Continuously-Reinforced Concrete Pavement in Pennsylvania

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●Pennsylvania's second continuously-reinforced concrete pavement was constructed on a section of Legislative Route 285 Section 6A (Traffic Route US 22), Berks County, during the period from May 8 to July 2, 1957, and from October 16 to 21. The experimental section, running from station 168+99 to station 277+05, is a 10,806-ft length of pavement, which was a portion of a 4.98-mi contract between Hamburg and Lenhartsville. The project was constructed under the supervision of the Pennsylvania Department of Highways in cooperation with the U. S. Bureau of Public Roads. Instrumentation was placed by Lehigh University and will be recorded and reported by that institution.

The objectives of this project can be stated as follows:

1. Study the effect of pavement thickness on service performance.
2. Study the effect of subbase thickness on service performance.
3. Determine the maximum stresses in the reinforcing steel at a crack, considering varying thicknesses of pavement.
4. Determine the effect of traffic upon stresses in the reinforcing steel.
5. Determine the thermal effects on the steel and concrete stresses in the pavements.
6. Determine the warping effects on the pavements.
7. Determine the magnitude of longitudinal movements of the pavements.
8. Determine the ultimate slab length.

SCOPE

The Hamburg project differs in several respects from the York project, which was constructed in 1956. The York pavement was placed in the fall of the year, whereas the Hamburg project was constructed in late spring and early summer. An exception to this is a short length of pavement placed in October.

The York road was designed for a uniform 9-in. pavement with a 6-in. depth of special subgrade material (subbase material) throughout, and 0.48 percent of longitudinal reinforcement steel (bar mats) by area, based on the total cross-sectional area of the pavement (1). At Hamburg, the steel was a uniform 0.50 percent throughout. Pavement thickness was varied to include 7-, 8-, and 9-in. thicknesses and special subgrade was placed in two depths: a minimum of 3 in. and a minimum of 6 in. These depths varied somewhat from the design, but in general, where the special subgrade was designed for 3 in. in the two eastbound lanes under each thickness of pavement, the corresponding thickness in the two westbound lanes was 6 in., and similarly, when the depth of special subgrade was 6 in. in the eastbound lanes, the depth in the westbound was 3 in.

The project is a four-lane, medial-separated roadway, with a maximum grade of 3 percent and two horizontal curves—one a $0^{\circ} 30'$ curve of 1,100 ft, the other a $1^{\circ} 00'$ curve of 3,224 ft. The limiting stations of each section are as follows:

Pavement Thickness (in.)	Stations	Length (ft)
7	168+99 to 188+97.5	1,998.5
8	188+97.5 to 232+64	4,366.5
9	232+64 to 277+05	4,441.0

Figure 1 shows the limiting stations of each section and the depth of special subgrade under each pavement thickness, as originally designed.

As mentioned previously, the bulk of the paving was placed in the spring and early summer. In June 1957, however, a serious slide condition developed near station 246, right, necessitating removal of large quantities of cut material (Fig. 2). As a result, a portion of the eastbound lanes from station 237+05 to 255+00 was not paved until October 1957. The pavement was opened to traffic on August 30, 1957, but eastbound traffic was detoured onto one of the westbound lanes, where one-way traffic was maintained from station 233 to 272. The entire roadway was opened to traffic on November 8, 1957.

PROCEDURE

Accurate records were kept throughout the project on every phase of the operation. The thousands of tests conducted make it impractical to list every value obtained, thus the data for the individual tests have been summarized and averaged for ease of analysis.

Table 1 shows the results of the gradings obtained at the batch plant throughout the duration of the project and indicates that all fine and coarse aggregates were ideally graded near the middle of the specification limits.

Tables 2, 3, and 4 list the physical tests conducted on the concrete in the field and other information pertinent to the placing of the concrete. The data have been separated

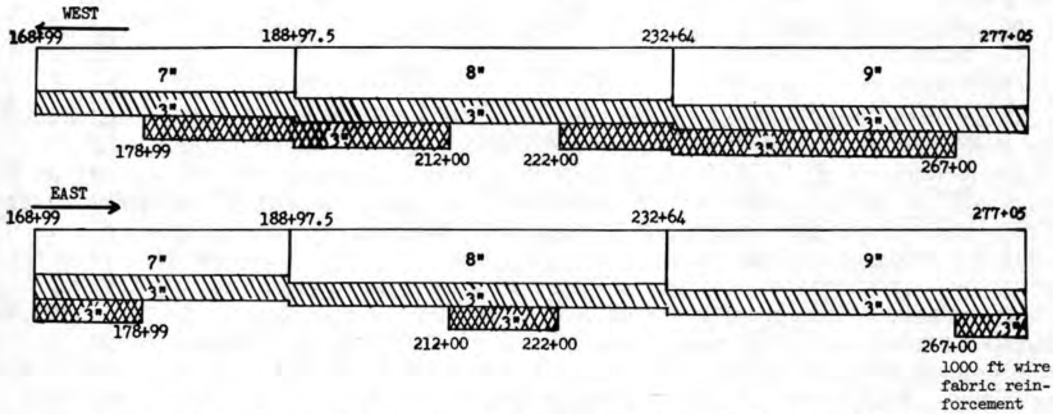

Figure 1. Pavement thickness and special subgrade (subbase) design.

Figure 2. Slide area near Station 246, eastbound lanes.

according to the three thicknesses of concrete and are combined into over all project averages in Table 5.

Concrete for the project was designed for a 2¼-in. slump and 3.5 percent air using 4.99 gal. of water per bag and 6.25 bags of cement per cubic yard. A small portion of high-early strength concrete was used in the right outside lane of the eastbound roadway between stations 237+05 and 255+00, so that the adjacent lane could be placed as soon as possible. In this section, the design called for a 1½-in. slump, 4.0 percent of air, 4.23 gal. of water per bag, and 8.02 bags of cement per cubic yard. Reinforcing steel throughout the project was placed at mid-depth in the pavement thickness. Tables 2, 3, and 4 indicate that the concrete complied closely with the design in every respect.

TABLE 1

AGGREGATE GRADATIONS

(a) Fine Aggregate, 61 Tests

Screen	No. 100	No. 50	No. 30	No. 16	No. 8	No. 4	3/8 in.
High	4.6	20.2	59.6	78.3	87.7	99.0	100
Low	2.0	11.6	45.8	62.1	81.1	96.1	100
Average	3.2	16.8	52.8	71.9	84.5	97.7	100
Spec. Limits	1-8	10-30	30-65	50-80	70-92	90-100	100

(b) 2B Coarse Aggregate, 86 Tests

Screen	No. 8	No. 4	1/2 in.	1 in.	1½ in.
High	3.4	8.3	59.5	99.2	100
Low	0.4	0.8	27.8	93.8	100
Average	1.2	3.5	44.1	95.9	100
Spec. Limits	0-5	0-10	25-60	90-100	100

(c) 3A Coarse Aggregate, 71 Tests

Screen	½ in.	1 in.	1½ in.	2 in.	2½ in.
High	3.4	8.6	66.3	98.2	100
Low	0.5	1.6	39.6	91.9	100
Average	1.5	4.9	49.0	95.7	100
Spec. Limits	0-5	0-15	35-70	90-100	100

CONCRETE PLACING

Concrete was placed in 23 individual runs, in accordance with the specifications of the Pennsylvania Highway Department. Figure 3 shows the location and limiting stations of the individual runs, and the daily air temperatures. The shortest run was 718 ft, the longest 3,953 ft, and the average 1,964 ft per day. (One run of 76 ft to complete a section was not included in the average.) Generally the concrete was consistent in uniformity and was placed on damp subgrade and struck off at half-depth. Vibrators were used along the longitudinal joints; the outside edges were spaded. After placing the steel, the remainder of the concrete was placed and spread to the proper depth. The spreader was followed by the finisher, bull-float, and hand finishers. At this point the pavement was marked off with a chain and station numbers were imprinted in the concrete. When sufficiently set, Kraft-type curing paper was placed on the concrete, which remained covered for a minimum of 72 hr of curing time. No expansion joints were constructed in the continuously-reinforced sections. However, at the end of a day's run, a split wooden bulkhead was used, with the steel protruding a minimum of 5 ft. At the beginning of the next day's run, the bulkhead was removed and concrete was placed immediately against the pavement placed the previous day.

TABLE 2

PHYSICAL TESTS ON CONCRETE, 7-IN. PAVEMENT; STA. 168+99—188+97.5

Lane	Weather	Air Temp. (°F)	Tests	Depth Sp. Subgrade (in.)	Depth Reinf. (in.)	Slump (in.)	Air Entr. (%)	Mod. of Rupture (lb)	Water per Bag (gal)
EB, out	Fair	73	No.	40	9	4	4	1[1]	7
			High	11¾	3⅝	3	4.6	597	5.33
			Low	5	3	1¾	3.7	597	4.65
			Avg.	-	3.3	2¼	4.1	597	4.84
EB, in	Fair	67	No.	39	6	2	2	1[2]	2
			High	3½	3½	2¼	4.2	627	5.04
			Low	7	3¼	2	3.5	627	4.98
			Avg.	-	3.5	2	3.9	627	5.01
WB, out	Partly Cloudy	73	No.	40	6	6	5	2[3]	8
			High	9¼	4	3	5.2	851	5.33
			Low	7	3¼	2	3.7	822	4.74
			Avg.	-	3.5	2½	4.2	837	5.10
WB, in	Partly Cloudy	79	No.	40	7	4	4	0	10
			High	9	3¾	2¾	4.3		5.40
			Low	3	3¼	2¼	2.8		5.07
			Avg.	-	3.4	2½	3.6		5.22

[1] At 9 days.
[2] At 12 days.
[3] At 10 days.

TABLE 3

PHYSICAL TESTS ON CONCRETE, 8-IN. PAVEMENT; STA. 188+97.5—232+64

Lane	Weather	Air Temp. (°F)	Tests	Depth Sp. Subgrade (in.)	Depth Reinf. (in.)	Slump (in.)	Air Entr. (%)	Mod. of Rupture (lb)	Water per Bag (gal)
EB, out	Fair and Windy	85	No.	85	21	7	7	1[1]	13
			High	10½	4	2½	4.5	647	4.89
			Low	4	3¾	1¾	3.2	647	4.65
			Avg.		3.9	2¼	3.9	647	4.81
EB, in	Fair	73	No.	88	18	8	8	1[2]	7
			High	10	4¼	2½	4.5	605	5.16
			Low	3	3½	1⅞	3.1	605	4.98
			Avg.		4.0	2	3.7	605	5.03
WB, out	Fair	74	No.	85	14	7	8	2	14
			High	10½	4¼	2½	4.1	851[2]	5.49
			Low	3½	3½	2	3.0	787[1]	4.82
			Avg.		4.0	2½	3.5	819[2]	5.16
WB, in	Cloudy	83	No.	86	18	8	8	3	16
			High	10	4¼	2½	4.5	692[1]	5.41
			Low	4¼	3¼	2⅛	2.9	532[2]	4.90
			Avg.		4.0	2¼	3.8	604[1]	5.09

[1] At 11 days.
[2] At 10 days.

TABLE 4

PHYSICAL TESTS ON CONCRETE, 9-IN. PAVEMENT; STA. 232+64-277+05

Lane	Weather	Air Temp. (°F)	Tests	Depth Sp. Subgrade (in.)	Depth Reinf. (in.)	Slump (in.)	Air Entr. (%)	Mod. of Rupture[1] (lb)	Water per Bag (gal)
EB, out	Cloudy	77	No.	54	11	6	6	2	5
			High	9½	4½	2¼	4.5	840	4.99
			Low	3½	4	1¾	3.1	647	4.73
			Avg.		4.3	2	3.9	744	4.82
EB, in	Cloudy and Windy	71	No.	54	9	5	5	1	5
			High	12	4½	2⅛	4.5	607	5.17
			Low	3	4¼	1¾	3.6	564	4.91
			Avg.		4.5	2	3.9	586	5.01
WB, out	Fair	84	No.	91	14	10	10	3	16
			High	10¾	4½	2¾	4.2	731	5.33
			Low	3¼	4	2⅛	2.8	598	4.98
			Avg.		4.4	2½	3.4	659	5.12
WB, in	Cloudy and Windy	77	No.	89	17	10	10	1	16
			High	9½	4¾	2½	4.0	492	5.34
			Low	3	3½	1¾	3.0	492	4.74
			Avg.		4.4	2	3.6	492	5.08

[1] At 10 days.

At the beginning and end of the experimental section (at stations 168+99 and 277+05) 24-ft, finger-type bridge expansion joints were installed between the continuously-reinforced pavement and the standard 10-in. pavement. Three inches were allowed for expansion at each of these joints. To remove water and debris which would run down through the joints, concrete boxes, outletting through the shoulder into drainage ditches, were constructed under these joints. The two adjacent lanes were tied together longitudinally by a formed keyway with hook-bolt dowels spaced 5 ft apart.

Additional reinforcement was inserted in the concrete at the end of each day's run to tie into the succeeding run. In the eastbound lanes, and the outside westbound lane, seven ungreased, 1 by 18-in. steel dowels were placed between the horizontal reinforcing bars protruding through the bulkhead. Dowels at station 237+05, eastbound outside, were coated with graphite. At station 178+52, westbound inside, seven graphite-greased dowels were placed. At station 204+50, westbound inside, five graphited dowels were used. As a comparison, no dowels were used in the bulk-

TABLE 5

PHYSICAL TESTS ON CONCRETE; PROJECT AVERAGES

Tests	Depth Sp. Subgrade (in.)	Depth Reinf. (in.)	Slump (in.)	Air Entr. (%)	Mod. of Rupture (lb)	Water Per Bag (gal)
No.	791	150	77	77	18	119
High	12	4¾	3	5.2	851	5.49
Low	3	3	1¾	2.8	492	4.65
Avg.	7	4.0	2¼	3.7	676	5.05

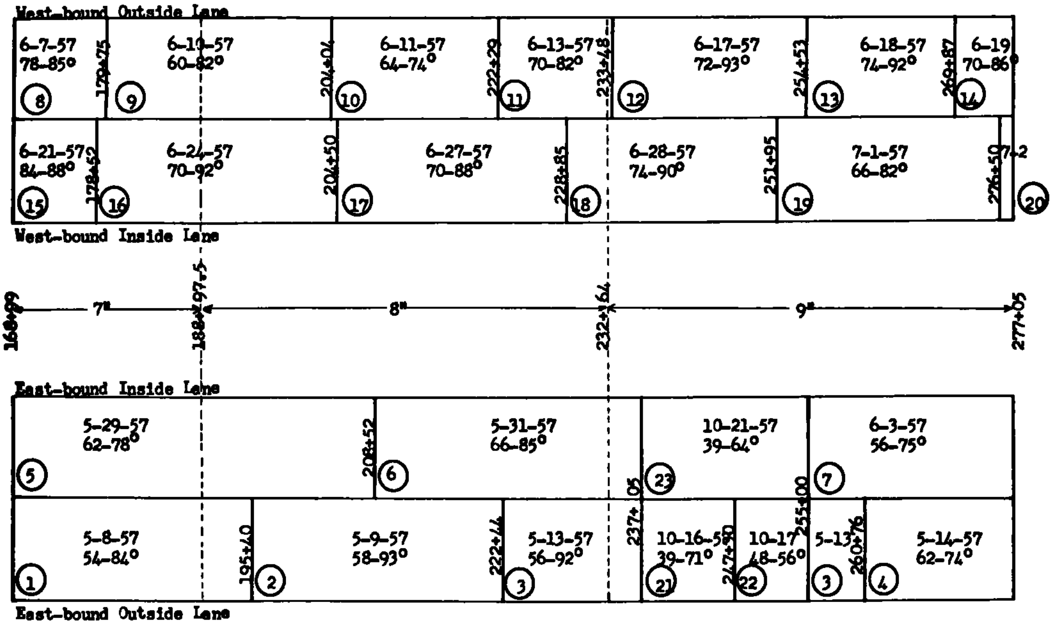

Figure 3. Limiting stations and air temperatures of individual pours.

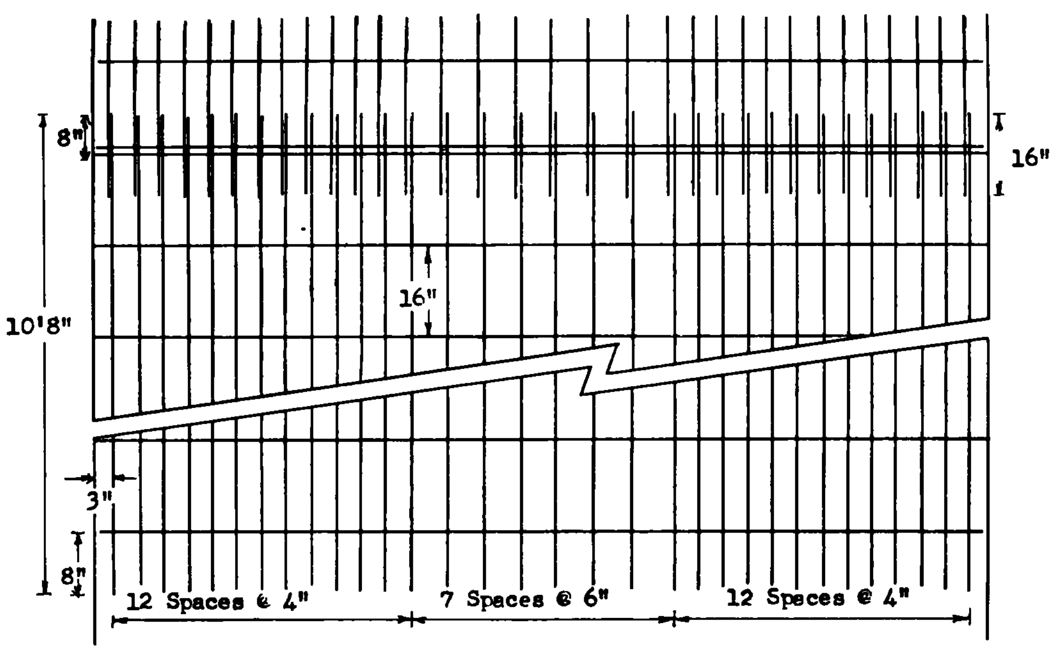

Figure 4. Wire mesh reinforcement, Type K-9.

heads at stations 228+85, 251+92, and 276+50, westbound inside.

Steel reinforcing for this project was Type L-7, L-8, and L-9 bar mats, for the 7-, 8-, and 9-in. pavements, respectively. Two 16-ft by 6-ft 2-in. bar mats were used per 12-ft width pavement lane, overlapped 12 in. longitudinally and 8 in. transversely. The bar mats were fabricated with No. 5 longitudinal bars and No. 3 transverse bars, and conformed to the Department's specifications for hard-grade steel. Reinforcement started and stopped 3 in. from the limits of continuous construction.

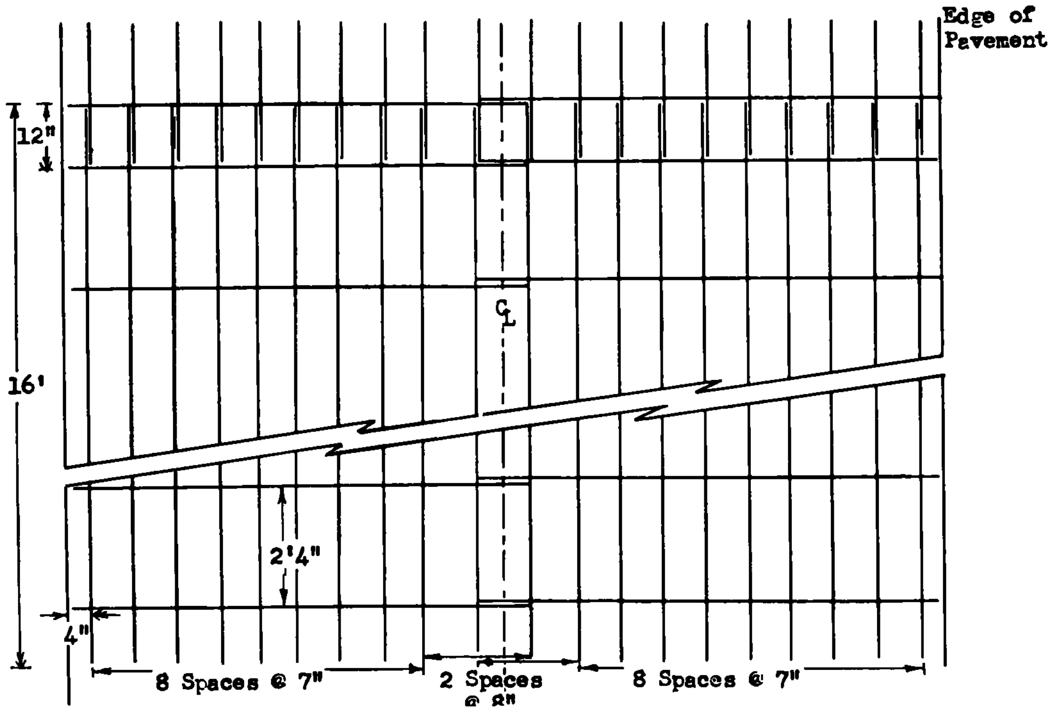

Figure 5. Bar mat reinforcement, Type L-9.

A wire mesh type of reinforcement was used for 1,000 ft in the two eastbound lanes between stations 267+07 and 277+05, right. These were 10 ft 8 in. by 11 ft 8 in. and were overlapped 16 in. longitudinally. They were fabricated transversely with No. 0 wires and longitudinally with ½-in. wires. Steel throughout the project was designed at 0.5 percent of the total cross-sectional area of the pavement. A sketch of the wire mesh reinforcement is shown in Figure 4 and of the bar mats in Figure 5, 6, and 7. Data from physical tests on the steel are given in Table 6.

CRACK FREQUENCY SURVEY

An extensive and comprehensive crack frequency and width survey has been established on this project to determine the pattern of crack development. This report covers the observations of the first three months. It is realized that this represents the early stages of cracking and that the resulting crack pattern in later years may be completely different.

The number of cracks was first counted at seven days. Surveys were made thereafter at 14 and 21 days, and at one, two and three months. It is anticipated that an annual survey will be conducted hereafter, to include the entire length of the experimental concrete slab.

Crack width measurements are not as extensive in scope. In general, three limited areas from each pavement thickness, in each lane, have been selected for measurement. These are located in the first 500 ft of each section, the last 500 ft, and 400 ft near the middle. In selecting these locations, consideration was given to the thickness of special subgrade material where an attempt was made to select contrasting depths.

Crack widths within these 400- and 500-ft sections are being measured by microscope to the nearest 0.002 in. Within these larger sections, selected 100-ft lengths have been chosen and brass plugs have been installed in the pavement at every crack within the 100 ft. The plugs are 10 in. apart and 1 ft from the edge of the pavement. Measurements will be made with an invar-type gage, and a correlation will be made between this measurement and that obtained with a microscope. When the section of pavement was

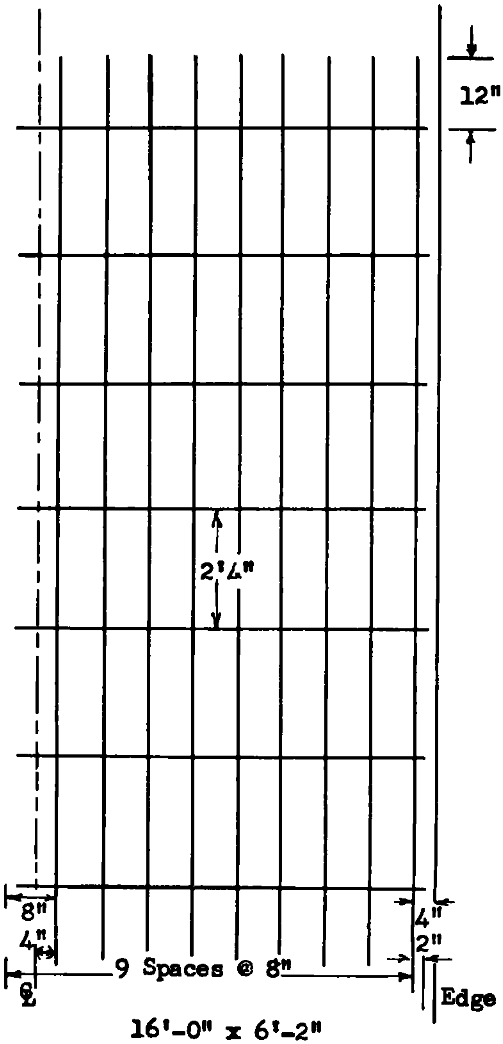

Figure 6. Bar mat reinforcement, Type L-8.

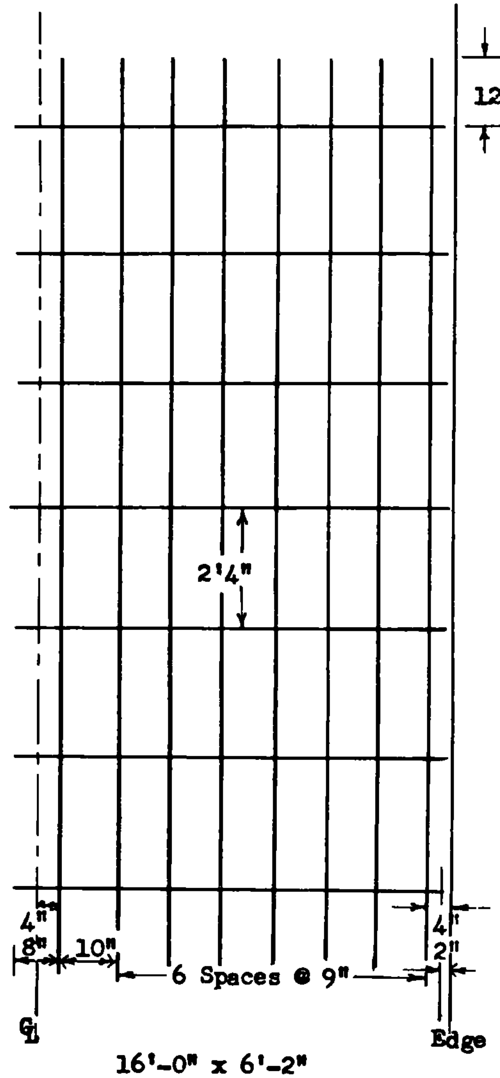

Figure 7. Bar mat reinforcement, Type L-7.

placed in October, a 100-ft section was selected in each of the eastbound lanes and brass plugs were installed in the fresh concrete every 10 in. In this way, measurements were obtained before and after cracking, thus permitting an accurate comparison

TABLE 6

PHYSICAL CHARACTERISTICS OF REINFORCING STEEL

Reinf. Type	Members	Spacing (in.)	Diam. (in.)	Elong. (%)	Area (sq. in.)	Yield Stress (psi)	Tens. Str. (psi)
K-9 Wire mesh	Main	4	1/2	-	0.20	89,000	95,000
	Sec.	16	5/16	-	0.0767	-	71,707
L-7 Bar mat	Main	9	5/8	-	0.31	67,000	122,581
	Sec.	28	3/8	-	0.11	-	116,364
L-8 Bar mat	Main	8	5/8	10.9	0.31	67,000	110,645
	Sec.	28	3/8	14.1	0.11	-	101,818
L-9 Bar mat	Main	7	5/8	12.5	0.31	67,000	116,452
	Sec.	28	3/8	12.5	0.11	-	129,091

of the two methods of crack width measurement.

Measurements to date have included 2- and 3-month readings with microscope and 3-month readings with gage. Another survey will be made in 6 months and semiannually thereafter.

The width survey data are presented in several different aspects. Table 7 lists the cracks according to the individual day's runs. Table 8 gives the same information with respect to pavement thickness. Table 9 gives the locations of the selected width measurement sections with the depth of special subgrade under each, and the number and width of cracks in each section.

At present not enough readings have been taken with the gage to establish definite width readings in the selected 100-ft sections. However, the locations of these sections, and other related data, are presented in Table 10.

TABLE 7

CRACK FREQUENCY SURVEY, BY INDIVIDUAL POURS[1]

Section	Length of Pour (ft)	Temp. Range (°F)	Number of Cracks 7 Days	14 Days	21 Days	1 Mo.	2 Mo.	3 Mo.
1	2,641	54-84	127	230	230	236	239	239
2	2,704	58-93	173	238	241	251	255	256
3	2,037	56-92	103	106	107	111	119	119
4	1,629	62-74	44	47	47	58	69	69
5	3,953	62-78	171	246	259	262	265	270
6	2,853	66-85	101	101	186	203	213	218
7	2,205	56-75	76	90	91	91	91	95
8	1,076	78-85	15	46	56	63	70	95
9	2,429	60-82	73	181	189	197	219	219
10	1,825	64-74	112	137	139	147[2]	151[2]	171
11	1,119	70-82	71	79	79[2]	95[2]	96[2]	118
12	2,105	72-93	213	219	230	235	238	248
13	1,534	74-92	151	152	170	179	179	185
14	718	70-86	51	52	63	65	69	71
15	953	84-88	18	44	57	69	72	82
16	2,598	70-92	109	161	183	194	200	219
17	2,435	70-88	178	[2]	[2]	[2]	203	229
18	2,307	74-90	146	206	212	221	239	241
19	2,458	66-82	102	152	152	160	202	234
20	76	-	0	0	0	0	0	0
21	1,025	39-71	32	44	55	57	-	-
22	770	48-56	10	24	31	32	-	-
23	1,795	39-64	74	91	100	102	-	-

[1] See Fig. 2 for stations of each pour.
[2] Partially covered with earth.

A total of 3,569 cracks has been recorded in 43,224 lineal feet of pavement, based on a 3-month survey. Computed on an over-all length this amounts to one crack every 12.1 ft. The true picture is quite different from this, however, as will be discussed later.

Sixty percent of the cracks recorded thus far have occurred within the first seven days; 79 percent occurred within 14 days; 85 percent within 21 days; and 90 percent of the total number of present cracks had occurred at one month.

According to Table 8, there are more cracks per 100 ft in the thinner sections of concrete. It is expected that this pattern will hold true during the life of the pavement. In the 7-in. sections there are 9.0 cracks per 100 ft; in the 8-in., 8.5; and in the 9-in., 8.2 cracks per 100 ft. There is a small increase in the number of cracks in the outside lanes as compared to those in the inside lanes.

It is perhaps too early to try to correlate the number of cracks and crack widths with the corresponding depth of special subgrade as shown in Table 9; but at present, an unusual condition seems to prevail. In most instances, there are fewer cracks and the widths are smaller in the locations where the special subgrade material is thinnest.

The data in Figure 8 show some interesting patterns. This graph indicates the number of cracks per 100 ft, continuously, for all four lanes from the beginning of the experimental section to the end. It is interesting to note the variance in the number of cracks per 100 ft at the beginning and the end of each day's run. This condition is most noticeable for the 7-day count and is a little less obvious at the 1-month count. Considering the 500 ft at each end of all pours, the number of cracks per 100 ft for the 7-day count at the beginning is 6.3; at the end, 3.1.

The same data for the 1-month count reveal that at the beginning of all sections there is an average of 8.8 cracks per 100 ft and at the end the average is 6.2 cracks per 100 ft. Thus there is a growing

TABLE 8

CRACK FREQUENCY SURVEY, BY PAVEMENT THICKNESS

Pavement Depth (in.)	Lane	Length (ft)	Number of Cracks 7 Days	14 Days	21 Days	1 Mo.	2 Mo.	3 Mo.
7	EB, out	1998.5	111	183	183	188	191	191
	EB, in	1998.5	127	150	159	159	161	163
	WB, out	1998.5	56	114	128	140	160	185
	WB, in	1998.5	89	126	143	161	167	183
8	EB, out	4366.5	256	355	359	371	378	379
	EB, in	4366.5	145	197	270	288	296	304
	WB, out	4366.5	213	329	335	359[1]	373[1]	413
	WB, in	4366.5	227	299[1]	319[1]	330[1]	349	390
9	EB, out	4441.0	122	151	169	186	202	202
	EB, in	4441.0	150	181	207	211	214	218
	WB, out	4441.0	418	426	465	484	491	509
	WB, in	4441.0	235	321	327	339	399	432

[1] Partially covered with earth.

tendency for the cracks to level off at a more uniform rate. It might be mentioned that the over-all crack average at one month was 7.2 cracks per 100 ft. It is thought that the crack pattern, as described, can be attributed to the fact that as the previous day's concrete is curing it pulls the freshly placed concrete, resulting in many cracks in the first several hundred feet. As more fresh concrete is placed, the bulk is such that the effect is diminished and fewer cracks appear. This pattern substantiates a similar condition noted by Van Breemen (2) who says, "This method of construction naturally involves the attachment together of sections of pavement having, at the time of attachment, materially different tensile strengths."

One exception to this pattern is a stretch running from station 235 to station 276 in the left outside lane, involving a period of three days when the air temperature ranged from 72F to 93F daily. Here, the crack pattern is quite uniformly high throughout, averaging 9.7 cracks per 100 ft at 7 days and 11.3 cracks per 100 ft at one month. It is believed that the high temperatures were the cause of this higher-than-usual crack pattern.

The average crack width as established by the section under survey is approximately 0.009 in. There are, however, some serious cracks which have developed. These are principally at stations 228+85, westbound inside (Figure 9); 254+46, westbound outside (Figures 10 and 11); 233+51, westbound outside; and 267+96 westbound outside lane in 8-in. and 9-in. concrete with special subgrade of 6- to 9-in. depths. It is perhaps significant that two of these cracks occurred in the same day's run, 3 ft from the beginning and 7 ft from the end. This particular section was placed on one of the hot days (72F - 93F). Another crack also occurred 6 ft from the beginning of a day's run. All of these cracks are severely spalled and in some spots loss of small pieces of concrete has occurred.

TABLE 9

THREE-MONTH MICROSCOPE CRACK WIDTH SURVEY

Station	Lane	Pavement Depth (in.)	Avg. Depth Sp. Subgrade (in.)	No. Cracks	Crack Width (in.) High	Low	Avg.
169+00-174+00	EB, out	7	8½	48	0.016	0.002	0.007
	EB, in		7½	47	0.032	0.004	0.009
	WB, out		7½	42	0.012	0.004	0.007
	WB, in		4½	48	0.012	0.002	0.007
177+00-181+00	EB, out	7	7 -11	41	0.032	0.002	0.010
	EB, in		8	34	0.020	0.002	0.012
	WB, out		8	41	0.016	0.004	0.007
	WB, in		6	30	0.016	0.002	0.008
183+97-188+97	EB, out	7	6½	42	0.020	0.002	0.007
	EB, in		7½	32	0.024	0.004	0.009
	WB, out		8	53	0.012	0.002	0.007
	WB, in		7½	51	0.016	0.002	0.007
188+97-193+97	EB, out	8	6½	36	0.020	0.004	0.009
	EB, in		6½	27	0.020	0.002	0.008
199+50-204+50	WB, out	8	9	46	0.014	0.002	0.008
	WB, in		7½	36	0.012	0.002	0.008
213+00-217+00	EB, out	8	8½	32	0.020	0.004	0.009
	EB, in		8	40	0.028	0.004	0.011
217+00-221+00	WB, out	8	4	36	0.014	0.004	0.008
	WB, in		5	35	0.012	0.004	0.008
227+64-232+64	EB, out	8	4	36	0.012	0.004	0.008
	EB, in		3	36	0.012	0.002	0.008
	WB, out		7½	54	0.016	0.004	0.008
	WB, in		7	47	0.197	0.004	0.013
232+64-237+64	WB, out	9	8	53	0.039	0.006	0.011
	WB, in		7	55	0.020	0.002	0.009
240+00-241+00	EB, out		5½	5			
	EB, in		5½	5			
262+00-266+00	EB, out	9	4½	27	0.012	0.002	0.006
	EB, in		3½	22	0.012	0.004	0.009
	WB, out		8	51	0.014	0.002	0.009
	WB, in		7½	36	0.016	0.004	0.012
272+05-277+05	EB, out	9	8	11	0.016	0.004	0.010
	EB, in		7 -11	16	0.012	0.004	0.009
	WB, out		4	49	0.012	0.002	0.008
	WB, in		4½	44	0.012	0.001	0.008

These cracks appeared approximately two months after completion of the paving. As the cooler weather of late summer and fall approached, the cracks began to widen, and became quite serious. When the last crack width readings were recorded (at the 3-month survey, the weather was still quite warm and the crack widths averaged 0.12 to 0.20 in. With the advent of cold weather, these cracks assumed widths of 0.25 to 0.35 in. When the cracks reached this condition, a decision was made to remove 10-in. cores from the cracked areas to determine the cause of the cracking. These cores revealed that the wide cracks occurred either because the bar mats failed to meet or because of insufficient overlap of the bar mats.

Figure 12 shows a core taken on the crack 5 ft from the beginning of a day's run. The bar protruding from the right half of the core terminates in the core half on the left. The bar mats probably failed to meet by an estimated ½ in. Figure 13 is another view of the same crack.

Figures 14 and 15 show the crack at station 254+46, which was 10 ft from the end of a day's run. No reinforcing steel was found in one-half of this core, indicating that the steel failed to meet by at least 5 in., and perhaps considerably more. The left half of the core shows one bar of steel, the right half a lack of steel; the steel bar is visible in the pavement.

TABLE 10

THREE MONTH CRACK WIDTH MEASUREMENTS
INVAR GAUGE WITH BRASS PLUGS
(100 FOOT SECTIONS)

Stations	Lane	Pavement Depth (in.)	Depth Sp. Subgrade (in.)	No. Cracks
173-174	EB, out	7	9	12
178-179	EB, out	7	10	11
187-188	EB, out	7	7	9
190-191	EB, out	8	6	8
216-217	EB, out	8	8	8
231-232	EB, out	8	4	10
240-241	EB, out	9	5½	5
262-263	EB, out	9	4½	8
274-275	EB, out	9	8½	4
173-174	EB, in	7	8	13
178-179	EB, in	7	8	9
187-188	EB, in	7	7½	6
190-191	EB, in	8	6½	6
216-217	EB, in	8	7½	11
228-229	EB, in	8	3	9
240-241	EB, in	9	5½	5
262-263	EB, in	9	3½	8
275-276	EB, in	9	11	4
172-173	WB, out	7	8	9
180-181	WB, out	7	8	14
185-186	WB, out	7	7	11
201-202	WB, out	8	9	10
217-218	WB, out	8	4	9
229-230	WB, out	8	7½	8
234-235	WB, out	9	7½	12
263-264	WB, out	9	8	12
275-276	WB, out	9	4	9
170-171	WB, in	7	5½	12
180-181	WB, in	7	8	10
185-186	WB, in	7	7½	10
201-202	WB, in	8	7½	7
220-221	WB, in	8	5	10
228-229	WB, in	8	7	3
234-235	WB, in	9	6½	11
263-264	WB, in	9	7½	9
274-275	WB, in	9	4	7

The crack at station 267+96 is shown in Figures 16 and 17. Two bars of reinforcing steel are visible in the core and in the pavement. The crack is 200 ft from the end of a day's run. The core indicated that the crack occurred at an overlap, but it was not possible to determine the length of the overlap, except that one half of the core had one steel bar and the other half had two bars, indicating that the overlap could have ranged from a minimum of 5 in. to the prescribed 12 in.

Another erratic cracking pattern has occurred at stations 223 to 226 in the westbound outside lane and in the outside 5 ft of the lane. The cracks describe an arc pattern by starting and ending at the pavement edge and extending into the lane as much as 5 ft. The average length of the cracks is approximately 12 ft. It is assumed this was caused by loading the pavement with earth and by the use of heavy earth-moving equipment in this area when additional material was removed from a cut after the pavement was placed.

ROUGHNESS SURVEY

The Department's profilometer was used shortly before the road was opened to traffic to determine the roughness or smoothness of the concrete surface. The instrument operates on the mechanical principle of measuring the vertical movements of a wheel suspension with respect to its supported frame. The results of this profilometer survey are as follows:

Date	Stations	Lane	Length (ft)	Meas. Total (in.)	Index (in./mi)
3-27-57	169+50-232+50	EB, out	6,300	30	25.21
3-27-57	169+00-277+00	WB, out	10,800	57	27.80

The profilometer survey will be conducted annually or semi-annually; in addition, a traffic count will be conducted and this information made available in future reports.

COSTS

Pavement unit bids for the various thicknesses of concrete were as follows:

Type of Pavement	Unit Price	Saving (%)
7-in. continuously reinforced	$4.45	+ 15.2
8-in. continuously reinforced	$4.75	+ 9.5
9-in. continuously reinforced	$5.35	- 1.9
10-in. standard reinforced	$5.25	-

INSTRUMENTATION

Four similarly constructed, instrumented test sections were installed in the project. One was located at station 273+00, eastbound outside lane (in the wire mesh section), and three were placed at stations 184+00, 199+50, and 258+00, all in the westbound outside lane. The purpose of these instrumented sections was to induce a crack in the pavement and to have gages properly located so that the strains in the steel and the strains in the pavement itself could be measured. In addition the width of the induced crack could be measured, and temperatures obtained in the concrete and subbase of the test sections. The crack was formed by installing a 4-in. piece of corrugated metal transversely in the center of the instrumented bar mat. The mat itself was placed on chairs so that it was at mid-depth in the concrete pavement. The standard bar mats were carefully placed and overlapped after the first layer of concrete was

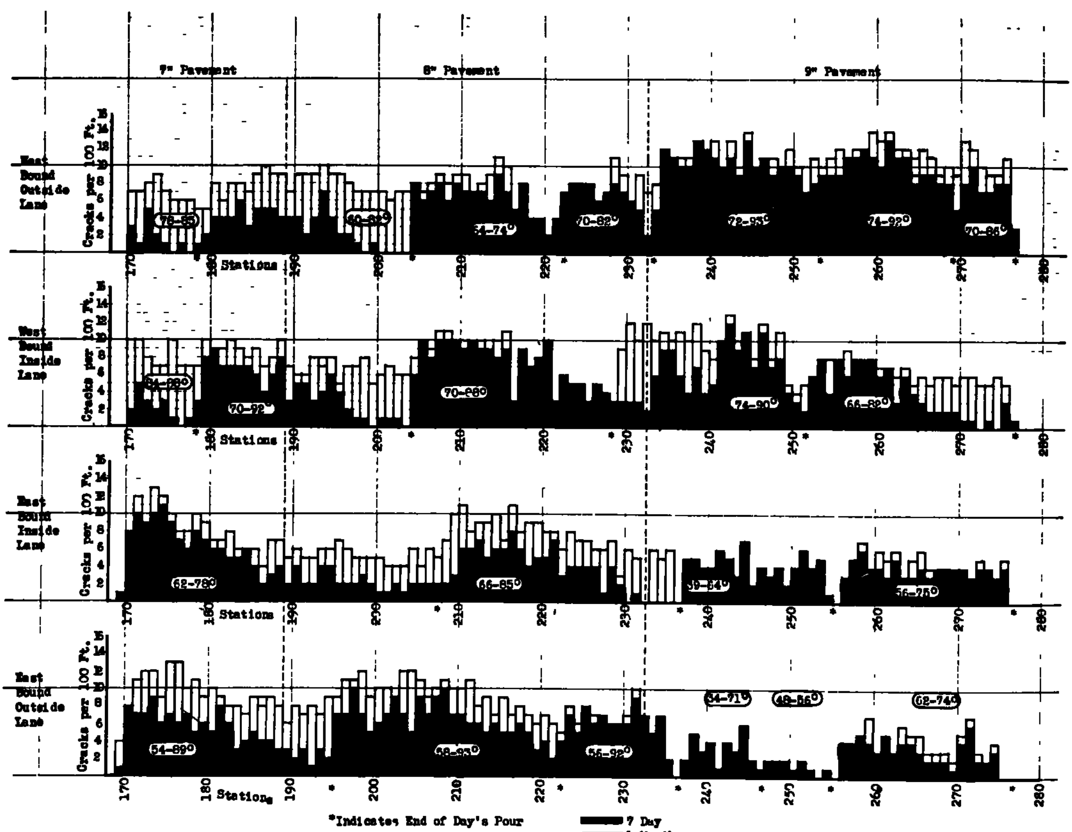

Figure 8. Crack frequency survey.

Figure 9. Crack at station 228+85.

Figure 10. Crack at station 254+46.

Figure 11. Crack at station 254+46.

Figure 12. Separate halves of core at station 228+85.

Figure 13. Location of core removed from pavement at station 228+85.

Figure 14. Core from pavement crack at station 254+46.

Figure 15. Close-up of core shown in Figure 14.

Figure 16. Pavement crack and core at station 267+96.

placed on both sides of the instrumented bar mat. The paver moved back to place the second layer of concrete and then carefully moved through the instrumented section, placing the concrete in small portions over the entire test section to obtain uniformity. The wires connected to the gages were led out through the special subgrade in a conduit terminating in an instrument panel located some distance off the shoulder. It is at this box that all measurements are obtained through instrument readings.

Six bars of the fabricated bar mat were instrumented with Bakelite SR-4 strain gages mounted on the reinforcing steel. These were of the AB-3 type with nominal $^{13}/_{16}$-in. length. Five temperature gages were installed in the pavement and in the special subgrade. These were placed 1 in. into the special subgrade material, 1 in. from the bottom of the slab, and 1 in. from the top of the slab. A typical location of these strain and temperature gages is shown in Figure 18.

Figure 19 shows the location of the Whittemore gage plugs used to measure the crack width. These are located 10 in. apart, spanning the preformed crack, and were set in the fresh concrete, one set near the shoulder and the other set near the longitudinal joint.

Plugs have been installed 100 ft apart on the westbound outside lane to measure the over-all movement of the pavement. Also, monuments have been erected at the quarter points of the test section to measure absolute movement at these points on all four lanes.

Data obtained from the described instrumentation are to be assembled and reported by Lehigh University (see paper by I. J. Taylor and W. J. Eney, this Bulletin).

Figure 17. Close-up of core shown in Figure 16.

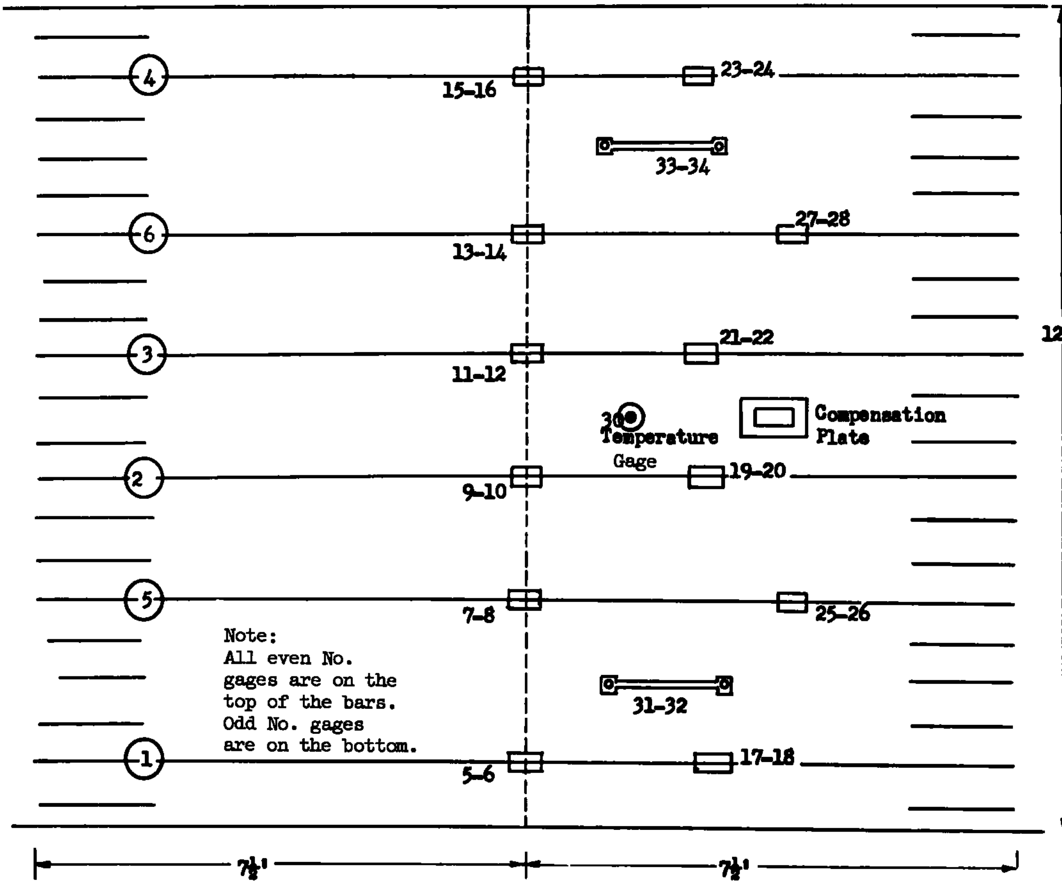

Figure 18. Typical location of strain and temperature gages.

SOIL DATA

At present, supplemental specifications covering embankment, subgrade, and stabilized shoulders are being applied on all major construction. These specifications, among other requirements, provide for moisture control and density measurements in the field.

These supplemental specifications for embankment and subgrade were not incorporated in the proposal for this project; however, the contractor agreed to comply with all of their provisions. The cooperation of the contractor, together with the effort of the Department's soil engineering personnel, made it possible to obtain significant data. The following information is available for completing an evaluation of the experiment:

1. A soil profile showing (a) the type of rock, granular material, or soil as it

TABLE 11

PHYSICAL CHARACTERISTICS[1] OF SOILS

AASHO Group	Liquid Limit	Plasticity Index	Aggregate (%)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Optimum Moisture (%)	Maximum Density (pcf)
A-1	28	6	54	17	6	13	10		
A-2	31	9	51	15	10	10	14	15.4	116.0
A-4	29	7	29	16	14	17	24	16.2	112.1
A-6	35	12	13	11	16	30	30	17.0	113.0

[1] Averages.

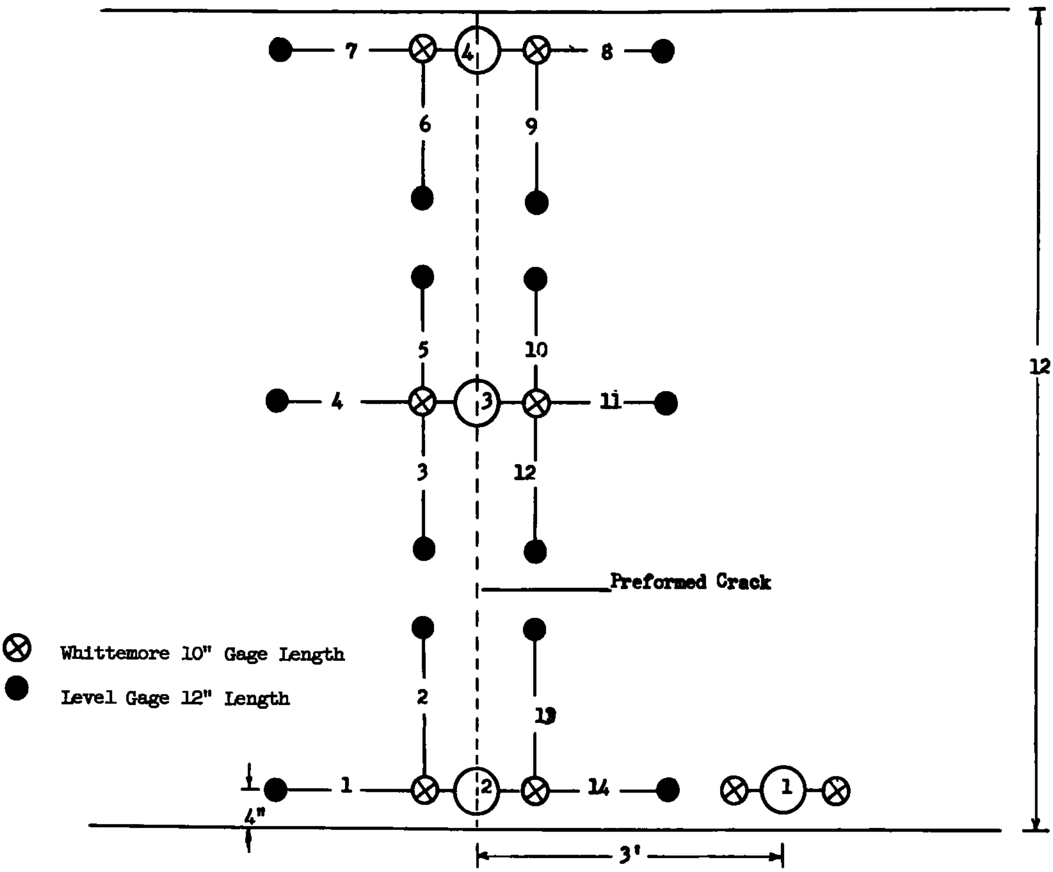

Figure 19. Typical location of Whittemore and warping gage plugs.

originally existed; (b) the general movement of material from excavation to embankment; (c) the location of density determinations by number, station, and elevation.

2. Laboratory reports showing the physical characteristics of special subgrade and stabilized shoulder materials; AASHO classification of soils and granular materials with their moisture-density relationships and California bearing ratio tests of representative samples of these materials.

3. Density determinations made in the field on all embankment, subgrade, special subgrade, and stabilized shoulder materials where they could be performed by the sand cone method.

4. Daily project records showing (a) type of equipment used, (b) weather data, and (c) comments by soils engineer on embankment materials.

5. Ground water fluctuation, measured by means of piezometers.

Embankments and subgrade were composed predominantly of shales and shaley sandy clay loams of the A-2 group (stone or gravel with sand and silt), with a small amount of the A-1 group (stone or gravel and sand with or without fines). Fair quantities of the A-4 group (silt and sand

TABLE 12

PHYSICAL CHARACTERISTICS OF SPECIAL SUBGRADE MATERIAL

Screen	Average Gradation	Spec. Limits	
		Grad. A	Grad. B
3 in.	-	100	-
2½ in.	100	-	100
1½ in.	95	40-90	-
¾ in.	74	-	40-90
No. 4	37	-	-
No. 10	25	15-50	15-70
No. 40	13	-	-
No. 200	9	0-15	0-15
Liquid Limit	22	30 Max.	30 Max.
Plasticity Index	3	6 Max.	6 Max.

with or without coarse fragments) and the A-6 group (clay) were present.

The contractor and Department personnel gained experience with these materials on the project prior to construction of the experimental section. As could be expected with these predominantly granular materials, good compaction and stability were obtained. Table 11 classifies these groups of soils and shows the average values obtained for each group as determined by laboratory tests on samples submitted from the field.

Special subgrade (subbase) material serves as an insulation course between the subgrade and pavement and provides for drainage under the pavement through the shoulder. As previously mentioned, it was placed in 3- and 6-in. depths under the various thicknesses of pavement as prescribed in the design. This material, as supplied from two stone plants, met special subgrade requirements as outlined under gradations A and B in the specifications. The physical characteristics of this material are given in Table 12.

SUMMARY

It should be emphasized that at the time of this report the project described is only six months old and has been open to traffic for a period of three months. It is anticipated that as the pavement ages and more information becomes available, definite conclusions can be drawn concerning its merits.

REFERENCES

1. Witkoski, F. C., and Mattson, W. E., "Preliminary Report on Experimental Continuously-Reinforced Concrete in Pennsylvania." Report No. 1-56-38.
2. Van Breemen, W., "Report on Experiment with Continuous Reinforcement in Concrete Pavement—New Jersey." HRB Proc., 30:61 (1950).