TRANSVERSE CRACKING OF NEW CONCRETE PAVEMENT
M 37 from Ballards to Casnovia
(Projects BF 41033D, C7U & C8R; BF 41033E, C9U & C10R; BF 61171A, C1U)

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At the request of R. L. Greenman, the Research Laboratory Division initiated a field study on October 10, 1962, regarding the extent and cause of transverse cracking which had developed on the M 37 relocation pavement constructed the preceding July and August. The project to be studied included 9.952 mi of 24-ft portland cement concrete, commencing 0.5 mi north of Ballards in Kent County, proceeding northwest and bypassing Sparta and Kent City, and joining old M 37 in Muskegon County near Casnovia. Eventually, the existing pavement will be the northbound roadway of a divided M 37.

The pavement was poured between July 9 and August 11, 1962, by the Pierson Contracting Co. Materials used in the 99-ft reinforced slabs included aggregate from Grand Rapids Gravel Co. Pit No. 14 (MSHD Inventory No. 14-38), and Port Huron air-entraining cement (except for pavement from Stas. 649+79 to 858+57, where the cement was Dundee air-entraining). Reinforcement was placed and the longitudinal joint located according to current standard plans. Locations of the 20 pours are shown in Fig. 1, with "pour" defined for purposes of this report as one day's paving operation. Pertinent construction data are given in Table 1.

Cracking and Roughness

A condition survey and photographic record of the project were completed in October 1962 (Figs. 2 and 3). In all, 388 transverse cracks were recorded, of which 210 were in the northbound lane and 178 in the southbound. Cracking per lane per pour is summarized in Table 1. It should be noted that the pours with most cracks (Nos. 2, 5, 13, 1) are not among the longest of the 20, but vary from 3467 to 2320 ft in length. Pavement riding quality, as recorded by the Department's standard roughometer measurements, was "good," with 122 accumulated inches per mile in the northbound lane, and 117 in the southbound. On the basis of cracking and roughness, the Present Serviceability Index as defined in the AASHO Road Test reports (quality rated on a scale from zero to 5, with 4 to 5 very good, 3 to 4 good, etc.), was 3.23 for the northbound lane, and 4.30 for the southbound. These values reflect physical condition of the pavement

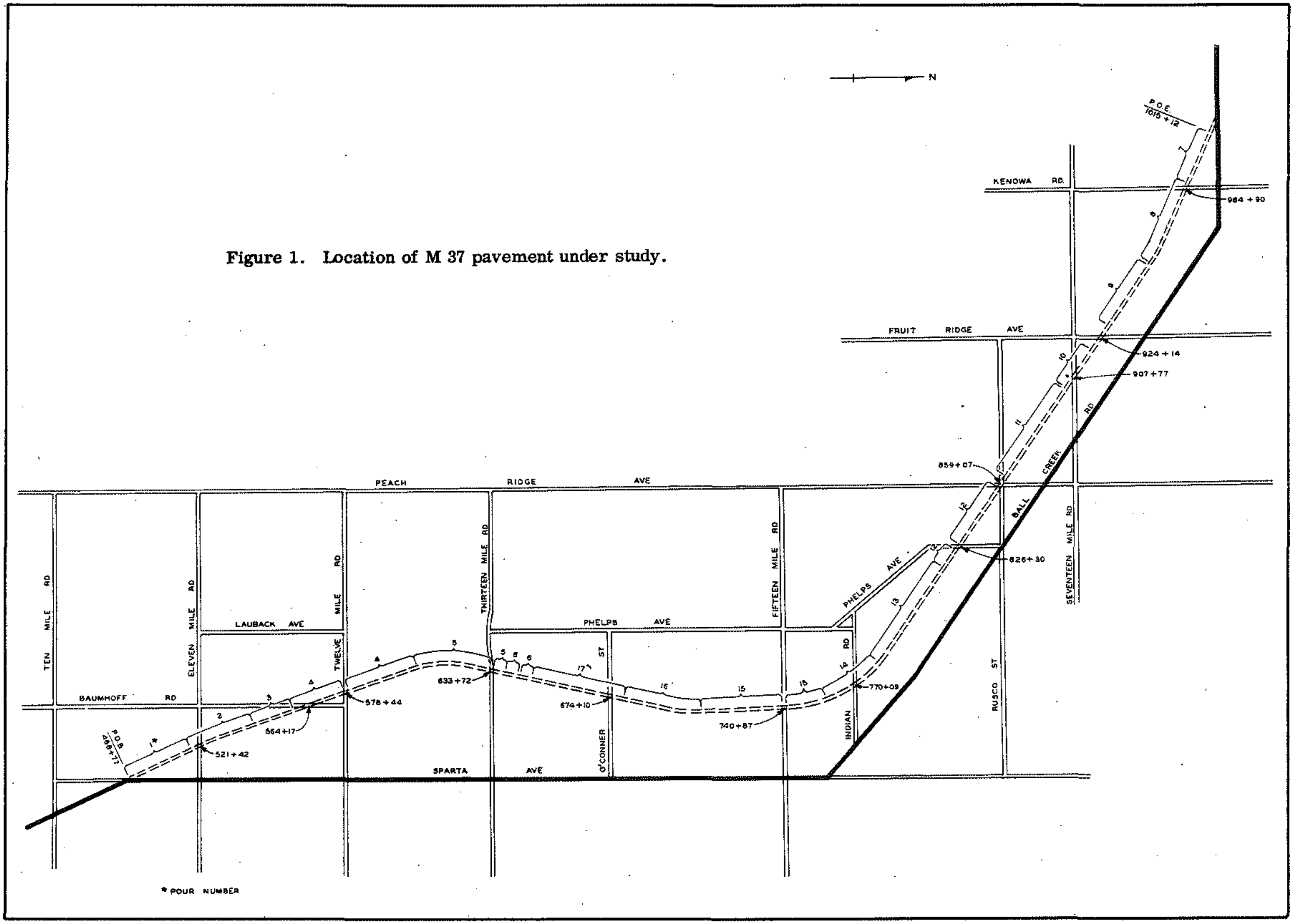


Figure 1. Location of M 37 pavement under study.

TABLE 1
SUMMARY OF CONSTRUCTION AND PERFORMANCE DATA

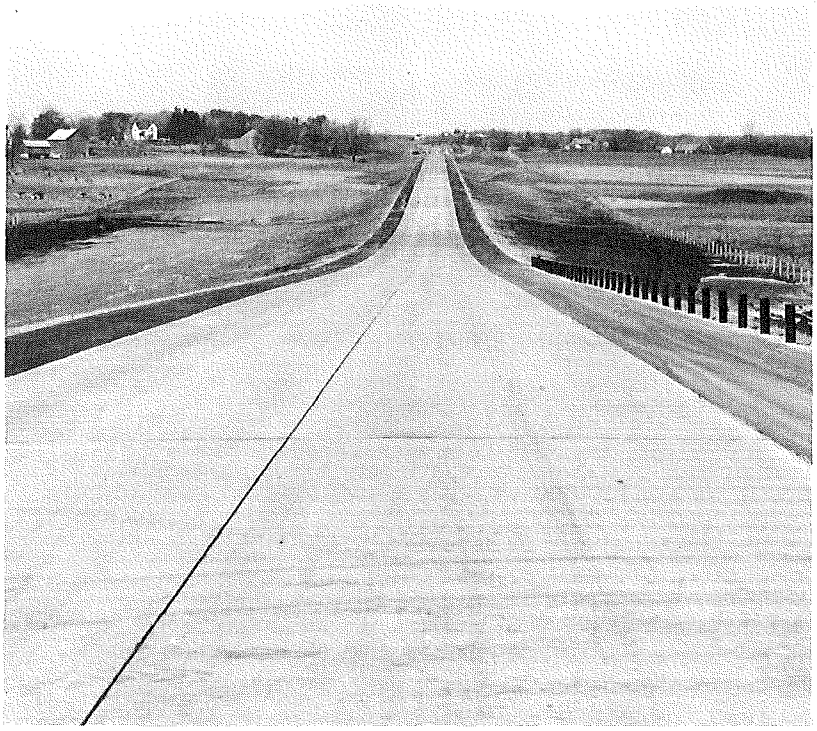
Pour No.	Pour Date	Station to Station	Length, ft	Pour Date Temperatures, F*			Concrete Compressive Strength, psi**			Average Moduli of Rupture, psi ***		Transverse Cracks			
												Northbound Lane		Southbound Lane	
				Min	Max	Variation	High	Low	Avg	7-Day	14-Day	Total	Per 1000 ft	Total	Per 1000 ft
1	7-9-62	491+00 to 514+20	2320	50	76	26	5310	4870	5100	---	---	17	7.3	18	7.8
2	7-10-62	514+20 to 545+58	3138	67	83	16(a)	4900	4650	4775	624	667	33	10.5	32	10.2
3	7-12-62	545+58 to 562+18	1660	55	84	29(a)	4940	4470	4710	---	---	0	---	0	---
4	7-13-62	562+18 to 578+03 579+02 to 601+84	3867	62	80	18(a)	5390	4870	5160	760	---	4	1.0	4	1.0
5	7-14-62	601+84 to 633+59 634+58 to 637+50	3467	54	79	25	5770	5000	5310	---	---	36	10.4	32	9.2
6	7-16-62	637+50 to 643+35 644+31 to 649+79	4600	63	79	16	5190 (only core)			770	---	1	0.2	1	0.2
7	7-18-62	1010+00 to 986+22	2378	53	84	31	5720	4660	5110	632	788	4	1.7	4	1.7
8	7-19-62	986+22 to 958+23	2799	65	84	19	5170	4700	4960	---	---	3	1.1	3	1.1
9	7-27-62	958+23 to 929+71	2852	60	79	19	5450	4920	5250	632	783	0	---	0	---
10	7-30-62	921+75 to 896+27	2548	53	80	27	5350	5180	5260	767	---	0	---	0	---
11	8-1-62	896+27 to 859+56	3671	51	81	30	5200	4520	4940	---	---	5	1.4	8	2.2
12	8-2-62	858+57 to 826+81 825+82 to 822+85	3473	58	84	26	5050	4870	4970	---	---	0	---	3	0.9
13	8-3-62	822+85 to 789+05	3380	65	86	21(a)	5090	4940	5040	---	---	33	9.8	28	8.3
14	8-4-62	789+05 to 754+64	3441	58	83	25(b)	5690	5390	5530	696	751	5	1.5	3	0.9
15	8-6-62	754+64 to 741+11 740+12 to 718+28	3537	61	82	21(c)	5310	4980	5150	---	---	0	---	0	---
16	8-7-62	718+28 to 684+61	3367	63	88	25	5830	5090	5400	755	---	4	1.2	1	0.3
17	8-8-62	684+61 to 649+79	3482	55	88	33	5660	5100	5390	664	770	14	4.0	10	2.9
18	8-9-62	Southbound unreinforced connection with existing M 37 southbound roadway.													
19	8-10-62	Six intersections	----	51	80	29	----	----	----	---	---	0	---	0	---
20	8-11-62	Two intersections	----	64	84	20	----	----	----	---	---	0	---	0	---

(a) Trace of precipitation.
(b) 0.02 in. precipitation.
(c) 0.03 in. precipitation.

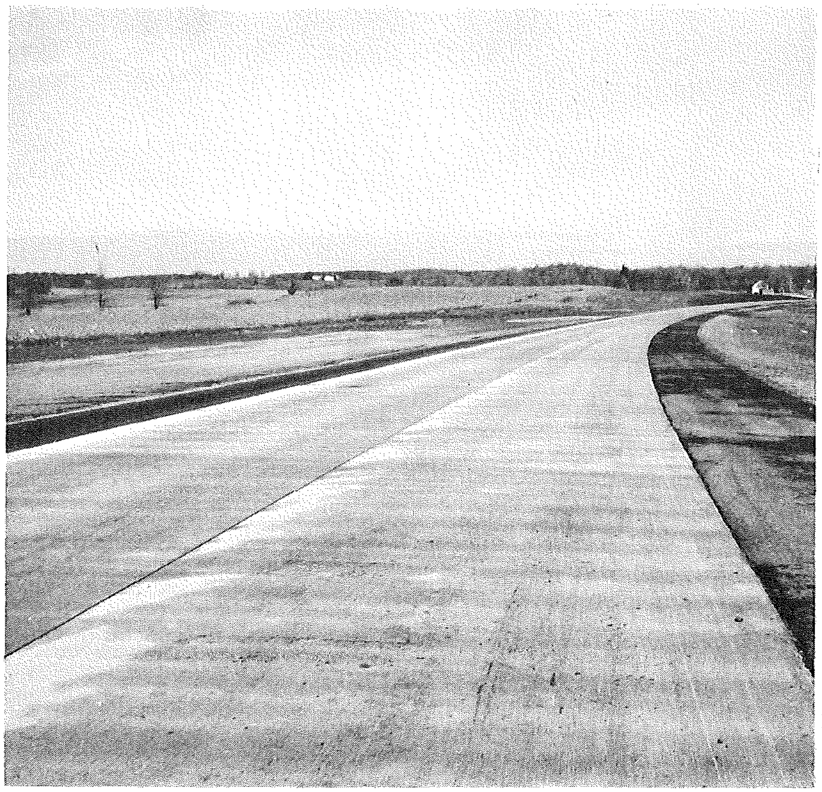
* Variation between maximum temperature on day of pour and minimum temperature the following night.

** One to five cores taken per pour. Core compressive strength corrected to conform to a cylinder whose height is twice its diameter; minimum design strength 3500 psi at 28 days.

*** Minimum 7-day strength = 550 psi; minimum 14-day strength = 600 psi.



Pour 14, looking north from Sta 782+00



Pour 5, looking north from Sta 613+00

Figure 2. General views of project (upper left and lower left); dark areas beside shoulders indicate muck excavations.

Pour 5, Sta 613+00

Figure 3. Typical transverse cracking (upper right and lower right).

Pour 14, Sta 778+75

three to four months after pour (October 1962) when the significant cracking had already occurred. Normally, Michigan concrete (rigid) pavements have an Average Serviceability Index of 4.0 shortly after pour.

Average roughness for the entire project was 119 in. per mi, somewhat better than the weighted arithmetic mean of 138 in. per mi for 36 similar projects tested and reported in 1962.

In addition to the initial pavement condition study in October 1962, the project was inspected again in February 1963. One new crack or fracture was observed along one joint but there were no new full-lane-width or two-lane-wide transverse cracks in addition to those recorded in October. In Pour 5, one of the worst-cracked portions of the pavement, a minor settlement had occurred along a short length of one lane between October and February. This was located in a cut section (Fig. 4), and probably resulted from frost action, grade failure, or both. No new cracking, however, was apparent in this area.

Analysis of Construction Factors

The major construction and performance factors studied in an attempt to account for the severe early cracking observed on the M 37 pavement were: a) temperature conditions during paving operations and the following 24 hr, b) early test strength of the concrete, c) grading operations in relation to eventual paving and failure, d) relative position or sequence of placement of the slabs that later showed most cracking within a particular pour, and e) location of cracks within a particular slab.

The temperature data in Table 1 indicate no significant correlation between temperature variation at the time of construction and cracking. In four pours where cracking was worst, maximum temperature variations were 16, 25, 21, and 26 deg in the first 24 hr; but six other pours which experienced greater temperature variations showed less cracking. In particular, it should be noted that precipitation was negligible or wholly absent on the pouring days.

Modulus of rupture and compressive strength test results (Table 1) indicate no reasonable correlation between early strength of concrete and early cracking. Cores obtained for compressive strength determinations showed pavement thickness to be both adequate and uniform; of 53 cores taken all but 11 were 9-in. thick or more, the exceptions being seven cores of 8.9-in. and four of 8.8-in. thickness.

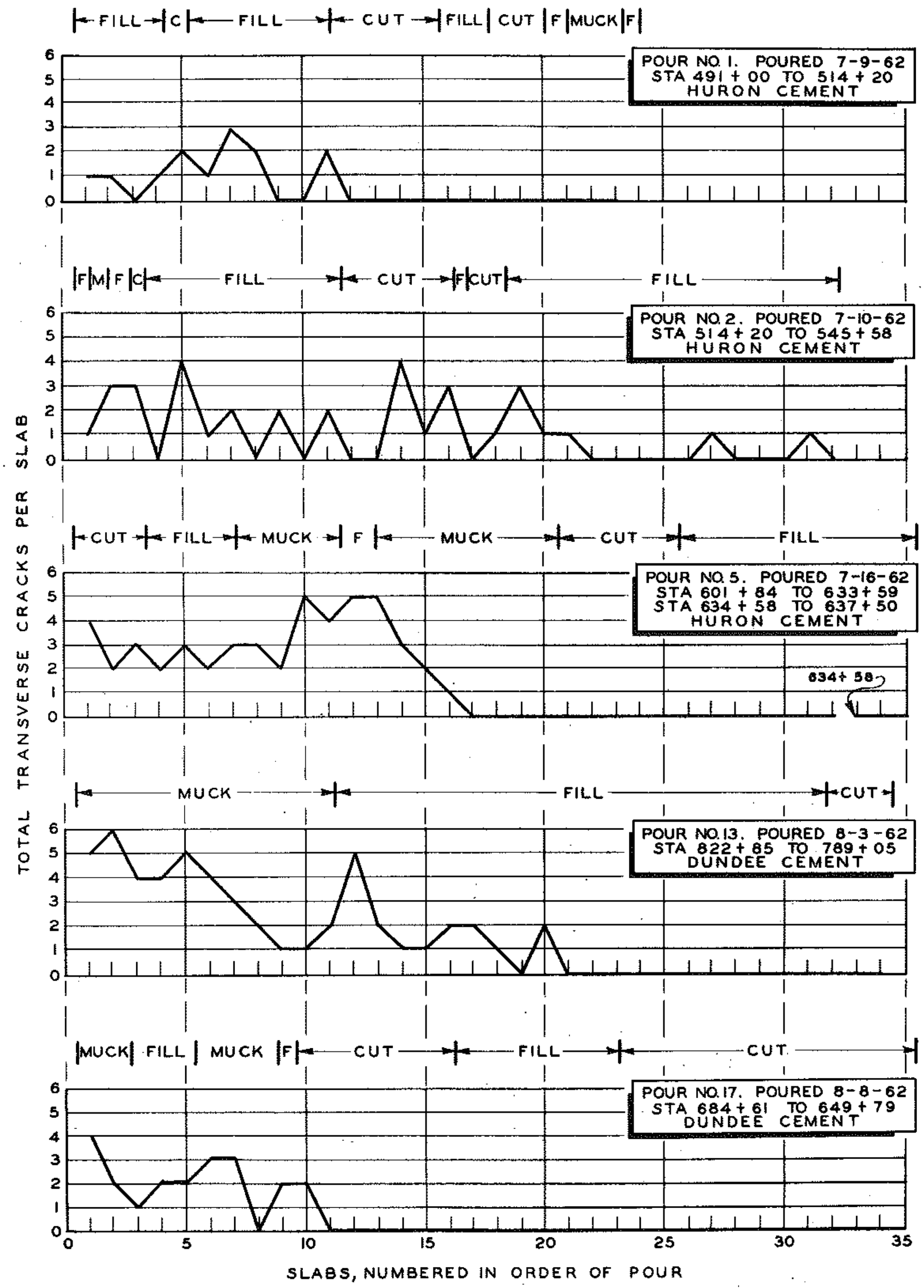


Figure 4. Transverse cracking in relation to sequence of slab construction within the five worst-cracked pours (arranged by pour number, or construction date). "Transverse crack" is defined for these graphs (and Table 3) as any continuous crack, regardless of whether one or two lanes in length.

Fig. 4 shows that foundation conditions are diverse beneath five of the pours where worst cracking occurred, and that no apparent relationship existed between grading area and cracking. Fig. 4 also shows that similar patterns of transverse cracking appear for concrete containing both Huron and Dundee cements. Table 2 indicates no correlation between cracks and foundation conditions, for all cut, fill, and muck areas along the length of the project.

TABLE 2
TRANSVERSE CRACKING IN CUT, FILL, AND MUCK AREAS

Type	Lin Ft	Total Cracks	Cracks Per 1000 Ft
Cut	16055 NB	56	3.4
	16055 SB	43	2.7
Fill	35845 NB	134	3.7
	35845 SB	123	3.4
Muck	4725 NB	20	4.2
	4725 SB	12	2.5

In April 1963, R. C. Mainfort of the Research Laboratory and K. A. Allemeier of the Soils Division inspected the project, accompanied by Karl Rock, District Soils Engineer, and William O'Connor, who had been project engineer for this construction. It was their unanimous opinion that the cracking of the concrete pavement was not due to soil conditions beneath the slabs, for the following reasons:

"1. Practically all the cracking is transverse and more or less equally spaced between contraction joints, which normally would not be true if due to subgrade or base failure.

"2. Very careful density checks were made during construction, the base was proof-rolled, and no weak spots were evident prior to placing the surface.

"3. ...It is not likely that there would be any soil failures so soon after construction as the concrete cracks appeared only two weeks after pouring.

"4. During construction several areas with poor soil conditions were found, but these were all corrected. There are no signs of pavement cracking in those areas where original soil conditions were the worst.

"5. There were no significant subgrade or other soil problems encountered during the past winter and spring at times when soil conditions are at their worst. Close observation by District personnel have shown no indication of soil support weakness throughout the life of this project. Further, there has been no appreciable increase in cracking since the first cracking was noted.

"6. The pavement at present presents a very smooth riding surface with no indication of any subgrade or base settlement. This is true even in the areas of heaviest cracking."

Thus, even though construction records indicate that considerable soil moisture was encountered during grading operations, there is no evidence that the cracking resulted from base failure.

Concrete Shrinkage as a Factor in Early Cracking

Table 3 indicates distribution of cracks by location in pavement slabs of the five worst-cracked pours, and shows no transverse cracking within 10 ft of any construction joint. Since transverse cracks caused by excessive loading frequently appear close to a transverse joint, excessive loading may be eliminated as a likely cause of the early cracking on this project. However, transverse cracks due to shrinkage would be expected to appear first at the mid- or quarter-points of a pavement slab, and Table 3 shows that this is where a majority of the cracks are located on this project.

Fig. 4 shows positions of cracked slabs in relation to sequence of construction within the five worst-cracked pours. It is apparent that the badly cracked slabs, in almost all cases, were those constructed during the first part of the day's operation. This indicates that something must have detrimentally affected the first slabs constructed each day, causing them to crack transversely. Since the cores do not show any significant difference in strength for the cracked sections, it appears that the concrete as mixed on the job was satisfactory, so that certain conditions encountered during the setting period must have been responsible for the subsequent excessive shrinkage.

TABLE 3
DISTRIBUTION OF TRANSVERSE CRACKS IN FIVE CRACKED POURS*

Pour No.	Stationing	Within 10 ft of Contraction Joint	10 to 40 ft from Contraction Joint	Within Center 20 ft of Slab
1	491+00 to 514+20	0	7	6
2	514+20 to 545+58	0	26	9
5	601+84 to 633+59 634+58 to 637+50	0	31	18
14	789+05 to 754+64	0	33	20
17	684+61 to 649+79	0	12	8

* "Transverse crack" defined for this tabulation (and Fig. 4) as any continuous crack, regardless of whether one or two lanes in length.

Some climatic factors commonly contributing to rapid evaporation of concrete moisture and consequent plastic shrinkage cracking of pavement slabs, include low humidity, heat from continuous sunshine, and wind. These climatic forces are resisted by prompt application of a specified curing treatment to the freshly finished pavement, and this curing treatment is particularly critical on very sunny or windy days, and when humidity is low. Although construction records are not sufficiently detailed for a definite determination, it appears likely that in the case of the pours suffering cracking, application of curing compound may have been delayed during periods when climatic conditions would cause rapid evaporation of concrete moisture. A short delay in commencing application of curing compound would probably not cause deleterious effects to the concrete unless the proper combination of climatic conditions existed. However, records indicate that cracking caused by improper curing of morning-poured slabs has often been experienced on numerous older projects.

Summary

1. The cracked slabs were almost always the first ones poured during a day's construction (Fig. 4).

2. Cracks were located at least 10 ft from contraction joints. Most were approximately at mid- or quarter-points of the slabs (Table 3).

3. Cracks appeared early after the concrete was poured, when traffic using the pavement consisted primarily of contractor's vehicles. No new transverse cracks appeared between October 1962 and February 1963, after the road had been opened to normal traffic.

4. No apparent correlation exists between transverse cracking and a) daily air temperature variation, b) concrete compressive strength, or c) grading operations (Table 1, Table 2, and Fig. 4).

Conclusions

Because of their locations within the slabs, it appears that the transverse cracks in this project resulted from shrinkage. The first concrete poured during the day in the distressed sections exhibited a tendency toward shrinkage cracking, while that poured later did not. It appears probable, therefore, that the cracks were due to a delay in beginning of curing operations coupled with such climatic factors as wind, sun, and low humidity.