design curve.
[c] The design procedure did not allow for a specific evaluation of this item, no adjustments were made.
[d] The factor " effect of climate on subbase and base course stability" is minimized or eliminated by specifications regarding gradation and plasticity.

Abbreviations

CBR_A = California Bearing Ratio (Army impact compaction)
CBR_O = California Bearing Ratio (Other methods of compaction)
R = Hveem stabilometer R-value (California method)
R_W = Hveem stabilometer R-value (Washington method)

GI = Group Index
LL = Liquid Limit
PI = Plasticity Index
MA = Gradation

Max. WL = Maximum wheel load using pavement daily
ADT = Average daily traffic, Colorado figures truck traffic is ≤10% ADT

EWL = Equivalent 5,000-lb. wheel load method
EWL_{50} = EWL method modified in 1950 by California
EAL = Equivalent 18,000-lb. single axle load

TABLE B

PROCEDURES FOR OBTAINING THE CBR VALUE OF THE SUBGRADE

Details of Test	Alabama	Colorado	Delaware	Kentucky	Maryland	New Mexico	New York	North Carolina	South Dakota	Puerto Rico	West Virginia	Wyoming
Compaction Test to Establish Moisture-Density Conditions for Design												
1 AASHO		x		x	x	x	x	x				x
2 Modified AASHO (Army) 1/30 cu ft mold										x		
3 Modified AASHO (Army) CBR mold	x		x									
Compaction of CBR Test Specimens												
1 Impact method	impact		Impact		Impact		-			Impact		
(a) Weight of hammer	10 lb		10 lb		5 5 lb		-	5 5 lb		10 lb		
(b) Height of drop	18 in		18 in		12 in		-	12 in		18 in		
(c) Number of layers	5		5		5		-	3		5		
(d) Height of specimen	5 0 in		5 0 in		5 0 in			4 5 in		5 0 in		
2 Static method		Static		Static		Static						
(a) Number of layers		-		-		1						
(b) Pressure		-		2,000 psi		variable						
(c) Height of specimen		-		5 0 in		variable						
3. Other methods												hand tampered, then static load
Number of CBR Specimens Tested	1	2	3	3	2	6	4	3		3		
Molded Dry Density of CBR Test Specimens in Terms of Maximum Density Determined in Compaction Test	100%	1 at 90% 1 at 95%	95%	100%	100%	2 at 90% 2 at 95% 2 at 100%	2 at 98% 1 at 101% 1 at 104%	96 9%		1 at 10 blows 1 at 25 blows 1 at 55 blows		100%
Moisture Content of CBR Test Specimens as Molded in Terms of the Optimum as Determined Above	Optimum Moisture Content	Optimum Moisture Content	Optimum Moisture Content	Optimum Moisture Content	Optimum Moisture Content	3 at Opt 3 at Opt minus 5%	Opt minus 2 5% Opt minus 1% Opt Opt. plus 2%	110% of Opt		Optimum Moisture Content		Optimum Moisture Content
Time CBR Specimens were Soaked	4 to 7 days for max. swell	4 days	4 days	until swell < 0 003 inches per 24 hours	4 days	5 days	Not Soaked	Not Soaked		4 days		4 days
Penetration upon which CBR is Based	0 1 or 0 2 in , larger CBR	0 1 or 0 2 in , larger CBR	0 1 inch	0 5 in when trend ratios either decrease or increase Otherwise use av	0 1 inch	Whichever gives min CBR, usually 0 4 or 0 5 in		0 1 or 0 2 in larger CBR		0 1 or 0 2 in , larger CBR		0 1 in
Reported CBR Value - %	7	2 5	5	5 5	2	4 5		2 3	4.5	6	6	5 5

General References
(1) "The Preparation of Subgrades, by O J Porter, Proc HRB, Vol 18 Part II 1938
(2) "Foundations for Flexible Pavements" by O J Porter, Proc HRB, Vol 22, 1942
(3) "Factors Underlying the Rational Design of Pavements," by F N Hveem and R M Carmany, Proc HRB, Vol 28, 1948
(4) "Suggested Method of Test for Compaction of Soils," by T E Stanton, ASTM Procedures for Testing Soils, July, 1950
(5) "Suggested Method of Test for Bearing Ratio and Expansion of Soils," by T E Stanton, ASTM Procedures for Testing Soils, July, 1950
(6) "Suggested Method of Test for CBR of Soils," Submitted by Corps of Engineers, U S Army, ASTM Procedures for Testing Soils, July, 1950

Appendix C

Supplemental Data on Design Methods

Alabama

The CBR method of design was employed to develop the information on pavement thickness requested for Problem A of the design correlation study. The thickness indicated to be necessary from the CBR chart (1) were arbitrarily increased 20 percent due to climatic conditions of the test road site and to possible irregular construction practices and a factor of 0.7 was used to convert the tandem axle loads to equivalent single axle loads.

The Group Index method (2) of design was used (value of GI of 8 and heavy traffic) to obtain the thicknesses requested for Problem B.

The estimates of the number of repetitions of load to cause failure of the various sections of the test pavements were developed from extrapolation of data obtained in traffic tests of airport pavements (3).

Arizona

Flexible pavement design in Arizona is based upon two important characteristics of soils and base materials, plasticity index and percent passing the No. 200 sieve. The interrelation of these two test constants and the approximate base thicknesses (under 1- to 2½-inch bituminous surfaces) is shown in Figure A. The thicknesses are for pavements carrying heavy traffic. In some instances the thickness is reduced as much as 3 inches where it is a matter of definite knowledge that the traffic will be light.

The following material was obtained from the Arizona report:

"To illustrate the use of the chart, assume that a subgrade sample has a PI of 20, and 60 percent passing the No. 200 sieve. A total base thickness of 12 inches is indicated by the chart. Then assuming that there is a material available that has a PI of 10 and contains 20 percent passing the No. 200 sieve, and another having a PI of 1 and containing 10 percent passing the No. 200 sieve, the economical base would consist of 6 inches of the first material as a subbase and 6 inches of the second material placed over it as a base. If the first material has a PI of 6 with 20 percent passing the No. 200 sieve, the economical design would have been 9 inches of the first material for subbase and 3 inches of the second as a base. The second material in both cases falls within the small rectangle in the lower left hand corner in which 0 additional base is indicated. All base materials must fall within this rectangle since our specifications require that base material shall have a PI of 5 or less and that the fraction passing the No. 200 sieve shall be between 3 and 12. Further requirements for base material not shown on the chart, are that 100 percent shall pass the 1-inch sieve and 45-65 percent shall pass the No. 3 sieve. Special Provisions are written when it is considered necessary to more closely control the grading. The subbase material in most cases is "pit run" material with very limited controls except on PI and percent passing the No. 200 sieve.

"This chart should be used with considerable judgment, taking into account such factors as degree of compaction, drainage conditions, climate and frequency of heavy axle loads."

The base thicknesses reported by Arizona in the design correlation study, computed from this chart were increased by 3 inches (for the 18,000-pound single axle and 32,000-pound tandem axle loads) as an adjustment for the WASHO climate. The values would be considered adequate for the higher, colder and wetter areas in Northern Arizona where conditions are considered comparable to those at the site of the WASHO Road Test. For the heavy axle loads (22,400-pound single axle and 40,000-pound tandem axle,) the base thickness was increased a total of 9 inches above that indicated necessary from the chart.

California

The Hveem stabilometer was used to test the subgrade and foundation course materials. The effects of precipitation and surface moisture conditions were compensated for by soaking the specimens over night before testing, but no allowance was made for possible frost damage.

Traffic was evaluated by the equivalent 5,000-pound wheel load method (EWL) and by the 1950 revision (EWL_{50}); designs were submitted for both methods of evaluating traffic. Normally design is based on the anticipated traffic for the 10-year period immediately following construction.

The slab strength of the surfacing was determined by the cohesiometer test and the "C" value was used to reduce the total design thickness determined by the "R" value.

The following comments were taken from correspondance with California regarding their report:

"You will note we have presented two apparently different solutions, one headed ' Using EWL ' and the other ' Using EWL_{50}. ' The only difference between these designs is the manner or formula by which the overall effect of traffic is converted to a single number (EWL).

"The first design 'Using EWL' was calculated by evaluating the traffic in a manner similar to present California State Highway practices. Actually there is only

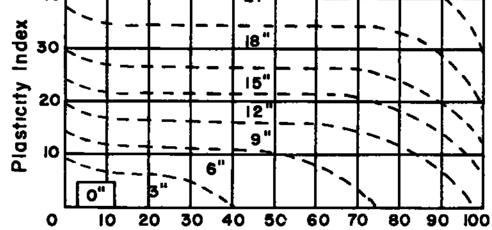


Figure A. Base thickness chart, Arizona.

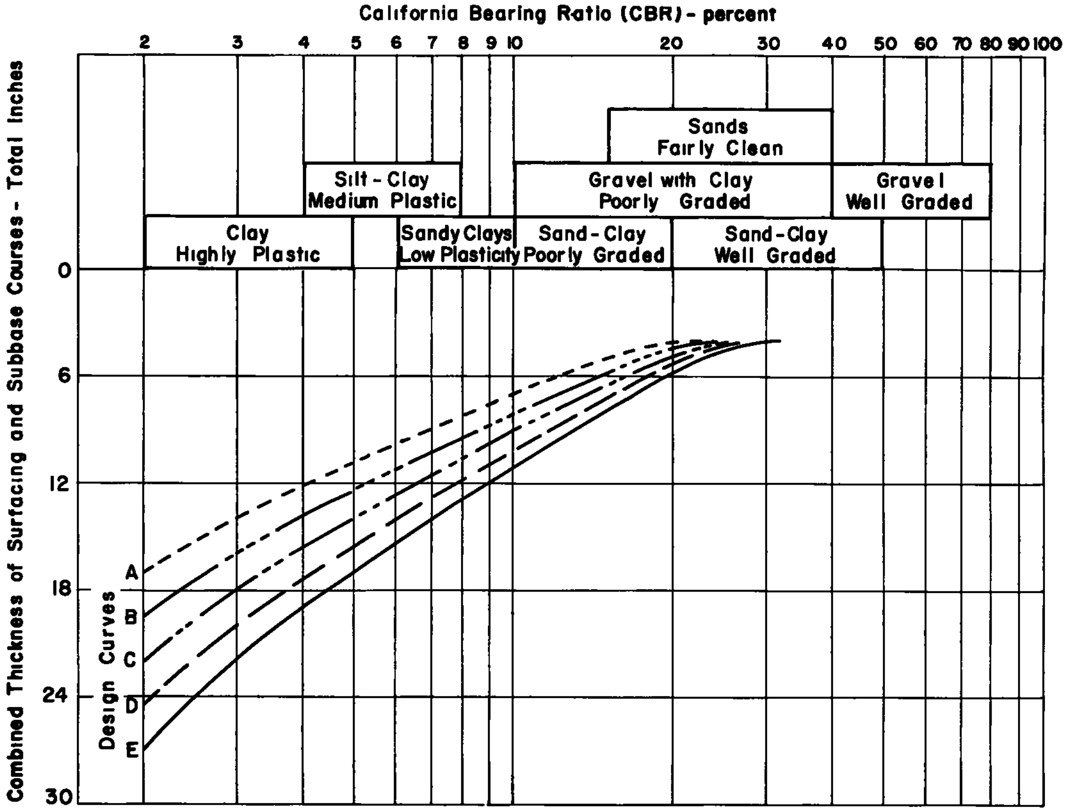


Figure B. Colorado design chart for flexible pavements.

a general similarity since such an exact mathematical solution is not practicable for everyday traffic evaluation and, therefore, constants have been developed based on certain assumptions, averaging of data, and factors of safety directed by experience. For simplication in our work on this problem we have used the approximations $EWL=2^X(r)$ and Traffic Index = $\frac{\log EWL - 2}{3} + \log EWL$ where $X = \frac{(\text{wheel load in lbs} - 5000)}{1000}$ and r= repetitions of this wheel load.

"The second design 'Using EWL_{80}' utilizes a method of evaluating traffic which is presently considered by the Materials and Research Department to be more appropriate. The method is not at present a California standard; however, it appears to more closely approximate the destructive effect of traffic than does the older EWL "formula." Equations used for this design were: $\log EWL_{80} = \sqrt{\frac{L}{5,000}}\,(\log r)$ and

Traffic Index = $\log EWL_{80}$. Where L = wheel load in pounds and r = repetitions of this wheel load.

"For any given traffic condition the values of the calculated Traffic Index (T.I.) will depend on which method of evaluation is used.

"In determining these values, EWL and EWL_{80}, a departure from prior practice was made in the manner of evaluating the effect of a tandem axle load. Previously a 32,000-pound load carried on two "tandem" axles was considered to be the same as two 16,000-pound single axles for calculating EWL constants. In such case the wheel load would be equal to 8,000 pounds. Recent experience in California has indicated that the bending or flexing of pavements under tandem axle loads does not bear any fixed or constant relationship to the effect of single axle loads. The relationship varies with the type of pavement. Evidence thus far available leads us to consider a 32,000-pound tandem axle as being equal to two 19,000-pound single axles. In this case the wheel load would be 9,500 pounds and the calculated EWL will, therefore, differ from that arrived at by the first stated method. In similar fashion experience has also indicated that a 40,000-pound tandem axle is equivalent to two 24,000-pound single axles. These relationships apply only to bituminous pavements supported by granular uncemented bases.

"A solution of Design Problem A began by converting the effect of the given traffic conditions to a single numerical value such as EWL or EWL_{50} and thence to a T.I. utilizing the above-mentioned methods and relationships. We used cohesion values of 300 for "the slab strength" of PMS and 100 for untreated bases and other soils. The 300 value was based on WASHO PMS test results while the 100 value is an assumption.

"Since the basement soil in question develops high expansion pressures as water is absorbed, a direct determination of the thickness of cover required (and thereby the thickness of subbase) cannot be made. This occurs whenever soils are expansive and to arrive at a balanced design it is necessary to select a thickness of cover heavy enough to balance the expansion pressure and that is also equal to the thickness of cover indicated by the stabilometer as necessary to support loads over the soils in the equilibrium state of moisture and density. It is necessary to keep in mind that the thickness of cover indicated by the stabilometer varies for each cohesion or T.I. value and, therefore, a balanced design also varies with the same factors.

"A solution of Design Problem A (5) (a)[1] is best accomplished by the following seven step trial and error method:

1. Assume a cohesion value.
2. Using the given T.I. and the assumed cohesion, determine the thicknesses of cover by stabilometer for each R-value in the three specimen set.
3. Plot thickness by stabilometer against thickness by expansion pressure for each of the three specimens.
4. Draw a smooth curve through the three plotted points.
5. Where this curve intersects a 45° line through the ordinate, the thickness by stabilometer is equal to the thickness by expansion pressure. This is the point of balanced design whenever expansion pressure controls the design.
6. Using the thickness determined by (5) and knowing the type and thickness of surface and base, calculate the combined cohesion value.
7. If this cohesion is equal to the one selected in (1) the solution is correct, otherwise repeat steps 1 to 6.

"By this trial and error analysis the total thickness of cover required over the basement soil was determined for the conditions outlined. By subtracting the base and pavement thicknesses from the total thickness the thickness of subbase was found and entered on the report form.

"An estimation of the number of trips to produce failure, Problem a (5) (b)[2], was found in a somewhat similar seven-step manner as that above. In this problem, however, the structural section was known and, therefore, the combined cohesion value could be assumed. Step 1 was an arbitrary selection of a T.I. which with the test data will give the known section. The other steps, all design thickness values, are similar to those outlined, predicated on a saturated condition of the soils. Any condition less than saturation will materially increase the probable total number of trips to produce evidence of failure.

"Design Problem B[3] was solved according to our current methods using minimums outlined in our Planning Manual. Here also, traffic was evaluated both by the EWL and the EWL_{50} methods "

[1] Problem (5) Determination of the thickness of subbase required to adequately carry the test loads for the constructed thickness of surface and base. The data on climate for the WASHO test site, the condition of materials as constructed, the traffic and the thickness of the pavement components were furnished.

[2] Problem 5 (b) Determination of the number of trips of the four-axle loads under 5 (a) to produce failure of the test sections.

[3] Problem B (a) Determination of the pavement thicknesses to carry the WASHO traffic for local climatic conditions. The condition of the materials (subgrade soil, base and subbase courses) to be selected by the designer. Problem B (b) Determination of thicknesses of pavement for five given traffic patterns with same conditions as for Problem B (a).

Colorado

The thicknesses of pavement reported by Colorado were developed using the modified version of their original CBR method of design (4).

The method employs the CBR test for evaluating the subgrade soil and the Hveem stabilometer test for evaluating the foundation course materials. It takes into account the anticipated traffic volumes for a period of 20 years, the damage to the pavement structure that is probable from the frost potential of the soils over which the pavement structure is to be placed and the capabilities of the subgrade soils to sustain loads when they are in different degrees of saturation. Based on an empirical evaluation of these factors the thickness of pavement for soils having different CBR values is determined from a series of five curves (see Figure B).

Delaware

Delaware used the CBR method described in "Tech. Memorandum No. 213-1," U.S. Waterways Expt. Station, Vicksburg, Miss. and basically followed in "Lab. Manual in Soil Mechanics," by R. F. Dawson, Pitman Pub. Corp., New York, Sec. XXIII.

A subgrade CBR value of 5 was used for determining the thicknesses of the pavement. This CBR value was considered conservative because normal climatic conditions are not likely to produce a subgrade condition as adverse as that caused by the 4 day soaking period used in the CBR test procedure.

REMARKS ON PROBLEM A

The 18,000 and 22,400-lb. single axle loads were converted to wheel loads of 9,000 and 11,200-lb. and the total pavement thicknesses determined for a subgrade soil with a CBR of 5.

The 32,000 and 40,000-lb. tandem axle loads were considered as single axle loads and the appropriate CBR design curve was used to obtain the total pavement thickness. No distinction was made between single and tandem axle loadings in the solution of this problem.

Although an average frost penetration of 24-in. was reported at the WASHO test road site, no effort was made to thicken the pavement to compensate for the effects of frost. It was indicated that the amount of moisture in the subgrade soil might not be productive of frost action.

In Problem A (optional) — The 3-in. surface course reported is standard in Delaware for heavy duty flexible pavements. (Where at least 300 trips per lane per day are tractor-trailer type.) Also, the 6 and 8-in. base thicknesses are fairly standard, the choice depending upon traffic.

REMARKS ON PROBLEM B

For Part (a) — Delaware used essentially the same thicknesses of the pavement components for their conditions of climate, traffic and materials for Problem B as for Problem A. Since the WASHO materials are quite similar to those normally used in Delaware, normal design standards were used. The moisture conditions in Delaware are believed to be more severe than those indicated for the WASHO area, however, it was considered that the adverse moisture condition was adequately compensated for by using a CBR value of 5. The average frost penetration in Delaware is about 8-inches, hence no additional subbase is used to compensate for the effects of this amount of frost penetration.

For Part (b) — The maximum wheel load (9,000-lb.) and a CBR subgrade value of 5 was used to determine approximately (± 1in.) the total required thickness of pavement. The standard 6-in. base in combination with 6 in. of subbase was used with the variable being thickness of surfacing, which depended on the traffic. Thus, for traffic patterns (a) and (b) a 2-in. surfacing was selected, and for traffic patterns (c) and (d) a 3-in. surfacing.

Idaho

Two designs were submitted for Problem "A." One was based on the Hveem Stabilometer test and the other on the "Idaho Soil Formula Number."

The stabilometer method is used (in Idaho) for the design of primary highways and for the more heavily traveled secondary roads. The "Soil Formula Number" is used to design roads carrying light traffic.

In caluclating WASHO designs by the California method, a traffic index of 7.4 was used. This corresponds to 1,000,000 EWL, the maximum traffic encountered in the state. The California design curves were used without adjusting for climatic conditions. The cohesiometer values were based on values cited by Messrs. Hveem and Carmany (5).

The Idaho "Soil Formula Number" is computed as follows:

$$\text{Soil No.} = A + B + C\ (D + E + F) + H$$

Where:

$$A = \frac{\text{Percent pass No. 10 sieve} - 50}{10} \qquad (1)$$

$$B = \frac{\text{Percent pass No. 40 sieve} - 30}{10} \qquad (2)$$

(If less than 30 percent passes No. 40 sieve, reverse order and subtract number)

$$C = \frac{40 - \text{Percent pass No. 40 sieve}}{40} \qquad (3)$$

(If percent passing No. 40 sieve is more than 40 percent, use C = 100 percent. Compute "C" to nearest 10 percent).

$$D = \frac{LL - 15}{3} \qquad (4)$$

$$E = PI - 5 \qquad (5)$$

$$F = \frac{FME - 15}{10} \qquad (6)$$

$$G = \text{Lineal Shrinkage to nearest whole number.} \qquad (7)$$

$$H = \frac{130 - \text{Max. dry wt. per cu. ft. compacted}}{3} \qquad (8)$$

The factor "C" is used to reduce the numerical value in accordance with the amount of material passing the 40 sieve. The reason for this is that the more predominant the granular material in a soil the more stable the material regardless of adverse soil characteristics.

The relation between "Soil Formula Number" and total thicknesses of pavement for light and heavy traffic are shown in Figure C.

Kansas

The triaxial compression test was used to evaluate the WASHO materials (6). The methods used in the correlation study were described by Kansas as follows:

" In order to use the Kansas method for design it is necessary to test all materials at saturation moisture and then apply a saturation coefficient in the formula, the value of this coefficient being based on the average annual rainfall in the project area. This procedure was followed for the WASHO test road materials with the various materials tested for the following conditions:

Material	Density - P.C.F.	Moisture - %
Subgrade	90.6	28.8
Subbase	136.6	7.4
Base	136.7	7.6

"Total materials of the gradings shown in our report (7) for the subbase and base materials were used in all tests. For triaxial compression, cylindrical specimens 4 inches

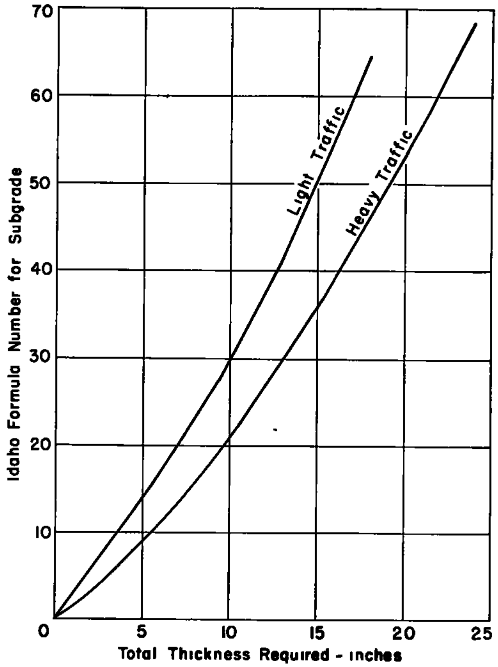


Figure C. Idaho flexible pavement thickness design chart; based on Equation "A".

in diameter by 8 inches high were molded under a load of 2,000 psi held for 5 minutes using double plungers. For the moisture density curves, a 6-inch diameter mold of $1/10$ cu. ft. volume was used, placing the material in four lifts and applying 56 blows per lift for compaction."

ADJUSTMENT FOR WASHO TRAFFIC

"The provisions for the Design Correlation Study specified 700 test vehicle trips per lane per day, of certain vehicles with a total of 200,000 trips. This made it necessary to alter procedures normally used in Kansas. Our normal total traffic in two lanes has been established for various traffic coefficients. For this study the WASHO truck traffic of 18,000-pound single axle loads is considered as 15 percent of the total traffic in two lanes. In order to express our traffic coefficients in terms of the WASHO traffic in one lane only, the volume of total traffic for each coefficient[4] was multiplied by 0.075 (using the high traffic figure in each case). For the 22,400-pound single axle load the coefficients were multiplied by 22,400/18,000 giving the same effect as using the heavier axle load in the formula[5]. For our design the 32,000-pound tandem axle load is considered equivalent to the 18,000-pound single axle load, and the 40,000-pound tandem equivalent to the 22,400-pound single axle load."

"The second variation is that of considering the effect of the relatively short period of time over which the 200,000 total trips were applied in relation to a traffic volume of 700 per lane per day continued for a period of from 10 to 20 years. It is obvious that less thickness should be required for 200,000 total trips than for 700 trips per day continued for 10 years. On the other hand, it is reasonable to assume that more thickness should be required for 200,000 total trips applied in a short period of time than for the same number of trips applied over a period of 10 or more years. In order to determine a reasonable coefficient to use in our computations, a method of interpolation was devised as follows:

"First, $7\frac{1}{2}$ percent of the normal total traffic for each coefficient was multiplied by 3,650 to determine the total trips (WASHO traffic) per lane in 10 years. These figures were then plotted on rectangular coordinate paper and a curve drawn through the points as shown on Figure D. Then point "A" was located at 200,000 trips and point "B" at 2,555,000 trips (700 per day for 10 years). A rectangle was then constructed from these two points with the curve AB approximating one diagonal. The other diagonal CD intersects the curve at "E" giving us a traffic coefficient $m=8/6$. This was used for computing the thickness of mat required on the subgrade for the 18,000-pound single and 32,000-pound tandem axle loads. A coefficient of $(\frac{22,400}{18,000} \times \frac{8}{6})$ or $10/6$ was used for the 22,400-pound single and 40,000-pound tandem axle loads."

An example showing the details for determining base thickness for the 18,000-

[4]See "Flexible Pavement Thickness Charts for High Volumes of Traffic" by H. E. Worley for total traffic ranges corresponding to the traffic coefficients.

[5]The formula for thickness, expressed in graphical form in Figure E for n=0.5 and S=0.1 inch, is set up for a maximum wheel load of 9,000 pounds.

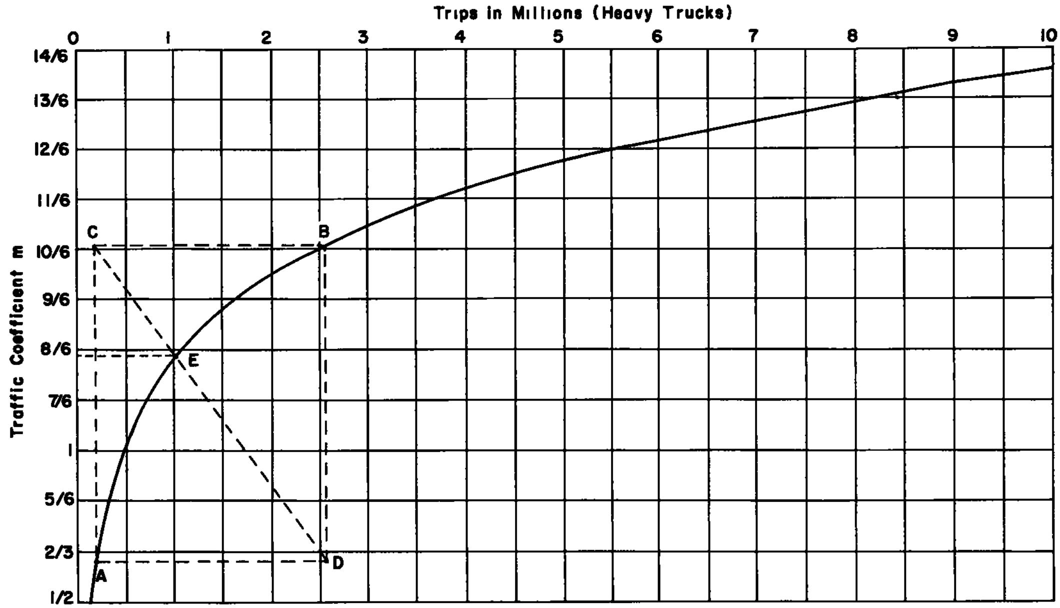


Figure D. Kansas method of determining design traffic coefficient.

pound single and the 32,000-pound axle loads follows:

Traffic coef. $m = {}^8/_6$, Saturation coef. $n = 0.5$

Subgrade test data:

v-1 psi.	Net Unit Strain	C Mod. of Def. psi.
2	0.0013	1,540
4	0.0049	820
6	0.0122	490

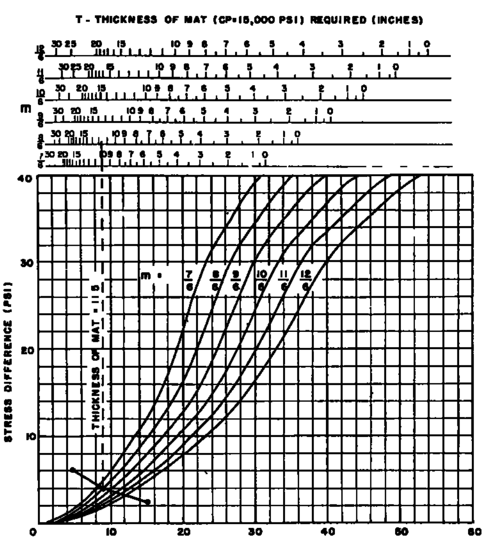


Figure E. Kansas thickness chart for n=0.5, S=0.1 inch.

Using Figure E, the thickness of a mat whose Cp = 15,000 psi. is determined as 11.5 inches. To change this thickness into equivalent pavement thickness which included A. C. surfacing and granular base and subbase components, the following values were used. The moduli of deformation for the AC = 25,000 psi.; Mat = 15,000 psi.; Base = 12,000 psi.; and for the Subbase = 12,000 psi. Therefore, using the conversion factor $\sqrt[3]{\frac{C_1}{C_2}}$, where C_1 and C_2 are the moduli of deformation of the materials, a thickness (t) of the C_1 material may be converted to an equivalent thickness (t_2) of the C_2 material.

$$t_2 = t_1 \sqrt[3]{\frac{C_1}{C_2}}$$

2-inch AC = 2.4 inch Mat; 4-inch AC = 4.8 inch Mat; Conversion factor (Mat to Base thickness)=1.08; Subtract 2.4 or 4.8 from total mat and multiply remainder by 1.08 to arrive at thickness of base and subbase.

In order to calculate the number of trips to fail the various sections, Kansas first computed the thickness required for each of several traffic coefficients. These thicknesses were then plotted on semi-logarithmic paper against the total number of trips corresponding to each traffic coefficient. The curve representing these points was used to estimate the number of trips for failure. Kansas defined failure in this case as "the point of change from satisfactory performance of the roadway to an unsatisfactory condition at which patching must be started."

Kentucky

This State utilizes the CBR test for evaluating the subgrade soil. Tests are made on soaked specimens of the material and no allowance or adjustment in the thickness of pavement is made for varying amounts of rainfall or for the possible detrimental effects of frost action.

The CBR pavement thickness curves being used at the present time are shown in Figure E. Each of the curves represents the necessary thickness of pavement for different volumes of traffic expressed in terms of 5,000-lb. EWL. The curves were developed for pavements having waterbound macadam bases or their equivalent.

The regular procedure was used to develop the thickness of pavement reported in the design correlation study.

The curve (Fig. F) used to obtain the thickness of pavement necessary was determined by computing the 5,000-lb. equivalent wheel loads for each of the test axle loads using the factor values listed as follows:

Wheel Load	Factor	Wheel Load	Factor
6,500-7,500	4	9,500-10,500	32
7,500-8,500	8	10,500-11,500	64
8,500-9,500	16		

The thicknesses of the subbase component of the total structure were increased 25

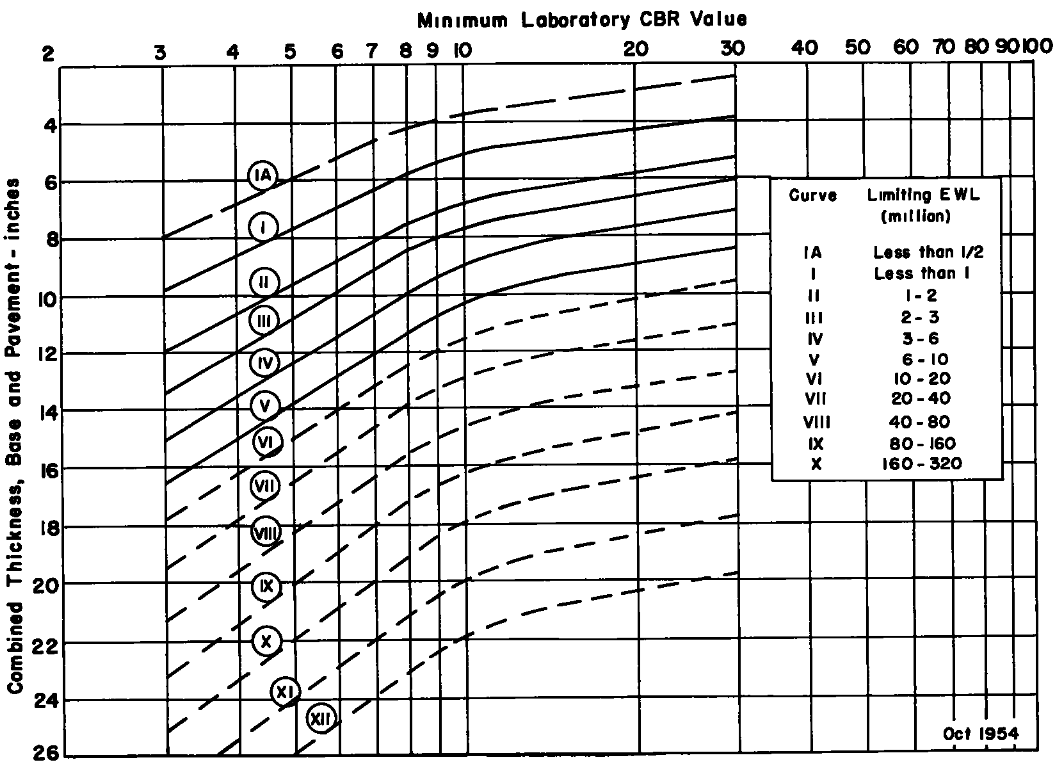


Figure F. Kentucky design curves for flexible pavements.

percent since it was considered that this material was inferior to waterbound macadam.

In the determination of the number of repetitions of the test axle loads that would produce failure of the pavement, failure was defined as the condition when resurfacing or reconstruction is required. To find the number of repetitions, the curves of Figure F and values cited above were used. For example, for a 9,000-lb. wheel load, a 5-CBR subgrade, and a 14-inch pavement, the total EWL lies between 6 and 10 million, say 10 million (curve 5), and the conversion factor is 16, dividing 10 million by 16 gives the number of wheel loads to produce failure of the pavement.

Maryland

The CBR test was used to evaluate the subgrade, subbase and base course materials. The thicknesses of pavement were obtained from CBR wheel load curves similar to those developed originally in California and as used at the present time in Virginia.

The following comments were submitted with the Maryland report.

"We have noted that one of the intended variables between Problem A and Problem B is the climatic conditions existing at Malad City, Idaho, and our region. Actually we have considerable variation of climatic conditions in our state, a condition which is common to several of the Eastern Seaboard States. Our own design attempts to encompass nearly all of these variables. Obviously it is necessary for us to be cognizant of the depth of frost penetration in the western part of Maryland, which compares closely to the frost penetration noted for the site of the test road.

"Referring to Problem A in the 'Requested Information,' we have noted subbase thicknesses varying from 17 inches to 21 inches, these thicknesses being necessary so that the total thickness indicated for our CBR value of the subgrade is satisfied. Under 'Optional Information,' a make up of the pavement components has been used where the subbase thickness has been held constant at 12 inches, and the surface thickness held constant at 2 inches. The thickness of the base course for this suggested section varies from 9 inches to 12 inches. The total thickness of the surface, base course and subbase course is equal to about the total thickness shown under 'Requested Information.' Under Problem A we have not filled in any of the columns under the tabulation 'Number of Trips to Produce Failure.' This information cannot be determined by any design method that we have used. We believe that this factor continues to be a worthy aim in all future research.

"Problem B states that a pavement thickness is to be determined for climatic conditions prevailing in the area where our design procedure is normally used. The thicknesses are the same as for the 'Optional Information' under Problem A. The subgrade material requires the total thickness shown, and the total depth was not reduced due to the slightly lower depth of frost penetration. For the assumed traffic patterns, a weighted average for the axle loads was obtained. Under each of the columns a, b, c and d, a possible design is noted. The designs under column c and d, however, are the only ones which conform exactly with the Maryland standard design for heavy duty gravel pavement."

Missouri

The following information on the Missouri method of design was submitted with the report of the correlation study:

"The Missouri Group Index method determines the thickness of the total pavement system (subbase, base, and bituminous surfacing) from the Group Index of the subgrade. Four curves based on daily truck and bus traffic volumes fix the thickness for a given Group Index and traffic volume.

"A Group Index of 9 was determined for the WASHO subgrade sample received at the Missouri State Highway Commission Laboratory. Hence, for this study, the design curves were entered at a Group Index of 9 and a line projected vertically to intersect the proper daily truck and bus traffic volume curve. This point of intersection is then projected horizontally to read an indicated total thickness of surface, base and subbase.

"However, this indicated thickness is subject to factors of experience and judgement as dry density of soil, drainage conditions, local experience, or similar items. It would seem that the light weight (light compared to Missouri soils of comparable Group Indicies) of this soil might warrant a thicker pavement system; but in this cooperative study, thickness has been chosen as dictated by the Group Index.

"Hence, in Problem A, a Group Index of 9 indicates a total pavement thickness of 9 inches. Thus, with combinations of base and surface equaling 6 inches, a subbase of 3 inches is required. This same approach was used for all thickness values (8)."

New Mexico

Normally, the design of flexible pavements in New Mexico is based on the use of soil test constants, however, for this study the CBR test was used. Soil specimens were tested in a soaked condition.

The thicknesses of pavement for the WASHO traffic were based upon the subgrade

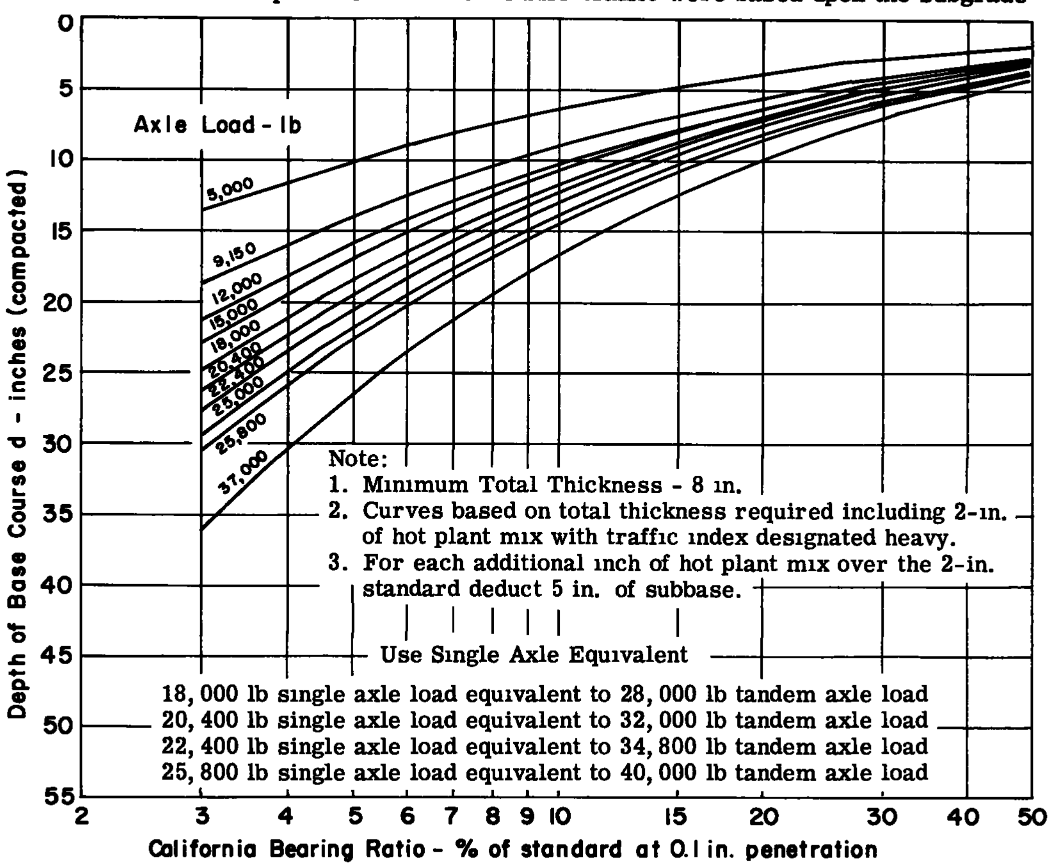


Figure G. New Mexico design curves for base course thickness.

CBR, the axle load, number of repetitions and the thicknesses of the asphaltic concrete surfacing.

The curves (Fig. G) were used to determine the total pavement thickness for the single axle loads. All tandem axle loads were converted to equivalent single axle loads.

The design curves are predicated on the use of 2 inches of hot plant mix surfacing (for heavy traffic) and on the reduction of 5 inches of subbase for each additional inch of surfacing.

The thicknesses reported for Problem B include an additional adjustment for the number of equivalent axle loads per day. The following example illustrates how the adjustments were made.

Data: CBR = 4.5, EAL = 133 (taken from example of equivalent axle load shown in

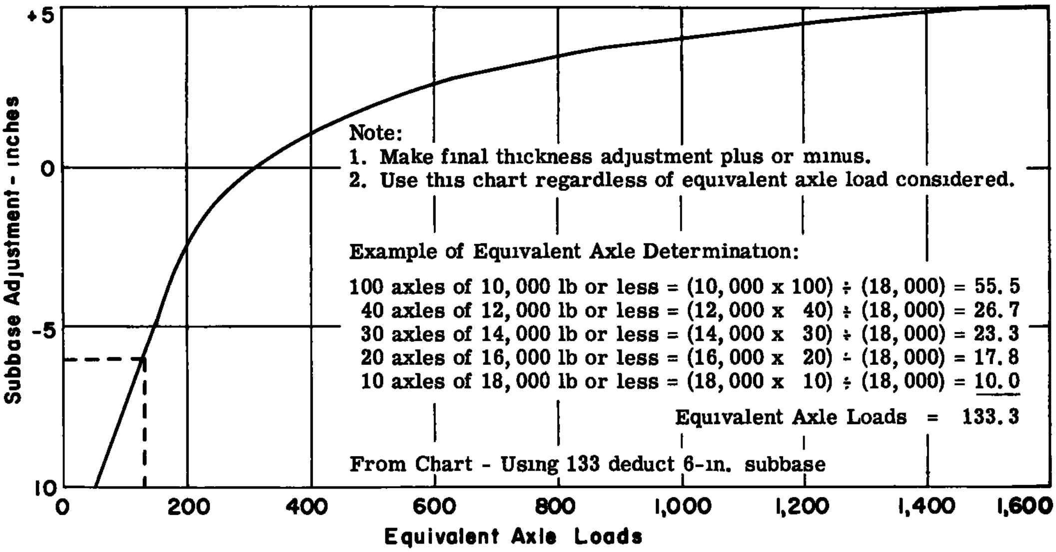


Figure H. New Mexico traffic adjustment chart.

Figure H, single axle loads of 18,000 and 22,400 lb. and tandem axle loads of 32,000 and 40,000 lb.

Method: (a) Determine from Figure G the total thickness of pavement. (b) Adjust the total thicknesses for EAL of 133, using the curve Figure H. (c) Deduct 5 inches of subbase for each additional inch of surfacing over 2 inches in thickness.

TOTAL THICKNESSES

Single Axle Loads	Thickness[a] From Fig. F	Thickness[b] From Fig. G	Thickness[c] AC-3-in.	Thickness[d] AC-4-in.
18,000-lb.	20-in.	14-in.	9-in.	8-in., min.
20,400-lb.[e]	21-in.	15-in.	10-in.	8-in., min.
22,400-lb.	22-in.	16-in.	11-in.	8-in., min.
25,800-lb.[e]	24-in.	18-in.	13-in.	8-in., min.

[a] Includes 2-in. surface.

[b] Thickness of pavement (including 2-in. surface) adjusted for traffic (EAL=133) Figure H.

[c] Thickness of pavement adjusted for traffic (EAL=133) and 3-in. A.C. surface course. (Deduct 5-in. subbase for each additional inch of surface course).

[d] Minimum thickness of pavement is 8 inches (see Figure H).

[e] Equivalent single axle loads for tandem axle loads (from Table in Figure G).

New York

Various types of tests were made on the subgrade soil including — CBR, Cone Bearing, and Unconfined Compression. Most of them were run on as-molded specimens. However, some were made on soaked specimens that had been subjected to freezing and thawing. The purpose of these tests was to develop information on the stability of the soil at different moisture contents and densities.

In the determination of the thicknesses of pavement, New York reported that the following factors were considered:

"1. Depth of frost penetration equals 30 inches.

2. Materials and conditions of construction, as stipulated in the problem data and indicated by our laboratory investigation.

3. Test vehicles shall have single axle loads of 18,000 and 22,400 lbs., and tandem

axle loads of 32,000 and 40,000 lbs.

4. Unrestricted traffic operation denotes 700 trips per day per lane throughout the year for each test vehicle.

5. Restricted traffic operations denotes 700 trips, per day per lane, for such test vehicles for all periods of the year, except during the frost melt period plus six weeks.

6. Subgrade conditions - as constructed shall denote an in-place density of approximately 89 pcf. and a moisture content of 23 percent.

7. Subgrade conditions - at equilibrium shall denote an in-place density of approximately 89 pcf. and a moisture content of at least 26 percent.

8. Any pavement distress related to subgrade failure shall identify under-design. Deterioration of the surfacing material due to inherent weaknesses, or distress due to weakening of the base course material due to frost, shall not define under-design."

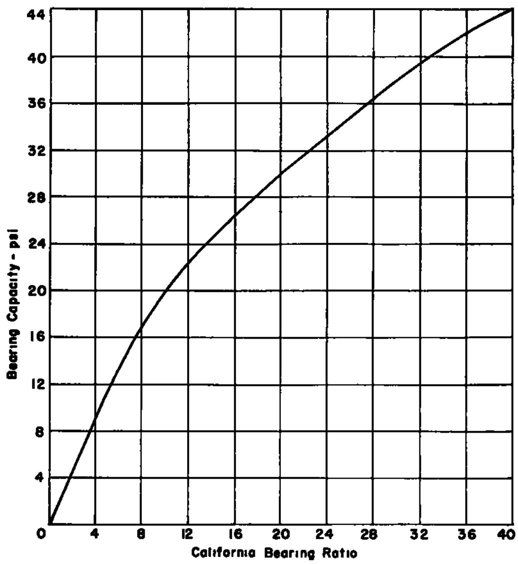


Figure I. Relation of bearing capacity to CBR; North Carolina.

The report of New York indicated that the status of knowledge on flexible pavement design principles is not sufficiently well advanced to permit more than an estimate of the thicknesses of pavement required to support given weights and volumes of vehicles under particular conditions of climate and materials. It was pointed out that minor variations in the thicknesses recommended should not be construed as implying a high degree of accuracy but to indicate trends only.

North Carolina

The required thickness of pavement determined by the North Carolina method is equivalent to that depth where the subgrade bearing capacity balances the vertical stress caused by the load.

Unsoaked CBR values are used to evaluate the bearing capacity of the subgrade. Possible increases in subgrade moisture after construction are considered by molding and testing samples at high moisture contents(9). The test specimens compacted at these moisture contents generally are between 95 and 100 percent saturated.

The effect of frost on the WASHO designs was considered, but no adjustments were made since the total thicknesses of pavement calculated were greater than the reported 22-inch depth of frost penetration. North Carolina reported that for an A-6 type of subgrade soil the total thickness of pavement should be equal to or greater than the depth of frost penetration, also that the subbase materials used in the pavement should not be frost susceptible.

A CBR value of 2.3 was used in the design. This value was obtained using soil molded at 110 percent of Std. AASHO optimum moisture content. According to experience in North Carolina this is the highest moisture content a soil of this type will attain in service.

A CBR value of 2.3 corresponds to a bearing capacity of 5 psi. (See Figure I). This value of bearing capacity was used to obtain the total thicknesses of pavement from the curves for different axle loadings shown in Figures J and K.

The thickness for the 18,000-lb. single axle load 9,000-lb. wheel load was obtained from Figure J. The thickness for the 22,400-lb. single axle load was obtained from the 10,000-lb. wheel load curves in Figure K. Since the pressure exerted by a 11,200-lb. wheel load is 11 percent greater than that of a 10,000-lb. wheel load, the thickness was selected for an equivalent bearing capacity of 4.5 psi.

The thickness for the 32,000-lb. tandem axle load was obtained from a curve developed

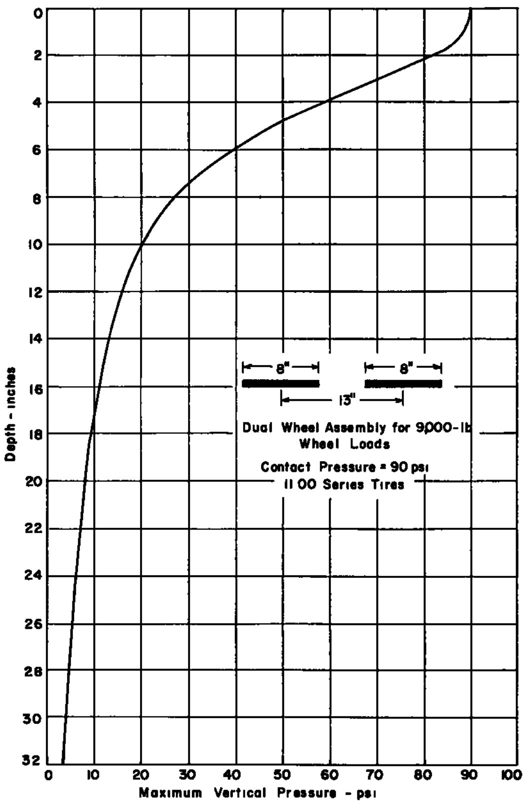


Figure J. Pressure computation (using Newmark's charts) for 9,000-lb. wheel load, North Carolina.

for an 8,000-lb. wheel load. The thickness for the 40,000-lb. tandem axle load was obtained from a curve for a 10,000-lb. wheel load.

It was not possible to determine from the North Carolina method of design the number of trips to produce failure. It was indicated that the thicknesses reported are those considered to be adequate for unlimited traffic.

Puerto Rico

The design of flexible pavement in Puerto Rico is based upon subgrade CBR values and the permissible wheel load. The following comments regarding the design correlation study were taken from the Puerto Rico report.

"First, our design curves (see Figure L) do not show the thickness of pavement and base necessary for frost heave protection. The reason is quite obvious since our roads are not subjected to freezing temperatures, but to comply with your requirements we are recommending subbase thicknesses in which the detrimental effects of frost action are taken into account to provide a permanent, sound road structure throughout the year. Starting with the premise that the combined thickness of a pavement and non-frost action base material should be from one half to full depth of frost penetration, our recommended subbase of 9-in. and 10-in. for the 18,000-lb. and 22,400-lb. single axle loads respectively are adequate as both pavements fall well above the limit of 12-in. which is half the depth of average frost penetration at the WASHO Test Road. Furthermore, the grading of the subbase and base material show less than 7 percent passing the No. 200-mesh sieve, classifying them as non-frost susceptible materials.

"For the 32,000-lb. and 40,000-lb. tandem axle loads, we feel that the combined thickness of pavement, base and subbase should extend to full depth of frost penetration (24-in.). The road structure supporting the 32,000-lb. tandem axle load

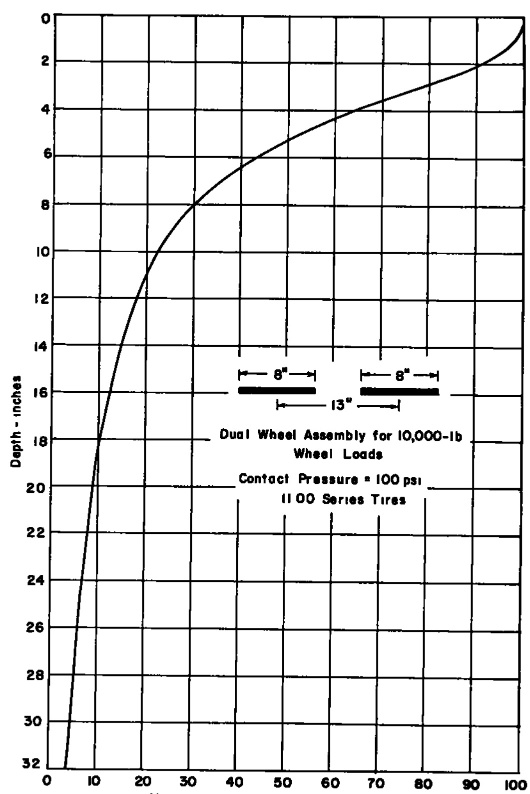


Figure K. Pressure computation (using Newmark's Charts) for 10,000-lb. wheel load, North Carolina.

will be a little over designed, but such high wheel load justifies the additional cost.

"Second, the total load transmitted to the road by a tandem axle is considered as a single axle load if the centers of such axles are within 40-inches apart; an assumption we adopted as our design is based on static wheel loads with no consideration whatsoever

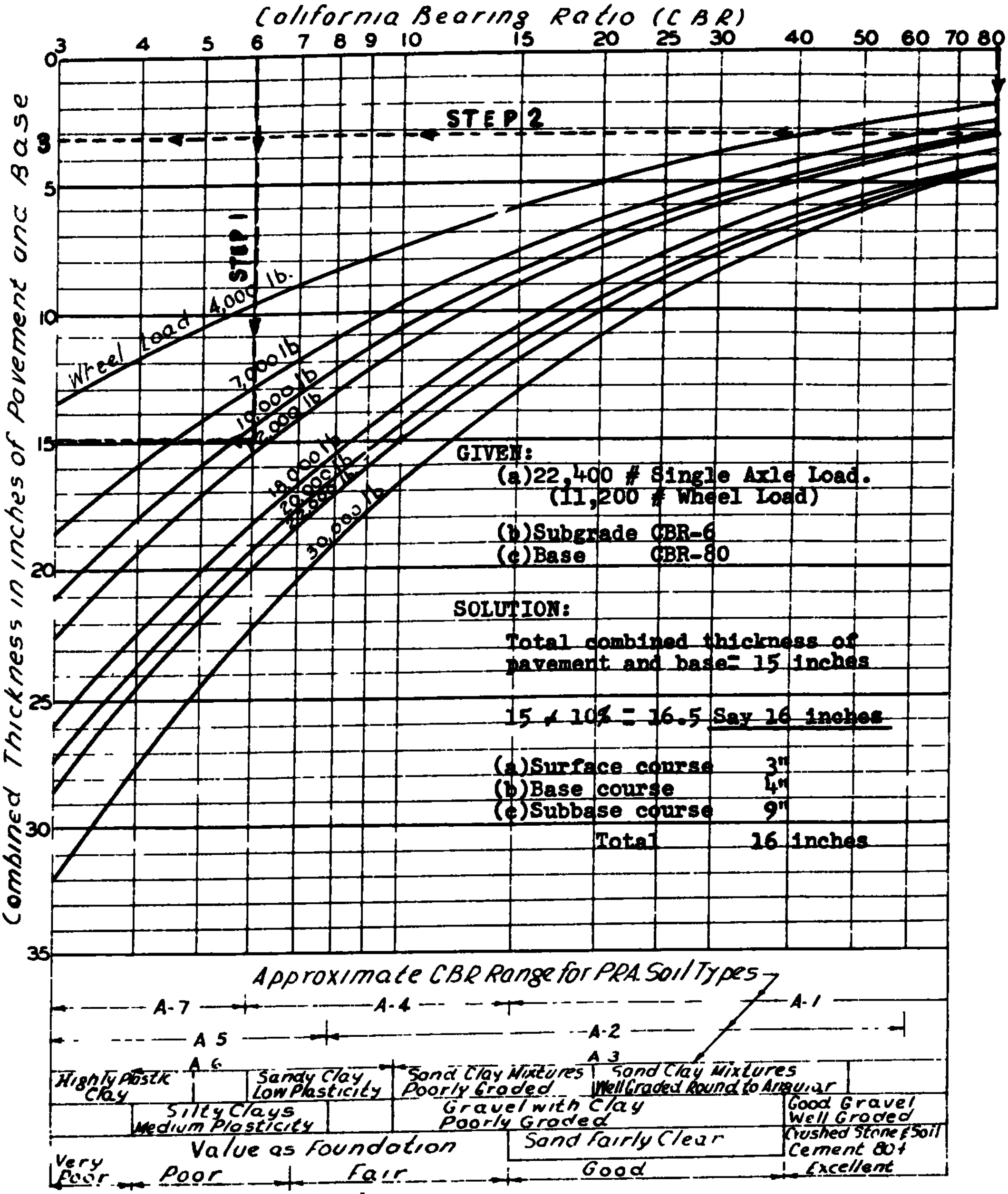


Figure L. Puerto Rico design chart for flexible pavements.

on the effect of moving loads, impact or traffic or number of trips to produce failure on the flexible pavement structure. For design purposes a tandem axle is considered a single axle and half its load a wheel load. It is further assumed that dual wheels are within 3 ft. centers and, as such, are considered as a single wheel load.

"Third, the total thickness of a road structure i.e., the wearing course, base and subbase, is governed by the relative supporting capacity or bearing power of the natural subgrade as it exists at the site of the highway. So, on Problem A by increasing the thickness of the surface course — bituminous concrete from 2 to 4 inches, and altering the base course 4 inches where the surface is 2 in. and 2 in. where the surface is 4 inches — it will not alter the thickness of the subbase course, in our opinion, which will remain constant.

"Fourth, on the optional information requested by you, either the base or subbase course might as well be omitted. The base and subbase samples are evaluated as excellent materials suitable for use as base or subbase (liquid limits and plasticity index do not exceed 25 and 6 respectively). Experience and sound judgment indicate that the better material should always be placed closer to the wearing surface and that is the reason why we are recommending 4 in. and 6 in. of base courses.

"On Problem B (for local climate and material conditions) our design is based on the following climatic conditions.

a. Length of Record . . . . 40 years
b. Av. Max. Annual Temperature . . . . 86.0 F
c. Av Min. Annual Temperature . . . . 66.9 F
d. Jan. Av. Temperature . . . . 73.2 F
e. July Av. Temperature . . . . 78.8 F
f. Av. Killing Frost Period . . . . None
g. Range of depth of Frost Penetration. . . . . None
h. Av. Precipitation (50-year record)

Jan. 3.61 in.	May 7.49 in.	Sept. 8.22 in.
Feb. 2.92 in.	June 6.17 in.	Oct. 8.16 in.
Mar. 3.15 in.	July 6.32 in.	Nov. 7.07 in.
Apr. 4.38 in.	Aug. 7.43 in.	Dec. 4.42 in.

i. Av. Annual Precipitation . . . . 69.34 in.

"For the same reason as for Problem A we are recommending a 4 to 6 inch base course and also to keep the cost of the road structure as economical as possible.

"As our curves are based on 60 psi. tire pressures, the combined thicknesses of pavement are base obtained are increased 10 percent for 70 psi.

"The method of evaluation of the subgrade soil, base and subbase material is the AASHO designation M-145-49, and the University of Columbia method of identification and description of soils."

South Dakota

The Wyoming CBR method of determining the thickness of pavement was used in the study. This method provides for numerical evaluation of the significance of the amount of precipitation, depth to water table, frost action, construction conditions in general, and traffic (10). Traffic is first evaluated in terms of equivalent 5,000-lb. wheel loads. The CBR value for the subgrade was estimated on the basis of liquid limit and group index values. The subbase and base course materials were evaluated by comparison to South Dakota standards.

Texas

The procedure used in the study to determine the thicknesses of pavement followed the Texas triaxial method (11). However, some adjustment in the values was made to compensate for the high density of the WASHO test traffic and for the relatively thick asphaltic concrete surfaces.

Triaxial tests were made on the material obtained from the test road at appropriate moisture contents and densities from which the strength class of each was established as follows:

Subgrade soil	- 4.75
Base	- 1.00
Subbase	- 3.20

Since the Texas design chart was developed for normal traffic in which the average of the ten heaviest wheel loads is considered, it was necessary to introduce an adjustment for the heavy density of the test road traffic in the development of the pavement thickness values that were reported in the correlation study. To do this use was made of data obtained in Texas from road life studies. The adjustments in the values i.e., increases in thickness, amounted to 25 and 46 percent for the single and tandem axle loads respectively. The values obtained from the design chart for the different test loads and as adjusted for heavy traffic are listed below together with additional adjustments for the relatively thick bituminous surfaces. The latter values were obtained from the California thickness design chart (12) using cohesiometer values of 270 and 1066 for the two and four inch surfaces.

Design Thicknesses

Wheel Load	Texas Design Chart	Modified for Heavy Traffic	Modified for Slab Strength	
			2-in. AC	4-in. AC
lb.		inches		
8,000-Tandem axle	14	20	15	12
9,000-Single axle	15	19	15	12
10,000-Tandem axle	16	24	20	15
11,200-Single axle	17	21	18	13

The number of axle load applications, Y, to produce failure was determined using the following formula:

$$Y = 3504 \times 10^{0.01465\ (\text{percent design})}$$

This relationship was developed from the road life studies mentioned previously. Pavement failure was considered evident when 5 percent or more of the surface area showed distress.

Washington

The method of flexible pavement design currently being used by this State is similar to that of California except in the degree of compaction used in the preparation of test samples. The following comments were taken from the Washington report.

Problem A: "Laboratory procedure for testing subgrade soil for Problem A involved special treatment for the particular problem and was not representative of normal or routine testing. The major point of difference involves the compacted density of the test specimen. Routine testing is accomplished with a prescribed compactive effort and density is controlled by molding water content. For Problem A, however, compactive effort was adjusted to give the specific density desired, i.e., 89 lbs. per ft.^{3}. Twelve test specimens ($2\frac{1}{2}$-in. high x 4-in. diameter) were compacted under identical conditions to 89 pcf. at 23 percent molding water content. Compaction was by a Triaxial Institute model kneading compactor operating with a foot pressure of approximately 65 psi. Forty blows were used on each specimen.

"Two of the specimens were tested immediately — one to determine stabilometer 'R' value and the other to determine swell pressure and stabilometer 'R' value after soaking. The remaining 5 groups of two specimens each were allowed to absorb water from their compacted state of water content to a predetermined water content within the range of 23 percent to 29 percent. The specimens were left in the original mold with no surcharge during this process. Following this the two specimens in each group were tested as were the two specimens mentioned previously. Data from this procedure are shown on an attached page. This establishes a relationship between swell pressure and stabilometer 'R' value for a subgrade soil compacted to 89 pcf. at 23 percent water content.

"Base and subbase samples were tested in the Hveem stabilometer after compaction in the kneading compactor with 40 blows at 250 psi. foot pressure. This is our normal method of testing such specimens.

"Traffic was evaluated according to the following formula which is the California formula for EWL_{50}.

$$\log \ EWL_{50} = \log XWL \sqrt{\frac{X}{5{,}000}} \qquad (1)$$

EWL_{50} = equivalent 5,000 lb. wheel load repetitions
XWL = other weight wheel load repetitions
X = weight of wheel load.

"Surfacing depths of untreated material were determined by use of the following formula which closely approximates the surfacing design curves ordinarily used in our routine work.

$$S = (3.5 - 0.038R) \log EWL_{50} \qquad (2)$$

where S = total surfacing depth; and
R = stabilometer R value.

"Allowable reductions in total surfacing depth were based on the equation given below:

$$\text{Net surfacing depth} = S \sqrt[3]{c/100} \qquad (3)$$

where $S = (3.50 - 0.038R) \log EWL_{50}$
C = cohesiometer value.

"Cohesiometer values used for the surfacing sections on the WASHO test road were:

4 in. bituminous concrete + 2 in. base = 275
2 in. bituminous concrete + 4 in. base = 200

"The answers offered for our solution of Problem A were derived by use of the above equations and test data mentioned previously. Total design thickness of surfacing necessary for each of the four traffic patterns was determined by plotting thickness necessary to restrain swell against thickness necessary to satisfy 'R' value requirements (as given by equations 2 and 3) and locating the equivalent surfacing thickness which would satisfy both requirements. The traffic was evaluated by equation 1, and data from the 'soaked' curve in Figure A were used in the previously mentioned plots. The 'soaked' condition data were used because the worst expected subgrade conditions should be used for design purposes.

"Our predictions of load repetitions necessary to cause failure require some clarification. Our test data give us a relationship between soil strength characteristics for two soil conditions: the immediate or 'as compacted' condition and the adjusted or soaked condition which approximates a saturated condition. These relationships are shown in Figure A which is a plot of original and residual swell pressure vs. stabilometer 'R' value (for the two conditions of soil moisture previously noted) of a soil specimen compacted to 89 pcf. at a molding water content of 23 percent.

"Our calculations of load repetitions to cause failure were made according to the following form:

Surface	4 in.
Base	2 in.
Subbase	0 in.
Total thickness	6 in.
Effectual thickness	6.9 in. (from Eq. 3)
Subgrade pressure	0.5 psi. (from wt. of overlying material.)
Equivalent R value	16 (from Fig. 1 soaked)
Log EWL_{50}	2.54 (from Eq. 2)
Log of 18,000 lb. axle repetitions	1.9 (from Eq. 1)
Log of 22,400 lb. axle repetitions	1.7 (from Eq. 1)
Log of 32,000 lb. tandem axle repetitions	1.71 (from Eq. 1[a])
Log of 40,000 lb. tandem axle repetitions	1.5 (from Eq. 1[a])

[a] One repetition of a tandem axle load assumed to be two repetitions of a single-axle load equal to ½ the tandem axle load.

"Estimates of load repetition to cause failure were made for both subgrade moisture conditions. Inasmuch as the first period of traffic load application to the test road occurred late in the fall soon after completion of the construction, it is reasonable to assume that subgrade conditions were essentially those that obtained during construction during this interval. Likewise, when testing resumed in the spring, it is not too unreasonable to assume that moisture contents would be at their greatest, or near the soaked condition. Calculations for both conditions indicated that the 6-inch sections would show distress during this initial load application period, while apparently the 14-inch sections would not. The 10-inch sections would possibly show some distress during the initial period, depending on the length thereof. Based on the above reasoning, the number of repetitions necessary to cause failure, as listed in the second table of the report form for Problem A were based on an 'as constructed' subgrade moisture condition for the 6-inch sections and on a 'soaked' condition for the 14-inch and thicker sections. The figures shown for the 10-inch sections are an average of the number of load repetitions calculated for both conditions of subgrade moisture."

Problem B: "Subgrade soil was tested in the Hveem stabilometer after compaction in the kneading compactor by our usual method — 40 blows at a foot pressure of 100 psi. Data from this test are shown on the attached sheet. Stabilometer 'R' values of subbase and base materials as determined for Problem A were used in Problem B. Design 'R' value for soil was determined at an exudation pressure of 400 psi. inasmuch as swell pressure of the soil for this state of compaction was negligible. Traffic and surfacing depths were determined as in Problem A, except that no reduction in total surfacing depth was made for thickness and strength of wearing surface.

"Required thickness of surfacing and pavement is determined by minimum standards plus consideration of the strength of base and subbase as shown by the stabilometer 'R' value.

"Typical weather conditions for which the design was made are those for the City of Olympia. These approximate conditions in Western Washington and are shown on the attached table.

"It should be noted that surfacing design for Problem B is based on test results of nearly saturated subgrade soil specimens. As such, the design will necessarily differ from that given for Problem A. Weather conditions for Western Washington justify such a basis for surfacing design in our opinion."

West Virginia

The method of design used by this State is similar to that of Kentucky. In the development of the thickness values reported in the design correlation study the CBR of the subgrade was estimated from the results of routine soil tests (plasticity and gradation) and from Proctor compaction data. The CBR value arrived at in this manner was adjusted to compensate for the low temperatures existing at the test road site.

The procedure for estimating the number of repetitions to produce failure involved working backwards through the design charts — as did Kentucky.

Wyoming

The current method (13) of flexible pavement design was employed in the study. The CBR test is normally conducted as follows:

1. The material is hand tamped into the mold at optimum moisture and subjected only to sufficient static load to bring it to maximum density, with optimum moisture and maximum density having been determined previously by AASHO designation T 99-49.

2. Soaking period 4 days with only a 10 pound surcharge regardless of soil type or estimated thickness of cover.

The subgrade soil was compacted to 95.0 pcf as compared to the maximum dry weight of 96.3 pounds at 24.4 percent optimum moisture. Since this is only slightly under maximum dry weight the 5.5 percent of standard bearing ratio at 0.1 inch penetration was used without correction.

The subbase material was of such grading and characteristics that it was estimated the modified CBR would be 60 percent or higher. Since the minimum design CBR for a subbase, with 6 inches of combined pavement and base between its surface and the wheel load, would range between 25 percent to 33 percent on any of the design curves 7, 9 or 12, there was no point in determining the actual modified CBR.

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12. The Factors Underlying the Rational Design of Pavements, F.N. Hveem and R.M. Carmany, Proceedings, Highway Research Board, Vol. 28, 1948.

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