Continuously-Reinforced Concrete Pavements in Pennsylvania—A Six-Year Progress Report

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After five and six years of service life, the two continuously-reinforced concrete pavements in York and Berks Counties, Pa., have supplied data sufficient for evaluating the effects of the variables under which the pavements were constructed. These projects, on Interstate Routes 83 and 78, respectively, are located on heavily-traveled arteries where approximately one-third of the traffic is rated as heavy truck.

The background history of the two projects is reviewed briefly and the design variables of each pavement are described. Significantly different data are obtained from these variables, particularly from the season of paving.

Included are data on crack frequency, crack width, traffic count, and roughness surveys. Annual end movement and performance of the terminal joints are described.

Shortly after completion of the Berks County project, several wide cracks developed and a subsequent investigation showed these to be lap failures, for the most part. Satisfactory repairs were made, but in 1960, a portion of the 7-in. pavement had to be replaced, essentially because of foundation failure and poor subbase densification. The investigation accompanying this repair work is reported in detail.

The York County pavement to date is performing adequately. The relative performance of both pavements is discussed and a suggested design for continuously-reinforced pavements is offered.

• TWO continuously-reinforced concrete pavements in Pennsylvania have accrued five and six years of service life. Both pavements are strategically located on heavily-traveled arteries and should contribute greatly to the evaluation of the merits of continuous paving. The background history of these two projects is similar in many respects, but the performance to date is remarkably different. A complete description of construction techniques and recorded data relative to these two projects is given elsewhere (1, 2). The following is a very brief description of the important features and variables of both pavements.

The York County project, slightly in excess of 2 miles, is on Interstate 83, the Baltimore-Harrisburg Expressway, 3 miles north of York, Pa. (Fig. 1). The pavement was placed in the fall (September and October) of 1956. It is uniformly 9 in. thick and rests on a 6-in. granular subbase throughout its length. Steel reinforcement is of the bar mat type and was designed for 0.5 percent of the cross-sectional area. The mats were fabricated longitudinally with hard grade No. 5 bars and transversely with No. 3 bars. The performance to date is judged to be quite normal and acceptable by present standards.

Unfortunately, the same is not true of the Berks County project at Hamburg, Pa. When this pavement was in the embryo stage, much thought was given to design vari-

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ables by Bureau of Public Roads and Pennsylvania Highway Department engineers who fully realized that failures might possibly be encouraged by the minimum design variables. Feeling that significant data would not be obtained unless a wide range of variables were included, the decision was made to permit construction of sections where assurance of adequate performance was not entirely known.

The Berks County pavement, just short of 2 miles in length, is a section of Interstate 78 and is located 2 miles east of Hamburg, Pa. (Fig. 2). The project was constructed in the spring and summer of 1957 with the exception of a short length of pave-

Figure 1. Interstate 83, Baltimore-Harrisburg Expressway, York County.

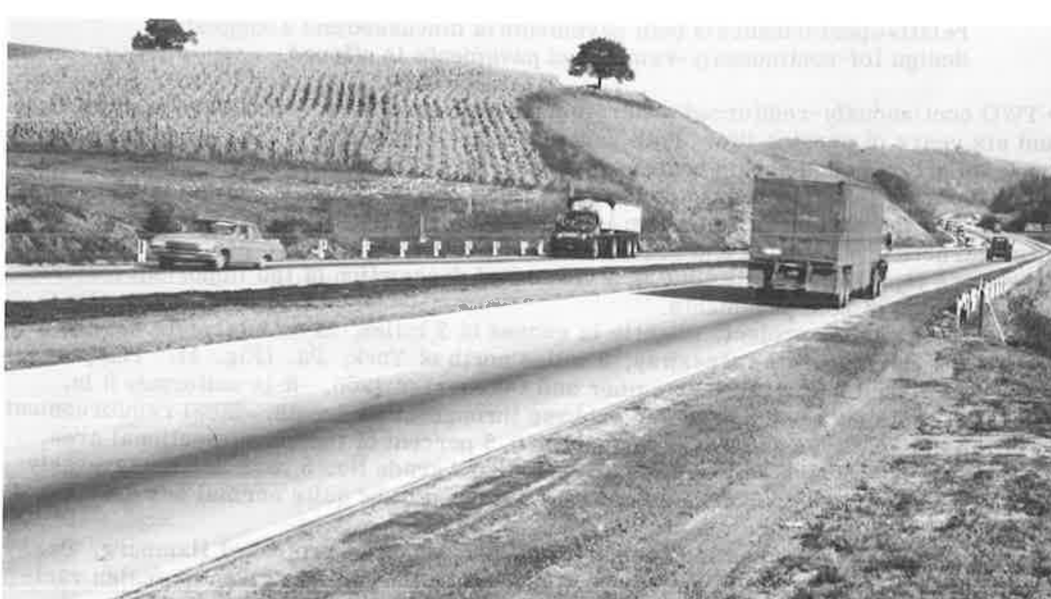


Figure 2. Interstate 78, US 22, Berks County.

ment (1,800 ft) placed in October because of a delay caused by a slide condition. Pavement thicknesses were varied to include 7-, 8-, and 9-in. depths and the subbase was designed for alternate depths of 3- and 6-in. minimums, but the final results varied erratically from the original intent as described later in this report. Reinforcing steel comprised 0.5 percent of the cross-sectional area and was of the bar mat type except for 1,000 ft of welded wire mesh.

YORK PAVEMENT

Much of the success of the York project, it is felt, can be attributed to careful workmanship, but most of all, to the time of year in which it was placed. During construction, ambient temperatures varied between an average high of 66 F and an average low of 44 F. Thus, during the critical curing period, even though the bar mats were overlapped only 20 diameters (12 in.), pavement stresses were not excessive and cracks developed in a normally expected pattern.

During the construction of both continuous pavements, Lehigh University, under a research agreement with the Commonwealth, worked in close accord with the Department of Highways and was responsible for a most comprehensive program of instrumentation. Data were obtained from brass plugs installed on each side of a plane of weakness near the edge of the pavement to measure crack openings; from resistance wire temperature gages in the pavement to indicate local temperatures; and from Bakelite SR-4 strain gages attached to the surface of the longitudinal steel reinforcing bars. These data are available in several published reports (3, 4, 5).

Records maintained by the Highway Department include crack frequency, crack width, traffic count, and roughness surveys. Crack frequency surveys were conducted weekly during the first month of pavement life, then monthly for six months, and annually thereafter. For the York pavement, it was not until the sixth year of service life that the crack pattern appeared to be leveling off. Even in the fifth year, the new cracks developing showed an increase of 25.4 percent over the total number recorded through the fourth year. However, in the sixth year, the rate of increase was only 1.5 percent.

In terms of distance between cracks, surveys indicate (Table 1) that, at the present time, the average crack spacing in the outside or traveling lane is 8.8 ft, whereas the corresponding spacing in the passing lane is 10.6 ft. There are no cracks within the first 100 ft of both ends of the continuous slabs. In the next 100 ft, an average of only 3 cracks per 100 ft is recorded, but immediately beyond 200 ft, the crack pattern is characteristic of that evidenced throughout the job, and for that matter, is consistent with the results obtained from other continuous pavements.

There has been some concern in this State over the appearance of the cracks on the York pavement, particularly the wide, irregularly spalled openings at the surface. The Materials Bureau has always felt these were only superficial and confirmed this opinion by removing a core over a typical crack. Immediately below the surface, the crack assumed hairlike proportions, and as it progressed toward the center of the core, or pavement slab, it became almost indiscernible. The true appearance of the crack, unspalled and void of traffic wear can be observed along the pavement edge. These conditions are shown in Figure 3. It is not felt that moisture of any appreciable amount can penetrate this opening.

Initial crack widths were recorded by a microscope capable of reading to thousandths of an inch, but after an invar-type gage was constructed, all subsequent readings were taken with this equipment. Unless measuring plugs have been installed in the pavement before the development of any cracking, the invar gage cannot be used to record an actual crack width, but it can be used to determine the extent to which any crack is opening or closing.

TABLE 1

CRACK FREQUENCY SURVEY, YORK PROJECT

Age (yr)	Average Distance Between Cracks (ft)			
	Northbound Lane		Southbound Lane	
	Outside	Inside	Outside	Inside
1/12	51.6	27.6	31.7	24.7
1/2	19.1	18.9	19.4	18.1
1 1/2	14.1	16.1	16.2	14.6
2	14.0	15.8	15.9	14.3
3	11.2	14.5	13.1	12.9
4	10.4	14.2	12.0	12.5
5	8.1	11.4	9.5	10.2
6	8.0	11.1	9.5	10.0

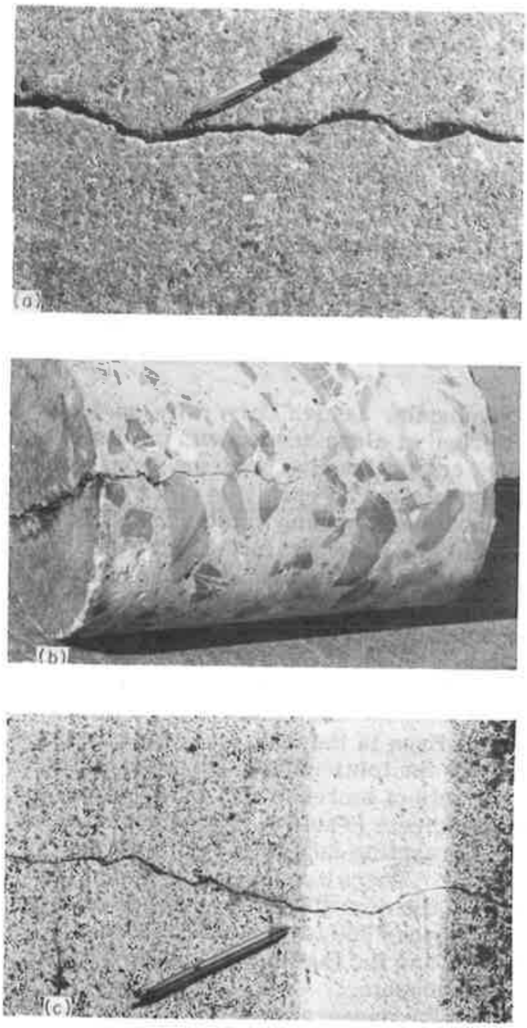


Figure 3. Typical crack on York pavement: (a) spalled appearance at surface, (b) core removed directly over crack, (c) appearance of crack at edge of pavement.

Thus it was necessary to correlate the first invar gage reading with a microscope reading taken at the same time. This was accomplished with a good measure of accuracy because the pavement was not opened to traffic for over a year and the surface condition of the crack was quite intact and unspalled.

Areas selected for crack width studies were 500-ft sections at the beginning, middle, and end of each traffic lane. Widths were recorded between brass plugs set in the pavement on both sides of the cracks and temperatures were recorded by a thermometer inserted into a 6-in., oil-filled brass tube imbedded in the concrete.

During the last 5½ years, crack width readings have been taken twice yearly during typical summer and winter variations. From a total of more than 249 measurements (Table 2), it has been observed that crack widths vary from an average of 0.004 to 0.042 in. per lane. The average crack width in the summer is 0.017 in. and in the winter it increases to 0.023 in., making a seasonal differential of approximately 0.006 in. per crack. This differential is 0.004 in. on the outside lanes and 0.008 in. on the inside lanes, indicative of the greater percentage of cracks occurring in the outside lanes. Crack widths on the first and last 500-ft sections of the continuous slabs were only slightly greater than those measured in the center section of the northbound lanes but were considerably greater in the southbound lanes for unexplainable reasons.

Pavement elongation has been negligible during five years of observation. According to data collected by Lehigh University, there was a measured growth of ¼ in. at 70°, after five years of service on the south end of the continuous pavement where a finger-type bridge expansion joint connects the project to conventional pavement. Seasonal differences in the length of the slab are not more than ⅜ in. At the north end of the project, four dowel-bar expansion assemblies were placed 61½ ft apart in the standard 10-in. pavement to allow end movement of the continuous slab. From observation it appears that the movement of the continuous pavement has influenced only the first expansion joint, and that total growth at this end has been less than at the south end. Present findings indicate that the series of four expansion joints provides a suitable end condition for the continuous reinforcement. Others have found the series of expansion joints not entirely successful. Two favorable situations however, not always available, may have been present to assure success: (a) construction in the fall of the year when low daily temperatures prevailed and (b) apparently high friction between the pavement and the base. Foundation keys or deliberately planned high friction between pavement and base are well worth considering in future designs.

Recent roughness surveys by the Bureau of Public Roads roughometer have indicated

TABLE 2

CRACK WIDTH SURVEY, YORK PROJECT

Lane	Age (yr)	First 500 Ft		Middle 500 Ft		Last 500 Ft	
		Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)
Northbound:							
Outside	1½	78	0.018	76	0.017	80	0.023
	2	55[a]	0.010	55[a]	0.010	59[a]	0.018
	2½	85	0.010	85	0.010	87	0.018
	3	37	0.017	37	0.016	32	0.025
	3½	86	0.013	81	0.013	85	0.022
	4	24	0.019	33	0.017	33	0.027
	4½	84	0.015	83	0.014	83	0.025
	5	29	0.019	34	0.016	34	0.030
	5½	85	0.017	85	0.015	86	0.028
	Avg. summer readings	84	0.015	82	0.014	84	0.023
	Avg. winter readings	30	0.018	35	0.016	33	0.027
	No. cracks surveyed	41		26		19	
Inside	1½	80	0.018	82	0.020	81	0.024
	2	57[a]	0.004	56[a]	0.012	59[a]	0.010
	2½	93	0.002	93	0.012	86	0.008
	3	32	0.015	32	0.023	40	0.017
	3½	86	0.005	81	0.014	85	0.011
	4	24	0.017	33	0.023	33	0.020
	4½	84	0.007	83	0.015	83	0.014
	5	29	0.018	34	0.026	34	0.026
	5½	85	0.012	85	0.018	86	0.018
	Avg. summer readings	86	0.009	85	0.016	84	0.015
	Avg. winter readings	28	0.017	33	0.024	36	0.021
	No. cracks surveyed	36		23		29	
Southbound:							
Outside	1½	76	0.024	80	0.013	87	0.012
	2	60[a]	0.032	59[a]	0.001	60[a]	0.021
	2½	90	0.033	94	0.002	95	0.022
	3	35	0.039	35	0.007	39	0.027
	3½	86	0.037	81	0.003	85	0.026
	4	24	0.043	33	0.008	36	0.030
	4½	84	0.039	83	0.005	83	0.028
	5	29	0.045	34	0.009	34	0.037
	5½	85	0.044	85	0.005	86	0.031
	Avg. summer readings	84	0.035	85	0.006	87	0.024
	Avg. winter readings	29	0.042	34	0.008	36	0.031
	No. cracks surveyed	34		25		24	
Inside	1½	78	0.015	84	0.011	85	0.014
	2	60[a]	0.026	59[a]	0.001	60[a]	0.021
	2½	86	0.002	88	0.000	88	0.020
	3	35	0.032	35	0.008	39	0.029
	3½	86	0.024	81	0.002	85	0.023
	4	24	0.033	33	0.009	36	0.028
	4½	84	0.023	83	0.002	83	0.023
	5	29	0.034	34	0.010	34	0.032
	5½	85	0.029	85	0.004	86	0.026
	Avg. summer readings	84	0.023	84	0.004	85	0.021
	Avg. winter readings	29	0.033	34	0.009	36	0.030
	No. cracks surveyed	43		30		26	

[a]Not included in average, being neither typical winter or summer temperature.

that the York continuous pavement shows no increase in surface roughness after five years of service. Relative roughness measured an average 110 units per mile. Surprisingly, the inner lanes showed a 5 percent lower reading than the outside lanes. The riding quality of adjacent standard pavement was slightly better, however, at 95 units per mile.

Traffic on the York pavement in the last three years has increased over 20 percent (Table 3 and Fig. 4). Surveys taken as late as September 1962 reveal that the average daily traffic is now running over 10,600 vehicles, 24 percent of which can be classified as heavy truck traffic. Information is not available relative to the amount of truck

TABLE 3

TRAFFIC COUNT, YORK AND HAMBURG PROJECTS

Classification	York Project 1959	York Project 1961	York Project 1962	Hamburg Project 1958	Hamburg Project 1959	Hamburg Project 1961	Hamburg Project 1962
Passenger vehicles	7,316	7,758	7,526	4,413	5,716	5,645	6,148
Light trailers, pick-ups, panels	-[a]	455	569	190	-[a]	311	299
2- and 3-axle trucks[b]	408	701	703	416	369	400	473
3- and 4-, or 5-axle semitrailers[c]	838	1,504	1,815	3,275	3,044	3,104	3,613
Busses	39	40	28	16	12	14	11
Total	8,601	10,458	10,641	8,310	9,141	9,474	10,544

[a]Included in passenger vehicles.

[b]Maximum gross weights: 33,000 lb for 2-axle, 47,000 lb for 3-axle.

[c]Maximum gross weights: 50,000 lb for 3- and 4-axle, 60,000 lb for 5-axle.

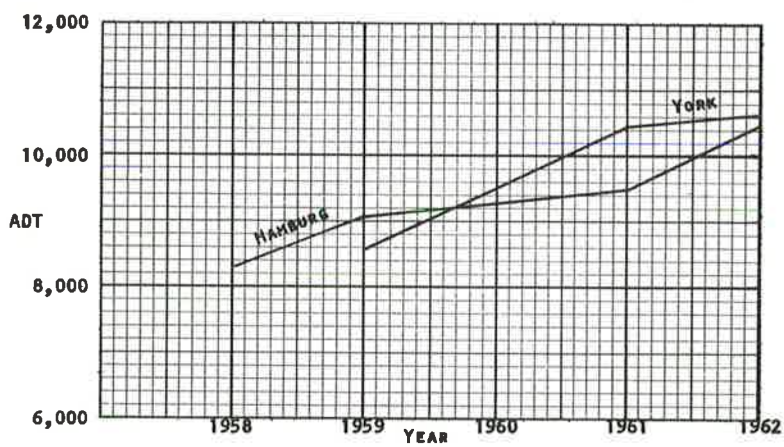


Figure 4. Traffic count, both pavements.

traffic in each lane, however every observation indicates that a very large percentage uses the outside lanes. There is every indication that traffic will substantially increase in each succeeding year as more connections are completed on the Interstate System.

Thus it can be said that the York pavement is behaving as a continuous pavement should: crack widths and frequency are within accepted tolerances and appear to have stabilized. The riding quality is satisfactory, no unusual conditions have been found to exist, and no maintenance has been required since the pavement was placed. It would be expected that many satisfactory years of service will be obtained from the York pavement.

HAMBURG PAVEMENT

The pavement at Hamburg is of a different breed, stemming partly from design variables as mentioned before. There have been a number of interesting conclusions reached and some very successful repairs have been made which will be of interest to those whose continuous pavements are giving similar difficulty.

The project was placed under entirely different weather conditions than the York job, which was constructed in the fall. During the period from May through July 1957 concrete was placed on the Hamburg pavement under temperatures ranging from an average low of 67 F to an average high of 85 F. In an 1,800-ft section placed in October of the same year, the corresponding average temperatures were 42 and 64 F.

The number of cracks appearing in the Hamburg pavement was significantly greater than that at York, being as much as 85 percent greater in surveys conducted up through one year. The frequency of cracking was always greater in the area comprising the beginning of the day's pour, but this effect leveled out after the first year or so. During the first year, the cracking encountered in the section placed in October was only one-half that recorded on the rest of the pavement, indicating the effect which is exerted by the season of paving. Even today, after five years, the crack pattern is considerably lower in this particular section.

As given previously in Table 1, the average distance between cracks at York ranged from 8.0 to 11.1 ft. At Hamburg, this same spacing varies from 4.9 to 8.5 ft (Table 4). The spacing between cracks in the inside lanes is an average 1½-ft longer than in the adjacent outside or travel lane. There is no appreciable difference in the average crack spacing of the 7- and 8-in. deep sections, but the 9-in. pavement shows a marked increase in distance between cracks. Average distance between cracks in the 7- and 8-in. pavements is 6.2 ft, and in the 9-in. pavement, it is 7.5 ft. But in the 9-in. section placed in October, the spacing is 8.9 ft which compares favorably with the data recorded at York.

Crack widths were also recorded at Hamburg on 100-ft sections at the beginning, middle, and end of each pavement thickness. From a total of 325 plugged cracks, readings indicate that average summer widths are 0.018 in. and average winter readings are 0.023 in. These figures, shown in Table 5, correspond almost identically

TABLE 4

CRACK FREQUENCY SURVEY, HAMBURG PROJECT

Pavement Thickness (in.)	Age (yr)	Average Distance Between Cracks (ft)			
		East Lane		West Lane	
		Outside	Inside	Outside	Inside
7	1/12	10.6	12.6	14.3	12.4
	½	8.2	9.2	8.1	8.8
	1	6.2	8.5	7.1	8.5
	2	5.8	8.0	6.4	8.1
	3	5.2	7.9	5.8	8.0
	4	-[a]	-[a]	5.1	7.0
	5	-[a]	-[a]	4.9	6.6
8	1/12	11.8	15.2	16.5	16.7
	½	8.9	9.6	7.9	8.8
	1	7.8	8.7	6.9	8.6
	2	7.3	7.6	6.4	8.1
	3	6.8	7.5	6.0	7.9
	4	6.4	7.0	5.4	7.1
	5	6.3	6.7	5.3	6.9
9	1/12	24.1	21.0	9.2	13.1
	½	16.8	14.1	8.0	8.4
	1	14.6	13.1	7.6	8.0
	2	11.2	10.2	7.5	7.8
	3	9.6	9.9	7.3	7.6
	4	8.2	8.8	6.4	7.4
	5	8.1	8.5	6.2	7.1

[a]Pavement replaced 1960.

TABLE 5

CRACK WIDTH SURVEY, HAMBURG PROJECT

Lane	Age (yr)	7-In. Pavement						8-In. Pavement						9-In. Pavement					
		1st 100 Ft		Mid 100 Ft		Last 100 Ft		1st 100 Ft		Mid 100 Ft		Last 100 Ft		1st 100 Ft		Mid 100 Ft		Last 100 Ft	
		Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)	Temp. (°F)	Width (in.)
East:																			
Outside	½	50[a]	0.012	50[a]	0.013	50[a]	0.018	50[a]	0.014	50[a]	0.017	54[a]	0.020	71[b]	0.011	52[a]	0.013	52[a]	0.018
	1	65[a]	0.008	65[a]	0.011	65[a]	0.020	64[a]	0.012	64[a]	0.015	64[a]	0.017	78	0.012	72[a]	0.011	72[a]	0.012
	1½	58[a]	0.011	58[a]	0.015	58[a]	0.021	56[a]	0.010	56[a]	0.017	56[a]	0.020	85	0.021	66[a]	0.014	58[a]	0.023
	2	86	0.011	86	0.016	86	0.019	86	0.017	86	0.019	86	0.022	34	0.032	86	0.016	86	0.022
	2½	37	0.015	37	0.019	37	0.023	37	0.023	37	0.023	37	0.027	92	0.022	37	0.019	37	0.026
	3	74	0.012	74	0.018	74	0.022	80	0.020	80	0.020	80	0.024	-	-	92	0.018	92	0.030
	4	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	84	0.021	84	0.022	84	0.024	32	0.034	80	0.020	80	0.034
	4½	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	24	0.026	24	0.026	24	0.030	80	0.024	32	0.024	32	0.033
	5	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	80	0.025	80	0.022	80	0.025	-	-	84	0.019	84	0.034
Avg summer readings		80	0.012	80	0.017	80	0.021	83	0.021	83	0.021	83	0.024	81	0.018	86	0.018	86	0.030
Avg winter readings		37	0.015	37	0.019	37	0.023	31	0.025	31	0.025	31	0.029	33	0.033	35	0.022	35	0.030
No. cracks surveyed		11		10		9		8		8		10		14		9		4	
Inside	½	36	0.018	36	0.017	36	0.016	40[a]	0.017	40[a]	0.016	40[a]	0.014	73[b]	0.012	35	0.019	42	0.023
	1	84	0.013	84	0.014	84	0.014	84	0.013	84	0.012	84	0.010	78	0.019	91	0.011	91	0.018
	1½	50[a]	0.015	50[a]	0.020	50[a]	0.017	60[a]	0.016	60[a]	0.014	60[a]	0.014	85	0.026	54[a]	0.018	54[a]	0.025
	2	86	0.016	86	0.018	86	0.018	84	0.017	84	0.014	84	0.013	34	0.039	84	0.015	84	0.024
	2½	28	0.022	28	0.025	28	0.024	28	0.025	28	0.020	28	0.019	92	0.030	28	0.022	28	0.026
	3	74	0.018	74	0.020	74	0.020	80	0.019	80	0.016	80	0.016	-	-	92	0.018	92	0.026
	4	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	84	0.021	84	0.016	84	0.017	80	0.048	80	0.020	80	0.029
	4½	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	24	0.027	24	0.025	24	0.025	83	0.037	32	0.025	32	0.033
	5	-[c]	-[c]	-[c]	-[c]	-[c]	-[c]	80	0.034	80	0.018	80	0.019	-	-	84	0.021	84	0.033
Avg summer readings		81	0.016	81	0.017	81	0.017	82	0.021	82	0.015	82	0.015	82	0.029	86	0.017	86	0.026
Avg winter readings		32	0.020	32	0.021	32	0.020	26	0.026	26	0.023	26	0.022	34	0.039	32	0.022	34	0.027
No. cracks surveyed		9		9		8		5		10		9		8		6		3	
West:																			
Outside	½	42[a]	0.013	70[a]	0.008	70[a]	0.011	70[a]	0.009	73[a]	0.012	64[a]	0.011	63[a]	0.011	63[a]	0.012	54[a]	0.008
	1	92	0.011	92	0.008	92	0.014	92	0.012	92	0.014	92	0.012	92	0.012	92	0.013	92	0.011
	1½	76	0.012	76	0.009	76	0.015	65[a]	0.013	65[a]	0.014	73	0.013	73	0.013	73	0.013	76	0.011
	2	87	0.015	87	0.012	87	0.017	87	0.016	92	0.019	92	0.016	92	0.017	92	0.015	92	0.015
	2½	32	0.016	32	0.015	32	0.019	32	0.018	32	0.023	32	0.020	32	0.024	32	0.019	32	0.016
	3	74	0.017	74	0.014	74	0.019	80	0.016	80	0.021	80	0.019	92	0.022	92	0.017	92	0.016
	4	84	0.020	84	0.015	84	0.019	84	0.017	84	0.022	84	0.021	80	0.024	80	0.019	80	0.019
	4½	32	0.031	32	0.016	32	0.023	24	0.022	24	0.029	24	0.027	32	0.031	32	0.023	32	0.019
	5	84	0.022	84	0.017	84	0.021	80	0.019	80	0.023	80	0.022	84	0.025	84	0.019	84	0.020
Avg summer readings		83	0.016	83	0.013	83	0.018	85	0.016	86	0.020	84	0.017	86	0.019	86	0.016	86	0.015
Avg winter readings		32	0.024	32	0.016	32	0.021	28	0.020	28	0.026	28	0.024	32	0.028	32	0.021	32	0.018
No. cracks surveyed		7		12		11		10		11		8		13		12		9	
Inside	½	58[a]	0.007	58[a]	0.012	58[a]	0.011	64[a]	0.010	64[a]	0.008	64[a]	0.008	70[a]	0.010	68[a]	0.012	68[a]	0.008
	1	92	0.010	92	0.013	92	0.011	92	0.012	87	0.010	87	0.005	91	0.011	91	0.013	91	0.011
	1½	68[a]	0.012	68[a]	0.014	68[a]	0.012	68[a]	0.012	80	0.010	80	0.006	72[a]	0.012	72	0.014	72	0.015
	2	92	0.014	92	0.017	92	0.016	92	0.016	92	0.013	92	0.016	92	0.014	92	0.020	92	0.016
	2½	32	0.017	32	0.024	32	0.021	34	0.021	34	0.020	34	0.020	34	0.018	34	0.025	34	0.021
	3	74	0.016	74	0.019	74	0.018	80	0.018	80	0.017	84	0.017	92	0.016	92	0.022	92	0.020
	4	84	0.016	84	0.020	84	0.019	84	0.018	84	0.018	84	0.018	80	0.017	80	0.025	80	0.025
	4½	32	0.021	32	0.026	32	0.026	24	0.026	24	0.028	24	0.026	32	0.023	32	0.031	32	0.029
	5	84	0.018	84	0.021	84	0.021	80	0.020	80	0.020	80	0.019	80	0.019	82	0.026	84	0.028
Avg summer readings		85	0.015	85	0.018	85	0.017	86	0.017	84	0.015	85	0.014	87	0.015	87	0.021	88	0.020
Avg winter readings		32	0.019	32	0.025	32	0.024	29	0.024	29	0.024	29	0.023	33	0.021	33	0.028	33	0.025
No. cracks surveyed		11		11		11		10		9		2		10		9		9	

[a]Not included in average being neither typical winter or summer temperature.

[b]Placed October 1957, 100-ft continuous brass plugs, 10-in. centers.

[c]Pavement replaced November 1960.

with those at York. There is a noticeable tendency for the cracks to creep in width over a period of years so that the readings recorded at five years are now approximately double the widths taken at six months. There is very little difference to be found in the variation of crack widths in the 7-, 8-, and 9-in. sections. In the westbound lanes, for example, an average of all cracks recorded shows a summer opening of 0.017 in. for the 7- and 8-in. pavements and 0.018 in. for the 9-in. pavement. Winter readings are correspondingly close. There is a very slight tendency for the crack widths to be narrower in the 7-in. section. It must be remembered that the first 100 ft of the 7-in. pavement and the last 100 ft of the 9-in. pavement as given in Table 5 are the actual ends of the pavement. All other beginning, middle and end 100-ft sections are contained within these extremities. A variation between summer and winter readings averaged 0.005 in. for the 7-in. pavement, 0.004 for the 8-in., and 0.007 for the 9-in. concrete. The difference between crack widths in the inside and outside lanes is not significant.

It might be mentioned that the temperatures appearing in the tables throughout this report are air temperatures inasmuch as the early readings were recorded as such before installation of the brass thermometer well, and there was no desire to confuse the issue by switching from one method to the other. An accurate record has been kept, however, of both methods and it has been found that, in the summer, concrete temperatures averaged 3° higher than air temperatures, whereas in the winter, there was practically no difference.

When the 1,800-ft section of 9-in. pavement was placed in October, brass plugs for crack width measurements were installed in the fresh concrete on 10-in. centers for a distance of 100 ft to permit true readings of crack widths as they developed. Precise readings were taken between each set of plugs the first two days after placement and at regular intervals thereafter. It has been encouraging that these readings correspond quite favorably with those where the initial width readings were obtained by microscope.

There is very little evidence to indicate what effect subbase depth had on pavement performance. If cracking is of significance, it can be reported that there is a slight trend indicating that fewer cracks have developed over the 6-in. subbase than over the 3-in. This is apparent for all three pavement depths. There is no evidence to prove that the wire mesh section performed any better or worse than adjoining bar mat sections.

The volume of traffic has increased tremendously at Hamburg and shows every indication of continuing so. In the past four years, an increase of 27 percent in total vehicular traffic has been noted (Table 3 and Fig. 4). Present average daily traffic is now over 10,500 vehicles of which 39 percent is heavy truck.

Recent roughometer surveys with the BPR unit showed a reading of 93 units per mile for the 9-in. pavement, 104 units for the 8-in. pavement, and 113 units for the 7-in. section. This is compared to an average reading of 76 units per mile for adjacent, standard pavement on the same route.

End movement of the pavement slab ranges from ¾ to 1 in. At the end of two years, permanent growth or creep has been approximately ¼ in. The elaborate bridge-type finger joint, built over a box culvert with drainage through the shoulder, has performed quite satisfactorily; however, it is felt that such expense need not be incurred and that the series of expansion joints, or such devices where 1½ to 2 in. of movement is provided, are adequate.

PAVEMENT REPAIR

Shortly following the completion of the Hamburg project, generally within three months, it became evident that a number of cracks were becoming unusually wide; some of them measuring ¼ to ½ in. at the surface (Fig. 5). An investigation conducted in the spring of 1958, when sufficient pavement was removed at the edge of the roadway to expose the steel, revealed in three instances that there was no overlap of reinforcing steel at all. At two locations, the wide cracks were not at overlaps. The average lap of steel in the remaining ten areas was 7½ in., ranging from 3 to 11 in. The specifications covering this project did not require the bar mats to be tied. It is apparent that this requirement should have been specified and certainly should be written into future contracts involving continuously-reinforced pavements.

After determining the cause of the cracking, arrangements were made to repair the defective areas. It was essential that the work be performed carefully. To insure this, detailed construction specifications were written. The concrete pavement repairs consisted of removal of the existing pavement, restoration of the continuity of the longitudinal reinforcing steel, and replacement of the pavement with high-early strength cement concrete.

In repairing the steel, No. 5 deformed steel bars of the same quality as the existing steel were required for splicing and were of sufficient length to provide an 18-in. overlap at both ends. The steel was welded at the center of the lap with a ½-in. bead, on one side only, for a length of 5 in. No. 3 transverse bars were placed and tied to the longitudinal bars in accordance with the pattern of the original bar mats.

Of 13 such areas repaired, only one patch was not successful. After four years, these repairs (Fig. 5) are performing adequately, and although new cracks have formed in the longer patches, they are of a pattern typical of a normal continuous pavement. The

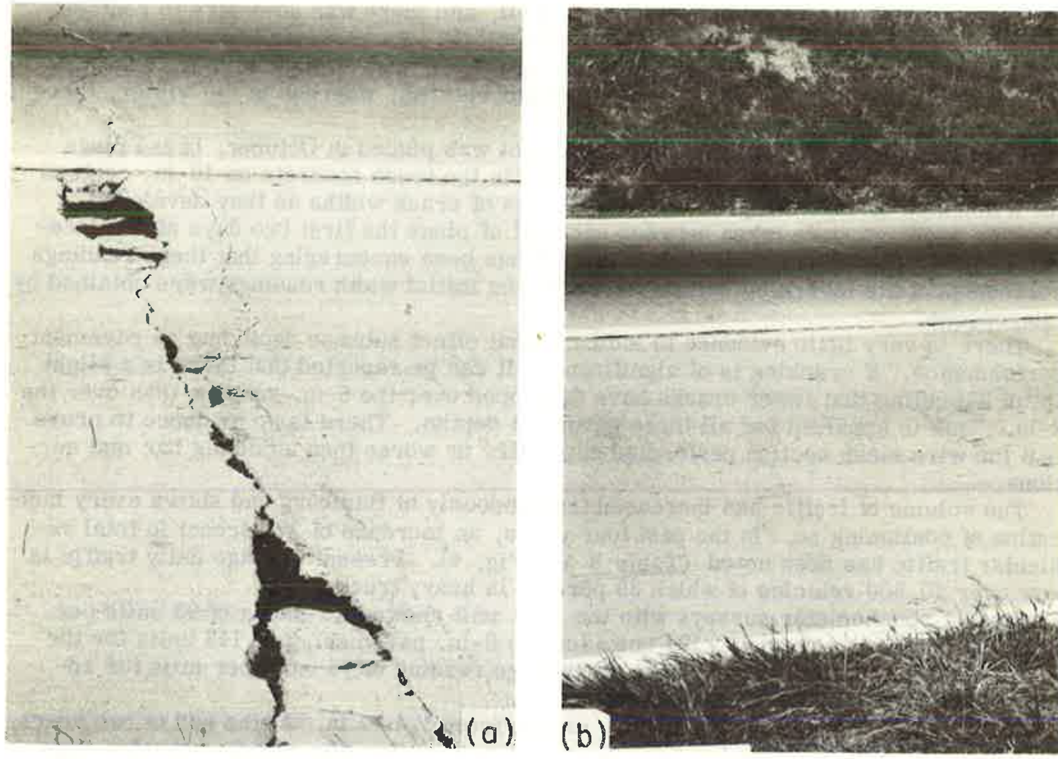


Figure 5. Hamburg pavement: (a) appearance of typical wide crack, (b) patched area after 4 year's service.

success of the repair operation has established a repair method that is apparently satisfactory and can be used where abnormal cracks develop on continuous pavements.

As if the crack failures were not sufficient trouble for the maintenance department, signs of major distress began appearing in the eastbound 7-in. lanes in 1959. More large cracks developed in several locations and these areas deteriorated progressively until large portions of the concrete, comprising as much as 200 sq ft, were broken, disintegrated, and were noticeably below original grade. The broken concrete constituted a hazard to traffic and had to be patched repeatedly with bituminous material. A typical area is shown in Figure 6. In addition to this type of failure, longitudinal cracking was encountered in several locations, primarily near these distressed areas and always within 6 to 8 in. of the center longitudinal joint. Pumping was evident along the edge of the outside traffic lane.

It was apparent that these failures were becoming worse. In the spring of 1960, the laboratory recommended that the 7-in. eastbound lanes be replaced. Bureau of Public Roads concurrence was secured, considering the major research aspect of the joint venture. A contract was awarded in September 1960 for the replacement of 5,340 sq yd of concrete with standard reinforced pavement, 10 in. in depth. Work commenced on October 19, 1960, when the contractor began breaking the concrete in the eastbound lane between stations 168 + 96 and 188 + 97.5, a distance of approximately 2,000 lineal feet.

The concrete on the inside lane shared none of the distress of that in the outside lane and was, in fact, in excellent condition. Much thought was given to the possibility of salvaging the inside lane, but considering the difficulty of joining two lanes of different thicknesses, the idea was dropped in favor of replacing both lanes.

The investigation, conducted in connection with the repaving, paralleled the earlier findings: The average overlap of steel was $10\frac{1}{2}$ in., the average depth was $3\frac{1}{4}$ in.

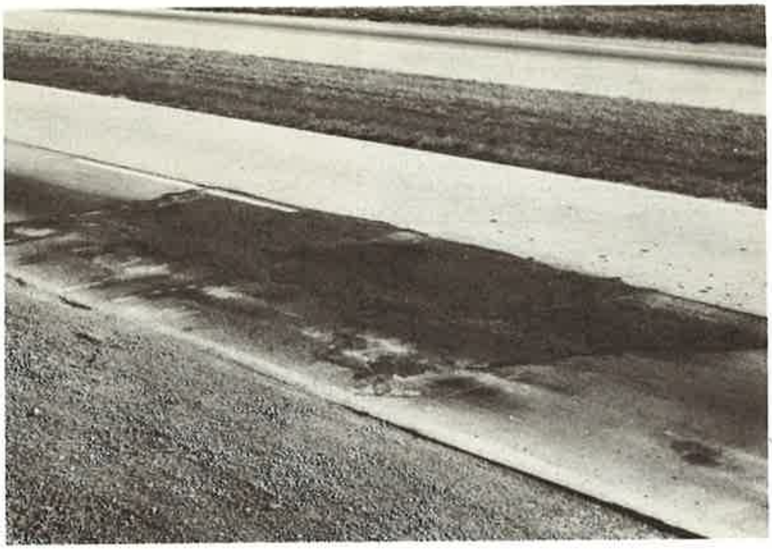


Figure 6. Failure in 7-in. pavement, Hamburg.

The overlap of steel ranged from 8 to 13 in., and the range in depth was from $2\frac{3}{4}$ to $3\frac{3}{4}$ in., measured from the top of the steel. Many of the steel bars were broken in the areas where pavement damage was the worst. There is no doubt that the overlap (12 in.) of steel on this project was inadequate and that the large transverse cracks and subsequent breaking of concrete between two such parallel cracks were probably the beginning of many of the failures. The majority of these areas occurred at an overlap. The quality of the concrete removed appeared to be sound and revealed an excellent distribution of aggregates.

SOIL INVESTIGATION

On October 19, 20, and 21, 1960, a soil investigation was conducted between stations 169 and 189, eastbound lanes, by the laboratory field soils office in cooperation with the Research Unit. The removal of the roadway section down to the subgrade provided an opportunity to investigate the subbase, subgrade, and drainage to determine if any or all of these were contributing factors to the failure of this section.

Records from construction included the following data for the eastbound lanes:

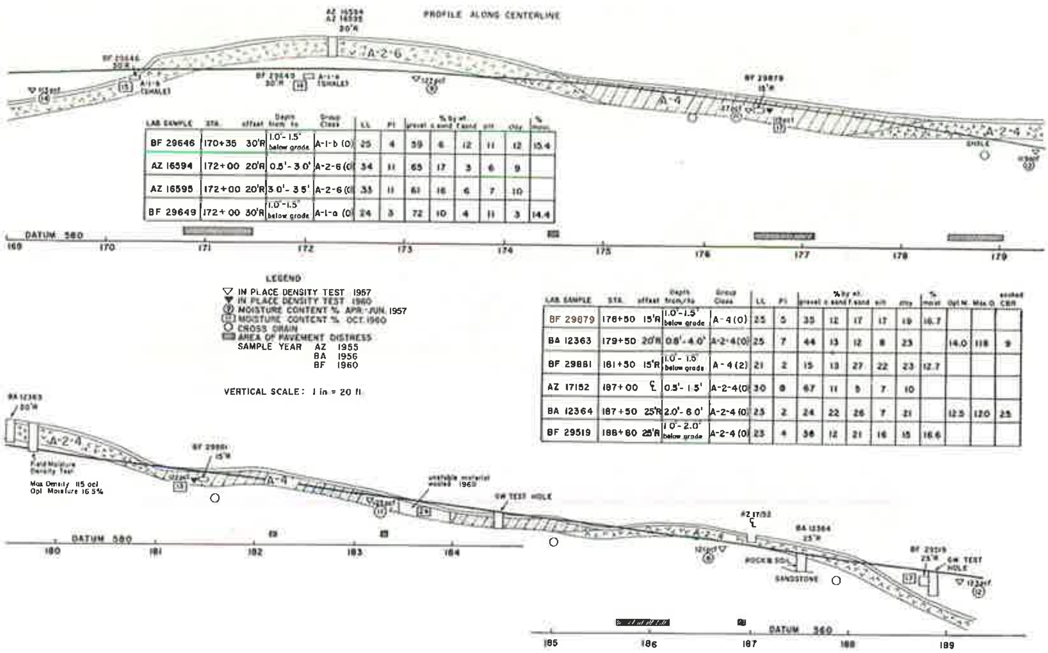
1. A soil survey with 5 soil classifications, 3 compaction tests, and 2 CBR tests (Fig. 7).
2. Sand cone density checks of the subgrade, 8 tests (Table 6).
3. Thickness measurements of the subbase every 50 ft (Fig. 8).
4. Sand cone density checks of the subbase, 4 tests (text).

Additional data obtained by the special investigation included the following:

1. Five soil gradations each for the subbase and subgrade with moisture content determinations (Fig. 7; Table 7).
2. Two sand cone density checks of the subgrade (Table 6).
3. Two holes drilled for ground water level.

Subbase

The subbase material for this project was a run of mill crushed limestone meeting the specification requirements of gradation A or B (Table 8). Of the initial 15 samples taken from the source of supply, three failed to meet specifications (two with 1 percent



LAB SAMPLE	STA.	offset	Depth from/to	Group Class	LL	PI	% by wt. gravel	c sand	f sand	silt	clay	% moist.
BF 29646	170+35	30'R	1.0'-1.5' below grade	A-1-b (0)	25	4	59	6	12	11	12	15.4
AZ 16594	172+00	20'R	0.5'-3.0'	A-2-6 (0)	34	11	65	17	3	6	9	
AZ 16595	172+00	20'R	3.0'-3.5'	A-2-6 (0)	35	11	61	16	6	7	10	
BF 29649	172+00	30'R	1.0'-1.5' below grade	A-1-a (0)	24	3	72	10	4	11	3	14.4

LAB SAMPLE	STA.	offset	Depth from/to	Group Class	LL	PI	% by wt. gravel	c sand	f sand	silt	clay	% moist.	Opt M.	Max D.	soaked CBR
BF 29879	176+50	15'R	1.0'-1.5' below grade	A-4 (0)	25	5	35	12	17	17	19	16.7			
BA 12363	179+50	20'R	0.8'-4.0'	A-2-4 (0)	25	7	44	13	12	8	23		14.0	118	9
BF 29881	181+50	15'R	1.0'-1.5' below grade	A-4 (2)	21	2	15	13	27	22	23	12.7			
AZ 17152	187+00	℄	0.5'-1.5'	A-2-4 (0)	30	8	67	11	5	7	10				
BA 12364	187+50	25'R	2.0'-6.0'	A-2-4 (0)	25	2	24	22	26	7	21		12.5	120	25
BF 29519	188+80	25'R	1.0'-2.0' below grade	A-2-4 (0)	23	4	36	12	21	16	15	16.6			

Figure 7. Soil survey, Hamburg project, stations 169 to 189.

TABLE 6

SAND CONE DENSITY TESTS ON SUBGRADE

Date	Station	Actual Density (pcf)	Percent Compaction Based on 117 pcf
May 1957	169 + 20	112.8	96.4
	173 + 06	127.0	108.5
	176 + 50	126.9	108.5
	179 + 40	118.8	101.5
	183 + 20	123.4	105.5
	186 + 72	120.9	103.3
	189 + 10	108.1	92.4[a]
	189 + 10	123.0	105.1
Oct. 1960	176 + 50	118.5	101.0
	181 + 50	121.8	104.0

[a]Rerolled; see following test.

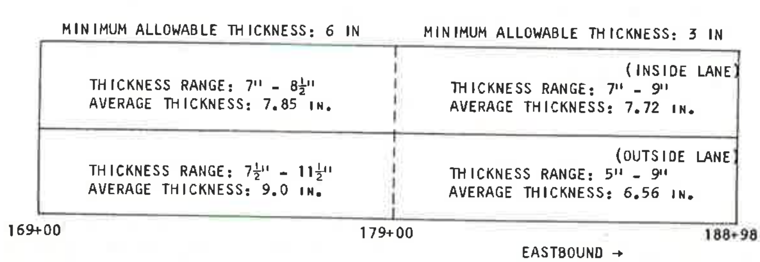


Figure 8. Thickness measurements of subbase.

TABLE 7

TESTS ON SUBBASE SAMPLES[a], 1960

Station	LL (%)	PI (%)	Aggr. (%)	C. Sand (%)	F. Sand (%)	Silt (%)	Clay (%)	Moist (%)	Remarks
170 + 35	23	3	73	10	5	7	5	9.4	Upper 3½ in. of 6½-in. thick subbase meets spec. gradation B
170 + 35	24	3	79	8	3	8	2	8.4	Lower 3 in. of 6½-in. thick subbase meets spec. gradation B
172 + 00	24	4	76	9	3	7	5	9.3	Meets spec. gradation B
176 + 50	23	2	62	16	5	10	7	9.2	Fails to meet specifications, excessive fines
181 + 50	23	3	68	11	5	10	6	11.1	Fails to meet specifications, excessive fines
188 + 80	22	2	72	13	5	7	3	7.3	Meets spec. gradation A

[a]Of 15 samples taken from source at time of construction, 12 met subbase specifications (2 samples contained 16 percent passing No. 200 sieve and 1 sample had plasticity index of 7 percent). Permeability test of a blend of samples listed showed a low permeability: 4.3×10^{-4} cm per sec at 20 C.

TABLE 8

SUBBASE GRADATIONS AT CONSTRUCTION-1957

Property	Average Gradation (%)	Specification Limits (%)	
		Gradation A	Gradation B
Sieve Size:			
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
LL	22	30[a]	30[a]
PI	3	6[a]	6[a]

[a]Maximum material passing No. 40 sieve.

excess of minus 200 material, and one with a plasticity index in excess by 1). Excessive amounts of shale were noted in two of the original samples. Generally, most of the original subbase samples met gradation B. The average PI for the 15 samples was 3 and the average percent of minus 200 was 9.6. The gradations made after three years of service, shown in Table 7, show no increase in the plasticity index but the average percent of minus 200 material is 13.5. This increase of 4 percent in the subbase in the failed section could be due to (a) finer subbase used in the failed section, (b) a gain of fines as a result of the use of screenings on the surface, (c) disintegration of "shaley" sand while in service, or (d) degradation of the subbase due to compaction.

The subbase thickness is quite variable and is in excess by a considerable amount from the minimum called for in the contract. The proposal called for 1,000 ft with a minimum subbase depth of 6 in. from station 169 + 00 to 179 + 00 and 1,000 ft with a minimum depth of 3 in. from station 179 + 00 to 189 + 00. The extensive irregularities in subbase depth as shown in Figure 8 could be expected to result in differential densification and nonuniformity, all of which is aggravated by traffic compaction.

Compaction figures for the subbase indicate possibly less compaction for the failed section. The sand cone apparatus, however, is not very satisfactory for so granular a material; therefore, the results are questionable. On the basis of 133 pcf as 100 percent AASHO T-99 density, four tests taken at the time of construction on the failed section showed an average of 78.5 percent compaction (range of 69 to 89 percent). In contrast, 34 other tests on the subbase of the eastbound lane showed an average of 88 percent, with only six below 78.5 percent. This indicates a possibility of less compaction for the failed stretch, providing a consistent testing method was used.

At the time of this investigation, the subbase contained a considerable amount of free water, especially in the bottom 2 or 3 in. The average moisture content was a high 9.1 percent.

Intrusion of the subgrade into the subbase does not appear to have occurred. Pumping does seem to have been a problem for this failed section, especially at station 176 + 50 where silt had intruded into the bituminous patching material. Frost heaving effects were not evaluated by the research unit but the subbase contained sufficient fines and enough moisture to have heaved.

Subgrade

The entire length of the failed section is in a shallow cut. The overburden is shallow (approximately 3 ft in thickness) and is derived from the steeply-dipping underlying Martinsburg shale which is somewhat sandy in this area. The original soil profile showed A-2-6 soil through most of the failed section with A-2-4 soil present at the eastern end. Later investigation showed the A-2-4 soil to be of greater extent with A-4 soil at the surface. CBR tests of the A-2-4 subgrade showed the stability of this material to be fair to excellent.

Eight density tests were taken in the cut section with the sand cone density apparatus at the time of construction. An average density of 117 pcf was taken as 100 percent AASHO T-99 density. The results of these tests are shown in Table 6. They indicate that satisfactory compaction was obtained for the upper part of the subgrade. Two density checks made in October 1960 indicate that satisfactory density is still present; however, at station 176 + 50, an 8-pcf loss indicates that some softening had taken place at this location.

Three moisture-density tests taken on the eastbound lane in the failed section at station 179 + 50 and 187 + 50 showed an optimum moisture average of 14.3 percent and a maximum density of 115 to 120 pcf. Moisture contents from the sand cone tests taken in April and May 1957 averaged 11.0 percent for the subgrade. The moisture determinations taken at the time of this investigation showed an average moisture content of 15.1 percent. At station 176 + 50, the upper part of the subgrade showed a gain of 6 percent in moisture. At stations 183 + 50 to 184 + 00, where the moisture content was 24 percent, the subgrade was wasted to a depth of $2\frac{1}{2}$ ft before the present reconstruction.

Fine grade material appears to be A-4 material which could be frost susceptible. The soil survey indicates that not much thickness of this material should have been used. It may have been used in the vicinity of stations 181 + 00 to 181 + 50 and 183 + 50 to 184 + 50.

Drainage

The longitudinal drain was placed at a depth of 3 to 4 ft below grade in shale, generally running below the center of the shoulder. After three years in service, the drain pipe, when ripped up, showed no staining from water or sediment in the pipe. The high moisture content in the subbase would indicate that this drain was not functioning for the following possible reasons: (a) irregularities of the bottom surface of the subbase causing ponding of the water, and (b) cutting off the access of the water to the longitudinal drain as a result of redressing the shoulders. The free water allowed to stand in the subbase could definitely contribute to pumping, excessive frost heave and softening of the subgrade at station 176 + 50.

Cross-drainage pipes (five for the failed section) have kept the side ditches from filling with water or sediment as intended. However, with the strike of the Martinsburg shale paralleling the roadway in this section and the rock dipping very steeply to the south, transverse movement of water in the rock subgrade would be difficult. Therefore, it is quite possible that water could be ponded in the soil subgrade at its contact with the upper irregular surface of the rock. Two shallow ground water holes as shown on the soil profile failed to locate the ground-water table.

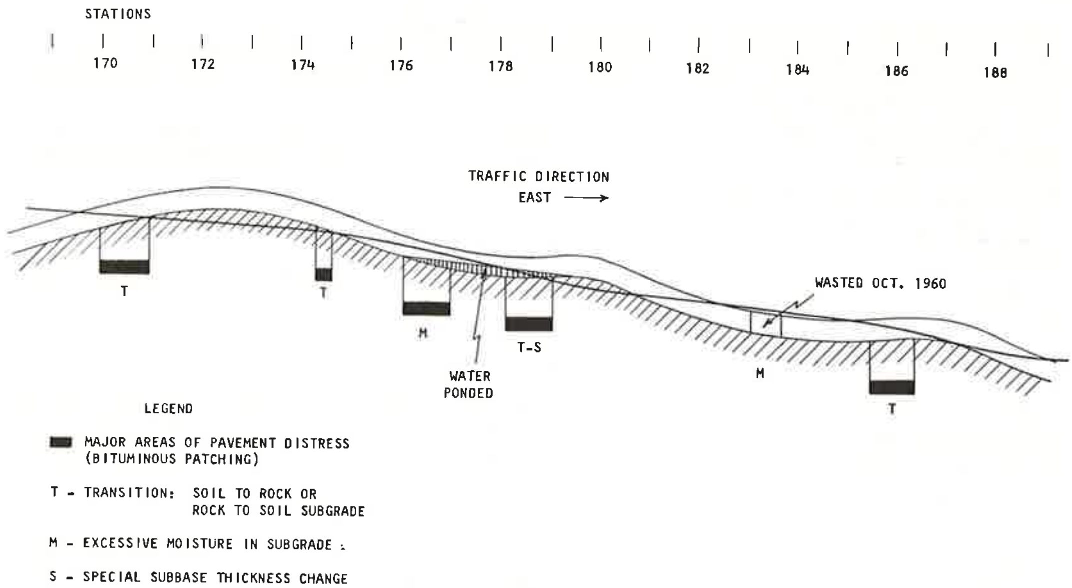


Figure 9. Failed section showing major areas of pavement distress.

SUMMARY OF SOIL INVESTIGATION

The grade line skirts along the original ground line making deeper cuts through three knobs (station 171 + 00 to 174 + 00, 178 + 50 to 181 + 00, and 186 + 00 to 188 + 00) into rock. This causes a non-uniformity of bearing of the subgrade as shown in Figure 9. The transition of soil to rock in the western flank of each knob is an area of pavement distress. At the transition of rock to soil coming out of a 7-ft cut at station 174 + 50, pavement failure was also present. At station 178 + 50 to 179 +00, the abrupt change in the subgrade is also in the area of the thickness change of the subbase, possibly further aggravating the non-uniform bearing condition.

In between the three knobs are two pockets of the natural soil derived from the Martinsburg formation below. Where this soil overburden is at its greatest depth below grade (stations 176 + 50 to 177 + 20 and 183 + 50 to 184 + 00) and where surface rolling would have the least effect at depth, unstable conditions exist in the subgrade. This is caused by excessive moisture with a resulting softening of the subgrade.

Compaction control was adequate and the type of subgrade was not poor, but the nonuniformity of the subgrade bearing was too great for the bridging action of the 7-in. pavement. This condition, aggravated by the overlap problem plus repeated application of heavy axle loads, was undoubtedly the cause of failure. If the grade line had either been lower or higher with a more uniform subgrade present, and drainage had functioned properly, it is believed that a well-constructed roadway of 7-in. continuously-reinforced pavement would not have failed at this location.

RECOMMENDATIONS

The current status of the two continuous pavements in Pennsylvania is that one project is performing as a normal member of the continuous pavement family, but there is also a problem pavement. From this situation, however, the department has learned how to repair crack failures satisfactorily and has obtained much valuable information concerning the design of continuously-reinforced pavements.

If the construction of another continuous pavement were to be considered, the following elements of design would probably be required:

1. A 6-in., well-compacted subbase.

2. A pavement depth of 9 in., certainly no less than 8 in.

3. Reinforcing bars of 20- to 30-ft lengths, set on chairs, staggered, and overlapped a minimum of 18 in. (for No. 5 bars) or alternate designs of prefabricated bar mats or welded wire fabric with adequate lap specified.

4. Reinforcing steel designed at 0.6 percent unless a steel with increased yield strength is employed. (The 0.5 percent at York was apparently satisfactory because of the lower temperature during time of construction.)

5. The use of inexpensive expansion joints at the ends of the pavement with the possible addition of foundation keys or built-in friction.

There is no assurance that this will be a perfect pavement, but it does embody the best design based on present knowledge.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of the Material Bureau's soil engineering department and particularly the work of W.G. Wigginton, who was responsible for the soil investigation and supplied much of the data presented in that connection.

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