Some Relationships of the AASHO Road Test To Concrete Pavement Design

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•THIS IS a progress report on performance of concrete test sections at the AASHO Road Test. Study was limited to the main factorial and replicate (Design 1) test sections in truck loops 3, 4, 5 and 6.

In a previous study (1), end of test data from Design 1 sections in the four truck loops were related to three design concepts. This study showed:

1. No differences in performance between the 3-, 6- and 9-in. subbase depths.
2. Equal or slightly better performance on the plain slab design than on the reinforced slab design.
3. That the PCA slab thickness design procedure based on Pickett's stress equation is dependable (1, 2).

Constructed Serviceability of Design 1 Sections presents data on the initial serviceability of Design 1 concrete test sections in the four truck loops. From histograms of these data it was concluded that:

1. The as constructed serviceability index of Design 1 test sections in the four truck loops was 4.7.
2. There were slight but insignificant differences in as constructed serviceability between the three subbase depths, the two slab designs and the four truck loops.

Analysis of Concrete Performance presents end of test serviceability and data on cracking for each Design 1 concrete test section in the four truck loops. The data are shown in both table and chart form, and are summarized in charts under the two slab designs, the four thickness levels in each loop, and under single and tandem axles.

The two slab designs were plain pavement with doweled transverse joints spaced at 15 ft and reinforced pavement with doweled transverse joints spaced at 40 ft.

Slab depths increased at 1½-in. increments from 3½ in. to 12½ in. There were four slab thickness levels in each loop that also increased at 1½-in. increments.

Major conclusions from Analysis of Concrete Performance are:

1. End of test serviceability showed no significant differences in performance on the 3-, 6- and 9-in. subbases.
2. End of test serviceability of the plain and reinforced slab designs showed that:
   - (A) At first slab thickness levels, the plain design performed better than the reinforced design under both single- and tandem-axle test traffic. Data presented in Subbase Pumping, Major Conclusions show that these differences in performance occurred after heavy subbase pumping started.
   - (B) At second slab thicknesses, the plain design performed better than the reinforced design under single-axle test traffic. Data presented in Subbase Pumping, Major Conclusions show that these differences in performance occurred after heavy subbase pumping started. Performance was about equal under tandem axles.
   - (C) At third and fourth slab thicknesses, performance was equal and excellent for both slab designs under both single and tandem axles.

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3. End of test serviceability under single- and tandem-axle test traffic showed that:
   (A) At first and second slab thicknesses, performance was better under single-axle test traffic than under tandem-axle test traffic. These marked differences in performance under single and tandem axles are not shown by the Road Test performance equations (3). These equations show better performance under single axles at all thickness levels.
   (B) At the third and fourth slab thicknesses, performance was virtually identical under both single- and tandem-axle test traffic. These marked differences in performance under single and tandem axles are not shown by the Road Test performance equations (3). These equations show better performance under single axles at all thickness levels.

4. The Road Test environment had a major influence on the start of cracking in the reinforced test sections at all slab thickness levels. In some states environment does not cause visible cracks in reinforced pavements that have carried large volumes of trucks for 10 to 20 yr. In these states performance of reinforced pavements at the Road Test will have little or no application.

5. At the end of traffic testing, the plain slab design showed definite superiority over the reinforced design in regard to major cracking (Classes 3 and 4). Major cracks were used in computing serviceability indexes (3). However, at about equal serviceability, pavements free of the distress characteristic of major cracking should cost less to maintain.

Subbase Pumping presents data showing the extent and severity of subbase pumping and the relationships of subbase pumping to pavement serviceability. Data on trace, moderate and heavy subbase pumping are shown in table and chart form for all Design 1 test sections in the four truck loops. In the HRB data systems these three types of subbase pumping are combined into a pumping score. This score equals trace pumping, plus 10 times moderate pumping, plus 50 times heavy pumping. A detailed study was made on the second thickness 8-in. test sections in loop 5. Work on subbase pumping data is not complete. The following conclusions reflect work done so far:

1. Trace subbase pumping occurred on all Design 1 sections in the four truck loops.
2. Moderate subbase pumping occurred on all first and second slab thicknesses, on 95 percent of third slab thicknesses, and on 63 percent of fourth slab thicknesses.
3. Heavy subbase pumping occurred on all first slab thicknesses, on 89 percent of second slab thicknesses, on 34 percent of third slab thicknesses and on 21 percent of fourth slab thicknesses.
4. Neither trace nor moderate subbase pumping influenced serviceability at any slab thickness level.
5. Heavy subbase pumping was not extensive or severe at third and fourth thickness levels and did not influence serviceability.
6. On second level slab thicknesses, severity of heavy subbase pumping decreased as stress decreased and loss in serviceability was related to the severity of heavy subbase pumping.
7. On first level test sections, repetitions of test traffic from the start of heavy pumping to the first serviceability loss (when serviceability index fell below 4.0 and did not recover) varied considerably within and between loops. However, averaged data show that the effects of severe subbase pumping decreased as stress decreased.
8. Differences in serviceability under single and tandem axles on first and second thickness levels occurred only after heavy subbase pumping started.
9. Differences in serviceability between the plain and reinforced designs in the first and second thickness levels occurred only after heavy subbase pumping started.

The following conclusions relate only to the detailed study of the second thickness 8-in. test sections in loop 5.

1. Where the accumulated percentage of heavy subbase pumping was 60 or less and not severe. A measure of severity—it is the accumulated percentage of section length with heavy subbase pumping measured after each period of rainfall. For

example, if these percentages were 65, 80 and 70 after three periods of rainfall the accumulated percentage would be 215:

(A) End of test serviceability was about equal to the end of test serviceability on third and fourth slab thicknesses in loop 5.

(B) The relationship of serviceability to applied loads (single or tandem) can be adequately described by the following statement: At 100,000 repetitions the serviceability was 0.4 less than the as constructed serviceability, and there was no further loss in serviceability during the test period.

2. Where the accumulated percentage of heavy subbase pumping was 90 or more (severe), performance was as stated above until heavy subbase pumping approached severe intensity. Severe heavy subbase pumping was accompanied by a rapid serviceability loss with indexes usually reaching a value of 1.5 before the end of test.

3. With regard to the second level, 8-in. test sections in loop 5, the Road Test performance equations for concrete are deficient in the following respects:

(A) They do not describe concrete performance prior to the start of heavy pumping.

(B) They give incorrect values for end of test serviceability where the accumulated percentage of heavy subbase pumping was 60 or less (not severe).

(C) They fail to show that performance was equal under single and tandem axles where the accumulated percentage of heavy subbase pumping was 60 or less (not severe).

(D) They give incorrect values for end of test serviceability where the accumulated percentage of heavy subbase pumping was 90 or more (severe).

With regard to observations and records of subbase pumping made at the Road Test it is believed that:

1. Trace subbase pumping is uncommon on pavements in service.
2. Moderate subbase pumping is rare on pavements in service.
3. Heavy subbase pumping in more than very small amounts is probably unique to the Road Test.
4. Road Test performance measurements influenced by heavy subbase pumping of medium or severe intensity are not relevant to pavements in service.

At the outset, three conclusions were cited from a previous study (1). The results of the current study agree with all three conclusions and give additional support to the third one. In the previous study, summaries of pavement performance from all sections, including those affected by subbase pumping, showed that the PCA design procedure is dependable. The performance of second level pavements that had little or no heavy subbase pumping affords further evidence that this procedure is dependable and conservative.

At the Road Test, concrete pavement research was conducted on the south tangents of six loops. Most of the research on the six test loops had to do with three elements of concrete pavement design. These were slab thickness, subbase thickness and two slab designs: plain slabs with doweled transverse contraction joints spaced at 15 ft and reinforced slabs with doweled transverse contraction joints spaced at 40 ft. Dowels were the same for both slab designs. Dowel sizes, mesh weights and other jointing details are given in Ref. (3).

In all six loops these two slab designs were used in combination with each variation in slab and subbase depth to make a complete factorial design. Also, certain design combinations were repeated in each loop to check on experimental error. The structural design combinations were constructed 24 ft wide with a sawed longitudinal center joint between the 12-ft lanes. Each lane of each design combination was a test section. These test sections are the main factorial design (Design 1) at the Road Test. Loops 3 to 6 also had a limited number of sections for the study of paved shoulders and the presence or absence of subbase. This Design 3 study is not included in this report.

Loop 1 was restricted to various non-traffic tests. Slab depths were 2½, 5, 9½ and 12½ in. and subbase depths were 0 and 6 in. There were 32 factorial and 16 replicate test sections.

Loop 2, often called the passenger car loop, carried 2 kip single-axle loads in lane 1 and 6 kip single axles in lane 2. In all loops, lane 1 was the inside lane (next to the median) and lane 2 was the outside lane. Slab depths were 2½, 3½ and 5 in. and subbase depths were 0, 3 and 6 in. There were 36 factorial and 4 replicate test sections.

Loops 3, 4, 5 and 6, the truck loops, had similar factorial and replicate designs. In each of the loops, four levels of slab thickness were used in combination with the two slab designs and subbase depths of 3, 6 and 9 in., making 48 factorial sections per loop. There were eight replicate sections in each loop making a total of 56 test sections per loop. Both slab depths and thickness levels increased at a 1½-in. increment from 3½ in. in loop 3 to 12½ in. in loop 6.

TABLE 1

CONCRETE PAVEMENT THICKNESS, LEVELS AND LOADS

Item	Loop 3	Loop 4	Loop 5	Loop 6
Slab depth (in.):				
3½	1st			
5	2nd	1st		
6½	3rd	2nd	1st	
8	4th	3rd	2nd	1st
9½		4th	3rd	2nd
11			4th	3rd
12½				4th
Mean des. thickness (in.):	7.2	8.6	9.6	10.8
Axle load (kips):				
Single	12	18	22.4	30
Tandem	24	32	40	48

The four thickness levels in loops 3 to 6 were varied around the mean of designs submitted by four agencies during the planning stages of the Road Test. These mean designs, along with the slab depths tested, the thickness levels, and the axle loads in the four truck loops are shown in Table 1. This table shows that in loops 3, 4 and 5 the mean design depths are from 0.1 to 0.7 in. greater than the third thickness levels. In loop 6 the mean design is 0.2 in. less than the third thickness level.

In all four truck loops single-axle test traffic operated in lane 1 (inside lane) and tandem-axle traffic operated in lane 2 (outside lane). As a result each individual test section received repetitions of one single- or one tandem-axle load.

> Authors' Comment.—This procedure made it possible to get the performance on each test section for repetitions of a specific load. It also permits performance comparisons for repetitions of specific single- and tandem-axle loads on two test sections of the same design.
>
> However, pavements in service carry a wide variety of single- and tandem-axle loads. Since all test sections carried only one load (either single or tandem) the Road Test did not yield any experimental data on the effects of mixed traffic. This fact and its significance are expressed in the following unanswered question from the Road Test Report (3). "For example, at the Road Test a million axle loads of one weight were applied in two years to each section. What would have been the situation had these loads, accompanied by several million lighter loads, been applied in 20 years?" Because the question is unanswered, it is not wise to use extrapolations of Road Test performance equations for design of pavements in service.

At the Road Test performance was measured by means of two values—number of repetitions and serviceability index. Development of the serviceability index method for determining the ability of a pavement to serve traffic is described in detail in Appendix F of Ref. (3). On concrete test sections the serviceability index was determined by a formula that used the average of slope variance measured in the two wheel

paths and the amount of cracking and patching. In the charts presented, both the index and the number of load repetitions at the time that the index was measured are shown.

This paper is a progress report on study of concrete pavement performance on the Design 1 test sections in the truck loops—3, 4, 5 and 6. In a previous study (1) end of test serviceability data for these same test sections were studied in relation to 3 design concepts. Data were summarized by:

1. Computing average repetitions to 1.5 serviceability index for the first level thicknesses in loops 3, 4 and 5 where all sections dropped to this index during the test period.
2. Computing percent of sections that survived testing with an index of 1.5 or higher and the average index of these surviving sections for second level pavements in all four loops.
3. Computing the average end of test index for third and fourth thickness levels in all four loops where all sections survived testing with an index above 1.5.

Summaries of serviceability were not made for the individual loops, nor for single and tandem axles. In computing averages, data from both single- and tandem-axle test sections were used. The results of these computations showed:

1. About equal performance on the 3-, 6- and 9-in. subbase depths with slightly better performance on the 3- and 6-in. subbase depths.
2. About equal performance for the plain and reinforced slab designs with a slight advantage for the plain design.
3. That slab thicknesses determined by the PCA design procedure (1) were close to or slightly above the minimum needed for dependable performance at the Road Test.

Constructed Serviceability of Design One Sections includes information on the rates of load application at the Road Test. Analysis of Concrete Sections presents performance in the truck loops based on end of test serviceability indexes and data on minor and major cracking. Subbase Pumping presents data on subbase pumping in the truck loops and its relationship to pavement serviceability.

CONSTRUCTED SERVICEABILITY OF DESIGN 1 SECTIONS

Data on as constructed serviceability of Design 1 test sections in the truck loops were summarized for the two slab designs, the three subbase depths and the four loops.

Figure 1 shows histograms for as constructed serviceability on the two slab designs. From the summary in Table 2, these values show no significant difference in as constructed serviceability.

Figure 2 shows histograms for as constructed serviceability on the 3-, 6- and 9-in. subbase depths. The summary also shows no significant differences in as constructed serviceability.

Figure 3 shows histograms for as constructed serviceability on the four truck loops. Summary values show slightly higher initial serviceability on loops 3 and 4 than on loops 5 and 6. One crew paved loops 3 and 4, but another crew paved 5 and 6. The differences are not enough to be significant. The mean as constructed serviceability index for loops 3 to 6 is 4.7.

A study has been started on time-rates of loading at the Road Test. While there

TABLE 2

AS CONSTRUCTED SERVICEABILITY INDEX

Item	Min.	Mean	Max.
Slab design:			
Plain	4.3	4.69	5.0
Reinforced	4.4	4.73	5.0
Subbase depth (in.):			
3	4.3	4.68	4.9
6	4.3	4.72	5.0
9	4.3	4.72	5.0
Loop No.			
3	4.3	4.74	5.0
4	4.5	4.76	4.9
5	4.4	4.67	4.9
6	4.3	4.61	4.8

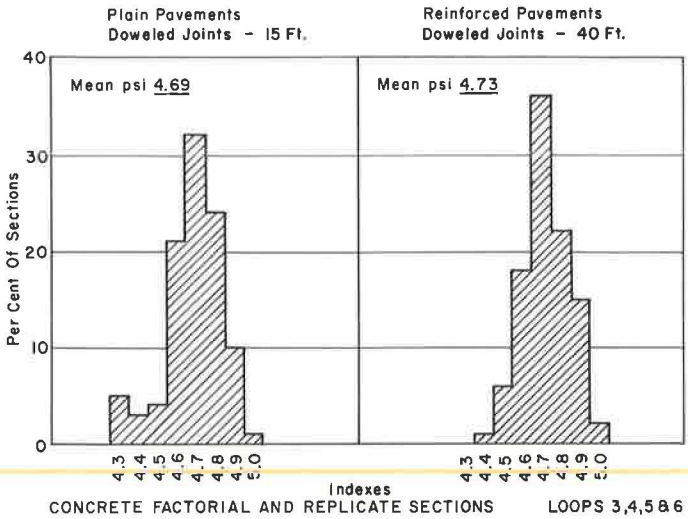


Figure 1. As constructed—serviceability indexes.

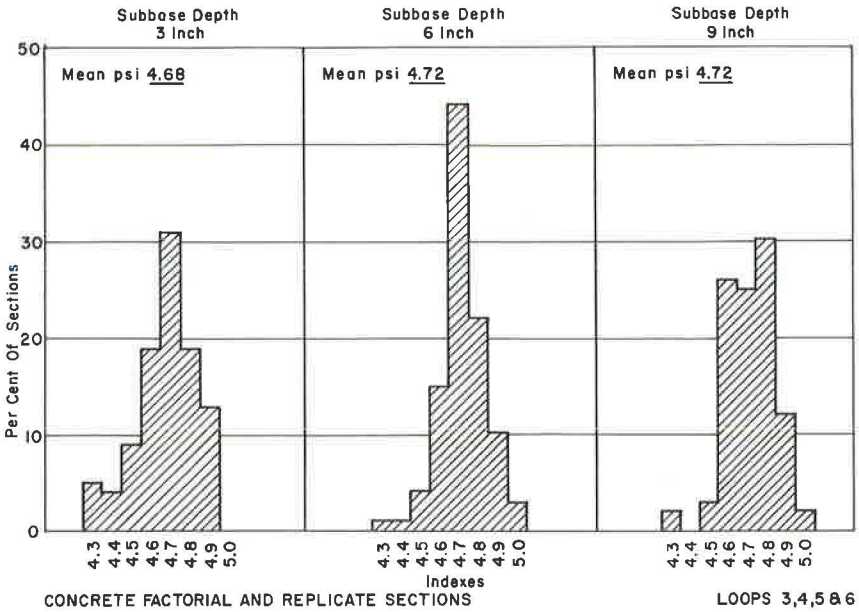


Figure 2. As constructed—serviceability indexes.

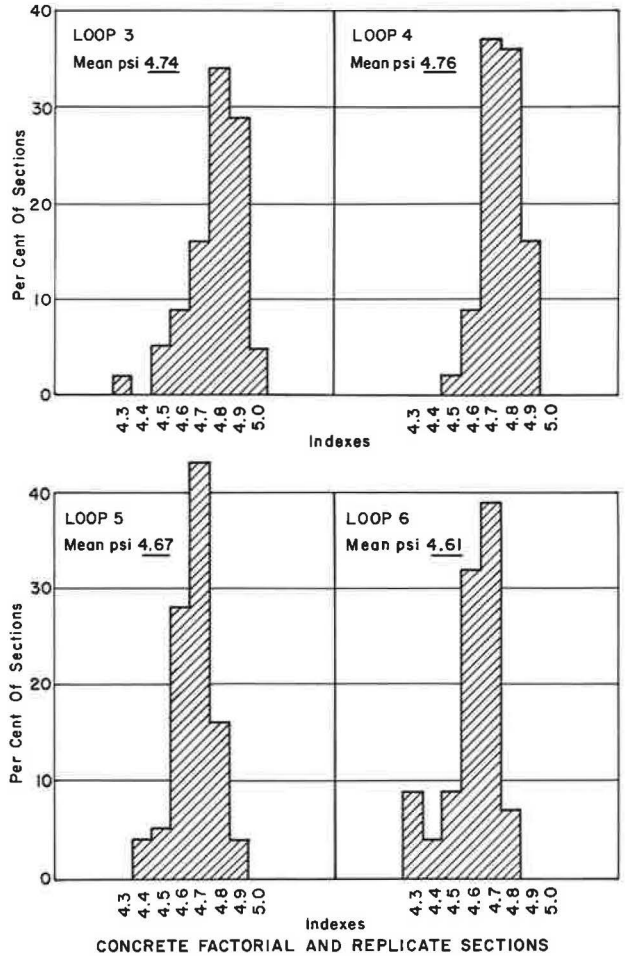


Figure 3. As constructed—serviceability indexes.

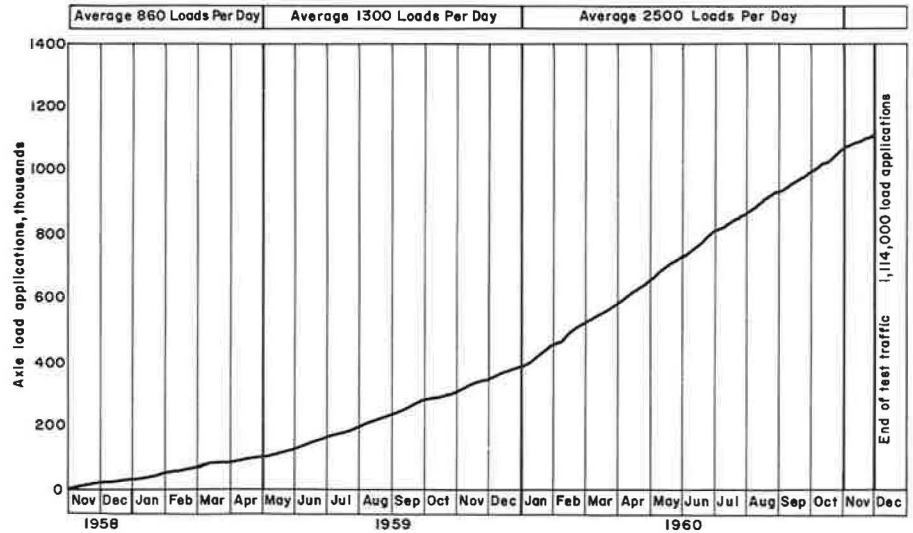
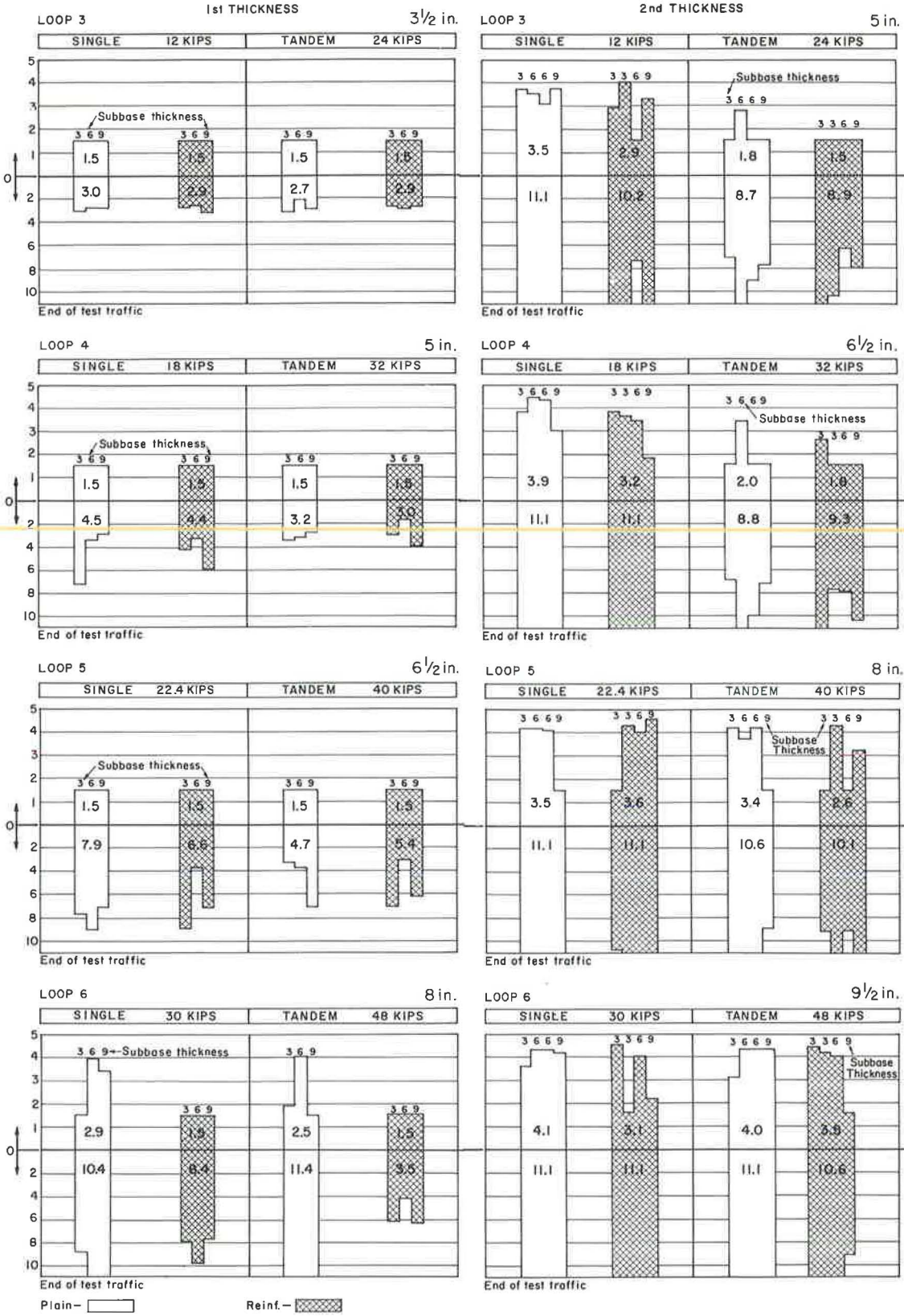
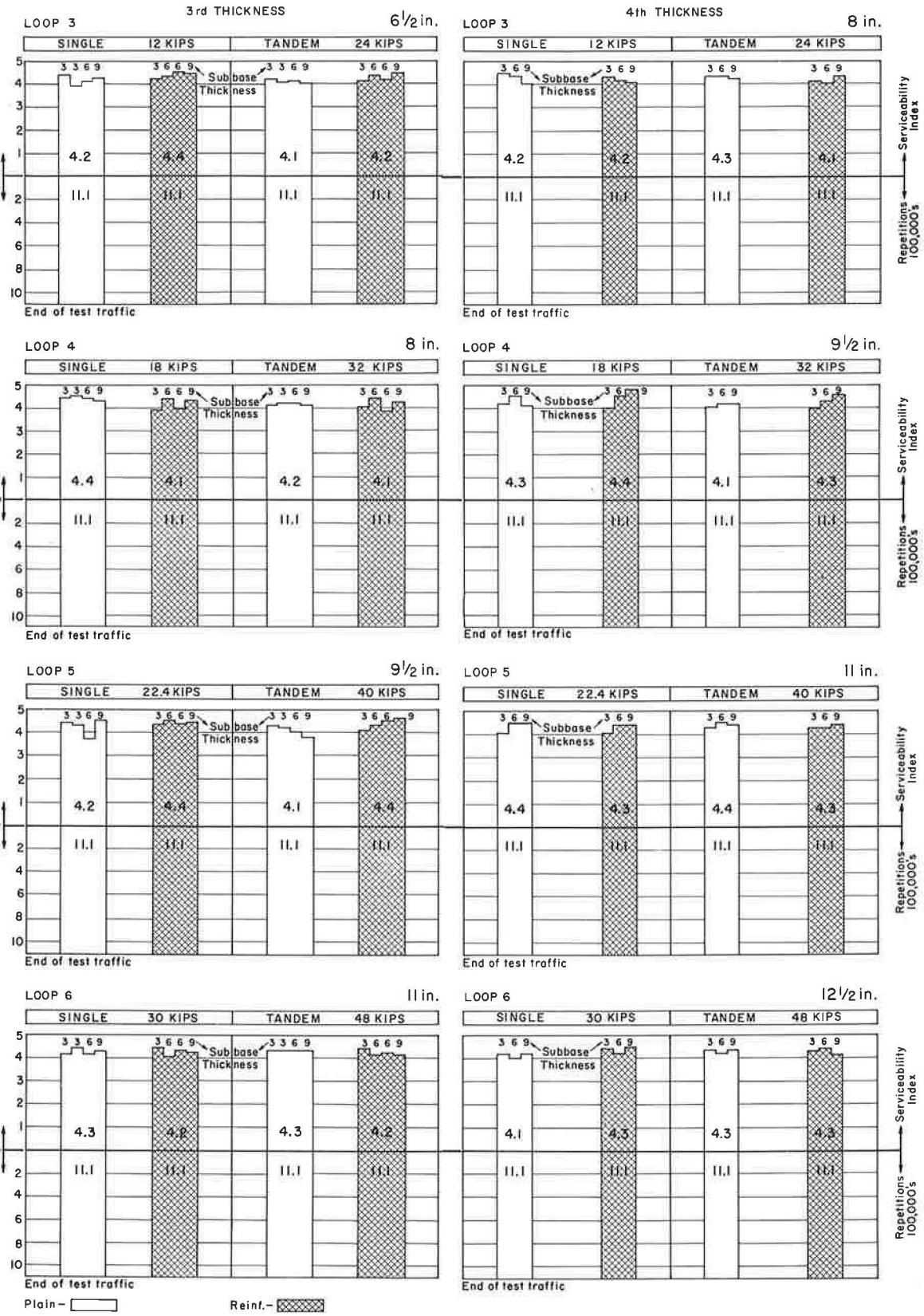


Figure 4. Rates of axle load applications per day at the AASHO Road Test.


1st THICKNESS
2nd THICKNESS
LOOP 3
3½ in.
SINGLE 12 KIPS
TANDEM 24 KIPS
Subbase thickness
3 6 9
1.5
3.0
2.9
2.7
End of test traffic
LOOP 3
5 in.
3 3 6 9
3.5
11.1
2.9
10.2
1.8
8.7
1.5
8.9
LOOP 4
5 in.
SINGLE 18 KIPS
TANDEM 32 KIPS
4.5
4.4
3.2
3.0
LOOP 4
6½ in.
3.9
11.1
3.2
11.1
2.0
8.8
1.8
9.3
LOOP 5
6½ in.
SINGLE 22.4 KIPS
TANDEM 40 KIPS
7.9
6.6
4.7
5.4
LOOP 5
8 in.
3.5
11.1
3.6
11.1
3.4
10.6
Subbase Thickness
2.6
10.1
LOOP 6
8 in.
SINGLE 30 KIPS
TANDEM 48 KIPS
2.9
10.4
8.4
2.5
11.4
3.5
LOOP 6
9½ in.
4.1
11.1
3.1
11.1
4.0
11.1
3.9
10.6
Plain
Reinf.

Figu



oncrete performance.

were minor variations between loops and between lanes in individual loops, averaged data show:

1. That there was essentially a single loading history for all traffic testing.
2. That the loading history had three distinct time-rates. These are shown in Figure 4 and are summarized in Table 3.

Authors' Comment.—The increases in time-rates are substantial. Road Test performance and the empirical equations based on this performance are dependent on one loading history with two major changes in time-rating of loading. Hence the performance and the equations do not have experimental application to any other loading history. This is another reason why it is believed to be unwise to use extrapolations of the Road Test equations for design of pavements in service.

TABLE 3

TIME-RATES OF LOADING

Repetitions	Time-Rates (loads per lane per day)
0— 101,000	860
101,000— 387,000	1,300
387,000—1,076,000[1]	2,500
(Ratios of time-rates are 1.0:1.5:2.9)	

[1] From this point to the end of test, loading histories were varied slightly so that 1,114,000 applications could be applied to all surviving test sections.

ANALYSIS OF CONCRETE PERFORMANCE

This section deals with concrete behavior as shown by end of test serviceability and cracking. Table 4 gives the following information for all Design 1 test sections in loops 3 to 6:

1. Section number.
2. End of test serviceability index for sections that had values above 1.5.
3. Repetitions to 1.5 index for sections that fell to this value during the test.
4. Repetitions at which minor and major cracking started.

The serviceability data in Table 4 are shown in graph form in Figure 5. The charts are arranged under the four thickness levels. They show both repetitions and end of test serviceability for single and tandem axles, the three subbase depths and the two slab designs. The charts thus permit quick performance comparisons at any thickness level under single or tandem axles. Study of Figure 5 shows:

1. No significant differences in performance for the 3-, 6- and 9-in. subbase depths.
2. Wide variations in repetitions to a 1.5 serviceability index in the first thickness level, especially in loops 5 and 6. Note, for example, that two first thickness 8-in. test sections in loop 6 survived test traffic under both single and tandem axles with a serviceability index of about 4.0—only slightly below performance at third and fourth levels.
3. There were wide variations in performance at the second thickness level in all four loops.
4. At the second thickness level in loops 5 and 6, more than half the test sections performed as well as third and fourth level sections.
5. At the third and fourth level in all four loops, performance was very uniform and very good for both slab designs, all three subbase depths, and under both single and tandem axles.

Authors' Comments.—The previous study (1), this study, the Road Test Report (3), a subbase experiment under highway traffic (4), laboratory studies (5) and results of pavement performance surveys (6) all show that concrete highway pavements perform as well or better on 3- to 6-in. subbases as on subbases more than 6 in. thick. This evidence shows that subbases more than 6 in. thick are not required to insure the performance of concrete pavements.

TABLE 4

CONCRETE BEHAVIOR

LOOP 3

1st Thickness 3½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
195	Plain	3	12 S	—	315	122	234
196	Doweled Joints 15 Ft.		24 T	—	318	120	282
239		6	12 S	—	289	122	273
240			24T	—	210	134	195
213		9	12 S	—	289	135	200
214			24T	—	297	106	195
209	Reinf.	3	12S	—	278	122	273
210	Doweled Joints 40 Ft.		24T	—	278	120	266
205		6	12 S	—	273	98	135
206			24T	—	295	79	180
231		9	12 S	—	324	183	289
232			24T	—	294	120	266

LOOP 4

1st Thickness 5 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
643	Plain	3	18 S	—	716	274	325
644	Doweled Joints 15 Ft.		32T	—	343	219	291
647		6	18 S	—	353	235	292
648			32T	—	328	201	236
677		9	18 S	—	291	274	292
678			32T	—	289	201	273
681	Reinf.	3	18 S	—	415	0	292
682	Doweled Joints 40 Ft.		32T	—	304	168	291
661		6	18 S	—	325	0	306
662			32T	—	175	0	168
673		9	18 S	—	592	136	338
674			32T	—	408	201	339

LOOP 5

1st Thickness 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
513	Plain	3	22.4 S	—	760	69	702
514	Doweled Joints 15 Ft.		40T	—	335	324	325
517		6	22.4 S	—	898	668	668
518			40T	—	369	337	337
505		9	22.4 S	—	705	445	446
506			40T	—	698	291	337
523	Reinf.	3	22.4 S	—	898	268	668
524	Doweled Joints 40 Ft.		40T	—	705	273	635
491		6	22.4 S	—	369	268	308
492			40T	—	305	183	291
549		9	22.4 S	—	708	11	339
550			40T	—	618	291	291

LOOP 6

1st Thickness 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
353	Plain	3	30 S	—	878	29	735
354	Doweled Joints 15 Ft.		48T	1.8	—	814	997
393		6	30 S	3.9	—	900	1100
394			48T	4.1	—	NONE	NONE
369		9	30 S	3.4	—	29	952
370			48T	—	1114	758	814
341	Reinf.	3	30 S	—	782	292	635
342	Doweled Joints 40 Ft.		48T	—	618	266	437
385		6	30 S	—	974	635	807
386			48T	—	415	266	353
347		9	30 S	—	768	274	706
348			48T	—	624	86	385

*S = Single, T = Tandem, R = Replicate Section

TABLE 4

CONCRETE BEHAVIOR (Cont'd.)

LOOP 3

2nd Thickness 5 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
225	Plain	3	12S	3.7	—	1021	1021
226			24T	—	705	266	299
245		6	12S	3.5	—	1021	988
221			R	3.1	—	775	810
246			24T	2.8	—	870	932
222			R	—	901	85	345
219		9	12S	3.7	—	273	324
220			24T	—	771	266	299
251	Reinf.	3	12S	2.8	—	11	337
203			R	4.0	—	289	870
252			24T	—	1100	266	668
204			R	—	1046	28	870
191		6	12S	—	725	273	385
192			24T	—	631	282	383
233		9	12S	3.3	—	200	836
234			24T	—	793	213	772

Doweled Joints 15 Ft.

Doweled Joints 40 Ft.

LOOP 4

2nd Thickness 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
649	Plain	3	18S	3.8	—	NONE	988
650			32T	—	689	NONE	408
697		6	18S	4.4	—	NONE	NONE
655			R	4.3	—	NONE	NONE
698			32T	3.4	—	1021	1021
656			R	—	1000	836	836
703		9	18S	3.0	—	988	988
704			32T	—	722	86	671
641	Reinf.	3	18S	3.8	—	274	810
705			R	3.6	—	274	810
642			32T	2.6	—	273	810
706			R	—	793	273	707
685		6	18S	3.4	—	252	810
686			32T	—	796	273	774
653		9	18S	1.8	—	274	603
654			32T	—	1036	273	810

Doweled Joints 15 Ft.

Doweled Joints 40 Ft.

LOOP 5

2nd Thickness 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
547	Plain	3	22.4S	4.2	—	NONE	NONE
548			40T	4.2	—	409	NONE
539		6	22.4S	4.2	—	NONE	NONE
533			R	4.1	—	79	NONE
540			40T	3.7	—	808	809
534			R	4.2	—	982	NONE
507		9	22.4S	—	1111	902	903
508			40T	—	898	NONE	870
519	Reinf.	3	22.4S	—	1104	287	730
521			R	4.3	—	107	NONE
520			40T	—	915	273	736
522			R	4.3	—	107	NONE
501		6	22.4S	4.0	—	268	1052
502			40T	—	901	273	736
531		9	22.4S	4.6	—	69	NONE
532			40T	3.2	—	291	1074

Doweled Joints 15 Ft.

Doweled Joints 40 Ft.

LOOP 6

2nd Thickness 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
351	Plain	3	30S	3.6	—	900	1049
352			48T	3.1	—	694	722
367		6	30S	4.3	—	983	NONE
389			R	4.3	—	80	NONE
368			48T	4.3	—	907	NONE
390			R	4.3	—	NONE	NONE
375		9	30S	4.2	—	NONE	NONE
376			48T	4.3	—	80	NONE
381	Reinf.	3	30S	4.5	—	928	NONE
371			R	1.6	—	325	774
382			48T	4.4	—	324	NONE
372			R	4.1	—	340	936
403		6	30S	4.0	—	200	900
404			48T	4.0	—	266	790
339		9	30S	2.2	—	274	774
340			48T	—	912	120	758

Doweled Joints 15 Ft.

Doweled Joints 40 Ft.

*S = Single, T = Tandem, R = Replicate Section

TABLE 4

CONCRETE BEHAVIOR (Cont'd.)

LOOP 3 — 3rd Thickness 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth (Inches)	Axle Loads * (Kips)	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
217	Plain	3	12S	4.4	—	107	NONE
193			R	3.9	—	324	NONE
218			24T	4.2	—	NONE	NONE
194			R	4.0	—	NONE	NONE
249	Doweled Joints 15 Ft.	6	12S	4.1	—	70	NONE
250			24T	4.1	—	NONE	NONE
207		9	12S	4.2	—	NONE	NONE
208			24T	4.0	—	NONE	NONE
199	Reinf.	3	12S	4.2	—	289	NONE
200	Doweled Joints 40 Ft.		24T	4.1	—	266	867
247		6	12S	4.3	—	273	NONE
237			R	4.5	—	603	NONE
248			24T	4.3	—	600	890
238			R	4.1	—	735	772
241		9	12S	4.4	—	324	NONE
242			24T	4.4	—	332	901

LOOP 4 — 3rd Thickness 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth (Inches)	Axle Loads * (Kips)	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
671	Plain	3	18S	4.4	—	80	NONE
687			R	4.5	—	NONE	NONE
672			32T	4.1	—	NONE	NONE
688			R	4.2	—	79	NONE
683	Doweled Joints 15 Ft.	6	18S	4.4	—	NONE	NONE
684			32T	4.2	—	5	NONE
651		9	18S	4.3	—	NONE	NONE
652			32T	4.1	—	NONE	NONE
691	Reinf.	3	18S	3.9	—	274	810
692	Doweled Joints 40 Ft.		32T	4.0	—	273	989
669		6	18S	4.4	—	274	1021
707			R	3.9	—	274	988
670			32T	4.4	—	273	1021
708			R	3.8	—	273	989
695		9	18S	4.3	—	274	988
696			32T	4.2	—	168	989

LOOP 5 — 3rd Thickness 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth (Inches)	Axle Loads * (Kips)	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
511	Plain	3	22.4S	4.4	—	NONE	NONE
541			R	4.3	—	NONE	NONE
512			40T	4.3	—	NONE	NONE
542			R	4.2	—	905	NONE
525	Doweled Joints 15 Ft.	6	22.4S	3.7	—	803	831
526			40T	4.0	—	771	808
535		9	22.4S	4.5	—	69	NONE
536			40T	3.8	—	951	982
553	Reinf.	3	22.4S	4.3	—	98	1052
554	Doweled Joints 40 Ft.		40T	4.1	—	201	982
543		6	22.4S	4.5	—	1052	NONE
503			R	4.3	—	268	NONE
544			40T	4.3	—	46	NONE
504			R	4.5	—	273	NONE
499		9	22.4S	4.4	—	268	1018
500			40T	4.6	—	273	NONE

LOOP 6 — 3rd Thickness 11 in.

Sec. No.	Design: Slab	Design: Subbase Depth (Inches)	Axle Loads * (Kips)	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
377	Plain	3	30S	4.2	—	NONE	NONE
363			R	4.4	—	NONE	NONE
378			48T	4.3	—	NONE	NONE
364			R	4.3	—	NONE	NONE
397	Doweled Joints 15 Ft.	6	30S	4.2	—	NONE	NONE
398			48T	4.3	—	NONE	NONE
365		9	30S	4.3	—	NONE	NONE
366			48T	4.3	—	NONE	NONE
391	Reinf.	3	30S	4.4	—	325	NONE
392	Doweled Joints 40 Ft.		48T	4.4	—	340	NONE
337		6	30S	4.0	—	292	807
345			R	4.3	—	292	NONE
338			48T	4.1	—	245	NONE
346			R	4.2	—	266	NONE
343		9	30S	4.2	—	341	NONE
344			48T	4.1	—	266	997

*S = Single, T = Tandem, R = Replicate Section

TABLE 4

CONCRETE BEHAVIOR (Cont'd.)

LOOP 3

4th Thickness 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
201	Plain	3	12S	4.4	—	NONE	NONE
202	Doweled Joints 15 Ft.		24T	4.3	—	106	NONE
235		6	12S	4.3	—	482	NONE
236			24T	4.3	—	NONE	NONE
185		9	12S	4.0	—	NONE	NONE
186			24T	4.2	—	NONE	NONE
211	Reinf.	3	12S	4.3	—	289	NONE
212	Doweled Joints 40 Ft.		24T	4.1	—	600	NONE
215		6	12S	4.2	—	273	1021
216			24T	4.0	—	244	1011
197		9	12S	4.1	—	289	1055
198			24T	4.3	—	953	NONE

LOOP 4

4th Thickness 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
675	Plain	3	18S	4.2	—	29	NONE
676	Doweled Joints 15 Ft.		32T	4.0	—	NONE	NONE
701		6	18S	4.5	—	169	NONE
702			32T	4.2	—	86	NONE
689		9	18S	4.1	—	70	NONE
690			32T	4.2	—	NONE	NONE
645	Reinf.	3	18S	4.0	—	274	810
646	Doweled Joints 40 Ft.		32T	4.0	—	273	810
665		6	18S	4.5	—	274	NONE
666			32T	4.3	—	273	1021
667		9	18S	4.8	—	274	NONE
668			32T	4.6	—	273	1085

LOOP 5

4th Thickness 11 in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
529	Plain	3	22.4S	4.1	—	702	986
530	Doweled Joints 15 Ft.		40T	4.3	—	905	NONE
497		6	22.4S	4.5	—	NONE	NONE
498			40T	4.5	—	NONE	NONE
509		9	22.4S	4.5	—	NONE	NONE
510			40T	4.4	—	NONE	NONE
515	Reinf.	3	22.4S	4.1	—	287	1018
516	Doweled Joints 40 Ft.		40T	4.3	—	291	NONE
545		6	22.4S	4.4	—	1052	NONE
546			40T	4.3	—	273	NONE
495		9	22.4S	4.4	—	NONE	NONE
496			40T	4.4	—	707	NONE

LOOP 6

4th Thickness 12½ in.

Sec. No.	Design: Slab	Design: Subbase Depth Inches	Axle Loads * Kips	Performance: Serviceability: End Of Test Index	Performance: Serviceability: Rep. At 1.5 Index 1000-S	Repetitions at start of cracking 1000-S: Minor Class 1 & 2	Repetitions at start of cracking 1000-S: Major Class 3 & 4
395	Plain	3	30S	4.2	—	834	NONE
396	Doweled Joints 15 Ft.		48T	4.3	—	658	NONE
349		6	30S	4.0	—	NONE	1081
350			48T	4.2	—	790	NONE
379		9	30S	4.2	—	NONE	NONE
380			48T	4.4	—	NONE	NONE
359	Reinf.	3	30S	4.4	—	1016	NONE
360	Doweled Joints 40 Ft.		48T	4.3	—	790	NONE
355		6	30S	4.2	—	635	NONE
356			48T	4.4	—	472	NONE
357		9	30S	4.5	—	NONE	NONE
358			48T	4.2	—	623	1029

* S = Single, T = Tandem, R = Replicate Section

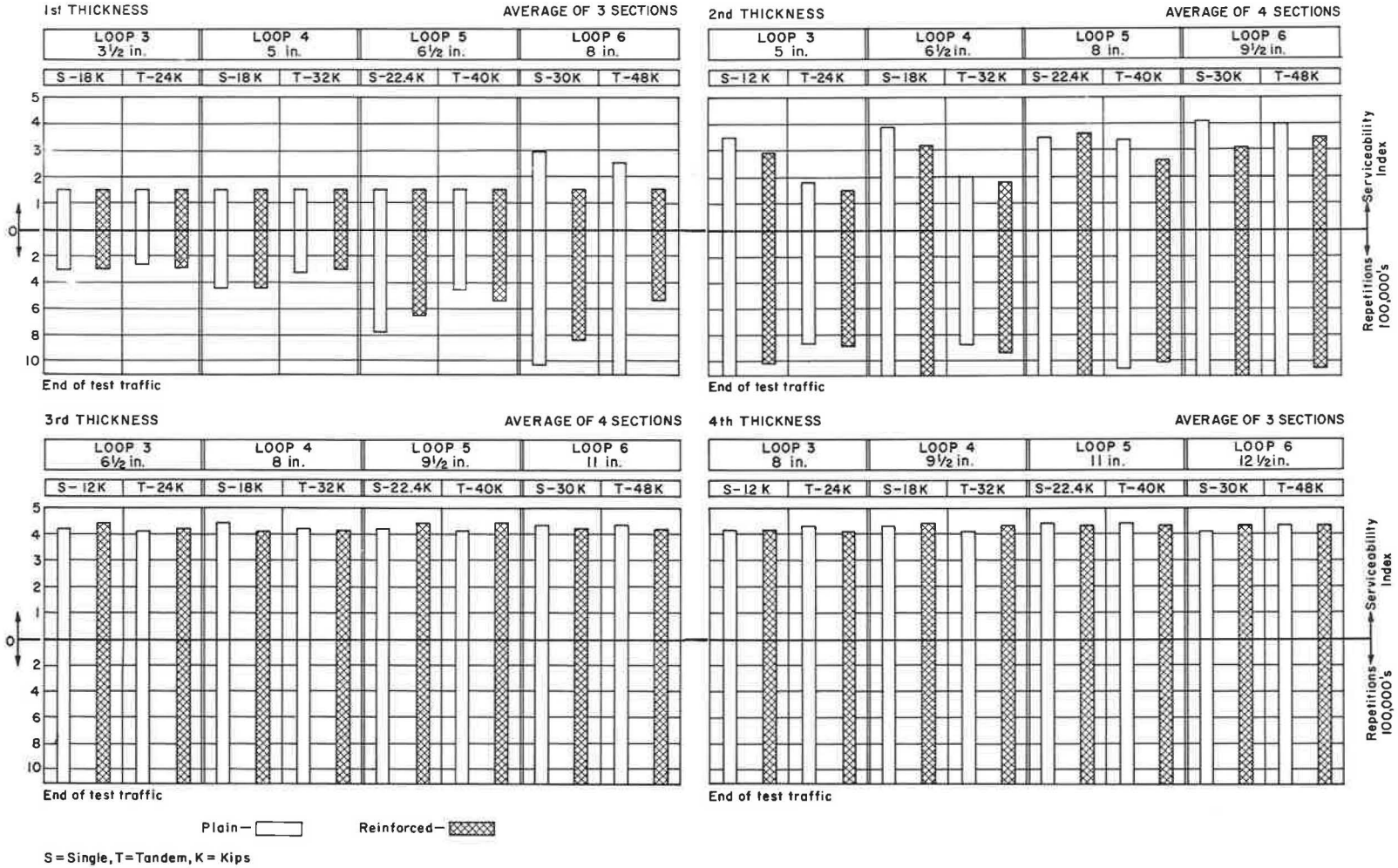


Figure 6. Summary of serviceability and repetitions, concrete test sections (factorial and replicate).

In Figure 6, data on serviceability and repetitions are averaged for the three subbase depths. Bar graphs of these averages are shown for the two slab designs under single and tandem axles for the four thickness levels in the four truck loops. In this case, and in all other data summaries, averages include values from both factorial and replicate sections.

At the first thickness level the graph records:

1. About equal performance on plain and reinforced designs in loops 3, 4 and 5.
2. In loop 6, the 8-in. plain design performed better than the 8-in. reinforced design.
3. In all four loops, performance was better under single-axle traffic than under tandem-axle traffic.

At the second thickness level the graph shows wide differences in performance:

1. Under single-axle test traffic, the plain slab design performed better than the reinforced slab design in loops 3, 4 and 6. In loop 5 the reinforced design was slightly better than the plain design under single-axle traffic.
2. Under tandem-axle traffic, the plain slabs performed better than the reinforced slabs in loops 5 and 6. In loops 3 and 4 there were only slight differences between the two slab designs under tandem-axle traffic.
3. Performance was better under single-axle traffic than under tandem-axle traffic in loops 3, 4 and 5. In loop 6, performance was about equal under single and tandem axles.

At the third and fourth thickness levels in all four truck loops, performance was equal and very good (serviceability indexes above 4.0) for both slab designs under both single- and tandem-axle test traffic.

In Figure 7, data on serviceability and repetitions have been summarized by computing average values from all four loops for each thickness level. The bar graphs show mean values for both slab designs under single- and tandem-axle test traffic. Figure 7 shows:

1. At the first thickness level the plain design performed better than the reinforced design under both single- and tandem-axle truck traffic.
2. At the second thickness level the plain design performed better than the reinforced design under single-axle test traffic. Under tandem-axle traffic, performance was equal for the two slab designs. Here average values tend to mask the differences in performance shown in Figures 5 and 6.

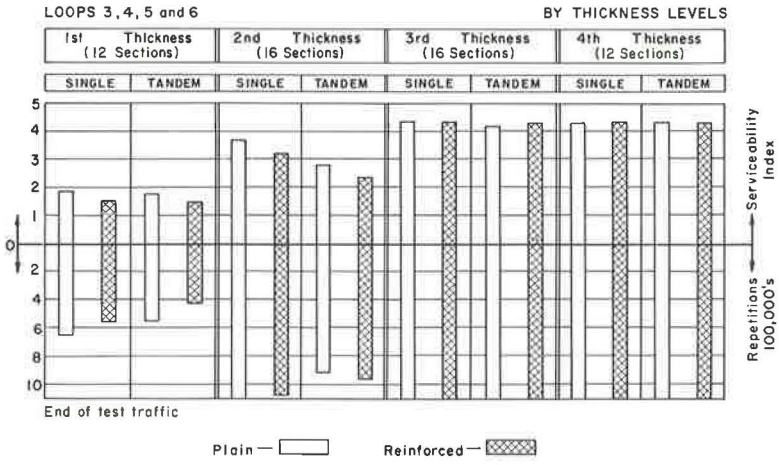


Figure 7. Summary of serviceability and repetitions, concrete test sections (factorial and replicate).

3. At the third and fourth thickness levels, performance was equal and very good (serviceability indexes above 4.0) for both slab designs under both single- and tandem-axle truck traffic.
4. At first and second thickness levels, performance was better under single-axle test traffic than under tandem-axle test traffic.
5. At the third and fourth thickness levels, performance was virtually identical under both single and tandem axles.

The data presented in Analysis of Concrete Performance on end of test serviceability can be summed up in three conclusions:

1. At first and second thickness levels the plain slab design performed slightly better than the reinforced design. However, at the third and fourth thickness levels both slab designs showed equal performance.
2. At first and second thickness levels performance was consistently better under single-axle test traffic than under tandem-axle test traffic. However, at third and fourth thickness levels, performance is equal under both single- and tandem-axle test traffic.
3. Performance is the same at the third and fourth thickness levels.

Authors' Comment.— These conclusions are in conflict with the Road Test performance equation for concrete (3). This equation shows:

1. Equal performance for the two slab designs, regardless of thickness level.
2. Better performance under single axles than under tandem axles, regardless of slab thickness-load relationships.
3. Increasingly better performance as slab thickness is increased, regardless of thickness level.

CRACKING

Table 4 gives the number of repetitions at which minor and major cracking started for all Design 1 test sections in the four truck loops. Minor cracking (classes 1 and 2) includes cracks not visible at 15 ft under dry surface conditions and cracks that could be seen at 15 ft but showed only minor spalling or crack widths less than ¼ in. Major cracking (classes 3 and 4) included cracks that had opened more than ¼ in., and had spalled or had been sealed. Examples of minor and major cracking are shown on page 124 (3).

The data show that cracking started in many reinforced sections during the early fall of 1959. Cracking was first observed at 273,000 or 274,000 repetitions in 31 of the 112 reinforced sections in loops 3 to 6. The data also show that cracking started in 57 percent of the reinforced sections between 250,000 and 300,000 repetitions. Data from the first thickness in loop 3 were excluded because five of six sections dropped to a 1.5 index before 300,000 repetitions of test traffic. Values for thickness levels are first thickness level, 56 percent; second thickness level, 59 percent; third thickness level, 59 percent; and fourth thickness level, 50 percent. It was concluded that the road test environment had a major influence on the start of cracking in the reinforced test sections at all four thickness levels.

Authors' Comment.— The cracking started in an environment similar to one that is believed to have caused high stresses due to restrained warping on another experimental project—the Arlington Test Track (7). In both cases:

1. There was a period of relatively low precipitation likely to produce a firm subgrade.
2. There were fairly low minimum night temperatures likely to keep the subgrade and the bottom of the concrete cool.

3. There were fairly warm sunshiny days likely to cause rapid increases in temperature on the top surface of the concrete and a much higher temperature in the top of concrete than in the bottom.

When these conditions prevail, the top of the slab tends to expand and warp the slab downward along the slab edges and at joints. The expansion and downward warping are resisted by the subgrade, producing tensile stresses in the bottom of the slab. These stresses tend to reach a maximum value at about 15 to 20 ft from a joint or edge (8).

It is not known whether stresses due to restrained warping (in combination with loads) caused the start of cracking in the reinforced sections at the Road Test. However, the crack pattern that did develop is an integral part of the experimental test results. This means that the experimental data show the performance of a group of reinforced test sections, 50 percent or more of which started cracking during a brief fall period—in spite of wide differences in the ratios of loads to slab thicknesses.

In some states, reinforced pavements do not develop a crack pattern like the one that occurred at the Road Test. This is true of reinforced pavements 8 to 10 in. thick on 4- to 12-in. subbases after 10 to 20 years of service on projects carrying large volumes of heavy truck traffic. These pavements do not have visible cracks. The very few cracks that do occur are isolated between long sections without cracks and are usually associated with abrupt changes in subgrade support, rather than climatic environment. In states where reinforced pavements do not exhibit cracking, except at isolated locations, Road Test performance on the reinforced sections will have little or no application.

The data on major cracking in Table 4 have been summarized on bar graphs in Figure 8. The bars show the percent of sections without major cracking and average repetitions at the start of major cracking for the two slab designs by thickness levels and loops. With regard to major cracking, Figure 8 shows:

1. About equal performance on first thickness levels except that the plain design showed slightly better performance than the reinforced design on the first level 8-in. test sections in loop 6.
2. At the second thickness level, performance was about equal in loop 3. In loops 4, 5 and 6 performance was better on the plain design than on the reinforced design.
3. At the third thickness level, performance was better on the plain slab design than on the reinforced design in loops 3, 4 and 6. In these loops no major cracking occurred on the plain design, but 62 to 100 percent of the reinforced test sections had major cracks. In loop 5 the percent of slabs with major cracking was equal, but the average number of repetitions to the start of cracking showed a slight superiority for the reinforced slab design.
4. At the fourth thickness level, performance was better on the plain slab design in loops 3 and 4 and about equal in loops 5 and 6.
5. Overall performance showed about equal performance on 7 of 16 load-thickness combinations. In one case (the third thickness in loop 5) performance was slightly better on the reinforced slab design. In the other eight load-thickness combinations, performance was superior on the plain design, with five of these eight combinations showing no major cracking.

It was concluded that the plain slab design showed definite overall superiority to the reinforced design with regard to major cracking.

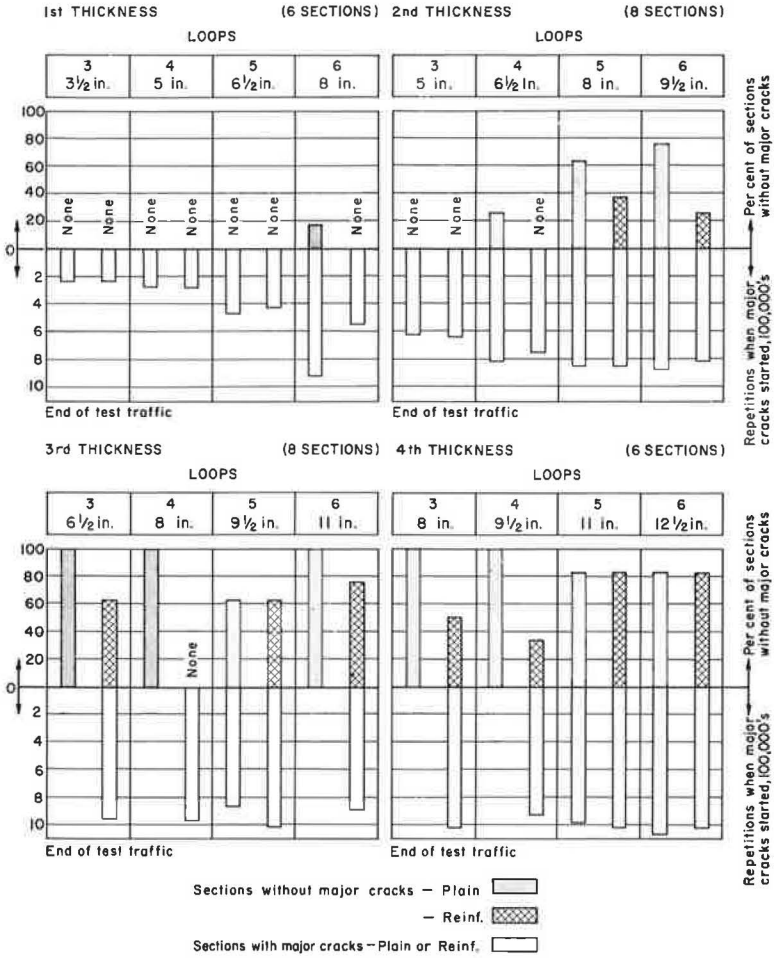


Figure 8. Major cracking — class 3 and 4—concrete test sections (factorial and replicate).

Authors' Comment[1].—Major (class 3 and 4) cracking was used in computing serviceability indexes. However, where the serviceability is about equal, a pavement without major cracking should be a better maintenance risk than a pavement with these cracks. It is true that there are more joints to maintain with a plain slab design. However, with a short joint spacing there is less movement at the joints and this tends to reduce the amount and frequency of maintenance required. Also, maintenance costs are usually higher for spalled or otherwise defective cracks than they are for joints.

SUBBASE PUMPING

This section deals with the extent and severity of subbase pumping at the Road Test and the relationships of subbase pumping to serviceability and performance. The data and analyses are on trace, moderate and heavy subbase pumping. (In the HRB data systems, trace, moderate and heavy subbase pumping are combined into a pumping

[1]The limitations set forth in the comments on start of cracking in reinforced sections also apply here.

score. This score equals trace pumping, plus 10 times moderate pumping, plus 50 times heavy pumping. In the Road Test Report the Pumping Index equals the Pumping Score divided by 100.) These types (or intensities) of subbase pumping are not defined in the Road Test Report (3) or in the Data System on pumping (R4243). However, examples of subbase pumping are shown in Figure 9.

Table 5 gives the data for all Design 1 concrete test sections in loops 3 to 6. These data are arranged across the table to make abridged section histories referenced to subbase pumping.

With regard to the extent of subbase pumping in loops 3 to 6, Table 5 shows the following:

Trace subbase pumping: (1) occurred on all Design 1 test sections.

Moderate subbase pumping: (1) occurred on all first and second level test sections, (2) occurred on 95 percent of the third level test sections, and (3) occurred on 63 percent of the fourth level test sections.

Heavy subbase pumping: (1) occurred on all first level test sections, and (2) occurred on 89 percent of the second level test sections, (3) occurred on 34 percent of the third level test sections (heavy subbase pumping was not severe on third and fourth level test sections), and (4) occurred on 21 percent of the fourth level test sections.

A major part of the data in Table 5 is shown in Figure 10. The bar graphs are performance histories showing Road Test performance in the truck loops up to the point heavy subbase pumping started. Serviceability and repetitions are plotted in the following order: (1) as constructed values, (2) at the start of trace subbase pumping, (3) at the start of moderate subbase pumping, and (4) at the start of heavy subbase pumping.

When moderate or heavy subbase pumping did not occur during the test period, end of test repetitions and serviceability indexes were used.

Bar graph histories are shown for the plain and reinforced slab designs, under single and tandem axles and by thickness levels and loops. The bar graph values are averages for the three subbase thicknesses.

Study of the bar graph histories in Figure 10 shows that:

1. Prior to the start of heavy subbase pumping there were no significant differences in serviceability on the plain and reinforced slab designs at any thickness level.
2. Prior to the start of heavy subbase pumping there were no significant differences in serviceability under single- and tandem-axle test traffic at any thickness level.
3. There was an initial loss in serviceability of about 0.4 prior to, or at the start of, trace subbase pumping. On most sections, trace subbase pumping started at 101,000 repetitions. Further study of performance histories showed that on most sections the initial loss in serviceability reached its low point at about 100,000 repetitions regardless of number of repetitions at which trace subbase pumping started. The initial serviceability loss occurred during the first period of spring weather after traffic testing started. Concrete pavements in service often exhibit lower serviceability during the first spring period than during subsequent spring periods or during other periods in the yearly weather cycle.
4. Prior to the start of heavy subbase pumping there were no further significant losses in serviceability at any thickness level.

To further check these conclusions, changes in serviceability between the start of trace subbase pumping and the start of heavy subbase pumping were computed. Where heavy subbase pumping did not occur during the test period, the end of test serviceability values was used. These computations are given in Table 6.

These mean changes (Table 6) do not show a significant loss in serviceability and hence support the conclusion that no losses occurred prior to the start of heavy subbase pumping.

Figure 9. (a) Test section where subbase pumping had not occurred; (b)trace subbase pumping along full length of test section; (c) initial stages of moderate subbase pumping; (d) initial stages of heavy subbase pumping; and (e) severe stage of heavy subbase pumping.

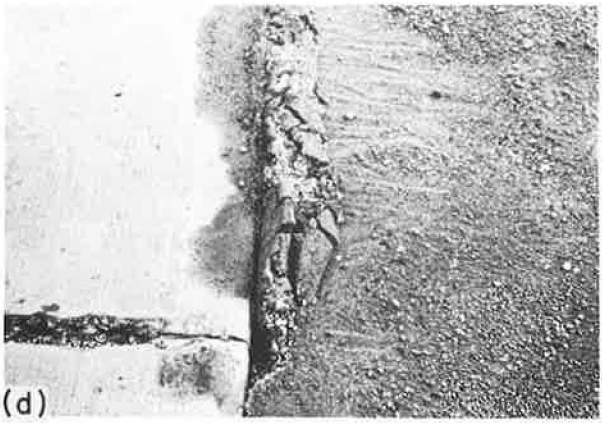


TABLE 5

SUBBASE PUMPING AND CONCRETE SERVICE

1st Thickness — LOOP 3 — 3½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
195	Plain	3	12S	4.3	4.1	4.1	3.7	1.5	77	101	274	250	315
196	Doweled Joints 15 Ft.		24T	4.5	4.1	4.1	4.0	1.5	101	143	267	265	318
239		6	12S	4.6	4.2	4.2	4.2	1.5	101	101	101	250	289
240			24T	4.6	4.2	4.2	4.2	1.5	101	101	101	170	210
213		9	12S	5.0	4.7	4.7	4.7	1.5	101	101	101	170	289
214			24T	4.9	4.7	4.7	4.7	1.5	101	101	101	180	297
209	Reinf.	3	12S	4.6	4.6	4.6	4.6	1.5	101	101	101	235	278
210	Doweled Joints 40 Ft.		24T	4.8	4.6	4.6	4.6	1.5	101	101	101	245	278
205		6	12S	4.8	4.4	4.4	4.4	1.5	101	101	101	135	273
206			24T	4.9	4.7	4.7	4.6	1.5	101	101	131	180	295
231		9	12S	4.7	4.5	4.5	4.5	1.5	101	101	101	275	324
232			24T	4.8	4.5	4.5	4.5	1.5	101	101	101	265	294

1st Thickness — LOOP 4 — 5 in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
643	Plain	3	18S	4.8	4.4	4.4	4.4	1.5	101	101	145	315	716
644	Doweled Joints 15 Ft.		32T	4.8	4.3	4.3	4.4	1.5	101	101	145	295	343
647		6	18S	4.8	4.3	4.4	4.4	1.5	101	145	145	280	353
648			32T	4.7	4.4	4.4	4.4	1.5	101	101	101	220	328
677		9	18S	4.6	4.2	4.2	4.2	1.5	101	101	101	275	291
678			32T	4.8	4.3	4.2	4.3	1.5	101	120	145	275	289
681	Reinf.	3	18S	4.6	4.3	4.3	4.3	1.5	101	101	101	315	415
682	Doweled Joints 40 Ft.		32T	4.7	4.4	4.4	4.4	1.5	101	101	101	225	304
661		6	18S	4.7	4.3	4.3	4.3	1.5	101	101	101	300	325
662			32T	4.6	4.2	4.2	4.2	1.5	101	101	101	150	175
673		9	18S	4.7	4.3	4.3	4.2	1.5	101	101	145	400	592
674			32T	4.7	4.2	4.2	4.2	1.5	101	101	101	360	408

1st Thickness — LOOP 5 — 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
513	Plain	3	22.4S	4.7	4.3	4.3	4.2	1.5	101	101	142	700	760
514	Doweled Joints 15 Ft.		40T	4.7	4.4	4.4	4.4	1.5	101	101	101	310	335
517		6	22.4S	4.7	4.2	4.2	4.3	1.5	101	101	287	665	898
518			40T	4.7	4.2	4.2	4.3	1.5	101	101	123	325	369
505		9	22.4S	4.5	4.2	4.2	4.2	1.5	101	101	270	410	705
506			40T	4.6	4.2	4.2	4.1	1.5	101	101	123	350	698
523	Reinf.	3	22.4S	4.6	4.2	4.2	4.4	1.5	101	101	649	700	898
524	Doweled Joints 40 Ft.		40T	4.7	4.2	4.2	4.4	1.5	101	101	586	620	705
491		6	22.4S	4.6	4.2	4.2	4.2	1.5	101	101	190	285	369
492			40T	4.7	4.2	4.2	4.2	1.5	101	101	143	275	305
549		9	22.4S	4.6	4.0	4.0	4.0	1.5	101	101	101	575	708
550			40T	4.7	4.2	4.2	4.2	1.5	101	101	101	275	618

1st Thickness — LOOP 6 — 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
353	Plain	3	30S	4.3	3.9	4.0	3.9	1.5	101	143	332	710	878
354	Doweled Joints 15 Ft.		48T	4.2	4.0	3.8	3.9	1.8	101	121	331	850	1114
393		6	30S	4.8	4.4	4.3	4.2	3.9	101	143	332	1100	1114
394			48T	4.7	4.4	4.3	4.3	4.1	101	245	284	—	1114
369		9	30S	4.5	4.2	4.1	4.0	3.4	101	130	349	880	1114
370			48T	4.3	4.0	4.0	4.1	1.5	101	331	672	755	1114
341	Reinf.	3	30S	4.7	4.3	4.2	4.1	1.5	101	143	292	710	782
342	Doweled Joints 40 Ft.		48T	4.7	4.2	4.2	4.2	1.5	101	101	101	410	618
385		6	30S	4.6	4.2	4.2	4.2	1.5	101	292	332	745	974
386			48T	4.6	4.3	4.3	4.3	1.5	101	101	101	345	415
347		9	30S	4.7	4.3	4.3	4.4	1.5	101	101	206	670	768
348			48T	4.8	4.4	4.4	4.4	1.5	101	101	145	570	624

*S = Single, T = Tandem

**When serviceability index fell below 4.0 and did not recover

TABLE 5

SUBBASE PUMPING AND CONCRETE SERVICE (Cont'd.)

2nd Thickness — LOOP 3 — 5 in.

Sec. No.	Design: Slab	Design: Subbase Depth in.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
225	Plain	3	12S	4.6	4.4	4.0	4.1	3.7	101	172	890	970	1114
226			24T	4.8	4.5	4.2	4.2	1.5	101	169	273	320	705
245	Doweled Joints 15 Ft.	6	12S	4.7	4.3	4.2	4.2	3.5	101	274	704	950	1114
221			R	4.9	4.6	4.2	4.0	3.1	101	172	749	750	1114
246			24T	4.8	4.5	4.3	4.3	2.8	101	598	772	905	1114
222			R	4.9	4.2	4.2	4.0	1.5	101	143	338	445	901
219		9	12S	4.9	4.4	4.2	4.1	3.7	144	176	629	970	1114
220			24T	4.8	4.5	4.3	4.3	1.5	101	169	282	570	771
251	Reinf.	3	12S	4.5	4.0	4.0	4.0	2.8	101	101	329	810	1114
203			R	4.7	4.4	4.4	4.4	4.0	101	101	280	—	1114
252	Doweled Joints 40 Ft.		24T	4.5	4.1	4.1	4.0	1.5	101	101	169	735	1100
204			R	4.7	4.4	4.4	4.3	1.5	101	273	413	885	1046
191		6	12S	4.7	4.4	4.4	4.3	1.5	101	101	172	670	725
192			24T	4.7	4.2	4.2	4.3	1.5	101	101	202	440	631
233		9	12S	4.8	4.6	4.3	4.0	3.3	101	176	868	960	1114
234			24T	4.9	4.5	4.5	4.2	1.5	101	101	273	635	793

2nd Thickness — LOOP 4 — 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth in.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
649	Plain	3	18S	4.8	4.3	4.4	—	3.8	101	346	NONE	990	1114
650			32T	4.6	4.3	4.4	4.0	1.5	101	131	413	410	689
697	Doweled Joints 15 Ft.	6	18S	4.9	4.3	4.3	—	4.4	101	730	NONE	—	1114
655			R	4.8	4.4	4.3	4.6	4.3	101	345	730	—	1114
698			32T	4.7	4.3	4.5	4.6	3.4	101	295	598	1000	1114
656			R	4.8	4.4	4.5	4.5	1.5	101	346	346	825	1000
703		9	18S	4.8	4.3	4.3	4.5	3.0	101	346	774	940	1114
704			32T	4.8	4.4	4.4	4.4	1.5	101	196	196	640	772
641	Reinf.	3	18S	4.9	4.4	4.5	4.6	3.8	101	276	685	965	1114
705			R	4.8	4.3	4.5	4.5	3.6	101	195	774	945	1114
642	Doweled Joints 40 Ft.		32T	4.7	4.4	4.4	4.4	2.6	101	101	196	780	1114
706			R	4.8	4.5	4.5	4.5	1.5	101	101	196	715	793
685		6	18S	4.8	4.5	4.5	4.6	3.4	101	276	774	925	1114
686			32T	4.8	4.3	4.3	4.4	1.5	101	101	346	750	796
653		9	18S	4.9	4.4	4.5	4.5	1.8	101	282	331	945	1114
654			32T	4.8	4.4	4.4	4.4	1.5	101	101	101	880	1036

2nd Thickness — LOOP 5 — 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth in.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
547	Plain	3	22.4S	4.4	4.0	4.2	—	4.2	101	316	NONE	—	1114
548			40T	4.7	4.0	4.2	—	4.2	101	586	NONE	—	1114
539	Doweled Joints 15 Ft.	6	22.4S	4.7	4.2	4.3	4.3	4.2	101	628	710	—	1114
533			R	4.7	4.2	4.2	4.3	4.1	101	316	601	—	1114
540			40T	4.7	4.2	4.4	4.3	3.7	202	586	771	1045	1114
534			R	4.7	4.1	4.3	4.2	4.2	101	586	1087	—	1114
507		9	22.4S	4.7	4.3	4.6	4.6	1.5	103	710	710	900	1111
508			40T	4.8	4.5	4.7	4.6	1.5	101	586	727	850	898
519	Reinf.	3	22.4S	4.6	4.2	4.2	4.1	1.5	101	270	331	715	1104
521			R	4.5	4.2	4.2	4.3	4.3	101	270	310	—	1114
520	Doweled Joints 40 Ft.		40T	4.7	4.2	4.2	4.4	1.5	101	101	686	715	915
522			R	4.6	4.2	4.2	4.3	4.3	101	101	716	—	1114
501		6	22.4S	4.6	4.2	4.2	4.2	4.0	101	270	270	—	1114
502			40T	4.8	4.3	4.3	4.4	1.5	101	101	275	785	901
531		9	22.4S	4.9	4.4	4.4	4.6	4.6	101	101	331	—	1114
532			40T	4.8	4.2	4.2	4.6	3.2	101	101	600	1085	1114

2nd Thickness — LOOP 6 — 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth in.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
351	Plain	3	30S	4.4	4.1	4.1	4.0	3.6	101	101	795	1050	1114
352			48T	4.3	4.1	3.9	3.8	3.1	101	122	145	695	1114
367	Doweled Joints 15 Ft.	6	30S	4.7	4.3	4.3	—	4.3	101	143	NONE	—	1114
389			R	4.6	4.2	4.2	4.2	4.3	101	130	898	—	1114
368			48T	4.7	4.2	4.2	—	4.3	101	575	NONE	—	1114
390			R	4.7	4.2	4.2	4.3	4.3	101	130	408	—	1114
375		9	30S	4.6	4.2	4.2	4.2	4.2	101	588	728	—	1114
376			48T	4.6	4.2	4.2	4.3	4.3	101	368	715	—	1114
381	Reinf.	3	30S	4.5	4.3	4.4	—	4.5	101	703	NONE	—	1114
371			R	4.6	4.3	4.3	4.4	1.6	101	130	703	760	1114
382	Doweled Joints 40 Ft.		48T	4.7	4.3	4.3	4.3	4.4	101	122	331	—	1114
372			R	4.7	4.3	4.3	4.2	4.1	101	284	348	—	1114
403		6	30S	4.4	4.2	4.2	4.4	4.0	101	171	629	—	1114
404			48T	4.7	4.2	4.1	4.3	4.0	101	202	575	—	1114
339(1)		9	30S	4.7	4.3	4.4	4.5	2.2	101	122	686	775	1114
340			48T	4.8	4.4	4.4	4.4	1.5	101	101	169	755	912

* S = Single, T = Tandem, R = Replicate

** When serviceability index fell below 4.0 and did not recover

(1) Section history shown page 148 HRB Special Report 61-E

TABLE 5

SUBBASE PUMPING AND CONCRETE SERVICE (Cont'd.)

3rd Thickness — LOOP 3 — 6½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
217	Plain	3	12S	4.9	4.7	4.6	—	4.4	131	274	NONE	—	1114
193			R	4.6	4.2	—	—	3.9	131	NONE	NONE	1114	1114
218	Doweled Joints 15 Ft.		24T	4.8	4.7	4.7	—	4.2	101	703	NONE	—	1114
194			R	4.6	4.3	4.2	—	4.0	131	267	NONE	—	1114
249		6	12S	4.7	4.5	4.2	—	4.1	172	974	NONE	—	1114
250			24T	4.8	4.3	4.3	—	4.1	169	647	NONE	—	1114
207		9	12S	4.9	4.4	4.3	—	4.2	172	974	NONE	—	1114
208			24T	4.8	4.2	4.4	—	4.0	169	647	NONE	—	1114
199	Reinf.	3	12S	4.7	4.6	4.4	—	4.2	101	728	NONE	—	1114
200	Doweled Joints 40 Ft.		24T	4.9	4.5	4.4	4.5	4.1	101	267	867	—	1114
247		6	12S	4.8	4.6	4.5	—	4.3	101	790	NONE	—	1114
237			R	5.0	4.7	4.2	—	4.5	171	715	NONE	—	1114
248			24T	4.8	4.6	4.4	4.6	4.3	101	714	890	—	1114
238			R	5.0	4.7	4.1	4.1	4.1	101	361	772	—	1114
241		9	12S	4.9	4.4	4.4	—	4.4	172	715	NONE	—	1114
242			24T	4.9	4.6	4.5	4.6	4.4	101	169	901	—	1114

3rd Thickness — LOOP 4 — 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
671	Plain	3	18S	4.9	4.3	4.3	—	4.4	101	346	NONE	—	1114
687			R	4.8	4.4	—	—	4.5	101	NONE	NONE	—	1114
672	Doweled Joints 15 Ft.		32T	4.6	4.4	4.2	—	4.1	101	586	NONE	—	1114
688			R	4.7	4.3	4.5	—	4.2	101	346	NONE	—	1114
683		6	18S	4.9	4.7	4.7	—	4.4	101	716	NONE	—	1114
684			32T	4.8	4.6	4.5	4.2	4.2	101	716	983	—	1114
651		9	18S	4.8	4.5	4.5	—	4.3	282	716	NONE	—	1114
652			32T	4.7	4.2	4.3	—	4.1	101	585	NONE	—	1114
691	Reinf.	3	18S	4.8	4.4	4.3	4.3	3.9	101	716	716	1100	1114
692	Doweled Joints 40 Ft.		32T	4.9	4.3	4.3	4.3	4.0	101	101	101	—	1114
669		6	18S	4.9	4.6	4.8	4.8	4.4	101	716	716	—	1114
707			R	4.7	4.3	4.2	4.2	3.9	101	132	132	1110	1114
670			32T	4.8	4.4	4.7	4.7	4.4	101	585	585	—	1114
708			R	4.7	4.3	4.3	4.3	3.8	101	101	101	1055	1114
695		9	18S	4.8	4.6	—	—	4.3	101	NONE	NONE	—	1114
696			32T	4.8	4.4	4.6	4.6	4.2	101	585	585	—	1114

3rd Thickness — LOOP 5 — 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
511	Plain	3	22.4S	4.7	4.3	4.6	—	4.4	168	768	NONE	—	1114
541			R	4.4	4.3	4.3	4.3	4.3	101	744	768	—	1114
512	Doweled Joints 15 Ft.		40T	4.8	4.3	4.4	—	4.3	101	586	NONE	—	1114
542			R	4.6	4.0	4.0	—	4.2	101	123	NONE	—	1114
525		6	22.4S	4.7	4.2	4.4	4.3	3.7	101	628	784	830	1114
526			40T	4.8	4.2	4.7	4.5	4.0	101	586	686	—	1114
535		9	22.4S	4.7	4.2	4.4	—	4.5	101	601	NONE	—	1114
536			40T	4.6	4.0	4.2	4.3	3.8	101	586	727	1010	1114
553	Reinf.	3	22.4S	4.7	4.2	4.2	—	4.3	101	122	NONE	—	1114
554	Doweled Joints 40 Ft.		40T	4.9	4.1	4.1	—	4.1	101	101	NONE	—	1114
543		6	22.4S	4.7	4.1	4.4	—	4.5	101	710	NONE	—	1114
503			R	4.7	4.2	4.2	—	4.3	101	101	NONE	—	1114
544			40T	4.7	4.0	4.0	4.3	4.3	101	101	727	—	1114
504			R	4.8	4.3	4.3	4.4	4.5	101	101	750(1)	—	1114
499		9	22.4S	4.6	4.4	4.4	—	4.4	101	101	NONE	—	1114
500			40T	4.8	4.4	4.4	—	4.6	101	101	NONE	—	1114

3rd Thickness — LOOP 6 — 11 in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
377	Plain	3	30S	4.6	4.0	4.3	—	4.2	369	749	NONE	—	1114
363			R	4.7	4.2	4.2	—	4.4	101	143	NONE	—	1114
378	Doweled Joints 15 Ft.		48T	4.6	4.3	4.4	—	4.3	284	615	NONE	—	1114
364			R	4.8	4.3	4.4	—	4.3	101	570	NONE	—	1114
397		6	30S	4.7	4.2	4.4	—	4.2	101	1042	NONE	—	1114
398			48T	4.6	4.3	4.3	—	4.3	101	615	NONE	—	1114
365		9	30S	4.6	4.2	4.2	—	4.3	101	749	NONE	—	1114
366			48T	4.7	4.2	4.2	—	4.3	101	779	NONE	—	1114
391	Reinf.	3	30S	4.6	4.2	4.2	—	4.4	101	281	NONE	—	1114
392	Doweled Joints 40 Ft.		48T	4.6	4.3	4.4	4.4	4.4	101	284	1022	—	1114
337		6	30S	4.6	4.3	4.2	—	4.0	101	130	NONE	—	1114
345			R	4.7	4.2	4.3	4.3	4.3	101	369	795	—	1114
338			48T	4.5	4.3	4.3	4.2	4.1	101	101	408	—	1114
346			R	4.7	4.4	4.4	—	4.2	101	368	NONE	—	1114
343		9	30S	4.6	4.2	4.2	—	4.2	101	582	NONE	—	1114
344			48T	4.7	4.3	4.2	4.3	4.1	101	130	331	—	1114

*S = Single, T = Tandem, R = Replicate

**When serviceability index fell below 4.0 and did not recover

TABLE 5

SUBBASE PUMPING AND CONCRETE SERVICE (Cont'd.)

4th Thickness — LOOP 3 — 8 in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
201	Plain	3	12S	4.8	4.4	—	—	4.4	206	NONE	NONE	—	1114
202	Doweled Joints 15 Ft.		24T	4.8	4.3	4.3	—	4.3	206	727	NONE	—	1114
235		6	12S	4.8	4.5	4.7	—	4.3	172	652	NONE	—	1114
236			24T	4.9	4.5	4.6	4.3	4.3	169	582	772	—	1114
185		9	12S	4.6	4.2	—	—	4.0	144	NONE	NONE	—	1114
186			24T	4.7	4.3	4.2	—	4.2	131	647	NONE	—	
211	Reinf.	3	12S	4.9	4.6	—	—	4.3	274	NONE	NONE	—	1114
212	Doweled Joints 40 Ft.		24T	4.9	4.4	4.2	—	4.1	101	772	NONE	—	1114
215		6	12S	4.9	4.5	4.6	—	4.2	172	890	NONE	—	1114
216			24T	4.8	4.3	4.2	—	4.0	101	647	NONE	—	1114
197		9	12S	4.8	4.3	4.2	—	4.1	172	974	NONE	—	1114
198			24T	4.8	4.4	4.3	4.3	4.3	101	647	901	—	1114

4th Thickness — LOOP 4 — 9½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
675	Plain	3	18S	4.7	4.2	4.2	—	4.2	145	171	NONE	—	1114
676	Doweled Joints 15 Ft.		32T	4.5	4.1	4.2	4.1	4.0	101	585	730	—	1114
701		6	18S	4.9	4.4	—	—	4.5	132	NONE	NONE	—	1114
702			32T	4.7	4.4	—	—	4.2	101	NONE	NONE	—	1114
689		9	18S	4.7	4.2	—	—	4.1	282	NONE	NONE	—	1114
690			32T	4.7	4.3	4.4	—	4.2	101	585	NONE	—	1114
645	Reinf.	3	18S	4.9	4.3	4.3	4.3	4.0	171	730	730	—	1114
646	Doweled Joints 40 Ft.		32T	4.7	4.3	4.3	4.3	4.0	101	274	274	—	1114
665		6	18S	4.7	4.4	—	—	4.5	171	NONE	NONE	—	1114
666			32T	4.7	4.3	4.6	—	4.3	101	774	NONE	—	1114
667		9	18S	4.8	4.8	—	—	4.8	282	NONE	NONE	—	1114
668			32T	4.8	4.7	4.8	—	4.6	101	585	NONE	—	1114

4th Thickness — LOOP 5 — 11 in.

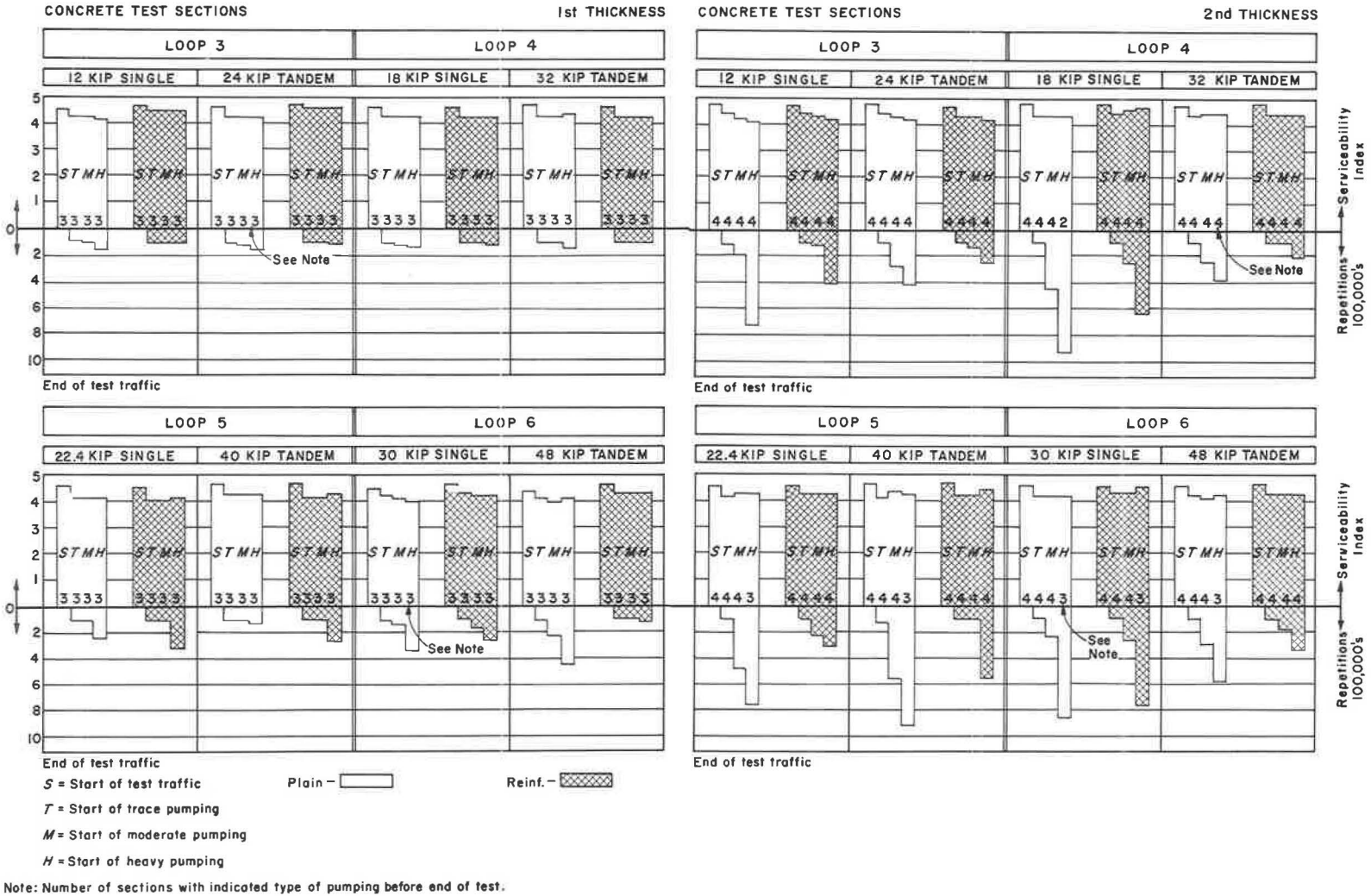
Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
529	Plain	3	22.4S	4.7	4.2	—	—	4.1	130	NONE	NONE	—	1114
530	Doweled Joints 15 Ft.		40T	4.6	4.1	4.3	—	4.3	101	649	NONE	—	1114
497		6	22.4S	4.7	4.4	—	—	4.5	720	NONE	NONE	—	1114
498			40T	4.8	4.2	—	—	4.5	101	NONE	NONE	—	1114
509		9	22.4S	4.6	4.3	—	—	4.5	681	NONE	NONE	—	1114
510			40T	4.7	4.3	—	—	4.4	314	NONE	NONE	—	1114
515	Reinf.	3	22.4S	4.7	4.3	4.3	—	4.1	168	270	NONE	—	1114
516	Doweled Joints 40 Ft.		40T	4.8	4.3	4.3	—	4.3	101	275	NONE	—	1114
545		6	22.4S	4.6	4.0	4.5	4.3	4.4	101	768	768	—	1114
546			40T	4.6	4.0	4.0	—	4.3	101	101	NONE	—	1114
495		9	22.4S	4.6	4.2	4.2	—	4.4	101	203	NONE	—	1114
496			40T	4.6	4.2	4.2	4.2	4.4	101	101	207	—	1114

4th Thickness — LOOP 6 — 12½ in.

Sec. No.	Design: Slab	Design: Subbase Depth In.	Axle Loads kips*	Serviceability Indexes: At Start Of Test	At Start Of Subbase Pumping: Trace	Mod.	Heavy	At End Of Test	Repetitions (1000-S): At Start Of Subbase Pumping: Trace	Mod.	Heavy	At First Loss **	At End Of Test
395	Plain	3	30S	4.7	4.3	4.3	4.4	4.2	686	686	897	—	1114
396	Doweled Joints 15 Ft.		48T	4.7	4.2	4.2	4.2	4.3	101	331	331	—	1114
349		6	30S	4.3	4.0	4.0	—	4.0	193	281	NONE	—	1114
350			48T	4.5	4.0	4.1	4.1	4.2	145	169	315	—	1114
379		9	30S	4.6	4.2	—	—	4.2	774	NONE	NONE	—	1114
380			48T	4.6	4.2	4.3	—	4.4	315	1022	NONE	—	1114
359	Reinf.	3	30S	4.7	4.2	—	—	4.4	101	NONE	NONE	—	1114
360	Doweled Joints 40 Ft.		48T	4.5	4.2	—	—	4.3	101	NONE	NONE	—	1114
355		6	30S	4.7	4.3	4.3	—	4.2	101	292	NONE	—	1114
356			48T	4.7	4.5	4.6	4.6	4.4	101	575	575	—	1114
357		9	30S	4.7	4.3	—	—	4.5	292	NONE	NONE	—	1114
358			48T	4.6	4.2	—	—	4.2	101	NONE	NONE	—	1114

*S = Single, T = Tandem

**When serviceability index fell below 4.0 and did not recover



Note: Number of sections with indicated type of pumping before end of test.

Figure 10. Summary of serviceability and repetitions as related to subbase pumping.

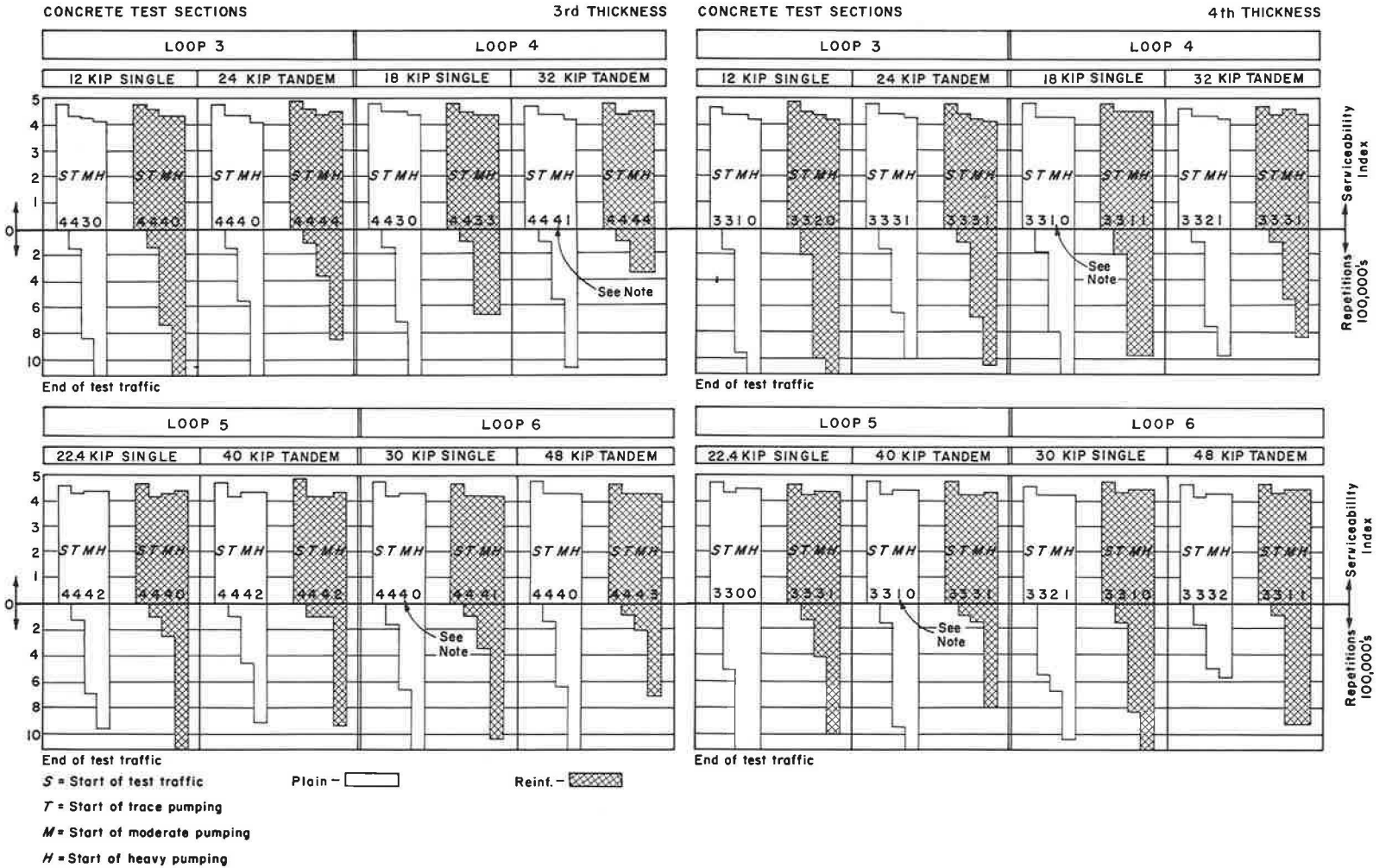


Figure 10. (continued)

As a further check on the conclusions, the mean losses in serviceability were first computed between the as constructed values and at the start of trace subbase pumping. Mean values for the four thickness levels are shown in Table 6. It is significant that these initial serviceability losses changed very little between thickness levels and did not decrease as slab thickness increased relative to load.

The next step was to check the validity of the following statement:

> On all Design 1 concrete test sections in loops 3 to 6 there was an initial 0.4 serviceability loss up to the start of trace subbase pumping, and there was no further loss in serviceability prior to the start of heavy subbase pumping—or during the test period on sections where no heavy pumping occurred.

TABLE 6

CHANGE IN SERVICEABILITY BETWEEN THE START OF TRACE AND HEAVY SUBBASE PUMPING

Thickness Level	Change	Mean
1	-0.10	-0.37
2	+0.08	-0.43
3	-0.20	-0.41
4	-0.01	-0.42
All 4	-0.02	-0.41

To check this statement 0.4 was subtracted from the as constructed serviceability index of each test section and the standard deviation was computed between this value and the serviceability index at the start of heavy subbase pumping—or the end of test serviceability index where no heavy subbase pumping occurred. Values were computed for the two slab designs and the two axle loads at each thickness level. Results of these computations are given in Table 7. These values show quite uniform concrete performance and no significant differences between the variables of load and design. The values support both the statement and the other conclusions.

The mean replicate difference in serviceability was 0.14 at the start of trace subbase pumping and 0.18 at the start of heavy subbase pumping, or at the end of the test where no heavy subbase pumping occurred. These replicate differences also show that concrete performance was quite uniform and that the deviation values are reliable.

> Authors' Comment.—The data and conclusions on subbase pumping thus far presented are at variance with the Road Test performance equations in the following respects:
>
> 1. The equations fail to show the initial loss in serviceability up to the start of trace subbase pumping.

TABLE 7

STANDARD DEVIATION IN SERVICEABILITY

Thickness Level	Mean	Plain		Reinf.	
		Single	Tandem	Single	Tandem
1*	0.12	0.10	0.10	0.14	0.14
2	0.20	0.27	0.20	0.22	0.10
3	0.20	0.17	0.17	0.14	0.22
4	0.20	0.17	0.14	0.24	0.24

*Data from the first level in loop 3 were omitted because all three types of subbase pumping started at the same number of repetitions on nine of twelve sections.

2. The equations fail to show that there were no further significant losses in serviceability prior to the start of heavy subbase pumping—or to the end of test where no heavy subbase pumping occurred.

3. The equations fail to show the equality of performance on Design 1 test sections at all thickness levels prior to the start of heavy subbase pumping—or to the end of test where no heavy subbase pumping occurred.

4. The equations fail to show equality of performance under single- and tandem-axle test traffic prior to the start of heavy subbase pumping—or to the end of test where heavy subbase pumping did not occur.

Table 5 shows repetitions to the first loss in serviceability—the point at which the serviceability index fell below 4.0 and did not recover. (The performance history of Section 339 is shown on page 148 (3, Fig. 115). The first loss in serviceability occurred at 775,000 repetitions.) This is approximately the point at which concrete test sections began to suffer damage from the effects of heavy subbase pumping (probably from non-uniform subbase support). The work on repetitions to the first loss in serviceability has thus far been limited to the first level test sections in the four truck loops. In Figure 11, the number of repetitions between the start of heavy subbase pumping and the first serviceability loss are related to computed stresses. These stresses (and others shown later) were computed for the maximum loop wheel load with a 20 percent load safety factor using the procedure described in the previous study (1, 2). Figure 11 shows:

1. Wide variations in the number of repetitions between the start of heavy subbase pumping and the first loss in serviceability.
2. That average values varied at a nearly constant rate where the stress was between 513 and 845 psi (loops 3, 4 and 5).
3. That there was a sharp increase in average repetitions to the first loss in serviceability where the stress was less than 513 psi (between loops 5 and 6).

Performance of the second level test sections are of special interest because of the wide variations in their performance, particularly in loops 4, 5 and 6. The following is a summary of major differences in end of test serviceability in these three loops:

Loop 4, Second Level, 6½ In., Stress: 424 Psi

Four sections survived test traffic with a mean serviceability index of 4.1, only slightly below end of test averages for the third and fourth levels.

However, six sections dropped to a 1.5 index at repetitions varying from 689,000 to 1,036,000.

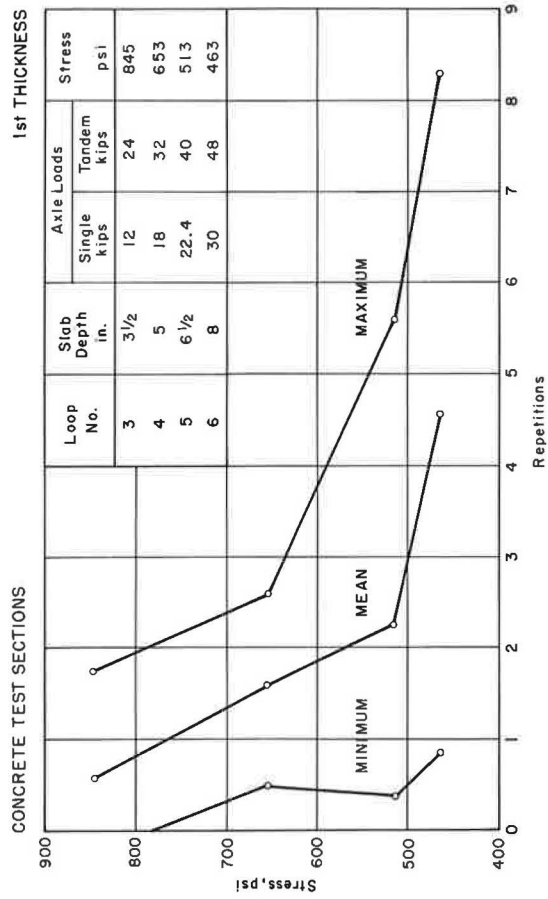


Figure 11. Repetitions from start of heavy pumping to first loss in serviceability (when serviceability fell below 4.0 and did not recover) as related to computed stresses.

Loop 5, Second Level, 8 In., Stress: 370 Psi

Eight sections survived test traffic with a mean serviceability index of 4.2—about equal to end of test values for third and fourth levels.

However, five sections dropped to a 1.5 index at repetitions varying from 898,000 to 1,104,000 repetitions.

Loop 6, Second Level, 9½ In., Stress: 346 Psi

Twelve sections survived with a mean serviceability index of 4.2—again equal to terminal values at the third and fourth thickness levels.

However, one section ended the test with an index of 1.6 and another dropped to 1.5 at 912,000 repetitions.

It is evident from this summary that concrete performance improved consistently as computed stresses dropped to values that are often used for design of pavements in service. (For concrete with an anticipated 28-day flexural strength of 700 psi, a stress of 350 psi affords a fatigue safety factor of 2.0, the value used for more than 100,000 load repetitions in the PCA design procedure.) But why the extremes of performance in these second level test sections? It was found that the differences in performance were related to the amount, or severity, of heavy subbase pumping and computed stresses. These relationships are shown in Table 8. The second level test sections were divided into five groups. The first group had no heavy subbase pumping and the other four groups had increasing amounts (or intensities) of heavy subbase pumping. In Table 8 the amount of heavy subbase pumping is the accumulated percentage of section length with heavy subbase pumping. The percent of section length with heavy subbase pumping was measured after each period of rainfall. The accumulated percentage is the sum of these values. For example, if on a given section these percentages were 10, 14 and 21 after three periods of rainfall, the accumulated percentage would be 45 (these values are illustrative only, not taken from Road Test data). If, on another section, these percentages were 80, 45 and 60 after three periods of rainfall, the accumulated percentage would be 190. Table 8 shows that as stress decreased the test sections were able to withstand increasing amounts of heavy subbase pumping without significant loss in serviceability. Mean values to the left of and below the heavy line in Table 8 are:

Loop	No. of Sections	Mean Serviceability Index
3	None	---
4	4	4.1
5	8	4.2
6	12	4.2

Table 8 also shows that sections with a serviceability index of 1.5 before the end of test had suffered the effects of severe subbase pumping. On 19 of 20 sections in this category, the accumulated percentage of heavy subbase pumping was 60 or more. Eighty percent of the 20 sections with a 1.5 index before the end of test had accumulated percentages of 90 or more.

Eight-inch concrete pavements are widely used on routes carrying heavy traffic. This led to preparation of detail performance history graphs for the 8-in., second thickness test sections in loop 5. These graphs are shown in Figure 12. The test sections are grouped together to illustrate the effects of heavy subbase pumping. Curves for the Road Test performance equations are also shown. Conclusions from Figure 12 are:

1. Where the accumulated percentage of heavy subbase pumping was 60 or less, the 8-in. second level pavements performed about as well as the third and fourth thickness levels.

TABLE 8

TERMINAL SERVICEABILITY AS RELATED TO HEAVY SUBBASE PUMPING AND COMPUTED STRESSES

CONCRETE TEST SECTIONS — 2nd THICKNESS

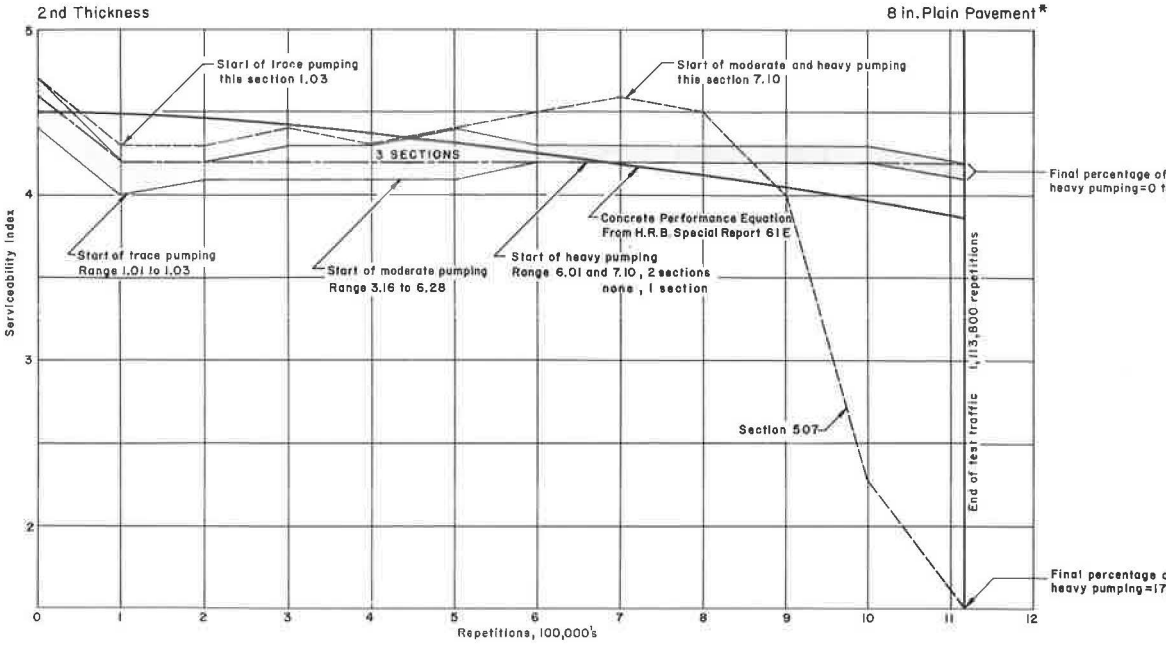
Loop & Slab	Axle Loads Kips	Stress psi	AMOUNT OF HEAVY SUBBASE PUMPING**																			
			NONE				0–30				30–60				60–90				90 +			
			Plain		Reinf.		Plain		Reinf.		Plain		Reinf.		Plain		Reinf.		Plain		Reinf.	
			S*	T*	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T
Loop 3 5"	12 S* 24 T*	473					3.7 3.1	2.8	3.3		3.7 3.5		4.0			1.5	2.8	1.5		1.5 1.5	1.5	1.5 1.5 1.5
Loop 4 6½"	18 S 32 T	424	4.4 3.8	***			4.3		3.8			1.5	3.6			3.4 1.5	3.4	2.6	3.0	1.5	1.8	1.5 1.5 1.5
Loop 5 8"	22.4S 40 T	370	4.2	4.2			4.2	4.2	4.3 4.0	4.3			4.6		4.1	3.7			1.5	1.5	1.5	3.2 1.5 1.5
Loop 6 9½"	30 S 48 T	346	4.3	4.3	4.5		4.3 4.2 3.6	4.3	4.0	4.4 4.1 4.0						4.3				3.1	2.2 1.6	1.5

*S = Single, T = Tandem

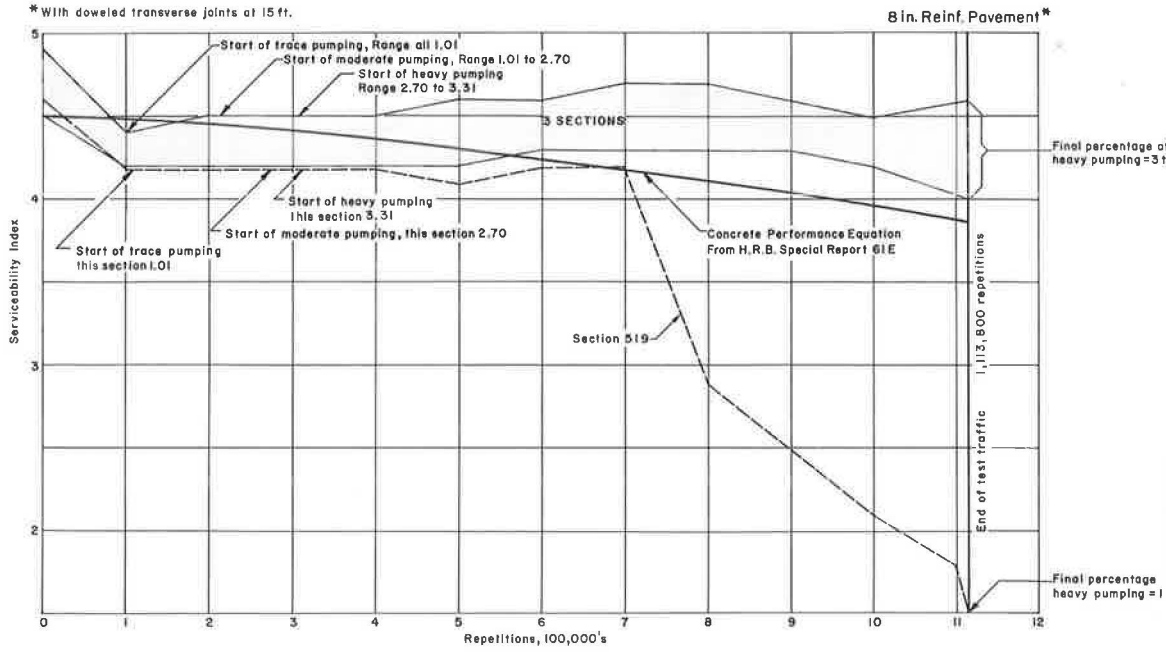
** Amounts shown are accumulated percentages of section length with heavy pumping, measured after each period of rainfall.

*** Terminal Serviceability Indexes

LOOP 5 – 22.4 KIP SINGLE AXLE LOADS

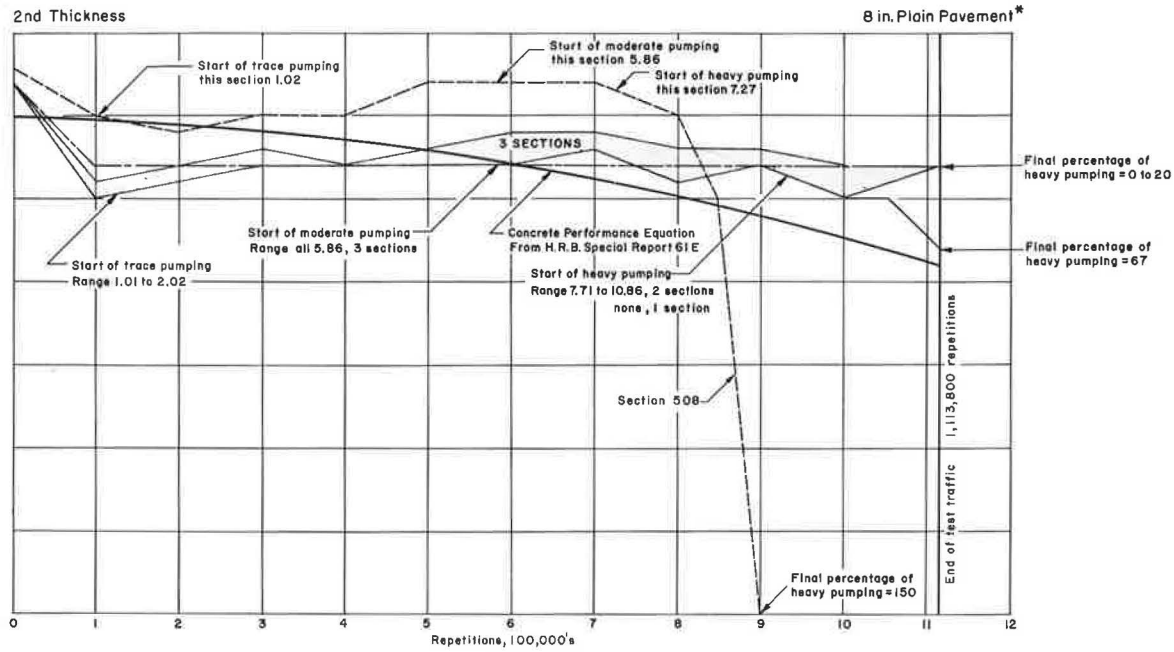


*With doweled transverse joints at 15 ft.

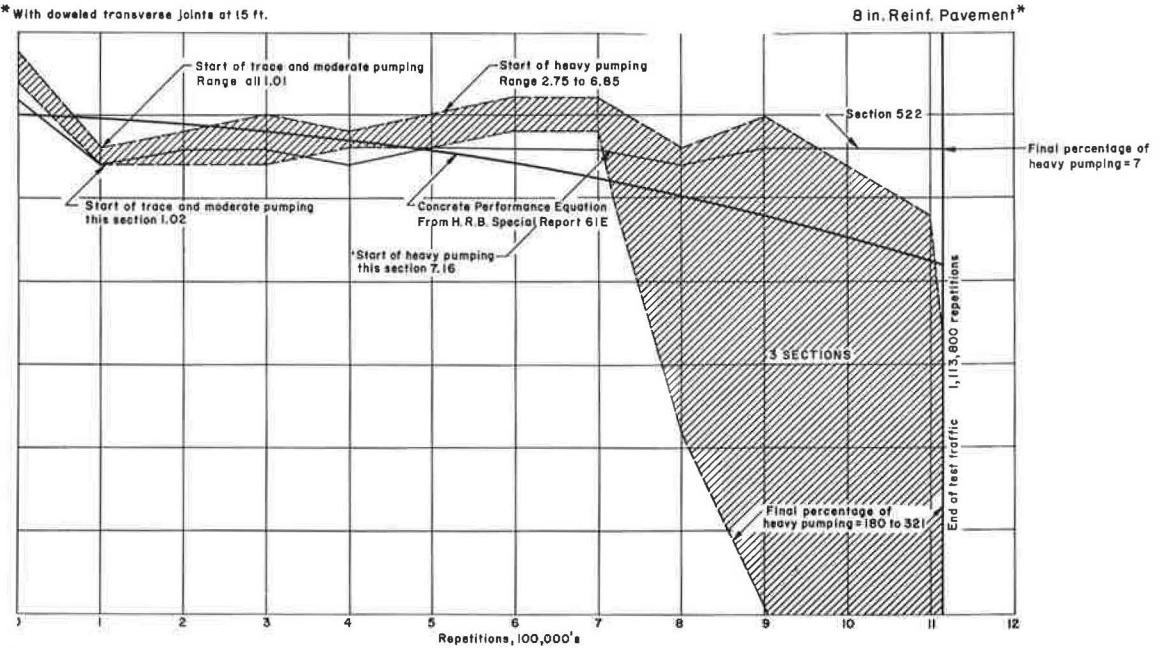


*With doweled transverse joints at 40 ft.

LOOP 5 – 40 KIP TANDEM AXLE LOADS



*With doweled transverse joints at 15 ft.



With doweled transverse joints at 40 ft.

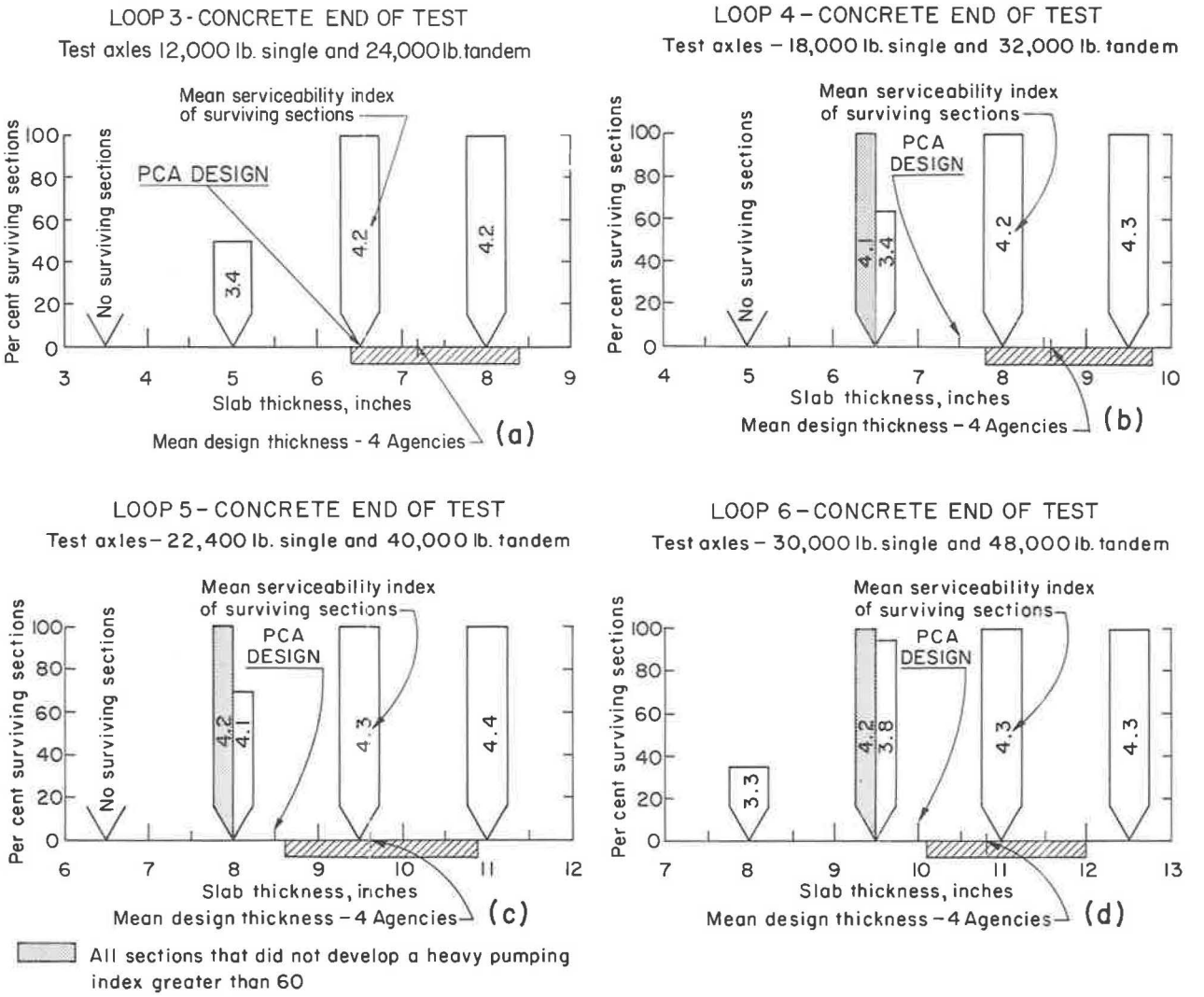

LOOP 3 - CONCRETE END OF TEST
Test axles 12,000 lb. single and 24,000 lb. tandem
Mean serviceability index of surviving sections
PCA DESIGN
No surviving sections
3.4
4.2
4.2
Per cent surviving sections
Slab thickness, inches
Mean design thickness - 4 Agencies
(a)
LOOP 4 - CONCRETE END OF TEST
Test axles - 18,000 lb. single and 32,000 lb. tandem
Mean serviceability index of surviving sections
PCA DESIGN
No surviving sections
4.1
3.4
4.2
4.3
Per cent surviving sections
Slab thickness, inches
Mean design thickness - 4 Agencies
(b)
LOOP 5 - CONCRETE END OF TEST
Test axles - 22,400 lb. single and 40,000 lb. tandem
Mean serviceability index of surviving sections
PCA DESIGN
No surviving sections
4.2
4.1
4.3
4.4
Per cent surviving sections
Slab thickness, inches
Mean design thickness - 4 Agencies
(c)
LOOP 6 - CONCRETE END OF TEST
Test axles - 30,000 lb. single and 48,000 lb. tandem
Mean serviceability index of surviving sections
PCA DESIGN
3.3
4.2
3.8
4.3
4.3
Per cent surviving sections
Slab thickness, inches
Mean design thickness - 4 Agencies
(d)
All sections that did not develop a heavy pumping index greater than 60

Figure 13.

2. Where the accumulated percentage of heavy subbase pumping was 60 or less, performance of the 8-in. test sections could be described by the following statement: At 100,000 repetitions of either single- or tandem-axle loads the serviceability index was 0.4 less than the as constructed values, and there were no further losses in serviceability during the test period.

3. Where the accumulated percentage of heavy subbase pumping was 90 or more, performance was as previously stated until heavy subbase pumping approached severe intensity. Severe heavy subbase pumping was accompanied by a rapid serviceability loss with indexes usually reaching a value of 1.5 before the end of test.

4. The performance shown in Figure 12 is at variance with the Road Test performance equations in the following respects:

(A) They do not describe concrete performance prior to the start of heavy subbase pumping.

(B) They give incorrect values for end of test serviceability where the accumulated percentage of heavy pumping was 60 or less (not severe).

(C) They fail to show that performance was equal under single and tandem axles where the accumulated percentage of heavy subbase pumping was 60 or less (not severe).

(D) They give incorrect values for end of test serviceability where the accumulated percentage of heavy subbase pumping was 90 or more (severe).

In the previous study (1) the relationships of design depths to end of test serviceability are shown in chart form for the four truck loops. These charts (Figs. 18, 19, 20 and 21 in Ref. 1) have been reproduced and revised to show end of test serviceability for second level test sections that were not affected by heavy subbase pumping (sections to the left of and below the heavy line in Table 8 of this report). These revisions are shown in Figure 13.

Figure 13a shows the relationships of design depths to the four thickness levels in loop 3. The PCA design depth and both the mean and range of design depths submitted by four agencies during the planning stage of the Road Test are shown on the slab thickness scale. In loop 3 all second level test sections were affected by heavy subbase pumping. As a result, no revision is shown.

Figure 13b shows the relationships of performance to design depth in loop 4. The right half of the second level bar graph ($6\frac{1}{2}$ in.) shows the performance of all second level test sections in loop 4. The left half shows performance of second level sections not influenced by heavy subbase pumping (accumulated percentage: 30 or less). These sections have a mean serviceability index of 4.1 and show that both the PCA and four agency designs have a wide margin of safety.

Figure 13c shows revised relationships of performance to design depth in loop 5. Here the eight test sections that were not affected by heavy subbase pumping (accumulated percentage of not more than 60) have a mean serviceability index of 4.2—only slightly below values for the third and fourth levels. This performance again shows that both PCA and the four agency designs are conservative and reliable.

Figure 13d shows performance design relationships for loop 6. In this loop the twelve sections not affected by heavy subbase pumping (accumulated percentage of less than 90) had a mean serviceability index of 4.2, almost equal to the third and fourth thickness values. Again this performance shows that both the PCA and four agency designs are adequate and reliable.

The final conclusion is that the PCA design procedure is somewhat more dependable than was indicated by the previous study (1).

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