Maryland's Two Continuously-Reinforced Concrete Pavements—A Progress Report

ALLAN LEE, Chief, Research Section, Maryland State Roads Commission

• IN RECENT YEARS the Maryland State Roads Commission has constructed two highway projects using continuously-reinforced concrete paving. Both of these projects are located along the Baltimore-Harrisburg Expressway. This expressway is part of the Interstate System, Route I-83, and in Maryland extends from the Baltimore Beltway, just north of the Baltimore City line, northward to the Pennsylvania line.

The first of these projects was constructed under contract B-578-31, and its pavement slabs were placed during June and July 1959. Paving occupies both the northbound and southbound roadways of this divided highway. Northbound and southbound roadways terminate at a common northern point, but the southbound roadway extends farther to the south than the northbound roadway. Total length of southbound roadway including bridges, control section, etc., is about 4.1 mi, whereas the length of the northbound roadway is about 2.6 mi. This project extends from the vicinity of the town of Hereford northward to the vicinity of the town of Parkton (Fig. 1). Its northern terminal is about 20 mi north of the Baltimore City line.

The second project was built under contract B-578-53. It occupies the southbound roadway only of the Baltimore-Harrisburg Expressway. Its northern terminal directly joins the southern limits of paving of the southbound roadway of contract B-578-31. The south limit of this project is near the Shawan Road Interchange (Fig. 2). The length of the project including structures, control section, etc., is about 6.8 mi. All of the paving for this project was placed between late September and mid-October 1960.

Subsequently in this report, the first job is referred to as Project 31, and the second one as Project 53.

A report covering materials, design, construction, and early test observations for Project 31 was presented by the writer at the January 1961 meeting of Highway Research Board, and is included in the Proceedings of the 40th Annual Meeting.

BASIC FACTORS

Complete details of the experimental features of Project 31 were presented in the report mentioned. A brief review of these features follows.

Nine sections of continuously-reinforced pavement, varying in length from 1,800 to 4,150 ft, are included in the project. In the southbound roadway three sections were joined together with continuous longitudinal steel for a total length of 9,750 ft. Two lengths of conventional jointed pavement are included as control sections, 1,900 ft long in the southbound roadway and 2,850 ft long in the northbound roadway.

The continuously-reinforced pavement is 8 in. thick, founded on a granular-type subbase of 6-in. minimum thickness. In "normal sections" the subbase extends entirely under the shoulder and drains into the surface drain ditch. In "superelevated sections" it drains into a longitudinal underdrain placed along the low side at least 1 ft outside of the edge of the concrete pavement.

The control sections are 9-in. thick, jointed at 40-ft centers, and founded on a granular subbase of the same thickness and details as noted.

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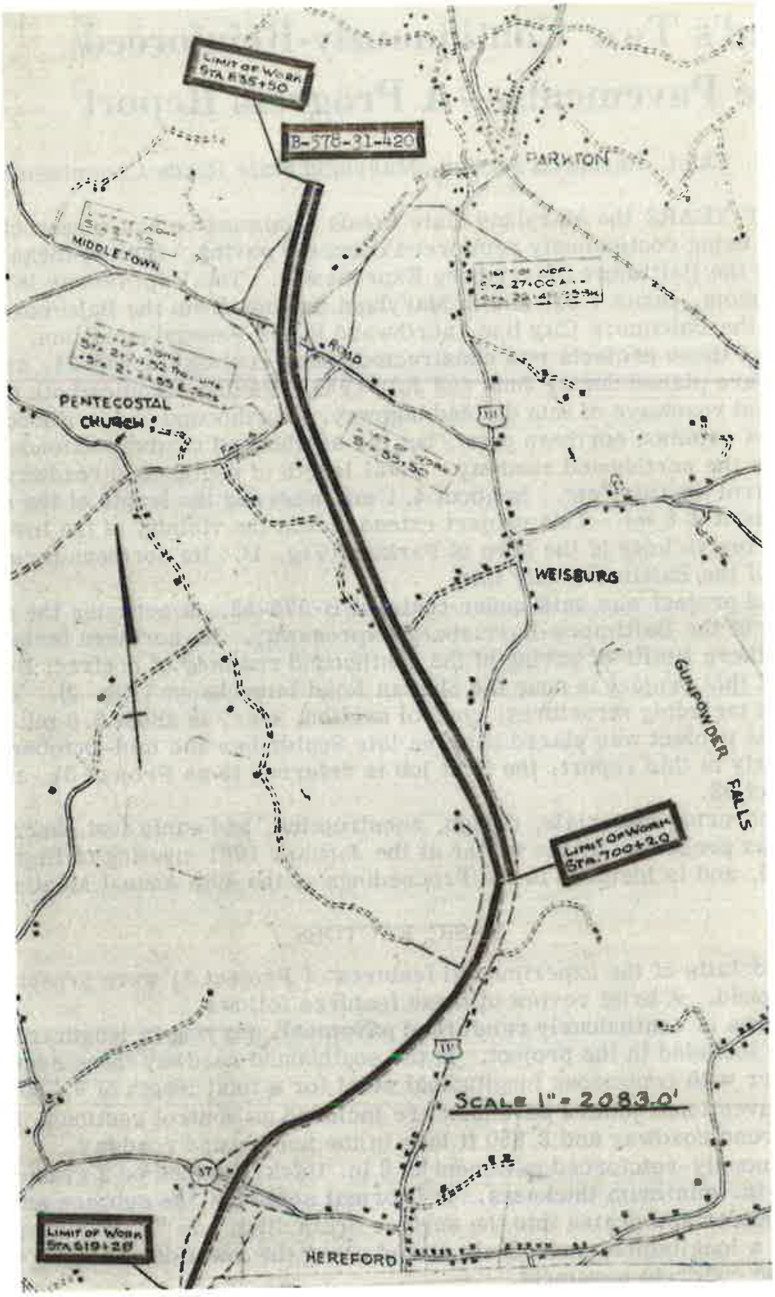

Figure 1. General location of experimental continuously-reinforced concrete pavement, Project 31.

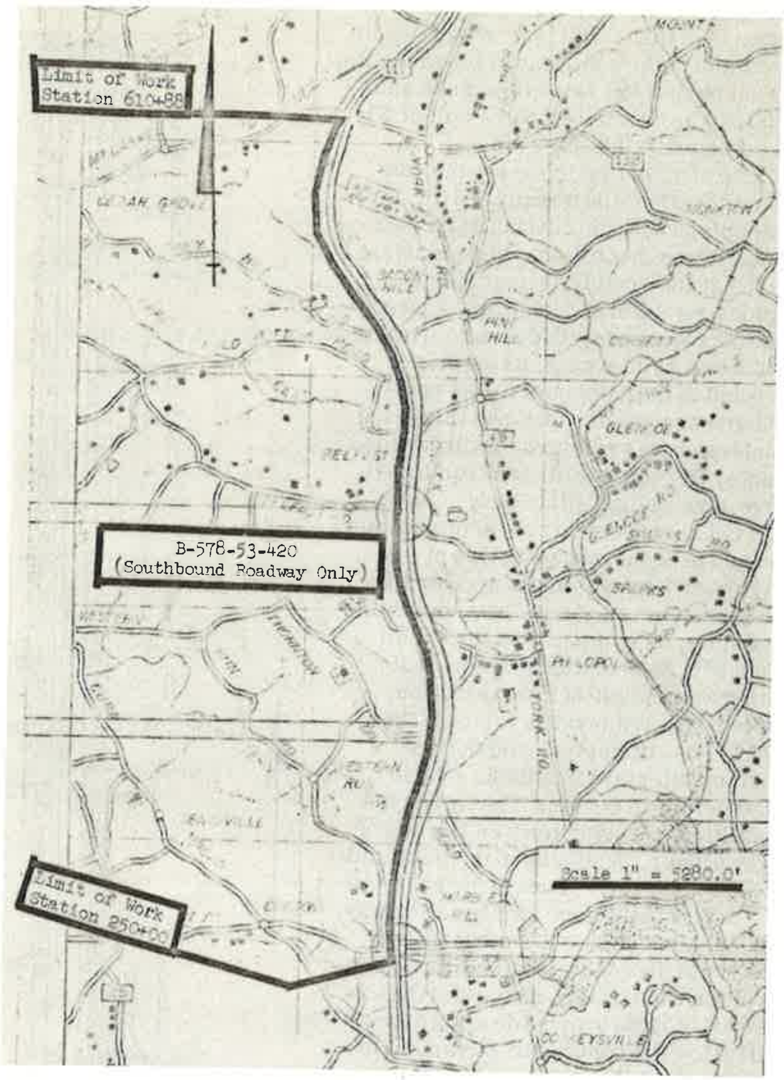

Figure 2. General location of experimental continuously-reinforced concrete pavement, Project 53.

The reinforcing in the continuously-reinforced sections consists of bar mats, and is varied both as to size of bar and percentage of steel. Number 5 bars were placed in percentages of 0.5, 0.6, and 0.7, whereas in several sections the percentage of steel was held at 0.5 but bar sizes were varied between No. 4, No. 5, and No. 6.

Three types of terminal joints were used at the ends of the continuously-reinforced sections of pavement. One type was the Goodrich rubber joint of 9 cells; another a fabricated steel plate type; and the third a "bituminous" type consisting of steel angles armoring the slab ends, and the open joint between slabs filled with a bituminous and cork mixture.

The location of test sites, steel percentages, etc., for Project 31 are shown in Figure 3.

Project 53 contains only a nominal program of experimental features. The continuously-reinforced pavement sections on this project are also 8-in. thick, varying in length from about 3,700 to 6,500 ft, except for one short section less than 600 ft long which ties into existing pavement at the south end of the project.

A granular subbase of the same thickness and lateral dimensions as described for Project 31 also was placed beneath this pavement.

A 2,000-ft long control section using the conventional jointed construction was placed for performance comparison with the continuously-reinforced sections. It was made 9-in. thick and was provided with the granula subbase described.

The continuously-reinforced sections of pavement on this project were provided almost in their entirety with bar mat reinforcing, using No. 5 bars at 0.6 percent of the pavement cross-sectional area. There was one exception to this—a 2,000-ft subsection was reinforced with welded wire fabric mats. Percentage of steel remained at 0.6, the wire size being 6/0.

Three different arrangements of terminal jointing were also used in connection with this project. The Goodrich rubber joint was again used on this project, but in somewhat smaller size, consisting of a 6-cell assembly, as compared to the 9-cell used for Project 31. A second arrangement of terminal jointing was the use of a series of four ordinary doweled type transverse joints. The dowels were of $1\frac{1}{4}$-in. diameter, and the preformed expansion material 1 in. thick. These joints were 20 ft center to center. The third type of terminal jointing was suggested by a Bureau of Public Roads' engineer. A subslab 6 in. thick and 10 ft long was placed directly beneath the roadway slab. A 10-in. deep wide-flange steel section was embedded 2 in. into this subslab, so that its top flange was flush with the roadway surface. The inside contours of the wide-flange shape and the top of the subslab were coated to provide a positive joint which will allow the continuous pavement to withdraw from the steel shape. Details of this type of joint are shown in Figure 4.

Three 12- by 12-in. lugs cast integrally with the pavement slab were used at several terminals of continuously-reinforced concrete sections in an effort to eliminate or reduce end movements. Figure 5 shows the details of these lugs. The location of continuously-reinforced sections, control section, terminal joints, etc., is shown in Figure 6.

It was previously noted that Project 31 paving was placed during June and July of 1959, and that for Project 53 was placed between late September and mid-October 1960. It does not seem necessary to present a detailed daily temperature log in this progress report, but some general differences in temperature for the two periods should be mentioned. During the paving period for Project 31 extreme variations occurred. A very cool period occurred during June, whereas in July high sum-

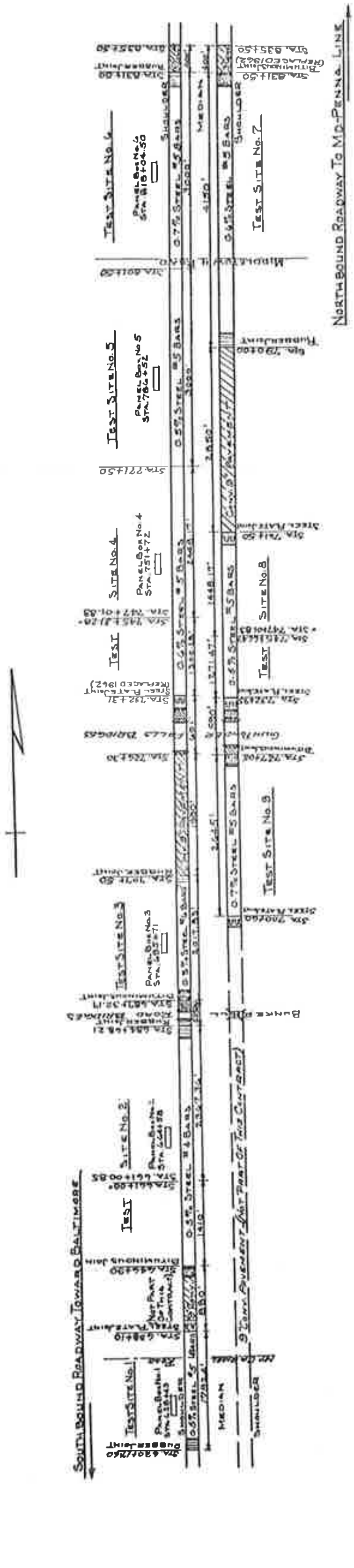

Figure 3. Location of experimental features, Project 31.

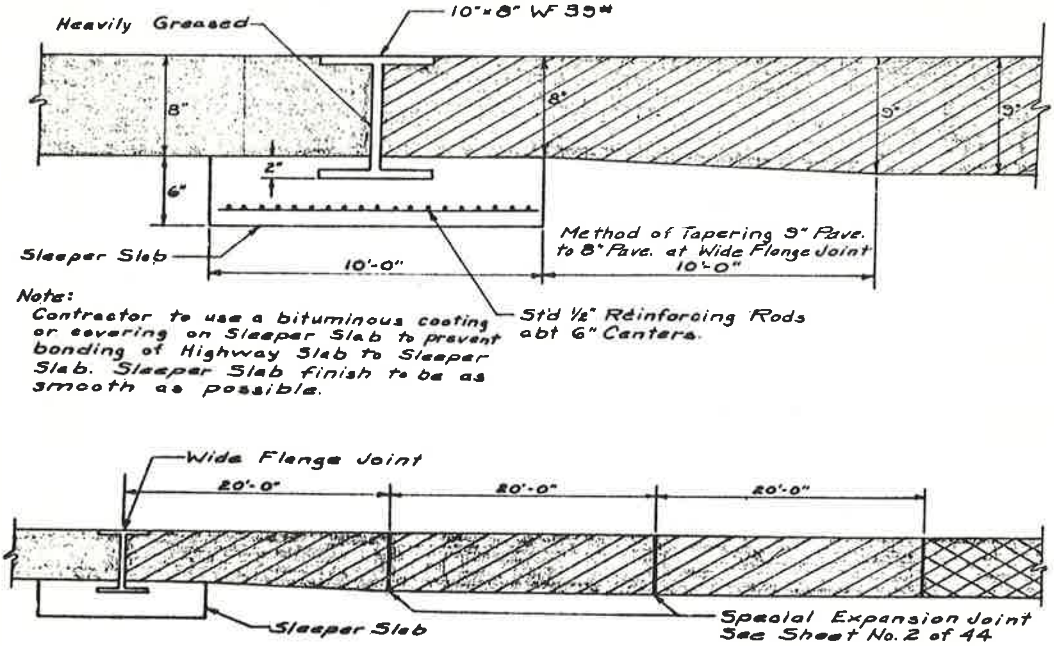

Figure 4. Wide-flange joint detail (not to scale).

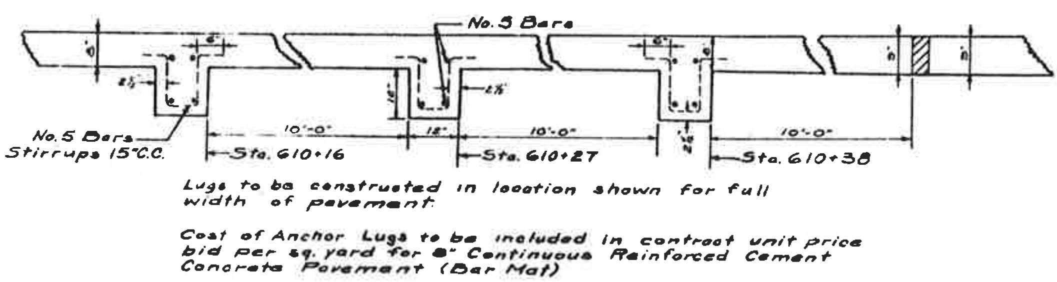

Figure 5. Details of 12- by 12-in. reinforced concrete anchor restraining lugs (not to scale).

mer temperatures, high winds, and low humidities were experienced. On the other hand, Project 53 was paved during a period of what might be described as ideal Fall weather. Very little variation in temperature occurred at any period during the paving and there was even very little variation between day and night temperatures.

It is well to emphasize some variations in design and construction between the two jobs. Project 31 used only 20 diameters lap for the bar mats. There was no attempt to stagger the ends of the mats. Only one paver was used. It placed the first lift of concrete for about 80 ft, then backed up, and placed the second lift after the steel was in place. The only vibration consisted of two internal vibrators along the inside faces of the steel forms.

For Project 53 the length of splice for bar mats was increased to 25 diameters. (The lap for the welded wire mats was in accordance with recommendations of the proponents of this material. The end transverse wire in one mat was placed in the same vertical plane as the adjoining mat.) Two pavers were used, and the complete width of the two separate lifts of concrete was thoroughly vibrated, using internal vibrators. A stagger of 2 ft was provided at the ends of adjacent mats.

TRAFFIC DATA

Very heavy interstate trucking has developed along this expressway. The Traffic Bureau of this Commission provides an annual report of axle loads of various magnitudes using the facility. This report is developed in conjunction with the Traffic Bureau's loadometer study. The latest study was made for a 24-hr period on July 17, 1962. During that period the total traffic was 6,434 vehicles, 1,993 of them being commercial vehicles, and 4,441 being passenger cars. The axle frequency weight distribution is given in Table 1.

CRACK PATTERNS

The January 1961 report stated that detailed crack surveys were made in the central 500-ft region of each of the continuously-reinforced sections of Project 31. A crack survey along similar lines has been carried out for Project 53. The cracks in the central 500 ft of sites 1, 2, 3, 5, and 6 have been recorded. Site 4 was subdesignated 4-BM and 4-WWF due to the fact that both bar mat and welded wire fabric reinforcing were used. The crack survey in this length of continuously-reinforced pavement covers 600 ft, about 300 ft in each of the bar mat and wire fabric reinforced areas. In addition, detailed crack surveys for 250 ft at each end of site 1 have been recorded. This was intended to ascertain any difference in crack spacing and patterns between the north end equipped with integral lugs, and the south end which did not have them. The short length of continuously-reinforced pavement south of Shawan Road Bridge has not been observed in detail for crack spacing.

The January 1961 report further explained that a crack is counted if it extends at least three-fourths of the distance between pavement edges; and also, if two closely spaced transverse cracks join to extend entirely across the pavement.

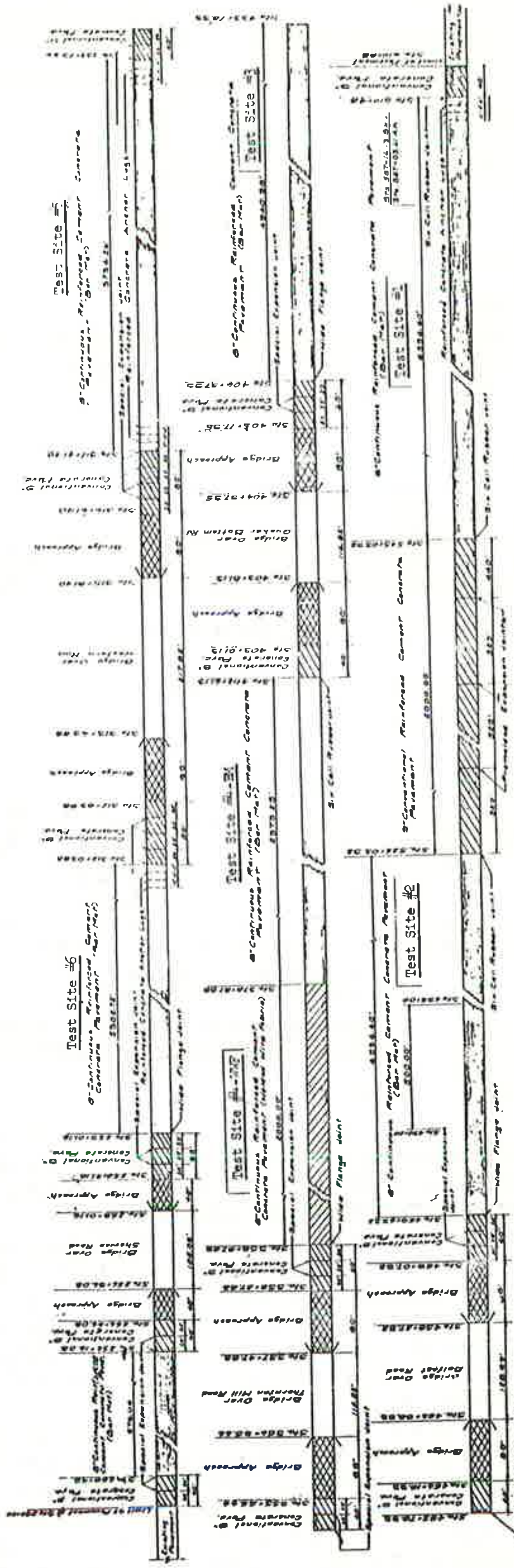

Figure 6. Proposed pavement layout of Interstate I-83—Baltimore-Harrisburg Expressway (Southbound Roadway only).

TABLE 1

AXLE FREQUENCY WEIGHT DISTRIBUTION ALL LOADED AND EMPTY COMMERCIAL VEHICLES BALTIMORE-HARRISBURG EXPRESSWAY INTERSTATE 83 NORTH OF MT. CARMEL RD.[a]

Axle Weight (lb)	Number of Vehicle Axles							
	Panel Pick-ups	Single-Unit Trucks			Tractor Semitrailer			Total
		2-Axle		3-Axle Dual-Tired	2-Axle Tractor		3-Axle Tractor 3-Axle Trailer	
		Single-Tired	Dual-Tired		1-Axle Trailer	2-Axle Trailer		
Under 8,000	588	92	516	45	193	1,434	34	2,902
8,000 - 8,499	-	-	47	-	45	331	3	426
8,500 - 8,999	-	-	7	4	14	172	11	208
9,000 - 9,499	-	-	11	-	20	181	-	212
9,500 - 9,999	-	-	7	-	11	97	-	115
10,000 - 10,999	-	-	29	4	37	172	11	253
11,000 - 11,999	-	-	7	4	14	88	3	116
12,000 - 12,999	-	-	18	14	17	163	6	218
13,000 - 13,999	-	-	18	5	40	159	11	233
14,000 - 14,999	-	-	4	-	25	203	22	254
15,000 - 15,999	-	-	4	5	25	225	8	267
16,000 - 16,999	-	-	7	-	8	305	8	328
17,000 - 17,999	-	-	15	-	6	216	3	240
18,000 - 18,999	-	-	-	-	3	208	-	211
19,000 - 19,999	-	-	-	-	3	79	3	85
20,000 - 21,999	-	-	7	-	20	115	8	150
22,000 - 23,999	-	-	7	-	11	141	3	162
24,000 - 25,999	-	-	-	-	-	35	6	41
26,000 - 27,999	-	-	-	-	-	4	-	4
Projected axles	588	92	704	81	492	4,328	140	6,425
Vehicles counted	294	46	352	27	164	1,082	28	1,993
Vehicles weighed	19	19	97	6	58	245	10	454

[a]24-hour period, Tuesday, July 17, 1962, with 1,993 commercial vehicles, 4,441 passenger cars, and 6,434 total traffic.

Table 2 has been prepared to present some information on transverse crack spacing for the projects. The data contained in this table leads to the following observations:

1. Practically no cracks occurred in Project 31 during the third year of pavement life.
2. At the end of three years, the crack spacing in the comparative sections of Project 31 reinforced with 0. 5, 0. 6, and 0. 7 percent longitudinal steel averaged 6. 3, 4. 8, and 3. 5 ft, respectively.
3. At the end of three years, the crack spacing in the comparative sections of Project 31 reinforced with 0. 5 percent longitudinal steel consisting of Nos. 4, 5, and 6 bars averaged 5. 8, 6. 5, and 7 ft, respectively.
4. At the end of two years, the over-all average crack spacing for all sections of Project 31 reinforced with 0. 6 percent steel consisting of No. 5 bars was about the same as that for all comparable sections of Project 53.
5. The integral concrete lugs in Project 53 had little effect on crack spacing normal to a free end area.

CRACK WIDTHS

The January 1961 report described a comprehensive program of crack width measurements taken at the pavement surface along Project 31. These measurements were in central areas, in areas near free ends, and in areas following transverse construction joints, for each of the nine continuously-reinforced sections.

A limited program of crack width measurements has been carried on for Project 53. In the portion of section 4 reinforced with bar mats (4-BM) an area near the transition point to wire fabric reinforcing was recorded. Also crack widths in an end area, and following a transverse construction joint were recorded for this 4-BM section. In the wire fabric-reinforced length (4-WWF) crack width measurements were recorded near the free end, and in the area close to the transition point to bar mat reinforcing.

Observed crack width measurements are given in Table 3. The portion of the table pertaining to Project 31 includes only those observations made after September 1960, as this date and all previous observations were included in the January 1961 report. The measurements for cracks in Project 53 are all which have been made so far—February and August of 1961, and March and September of 1962.

From the data in Table 3, a brief analysis of the crack widths recorded in 1962 for Project 31 follows:

1. During the March 1962 readings, the average measured crack widths in the central 500-ft areas ranged from 0. 0100 to 0. 0260 in.
2. A total of 36 cracks in the central 500-ft areas of the nine test sections (four in each section) have been observed for surface width during the life of this pavement. Thirty-two of them (about 90 percent) exhibited a width of less than 0. 03 in. during the March 1962 readings.
3. A comparison of all recorded crack widths, in the central 500-ft areas, for the several steel percentages, observed during the March 1962 and September 1962 readings is given in Table 4.
4. The average widths of all cracks in the several "areas" or "zones" selected for observation, were of the following magnitudes during the March 1962 readings: in the central 500-ft areas, 0. 0183 in.; in the end areas 500 ft ± from a free end, 0. 0153 in. in areas following a transverse construction joint, 0. 0173 in.

FAILURES AND POSSIBLE CAUSES

The January 1961 report in connection with Project 31 emphasized the extreme care with which this project was built, and the excellent cooperation of the contractor knowing that it was an experimental project. Despite these efforts toward excellent construction, a number of failures have developed in Project 31. Before the project was opened to traffic, a crack of such magnitude occurred in one area that it was deemed advisable to have it repaired by the contractor before he left the job. Subsequently, a number of additional cracks about which it was felt that it was unwise to leave were

TABLE 2

CRACK SPACING, CENTRAL 500 FT OF EACH SECTION

Project	Location	Reinforcing		Approx. Age (mo)	Avg. Crack Spacing (ft)
		Percent	Bar No.		
31	Site 1	0.5	5	12	7.25
				15	7.14
				27	6.50
				39	6.50
	Site 2	0.5	4	12	6.33
				15	6.17
				27	5.81
				39	5.81
	Site 3	0.5	6	12	7.46
				15	7.35
				27	6.95
				39	6.95
	Site 4	0.6	5	12	5.00
				15	5.00
				27	4.71
				39	4.71
	Site 5	0.5	5	12	7.25
				15	7.25
				27	7.14
				39	7.14
	Site 6	0.7	5	12	3.97
				15	3.85
				27	3.43
				39	3.31
	Site 7	0.6	5	12	5.21
				15	5.15
				27	4.80
				39	4.80
	Site 8	0.5	5	12	5.90
				15	5.78
				27	5.37
				39	5.37
	Site 9	0.7	5	12	4.00
				15	3.93
				27	3.67
				39	3.67
53	Site 1:				
	N[a]	0.6	5	7	12.50
				13	11.35
				24	11.35
	C[b]			7	3.50
				13	3.18
				24	3.14
	S[c]			7	11.35
				13	10.85
				24	10.00
	Site 2	0.6	5	7	4.62
				13	4.46
				24	4.46
	Site 3	0.6	5	7	6.50
				13	6.18
				24	6.10
	Site 4:				
	BM[d]	0.6	5	7	5.20
				13	4.95
				24	4.80
	WWF[e]	0.6	–[f]	7	13.45
				13	11.30[g]
				24	10.88
	Site 5	0.6	5	7	4.39
				13	4.35
				24	4.35
	Site 6	0.6	5	7	7.25
				13	7.14
				24	7.14

[a] 250 ft at north end where lugs were provided.
[b] 500 ft at center.
[c] 250 ft at south end, no lugs.
[d] 317 ft near center, reinforced with bar mats.
[e] 283 ft near center, reinforced with welded wire fabric.
[f] 6/0 wires.
[g] Wide crack spacing in Site 4-WWF probably due to occurrence of several major transverse cracks which, in effect, broke area down into several short lengths of continuously-reinforced pavement.

TABLE 3

OBSERVED CRACK WIDTHS

Project	Section No.	Central 500-Ft Area: Station	Crack Width (in.) Feb. 1961	Sept. 1961	March 1962	Sept. 1962	End Area 500 Ft ± from Free End: Station	Crack Width (in.) Feb. 1961	Sept. 1961	March 1962	Sept. 1962	Following Transverse Construction Joint: Station	Crack Width (in.) Feb. 1961	Sept. 1961	March 1962	Sept. 1962
31[a]	1	627+10	0.0172	0.0207	0.0220	0.0256	632+99	0.0161	0.0155	0.0197	0.0188	624+11	0.0215	0.0212	0.0304	0.0262
		+30	0.0182	0.0216	0.0255	0.0294	633+07	0.0155	0.0160	0.0195	0.0268	+20	0.0435	0.0502	0.0565	0.0600
		+49	0.0238	0.0122	0.0313	0.0217	+18	0.0189	0.0189	0.0243	0.0244	+39	0.0208	0.0248	0.0272	0.0244
		+64	0.0125	0.0145	0.0161	0.0176	+35	0.0083	0.0215	0.0147	0.0188	+77	0.0190	0.0228	0.0230	0.0196
	2	666+35	0.0204	0.0175	0.0228	0.0218	678+99	0.0227	0.0217	0.0245	0.0200	660+06	0.0153	0.0144	0.0203	0.0190
		+48	0.0254	0.0264	0.0295	0.0287	679+08	0.0148	0.0146	0.0184	0.0176	+19	0.0116	0.0109	0.0152	0.0174
		+61	0.0126	0.0099	0.0118	0.0126	+15	0.0264	0.0227	0.0287	0.0248	+30	0.0136	0.0107	0.0156	0.0118
		+98	0.0238	0.0245	0.0281	0.0260	+21	0.0235	0.0230	0.0265	0.0262	+38	0.0085	0.0081	0.0133	0.0177
	3	693+48	0.0138	0.0156	0.0186	0.0193	702+18	0.0205	0.0159	0.0222	0.0198	699+38	0.0133	0.0127	0.0165	0.0127
		+66	0.0126	--[b]	0.0158	0.0048	+39	0.0193	0.0163	0.0214	0.0153	+41	0.0105	0.0034	0.0097	0.0100
		+82	0.0548	0.0183	0.0555	0.0274	+50	0.0259	0.0035	0.0169	--[c]	+43	0.0236	0.0200	0.0296	0.0284
		694+08	0.0102	--[b]	0.0140	0.0080	+60	0.0130	0.0102	0.0195	0.0176	+80	0.0272	0.0250	0.0302	0.0279
	4	749+01	0.0217	0.0201	0.0217	0.0210	739+01	0.0068	0.0040	0.0084	0.0090	755+51	0.0174	0.0115	0.0129	0.0160
		+06	0.0213	0.0056	0.0094	0.0138	+21	0.0231	0.0086	0.0129	0.0161	+57	0.0128	0.0101	0.0103	0.0167
		+33	0.0092	0.0038	0.0074	0.0108	+28	0.0136	0.0036	0.0055	0.0045	+62	0.0102	0.0072	0.0152	0.0084
		+51	0.0204	0.0163	0.0189	0.0198	+35	0.0148	0.0047	0.0091	0.0143	+72	0.0276	0.0149	0.0189	0.0152
	5[d]	782+75	0.0305	0.0365	0.0445	0.0432						797+76	0.0181	0.0100	0.0127	0.0074
		+82	0.0157	0.0086	0.0123	0.0122						798+15	0.0196	0.0098	0.0126	0.0116
		+92	0.0201	0.0131	0.0184	0.0148						+30	0.0334	0.0211	0.0241	0.0311
		783+04	0.0146	0.0088	0.0159	0.0974						+42	0.0474	0.0100	0.0242	0.0160
	6	812+63	0.0069	0.0029	0.0055	0.0051	826+27	0.0231	0.0133	0.0180	0.0144					
		+93	0.0165	0.0083	0.0124	0.0110	+37	0.0028	0.0023	0.0044	0.0093					
		813+28	0.0134	0.0083	0.0103	0.0101	+79	0.0171	0.0139	0.0147	0.0195					
		+44	0.0223	0.0113	0.0118	0.0138	827+61	0.0202	0.0144	0.0162	0.0255					
	7	808+08	0.0208	0.0078	0.0129	0.0103	825+81	0.0155	0.0109	0.0128	0.0158	799+94	0.0199	0.0105	0.0052	0.0053
		+30	0.0094	0.0047	0.0091	0.0060	+93	0.0241	0.0095	0.0122	0.0092	800+05	0.0202	0.0141	0.0193	0.0169
		+44	0.0178	0.0111	0.0157	0.0113	826+31	0.0107	0.0072	0.0076	0.0106	+13	0.0324	0.0186	0.0228	0.0245
		+59	0.0190	0.0059	0.0097	0.0042	+76	0.0146	0.0097	0.0111	0.0084	+23	0.0217	0.0147	0.0134	0.0152
	8	747+06	0.0251	0.0131	0.0155	0.0159	739+89	0.0218	0.0104	0.0129	0.0162	760+27	0.0106	0.0071	0.0082	0.0066
		+80	0.0336	0.0190	0.0254	0.0219	740+59	0.0134	0.0086	0.0097	0.0122	+47	0.0016	--[b]	0.0013	0.0000
		748+87	0.0490	0.0258	0.0359	0.0330	+70	0.0334	0.0464	0.0312	0.0233	+53	0.0032	0.0006	0.0017	0.0052
		749+06	0.0177	0.0104	0.0132	0.0168	741+38	0.0233	0.0126	0.0166	0.0144	+56	0.0030	0.0052	0.0076	0.0052
	9	710+96	0.0207	0.0117	0.0145	0.0151	705+53	0.0096	0.0044	0.0065	0.0084	723+70	0.0179	0.0121	0.0133	0.0171
		711+40	0.0124	0.0042	0.0097	0.0060	+86	0.0098	0.0074	0.0075	0.0100	+83	0.0148	0.0126	0.0125	0.0180
		+84	0.0108	0.0047	0.0084	0.0085	706+35	0.0122	0.0075	0.0099	0.0086	724+10	0.0167	0.0079	0.0133	0.0075
		712+16	0.0115	0.0083	0.0087	0.0093	+54	0.0094	0.0019	0.0055	0.0063	+27	0.0454	--[c]	--[c]	--[c]
53[f]	4-BM	378+92	0.0250	0.0224	0.0278	0.0234	396+85	0.0200	0.0330	0.0336	0.0379	399+02	0.0650	0.0777	0.0803	0.0849
		379+07	0.0300	0.0304	0.0371	0.0374	+91	0.0200	0.0308	0.0359	0.0365	+05	0.0300	0.0310	0.0415	0.0365
		+17	0.0700	0.0685	0.0748	0.0745	397+00	0.0400	0.0581	0.0573	0.0548	+09	0.0500	0.0482	0.0533	0.0512
		+27	0.0150	0.0149	0.0208	0.0208	+21	0.0200	0.0214	0.0271	0.0273	+11	0.0300	0.0217	0.0261	0.0265
		+44	0.0040	0.0029	0.0091	0.0091	+33	0.0150	0.0159	0.0193	0.0210	+22	0.0300	0.0276	0.0311	0.0342
		+50	0.0750	0.0674	0.0694	0.0683	+45	0.0400	0.0284	0.0355	0.0296	+37	0.0350	0.0360	0.0400	0.0418
	4-WWF[g]	377+94	0.0400	0.0490	0.0495	0.0494	363+57	0.0200	0.0221	0.0226	0.0258					
		378+15	0.0100	0.0150	0.0204	0.0209	+76	0.0040	0.0005	0.0030	0.0088					
		+27	0.0080	0.0045	0.0139	0.0151	+93	0.0030	0.0011	0.0059	0.0155					
		+36	0.0350	0.0334	0.0361	0.0354	364+05	0.0100	0.0186	0.0194	0.0099					
		+57	0.0100	0.0155	0.0183	0.0189	+27	0.0050	0.0023	0.0207	0.0055					
		+71	0.0140	0.0160	0.0247	0.0234	+63	0.0070	0.0073	0.0173	0.0090					

[a]Averages:

Section	Crack Width (in.) March 1962	Sept. 1962
0.5%	0.0236	0.0249
0.6%	0.0131	0.0123
0.7%	0.0102	0.0099

[b]"Minus" width indicated, evidently instrument error.

[c]Patched area, plugs removed during repair operations.

[d]No free end in section.

[e]Data for following a transverse construction joint same as that for 500 ft from free end. Set of 4 cracks is common to end area and following construction joint.

[f]Averages:

Reinforcement	Crack Width (in.) March 1962	Sept. 1962
Bar mat	0.0398	0.0389
Wire fabric	0.0272	0.0272

[g]A transverse construction joint did not occur.

TABLE 4

CRACK WIDTHS 1962

Percent Long. Steel	Crack Width (in.) March 1962	Sept. 1962
0.5	0.0236	0.0249
0.6	0.0131	0.0123
0.7	0.0102	0.0099

repaired by cutting out sections of concrete slab, welding in new bars if necessary, recompacting the subbase, and repouring the slab.

An inspection during the latter part of October 1962 indicated a total of 39 "areas" along both roadways of Project 31 where repairs as described had been made, or were scheduled to be made within a few weeks. Twenty-six of these repaired "areas", or two-thirds of the total, occurred at laps in the bar mats. It will be remembered that bars were spliced only 20 diameters for this project. An "area" in this case is the length of patching measured longitudinally along the roadway by the width of the travel lane in which the patch occurs. The longitudinal dimensions of the patched areas varied from slightly more than 2 ft to just under 10 ft. During this inspection most of the repaired areas were in satisfactory condition.

As these areas were being repaired, samples of the concrete removed were carefully examined. It is believed that the principal cause of failure was probably a lack of bond between the two lifts of concrete pavement and between the concrete pavement and the reinforcing steel. As reported in January 1961 only one paver was used on this project. It moved ahead some 75 or 80 ft in placing the first lift, then backed up and after the steel was in place advanced to place the second lift. Concrete was of a low slump and no vibration was used except the usual two internal vibrators along the face of the steel forms. As previously mentioned, extreme temperature ranges and periods of high winds occurred during the paving of this project.

Also on Project 31 there have been some failures of terminal joints. One of these was in connection with the bituminous joint. The armoring angle on one side of a joint began to "bang" severely under the heavy truck traffic using the roadway. Attempts were made to correct this condition by drilling and plug welding to the anchors embedded in the concrete. However, this was not successful and it was found necessary to remove the top flange of the angle completely and cover the entire area with bituminous concrete. A subslab was not used under this joint and the failure was evidently due to welded anchors breaking under traffic. Also one of the fabricated plate type of terminal joints showed extreme distress under the heavy truck traffic of the highway and had to be entirely removed and the space between slabs backfilled and surfaced with bituminous concrete. This terminal joint also was not equipped with a subslab. This had been a decision made by all interested parties previous to the building of the project.

Project 53 is not as old as Project 31, but was subjected to the severe temperatures encountered in the winter of 1960-1961. In all of the areas of this project which were reinforced with No. 5 bar mats, the performance has been very good. No detrimental cracks have been found and about the only place where many closely spaced cracks seem to occur is on the last poured side of construction joints. This is the usual performance of these areas. In the 2,000-ft area reinforced with welded wire fabric, the performance was not as satisfactory. Before the pavement was opened to traffic, four very wide cracks developed and several more have subsequently formed at the splices of the welded wire fabric sheets. In the use of this type of mat it was agreed that the splice would be in accordance with the recommendations of the proponents of this material. This recommendation was that the end transverse wire of one mat be placed directly over the end transverse wire of the adjoining mat. This procedure was carefully followed, the mats were tightly wired together, and an inspector was detailed to see that this condition prevailed before concrete was placed. As soon as the four wide cracks mentioned developed, exploratory cuts were made near one pavement edge of each crack. The steel was exposed and at two of the cracks despite the precautions taken, it was found that "creep" of the mats had occurred so that there was no effect of the transverse wires, and the only bonding present was that of the plain round wires. The proponents of this material have changed their recommendations so that at present a definite overlap of the end transverse wires occurs. The areas containing these wide cracks have not so far been repaired. They have been backfilled with bituminous material. It appeared that end movements of this particular section of continuously-reinforced pavement were being taken in these wide cracks rather than at the wide-flange terminal joint which is at the end of the section.

In an attempt to confirm this assumption, eight wide cracks in this section were plugged in March 1962. It was necessary to place them at a fairly good distance from the cracks, and they were thus out of the range of the Whittemore gage. A reading to the nearest 1/64 in. was taken and considered as a zero reading. In September 1962 readings were again taken to the nearest 1/64 in., and all cracks showed significant movements. Closures had occurred at all of the eight cracks, ranging from a minimum of 4/64 in. to a maximum of 17/64 in.

ANNUAL END MOVEMENTS OF CONTINUOUSLY-REINFORCED SLABS

Terminal Joints

The program of observations of end movements of continuously-reinforced sections has been continued. All free ends of continuous sections on Project 31 are recorded (Table 5). However, the observations for Project 53 are limited. The north end of section 1 was selected as a free end with lugs; the north end of section 4-BM and the south end of section 4-WWF were selected as ordinary free ends but with different types of terminal joints—rubber and wide flange, respectively. The south end of section 2 is also an ordinary free end, equipped with a wide-flange terminal joint. It was selected as a duplicate to the south end of section 4-WWF, because the wide cracks in this section probably affect the end movements.

Maximum lengthening in September 1962 of any free end on Project 31 was about 1 1/8 in. at the south end of section 8. The average lengthening for the 14 free ends observed on Project 31 was about 5/8 in.

In connection with Project 53, the north end of section 1 showed a considerable lengthening in September 1962, even though it had been constructed with integrally cast lugs. This lengthening averaged about 1 1/8 in. At this same period the north end of section 4-BM had lengthened about 9/16 in. from the original, and the south end of section 2 had lengthened about 5/8 in. from February 1962. The south end of section 4-WWF showed close to 1-in. lengthening measured from original, but as previously noted the adjacent area is badly cracked, which may have some effect on this particular end movement.

In general the end movements of the continuously-reinforced pavement sections are not considered excessive.

Table 6 gives records of movements across terminal joints. For Project 31 the maximum movement measured from original position was about 2 3/16 in. closure. Two of the terminal joints were removed.

In Project 53, the rubber joints observed had not moved more than 1 in. from the original, according to September 1962 readings. In connection with the series of doweled joints, observations indicate that most of the movement takes place at the first joint, directly abutting the continuously-reinforced section. For wide-flange types of joints, movements have been recorded between the center of the steel section and plugs set in the continuously-reinforced pavement, and also set in the jointed pavement on the opposite side of the steel section. The nominal distance each side of the center line of steel section was 8 in. and most readings have been with a Whittemore-type hand gage. The fractional readings were out of range of this device; this comment also applies to readings across doweled joints. Movements at wide-flange types of joints have been very small.

End Anchorages

On Project 31 there was no attempt to provide end anchorages for any of the continuously-reinforced sections.

However, several ends of continuously-reinforced sections on Project 53 were provided with integrally cast lugs to determine if they had any effect on restraining movements at these points. These lugs were placed at the north end of section 6, at the north and south ends of section 5, and at the north end of section 1.

The lugs were 12 by 12 in., directly beneath the roadway slab, and cast integrally with it. The first lug is 10 ft from the end of the continuously-reinforced section, and there is a clear distance of 10 ft between lugs. Three lugs as described were provided for each anchorage, and they were reinforced with No. 5 stirrup-type bars.

It has already been mentioned that considerable end movement occurred at the north

TABLE 5

END MOVEMENTS, CONTINUOUSLY-REINFORCED SECTIONS

Project	Section	Location	Movement[a, b] (in. × 1/64)							
			North End				South End			
			March 1961	Aug. 1961	Feb. 1962	Sept. 1962	March 1961	Aug. 1961	Feb. 1962	Sept. 1962
31	1	Shoulder	- 8	+39	+ 6	+52	-26	+31	-28	+27
		Median	- 9	+41	+ 5	+56	-32	+23	-30	+24
	2	Shoulder	-18	+32	- 6	+45	-14	+47	- 8	+46
		Median	-18	+31	0	+49	-14	+47	- 4	+49
	3	Shoulder	-17	+16	-25	+23	-18	+20	-12	+28
		Median	-17	+24	-25	+20	-20	+16	-15	+24
	4[c]	Shoulder	--	--	--	--	- 8	+36	0	+41
		Median	--	--	--	--	-11	+32	- 6	+39
	5[d]		--	--	--	--	--	--	--	--
	6	Shoulder	- 6	+32	-10	+35	--	--	--	--
		Median	- 5	+32	-10	+36	--	--	--	--
	7	Shoulder	-22	+22	-32	+16	- 8	+43	+14	+42
		Median	-22	+30	-24	+ 9	-11	+40	+10	+40
	8	Shoulder	- 7	+44	+ 6	+49	- 8	+69	+21	+76
		Median	0	+52	0	+45	- 1	+58	+ 6	+66
	9	Shoulder	0	+43	+ 5	+56	-17	+34	+ 1	+41
		Median	0	+47	+ 4	+57	-16	+44	+ 9	+53
53	1	Shoulder	- 8	+52	+36	+77	--	--	--	--
		Median	- 9	+52	+27	+68	--	--	--	--
	2[g]	Shoulder	--	--	--	--	--	--	--[h]	+34
		Median	--	--	--	--	--	--	--[h]	+42
	4-BM[j]	Shoulder	-28	+27	-14	+40	--	--	--	--
		Median	-28	+32	-16	+34	--	--	--	--
	4-WWF[k]	Shoulder	--	--	--	--	-65	+47	+24	+55
		Median	--	--	--	--	-87	+47	+24	+56

[a]From initial reading made at age of 1 or 2 weeks.
[b]+ = lengthening; - = shortening.
[c]North end not free, continuous with section 5.
[d]Neither end free, continuous with sections 4 and 6.
[e]South end not free, continuous with section 5.
[f]No observations made for south end.
[g]No observations made for north end.
[h]Plugs to record end movements of south end not set until February 1962.
[j]South end not free, continuous with section 4-WWF.
[k]North end not free, continuous with section 4-BM.

end of section or site 1, which was monumented for end movement observations. It appears that for the type of soil and other conditions existing at this site, these lugs were ineffective. No unusual cracking has occurred at the several ends that were thus anchored.

General Conditions of Concrete Shoulder Trucking Lanes vs Median Lanes

Neither project has attained any great age, Project 31 being only about 3 ½ years old, and Project 53 only slightly more than 2 years old.

Most of the badly cracked areas of Project 31 have been repaired and the remaining

TABLE 6

TOTAL MOVEMENT ACROSS TRANSVERSE TERMINAL JOINTS

PROJECT 31

ROADWAY LOCATION	DESCRIPTION OF PAVEMENT ABUTTING TERMINAL JOINTS	TYPE OF JOINT	EDGE	2/61	8/61	2/62	9/62
SOUTH END — SOUTHBOUND ROADWAY	TWO SECTIONS OF 9" JOINTED PAVEMENT AND EXISTING 9" PAVEMENT / SECTION 1	RUBBER	SHOULDER	+30	-34	+12	-40
			MEDIAN	+29	-35	+9	-39
	SECTION 1 / EXISTING 9" PAVEMENT & 2 SECTIONS OF 9" JOINTED PAVEMENT	FABRICATED STEEL	SHOULDER	+2	-58	-20	-75
			MEDIAN	+4	-56	-20	-74
	EXISTING 9" PAVEMENT & 2 SECTIONS OF 9" JOINTED PAVEMENT / SECTION 2	BITUMINOUS	SHOULDER	+22	-47	+10	-45
			MEDIAN	+23	-48	+11	-48
	SECTION 2 / STRUCTURE APPROACH	RUBBER	SHOULDER	+32	-8	+28	-13
			MEDIAN	+30	-11	+26	-15
	STRUCTURE APPROACH / SECTION 3	BITUMINOUS	SHOULDER	+17	-22	+14	-27
			MEDIAN	+17	-22	+16	-26
	SECTION 3 / CONTROL SECTION 9" JOINTED PAVEMENT	RUBBER	SHOULDER	+4	-43	-3	-55
			MEDIAN	+9	-34	+2	-50
	STRUCTURE APPROACH / SECTION 4	FABRICATED STEEL	SHOULDER	+9	-36	-10	Joint removed & filled with Bit.Conc. (1962)
			MEDIAN	+9	-37	-6	
	SECTION 6 / 400'± SECTION 9" JOINTED PAVEMENT	RUBBER	SHOULDER	+11	-53	-7	-57
NORTH END			MEDIAN	+17	-46	0	-54
NORTH END — NORTHBOUND ROADWAY	400'± SECTION 9" JOINTED PAVEMENT / SECTION 7	BITUMINOUS	SHOULDER	+21	-48	+11	Joint replaced with concrete (1962)
			MEDIAN	+21	-48	+4	
	SECTION 7 / CONTROL SECTION 9" JOINTED PAVEMENT	RUBBER	SHOULDER	+8	-82	-39	-80
			MEDIAN	+11	-84	-40	-88
	CONTROL SECTION 9" JOINTED PAVEMENT / SECTION 8	FABRICATED STEEL	SHOULDER	-41	-123	-83	-145
			MEDIAN	-36	-112	-70	-134
	SECTION 8 / STRUCTURE APPROACH	FABRICATED STEEL	SHOULDER	+6	-59	-11	-69
			MEDIAN	+3	-57	-10	-69
	STRUCTURE APPROACH / SECTION 9	BITUMINOUS	SHOULDER	+16	-30	+5	-39
			MEDIAN	+16	-29	+2	-39
	SECTION 9 / TWO SECTIONS OF 9" JOINTED PAVEMENT AND EXISTING 9" PAVEMENT	FABRICATED STEEL	SHOULDER	+16	-46	-5	-67
SOUTH END			MEDIAN	+16	-47	-5	-69

PROJECT 53

ROADWAY LOCATION	DESCRIPTION OF PAVEMENT ABUTTING TERMINAL JOINTS	TYPE OF JOINT	EDGE	2/61	8/61	2/62	9/62
NORTH END — SOUTHBOUND ROADWAY	9" EXISTING JOINTED PAVEMENT & 1 SECTION 9" JOINTED PAVEMENT / SECTION 1	RUBBER	SHOULDER	+10	-40	-14	-58
			MEDIAN	+9	-43	-13	-61
	SECTION 1 / CONTROL SECTION 9" JOINTED PAVEMENT	RUBBER	SHOULDER	+13	-48	-7	-43
			MEDIAN	+11	-51	-11	-51
	CONTROL SECTION 9" JOINTED PAVEMENT / SECTION 2	RUBBER	SHOULDER	+9	-55	-7	-55
			MEDIAN	+9	-51	-9	-55
	SECTION 2 / STRUCTURE APPROACH	WIDE FLANGE N. Side Cont. Pvm.	SHOULDER	+.0559	-.0960	+15/64	-.0087
			MEDIAN	+.0546	-.0591	+21/64	+.0251
		S. Side Conv. Pvm.	SHOULDER	+.0607	+.0555	+12/64	+.2129
			MEDIAN	+.0511	+.0158	-3/64	+.1470
	STRUCTURE APPROACH / SECTION 3	RUBBER		NO READINGS			
	SECTION 3 / STRUCTURE APPROACH	WIDE FLANGE		NO READINGS			
	STRUCTURE APPROACH / SECTION 4-BM	RUBBER	SHOULDER	+11	-32	+2	-30
			MEDIAN	+6	-33	-6	-32
	SECTION 4-WWF / STRUCTURE APPROACH	WIDE FLANGE N. Side Cont. Pvm.	SHOULDER	+.0083	-.0198	+4/64	+.0698
			MEDIAN	+.0018	-.0024	+3/64	+.0309
		S. Side Conv. Pvm.	SHOULDER	+.0094	+.0047	+5/64	+.0199
			MEDIAN	+.0121	+.0063	+2/64	+.0225
	STRUCTURE APPROACH / SECTION 5	SERIES OF DOWELLED EXPANSION JOINTS	#1 SHOULDER	+.1370	-26/64	+4/64	-21/64
			#1 MEDIAN	+.1715	-23/64	+8/64	-17/64
			#2 SHOULDER	+.0008	-8/64	+1/64	-7/64
			#2 MEDIAN	+.0043	-8/64	-2/64	-7/64
			#3 SHOULDER	+.0109	-.0635	-1/64	-.0237
			#3 MEDIAN	+.0022	-3/64	0	-3/64
			#4 SHOULDER	-.0003	-.0383	0	-.0084
			#4 MEDIAN	+.0011	-.0400	+1/64	-.0278
	SECTION 5 / STRUCTURE APPROACH	SERIES OF DOWELLED EXPANSION JOINTS	#1 SHOULDER	+.1239	-27/64	-3/64	-24/64
			#1 MEDIAN	+.1410	-27/64	0	-22/64
			#2 SHOULDER	+.0196	-8/64	+4/64	-6/64
			#2 MEDIAN	+.0020	-.1171	+1/64	-5/64
			#3 SHOULDER	+.0081	-.0170	+2/64	-.0355
			#3 MEDIAN	-.0004	-5/64	+3/64	+.0364
			#4 SHOULDER	+.0003	-.0529	0	-.0323
			#4 MEDIAN	+.0081	-.0233	+1/64	+.0066

NO READINGS OF JOINTS TAKEN SOUTH OF THIS JOINT.

NOTE: + Indicates opening of joint.
- Indicates closing of joint.

[a]Movements in 1/64 in. from initial reading made at age of one to two weeks.
[b]Movements in 1/64 in. or as indicated from initial reading.

areas present a fairly good general appearance, especially in summer periods when transverse cracks are tightly closed. A few of the sections do not show up as well in the cold winter season when cracks are open. The conventional control section is in excellent condition.

As previously stated, the bar mat reinforced sections of Project 53 present a very good general appearance. The appearance of the 2,000-ft length of welded wire fabric reinforced pavement is poor due to the numerous wide cracks. The conventional control section for this project is in very good condition, but it contains many more transverse cracks than the control section for Project 31.

As previously noted, terminal joints for Project 31 were of the following three types: 9-cell Goodrich rubber joint, a bituminous fill placed between steel angle-armored slab ends, and fabricated steel plate type. Project 53 also used three types of terminal joints: the Goodrich rubber joint was again used, but of 6-cell construction; wide-flange steel section type of joint; and the multiple-doweled joint type. Up to the present the rubber joints and the steel wide-flange joints seem to have performed somewhat better than the others. The multiple-doweled joints would probably rank next in satisfactory performance; some spalling has occurred at these joints, but it is not necessarily associated with the type of joint. Precompressed, self-expanding filler material might improve these multiple-type joints. Weld failures have occurred in both the "bituminous" and fabricated plate joints, and some removal of both of these types has occurred. However, neither of these types of joints was provided with subslabs, this being agreed on as an experimental feature during the planning of the experiment. It is possible that subslabs could have improved their performance considerably.

Road roughness determinations were made along Project 31 in October 1959 and June 1962; they were made along Project 53 in June 1962. These measurements were made by this Commission's roughometer which is of the Bureau of Public Roads type. In all cases the roughometer was towed along the outer wheelpath of the lane being measured. Roughness data for the two projects are given in Table 7.

Table 7 pertaining to Project 31 gives a number of changes in roughness between the October 1959 and June 1962 readings. The changes are erratic, and a definite trend is not indicated so far. There are 11 sections, counting the two conventional pavement controls. In the shoulder lanes 5 sections showed increased roughness, 4 showed lower roughness readings, and 2 sections were the same. In the median lanes 10 of the sections decreased in roughness readings, and 1 remained the same. It is possible that the many patched areas had some effect on these roughness evaluations.

Only one determination of roughness has been made on Project 53, and a comparison between different dates is, of course, impossible.

This report has previously mentioned the considerable amount of heavy truck traffic which is using this expressway. Although it is usual for most of the trucks to use the shoulder lanes, observations indicate that the median lane gets a good share of truck traffic also.

A casual observation does not indicate that the shoulder lanes have so far been affected by traffic to a greater extent than the median lanes. After these projects have been in use for a significant period—perhaps 10 years—it is felt that a more definite indication should be available.

Performance and Cost of Continuously-Reinforced Pavement vs Conventional Pavement

The Baltimore-Harrisburg Expressway, Interstate I-83, is a concrete pavement project in its entirety in Maryland. Design and construction phases covered a long period, design having begun sometime in 1949; construction was completed in late 1960 when Project 53 was opened to traffic. Cost index factors could be applied to the very old jobs, and a comparison made with the continuously-reinforced projects.

However, Projects 31 and 53 and the two conventional paving projects between Project 31 and the Pennsylvania line were advertised between November 1957 and January 1960 and bid costs submitted by the contractor of each project are given in Table 8. Project 32 adjoins Project 31 directly to the north, includes both roadways of the divided

TABLE 7

AVERAGE ROUGHNESS UNITS PER MILE

Project	Section or Site	Avg. Roughness Units per Mile			
		Measurement Oct. 1959		Measurement June 1962	
		Shoulder Lane	Median Lane	Shoulder Lane	Median Lane
31	1	100	103	100	103
	2	92	94	91	85
	3	86	86	100	79
	Control southbound rdwy.	90	87	90	70
	4	106	120	121	111
	5	106	114	109	107
	6	100	107	90	100
	7	95	93	94	85
	Control northbound rdwy.	89	102	98	93
	8	111	116	107	89
	9	95	90	101	88
	Total:				
	Continuously-reinforced	99	103	101	94
	Conventional control	90	95	94	82
53[a]	1	--	--	88	95
	Control	--	--	101	105
	2	--	--	86	95
	3	--	--	92	88
	4-BM	--	--	85	100
	4-WWF	--	--	83	88
	5	--	--	87	85
	6	--	--	85	87
	Total:				
	Continuously-reinforced	--	--	87	91

[a]Southbound roadway only.

highway to a point north of Parkton, and is about 1.9 miles long. Between this contract and the Pennsylvania line is Project 35, about 4.4 miles long, and also including both roadways of the divided highway.

Although the contract bid prices for Project 31 showed identical unit prices for conventional and continuously-reinforced pavement, those for Project 53 indicated premiums of $0.66 per sq yd for bar mat reinforcing, and $0.76 per sq yd for welded wire fabric reinforcing. It must also be remembered that the terminal joints at the ends of continuously-reinforced sections are separate bid items, and when their cost is transformed to an equivalent square yard basis can add significantly to the continuously-reinforced pavement costs.

For Project 31 bid prices received were $800 for the bituminous joint, $1,200 for the fabricated steel plate joint, and $2,800 for the rubber type joint. Design changes in the fabricated steel plate joint after receipt of bids resulted in an increase of about $1,000 for each of these joints. Aggregate cost of the 14 terminal joints used on this project was $28,200, or about $0.37 per sq yd of continuously-reinforced concrete.

TABLE 8

BID COSTS FOR FOUR PROJECTS

Project	Date of Bid	Type of Construction	Bid Price of Pavement ($ per sq yd)[a]
32	11-57	Conventional	6.50
31	1-58	Continuously-reinforced	6.00
		Conventional (control)	6.00
35	3-58	Conventional	5.50
53		Continuously-reinforced (bar mat reinforcement)	5.69
	2-60	Continuously-reinforced (welded wire fabric reinf.)	5.79
		Conventional	5.03

[a]Bid price for conventional pavement includes reinforcing steel, longitudinal tie device, doweled joints, etc. Bid price for continuously-reinforced pavement includes reinforcing steel, tie devices, etc., but not terminal joints.

The rubber type of joint proved popular with Maintenance and District forces, and it was requested that this type of joint be used on Project 53. It was included in the bid proposal but resulted in a submitted contract price of $3,315. In an attempt to reduce the total price of terminal joints, and also to investigate this question of terminal jointing further, the three types previously described in this report were substituted, and prices for them were negotiated with the contractor. These negotiated prices were $400 for the series of doweled joints, $490 for the wide-flange joint, and $2,980 for the smaller 6-cell rubber joint. The total cost of the 12 terminal joints used north of the Shawan Road Bridge was $18,060 which is equivalent to an increase of $0.20 per sq yd for the continuous pavement in this same area.

It is not possible at this time to make a definite statement as to whether these premiums in cost are justified. The performance of the first continuously-reinforced pavement, Project 31, so far is not as good as either its own conventional control sections, or the adjacent conventional paving contracts. As indicated previously, the lack of full depth vibration, and the use of only one paver probably contributed to the lack of bonding and subsequent failures. The length of splice, and non-stagger of mats could also very well have contributed to the failures.

On the other hand, the bar mat reinforced sections of Project 53 have so far performed very well. Vibration, two pavers, staggered mats, and increased splice length were used on this project. But still, the increased cost does not yet appear justified, because the age of the pavement is still quite low.

It will be necessary to compile carefully pavement maintenance costs for all of the separate sections given in Table 8 over a rather long period before any reasonable conclusions can be drawn.

SUGGESTED IMPROVEMENTS

The experience in Maryland to date in connection with continuously-reinforced pavements is limited. Based on this limited experience, the following are suggested:

1. It is extremely important to vibrate both lifts of a continuously-reinforced pavement and to use two pavers when two lift construction procedure is followed.
2. Although it has not been used, preplacing the steel in very long lengths and completely randomizing splice locations would be a preferred type of construction. With this method of construction, the concrete would be placed in one lift and would be thoroughly vibrated for its entire depth.

Figure 7. Pavement construction showing internal vibration of concrete.

Figure 8. Pavement construction showing internal vibration of concrete, and staggered ends of bar mats.

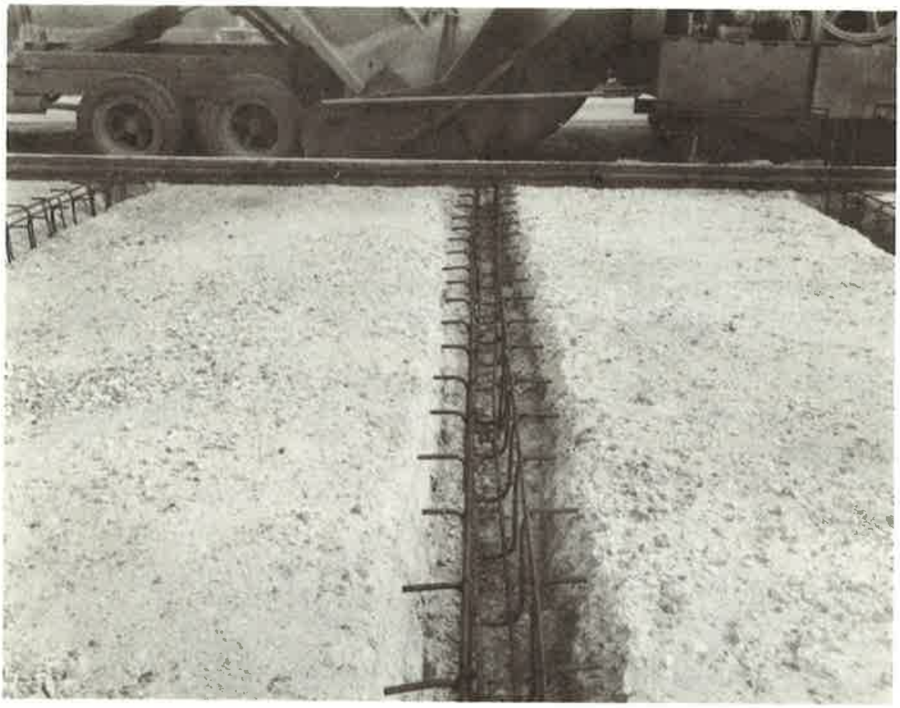

Figure 9. Details of reinforcing steel cage in end restraint lugs.

Figure 10. Placing reinforcing steel and trimming subbase at end restraint lugs.

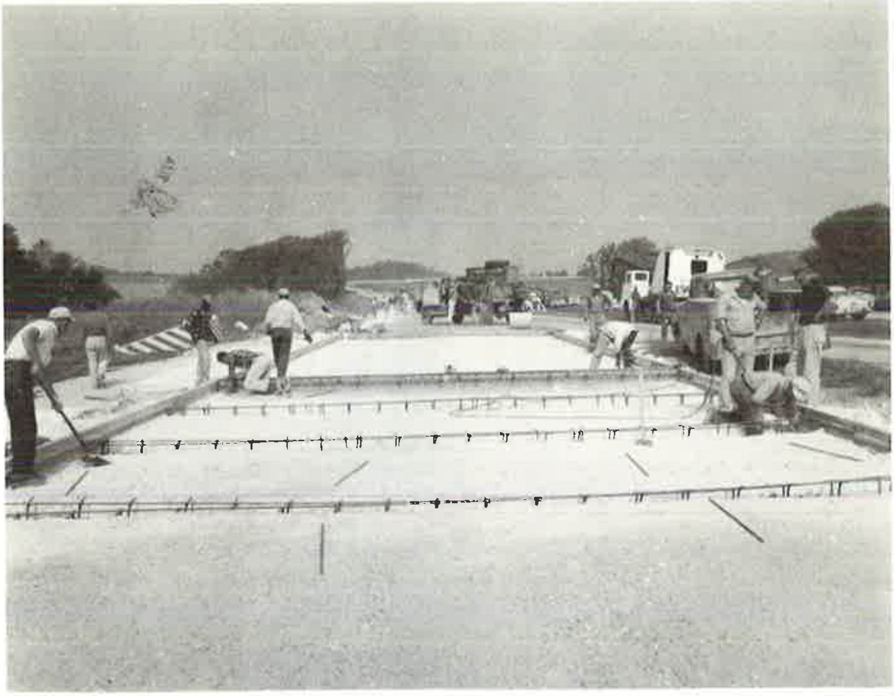

Figure 11. Trimming subbase at end restraint lugs.

Figure 12. Concrete pouring in vicinity of end restraint lug.

3. The 20-diameter lap which Maryland used on Project 31 seems to be too short. The 25-diameter lap used on Project 53 is better and although there is nothing definite to base it on, the authors would be inclined even to lengthen this amount of lap a little. The method of splicing the wire fabric on Project 53 was entirely too short and it would appear favorable to lengthen it considerably.

4. The simplest type of terminal joint should be used. The multiple-doweled joint and the wide-flange joint have performed satisfactorily so far.

5. If it is decided to use end anchorages they apparently must be quite massive to be effective.

Figures 7 through 12 show some of the construction details for Project 53.