Performance of Treated and Untreated Aggregate Bases

A. C. BENKELMAN, R. IAN KINGHAM, and H. M. SCHMITT

Respectively, Flexible Pavement Research Engineer, AASHO Road Test; Engineer-Observer at the AASHO Road Test for the Canadian Good Roads Association; Assistant Flexible Pavement Research Engineer, AASHO Road Test

• There were three major experiments included in the study of flexible pavement performance at the AASHO Road Test, the factorial, the special base, and the paved shoulder experiment. Of the three, the factorial experiment was by far the most comprehensive. It included study of sections in the four major loops having three levels of surfacing thickness, three levels of base, and three levels of subbase thickness, a 3 × 3 × 3 factorial. In Loop 2 (the light-axle load loop), only two levels of subbase thickness were employed in a 3 × 3 × 2 factorial. In this experiment, the materials composing the asphaltic concrete surfacing, the crushed stone base course, and the sandy gravel subbase were uniform throughout, as was also the embankment soil on which the pavement was laid.

The design of the factorial experiment was such that it was possible to make a statistical analysis of the performance data, *i.e.*, in part, to determine the extent to which each of the components of the pavement contributed to its performance. The equation that was developed from the analysis pointed to the fact that the surfacing material per unit of thickness was about three times as effective as the base course, and four times as effective as the sub-

TABLE 1

CHARACTERISTICS OF MATERIALS, FLEXIBLE PAVEMENTS [1]

Item	Subbase	Crushed Stone Base	Gravel Base	Cement Treated Base	Asphalt Treated Base	Asphaltic Concrete	
						Surface Mix	Binder Mix
Aggregate gradation, % passing:							
1½-in. sieve		100	100				
1-in. sieve	100	90	98	100	100		100
¾-in. sieve	96	80		96	96	100	
½-in. sieve	90	68	74	90	90	92	75
No. 4 sieve	71	50	49	71	71	65	36
No. 40 sieve	25	21	23	25	25	22	13
No. 200 sieve	7	11	9	7	7	5	4
Plasticity index, minus No. 40 material	N.P.	N.P.	3.5				
Max. dry density[2] (pcf)	138	139	140	138	149[3]	151[3]	154[3]
Field density (% max. dry dens.)	102[4]	102	104	101	97	97	97
Asphalt[5] content (% total mix)					5.2	5.4	4.5
Cement[6] content (% by wt.)				4.0			
7-Day compressive strength (psi)				840			
Laboratory tests:							
Marshall stability					1,600	2,000	1,800
Marshall flow					10	11	11
Total voids (%)					6.2	3.6	4.8

[1] Identification: Subbase, uncrushed natural sand-gravel; Crushed stone base, crushed dolomitic limestone; Gravel base, uncrushed natural gravel; Treated bases, asphalt cement or portland cement and subbase material.
[2] AASHO T99–57.
[3] Laboratory density using Marshall procedure.
[4] Before subgrading.
[5] 85–100 penetration grade asphalt.
[6] Type I portland cement.

base course in improving pavement performance. A thickness index, developed from observed performance data, shows these relationships.

$$D = 0.44D_1 + 0.14D_2 + 0.11D_3 \qquad (1)$$

in which

D = the thickness index;
D_1 = the asphalt concrete surfacing material thickness;
D_2 = the crushed stone base material thickness; and
D_3 = the sand gravel subbase material thickness.

Performance was a function of the thickness index D and with certain limitations (see HRB Special Report 61E), D could be made up of any combinations of D_1, D_2 and D_3.

Had it been possible to repeat the layout of sections in the factorial experiment using different types of surfacing, base and/or subbase material, as well as different subgrade soils, more comprehensive analyses of performance could have been made and more specific design relationships including strength terms could have been developed. Due to limitations of funds, time and space, it was not possible to do this. However, sufficient space was available to include a limited study of different types of base material and a limited study of paved shoulders.

SPECIAL BASE EXPERIMENT

In the special base study, four different types of base course were included: crushed stone, a well-graded uncrushed gravel, a cement-treated material, and a bituminous-treated material. The crushed stone was the same material as that used in the construction of the factorial sections. The cement-treated and bituminous-treated material consisted of the sand gravel subbase that was used in the factorial test sections combined with either 4 percent by weight of portland cement or 5.2 percent of paving asphalt. The characteristics of these materials are given in Table 1 and those of the embankment soil in Table 2.

Three of the four types of base course were included in six structural sections in each flexible tangent of the four major loops (two replicate sections for each base type). The sections were 160 ft long, and the base was constructed as a wedge, *i.e.*, the thickness of the material

TABLE 2

CHARACTERISTICS OF EMBANKMENT SOIL

Classification (AASHO M–145)	A–6
Average values, borrow pit samples:	
Max. dry density, AASHO T–99–49 (pcf)	116
Optimum moisture content (%)	15
Liquid limit (%)	29
Plasticity index	13
Grain size, finer than (%):	
No. 200	81
0.02 mm	63
0.005 mm	42
Specific gravity	2.71
Average of construction tests:	
Density (% max. dry dens.)	97.7
Moisture content (%)	16
Constructed embankment tests:	
Laboratory CBR, soaked	2–4
Field in-place CBR, spring	2–4
Modulus of subgrade reaction, spring, k	45

TABLE 3

DESIGN OF SPECIAL BASE TYPE WEDGE SECTIONS

Loop	Base Type	Thickness (in.)						
		Surfacing	Subbase	Base				
				Range	Average for Subsection			
					1	2	3	4
3	Bituminous	3	0	2–11	9.9	7.6	5.4	3.1
	Stone	3	0	2–14	12.5	9.5	6.5	3.5
	Gravel	3	0	2–14	12.5	9.5	6.5	3.5
4	Cement	3	4	2–10	9.0	7.0	5.0	3.0
	Stone	3	4	2–16	14.3	10.8	7.3	3.8
	Gravel	3	4	2–16	14.3	10.8	7.3	3.8
5	Bituminous	3	4	3–16	14.4	11.1	7.9	4.6
	Cement	3	4	3–12	10.9	8.6	6.4	4.1
	Gravel	3	4	3–18	16.1	12.4	8.6	4.9
6	Bituminous	4	4	3–18	16.1	12.4	8.6	4.9
	Cement	4	4	3–13	11.8	9.3	6.8	4.3
	Stone	4	8	3–19	17.0	13.0	9.0	5.0

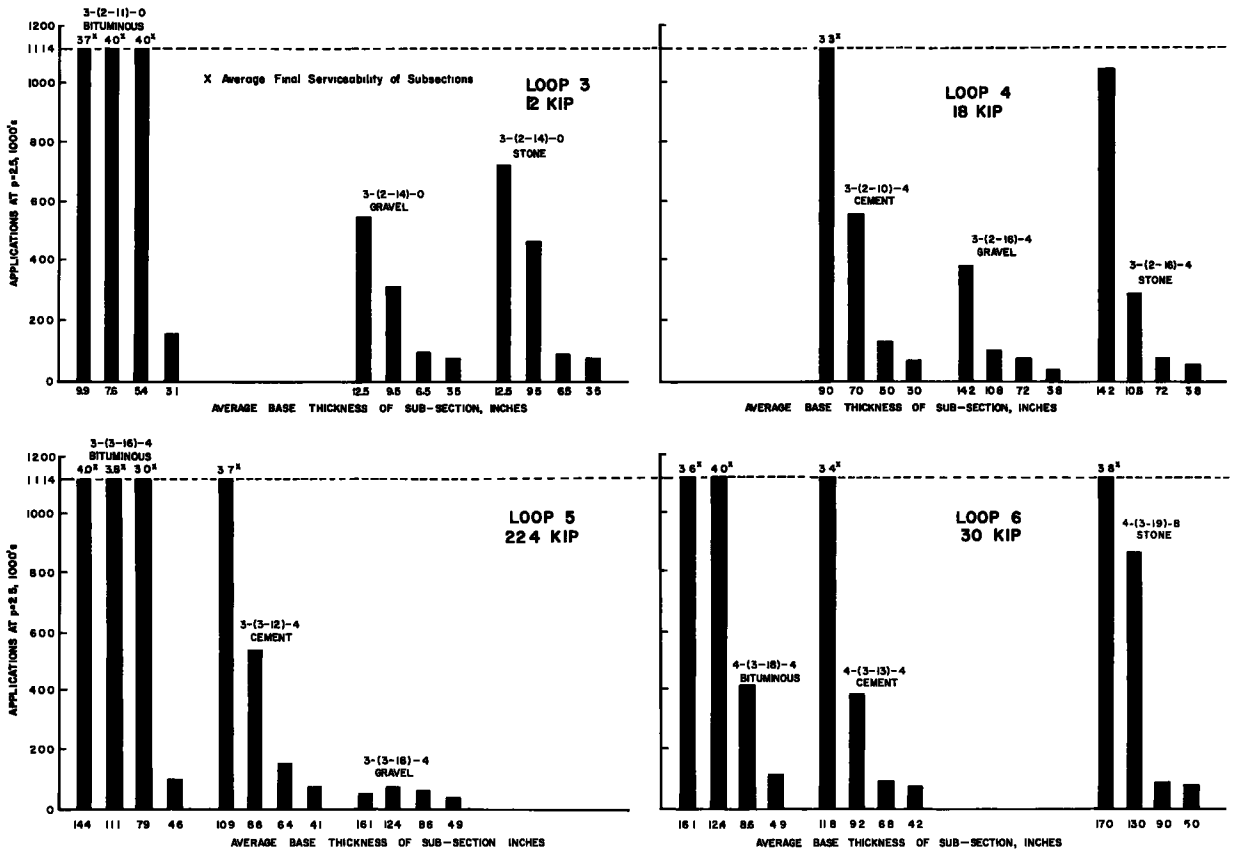

Figure 1. Special base type experiment, performance data for single-axle loads (averages for each pair of replicate sections).

decreased at a uniform rate from one end of the section to the other in the direction of traffic. Each structural section comprised two test sections, 12 ft or one traffic lane in width, each subjected either to single- or tandem-axle loads.

The test sections were divided into 40-ft subsections, and the base thickness of each subsection was considered in the major analysis of performance to be represented by its mean thickness of base. It was necessary to approach the analysis of performance of the special base sections in this way since the method of determining the condition of the pavement used at the test road was such that determinations could not be made effectively on lengths less than about 40 ft.

Table 3 gives pertinent data regarding the design of the special base sections. In addition to listing the thickness of the surfacing and subbase, the table gives the range in thickness of the bases and the average thickness of each of the 40-ft subsections for each of the sections in the four loops. Only one thickness of surfacing was used in each of the loops; 3 in. in Loops 3, 4, and 5, and 4 in. in Loop 6. Also, no subbase was used in Loop 3, and 4 in. was used in Loops 4, 5, and 6 except that in Loop 6 an 8-in. subbase was provided for the sections with stone base.

PERFORMANCE DATA

Basic data on the performance of the special base sections are shown in Figures 1 and 2. The values plotted are the averages for the pairs of replicate subsections. The effect of the thickness of the base upon performance is clearly shown except for the gravel base sections in Loop 5.

The gravel base sections failed early in the test and are omitted from the analysis of performance. On Loops 3 and 4 there was a fairly orderly effect of thickness of the gravel material. However, on Loop 5, the serviceability of all gravel subsections dropped to 1.5 at practically the same number of axle-load applications (less than 100,000), indicating that increasing the base thickness within the range provided in Loop 5 did not improve its performance. It appears that the gravel material possessed a level of internal stability that might be considered adequate for the loads

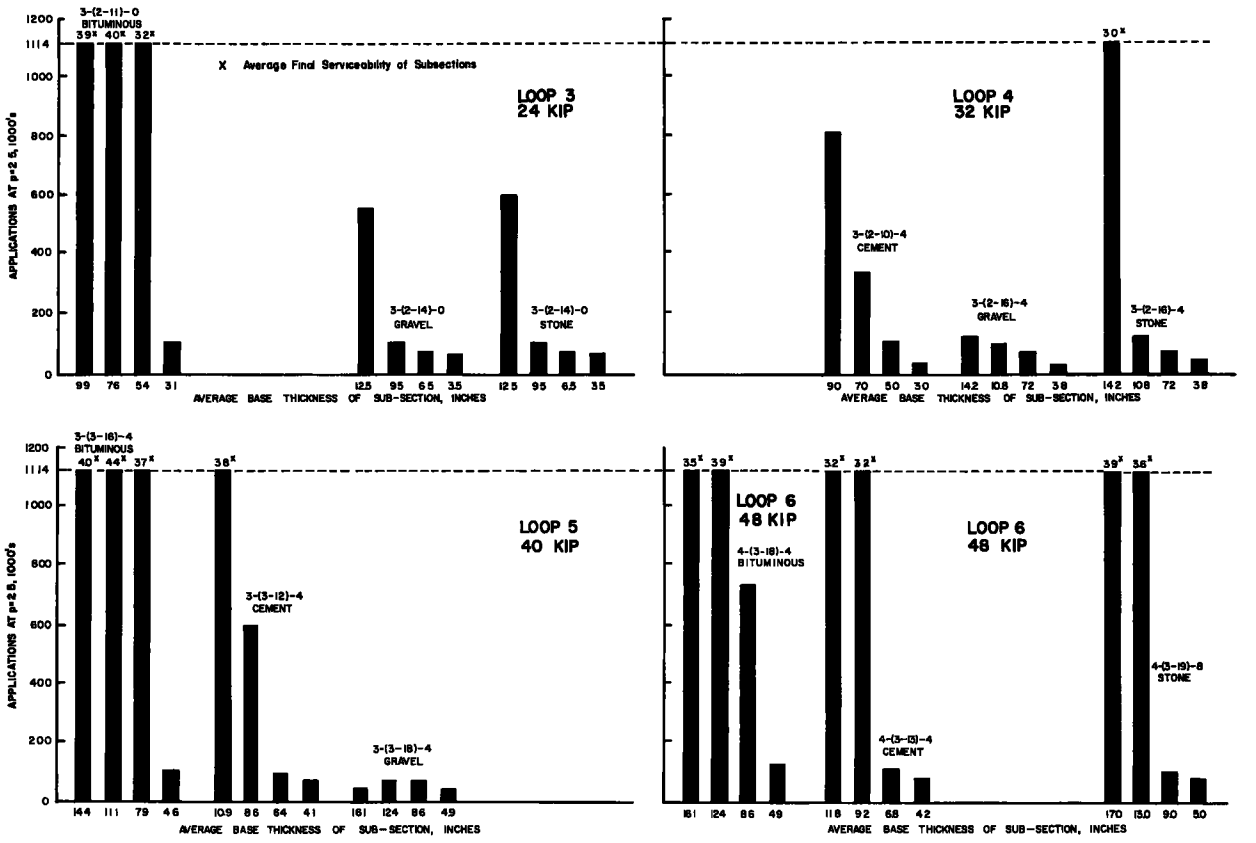

Figure 2. Special base type experiment, performance data for tandem-axle loads (averages for each pair of replicate sections).

operating on Loop 3, nearly so for the loads on Loop 4, but definitely not for those on Loop 5.

In a graphical analysis of performance of the stone, cement and bituminous base wedge sections, the relationships between changes in serviceability and changes in thickness of the base material were first developed for each pair of replicate sections at several levels of axle-load applications (Fig. 3, 4, and 5). The plotted points represent mean serviceability vs mean base thickness for each pair of replicate subsections. The family of curves was formed by connecting the plotted points for each of the six selected levels of axle-load applications.

From curves constructed in this manner it was possible to obtain values of base course thickness for various levels of axle-load applications at any desired serviceability level. Table 4 gives these values for 100, 300, 500, 700, 900, and 1,114 thousand axle-load applications at a serviceability level of 2.5. The actual thicknesses are not directly comparable across loops, or within Loop 6, since the thickness of surfacing and subbase was not the same for all sections included in the study. Therefore, in order to make desirable across-loop comparison of the performance of the different bases and comparison within Loop 6, the base thicknesses shown in the table for Loops 3 and 6 were adjusted to correspond with the thicknesses of surfacing and subbase used in Loops 4 and 5, *i.e.*, 3 in. of surfacing and 4 in. of subbase. In making the necessary assumptions, consideration was given to the strength characteristics of the various materials. For example, the Marshall stability of the bituminous-treated base was nearly as high as that for the surface and binder courses (1,600 vs 2,000 and 1,800) and the compressive strength at 7 days for cement-treated base was 840 psi. The adjustments were made on the following basis:

From Eq. 1, the performance analysis of the factorial section:

1 in. bituminous surface = 3 in. stone base, approximately;

1 in. bituminous surface = 4 in. subbase, approximately;

3 in. stone base = 4 in. subbase, approximately.

Assumed:

1 in. bituminous surface = 1 in. bituminous base; and

1 in. bituminous base = 4 in. subbase.

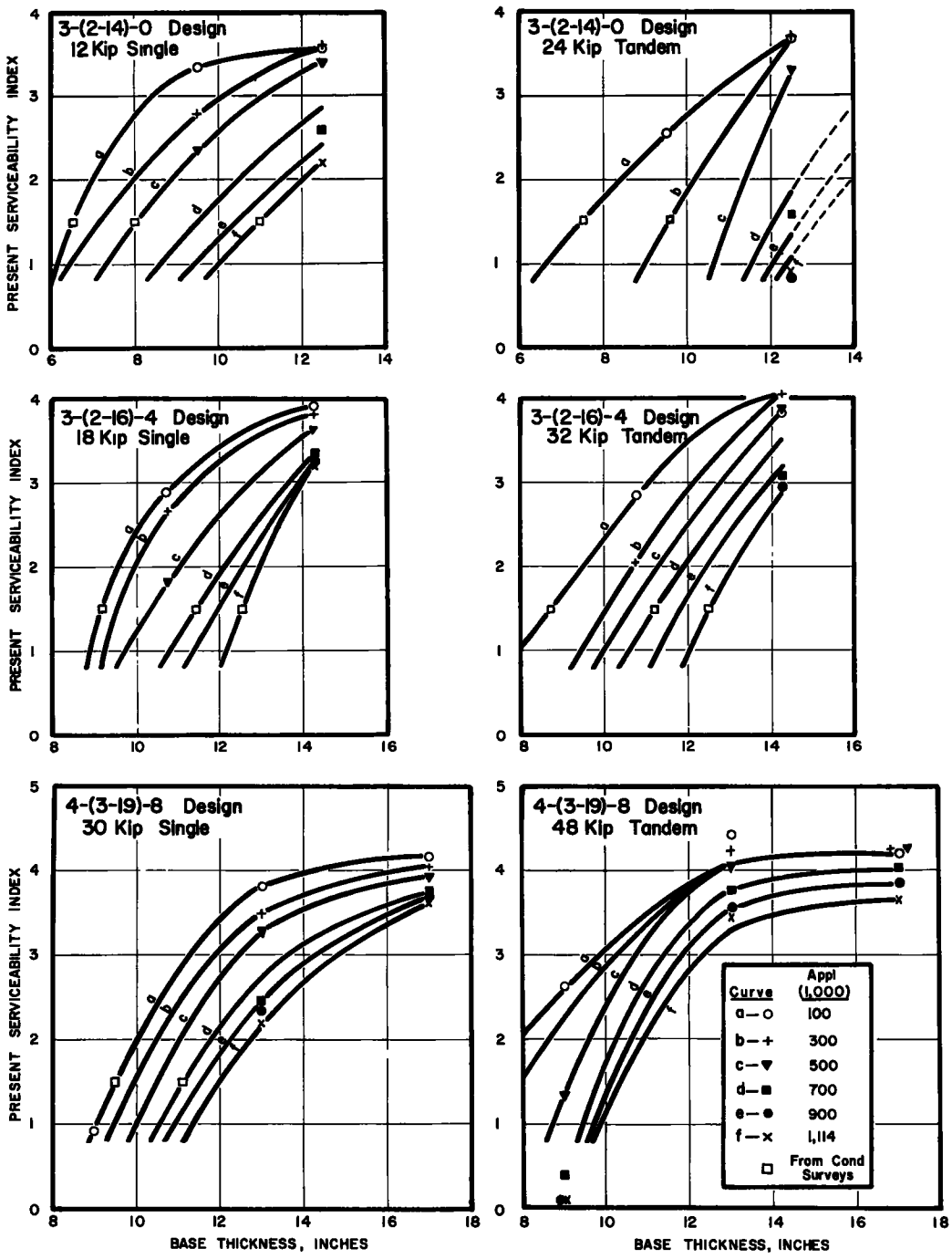

Figure 3. Special base type experiment, crushed stone base performance data (averages of two replicate sections).

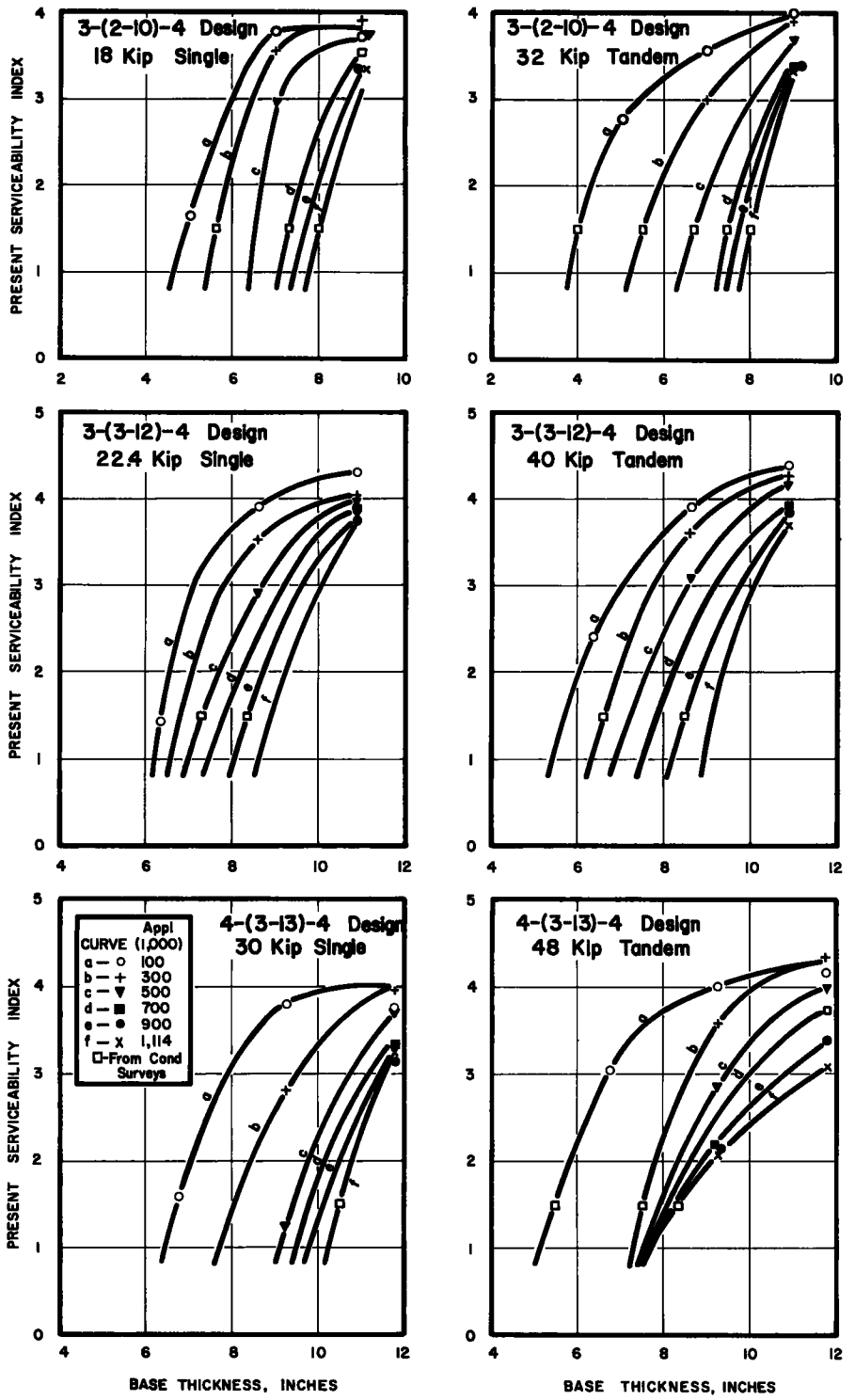

Figure 4. Special base type experiment, cement-treated base performance data (averages of two replicate sections)

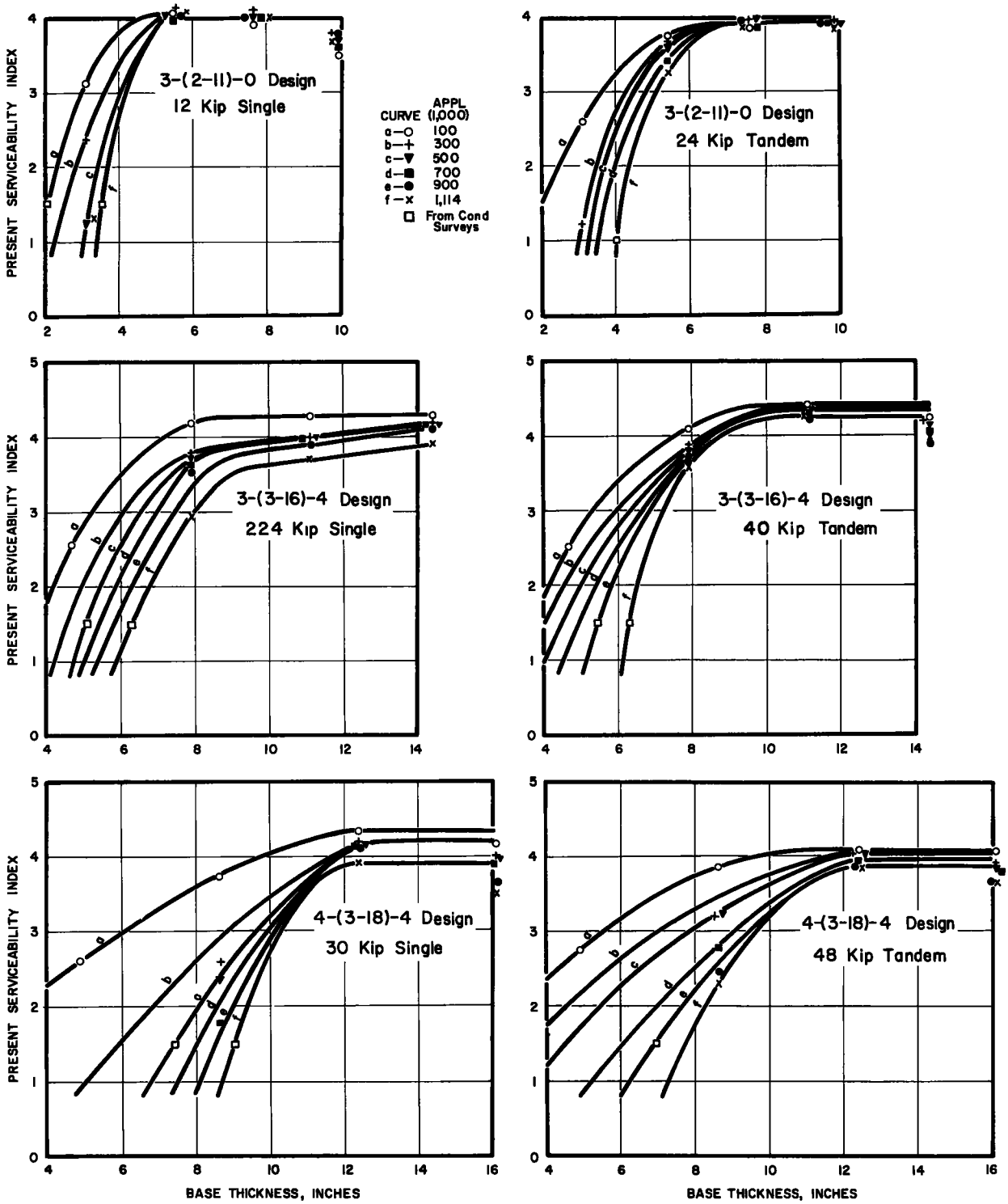

Figure 5. Special base type experiment, bituminous-treated base performance data (averages of two replicate sections).

TABLE 4

SPECIAL BASE TYPE STUDY,
THICKNESS OF BASES CORRESPONDING TO A SERVICEABILITY LEVEL OF 2.5

Applications	Base Type	Lane	Thickness (in.)					
			Actual				Adjusted[1]	
			Loop 3	Loop 4	Loop 5	Loop 6	Loop 3	Loop 6
100,000	Stone	1	7.6	10.1	....	10.6	4.6	16.6
		2	9.5	10.3	....	8.8	6.5	14.8
	Cement	1	....	5.6	6.8	7.4	....	8.7
		2	....	4.7	6.4	6.2	....	7.5
	Bituminous	1	2.6	....	4.7	4.7	1.6	5.7
		2	3.0	....	4.7	4.3	2.0	5.3
300,000	Stone	1	8.9	10.6	....	11.1	5.9	17.1
		2	10.9	11.4	....	9.4	7.9	15.4
	Cement	1	....	6.1	7.4	8.9	....	10.2
		2	....	6.3	7.3	8.1	....	9.8
	Bituminous	1	3.2	....	5.5	7.8	2.2	8.8
		2	3.8	....	5.2	5.6	2.8	6.6
500,000	Stone	1	9.9	11.8	....	11.7	6.9	17.7
		2	11.8	12.0	....	10.1	8.8	16.1
	Cement	1	....	6.9	8.2	10.2	....	11.5
		2	....	7.5	8.0	8.8	....	10.1
	Bituminous	1	3.7	....	6.0	8.8	2.7	9.8
		2	4.0	....	5.6	6.6	3.0	7.6
700,000	Stone	1	11.6	12.8	....	12.5	8.6	18.5
		2	13.4	12.6	....	10.7	10.4	16.7
	Cement	1	....	7.9	8.7	10.6	....	11.9
		2	....	8.1	8.6	9.2	....	10.5
	Bituminous	1	3.7	....	6.4	9.2	2.7	10.2
		2	4.3	....	6.0	7.9	3.3	8.9
900,000	Stone	1	12.7	13.1	....	13.1	9.7	19.1
		2	14.1	13.1	....	11.1	11.1	17.1
	Cement	1	....	8.3	9.1	10.9	....	12.2
		2	....	8.3	9.3	9.7	....	11.0
	Bituminous	1	3.8	....	6.9	9.5	2.8	10.5
		2	4.5	....	6.3	8.5	3.5	9.5
1,114,000	Stone	1	13.2	13.4	....	13.6	10.2	19.6
		2	14.4	13.7	....	11.5	11.4	17.5
	Cement	1	....	8.6	9.6	11.1	....	12.4
		2	....	8.6	9.7	10.2	....	11.5
	Bituminous	1	3.9	....	7.3	9.8	2.9	10.8
		2	4.6	....	6.8	8.9	3.6	9.9

[1] Adjusted to correspond with thicknesses of surfacing and subbase used in Loops 4 and 5.

From average ratios of thickness of bituminous base and cement base (Table 4) for Loops 5 and 6:

1 in. bituminous base = 1.30 in. cement base; and

1 in. bituminous surface = 1.30 in. cement base.

The relationships shown in Figure 6 were developed from Table 4 (adjusted thicknesses for Loops 3 and 6). Since there was no consistent indication of curvilinearity, straight lines were fitted to the plotted points indicating that the design of thickness of the pavement varies as a direct linear function of the load. This is not in strict agreement with the results obtained from the performance analysis of the factorial sections. Here the design of the pavement (thickness index) varies as a near linear function of the square root of the load. The relationships in Figure 6 serve to compare the three types of base with respect to their ability to give the same level of performance under a range of single- and tandem-axle loads and at six levels of axle-load applications. The thicknesses of base are those needed when the surfacing was considered to be 3 in. and the subbase 4 in.

Figure 7 shows a similar comparison of the three types of base under a range of axle-load applications for each single- and tandem-axle load included in the test. The values used to develop the curves were taken directly from the relationships shown in Figure 6. Extrapolation of interpolation was used when necessary. For example, a curve is shown for each of four loads in Figure 6 even though only three loads were actually applied to a particular base type.

Additional information on the performance of the special base type sections is given in

TABLE 5

SPECIAL BASE SECTION PERFORMANCE DATA, BASE THICKNESS NOT ASSOCIATED WITH CLASS 2 SURFACE CRACKING, FEBRUARY 20, 1960, 500,000 AXLE APPLICATIONS

Type of Base	Lane	Base Thickness[1] (in.) Loop 3	Loop 4	Loop 5	Loop 6
Gravel	1	9.3	OT	OT	—
		9.5	OT	OT	—
	2	10.4	OT	OT	—
		11.3	OT	OT	—
Stone	1	7.7	9.2	—	11.0
		7.7	9.2	—	11.0
	2	9.4	9.1	—	7.6
		10.4	9.2	—	7.6
Cement	1	—	6.2	6.9	9.1
		—	6.3	7.0	9.1
	2	—	6.2	6.9	7.7
		—	6.4	6.9	7.7
Bituminous	1	2.4	—	5.3	6.7
		2.6	—	5.3	6.7
	2	3.1	—	5.3	5.7
		3.1	—	5.3	5.7

[1] OT = out of test. Thickness is average of two subsections; for thickness of surfacing and subbase see Table 12.

TABLE 6

SPECIAL BASE SECTION PERFORMANCE DATA, BASE THICKNESS NOT ASSOCIATED WITH CLASS 2 SURFACE CRACKING, NOVEMBER 30, 1960, 1,114,300 AXLE APPLICATIONS

Type of Base	Lane	Base Thickness[1] (in.) Loop 3	Loop 4	Loop 5	Loop 6
Gravel	1	OT	OT	OT	—
		OT	OT	OT	—
	2	OT	OT	OT	—
		OT	OT	OT	—
Stone	1	11.4	11.0	—	11.0
		13.0	13.2	—	11.2
	2	13.4	11.6	—	8.0
		13.5	12.6	—	9.2
Cement	1	—	7.8	8.0	9.5
		—	7.5	8.8	10.2
	2	—	7.5	8.2	8.0
		—	7.5	8.2	8.1
Bituminous	1	2.6	—	5.3	7.6
		2.8	—	6.0	8.0
	2	3.2	—	5.6	6.8
		3.8	—	5.6	6.8

[1] OT = out of test. Thickness is average of two subsections; for thickness of surfacing and subbase see Table 12.

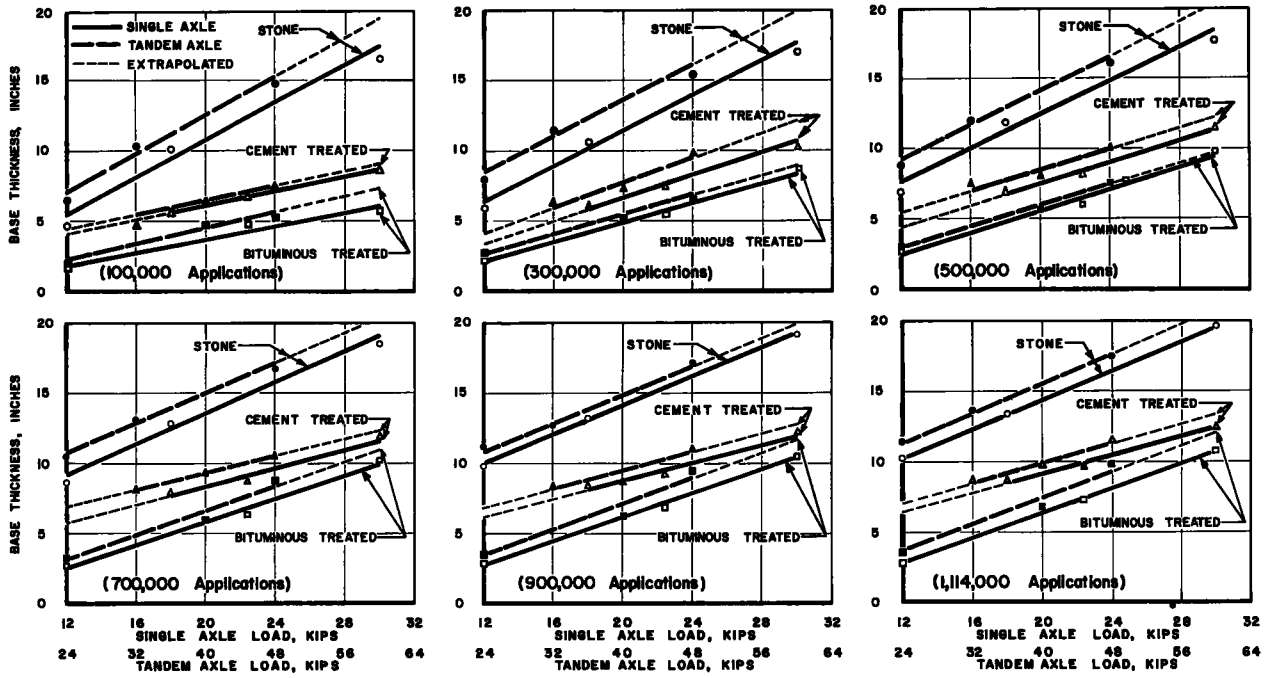

Figure 6. Special base type experiment, relationship between base thickness and axle load at $p = 2.5$ (surfacing, 3 in.; subbase, 4 in.).

Tables 5 and 6. The thicknesses of base represent the amount necessary to prevent Class 2 cracking of the surfacing at two levels of axle-load applications. The values are applicable for the basic designs of the sections (Table 3).

Rut depths in the wheelpaths of all flexible pavements were measured every two weeks during the period of traffic operation. This made it possible to develop plots for the many different designs of pavement showing the progression of rutting with axle-load applications. Typical examples of these plots for certain of

TABLE 7

Single-Axle Loads (kips)	Design (in.)			Minimum Base (in.)			Rutting Depth (in.)					
	Surface	Base	Subbase	Bituminous	Cement	Stone	Bituminous		Cement		Stone	
							(1)[1]	(2)[2]	(1)	(2)	(1)	(2)
12	3	variable	0	4	5[3]	—	0 18	0 23	—	—	—	—
18	3	variable	4	6[3]	8	14			0 08	0 18	0 23	0 42
22 4	3	variable	4	7	10	14[3]	0 22	0 39	0 10	0 18		
30	4	variable	4	9 5	12		0 34	0 50	0 18	0 32		
30	4	variable	8			13					0 32	0 42

[1] Late summer 1959.
[2] Fall 1960.
[3] Interpolated or extrapolated.

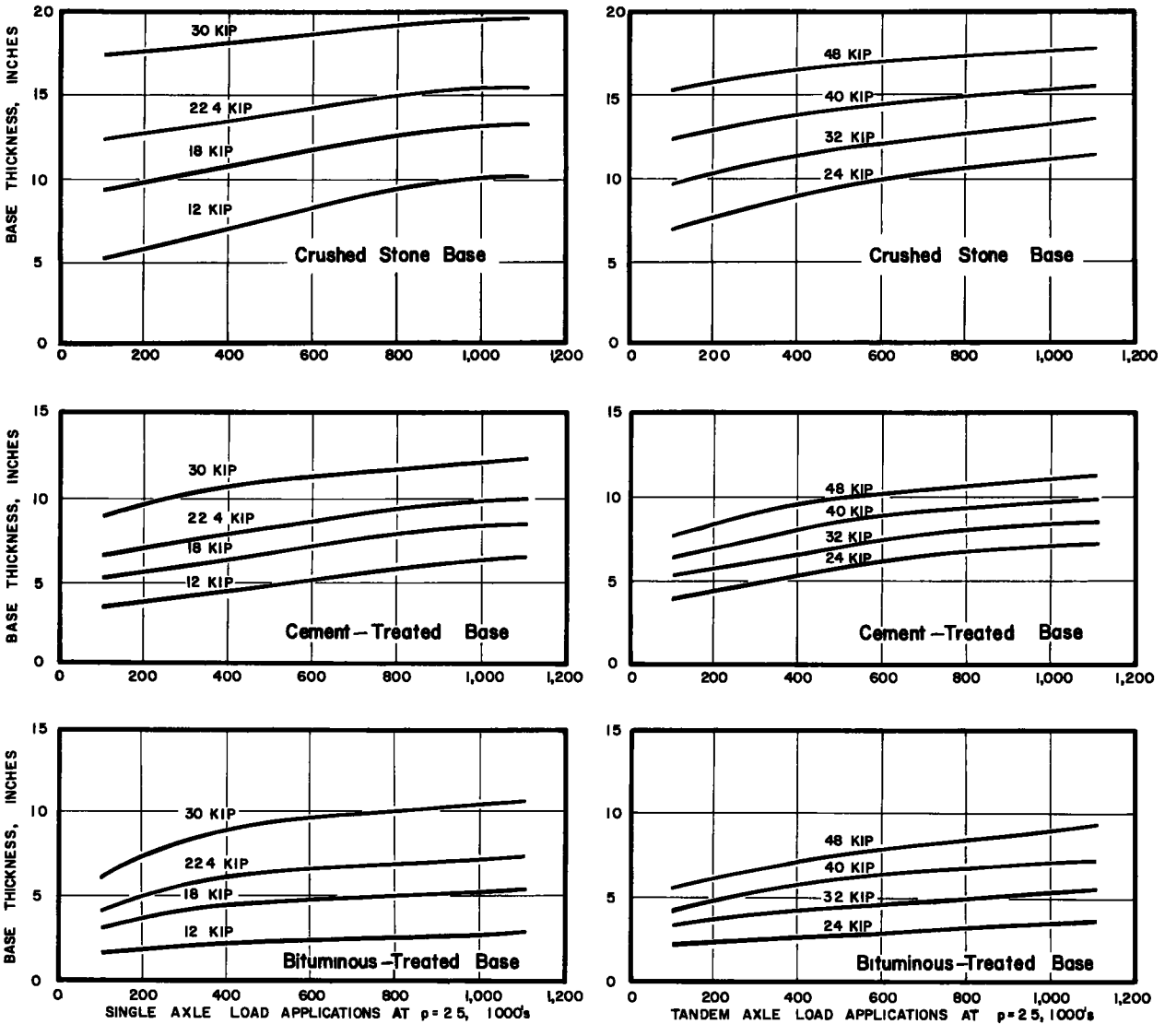

Figure 7. Special base type experiment, relationship between base thickness and axle load application at $p = 2.5$ (surfacing, 3 in.; subbase, 4 in.).

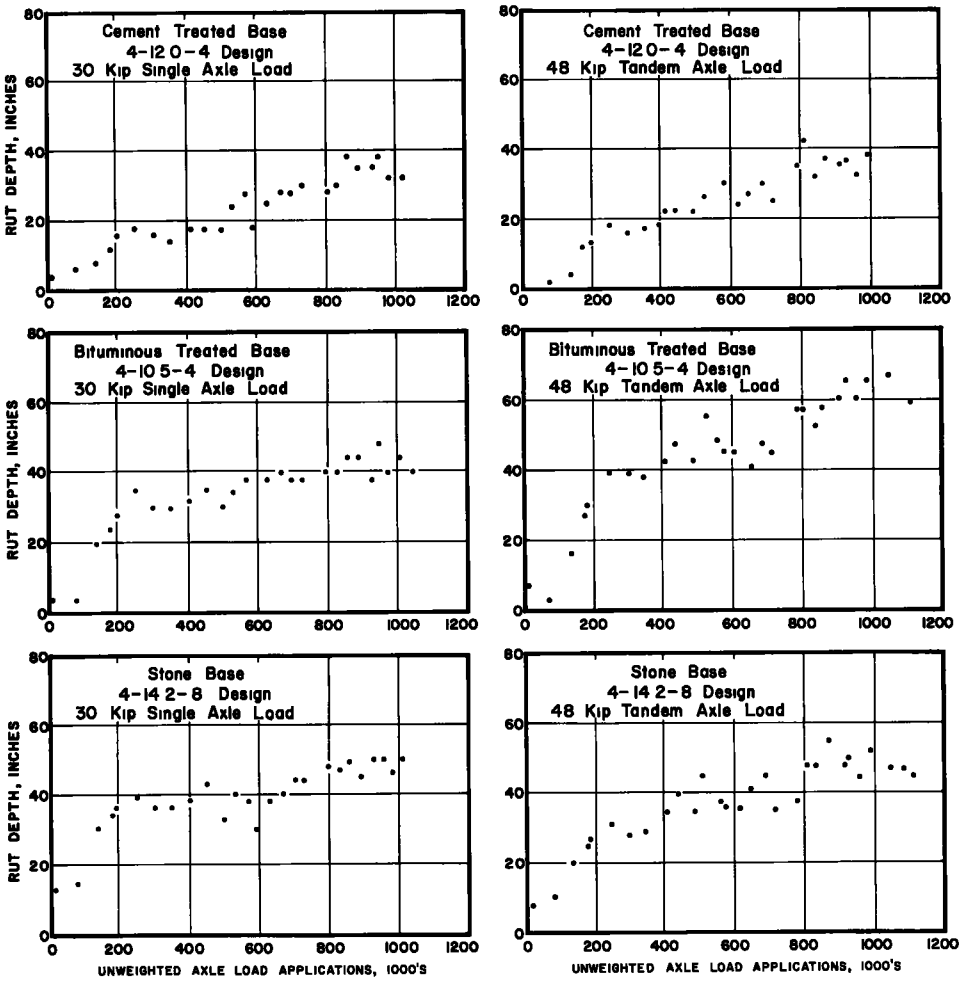

Figure 8. Effect of axle application on depth of rut; typical sections from special base experiment.

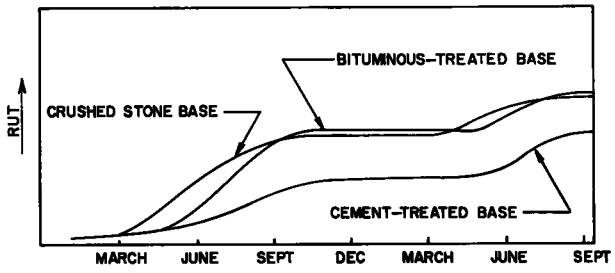

Figure 9. Relative effect of seasons on rutting.

the special base sections are shown in Figure 8. They are for designs or thicknesses of pavement that survived the 1,114,000 applications of the test loads, and show quite clearly that a greater increase in the progression of rutting occurred during the first year of traffic operation than during the second. The same trend was observed for the factorial sections that survived the test. This constitutes strong evidence that the rate of rut development was decreasing with time or load applications.

Figure 9 shows rutting vs load applications for sections having the three types of base material. It is intended to show the trend of rut development with time during the course of the Road Test and the relative level of the depth of rutting on the surface for sections containing the three types of base. Rutting of stone base sections began early in the spring, continued at a somewhat slower rate during the summer, and remained fairly constant during the fall and winter months. In contrast, rutting of bituminous-treated base sections did not begin until warm weather when it developed at a relatively rapid rate until the fall and winter when it remained fairly constant.

The difference in the trend of rutting for thicknesses of crushed stone and of bituminous-treated base during the spring months is considered to be due to the added strength of the bituminous material at low temperatures, its consequent lower deflections and its greater resistance to consolidation and displacement. It is emphasized that the schematic representation shown in Figure 9 is for pavements that

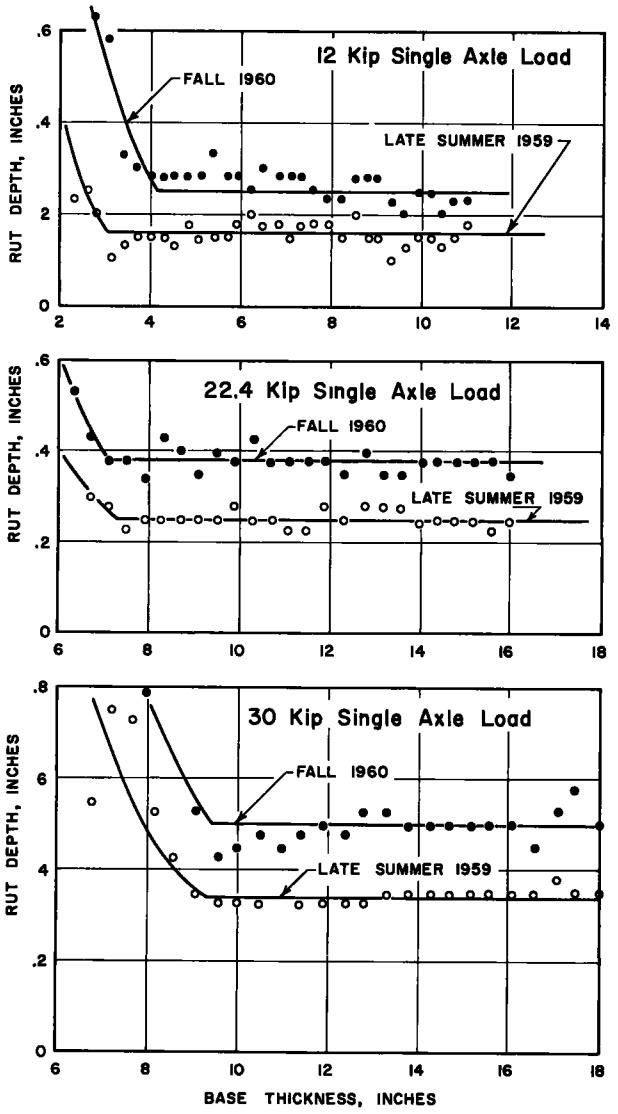

Figure 10. Effect of thickness of bituminous-treated base on depth of rut.

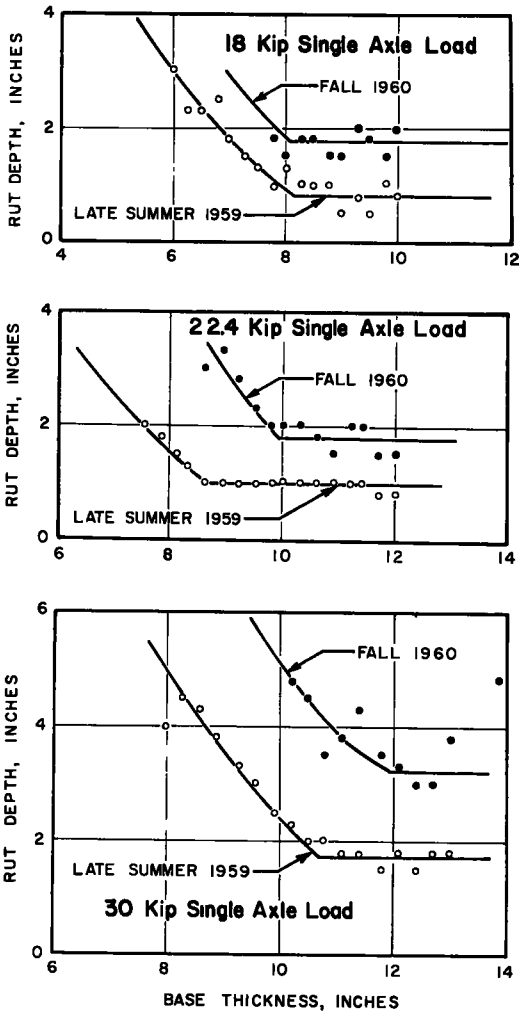

Figure 11. Effect of thickness of cement-treated base on depth of rut.

survived the Road Test. The lower level of rutting of the sections with cement-treated bases is because all of the rutting took place in the surfacing course itself. It is considered that this situation would continue to exist as long as the thickness of the cement-treated base is sufficient to prevent eventual cracking of the material into small pieces with subsequent vertical or transverse displacement of the pieces themselves. In this connection, examination of several failed areas in the cement base section revealed extensive cracking of the material with some pulverization present.

Because of the wide range in base thicknesses provided in the special base study it was possible to relate rut depth to thickness for each base type and for several levels of axle loadings. These relationships are shown in Figures 10, 11, and 12 for bituminous-treated, cement-treated, and crushed stone bases. All data are for the single-axle lanes and the plotted points are means of the rut depth in the inner and outer wheelpaths of the two replicates, *i.e.*, the mean of four values. Measurements of the rut depths were made periodically at 5-ft intervals during the test traffic phase. The lines fitted to the points by eye indicate clearly that there was a level of base thickness above which the surface rut depth remained essentially constant and below which it increased rapidly. These levels of base thickness are given in Table 7, as are the approximate levels of depth of rutting. The values disregard the variations in surfacing and subbase thickness from loop to loop.

In connection with the problem of rutting, it is of interest to examine the loss in serviceability occasioned by the change in slope variance and that due to depth of rutting. The data in Figure 13 show quite clearly that although the loss in serviceability of the cement-treated bases due to rutting was appreciably less than

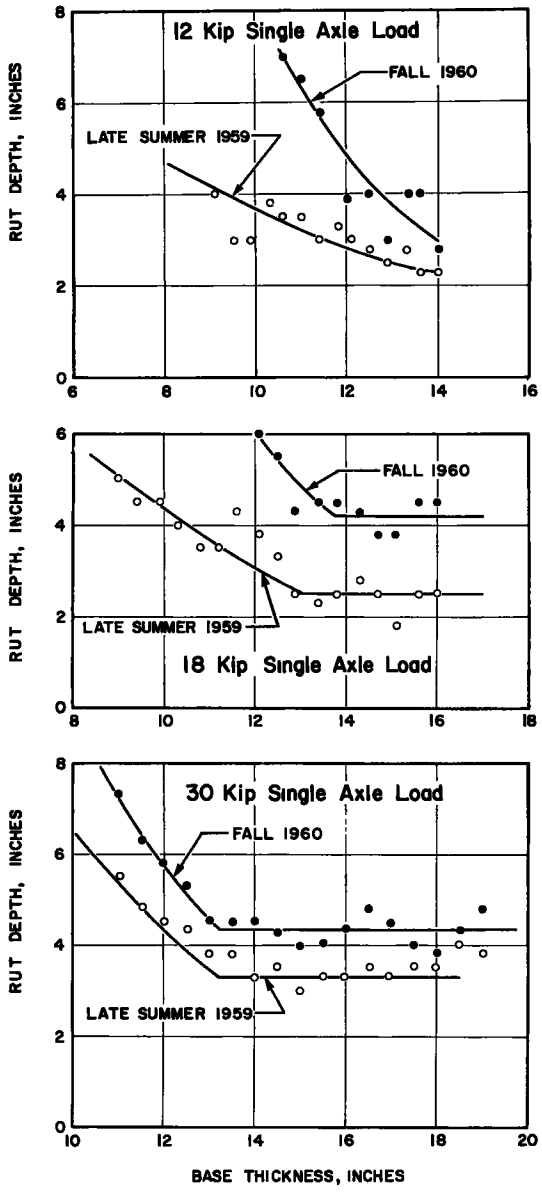

Figure 12. Effect of thickness of crushed stone base on depth of rut.

for the bituminous-treated bases, the loss due to slope variance was considerably greater. This indicates that the permanent vertical movements (rutting in the wheelpaths) due either to lateral displacement or consolidation that developed in the bituminous base sections was of a more uniform character than those in the cement base sections.

SUMMARY

The design of the base type experiment was such that no mathematical analysis was attempted. The analysis was essentially graphical.

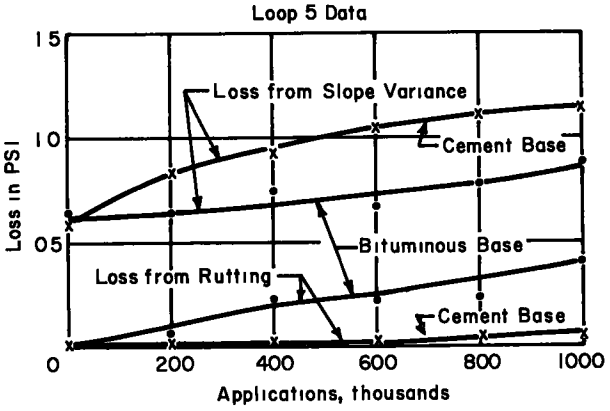

Figure 13. Serviceability loss for treated base.

The results of the analysis are presented in the form of graphs. From them the thickness of the stone, cement-treated, and bituminous-treated bases necessary to maintain a level of serviceability of 2.5 at any desired number of axle-load applications can be obtained. For example, for the 18-kip single-axle load at 1,000,000 applications the required thickness of base (where the surfacing thickness was 3 in. and subbase thickness 4 in.) is shown to be about 13, 8, and 6 in. of stone, cement-treated and bituminous-treated base, respectively. For the same load at 500,000 applications these values are about 12, 7, and 5 in. These values suggest that there was considerable difference in the performance of the treated and untreated bases; also a lesser difference in the performance of the cement- and the bituminous-treated bases. These differences in performance of the three base types are typical of those found in all the loops and at other levels of serviceability.

The loss in serviceability of the cement-treated base sections was due largely to high slope variance; that of the bituminous-treated base sections was due more to a relatively high level of depth of rutting.

The sections containing the untreated gravel base failed early in the test, to this degree their performance was vastly inferior to the stone, bituminous- and cement-treated bases. At low levels of load applications no effect of thickness of the untreated gravel base was evident for the loads operating on Loop 5 (22.4-kip single and 40-kip tandem). On Loop 4 (18-kip single and 32-kip tandem), there was a minor effect of its thickness, and on Loop 3 (12-kip single and 24-kip tandem), a fairly orderly effect of thickness was found. Apparently the material lacked the level of internal stability necessary to support the loads on Loop 5. On Loop 3 the stability of the material was apparently sufficient to support the loads.

In subsections containing the stone, cement-treated and bituminous-treated bases that survived the test, the rate of progression of rutting was lower during the second year of traffic than during the first.

There was a level of thickness of the stone, cement-treated and bituminous-treated bases above which the depth of rut on the surface remained constant with increase in base thickness, and below which it increased rapidly with decrease in thickness.

The bituminous-treated base and bituminous concrete surface offered considerably more resistance to consolidation and displacement at low than at high temperatures.

The results of the special base study at the Road Test should have considerable influence upon the design and construction of flexible pavements. The fact that relatively low cost aggregates can be used for stabilization should make this type of construction practical and economically feasible. Local conditions, availability of materials, and costs should be the means of determining which type of stabilization, cement, bituminous or other, will best serve existing requirements.