Soil-Cement Construction Using Loess Soil

STEPHEN E. ROBERTS and ELDON P. SCHOENEMAN
Respectively, Research Engineer, and Research Project Engineer, Iowa State Highway Commission

Construction of approximately 26 miles of soil-cement base composed entirely of cement, water and loess soil is reported. Two projects are involved; the first, on Iowa 37, was built in 1961, and the second, on Iowa 333, in 1963. Information obtained during the construction of Iowa 37 brought about changes in construction procedure and specifications, including: (a) changing the required density from 90 to 95 percent of the maximum density as determined by AASHO Designation: T 99; (b) eliminating the 0.05-ft tolerance on the finished base; (c) disallowing use of a spike drag; and (d) changing surface treatment from a single to a double bituminous seal. Data relative to routine and special testing are included. A comparison is made between the results of freeze and thaw testing of laboratory specimens and cores taken from the 12 experimental base sections on Iowa 37. A similar comparison is made for compressive strength.

•THE WESTERN PART of Iowa contains an area in which granular materials suitable for highway construction are not readily available from local sources. This area is covered almost entirely by a thick deposit of loess soil.

The stabilization of Iowa loess with portland cement was investigated by Handy, Davidson and others (1, 2). Their studies strongly suggested that the loess soil of western Iowa can be used effectively for soil-cement base construction. This favorable conclusion was a major factor in the decision to use soil-cement on two pavement projects constructed in western Iowa during the past few years.

This report is concerned with the general design and construction procedures and problems, and with laboratory and field data obtained in connection with the soil-cement construction.

DESIGN

The first of the two soil-cement bases was constructed on 12.8 miles of Iowa 37 in 1961; the second was constructed on 13 miles of Iowa 333 in 1963. Location of the projects is shown in Figure 1.

On both projects, the soil-cement base is 7 in. thick and 23.5 ft wide. No subbase was constructed. Design requirements included placement of a 3-in. hot-mix asphalt concrete mat 1 to 3 years after completion of the base. An interim surface consisting of a single bituminous surface treatment was placed on Iowa 37; a double surface treatment was used on Iowa 333.

The design cement content of the base was determined from the results of freezing and thawing tests of compacted soil-cement mixtures made according to AASHO test method T 136-57. The maximum permissible loss during 12 cycles of freezing and thawing was set at 10 percent, which is the maximum recommended by the Portland Cement Association for A-4 soil (3).

Paper sponsored by the Committee on Soil-Portland Cement Stabilization and presented at the 44th Annual Meeting.

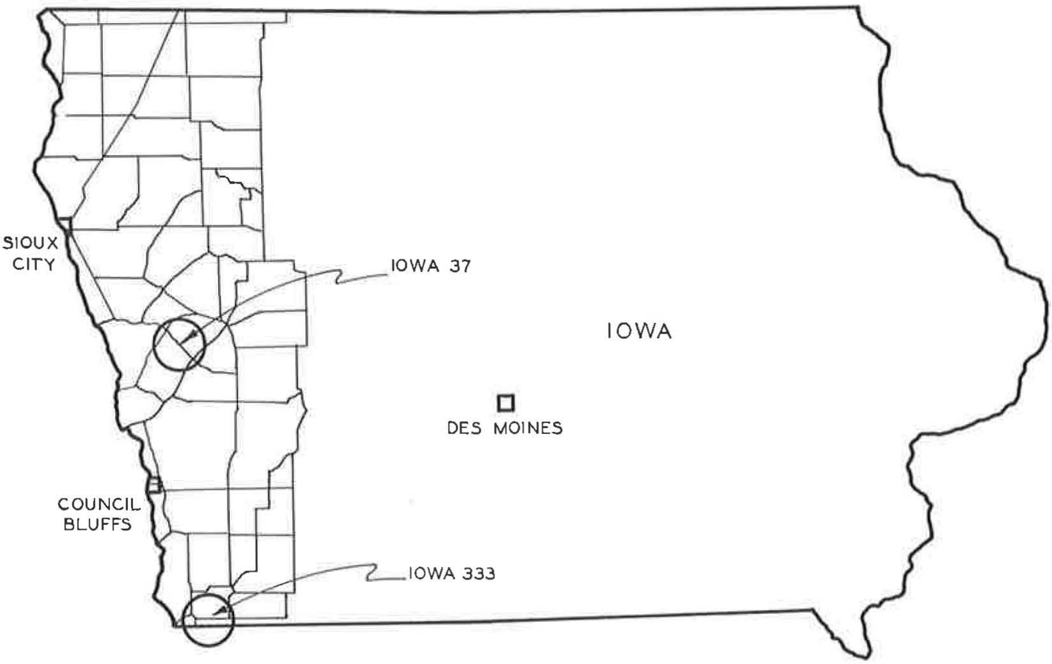

Figure 1. Location of soil-cement projects.

Figure 2 contains curves relating weight loss to the number of freeze-thaw cycles for compacted mixtures of soil from the Iowa 37 borrow area and four different amounts of cement. Similar curves were prepared for mixtures containing the soil used in the base on Iowa 333.

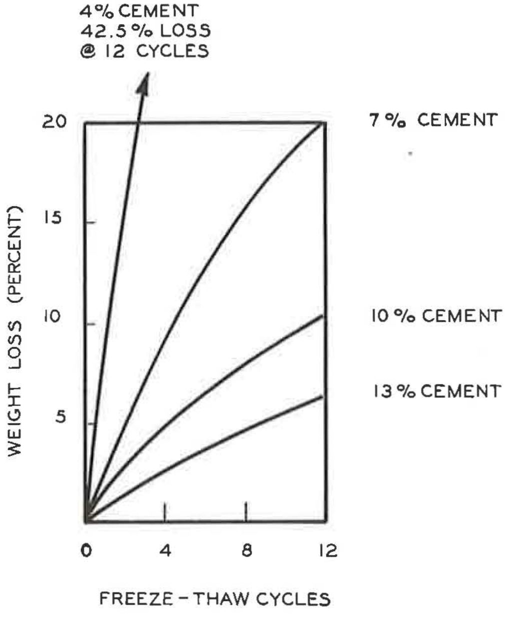

Figure 2. Soil-cement design curves, Iowa 37.

The design cement content for the base on Iowa 37 was set at 11 percent of the dry weight of the soil; for Iowa 333 it was set at 10.75 percent. Iowa 37 also contains 12 experimental base sections in which the cement content was specified to be 7, 9, 11 or 13 percent.

MATERIALS

The design for both projects required that the soil for the base be obtained from borrow areas selected and purchased by the state. Classification of the borrow soil varied from A-4(8) to A-6(10). Table 1 shows additional soil data.

TABLE 1

SOIL DATA INFORMATION[a]

Soil Characteristics	Iowa 37	Iowa 333
Percent passing No. 200 sieve	98-100	99-100
Percent 5-μ clay	18- 24	20- 28
P.I.	9- 15	10- 16

[a]Type I cement was used in both projects.

CONSTRUCTION

The fact that the base contained soil from borrow areas dictated many of the construction procedures. In each project the soil was obtained from a single borrow area located adjacent to the roadway, and a stationary mixing plant was set up at that location.

Although separated in time by 2 years, the Iowa 37 and Iowa 333 pavements were built by the same contractor. To a large extent, the same equipment was employed on both projects. Construction procedures were similar, but those used on Iowa 333 reflected some changes which were made in an effort to overcome the finishing problems encountered on Iowa 37.

The soil-cement was mixed in a continuous flow-type pug mill. The mixture was delivered to the grade in trucks and was placed by two Jersey spreaders. The spreaders were mounted on crawler-type tractors equipped with scarifying teeth to break up the material compacted by the tracks. Compaction was accomplished with sheepsfoot rollers, pad-type vibrators and pneumatic rollers. On the first project, Iowa 37, the contractor attempted to obtain the required compaction with pad-type vibrators alone. This proved unsuccessful; however, these vibrators were used effectively to compact the sloping edge of the base. On Iowa 333, the contractor began operations with a regular sheepsfoot roller and a vibrating sheepsfoot roller. Use of the vibrating roller was discontinued after the first few days because it did not compact to the required density and because it had large, smooth feet which caused compaction planes in the base.

On Iowa 37 the base was cured with RC-0 or MC-3 applied not later than 24 hours after completion. The application rate was 0.25 gal/sq yd. On Iowa 333, the material used for curing was MC-0 or MC-1 at the rate of 0.2 gal/sq yd. On both projects it was necessary to spread blotter sand on the surface before allowing limited traffic at the end of 7 days.

DISCUSSION

Accepted practices, such as those described in PCA publications (3, 4), were generally followed in the design and construction of the soil-cement base. The Iowa 37 project was purposely experimental, whereas Iowa 333 was planned as a standard highway improvement representative of the type of soil-cement construction possible in areas of the state where loess soil is prevalent. The experience and data gained from both projects has proven valuable, although much remains to be done before optimum design and construction procedures can be prescribed.

Soil Pulverization

PCA (4) reports that most specifications require that a minimum of 80 percent of the soil-cement mixture pass a No. 4 sieve, exclusive of any gravel or stone; the final pulverization test is made at the conclusion of mixing operations.

The specifications for Iowa 37 and Iowa 333 required that at least 80 percent of the soil pass a No. 4 sieve before the addition of the cement. Since the cement content was 11 percent of the dry soil weight, this specification was equivalent to requiring that 82 percent of the soil-cement mixture pass the No. 4 sieve.

Pulverization of the soil for Iowa 37 was not a serious problem. The top 1 ft of soil in the borrow area was removed and wasted. The underlying soil was disced and then pushed by a bulldozer into a bulkhead feeder. Large lumps of soil were either broken or removed by a single vibrating screen. The in-place moisture ranged from 16 to 19 percent. This was reduced about 2 percent by aeration during discing.

Pulverization of the soil for Iowa 333 proved to be difficult. The difficulty may have been caused by the slightly larger clay content of this soil plus a greater in-place moisture content, which was found to be as high as 25 percent. The contractor tried several combinations of mechanical processing and aeration in his efforts to pulverize the soil. The most successful method involved making several passes with a P & H stabilizer in the borrow area, but even following this treatment, only about 70 percent of the soil would pass the No. 4 sieve. It was found that the soil was most friable when it contained about 18 percent moisture, and that extensive processing and drying promoted the formation of firm clay balls which would not break up in the mixer.

The effect of the degree of pulverization was reported by Felt (5) in 1955. He concluded that the quality of silty and clayey soil-cement mixtures was highest when 100 percent of the soil (exclusive of gravel and stones) was pulverized to pass a No. 4 sieve. He further stated, however, that the quality was not seriously affected by as much as 30 percent of unpulverized soil, provided the soil lumps were at optimum moisture or slightly above when compacted.

The purpose of pulverization is to insure an intimate mixture of soil grains and cement. The end result is a product of both the initial pulverization and the efficacy of the mixing operation.

Mixing

The soil-cement for both Iowa 37 and Iowa 333 was mixed in a 10-ft, twin-screw pug mill. Production varied from 150 to 180 tons of mixture per hour. To attain this rate, the mixing time was limited to about 15 sec. This may not have been the optimum length of time; PCA (4) reports that a 30-sec mixing time is customary.

A pertinent question is whether or not soil-cement containing fine-grained, cohesive soil can be mixed effectively in a pug mill type mixer. It was observed that the mixing action was considerably influenced by the initial moisture content of the soil and that balls forming where the soil and cement were introduced into the mixer did not always break up during passage through the pug mill. These became coated with cement on the outside and thereafter seemed to act as individual aggregate particles.

British practice (6) is to require a single-pass mix-in-place plant for cohesive soils and to permit stationary plants only for mixing granular soils with low cohesivity. Experience thus far in Iowa does not dictate adoption of the British practice, but it does suggest that there is room for improvement in the mixing action of stationary plants for producing soil-cement from fine-grained soil.

Cement Content

The cement was introduced into the pug mill through a vane-type feeder. A major problem with the cement feed was caused by the fact that the cement feeder and the soil feeder were not interlocked. In spite of close attention by the contractor and the inspectors, the two feeders were not always started and stopped simultaneously.

The average cement content of the soil-cement mixture was determined by observing the total tons of soil-cement produced from one or more carloads of cement. This method is subject to error due to the difficulty of determining the precise beginning and end points for any particular carload of cement passing through the mixer. Nevertheless, it appears to be a reasonably reliable method for estimating the average cement content of the base mixture on normal construction projects.

On Iowa 37, the design cement content was 11 percent of the dry weight of the soil, except in the experimental sections. During construction of the non-experimental sections, 46 cement checks were made, each involving one or more carloads of cement. The results of these tests are summarized in Figure 3. The average of 46 tests was 11.32 percent with a standard deviation of 0.65 percent.

The design cement content of the base on Iowa 333 was 10.75 percent of the dry weight of the soil. There were no experimental sections and no planned variation in cement content. The results of the field checks for cement content are summarized in Figure 4. The average of 71 tests was 11.30 percent; standard deviation was 1.18 percent.

On the Iowa 37 project, only four of the 46 field checks indicated an average cement content different from the design amount (11 percent) by more than 1.0 percent. It was expected that the same degree of control would be exercised on Iowa 333. The results there were disappointing because 27 out of 71 checks showed an average cement content different from the design amount (10.75 percent) by more than 1.0 percent.

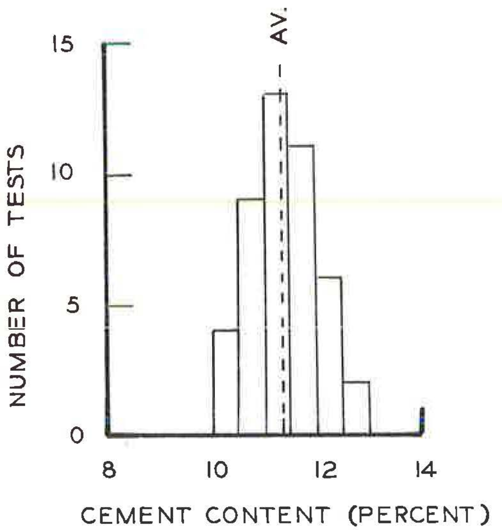

Figure 3. Field checks of cement content, Iowa 37.

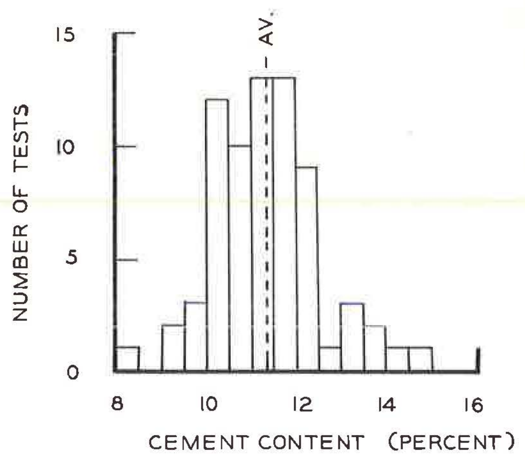

Figure 4. Field checks of cement content, Iowa 333.

It must be recognized that estimates of cement content made from the records of the materials passing through the plant are of little more than historical value. If the cement content is below the amount specified, it can be corrected only by drastic action, such as tearing up and replacing a portion of compacted base.

Before the construction of Iowa 37, a brief laboratory investigation was made of the California (6) and Washington (7) methods for measuring cement content. The California method is essentially a chemical titration procedure; the Washington method depends on the change of conductivity of water with the addition of cement. Neither method gave satisfactory results, perhaps because of the fine-grained nature of the soil. The possibility that the conductivity may be influenced by the presence of clay was suggested by LeClerc and Sandahl (7) in their report on the Washington method.

The principal objective of the experimental base construction on Iowa 37 was to observe the physical properties and performance of a soil-cement base containing quantities of cement other than the design percentage. The 12 experimental sections were scattered throughout the 12.8 miles of base construction.

The cement feed was calibrated to provide an intended cement content of 7, 9, 11 or 13 percent. Field checks were made as previously described, and cement content by chemical analysis was determined from samples sent to the laboratory.

The first cement tests by chemical analysis were made on samples taken from the pug mill during construction. The results varied considerably from the intended cement percentages and were suspected to be in error. It was demonstrated, however, by means of laboratory prepared samples that the chemical analysis test could give results accurate to 0.2 percent of the actual cement content. Consequently, when cores were later obtained from the experimental base sections, a portion of each core was analyzed for cement content.

Figure 5 compares for each experimental section the intended cement content, the cement measured by field checks, and the cement determined by chemical analysis. In 9 of the 12 experimental sections, the field check results showed a higher cement content than that obtained by analysis.

Density

The required density of Iowa 37 was 90 percent of maximum field density determined according to AASHO standard method T 134-57. It was customary for the plant inspector to determine maximum density at least once a day. Throughout most of the

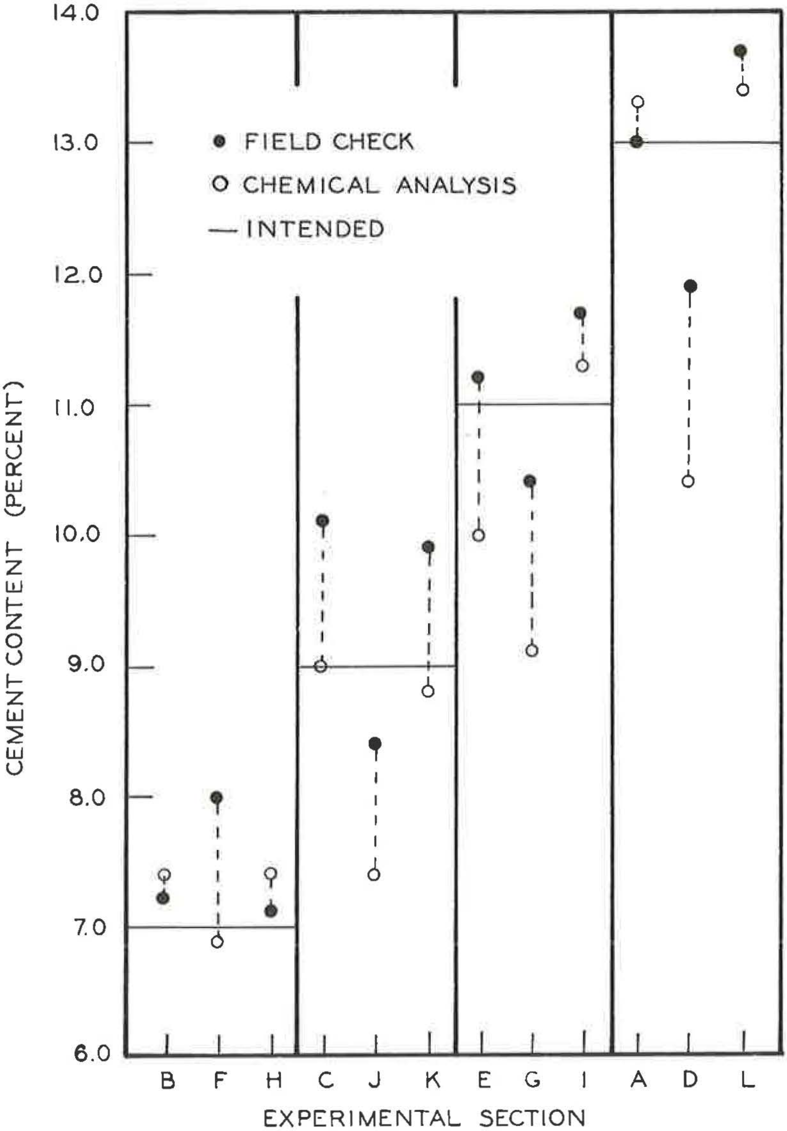

Figure 5. Comparison of intended cement content, field checks, and chemical analysis, Iowa 37.

job the maximum dry density was 98.6 pcf at an optimum moisture content of 21.8 percent.

The density of the compacted base was determined by the oil method. Figure 6 summarizes the results of tests by this method. The average of 121 tests was 93.5 percent of maximum density, with a standard deviation of 3.2 percent.

The density of cores drilled from the experimental base sections at the age of 5 or 6 days is shown in Figure 7. The average of 71 cores was 94.8 percent; standard deviation was 3.6 percent.

Since the average field density was 93.5 percent of maximum and the average core density was 94.8 percent of maximum, it was concluded that compaction to 95 percent of maximum could have been readily obtained. Even this is less than the 100 percent recommended by PCA (4) and some state highway departments (8).

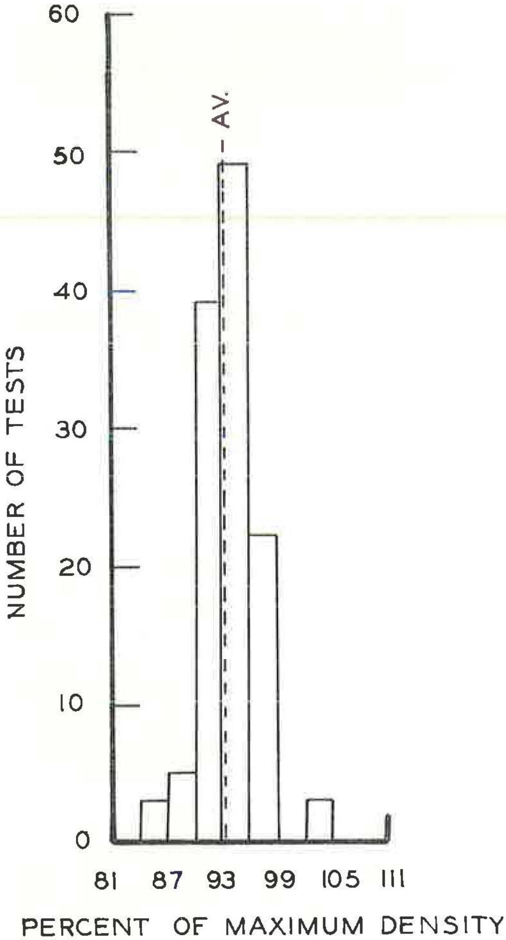

Figure 6. Field density tests, Iowa 37.

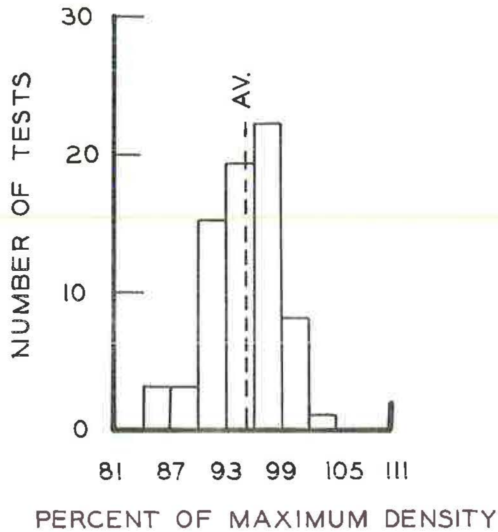

Figure 7. Density of soil-cement cores, Iowa 37.

The specified minimum density for the Iowa 333 base was 95 percent of maximum. Because the soil in the borrow area was not uniform, the maximum field density varied from 97.0 to 101.8 pcf. The field tests of density are summarized in Figure 8. The average of 150 tests was 97.6 percent, with a standard deviation of 4.0 percent.

Finishing

In bringing a soil-cement base to grade and profile, it is frequently necessary to work with very thin cut and fill sections. The specifications for Iowa 37 required that the grade and profile of the base be true to 0.05 ft or less. In meeting this specification, the contractor spent considerable time and effort on finishing operations.

The finishing operations normally require the use of a spring-tooth harrow, spike drag, or similar device to roughen and scratch the surface of the compacted material. On Iowa 37 the contractor used two devices for this purpose. One of them was equipped with large teeth which became smooth and round on the ends (Fig. 9). The teeth left slick, shallow grooves in the compacted base, such as are shown in Figure 10. After the base had cured for about 7 days, the top ½- to 1-in. became separated from the lower portion in many areas, such as the one shown in Figure 11.

When Iowa 333 was constructed, an effort was made to reduce the amount of work needed to obtain an acceptable surface, and the 0.05-ft requirement for grade and profile was eliminated. During construction of the first 6 miles of the project, a heavy drag was used along with a spring-tooth harrow. This heavy drag had thin blade-like teeth with sharp points. It was reasoned that this drag would scarify to a greater depth than the harrow, but that it would not cause the slick grooves produced by the heavy spike drag used on Iowa 37. Unfortunately, compaction planes did develop much as they had on Iowa 37, and use of the heavy drag was discontinued. This reduced the incidence of compaction planes, but did not eliminate them entirely.

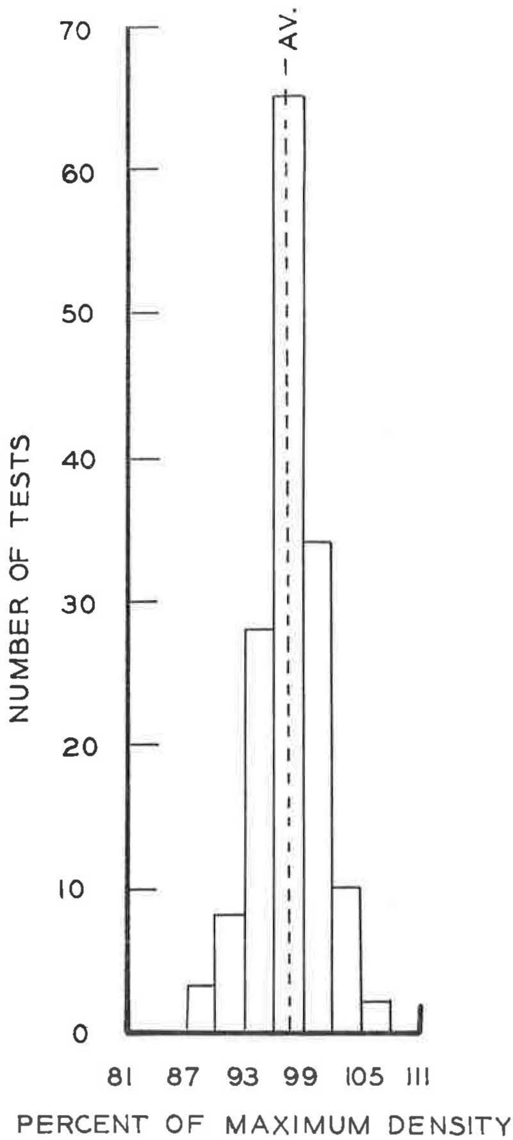

Figure 8. Field density tests, Iowa 333.

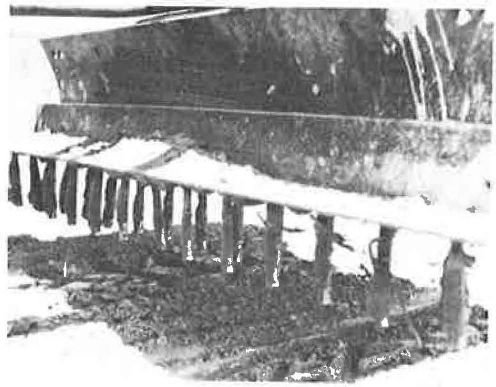

Figure 9. Spike drag with large blunt teeth used on Iowa 37.

Figure 10. Core with top 3/4 in. broken off during drilling (note slick grooves made by spike drag), Iowa 37.

Figure 11. Soil-cement base with top 3/4 in. broken away, Iowa 37.

Wearing Surface

When Iowa 37 was constructed in 1961 it received a single-course bituminous seal, consisting of 0.28 gal/sq yd of MC-4 and 31 lb/sq yd of cover aggregate. A hot-mix asphalt concrete surface was programmed for 1964. It was expected that most of the shrinkage cracks in the base would appear during the 3-year interval. Previous experience in Iowa and elsewhere (8) has suggested that cracking in the asphalt concrete will be retarded, or possibly reduced, if application of the mat is delayed until 2 or 3 years after construction of the base.

During the spring of 1962, and again in 1963, maintenance of the surface seal became a serious problem. Investigation revealed that moisture had penetrated through closely spaced cracks in the seal and destroyed the bond between the asphalt and the soil-cement. At first only small bits of the surface were picked up or otherwise removed by traffic. These small areas grew rapidly, however, and it soon became necessary to make hundreds of surface patches throughout the entire project. Figure 12 shows an extensively damaged area before patching.

On Iowa 333 a double bituminous seal was applied at the time of construction. The MC-4 was applied at the rate of 0.35 gal/sq yd for the first course and 0.30 gal/sq yd for the second. One-half-inch cover aggregate was placed at an average rate of 30 lb/sq yd for the first course and 25 lb/sq yd for the second. No surface damage has been observed on Iowa 333.

Moisture Content of Base

The moisture content of the soil-cement mixture was checked frequently during construction of Iowa 37. The objective was to insure production of a mix having a uniform moisture content about 2 percent greater than Proctor optimum (21.8 percent) when it left the pug mill. The moisture content of the base was measured again when the density was determined following compaction. It was also determined from cores and samples taken at various times after construction. The results of all moisture tests are summarized in Figure 13.

The moisture content of the samples taken from the pug mill indicated that good moisture control was exercised during mixing. Moisture measurements made in conjunction with the density tests showed that the base was compacted at an average moisture content slightly above optimum. The tests made at age 8 days revealed that adequate moisture was retained in the base during initial curing of the soil-cement.

The average moisture content of the base at ages 8 and 12 months was over 24 percent, which was surprisingly high, especially since the average moisture content of the soil in the first 6 in. below the soil-cement was 16.7 percent.

Figure 12. Surface damage due to failure of single bituminous seal, Iowa 37.

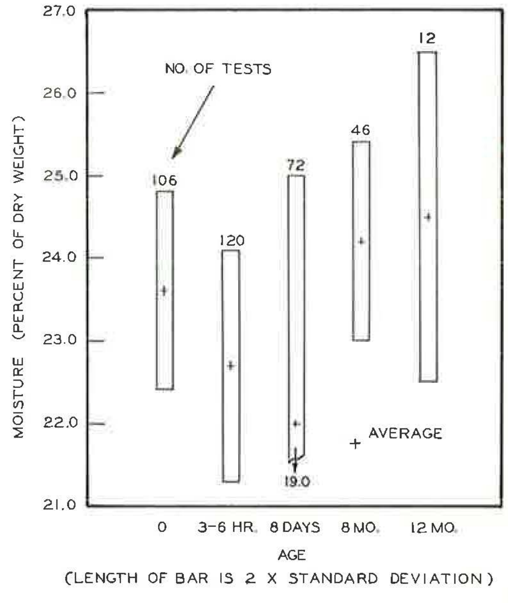

Figure 13. Moisture content of soil-cement, Iowa 37.

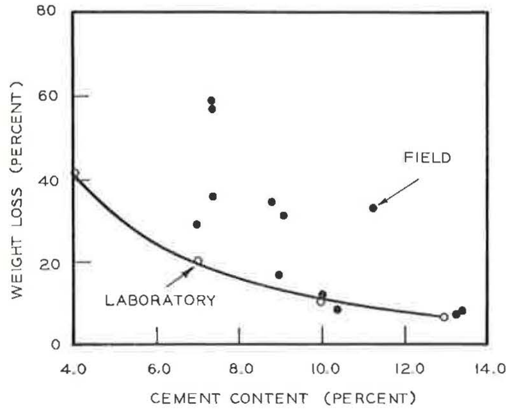

Figure 14. Freeze-thaw resistance of laboratory specimens and cores, Iowa 37.

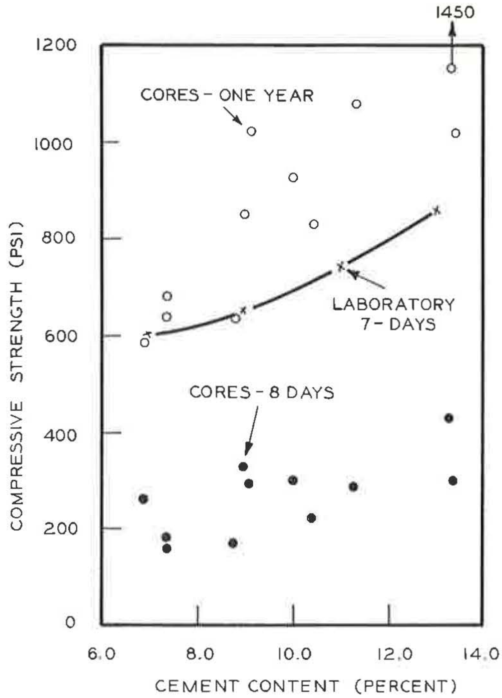

Figure 15. Compressive strength of laboratory specimens and cores, Iowa 37.

Resistance to Effects of Freezing and Thawing

Resistance to the effects of freezing and thawing is usually determined from specimens of soil-cement prepared in the laboratory under the best possible conditions relative to mixing, compaction, and curing. It has been suggested that field operations produce soil-cement which is inferior to that produced in the laboratory.

In connection with the Iowa 37 project, a comparison was made between the freeze-thaw resistance of laboratory specimens and that of cores drilled from the experimental sections at age 6 days and tested at age 8 days (Fig. 14).

Compressive Strength

Figure 15 shows compressive strength and cement content of soil-cement from the Iowa 37 project. The points on the curve represent the strength of specimens prepared in the laboratory. The closed circles represent the average strength of cores from each experimental section drilled at age 6 days and tested at age 8 days. The open circles represent the average strength of cores drilled and tested at the age of approximately 12 months. Both the laboratory specimens and the field cores were immersed in water for 24 hours before testing.

CONCLUSIONS

In general, the construction of a soil-cement base containing loess soil requires the same equipment and workmanship that is needed for any soil-cement pavement construction. Some of the problems are accentuated by the characteristics of the soil; consequently, special attention must be given to soil pulverization, mixing, and finishing. The following specific conclusions apply only to the soil-cement construction discussed in this report:

1. Soil Pulverization—The clay content and the moisture content of the soil seemed to control the degree of pulverization that could be attained. There appeared to be a particular moisture content at which the soil was most friable.

2. Cement Content—On the basis of field checks, control of the cement proportioning on Iowa 37 was fair to good; on Iowa 333 it was poor. Much work remains to be done

in Iowa on the effect of cement variation in soil-cement mixtures and the use of rapid methods for determining cement content.

3. Finishing—The use of a heavy spike drag with blunt teeth produced compaction planes in the soil-cement on Iowa 37. A similar heavy drag with sharp pointed teeth caused compaction planes on Iowa 333.

4. Surface—A single bituminous surface treatment on Iowa 37 was inadequate to protect the soil-cement base. A double surface treatment on Iowa 333 appears to have been satisfactory.

5. Freeze-Thaw Loss—The average freeze-thaw loss of cores drilled from the experimental sections of Iowa 37 was substantially greater than the loss suffered by corresponding laboratory specimens except for sections containing at least 10 percent cement.

6. Compressive Strength—The average compressive strength of cores from Iowa 37, when tested at age 8 days, was about 400 psi less than the strength of laboratory specimens tested at age 7 days. Cores drilled and tested after 1 year showed strength equal to or greater than the 7-day laboratory specimens.

ACKNOWLEDGMENTS

The Iowa 37 project was constructed with Federal participation. Appreciation is expressed to the U.S. Bureau of Public Roads for help in planning the experimental sections. The authors also wish to acknowledge the assistance of design, materials, and construction personnel of the Iowa State Highway Commission in obtaining the material for this report.

REFERENCES

1. Handy, R.L., Davidson, D.T., and Chu, T.Y. Effect of Petrographic Variations of Southwestern Iowa Loess on Stabilization with Portland Cement. Highway Research Board Bull. 98, pp. 1-20, 1954.
2. Handy, R.L., and Davidson, D.T. Portland Cement Contents Required to Stabilize Eastern and Western Iowa Loess. Proc., Iowa Acad. of Sci., Vol. 64, pp. 276-313, 1957.
3. Portland Cement Association. Soil-Cement Laboratory Handbook. 55th ed., 1959. 62 pp.
4. Portland Cement Association. Soil-Cement Construction Handbook. 1956. 99 pp.
5. Felt, Earl J. Factors Influencing Physical Properties of Soil-Cement Mixtures. Highway Research Board Bull. 108, pp. 138-162, 1955.
6. California Division of Highways. Determination of Cement Content in Cement-Treated Aggregate by the Method of Titration. Materials Manual, Vol. 1, Test Method No. Calif. 338-A, 1960.
7. LeClerc, R.V., and Sandahl, H.E. A Rapid Method for Determining Cement Content of Plastic Cement-Treated Base. Highway Research Board Bull. 267, pp. 1-13, 1960.
8. Soil Stabilization with Portland Cement. Highway Research Board Bull. 292, 1961. 212 pp.