PERFORMANCE OF SOIL-CEMENT TEST PAVEMENT IN RHODE ISLAND

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A test road containing 2 control sections with conventional design and 5 sections with different soil-cement base and subbase was constructed in July 1967. Performance of the test road has been evaluated by using the Benkelman beam test, plate bearing test, roughometer test, crack survey, and frost study. Results obtained to date indicate that the soil-cement pavement possesses greater rigidity but develops cracks; the total length of the cracks increases with increasing curing time. An addition of 1 percent Na_2SO_4 seems to increase the rate of crack development. Cracking could result in pavement surface roughness; however, no conclusive results indicate that cracking could cause a reduction of pavement stiffness.

•AN INVESTIGATION was made of the feasibility of using stabilized local silty soils as base and subbase course materials for construction of flexible pavements in Rhode Island. A 4,130-ft test road was constructed in July 1967 for confirming and modifying the predicted conclusions of the laboratory studies (1) and for evaluating under field conditions the long-term properties of various stabilized soils.

The test road, a 2-lane highway with 10-ft shoulders, is essentially a section on RI-214, a state secondary highway in Middletown, Rhode Island. The average daily traffic (ADT) on the test road, according to a previous report (2), was 4,180; approximately 2 percent of the traffic is trucks, and 81 percent of the trucks are single-axle straight trucks. Since the road was completed, the ADT has steadily increased to 7,000 in 1970.

The test road is composed of 2 control sections of conventional design and 5 experimental sections of different materials in base and subbase courses as shown in Figure 1. All sections are surfaced with 3 in. of bituminous concrete. Moisture and temperature gauges are installed as one unit at stations 16+00, 22+00, and 26+00. The gauges are located beneath the centerline and 11 ft from the centerline on each side at depths of 6, 11, 15, 19, and 24 in. at stations 16+00 and 26+00 and at depths of 11, 15, 19 and 24 in. at station 22+00.

The soil used for construction has classifications ranging from A-2 (4) to A-4 (3) and is predominantly A-4. The index properties of a typical soil are as follows:

Property	Value
Specific gravity	2.70
Atterberg limits, percent	
Liquid limit	21
Plastic limit	NP
Textural composition, percent	
Gravel, 3 in. to 2.00 mm	20.5
Sand, 0.074 to 0.005 mm	46.0
Clay, 0.005 mm	4.0
AASHO classification	A-4(3)

Type 1 portland cement was used throughout. A trace amount (1 percent) of sodium sulfate, which was supplied in granular form, was used in sections 6 and 7 because it was concluded from previous laboratory studies (1) that an addition of 1 percent Na_2SO_4

could result in a greater strength and a considerably more rapid strength gain. Details on design and construction of the test road are given elsewhere (3, 4).

Performance of the test road and the results of laboratory tests on field and laboratory compacted samples in the first year after completion of the test road are given in other reports (2, 5). This paper presents the results of field studies obtained to date.

PERFORMANCE OF TEST PAVEMENT

The test pavements were evaluated according to their relative performance under loading and environmental influence. The performance under loading was determined by using the Benkelman beam test, plate bearing test, and roughometer test; the performance under environmental influence was evaluated on the basis of cracking and response to freezing temperature.

Benkelman Beam Test

Since the summer of 1967, Benkelman beam tests have been conducted annually in the spring and summer at the locations shown in Figure 2. The truck used for testing had a rear axle load of 18 kips and a tire pressure of 80 psi. Detailed testing procedures are given in another report (5).

Typical pavement surface deflection profiles under the test truck are shown in Figure 3. Each data point is the average of 4 measurements. There is a fairly constant deflection in both lanes, and pavement materials are rather uniformly distributed through each section. Sections 1, 2, and 4 give greater deflections and steeper slopes of profile than other sections because of the use of penetrated rock as base course material in those sections. The penetrated rock generally gives lower supporting capacity than soil-cement for the latter possesses a measurable flexural strength.

A comparison of pavement deflection measured in spring and summer is shown in Figure 4. Deflections in the spring are greater than those in the summer probably because of greater rainfall in the spring and effects of the spring thaw. According to the Newport Water Department Weather Station, the accumulated 3-day and 7-day rainfall immediately prior to Benkelman beam tests were as follows:

Test Date	7 Days (in.)	3 Days (in.)
Summer		
8-9-67	0.96	0.17
8-26-68	0.11	0
8-29-69	0.02	0.02
8-24-70	1.34	1.23
Spring		
4-18-68	0.66	0.66
4-1-69	0.49	0.38
3-23-70	1.85	1.64
4-8-71	1.60	1.05

Although moisture readings were obtained for varying depths up to 24 in., only some of the values indicate a higher moisture content in the spring. The rest of the readings varied so little or were so erratic that it was not possible to draw reliable conclusions. Higher moisture contents at greater depths might have occurred, but no field readings are available to verify this possibility.

The curve of deflection measured in the summer (Fig. 4) indicates a trend of decreasing surface deflection with increasing time and eventually approaches a constant for all sections except sections 2 and 4. For the soil-cement sections, this effect is primarily attributed to the strength increase with time (Fig. 5). Because the strength of gravel is not a function of elapsed time after compaction, the same reasoning cannot be applied to the decrease in deflection with time for control sections 1 and 4. The

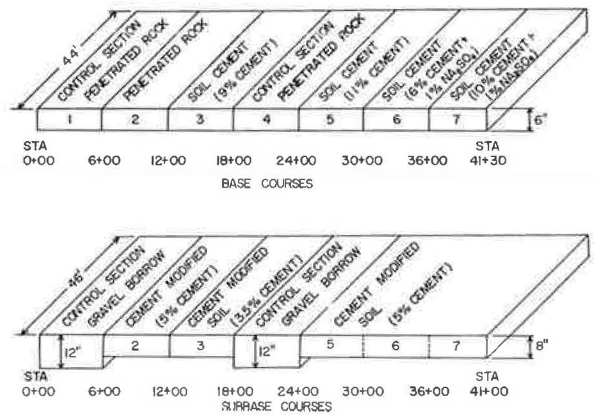


Figure 1. Bases and subbases of sections of experimental road.

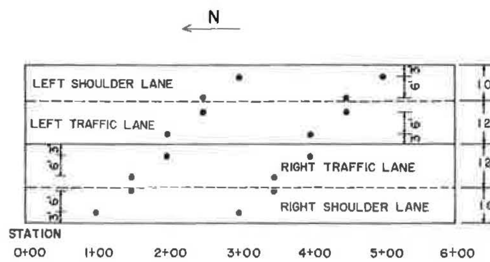


Figure 2. Layout of Benkelman beam deflection test sites.

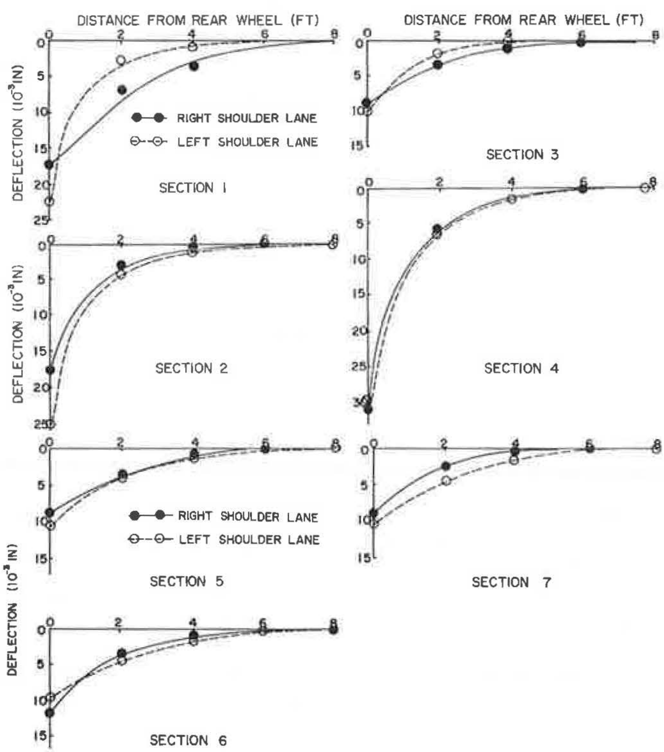


Figure 3. Typical pavement deflection profile from Benkelman beam test on August 1967.

Figure 4. Mean maximum pavement deflection measured in Benkelman beam test.

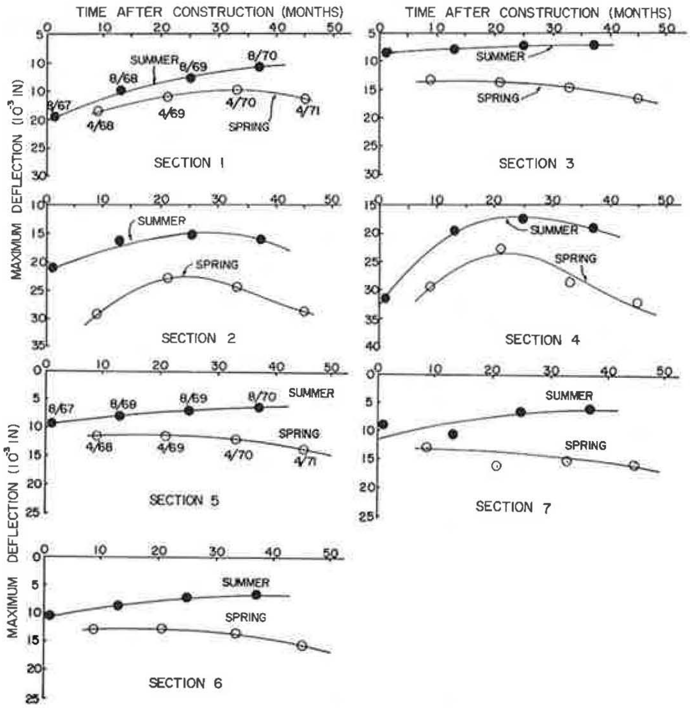
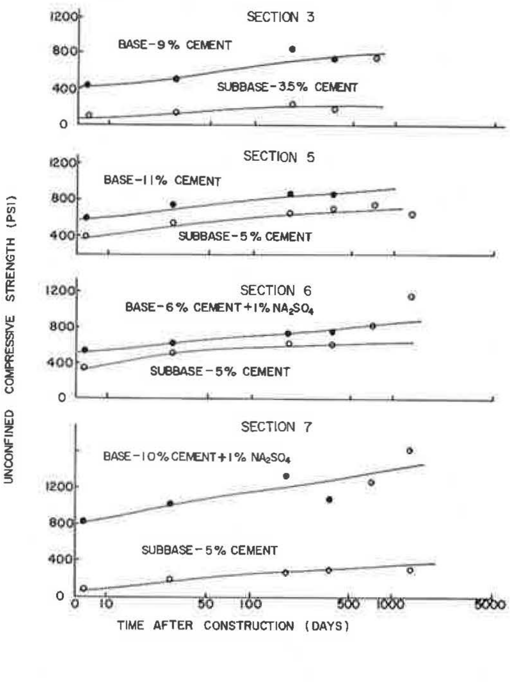


Figure 5. Unconfined compressive strength of base and subbase materials.



decrease in deflections could be the result of reorientation of particles to a more stable position in the gravel layer due to traffic.

Deflections in sections 2 and 4 first decrease then increase slightly with time. The deflection curve for the spring season illustrates also a tendency of slightly increasing deflection with elapsed time. Factors that could cause an increase in pavement deflection include an increase in subgrade moisture due to precipitation and a deterioration of the pavement material as a result of cracking. The rainfall data (Table 2) indicate a considerably higher rainfall immediately before the Benkelman beam tests conducted in 1970 and 1971. The greater rainfall is presumably the primary cause for the increased deflection shown in Figure 4.

Except for the 2 control sections, 1 and 4, all experimental sections developed cracks. A detailed crack study indicates an increasing amount of cracking with increasing curing time (Fig. 10). Development of cracks could result in an increase in pavement deflection due either to the decrease in load-spreading capacity of the soil-cement layer or to the decrease in load-supporting capacity of subgrade soil because of increasing moisture content caused by the intrusion of surface water through the cracks. The effect of cracking on pavement deflection is given in Table 1. No consistent evidence indicating the destructive effect of cracking is noted from the results obtained to date. Therefore, the tendency of increasing pavement deflection with elapsed time would be primarily caused by the greater rainfall immediately preceding the later tests.

The mean maximum deflection is also shown as a histogram in Figure 6 for easy comparison among sections as follows:

1. The beneficial effect of using a soil-cement base is proved by the fact that the sections with soil-cement bases (sections 3, 5, 6, and 7) exhibit much smaller deflections than those sections having penetrated rock bases (sections 1, 2, and 4).
2. Even though the 2 control sections, 1 and 4, have identical layer thickness, section 4 gives greater deflection then section 1 possibly because of a stronger subgrade support under section 1 (bedrock underlying the pavement was found during excavation).
3. No clear indication of the advantage of substituting an 8-in. thick, 5 percent soil-cement subbase for a 12-in. thick gravel subbase is revealed from the comparison between the deflection in section 2 (with 8-in. 5 percent soil-cement) and deflections in control sections 1 and 4 (with 12-in. gravel) because section 2 deflects as much as section 4 and more than section 1.
4. Regardless of a cement content that is comparatively lower in section 6 (with 6 percent cement plus 1 percent sodium sulfate base) than in section 5 (with 11 percent cement base), section 6 deflects as little as section 5. Both sections contain a 5 percent cement subbase. The addition of 1 percent Na_2SO_4 substantially increases the strength of the cement-stabilized soil. On the contrary, section 7 contains a 10 percent cement plus 1 percent Na_2SO_4 and unexpectedly deflects as much as section 6. A possible reason for this is that the subbase material in section 7 has the same cement content but only about 50 percent of the strength of the material in section 6 (Fig. 5). Because of the effect of unequal subbase support, one can hardly evaluate the advantage of using one material over another in the base course simply from the relative performance in deflection of each pavement section.

Plate Bearing Test

Five different plate load intensities, 5, 10, 15, 20, and 25 kips, were applied statically to a 12-in. diameter plate by using a hydraulic jack. Deflection of the loaded plate was measured at opposite ends of a plate diameter by means of 0.001-in. dial gauges mounted on a reference beam. Two permanent test sites in each section are located on the boundary separating the traffic and shoulder lanes, 150 ft from the beginning of each section on the right and 150 ft from the end on the left.

Tests were conducted annually in different seasons. Results of the test conducted in April 1971 are shown in Figure 7. Each curve represents the average of test results at 2 locations. In general the slope of the load-deflection curves is steeper for the soil-cement sections than for the control sections. The slope of the curve is a function

gure 6. Histogram of mean maximum pavement deflection easured in Benkelman beam tests.

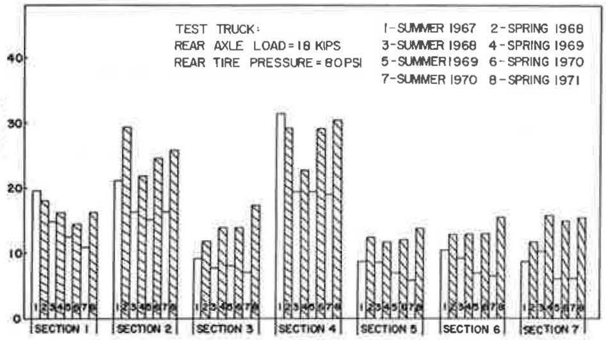
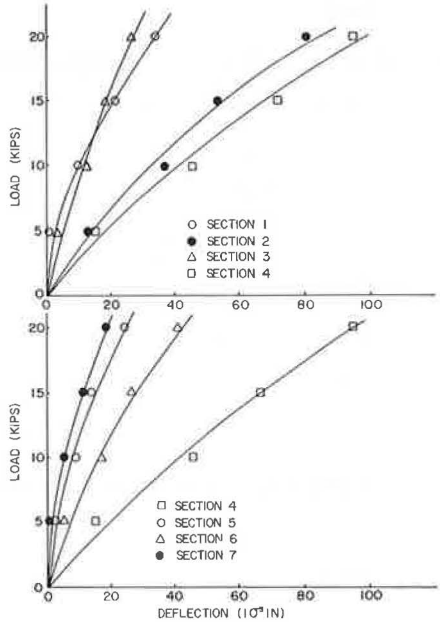


Figure 7. Results of plate bearing test on April 1971.



ıble 1. Maximum pavement deflection measured in Benkelman beam test.

		August 1969 Deflection (10^{-3} in.)				April 1971 Deflection (10^{-3} in.)			
ction	Station	Right Shoulder	Right Traffic Lane	Left Shoulder	Left Traffic Lane	Right Shoulder	Right Traffic Lane	Left Shoulder	Left Traffic Lane
	13+00	0.014				0.040			
	13+50	0.010[a]	0.004[a]			0.013[a]	0.012[a]		
	14+00		0.011		0.007		0.016		0.011
	14+50			0.005[a]	0.006			0.015[a]	0.011[a]
	15+00	0.020		0.008[a]		0.029[a]		0.023[a]	
	15+50	0.006	0.004			0.015[a]	0.013[a]		
	16+00		0.010[a]		0.006[a]		0.019[a]		0.012[a]
	16+50			0.004	0.006			0.009	0.012
	17+00			0.011				0.029	
	25+00	0.009				0.028			
	25+50	0.007	0.007			0.017[a]	0.010[a]		
	26+00		0.008[a]		0.005[a]		0.018[a]		0.012[a]
	26+50			0.004[a]	0.007[a]			0.011[a]	0.015[a]
	27+00	0.011		0.008		0.031		0.019	
	27+50	0.010[a]	0.007[a]			0.018[a]	0.012[a]		
	28+00		0.007[a]		0.006[a]		0.009[a]		0.009[a]
	28+50			0.004	0.005			0.010	0.012
	29+00			0.006[a]				0.022[a]	
	31+00	0.011				0.042[a]			
	31+50	0.009[a]	0.009[a]			0.020[a]	0.017[a]		
	32+00		0.006[a]		0.010		0.008[a]		0.014[a]
	32+50			0.002	0.005[a]			0.011	0.019[a]
	33+00	0.008		0.003		0.031		0.015[a]	
	33+50	0.004	0.008			0.016	0.018		
	34+00		0.008		0.004		0.011		0.012
	34+50			0.005	0.012			0.013	0.012[a]
	35+00			0.008[a]				0.024[a]	
	37+00	0.004			0.008[a]	0.007[a]			0.004[a]
	37+50	0.005[a]	0.013	0.003	0.004	0.015[a]	0.018[a]	0.010	0.011
	38+00		0.010	0.004			0.008	0.020	
	39+00	0.002			0.008	0.037			0.013[a]
	39+50	0.004	0.009	0.006	0.005	0.017[a]	0.026	0.008	0.012
	40+00		0.009[a]	0.004[a]			0.139[a]	0.026[a]	

ıcks developed around test site.

Table 2. Pavement deflection under 15-kip plate load.

Section	Station	Lane	Deflection (10^{-3} in.) July 1969	Deflection (10^{-3} in.) April 1971
3	13+50	Right	0.017[a]	0.019[a]
	16+50	Left	0.038	0.015[a]
5	25+50	Right	0.029	0.029[a]
	28+50	Left	0.017[a]	0.013
6	31+50	Right	0.024[a]	0.023[a]
	34+50	Left	0.021[a]	0.017[a]
7	37+50	Right	0.011	0.014[a]
	39+50	Left	0.018	0.015

[a]Cracks developed around test sites.

Figure 8. Pavement deflection under 15-kip plate load.

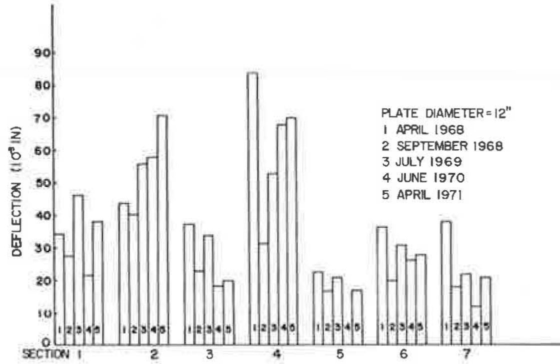


Figure 9. Crack patterns mapped in March 1971.

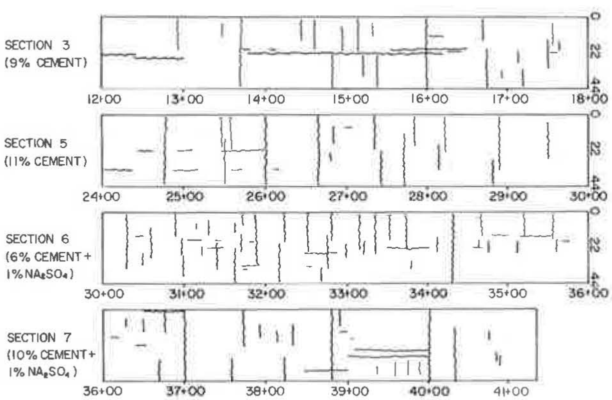


Figure 10. Length of surface crack in test pavements.

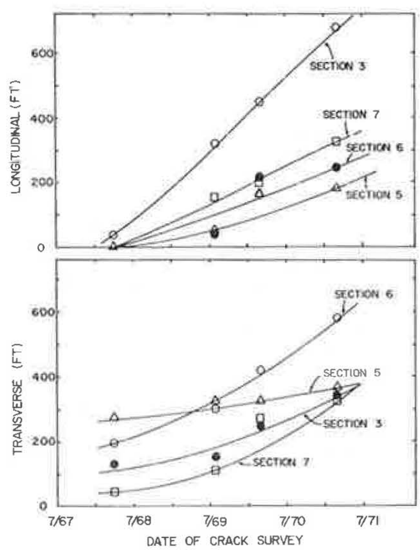


Table 3. Roughometer test results.

Direction	Section	Shoulder Lane Roughness Index (in./mile) May 68	March 69	Oct. 69	Oct. 71	Traffic Lane Roughness Index (in./mile) Aug. 67	May 68	March 69	Oct. 69	Oct. 71
Southbound	1	88	105	89	—	88	79	98	84	—
	2	114	119	119	104	101	88	98	101	113
	3	97	110	99	126	106	92	114	106	121
	4	97	101	98	113	106	92	105	92	110
	5	79	105	95	119	97	92	105	92	117
	6	97	114	107	123	114	101	114	112	121
	7	130	130	121	114	109	115	130	112	115
Northbound	1	97	132	109	—	88	79	114	96	—
	2	105	114	110	115	88	92	105	97	107
	3	79	98	105	124	97	84	105	105	120
	4	97	98	114	115	97	84	98	97	105
	5	88	114	108	121	101	92	98	105	125
	6	97	123	113	103	114	101	114	107	126
	7	120	110	87	105	94	111	120	93	110

of the stiffness of the pavement material; therefore, it is an alternate measure for load-carrying capacity of the pavement sections.

Pavement deflection under a 15-kip plate load is shown in Figure 8. (The intensity of plate load, 15 kips, was selected arbitrarily.) The results follow generally those of the Benkelman beam test. A study of the influence of cracking on pavement deflection under plate loads is given in Table 2. No consistent results indicate that cracking causes an increase in pavement deflection.

Roughometer Tests

The riding quality of the test pavements was determined in terms of a roughness index. Tests were conducted by the Rhode Island Department of Transportation using the BPR roughometer. Three runs on each traffic lane and one on each shoulder lane were made in the tests in August 1967 and May 1968; however, only two runs were made on each traffic lane and one run on each shoulder lane in the tests in March and October 1969 and October 1971. The roughometer was not available for tests in 1970. Test results are given in Table 3.

In general, the surface roughness of shoulder lanes is individually greater than that of traffic lanes for all sections. That condition is presumably caused by either faster traffic or greater confinement effect, or both, in the traffic lane. The faster traffic is, the greater is the impact action, which gives greater smoothing effect; increasing confinement increases pavement stiffness and thus decreases pavement deflection under the test truck. The test results also suggest that control sections 1 and 4 possess smoother surfaces than soil-cement sections. The reason may be that the control sections can be more easily smoothed by traffic than the soil-cement sections can because the penetrated rock base is generally less stiff than the soil-cement base. In addition, as is discussed later, the soil-cement sections develop cracks; cracking disintegrates the pavement and could, therefore, increase pavement roughness.

Cracking Behavior

Surface cracks were first noticed in the winter immediately after completion of construction. Development of cracks was studied by careful surveying and mapping annually. The depths of the cracks were determined by taking core samples across a crack. It was found that the cracks generally go through the entire base course but only to about the middepth of the subbase layer. The widths of the cracks are in general smaller than $\frac{1}{8}$ in., and once cracks developed no further change in width was noted. Cracks were observed in the sections with soil-cement layer only. Thus, the development of surface cracks must be due essentially to the presence of the soil-cement layer.

Surface cracks in the pavement with a soil-cement layer may be a result of thermal stress, cement hydration, stress due to moisture change, non-uniform frost heave, differential settlement, fatigue failure in surface layer or in the soil-cement layer or both, weak bond between two construction strips due to inadequate mixing, and the like. Among all of these possible causes, that of differential frost heave and settlement does not appear likely because neither detectable difference in elevation on either side of cracks nor surface unevenness was observed in surface leveling. In addition, because no alligator cracking developed, the cracking is probably not due to fatigue failure either. Except for some cracks, both transverse and longitudinal, that apparently developed along the construction joint because of inadequate mixing, most cracks are caused by thermal stress, cement hydration, and stress due to moisture change.

The location and length of the cracks observed in March 1971 are shown in Figure 9. All surface cracks develop in transverse and longitudinal directions only. Figure 10 shows the crack length surveyed in April 1969, March 1970, and March 1971. Cracking increases with time for all sections. The length of longitudinal cracking is greatest in section 3 (9 percent cement) and least in section 5 (11 percent cement). Most of the longitudinal cracking in section 3 developed along the centerline of the pavement (Fig. 9). At the beginning, transverse cracks developed the most in section 5 (11 percent cement) and the least in section 7 (10 percent cement plus 1 percent Na_2SO_4). The rate of increase in crack length with time, however, was fastest in section 6 (6 percent cement plus 1 percent Na_2SO_4) and slowest in section 5. An addition of 1 percent Na_2SO_4 apparently causes an increase in the rate of transverse crack development. Based on the present data, it would appear that section 6 will eventually have the greatest amount of transverse cracking, section 5 will have the least, and sections 7 and 3 will have amounts between these two. More data are needed to lead to a final conclusion, however

Response to Freezing Temperature

In general, the average daily air temperature in the vicinity of the test road reaches a maximum in July and a minimum in January. Freezing temperatures usually occur from December to March. The freezing index and duration of freezing obtained from records of the Newport Water Department are given as follows:

Period	Freezing Index (deg-days)	Duration of Freezing (days)
1967-68	315	62
1968-69	100	32
1969-70	274	44
1970-71	273	53

The response of the test road to freezing temperature was evaluated on the basis of its resistance to the penetration of freezing temperature and the amount of frost heave. Penetration of freezing temperature was determined by using temperature gauges installed in the pavement. No significant frost penetration was detected in the 1968-69 winter because of low freezing index and short duration of freeze. The maximum depth of frost penetration ranged between 14 and 16 in. in the 1967-68 winter and between 8 and 12 in. in the 1969-70 and 1970-71 winters. Unfortunately, conclusions regarding the relative response of each section to frost penetration can hardly be drawn from the data available.

Level of the test road surface was determined by means of an engineer's level at least once a year to detect frost heave. The overall elevation of the pavement surface was higher in the winter than in the summer probably because of the frost action. However, no indication of differential heaving in individual sections and between sections was seen.

SUMMARY AND CONCLUSIONS

Performance of the test road evaluated to date is summarized in the following:

1. At any corresponding elapsed time after construction, the deflections measured by Benkelman beam and plate bearing tests are all greater in the spring than in the summer. Much smaller deflections are yielded by the sections with soil-cement base than by the sections with penetrated rock base (Figs. 6 and 8). The beneficial effect of increasing cement content in the base course, however, is not apparent because of the masking effect due to the weaker subbase in section 7.

2. The surface roughness is generally greater in shoulder lanes than in traffic lanes It seems that the control sections possess a better riding surface than experimental sections (Table 3).

3. All pavement sections with soil-cement bases develop cracks because of thermal stress and cement hydration. The total length of cracks increases with increasing curing time. Results of the crack study seem to suggest that the base course with higher cement content (without Na_2SO_4) develops more transverse cracks at the beginning and the cracks increase with time at a slower rate; furthermore, an addition of 1 percent Na_2SO_4 increases the rate of transverse crack development (Fig. 10). However, more data are required before a final conclusion can be drawn.

4. No significant frost penetration was observed in the 1968-69 winter. The depth of frost penetration varied from 14 to 16 in. in the 1967-68 winter and from 8 to 12 in. in the 1969-70 and 1970-71 winters. The overall surface elevation was higher in the

winter than in the other seasons, and that could be due to frost action. No differential frost heaving in each section and between sections was observed, however.

The pavements constructed with soil-cement base possess greater rigidity and thereby deflect less under loading. With a greater rigidity in the soil-cement layer, the riding quality of the pavements can hardly be improved by the traffic. Furthermore, all soil-cement pavements develop cracks that increase with increasing curing time. Formation of cracks could increase the pavement surface roughness; however, no conclusive evidence to date indicates that cracking would reduce the pavement stiffness and increase surface deflection.

ACKNOWLEDGMENTS

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REFERENCES

1. Nacci, V. A., Moultrop, K., and Huston, M. T. Stabilization of Silty Soils With Portland Cement and Sodium Sulfate. Univ. of Rhode Island, Eng. Bull. 9, Aug. 1966.
2. Roderick, G. L. Condition, Postconstruction Report No. 2. July 1968.
3. Initial-Preconstruction Report No. 1. Univ. of Rhode Island, June 1966.
4. Condition-Postconstruction Report No. 1. Univ. of Rhode Island, Oct. 1967.
5. Roderick, G. L., and Huston, M. T. Rhode Island 214 —Soil-Cement Test Section. Highway Research Record 263, 1969, pp. 37-46.