Rhode Island 214—Soil-Cement Test Section

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An 0.8-mile test road with two control sections and five test sections with cement modified subbases, soil-cement bases with and without Na_2SO_4, and rock base, was constructed the summer of 1967. Moisture-temperature cells were installed at selected sites. Final cement contents were greater than the design because of difficulty in attaining full-depth processing. Benkelman beam deflections were less on control sections and greater on other sections in the spring than in the fall. Pavement roughness improved in the same period. Base courses had primary influence on plate bearing deflections; sections with Na_2SO_4 in the base were less rigid than those without. Surface cracks developed, due to temperature contraction of bases, in all sections with soil-cement bases; the amount of cracking was related to pavement rigidity. Sections with rock bases did not crack. No frost heave occurred. The maximum depth of frost penetration was 19 in. on two brief occasions. Subgrade moisture varied by 2 to 6 percent with lows in fall and highs in spring. Cement-treated subbase moisture was low in fall and high in spring, whereas gravel borrow subbase moisture remained constant. The overall condition of the road is good. Observations are to be continued.

•IN 1963 a laboratory study was initiated to determine the best practical method of stabilizing the abundant silty soils of Rhode Island. Study of various trace chemicals with portland cement led to the conclusion that Na_2SO_4 was the most beneficial. The results of the study have been detailed by Nacci, Moultrop and Huston (1). To confirm or modify the conclusions of the laboratory study, and to determine the feasibility of using soil-cement road construction in Rhode Island, an experimental test road was constructed and is being evaluated. This paper presents some of the results obtained to date.

DESCRIPTION OF THE TEST ROAD

The test road is an approximately 0.8-mile section of R. I. 214, a state secondary road, in Middletown, Newport County. This area normally has considerable frost action. The roadway is 44 ft wide, consisting of two 12-ft traffic lanes and two 10-ft shoulders of the same structural design. Figure 1 shows a schematic presentation of the base and subbase composition of each of the seven sections; each is surfaced with 3 in. of bituminous concrete. The control sections are of the normal state design; the test sections were designed to be of like capacity. Cement contents of the base courses were determined by Portland Cement Association test methods (2).

During construction, soil moisture cells (Soiltest MC-310A) were installed beneath the centerline and 11 ft either side of centerline at stations 16 + 00, 22 + 00 and 26 + 00 (sections 3, 4 and 5). In sections 3 and 5, the cells were installed at depths of 6, 11, 15, 19 and 24 in. beneath the surface; in section 4 the depths were 11, 15, 19 and 24 in. Periodic

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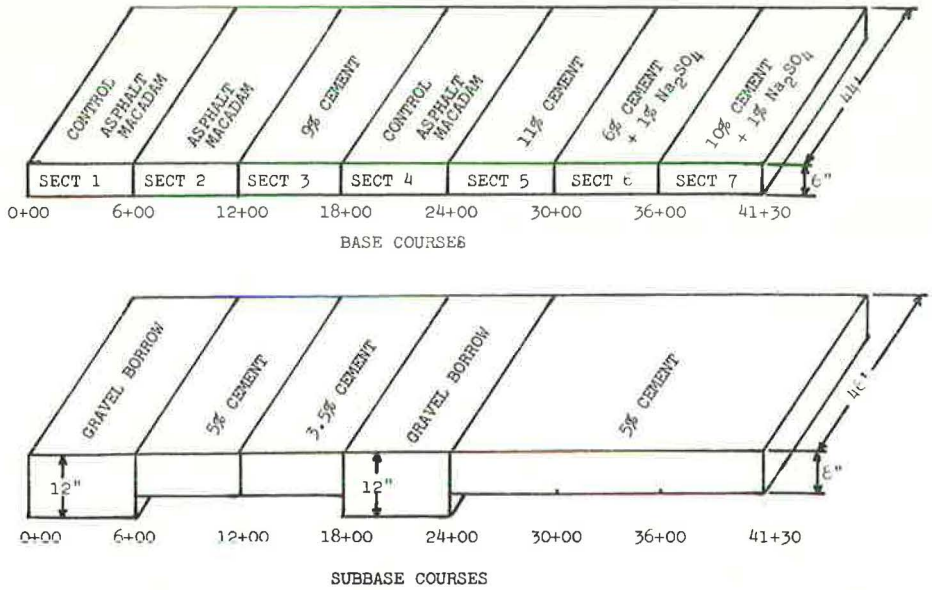

Figure 1. Composition and sequence of test and control sections.

resistance readings of the cells are converted to temperature and moisture contents. Well points were installed at each side of the road at the instrumented sites for observation of water table fluctuations.

Only the C horizon material at the site was used for construction of cement-treated bases and subbases; the B horizon soil contained organic material detrimental to cement reactions. The glacial till was quite stoney; stone sizes ranged from boulders with maximum dimension of about 2 ft to gravel. The maximum stone sizes allowed in the finished cement-treated courses were 4 in. in the subbases and 3 in. in the bases. Table 1 gives the properties of a typical soil of the group. Classifications ranged from A-2-4 to A-4(3), predominantly A-4.

Type 1 portland cement was used throughout. Sodium sulfate was supplied in granular form.

CONSTRUCTION

Specifications for construction of test sections were modified from PCA suggestions (3); detailed specifications were included in the initial-preconstruction report (4).

TABLE 1

PHYSICAL PROPERTIES OF TYPICAL SOIL

Textural composition:	
Gravel (3 in.-2.00 mm), %	20.5
Sand (2.00-0.074 mm), %	29.5
Silt (0.074-0.005 mm), %	46.0
Clay (0.005 mm), %	4.0
Consistency limits:	
Liquid limit, %	21.2
Plastic limit, %	NP
Classification	
Textural	Gravelly silt-loam
AASHO	A-4(3)
Optimum moisture (with 9% cement), %	12.0
Maximum dry density, pcf	125

Since only C horizon material was to be used in cement treatment, it was removed and stockpiled in the fall of 1966. The B material was placed in the subgrade. After a rainy spring, construction of subbases began in late June 1967. Because of the stoney nature of the material it was necessary to screen it before replacing it on the area from which it was taken.

Pulverization and mixing of the materials was done in place with a Trav-L-Plant multiple-pass rotary mixer. A bulk cement truck with a compressed air distributing system and a pressure distributor truck were used for applying cement and water to the roadway. Normally, one section (600 ft) of subbase or base was constructed

TABLE 2

CEMENT CONTENTS OF SUBBASES AND BASES

Section	Station	Cement (% dry wt soil)		
		By ASTM	Field Estimate	Design
Subbase				
Sect 2	7 + 50	7.5	5.5	5
	10 + 50	7.5		
Sect 3	13 + 50	—	3.5	3.5
	16 + 50	4.0		
Sect 5	25 + 50	8.9	5.2	5
	28 + 50	10.6		
Sect 6	31 + 50	6.8	5.4	5
	34 + 50	11.2		
Sect 7	37 + 50	6.8	5.3	5
	39 + 50	5.8		
Base				
Sect 3	13 + 50	21.0	9.5	9
	16 + 50	15.8		
Sect 5	25 + 50	20.5	10.8	11
	28 + 50	11.5		
Sect 6	31 + 50	—	6.5	6
	34 + 50	7.6		
Sect 7	37 + 50	12.2	10.3	10
	39 + 50	9.6		

per day. Each section was processed in 5 or 6 strips, 8 to 9 ft wide; compaction of one strip was concurrent with processing of the adjacent one. Na_2SO_4 was added to the bases of sections 6 and 7 with the mix water. The water in the distributor was heated to 120 F, bagged Na_2SO_4 dumped in to give a 20 percent solution, and the material kept circulating in the tank. No difficulty was encountered in keeping the Na_2SO_4 in solution.

Cement-treated subbases were finished on July 5, bases on July 10, rock bases on July 13 and the surface on July 27, 1967. Rain hampered construction on occasion. In particular, the last soil-cement base strip to be processed, the right shoulder of section 6, was drenched by a downpour after mixing. Compaction was delayed for several hours and was inadequate; however, the section was left in that condition.

No difficulty was met in meeting the pulverization requirements. Two passes of the truck per processing strip were usually required to spread the cement. Cement spread was checked on each pass by weighing the amount caught on a canvas of known area. Samples were taken, over the full depth, from the processed material for subsequent cement content determinations by the ASTM method (D806-57). Table 2 gives determined cement contents and the average of field checks. Determined cement contents are consistently higher (and in some cases considerably higher) than field estimates. Although this may be partly due to the inadequacy of the cement content test, the larger discrepancies were apparently caused by failure to obtain mixing to the full depth intended. Cores taken after construction showed in many cases that the bottom inch or more was more weakly cemented. The rotor blades of the mixer should have been replaced more frequently.

In applying water with Na_2SO_4 in the bases of sections 6 and 7 it was found that less water (solution) was required to obtain optimum compaction moisture. Therefore, the amount of Na_2SO_4, based on field application, was about 0.8 percent rather than the 1 percent design.

A light steel-wheeled roller was used on the initial compaction pass to push down stones; subsequent compaction was with a pneumatic roller. In all cases compaction was above the specified 95 percent, with an average of 99 percent of maximum density attained.

The moist base course soil was used as curing material for completed subbases. Completed bases were covered with a bituminous seal. A thin layer of sand prevented pick up of the seal by construction equipment. Sections with Na_2SO_4 appeared to harden more rapidly than those without.

POSTCONSTRUCTION FIELD TESTS

The test road will be under observation for a number of years. A program of periodic field tests and condition studies will be conducted. The following is a discussion of the results through June 30, 1968.

Traffic Count

During the week of January 11-17, 1968, an automatic traffic counter was used. The WADT was 4182 vehicles; 71 percent of the traffic was between 7:00 a. m. and 6:00

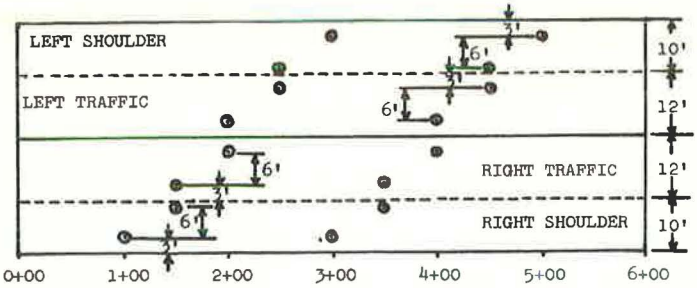

Figure 2. Layout of Benkelman beam deflection test sites.

p. m. On May 2, a visual count of traffic and vehicle types was made between 7:00 and 6:00. The total was 3365 vehicles of which less than 3 percent were trucks with dual wheels.

Benkelman Beam Deflection Test

Benkelman beam deflections were obtained at permanently marked sites August 9-11, 1967, and again April 4, 1968. Figure 2 shows the location of the 16 test sites of section 1; all other sections were tested at like points.

A modified Canadian Good Roads Association test procedure was used. Rebound surface deflections were measured with the dual wheels over the beam probe and at 2, 4, 6, 8.83 and 50 ft ahead of it. The truck had 11-in. x 20-in. 12 PR dual tires at 13.5 in. center-to-center spacing and 72 in. between centers of duals. Tire pressures were maintained at 80 psi; the rear axle load was an evenly distributed 18,000 lb. During testing the air temperature varied from 64 to 89 F in the fall and 59 to 73 F in the spring; pavement temperature varied from 72 to 103 F in the fall and 57 to 95 F in the spring. Table 3 gives the results for both series of tests. Figure 3 shows mean deflection data.

The two control sections gave smaller average deflections under a 9000-lb wheel load in the spring than in the fall. All other sections gave larger deflections, including section 2 with a rock base over cement-treated subbase. This suggests the difference in deflection behavior is due to the subbase; decreased deflection in control sections may be due to densification of the subbase under traffic. The moisture of the gravel borrow subbase remained nearly constant while that of cement-treated subbase was greater in the spring.

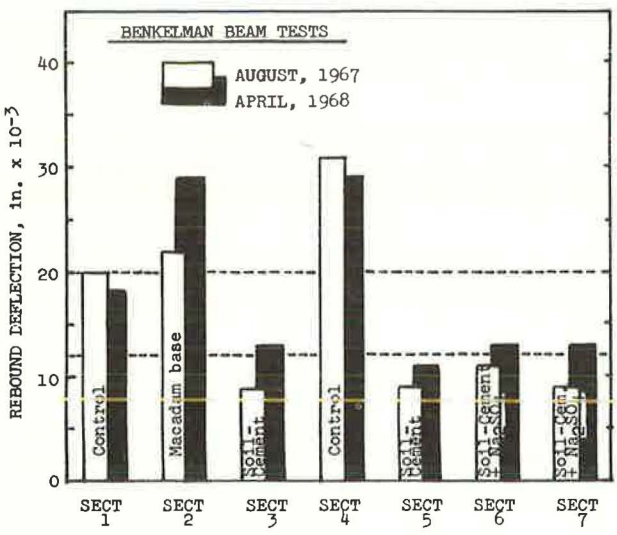

Figure 3. Mean Benkelman beam deflections.

Reasonable allowable deflections of 0.020 in. for sections with granular bases and 0.012 in. for sections with soil-cement bases were assumed on the basis of suggestions elsewhere (5). The dashed lines in Figure 3 represent these allowable values. In August, only sections 2 and 4 exceeded the allowable, but in April mean deflections were greater than allowable for all but sections 1 and 5. More detailed study of the data revealed that, in all cases, the April deflections were greater than allowable in the outer

TABLE 3

BENKELMAN BEAM DEFLECTION TEST RESULTS

Section	Mean Max. Defl, $\bar{D}$ (in. × 10^{-3})		Standard Deviation, σ (in. × 10^{-3})		Coeff. of Variation, V (%)	
	Aug 67	Apr 68	Aug 67	Apr 68	Aug 67	Apr 68
1	20	18	7	7	34	37
2	22	29	14	11	64	36
3	9	13	4	6	49	49
4	31	29	6	8	20	29
5	9	11	3	6	40	54
6	11	13	5	4	44	34
7	9	13	3	5	32	40

wheelpath of the shoulders; however, deflections were less than the allowable in the inner wheelpath and traffic lanes of sections 1, 3, 5 and 6 and in the traffic lanes of section 7. Sections 2 and 4 had greater than allowable deflections in all lanes, both fall and spring; again, the largest values were in the outer wheelpaths of the shoulders.

Roughometer Tests

Roughometer tests, with a BPR-type roughometer, were conducted on August 16-17, 1967, and again on May 14, 1968. Figure 4 shows the results in terms of the roughness index, RI, for the traffic lanes. Each RI value is the average of several runs. The riding quality of the pavement improved, with the exception of section 7. The reason for the increased roughness of section 7 is not apparent; however, the event marker of the roughometer was inoperative during the May test and a portion of the accumulated deflection assigned to section 7 may belong to section 6. The sum of RI values for the two sections is less in May in the southbound lane and only slightly higher in the northbound.

The improvement in riding quality is probably due to smoothing of surface irregularities by traffic. One run on each shoulder in May showed that these lanes, with less traffic, had a higher RI than traffic lanes in most cases.

Studies in Illinois (6) relate RI to the riding quality of flexible pavements as:

RI< 60—very good, smooth
60<RI<105—good, smooth to slightly rough
105<RI<145—fair, rough

On this basis section 7 rates fair while all other sections are good.

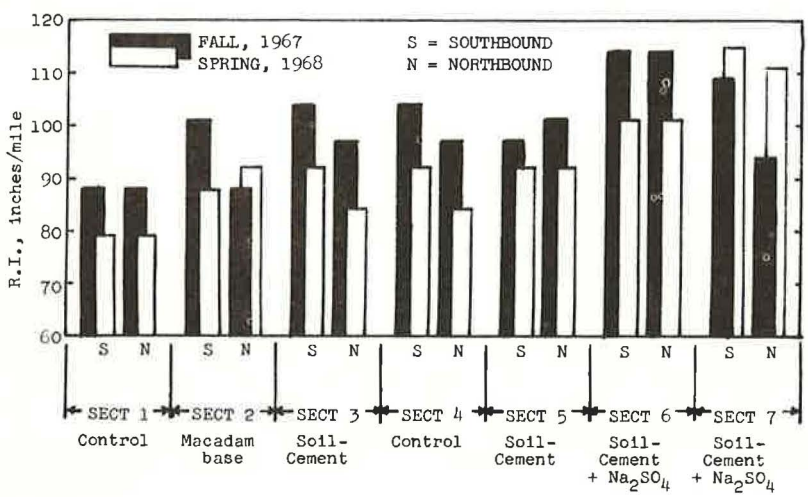

Figure 4. Roughometer test results.

Plate Bearing Test

Nonrepetitive plate bearing tests were conducted on the pavement surface of all sections between March 14 and April 4, 1968. During this period the moisture in the subgrade remained fairly uniform and there was no frost in the road. Air temperatures during testing varied from 24 to 58 F.

Tests were made at two sites on each section on the line dividing shoulders and traffic lanes, 150 ft from each end of the section, once on the right and once on the left. Loads were applied to a 12-in. diameter rigid plate by means of a hydraulic jack reacting against a large dump truck filled with sand. Surface deflections were taken at two points on the circumference of the plate.

Figure 5 presents results, after correcting loads for deadload and gage calibration, for 5 load increments. Deflections for control section 4 were considerably larger than for control section 1. This is probably due to a soft subbase condition at time of completion of the base course; a portion of section 4 near station 19 + 50 was barricaded against heavy equipment at that time. Comparison of deflections for control section 1 and section 2, rock base with 5 percent cement-treated subbase, indicates the difference in subbase had little effect on deflections. Nearly the same values were obtained for the rock base over 12 in. of gravel borrow and 8 in. of cement-modified soil.

Sections 3 and 5, with soil-cement base, gave smaller deflections than sections 6 and 7, with soil-cement plus Na_2SO_4. The relatively large deflection at station 31 + 50 (section 6) was probably due to the rain and delayed compaction as mentioned earlier. No reason is apparent for the relatively large deflections of section 7; it is hoped cores scheduled to be taken from the roadway will yield an explanation. From the present data, it appears sections with Na_2SO_4 are less rigid than those without. However, this apparent lesser rigidity may be due to the temperature cracking pattern developed during the winter months. Unfortunately, plate bearing data were not obtained before winter.

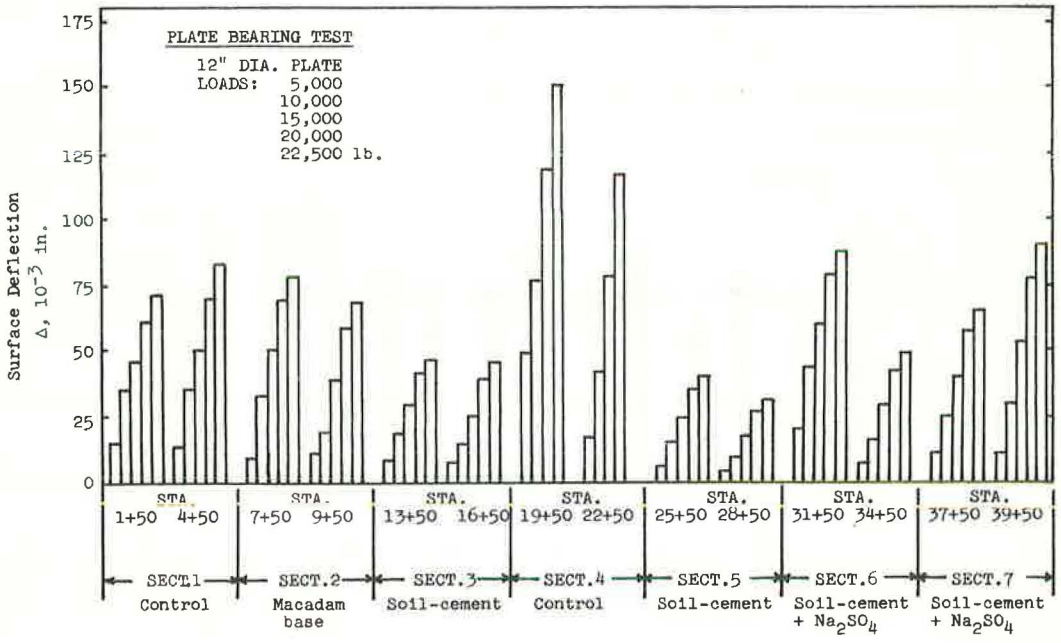

Figure 5. Plate bearing test results, spring 1968.

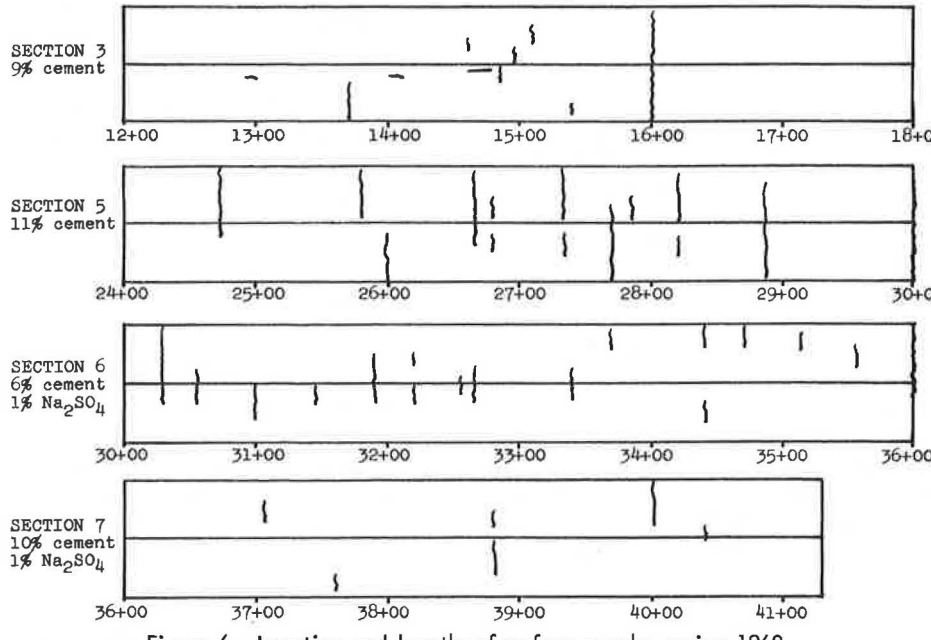

Figure 6. Location and lengths of surface cracks, spring 1968.

Crack Survey

The first cracks to develop in the pavement surface were noted on January 8 during the first cold period of the winter. Subsequent cracking occurred during the remainder of the winter, again primarily during cold periods. On April 4, a crack survey was made with width, length and position of all surface cracks recorded. Figure 6 shows the position and relative lengths of cracks in the sections affected. Table 4 summarizes results of the study. Section 3 also had 38 ft of longitudinal cracks.

All cracks were from 0 to $\frac{1}{8}$ in. wide, displayed very little or no raveling, and once developed there was no increase in width. There was no detectable differences of elevation on the two sides of cracks, i.e., they did not result from heave. Since no cracks developed in sections with rock bases, and since cracking occurred in cold weather, it was concluded the cause was temperature contraction of soil-cement bases. The first cracks developed at the instrumentation sites at stations 16 + 00 and 26 + 00, apparently due to weak zones resulting from installation of moisture cells.

There is an apparent correlation between surface cracking and plate bearing test results. Section 5, with a soil-cement base, developed the greatest amount of surface cracks and is also the most rigid as shown by plate bearing results. Section 7, with soil-cement plus Na_2SO_4 base, had the least cracking and the least apparent rigidity. Presumably, the sections with lesser amounts of surface cracking developed a greater number of small cracks which were not reflected through the wearing surface. Whether or not this cracking pattern was the result of a lesser base rigidity, the influence of Na_2SO_4, or some other factor, is not known. No plate bearing tests were made before the cracks de-

TABLE 4

TRANSVERSE CRACKS, APRIL 1968

Section	Cracks (ft)	Percent of Total
1	0	0
2	0	0
3	133	20.2
4	0	0
5	279	42.5
6	198	30.1
7	47	7.2
Total	657	100.0

TABLE 5

RANGE OF SUBGRADE MOISTURES

Station	Depth (in.)	Moisture (%)		
		Right	Center	Left
16 + 00	19	13.0-15.0	14.0-17.0	13.0-16.0
Soil-cement	24	12.0-15.0	12.5-18.5	12.5-16.0
22 + 00 Control	24	20.5-24.0	17.5-20.5	18.0-23.0
26 + 00	19	14.5-18.5	14.5-16.5	12.5-15.5
Soil-cement	24	14.5-18.5	15.0-17.0	12.5-15.5

veloped; therefore, the apparent rigidity may be due to the cracking mechanism or vice versa.

After a period of hot weather, many of the surface cracks noted in April have closed and are no longer visible.

Frost Action

Continuous air temperature data were obtained from a weather station near the test site. Analysis of the records established a freezing index of 325 degree-days for the winter of 1967-68. The lowest temperature was -5 F on January 9, the only time below zero. Pavement temperature measurements at stations 16 + 00, 22 + 00 and 26 + 00 showed that freezing temperatures penetrated more than 6 in. for only two brief periods, January 6-15 and February 13-22. The maximum measured depth of penetration was 19 in. each time and this depth was not maintained for more than a day or two.

There was no evidence of frost heave at any time in any section. Periodic checks of surface elevation showed no change.

Subgrade Moisture

As expected, subgrade moisture fluctuated to some extent throughout the test period. Moisture cell readings were taken at least twice weekly and more often during the winter months. In general, low moisture contents occurred in late September and during the January freeze period. The higher moisture contents were in late March and early April. Table 5 gives the maximum and minimum subgrade moistures at each instrumented site.

The greater than design cement content of cement-treated subbases changed the resistance properties of the material so resistance readings could not be converted to

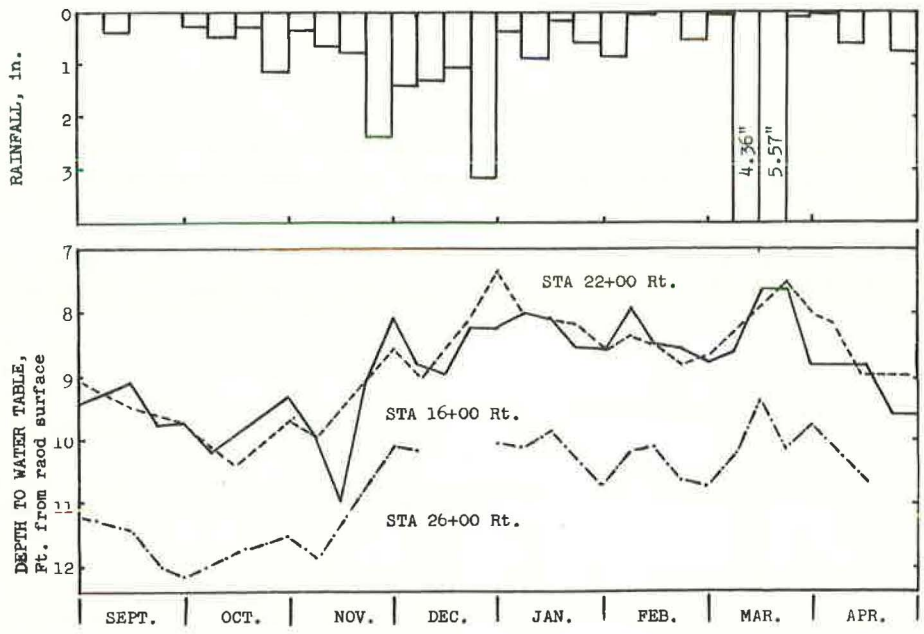

Figure 7. Water table fluctuation and rainfall.

moisture contents. Also, the gravel borrow material for control subbases was not available in time to establish moisture cell calibrations before the cells had to be installed. However, resistance readings do indicate the direction of moisture change if not magnitudes. Resistance data show that the cement-treated subbases had their lowest moisture in the fall and highest in the spring, and the gravel borrow subbase maintained a nearly constant moisture since shortly after completion of construction.

Since the first surface cracks appeared at the instrumented sites, resistance readings in the soil-cement bases reflect moisture accumulation in the cracks rather than any change in the base itself.

The depth to the water table was measured at 4 ft from each edge of the pavement at each of the instrumented sites. The lowest water table occurred in late September-early October and the highest in late December and late March. Figure 7 shows partial results. The depth of the water table on the right (downhill) side of the road and accumulated rainfall are plotted at one-fourth month intervals. Rises in the water table occurred with or shortly after periods of substantial rainfall.

SUMMARY

1. Cement Content—Determination of cement contents, by ASTM D806-57, were consistently greater than estimates from field checks during cement application. The larger discrepancies were due to insufficient depth of mixing.
2. Traffic—The WADT is 4182 vehicles, of which less than 3 percent are trucks with dual wheels.
3. Benkelman Beam—Control sections deflected less in spring than in fall while all other sections deflected more. Apparently subbases of control sections became more stable under traffic.
4. Roughometer—Pavement riding qualities improved during the test period due to smoothing of surface irregularities by traffic.
5. Plate Bearing—Base courses had primary influence on deflections. Sections with soil-cement plus Na_2SO_4 appear to be less rigid than sections with soil-cement alone.
6. Cracks—No surface cracks appeared in sections with rock bases. Cracks caused by temperature contraction of base slabs occurred in all sections with soil-cement bases. There is an apparent correlation between cracking and plate bearing deflections.
7. Frost Action—There was no evidence of frost heave. The maximum frost penetration depth was 19 in. for only two brief periods.
8. Pavement Moisture—Subgrade moistures fluctuated by 2 to 6 percent; the lows were in September and January and the highs in March-April. Cement-treated subbase moisture was low in fall and high in spring, while rock borrow subbase moisture remained nearly constant. Depth to the water table correlated well with rainfall.

CONCLUSIONS

On the basis of the partial results obtained at the time of writing, the following conclusions and observations are made:

1. Rhode Island silts of the type encountered on this project can be adequately stabilized for highway purposes by addition of cement or cement plus sodium sulfate. For the amount and type of traffic using the road, adequate stability could probably have been attained with lesser amounts of cement than were used.
2. The objective of determining the long-range effects of sodium sulfate must await further observations. Inclusion of sodium sulfate apparently accelerates the initial cement reactions leading to greater early strengths. There is some indication that sodium sulfate may influence the temperature cracking pattern of soil-cement bases; however, further testing is needed.
3. Although the anticipated costs of control and test sections were comparable, actual construction costs are not yet available. For this project, it is felt that actual construction costs for the soil-cement (and sodium sulfate) test sections may be considerably higher than those for the control sections.

ACKNOWLEDGMENTS

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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. No. 9, Aug. 1966.
2. Soil-Cement Laboratory Handbook. PCA, 1959.
3. Suggested Specifications for Soil-Cement Base Course. PCA.
4. Initial-Preconstruction Report. Submitted to Rhode Island DPW and USBPR, Univ. of Rhode Island, June 17, 1966.
5. Carneiro, B. L. Benkelman Beam—Auxiliary Instrument of the Maintenance Engineer. Highway Research Record 129, p. 28-55, 1966.
6. Chastain, W. E., and Burke, J. E. Experience with a BRP-Type Roadometer in Illinois. HRB Bull. 328, p. 52-58, 1962.