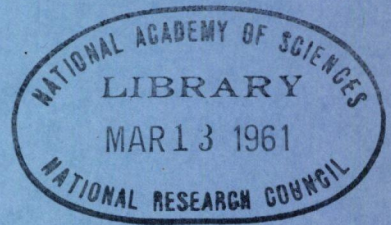


HIGHWAY RESEARCH BOARD

Bulletin 267

*Soil Stabilization by  
Admixing Portland Cement*



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No. 267

**National Academy of Sciences—  
National Research Council**

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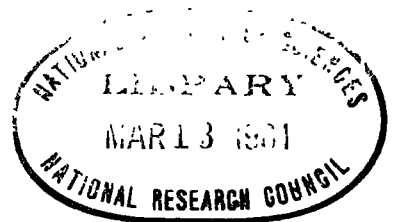
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***Soil Stabilization by  
Admixing Portland Cement***

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# A Rapid Field Method for Determining Cement Content of Plastic Cement-Treated Base

ROGER V. LE CLERC, Supervising Highway Engineer, and HENRY E. SANDAHL, Associate Material Engineer, Washington State Highway Commission, Olympia

A method for determining the cement content of freshly-mixed cement-treated base by means of an electrical conductivity cell is described. The procedure, developed originally to check uniformity of cement distribution in road-mixed cement-treated base mixtures, is now being used for control of cement percentages in plant-mix production of cement-treated base.

The method is based on the resultant change in the electrical conductivity of water when small quantities of cement are added. A calibration curve is first constructed by measuring the conductivity of solutions prepared by adding one quart of water to small batches of aggregate containing known quantities of cement. Samples of plant-mixed treated material are then procured and their electrical conductivity determined by the same procedure. The amount of cement in the sample is then determined from the calibration curve. This amount, together with the initial sample weight and moisture content, is then used to calculate the cement content of the mixture. Cement contents, based on the average of results on three samples, are available in 20 to 25 min from time of sampling.

A brief description of the development of the test procedure, a detailed description of the procedure and its use by field forces, illustrations of test apparatus and data sheets, and a comparison of test results with actual "yield" figures from several jobs, are presented.

● EFFORTS to investigate the uniformity of cement distribution achieved by various methods of mixing cement-treated base (CTB) (cement-treated base as used in Washington consists of gravel or crushed ledge rock, substantially all passing a 1-in. sieve and not more than 15 percent passing a US No. 200 sieve, to which portland cement in the amount of 3 percent to 7 percent by weight of dry aggregate is added) pointed out the need for a rapid method of determining cement contents in the field. Such a test would also provide a method for controlling and checking cement contents of cement-treated base mixed in a central plant.

The test procedure developed is based on the resultant change in conductivity of water after the addition of cement. Suitable calibration curves are first obtained by batching small test mixtures of cement-treated base aggregate containing known quantities of cement, diluting the mixtures with a large quantity of water, and measuring the conductance of the diluted mixture with a conductivity meter. To determine cement contents of mixed cement-treated base, representative samples are subjected to the same dilution procedure and the conductivity similarly determined. Reference to the calibration curve gives the amount of cement in the sample.

## DEVELOPMENT OF TEST

The use of conductimetric methods for determining cement contents of aggregate

mixtures containing cement was described by L. R. Chadda (1). His procedure was designed primarily for determination of cement content in concrete, and has as its basis the fact that cement in contact with large quantities of water releases free lime and other chemicals in a concentration proportional to the amount of cement present. The chemicals in the water increase the conductivity, which can be measured with a standard conductivity cell. Possibly because the free lime is sparingly soluble in water, changes in concentrations of cement above 5 percent do not affect the conductivity significantly, and this constitutes a limitation to be considered in the test procedure.

The procedure described by Chadda calls for use of 10 grams of the fine portion (passing 10-mesh sieve) of a freshly mixed batch of concrete. The 10-gm sample is diluted with 200 ml of distilled water, shaken thoroughly, and the conductivity of the resultant suspension measured.

This procedure offered hope for a needed rapid field test for measuring the cement content of cement-treated bases processed in continuous mix plants. Existing methods of checking on the amount and uniformity of cement in the final CTB product were limited to a chemical test for determining cement contents. This required either an elaborate field laboratory together with laboratory-trained personnel, or the services of a central laboratory. The naturally delayed results of the latter are usually of historical value only.

The envisioned conductimetric test procedure contemplated the determination of a calibration curve by mixing various quantities of cement with representative samples of CTB aggregate and water to simulate field mixing. The mixed samples would then be diluted with a large volume of water, and, after agitation and an appropriate time interval, the conductivity of the suspension would be measured by means of a conductivity cell. The data obtained would be plotted as conductivity vs weight of cement to form the calibration curve. To determine cement content of the freshly mixed CTB, samples would be taken, subjected to the same process of dilution, agitation, and measurement of conductivity, with proper adherence to timing limits used in the calibration. The cement content of the fresh CTB would be available from the calibration curve once the conductivity of the sample was known.

In order to adapt the conductimetric test procedure to field control of CTB, certain modifications in Chadda's procedure were indicated. A sample size of 10 grams, for instance, could hardly be considered representative unless it had been carefully prepared from a larger sample. This would require techniques and abilities beyond those expected of the ordinary inspector, especially under typical field conditions. Likewise, the logistics and expense associated with the consumption of large quantities of distilled water in the field argued for use of the readily-available CTB mixing water. In addition, revisions in procedural timing and quantities would be necessary or desirable. If these modifications could be brought about with reasonable retention of accuracy, a useful test would result.

Results of preliminary tests to evaluate the effect of the variables involved in the contemplated modifications were used to establish the value or level of each variable incorporated into the proposed test procedure. The effects of these variables are discussed in the following:

#### Effects of Raw Water, Type and Brands of Cement, and Mineral Aggregate

After analyzing a few test results it was believed that no appreciable loss in accuracy would result from using locally available water in place of distilled water for the test. Obviously, the conductivity of the water used for mixing may vary from one job to the next. Because local mixing water will always be present in the sample taken for cement determination, use of distilled water did not seem to offer sufficient additional benefits to warrant the inconvenience associated with its use.

One or more of several different types and brands of cement can be expected on any one cement-treated base job. Slight differences in chemical contents, and in conductimetric properties of their water suspensions, can therefore be expected in the cements used from one job to the next. Likewise, the mineral aggregates for cement-treated base on different projects may vary in their effect on the conductivity of water in which they are immersed.

Preliminary test results suggested that these variations could be nullified by using a calibration curve prepared from tests on the same aggregate and cement as were to be used on production. The problem of variation in water properties could be similarly solved. Because the construction of a calibration curve was being considered as a field operation, representative samples of water, cement, and aggregate for the necessary tests could be easily secured. Their individual effects on conductivity could then be considered as "background" in both the test and the calibration, and thus effectively eliminated in the final analysis.

#### Effects of Sample Size and Grading

Considering the maximum size (essentially  $\frac{3}{4}$  in.) and the grading of the aggregates specified for CTB, a 500-gm sample seemed adequate to represent the total product, particularly if three such samples were taken concurrently and test results averaged. To determine whether a sample this size would be satisfactory, several batches of aggregate ranging in weight from 500 gm to 2,000 gm were mixed with cement and subjected to the proposed procedure. There was no discernible difference in the accuracy of results between the smallest sample and the largest. Accordingly, the 500-gm sample, being more convenient to handle, was chosen for the test procedure.

Also investigated was the possibility of error being introduced by variation in the grading of the samples. Such error would stem from a difference in conductivity of the fine and coarse fractions of the aggregate, or from the tendency of the cement, when mixed, to cling to the fine rather than the coarse material.

Because there has been no significant difference in conductivity between the different size fractions of aggregate in the cases investigated, and because any slight error associated with the variation in grading will probably be less than the possible errors arising from the extra handling connected with some sort of splitting and recombining operation, alteration of the sample was not attempted.

#### Effect of the Length of Tempering and Diluting Times

The test procedure involves two timed intervals associated with the addition of water to the cement aggregate mixture. They are the tempering period and the dilution period.

The tempering period in the calibration procedure is the interval between the addition of tempering water and diluting water. The counter part in the actual test procedure is the period between the addition of mixing water to the aggregate and cement in the plant and the addition of the diluting water to the sample. This interval is necessary to allow time for the samples taken at the plant to be carried to the testing station, weighed, and placed in mixing containers.

The tempering water in the calibration procedure represents the mixing water in the actual process and usually approximates 7 percent by dry weight of mix. In lab tests, variation of the water content over a range of 4 percent to 11 percent produced no measurable effect in the final conductivity of the samples when tempering time was 10 min or less. Beyond a 10-min interval, however, the tempering water did appear to have some effect on the conductivity reading obtained. Inasmuch as the 10-min period was found to be entirely adequate for securing and preparing test samples, this limit was set for the tempering period, thereby reducing potential error from uncontrolled variations in amount of mixing water.

The dilution period begins with the addition of the diluting water (end of the tempering period) and ends with the conductivity measurement. As might be expected, all other factors being equal, the longer the dilution period, the higher the conductivity reading, within the 5 percent cement concentration limit. Figure 1 shows typical calibration curves based on different dilution periods. Whereas the longer dilution periods result in steeper curves and a better spread in values, the duration of the test and the availability of test results would be unduly delayed if they were used. A 10-min dilution period has been chosen as an expedient compromise.



### Effect of Amount of Dilution

The cement-in-water concentration which forms the upper limit of applicability is 5 percent, according to Chadda (1). With a CTB sample weight of 500 gm and with cement contents of 2 percent to 7 percent cement weights will vary from 9 to 30 gm, assuming a mixing water content of 7 percent by dry weight. A 600-ml quantity of water would provide the 5 percent concentration limit for a 500-gm sample containing 7 percent cement. A quart of water used for dilution would satisfy the minimum quantity requirements with somewhat more than 50 percent margin, and would also have the advantage of being relatively simple to measure in the field. A quart jar or plastic container filled to overflowing was considered an ideal measuring device from an operational standpoint.

Accordingly, initial test procedures were based on the use of a 500-gm sample and dilution with 1 quart of water. For a 500-gm sample the quart of water was found to be almost a lower limit as far as practical considerations were concerned. Use of a lesser quantity of water made it

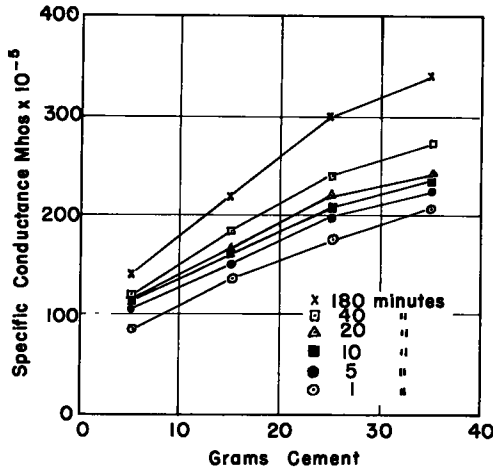


Figure 1. Typical curves showing effects of varying the dilution period.

difficult to obtain sufficient depth of suspension in which to immerse the probe of the conductivity cell, and although the procedure was later changed to call for the suspension to be decanted into a smaller vessel for the conductivity reading, this lower limit still applied in relation to the quantity of suspension available.

Tests with a larger quantity of dilution water (Fig. 2) indicate that the conductivity readings were dependent primarily on the cement-water ratio. The use of greater water quantities does not appear to give sufficient benefits to compensate for the operational inconvenience associated with the larger volumes. In the event a larger sample size is deemed necessary, however, the use of larger volumes of dilution will have to be considered. A sample dilution ratio of 500 gm/1 qt has been arbitrarily established as optimum until further planned investigations indicate a modification is in order.

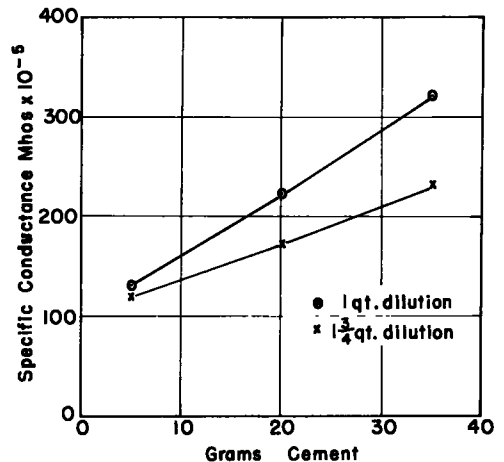


Figure 2. Typical curves showing effect of varying the dilution quantities.

### Effect of Agitation of the Sample After Dilution

The conductivity of the suspension after dilution depends on the amount of lime and other chemicals which go into solution prior to the measurement. Continuous agitation of the mixture after dilution would seem to provide for the most thorough solution of the chemicals involved. However, unless some mechanical means could be employed, continuous agitation of the samples would be difficult and inconvenient to achieve in the

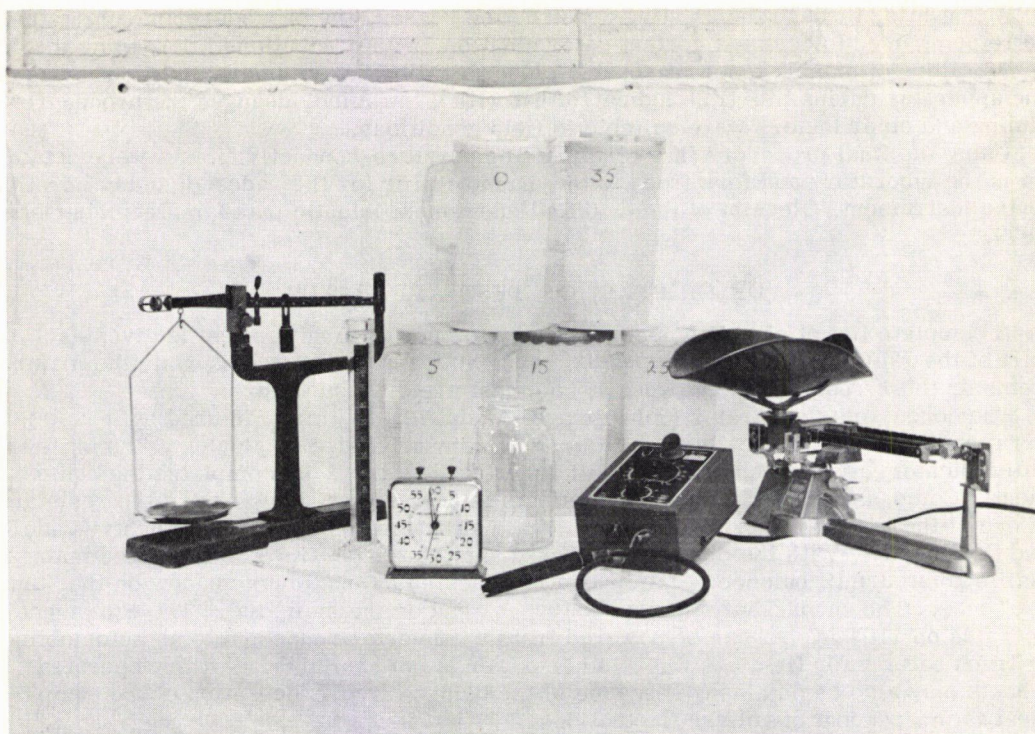


Figure 3. Electrical conductivity test apparatus for CTB.

field if more than one sample were to be run at a time. In the hope that the final test procedure could be kept quite simple, a procedure calling for 1 min of manual agitation or shaking of the sample immediately after dilution, and 10 sec of shaking immediately prior to the conductivity measurement, was proposed for trial. Subsequent tests indicated that up to a total elapsed time of 10 min there were no significant differences between conductivity readings obtained following this procedure and those obtained following an almost constant agitation. It is quite possible that this apparent equivalence would not hold over a longer period of time and inasmuch as the 10-min period was considered satisfactory, the effect of agitation over longer time intervals was not investigated.

#### Effects of Temperature

Temperature affects the conductivity of a cement-water solution in two ways. The conductivity of a solution is, of course, a function of the temperature. Other things being equal, it varies directly with the temperature. Most conductivity cells have a temperature-compensating device incorporated in their design for this. In addition to affecting the conductivity of the solution, temperature will also affect the solubility of chemicals from the cement during the dilution period. Naturally, the compensating device on the standard conductivity cells could not be expected to correct for this.

Inasmuch as widely different water and mix temperatures could be expected from day to day, and within any one day on a single CTB job, the possibility of correcting all conductivities to a standard temperature seemed both desirable and mandatory. Satisfactory over-all correction for the temperature effects would eliminate the undesirable necessity of identical temperatures for tests and calibration curves. Correspondence with the manufacturer indicated the possibility of an equipment design modification to enable this correction.

Meanwhile, through the existing construction season, the procedure and apparatus were being used for cement content determination, with precautions for keeping the temperature of sample tests reasonably close to calibration temperatures. The use of the apparatus during this time indicated that with a few minor changes the procedure timing and other factors were suitable to field conditions.

Using the final procedure that resulted, temperature-conductivity data were obtained in the laboratory and forwarded to the manufacturer for the redesign and calibration of the instrument. Receipt of the modified instrument is anticipated by December of 1959.

### DESCRIPTION OF TEST APPARATUS

A complete list of all equipment necessary for performing this test is given as a part of the Field Instructions, Appendix, and pictured in Figure 3. Only the major items or those requiring some special comment are discussed here.

The conductivity apparatus (Solu Bridge, Model RD-15, manufactured by Industrial Instruments Co.) is basically a wheatstone resistance bridge employing a "tuning-eye" null indicator. A neoprene dip cell with a cell constant of 2.00 completes the equipment. Compensation for temperature effects is accomplished by varying the resistance of one of the legs of the bridge through a dial calibrated in degrees (both centigrade and fahrenheit). With the dip cell immersed and the temperature dial set, the main dial is rotated until balance of the bridge is indicated by maximum shadow on the "tuning eye" tube. The conductivity in mhos  $\times 10^{-5}$  is read on the main dial. The equipment operates on 110V AC but can be powered from a converter connected to an automobile or truck battery for field use where other power is not available. Battery operated models may also be obtained. Because of the bridge circuit, operation of the equipment is independent of voltage fluctuations.

Plastic containers in two or three sizes are required for mixing and measuring. The basic containers for mixing are a 2-qt size with a tight fitting lid. These are numbered from 1 to 5 for easy identification. If they are of such a configuration that a sufficient depth of suspension is available for cell immersion, readings can be made directly in the mixing container. Otherwise, the supernatant liquid is poured into a smaller vessel (about 1 pt) with a cross-sectional area just large enough to accommodate the dip cell for the conductivity readings.

A plastic container of 1-qt capacity, filled to overflowing, is used for measuring the diluting water. Such a container, rather than burettes or other volumetric vessels of glassware, was chosen because of time and breakage considerations.

### DESCRIPTION OF TEST PROCEDURE

The first step in performing the test is the preparation of a calibration curve, which is simply a plot of weight of cement in grams against the conductance of the suspension in mhos  $\times 10^{-5}$ . The points on the curve are obtained by testing 5 known concentrations of mix in the following manner:

Five 450-gm samples of the dry aggregate, graded approximately as it will be used on the job, are obtained and one of the samples placed in each of the numbered plastic containers. To container number two are added 5 gm of cement; to containers number three, four and five are added 15 gm, 25 gm and 35 gm, respectively; no cement is added to container number one.

Next an estimate of the water content of the processed CTB is made, this amount added to each container at 1-min intervals, and the aggregate, cement, and water thoroughly mixed.

Exactly 10 min after addition of the tempering water, 1 qt of water is added, in sequence, to each of the samples. Immediately after each dilution, the plastic containers are covered, shaken 60 times, and then allowed to stand. One minute before the conclusion of the dilution period, the samples are again shaken (10 times) in preparation for the conductivity readings. The temperature of the supernatant liquid is read and the temperature dial on the instrument adjusted to the proper value. The cell is then inserted, with care being taken to immerse it completely, and the conductivity

reading made exactly 10 min after dilution. As mentioned previously, it may be necessary to decant the supernatant suspension into another vessel in order to obtain sufficient depth for complete probe immersion.

When the readings of all five samples have been recorded a calibration curve is drawn plotting grams of cement on the abscissa and conductance on the ordinate. Once the conductivity is known, the cement content of a CTB sample may then be determined by reference to this curve.

The determination of the cement content of a sample of the job-mixed cement-treated aggregate is made by following the same routine as outlined for the calibration, omitting only the addition of tempering water. The process is initiated by obtaining, at 1-min intervals, 3 samples of processed CTB mix as it is emptied from the pugmill. (An additional large sample should be secured to enable the determination of the moisture content of the CTB. With two operators this can be run concurrently with the conductivity test and results be available at the same time, provided the alcohol burning method is used.) The timer is started at the time the mixing water is added in the pugmill to the CTB materials from which sample number one will be taken.

The samples, which should weigh between 500 and 525 gm, are each numbered, weighed, and placed into one of the 2-qt plastic containers. At the appropriate time 1 qt of diluting water is added to each of the samples and the test is carried out as described above for the calibration.

At the conclusion of the test the cement content is computed for each of the samples by using the following formula:

$$\text{Cement content} = \frac{\text{Weight of cement (gm)}}{\text{Dry weight of CTB mix} - \text{Weight of cement (gm)}} \times 100$$

It has been recommended to the field laboratories that the reported cement content be an average of at least three determinations. Also, inasmuch as the time schedule is set up for the calibration procedure and can accommodate five samples, a "known" or referee sample may be run with the three unknowns. The "known" should have a cement content close to that being used on the project. This will provide the operator with a constant check on the reliability of the calibration curve. A change in the source of mixing water during operations could cause a considerable shift in the calibration curve, which, if undetected, would give erroneous results.

It was stated earlier that the samples of CTB mix should be in the neighborhood of 500 to 525 gm. A range of weights rather than an exact value is specified in order to reduce the errors inherent in picking out large aggregate particles to adjust to a definite weight.

The time interval of either the tempering or the diluting period, or both, may be altered to suit local conditions. The only restriction is that the same schedule be used for production testing as for calibration.

#### DISCUSSION OF TEST PROCEDURE AND ITS FIELD USE TO DATE

The conductivity procedure for determining cement contents has been used with generally successful results on many recent CTB projects. There have also been some jobs on which the results left something to be desired. In the great majority of cases however, the test has given results which show a close check with the cement contents calculated from daily "yield" quantities. The acceptance by field inspectors has been remarkable, some inspectors being quite enthusiastic in their comments.

Table 1 gives data from four projects on which the test was used for control of cement contents.

A frank discussion of the use of a new test procedure should not ignore the possible shortcomings as revealed by the instances in which the test did not live up to expectations. The troubles encountered to date have been investigated and the causes are generally not too difficult to ascertain. Likewise, corrective measures which have been suggested are simple and apparently effective.

The complaint most frequently heard is that the results on the three test samples show a great variance. Naturally, because this is an "end result" test, trouble anywhere in the sampling or testing would show up at this point.

Inasmuch as plant-mixed cement-treated base does tend to vary in its cement content, part of the "trouble" may not be trouble at all but a true measure of the variations that actually exist. One of the purposes of the test is to check uniformity of mix, for if there were no valid reason to suspect lack of uniformity, there would be little reason for the test.

Another complaint has been the difficulty in reading the conductivity scale on the instrument with any great precision in the range above 200 mhos  $\times 10^{-5}$ . The scale range

TABLE 1  
CEMENT CONTENTS—BY TEST AND BY YIELD QUANTITIES

Project	Cement Content in Percent		
	By "Yield"	By Conductivity Test	Error
Cont. 6073, PSH No. 2, Dryden to Cashmere	4.1	4.2	+0.1
Cont. 6081, PSH No. 11, Coker Road to Tokio	3.6	3.5	-0.1
Cont. 6092, PSH No. 11, Ritzville to Coker Road	3.4	3.5	+0.1
Cont. 6093, PSH No. 10, SSH 11-G to Wheeler Road	3.6	3.7	+0.1

on the instrument being used is 10-1000 mhos  $\times 10^{-5}$ . Because test conductivities rarely exceed  $300 \times 10^{-5}$  mhos, readability could be improved if the instrument were recalibrated to give a full-scale reading of this value. This will be accomplished during the modification of the instrument previously described and considerable improvement in readability is expected.

Troubles have been encountered where the source of mixing water is subject to random change during the progress of the job, and/or where water of different conductimetric properties is used for calibration and for test purposes. In these instances, where the trouble can be recognized by periodic conductivity measurements of the water, or by two calibration curves which are quite different, two corrective measures have been used successfully. An adequate supply of water has been secured and used exclusively for calibration and test purposes. Although effective, this is somewhat inconvenient and impractical, especially on large projects. A better remedy is to run the "referee" sample with the unknown samples, and compare results. It has been found that when the conductivity of the water is subject to change, different calibration curves are generally obtained. However, the slope or curvature of the calibration curves in the mid-range is practically the same for the different curves. The results on the "referee" sample establish a known point which, together with the common slope or curvature, determines a portion of a calibration curve for the particular and immediate conditions of the test. The difference between the conductivity on the "referee" sample and that given by the curve may also be treated as a "correction" to be applied to the sample readings.

This latter corrective measure is also applicable to suspected errors arising from aggregate which is variable in its effect on the conductivity of water, or from reduced sensitivity of the conductivity cell due to contamination on electrodes. The use of the "referee" sample has been suggested for all cases where trouble is encountered, or suspected, and consideration is being given to making it a part of the procedure.

Preliminary tests were made in the Commission, laboratory and in another laboratory (2) to check the accuracy of the proposed test method by mixing large-size laboratory batches of cement-treated base, taking samples thereof, and comparing results with the known cement content. In neither case did the results check too closely. The

tests from the Commission's laboratory showed a random variation of results—some higher and some lower than the known. Considerable variation was also apparent among the three samples used in any one "test." The results reported by the other laboratory did not check too well either, but differed from this laboratory's results in that values for the three samples comprising a "test" were remarkably consistent and checked well with one another. The materials used in this investigation included fine-grained soils with high cement contents. There is the possibility that the conductivity was influenced by the clays present, and that the high cement contents approached or exceeded the 5 percent cement-in-water concentration where the test's sensitivity is admittedly low.

At first it was believed that the lack of conformity was due to the difficulty involved in obtaining a "representative" sample inasmuch as extreme accuracy is apparent when tests are made on small CTB mixes prepared entirely within the 2-qt test containers. To check this belief a further series of evaluation tests was run. In this investigation, the test was used to determine "quantitatively" the total amount of cement in the mixed batch. This was done by splitting the entire batch into a number of samples and testing each sample. A comparison of the sum of the weights of cement found in each sample with the weight of cement added to the batch was used as a check on the accuracy of the procedure.

In this series the test procedure was modified to incorporate the "referee" sample, and the equipment was modified to enable more accurate reading of the scale. Results of the tests (Table 2) show that in seven trials, using five different aggregates, maximum error in determining the total amount of cement was 2.4 percent, and in six of the seven trials the error was 1 percent or less. It was noted, however, that there was considerable variation in cement content between the five samples of any one batch.

The fact that it was possible to account for essentially all of the cement in each of the foregoing tests confirms the authors' contention that the test is accurate and that the previous apparent inaccuracy was indeed due to "difficulty involved in obtaining a representative sample."

This then brings up speculation on the subject of just what is meant by a certain "percent cement," or what is meant by the "design cement content." Does it mean that

TABLE 2  
"QUANTITATIVE" TESTS—CEMENT CONTENT BY ELECTRICAL CONDUCTIVITY

Aggregate		Weight of Cement Used (gm)	GMS/% Cement Recovered					Total Weight Cement (gm)	Error	%
Textural Class	Weight (gm)		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5			
Silty sandy gravel	2250	100	18.2/3.9	19.4/4.2	17.5/3.7	19.0/4.6	23.5/5.3	97.6	-2.4	2.4
Silty sandy gravel	2250	100	21.7/4.8	20.0/4.2	20.7/4.7	17.5/4.1	20.0/4.5	99.9	-0.1	0.1
Silty sandy gravel	2250	100	16.5/3.7	17.8/4.1	19.4/4.4	22.2/5.0	24.0/4.9	99.9	-0.1	0.1
Silty sand	2250	100	18.4/4.1	19.0/4.3	19.8/4.6	20.2/4.6	22.8/4.6	100.2	+0.2	0.2
Silty sandy gravel	2250	100	18.5/4.0	20.0/4.3	17.5/4.1	20.3/4.6	24.5/5.4	100.8	+0.8	0.8
Silty sandy gravel	2250	105	17.0/3.8	18.0/3.9	21.0/4.8	23.0/5.4	26.0/5.5	105.0	0.0	0
Sandy gravel	2250	100	19.4/4.3	20.0/4.3	19.4/4.2	20.7/4.5	21.3/5.30	100.8	+0.8	0.8

with thorough and uniform mixing, each and every shovelful of CTB on the roadway should contain this amount of cement, within reasonable tolerance? Does it mean that this content should be expected regardless of the grading of the material, providing the grading is within the specification limits for the product?

Before a decision can be made on the merits of sampling methods and the accuracy of the test, an agreement on the meaning of the term "design cement content" will have to be reached. Assuming that the answer to the above two questions is "yes," it is felt that the proposed test is sufficiently accurate to be of great use in the control of plant-mix cement-treated base projects. If the answer to the above questions is "no, but on the average yes," then it is believed that the average of the conductivity test results will also give a sufficiently accurate measurement of the cement content.

With this test procedure it is also possible to check uniformity of cement distribution on the roadway in road-mix projects. While the results obtained may be questioned

as to the accuracy of their absolute values (because of the difficulty in accurately duplicating construction "tempering" conditions) the values will still be significant in their relation one to another. If the mixture is uniform as regards cement distribution, the values obtained in the test should check one another fairly well. If not, there would be no great degree of correlation. The extent to which accuracy is lost through variation in tempering time between calibration and test runs has not been measured, but it is not believed to be of appreciable degree. An investigation of this, together with a re-examination of the effects of the previously discussed variables, and statistical analysis of results, will be initiated following receipt of the modified conductivity apparatus.

### CONCLUSIONS

It has been demonstrated to the authors' satisfaction that the proposed test equipment and procedure make it possible to obtain a sufficiently accurate determination of the cement content of any given sample or series of samples of CTB in a period of approximately 20 min. In applying the test, however, it should be borne in mind that the results must be treated as individual statistics. Therefore the greater the number of samples, the more significant the results. Evaluated in this manner, data from the test can serve as a reliable means of determining the cement content of CTB mixes.

### ACKNOWLEDGMENTS

The authors wish to express their appreciation to Henry Fowler and Louis Charneski of the Materials Laboratory staff for the testing associated with the many performances of the various versions of the test procedure and the repetitious measurements of conductivity; and to Robert Rosenthal, Chief Chemist of the Industrial Instrument Co. for his friendly aid and advice.

To the many inspectors and engineers in the Washington Highway Department who have used the tests, go our thanks for their cooperation, assistance and constructive (though not always laudatory) suggestions and criticism.

### REFERENCES

1. Chadda, L. R., "The Rapid Determination of Cement Content in Concrete and Mortar." Indian Concrete Journal, 29:8, 258-260 (Aug. 1955) Highway Research Abstracts (Jan. 1956).
2. Portland Cement Association. Private correspondence with the authors (April 1959).

## *Appendix*

WASHINGTON STATE HIGHWAY COMMISSION  
DEPARTMENT OF HIGHWAYS  
Materials Laboratory

CEMENT CONTENT DETERMINATION  
BY  
ELECTRICAL CONDUCTIVITY  
(10-Min. Schedule)\*\*

#### Apparatus:

- |                                  |  |
|----------------------------------|--|
| 1 - Conductivity Cell with Probe | (Solu-Bridge Soil Tester RD-15 with probe, CEL-R2 (K = 2.00) manufactured by Industrial Instruments, Inc.) |
| 6 - 2-Qt. Plastic Containers     | (Plastic pitchers with removable caps containing pouring spout have been found satisfactory.)              |

- 4 - 1-Pt. Plastic Containers (Should be tall and of a diameter just large enough to receive probe.)
- 1 - 1000 Gram Balance (for mix)
- 1 - 100 " " (for cement)
- 1 - Large spoon
- 1 - 50 cc Graduate (for measuring tempering water in calibration routine)
- 1 - Time clock
- 1 - Stop Watch
- 1 - Thermometer (0° - 200°F.)
- 1 - Scoop (Approx. 2# capacity)
- 2 - 1-Qt. jars (some type plastic preferable, 1 for measuring, 1 for rinsing probe)
- 1 - Roll waxed paper (for sampling)
- 2 - 5-gal.water cans\*
- For field operation: (with car as lab.)
- 1 - 6 or 12-volt converter (converts to 110 V)
- 1 - board (for table)
- 2 - 5-gal.water cans
- \* Should be included if field lab has no water supply.
- \*\* See Page 2 footnote
- Revised August, 1959

Calibration:

Use water, aggregate and cement to be used on job. Obtain 5 samples of 450 gms. each. Grading should be that of total grading of aggregate. Place in plastic shakers. Add cement as follows:

#1	- -	0 gms.
#2	- -	5 gms.
#3	- -	15 gms.
#4	- -	25 gms.
#5	- -	35 gms.

Determine approximate moisture content to be used with mix and add suitable water, following the time schedule given below. (To "decant", pour solution into 1-pt. container where temperature and conductivity readings are made.)

	<u>Time</u>	
	0 min.	- - - - - Add X% *H <sub>2</sub> O to "0" and mix
	1	- - - - - " " " " "5" " "
	2	- - - - - " " " " "15" " "
	3	- - - - - " " " " "25" " "
	4	- - - - - " " " " "35" " "
Tempering	10	- - - - - " 1 qt. H <sub>2</sub> O to "0" and shake 60 times
Period**	11	- - - - - " " " " "5" " " " "
	12	- - - - - " " " " "15" " " " "
	13	- - - - - " " " " "25" " " " "
	14	- - - - - " " " " "35" " " " "
	19	- - - - - Shake "0" 10 times, decant, insert and read thermometer
	20(a)	- - - - - Read conductivity of "0"



Diluting	(b)	- - - - -	Shake "5" 10 times, decant, read temperature
Period**	21(a)	- - - - -	Read conductivity of "5", repeat 10(b) for "15"
	22	- - - - -	" "
	23	- - - - -	" "
	24	- - - - -	" "

Make a calibration curve plotting conductivity vs. grams cement.

#### Cement Determinations:

With stop watch, determine when water is added to cement-aggregate mixture in pugmill. Obtain sample #1 one minute after water has been added, weigh and record value (sample should weigh between 500 and 525 gms.). Take sample #2 at two minutes and sample #3 at three minutes. At 10 minutes add 1 qt. water to sample #1 and proceed as in calibration procedure.

\* X% is estimated H<sub>2</sub>O content for mix.

\*\* These times may be adjusted to suit. Appropriate changes should also be made in the cement determination procedure to compensate. (If a 5-min. dilution is used, for instance, the conductivity should be read 5 minutes after the quart of water is added. If a 5-minute tempering schedule is used, the quart of water should be added 5 minutes after the X% H<sub>2</sub>O is added to the cement and aggregate. Always use same schedule for calibration and for determination of unknown.

#### Compute Cement Content as Follows:

From calibration curve determine grams of cement for each sample.  
Using water content of mix determine dry weight of sample.  
From following equation determine cement content:

$$\text{Cement Content} = \frac{\text{weight of cement (gms.)}}{\text{dry weight of aggregate} \text{ ----- } \text{weight of cement}} \times 100$$

#### Example:

Sample No.	1	2	3
Wet Wt. of Sample	509		
Dry Wt. of Sample	473*		
Weight of Cement	19.8	"	"
Weight of Aggregate	453.2		
% Cement	4.4		

\* Est. Water Content = 7.5%

#### Notes:

- (1) All containers should be rinsed at least three times with clean water before being used again.
- (2) Conductivity probe and thermometer should be kept immersed in jar of clean water between readings. Water in the jar used for this purpose should be changed after each set of 3 readings.
- (3) It is suggested that a "known" or referee sample be run, as the fourth sample, with each batch of three "unknowns". This would enable the operator to check the calibration curve on each run. We suggest that the "known" be made up as either a 15 gm. or a 25 gm. specimen whichever comes closest to the cement content used on the job.
- (4) On the following page is a copy of a suggested report form complete with test data from an actual job.

CEMENT CONTENT DETERMINATION -- CTB MIX  
SOLU -- BRIDGE ELECTRICAL CONDUCTIVITY METHOD

Contract 6081 Section Coker Rd. to Tokio P.S.H. 11  
 Type of Mixing Plant Date 6-30-59 Soak Schedule 5 min  
 Contractor Acme Water Conductivity Rdg. 23 at 62 °F.  
 Inspector H. Noah Resident Engineer Walt Hansen

SAMPLE NO.	1	2	3	4
Conductance	163	171	170	170
Est. % Moisture	9.4	9.4	9.4	
Wet Wt. of Sample	500	500	500	
Dry Wt. of Sample	457	457	457	450
Wt. of Cement	14.0	15.0	15.0	15
Wt. of Aggregate	443.0	442.0	442.0	
% Cement	3.2	3.4	3.4	

Average % Cement 3.3

Reteree ↗

$$\text{Dry Wt.} = \frac{\text{Wet Wt.}}{1 + \frac{\% \text{ Moist.}}{100}}$$

$$\text{Wt. of Aggreg.} = \text{Dry Wt.} - \text{Wt. of Cement}$$

$$\% \text{ Cement} = \frac{\text{Wt. of Cement}}{\text{Wt. of Aggreg.}}$$

Remarks: % cement based on yield for day = 3.3

Distribution  
 Materials Lab ✓  
 District Engr.  
 District Soils  
 Res. Engr.

# Cement Requirements of Selected Soil Series In Iowa

R. L. HANDY and D. T. DAVIDSON, respectively, Associate Professor; and Professor of Civil Engineering, Iowa Engineering Experiment Station, Iowa State University, Ames

Previous work has shown good correlation between cement requirements for soil-cement and specific horizons in 43 agricultural soil series in several Great Plains States, Washington, and Idaho (1).

To check the validity of such correlations further and to expand the results to Iowa, a number of loess, sand and glacial till soil series were sampled in various horizons and tested. Instead of selecting modal samples from a series, many series are represented by modal samples and by extremes to provide a more rigorous test. Zonal great soil groups represented are Brunizem and Gray-Brown Podzolic. The dominant clay mineral is montmorillonite.

Cement requirement correlations ranged from good to poor. Reasons for poor correlations are that cement requirements for some fine-grained Iowa soils were abnormally high due to freeze-thaw sensitivity, and that some series are too broadly defined to distinguish adequately the sensitive from non-sensitive soils. Major differences relating to great soil group and B horizon structure were also found.

Investigations of Iowa fine sands showed good correlation of cement requirements with geologic origin, which is not reflected in the soil series designations on published soil maps. The sands are a valuable resource for use in soil-cement.

● **AGRICULTURAL** soil maps are useful to highway and foundation engineers, and recently the basic mapping unit, the soil series, has proved to be a reliable criterion for judging the amount of portland cement needed to convert the soil to soil-cement (1). This correlation was demonstrated with samples from the different soil layers, or horizons, from each series. Samples were then tested to find the cement requirement. Results were checked by sampling the same series and horizons at several locations. Usually the requirements remained constant, and the variation was never more than one percent of cement. Tests were conducted on A, B, and C horizon samples from 43 soil series in several western states.

This led to the search for additional correlations, and application of the method to soils of Iowa. A wide variety of sandy, silty, and clayey soils were tested, representing glacial till, loess, and sand parent materials. In many series the sampling sites were selected not only to represent "average" or modal profiles, but also the extremes, to provide a more severe test.

Published U.S.D. A. county soil maps were helpful for series identification and sampling. Unfortunately most maps are old, and most series on the old maps have been re-defined. Therefore sampling is necessarily done by workers familiar with recent advances in soil mapping in a particular geographic area. This of course holds

true whether sampling is for a research project or for an actual field use—whenever correlations are to be made with soil series.

### PARENT MATERIAL

In approximately 82 percent of the area of Iowa the soils have developed in loess or in glacial drift, divided about equally between the two (2). The parent materials for soils over most of the remaining areas are alluvium.

Representative loessial and till soil series were selected for study. In addition four samples of upland glacio-fluvial and eolian sand were tested. Although a complete representation of Iowa series was impossible, the series most significant to engineers, for example those in hilltop positions where there is more likelihood of roadcuts and excavation of borrow, are represented. The loessial series are of interest because the loess parent material presents wide systematic textural variations believed related to distance from a source. This relation could be useful in correlation to cement requirement. Near major river valleys such as those of the Missouri, Mississippi, and Iowa, the loess is an A-4 silt with little or no soil profile. Fifty to eighty miles away the loess gradually changes to

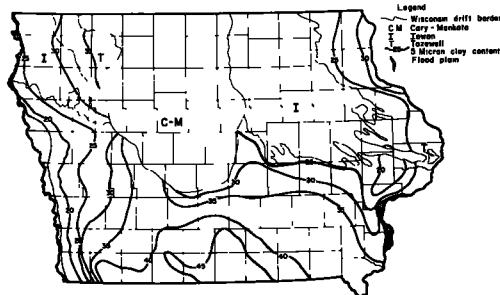


Figure 1. Map showing Wisconsin drift borders and contoured 5 micron clay contents of C horizon loess.

A-6 and then A-7-6 clay with a very strong soil profile (Fig. 1).

The Wisconsin age loess usually overlies Illinoian age (Loveland) loess or, more commonly, Kansan age glacial till which otherwise underlies the Loveland. Where loess is thin, the till outcrops on eroded valley slopes (Fig. 2) or may be intercepted by deeper roadcuts. In some roadcuts a tough, gray, clayey layer, aptly termed gumbotil, is found between the loess and glacial till. This is a paleosol, or ancient soil profile, weathered into the Kansan till during the long interval prior to loess deposition. An analogous paleosol is in the Loveland loess (3). Gumbotil is usually very high in montmorillonitic clay mineral and causes interesting problems, such as seepages, slumps, and tenaciously muddy roads. Color and morphology of the buried paleosol relate to preloess topography and erosion (4) and are somewhat predictable from the present landscape. For example, gumbotil is very clayey, thick, and gray-colored in flat, uneroded upland positions, where it is much like a modern Planosol. In better drained positions it is reddish, thinner, and resembles a Gray-Brown Podzolic.

### GREAT SOIL GROUPS

Two zonal great soil groups occur in Iowa, Brunizems (formerly called Prairie soils), formed under grass, and Gray-Brown Podzolic soils, formed under forest. Brunizems cover about 68 percent of the state and are the well-drained, dark-colored topsoils currently associated with an over-abundance of corn. Gray-Brown Podzolics occur interspersed with the Brunizems but are more prominent in the eastern and southern parts of the state. The Gray-Browns are somewhat similar to Brunizems in clay content and profile, but are more acidic and have a distinctive gray-colored topsoil, or A horizon. Both groups show marked clay accumulation in the subsoil, or B horizon.

In southern Iowa, upland remnants of the Kansan till plain occur as wide flats which have been etched away at the margins to leave long, projecting interfluvial fingers. Loess on these flat areas is usually poorly drained, partly because it is underlain by the impermeable gumbotil. As a consequence two intrazonal great soil groups are prominent:

Wiesenbodens (Humic Gley soils) are the poorly drained counterpart of Brunizems,

occurring where profile development has been inhibited by high water table. They are characterized by a thick, very dark brown or black A horizon over a weak, gray-colored B. With proper drainage they are excellent for agricultural use.

Somewhat similar to Wiesenbodens in position but not in profile are the Planosols. Here the poor drainage, instead of inhibiting profile development by waterlogging, has enhanced profile development due to increased infiltration and intensified leaching. Planosols formed either under forest or under grass are acidic throughout their profile, and the A horizon has a distinctive ash-gray (under grass) to white (under forest) layer, labelled the A<sub>2</sub> horizon. The B horizon is extremely high in clay. Planosols should logically make poor soil-cement.

TABLE 1  
CLASSIFICATION OF MAJOR SOIL SERIES IN WESTERN, SOUTHERN AND EASTERN IOWA

Parent Material	Great Soil Group					
	Regosol	Gray-Brown Podzolic	Brunizen (Prairie Soil)	Wiesenboden (Humic Gley)	Planosol	
					Grassland	Forest
W. Iowa loess, coarse ↓ fine	HAMBURG IDA ←		Monona <sup>1</sup> Marshall Munden SHARPSBURG Winterset			
E. Iowa loess, coarse ↓ fine		Fayette Downs Clinton Weller Pershing	Tama Muscatine Otley Mahaska Grundy Seymour	Garwin Taintor Haig	Sperry Edina	Berwick Marion
Kansan till, unweathered ↓ weathered	Steinauer	← Lindley Gara	Burchard <sup>1</sup> Shelby Lagonda <sup>1</sup>	CLARINDA →		

<sup>1</sup>Series showing characteristics of more than one great soil group are indicated by position or by arrows. Series more or less central in a group are capitalized.

SERIES

Series on Loess

Loessial soil series in Iowa are given in Table I. Those series with essentially the same parent material are horizontally on line; for example, the Fayette is the forested equivalent of the Tama. Intergrades are also indicated; the Downs is a Gray-Brown Podzolic with some characteristics of a Brunizem, probably because of a late invasion by trees. Similarly, the Muscatine is a wet Brunizem, with tendencies towards a Wiesenboden.

The Hamburg, Ida, and Monona series are in the classic thick loess area bordering the Missouri River plain in western Iowa (Fig. 3). The Hamburg series is a Regosol, found where soil profile development has not kept pace with erosion. It is essentially unaltered C horizon calcareous loess. The Ida series is also a Regosol, but shows faint beginnings of becoming a Brunizem, with a brown, calcareous A horizon. The Monona series is a weak Brunizem, with a brown A horizon and indistinct B horizon leached of carbonates.

The Marshall series is a nicely developed Brunizem with a moderately clayey B

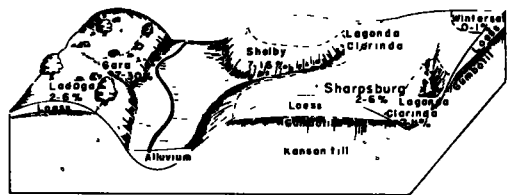


Figure 2. Block diagram illustrating typical topographic occurrences of till and loess soils in the Shelby-Sharpsburg-Winterset Soil Association area, southwest Iowa. From "Understanding Iowa Soils" (2).

horizon, and is found in an extensive belt to the east of the Monona-Ida-Hamburg association area. Farther to the southeast, the loess is thinner and finer, and the major Brunizem is the Sharpsburg series, with Ladoga the forested counterpart (Fig. 2).

In eastern Iowa, the Tama series is much like the Marshall and develops from similar parent material. Fayette is the common forested counterpart. The approximate



Figure 3. Soil association areas studied. Dashed lines indicate gradational boundaries. Numbers show sample locations.

eastern Iowa equivalent of the Sharpsburg, developed on moderately clayey, leached loess, is the Otley. However, the forested counterpart, the Clinton series, and the poorly drained counterparts, Mahaska and Taintor, are more abundant in this particular area.

In south-central Iowa the loess is progressively finer, and the Grundy and Weller series represent Brunizems and Gray-Browns, respectively. Somewhat more poorly drained and finer textured is the Seymour series, a Brunizem. Also abundant are the Haig and Edina representing planosol influences, but the B horizons are so thick and clayey they are not well suited for soil-cement.

### Series on Till

Also in western, southern, and eastern Iowa are the till soil series indicated in Table I. The nomenclature is simplified because, except for younger till sheets in northern Iowa, the glacial till parent material does not vary systematically across the state. Most is Kansan in age, but a rim of Illinoian till is in the eastern part of the state.

On rapidly eroding slopes, the essentially unweathered calcareous till Regosol is now designated the Steinauer series. The Burchard series is a weak Brunizem leached only in the A and B horizons, analogous to the Monona series on loess. These series have been mapped as Shelby in the past. Shelby is now restricted to a well-developed Brunizem on leached till. The forested counterpart of the Shelby is the Lindley; an intergrade between the two is now mapped as Gara. Surficial outcrops of gumbotil are included on older soil maps with Shelby, but now may be mapped Clarinda, a Wiesenboden, or Lagonda, a planosolic Brunizem (Fig. 2).

## PROCEDURE

### Sampling

Most of the series tested were represented by samples from two to four sections which were selected to represent not only the mode but also the range of each series. For example, the Marshall series was sampled at three locations, one near the center of the Marshall area and the others from near the edges, where the Marshall is transitional to the Monona on the west and the Sharpsburg on the east (Fig. 3).

Most sections are located in roadcuts or quarries. Sampling was done by trimming back to a fresh surface, then cutting a downslope channel to obtain accurate composite samples of each layer. Pedological A, B, C<sub>1</sub> (leached C), and C horizons were sampled after field identification by two or three experienced persons to minimize bias. Supplemental augering was done where necessary, and special zones in or under the C horizon were sampled separately.

Mapping and definitions of soil series is constantly changing as finer distinctions are made, and very few of the soil series could be accurately identified merely from location on published U.S.D.A. Soil Survey maps, many of which were prepared in Iowa in the 1920's. Each series was therefore re-identified and fitted into up-to-date nomenclature.

## Testing

Particle size analyses were made by the hydrometer method using the Iowa State air-jet dispersion device and sodium metaphosphate as the dispersing agent (5). Plasticity index and classification tests were performed according to standard ASTM methods (6). Cement requirements were determined in the Portland Cement Association Laboratory in Skokie, Illinois, according to standard methods (7). These include the following: (a) a moisture-density test to determine maximum density and optimum moisture content for compaction; (b) wet-dry and freeze-thaw tests, 12 cycles each on separate specimens, to determine how much cement is required to hold loss of loosened surficial material to within permissible limits; and (c) compressive strength tests to show if setting reactions are proceeding properly—strength should increase both with increas-

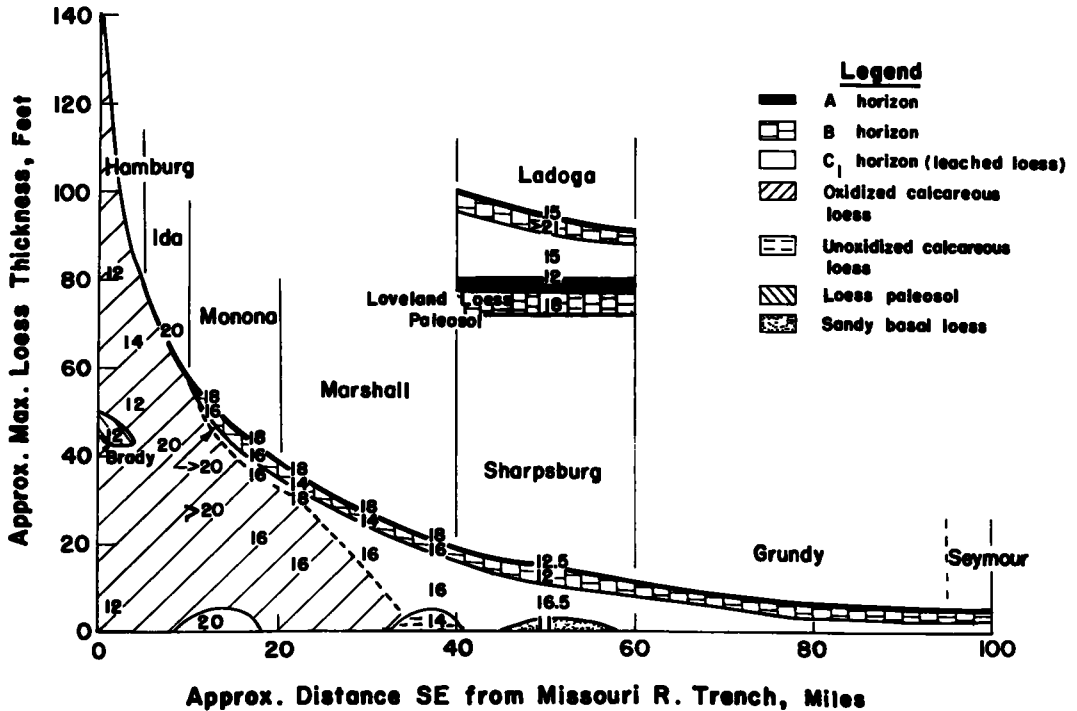


Figure 4. Cement requirements of western Iowa loessial soils. As the loess thins it becomes finer, leached of carbonates, and weathered into heavier textured soil profile. Thickness and distance scales very approximate.

ing age and cement content. Permissible weight losses during wet-dry or freeze-thaw tests are set at 10 percent for A-4 and 7 percent for A-6 and A-7 soils. Specimens are brushed between cycles to remove loose material.

## RESULTS

### Loess

Minimum cement requirements are indicated in Figures 4 and 5 for various loessial soil series.

**Hamburg.**—Four samples of coarse calcareous loess mapped in the Hamburg series required 12 percent cement, and one required 14 percent. A sample of a weak, leached paleosol identified as Brady soil (8) shows no difference in cement requirement, the requirement still being 12 percent.

**Ida.**—Samples of Ida A horizon and C horizon loess required 20 percent cement due to failure by excessive scaling in the freeze-thaw test. This loess is apparently in a critical clay content range for failure during freezing and thawing; the critical range is indicated by the vertical dashed lines in the top graph of Figure 6.

**Monona.**—Samples of coarse Monona leached and calcareous C horizon loess required over 20 percent cement, and are also in the critical clay content range (top, Fig. 6).

In the B horizon samples and in a finer C horizon sample, the higher clay content reduced the requirement to 16 percent. The A horizon requirement was 18 percent.

**Marshall.**—Marshall C horizon samples required 16 to 18 percent cement, somewhat in the critical clay range. As in the Monona, the more clayey B horizon required less cement than the C, 14 to 16 percent, and all A horizon samples required 18 percent.

**Sharpsburg.**—Sharpsburg C horizon loess

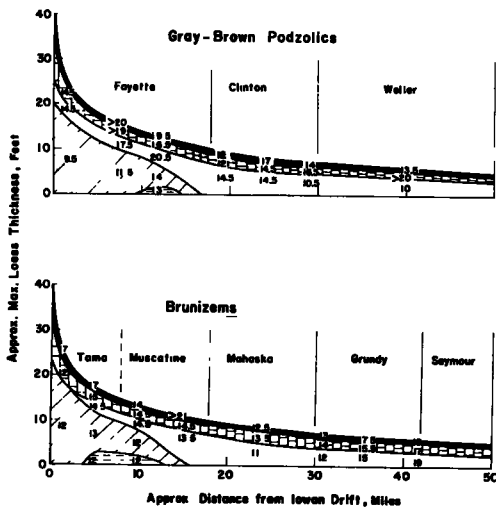


Figure 5. Cement requirements of eastern and southern Iowa loessial soils. Legend is the same as in Figure 4.

is less critical for freeze-thaw loss, and the requirement was found to be 16.5 percent cement. The A and B horizons required only 12.5 and 12 percent, respectively, indicating the beneficial influence of clay. A sandy basal loess sample required 11 percent. The presence of either sand or clay is apparently effective at reducing cement requirement in these western Iowa Brunizems.

**Ladoga.**—The Gray-Brown Podzolic equivalent of the Sharpsburg gives some interesting contrasting requirements in the A and B horizons. The Gray-Brown A and B are bad actors compared with the Sharpsburg, and required 16 and over 21 percent cement, respectively. The C horizon was not affected, and required 16 percent cement. Possible influences of podzolization are discussed under Fayette.

**Loveland Loess and Paleosol.**—Samples of plastic Loveland loess from underneath the Wisconsin loess at the section sampled for Ladoga have cement requirements not unlike the Weller: 12 and 11.5 percent for the A and A<sub>3</sub>-B<sub>1</sub> horizons, and 18 percent for the clayey B<sub>2</sub>.

**Grundy.**—The Grundy continues trends initiated in the Sharpsburg: more clay, less sensitivity to freeze-thaw, less cement. This trend reached a climax in the least clayey

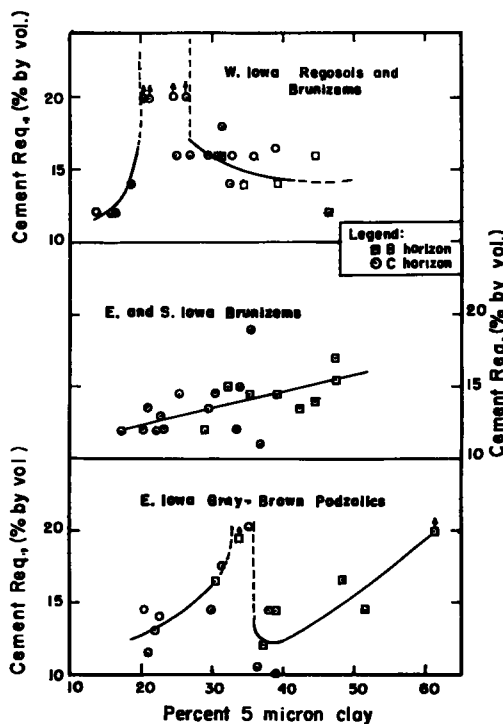


Figure 6. Relations of cement requirement of Iowa loessial soils to 5 micron clay content.



Grundy C horizon sample, which had a requirement of 12 percent. With more clay, however, failures began in the wet-dry test, and cement requirement mounted rapidly.

**Tama.**—Thick eastern Iowa loess under the Tama series, a Brunizem, required 12 percent cement in the B and C horizons and 17 percent in the A, or very close to the Hamburg C and Monona A of western Iowa. Most interesting is that the C horizon Tama is not overly sensitive to freeze-thaw, even though the clay content would put it in the critical range of the western Iowa samples (Fig. 6, middle graph).

**Tama-Muscatine-Mahaska-Grundy.**—Some relationships are shown between intergrading eastern Iowa loessial Brunizem soil profiles and cement requirement, but the requirements do not necessarily coincide with series breaks (Fig. 4). For example, the C horizon loess requirement was 12 to 13.5 percent cement in the Tama and Muscatine series, reached a low of 11 percent cement in the Mahaska, and climbed rapidly in the Grundy, from 12 to 17 percent, as losses in the wet-dry test became critical due to the high clay content. The major change in cement requirement thus took place within the confines of the Grundy. The cement requirements of the B horizons for these series was usually 1.0 to 2.5 percent higher than for the C. Requirement ranged from 13.5 to 15 percent to even higher in the already too clayey Grundy. The Edina series was not sampled, but it probably has cement requirements higher than the Grundy.

**Fayette.**—Cement requirements of the Fayette series, the Gray-Brown equivalent of the Tama (Fig. 4), are inconsistent, because the series is too broadly defined to correlate adequately with some very critical freeze-thaw losses. Coarse, sandy loess under the Fayette series required 9.5 percent cement in the C horizon and 14.5 percent in the C<sub>1</sub> and B. With more clay the B horizon became critically susceptible to freeze-thaw, and the requirements jumped to 17.5 and 19 percent for the C<sub>1</sub> and B, respectively. Then in finer loess the C horizon became critical, requiring 20.5 percent, but the B horizon was over the hump.

This critical clay content range in the Fayette but not in the equivalent Brunizems (Fig. 6, lower and middle graphs) suggests a limited deleterious influence from podzolization. This is also true in the A horizon of the Fayette, which required 13.5 to 20 percent, averaging 17.7 percent for three samples. As previously mentioned, the Ladoga, a Gray-Brown from western Iowa, also showed deleterious influence. However, the bad effect of forest vegetation does not carry over into the Clinton and Weller, which series are even more acidic than the Fayette. In the Fayette the pH is 4.5 to 5.1 in the A and B horizons; in the Weller it varies from about 3.8 to 4.5 (2).

Perhaps the slightly different array of exchangeable cations or the traces of forest-derived organic matter could cause a structural effect in compacted samples, increasing capillary conductivity and causing excessive freeze-thaw losses.

**Clinton-Weller.**—The Clinton series is developed in finer loess than the Fayette and continues the trend toward lower cement requirement. In the coarser of the Clintons sampled, the C horizon requirement was 14.5 percent, and that in the higher clay B horizon was 12 percent. In the finest Clinton section and in the Weller section the C horizon reached an optimum for soil-cement, 10.5 percent and 10 percent, respectively. However, as previously noted for the Grundy, the B is too clayey, and required 16.5 and more than 20 percent, respectively, due to losses in the wet-dry test. The unusually high requirement for the Weller B horizon could be partly due to theft of calcium from hydrating cement by the clay, inasmuch as the natural base saturation is of the order of 50 to 60 percent.

**Summary-Loessial Series.**—In western Iowa the cement requirement of coarse loess usually mapped in the Hamburg series is 12 percent. However, in slightly finer loess, freeze-thaw losses suddenly become very critical, and cement requirements leap to more than 20 percent. Loess mapped as Hamburg, Ida, or Monona and containing over 17 percent 5 micron clay should always be regarded as suspect. In the Marshall and Sharpsburg the cement requirements are steadily pushed down by the increase in clay content, until the requirement again reaches a low of 12 percent in the relatively heavy textured Sharpsburg B horizon.

Eastern Iowa Brunizems on loess do not show the same susceptibility to freeze-thaw, and here in general more clay means that more cement is required. Best for stabilization are the Tama, Muscatine, Mahaska, and coarser Grundy C horizons, which require

11 to 13 percent cement. B horizons take more cement, and the requirement jumps to 19 percent in the finer Grundy B and C horizons, where wet-dry losses become critical.

The A horizons of most loessial Brunizems require 18 percent or more cement and should not be used. Exceptions may be the Sharpsburg and Mahaska, samples of which were stabilized with 12.5 percent cement.

Gray-Brown Podzolics on loess show a critical sensitivity to the freeze-thaw test, much like western Iowa Brunizems, but at higher clay contents. Cement requirements start low in the coarse Fayette, reach a peak in the medium Fayette B and the fine Fayette C, and fall off again in the Clinton. Then the clay content becomes too high in the Clinton and Weller B horizons, and failures occur in the wet-dry test. The critical clay content range occurring in the Fayette probably is related to some influence of podzolization. This influence extends through the A, B, and C<sub>1</sub> horizons, but not into the calcareous C. Acidity alone does not explain it, inasmuch as the acidity in the Clinton and Weller, which require less cement is equal or greater.

### Till

Cement requirements of till series are given in Table 2. Note that the series correlation is not good, probably because series definitions and variability of the parent

TABLE 2  
CEMENT REQUIREMENTS OF SOIL SERIES  
ON KANSAN AND ILLINOIAN TILL

Horizon	Brunizems				Gray-Brown Podzolic			
	Burchard	Shelby			Lindley			Ill. Till
					Kansan Till			
A	13	14	12	-	10.5	8	-	-
B	13	15	14	-	13.5	16.5	15	12.5
C <sub>1</sub>	-	16	12	-	12.5	12.5	12.5	13
C <sub>ca</sub>	13.5	-	-	-	-	-	-	-
C	17	11	15	11	13.5	12	-	-

material are too broad. Calcareous C horizon Kansan till mapped under the Shelby, Lindley, and Burchard series was usually stabilized with 11 to 13.5 percent cement, but one sample required 15 percent and another 17 percent because of high losses during the wet-dry test, probably from deleterious expansions of the montmorillonitic clay. Although C horizon cement requirements do not plot well against clay content (lower half of Fig. 7) the clay content becomes critical when the amounts are greater than about 37 percent. Eight of the 13 calcareous and leached C horizon till samples with 5 micron clay contents of 37 percent or less may be stabilized with 11 to 13.5 percent cement. The average requirement was about 12 percent. The five samples with over 37 percent clay required 13 to 17 percent cement, the average requirement being about 13 percent.

If clay content is critical, one would expect till B horizons to require more cement, and most do. However, an inverse relationship exists (top half of Fig. 7), and the higher clay content B horizons tend to require less cement—several percent less than equivalent clay content C horizon samples. Furthermore, most B horizon samples failed in the freeze-thaw test rather than the wet-dry test, as did the C horizon samples with the same clay contents. This suggests an important contribution from the characteristic blocky structure of the B horizon, reducing volume change losses during wet-dry cycles. The compacted density of five B horizon samples with an average clay content of 37.3 percent is 106.2 pcf; of ten C horizon samples with a clay content of 37.5 percent, it is 110.8 pcf. The B horizon blockiness tends to reduce density, which may

be directly or indirectly related to the increased resistance to wet-dry volume change. Only the lowest clay content B horizon sample, a Lindley, failed during the wet-dry test, and requirement was boosted to 16.5 percent. A gumbotil sample also showed benefit from having been a B horizon; although it contained 53 percent 5 micron montmorillonitic clay, the cement requirement was only 12 percent, and failure was by freeze-thaw. Another gumbotil sample with 70 percent clay failed in the wet-dry test and required 18 percent cement.

The A horizon Shelby and Burchard series required 12 to 14 percent cement, compared with only 8 to 10.5 percent for Lindley A horizons. In contrast to loessial series, podzolization in the Lindley has no deleterious effect, but is beneficial in the A horizon because it reduces the clay content to 15 or 20 percent and cuts the cement requirement. Unfortunately, Lindley A horizon soil is not abundant enough to provide a source for material; these results merely point out that A horizon material in the Lindley, Shelby, or Burchard series can beneficially be incorporated into soil-cement.

### Sand

Because of possible economic importance, upland sand deposits on and near the Iowan drift in eastern Iowa have in recent years been extensively mapped, sampled, and the engineering properties studied (9) (Fig. 8). Four representative deposits were sampled for soil-cement tests. One sand, coarser than the rest is fluvial in origin (that is, deposited from water). The other three are finer and eolian, although one is rather coarse because of local derivation from sandy drift.

Because of difficulties in interpreting origin, the Iowa sands have been confusing for agricultural soil surveyors. As a result the sands are identified as belonging to a wide variety of series, such as Knox, Carrington, and Fayette. Although no attempt is made here to correlate cement requirement to modern series equivalents, on future soil maps the eolian Brunizem sands will probably be mapped as Hagener (Riecken, F.F., personal

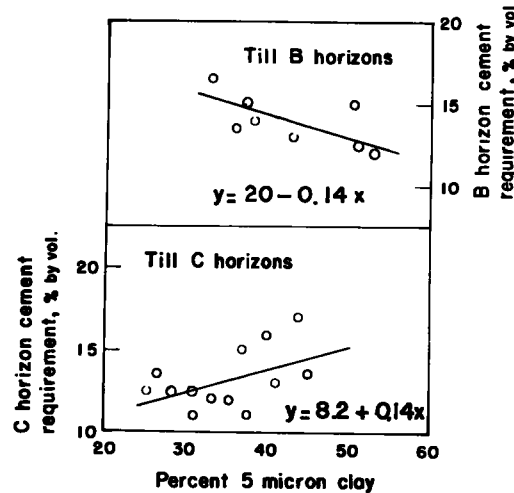


Figure 7. Relations of cement requirement of Iowa till soils to 5 micron clay content.

communication (1956))(formerly mapped as Thurman, Carrington, Lindley, Knox), and the Gray-Brown Podzolic equivalent will be the Chelsea (formerly mapped as Knox, Lindley, Sparta, Plainfield). Coarser eolian sands derived from local wind action on glacial drift will be mapped as Dickenson if a Brunizem (formerly Carrington, Shelby) or Lamont (Riecken, F.F., personal communication (1956)) if a Gray-Brown Podzolic.

TABLE 3  
CEMENT REQUIREMENTS OF EASTERN IOWA SANDS

Sample No.	Origin	% Coarse Sand (> 0.42mm)	Cement Requirements, (% by vol.)
S-31-1	Fluvial	24.9	7.5
S-28-4	Eolian (drift)	16.6	9.0
S-6-2	Eolian (banded)	6.2	8.5
S-6-2a	Eolian	3.2	9.0
S-57-4	Eolian	0.8	8.5

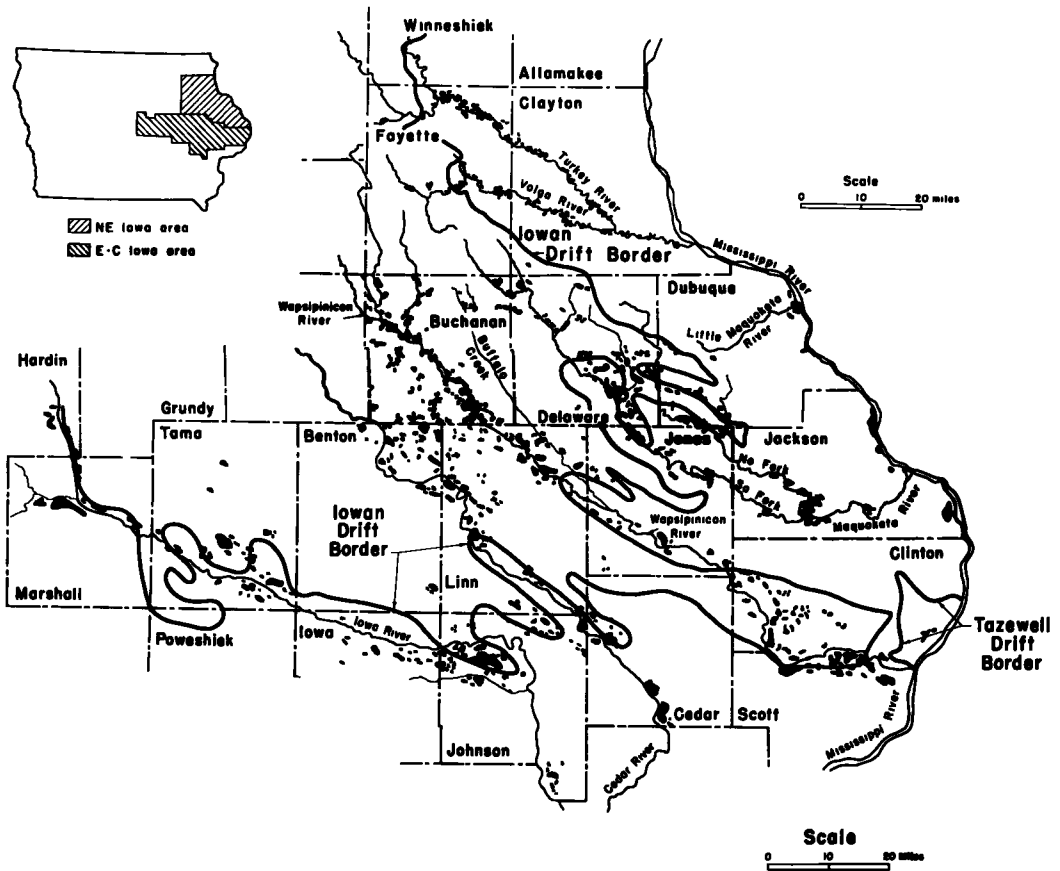


Figure 8. Sand deposits in eastern Iowa.

Many eastern Iowa sand deposits contain bands richer in clay and iron oxide minerals. Most such bands lie nearly horizontal, but many dip, intersect one another, or are wavy. They are believed to be secondary in origin, perhaps miniature repeated  $B_2$  horizons. One severely banded section was sampled separately for soil-cement tests, to see if banding has any effect on cement requirement.

**Results.**—Results of soil-cement tests with the five sandy soils are given in Table 3. The fluvial sand required 7.5 percent cement; the eolian sands all required 8.5 to 9.0 percent, regardless of local derivation or secondary banding. The eastern Iowa sand deposits should be considered a valuable resource for use in soil-cement.

### CONCLUSIONS

Conclusions from the investigation may be stated as follows:

1. Not all soil series may be successfully correlated with cement requirement, particularly when requirements are high because of an unusual sensitivity.
2. Medium-textured loess and loessial soils in the Ida, Monona, and Marshall series of western Iowa are critically susceptible to damage by freeze-thaw, probably due to high moisture mobility during freezing. However, this damage is reduced by increased contents of clay. Even more effective is the presence of sand.
3. Eastern Iowa Brunizems on loess do not show the critical susceptibility to freeze-thaw, but medium-textured Gray-Brown Podzolics, notably in the Fayette series, do. Perhaps differences in exchangeable cations or presence of traces of forest-derived organic matter allow increased moisture movement during freezing.

4. Clay content reaches an optimum for freeze-thaw resistance in fine-textured loess or loessial B horizons. Then further increases in clay content accelerate wet-dry losses and raise the cement requirement. The optimum clay content is reached in the Clinton, Mahaska, and Sharpsburg B, and in the Clinton-Weller and Mahaska-Grundy C horizons. Weller B and Grundy-Seymour B and C horizons are too high in clay.

5. High clay contents in C horizon Kansan glacial till also accelerate wet-dry losses and increase the cement requirement. However, B horizon samples with the same clay content resist wet-dry losses and require less cement. The blocky structure in the B horizon of till series is of decided benefit.

6. Sand deposits common in eastern Iowa may be readily stabilized with 7.5 to 9.5 percent portland cement. Cement requirement correlates with postulated origin and, when the areas are re-mapped, should correlate with soil series.

#### ACKNOWLEDGMENT

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#### REFERENCES

1. Leadabrand, J.S., Norling, L.T., and Hurless, A.C., "Soil Series as a Basis for Determining Cement Requirements for Soil-Cement Construction." HRB Bul. 148, 17 pp. (1957).
2. Simonson, Roy W., Riecken, F.F., and Smith, Guy D., "Understanding Iowa Soils." Sm. C. Brown Co., Dubuque, Iowa (1952).
3. Daniels, R.B., and Handy, R.L., "Suggested New Type Section for the Loveland Loess in Western Iowa." Jour. Geol., 67:1:114-119 (1959).
4. Ruhe, R.V., "Geomorphic Surfaces and the Nature of Soils." Soil Science, 82: 441-456 (1956).
5. Chu, T.Y., and Davidson, D.T. "Simplified Air-Jet Dispersion Apparatus for Mechanical Analysis of Soils." HRB Proc., 32:541-547 (1953).
6. American Society for Testing Materials. "Procedures for Testing Soils." ASTM, Philadelphia, Pa. (1958).
7. Portland Cement Association. "Soil-Cement Laboratory Handbook." PCA, Chicago (1956).
8. Handy, R.L., and Davidson, D.T., "Evidence of Multiple Loess Deposition in Western Iowa." Iowa Acad. Sci. Proc., 63:470-476 (1956).
9. Wickstrom, A.E., "Fine Sands in Eastern Iowa." Unpublished M.S. Thesis, Iowa State Univ. Library, Ames, Iowa (1957).

## Appendix

TABLE 4  
TEST RESULTS FROM WESTERN IOWA LOESS SOILS

Series and Iowa No.	Horizon	Gradation				Consistency		Maximum Density (pcf)	Optimum Moisture, (%)	Required Cement Content, (% by vol)
		Gravel, > 2mm	Sand, 0.074-2mm	Silt, 5-74 $\mu$	Clay, < 5 $\mu$	LL	PI			
W. Iowa Loess:										
Hamburg I	C	0	3.2	80.3	16.5	30.3	5.2	102.9	17.9	12
	AB, Brady	0	6.2	70.9	22.9	31.8	9.4	107.8	16.5	12
	C	0	8.2	78.2	13.7	27.3	2.6	107.7	15.8	12 <sup>1</sup>
" X	C	0	0.9	80.6	18.5	32.1	10.1	103.0	18.5	14
	D, Stratified	0	0.7	83.3	16.0	33.9	10.9	102.3	19.0	12
Ida III	A	0	0.0	87.7	32.3	46.1	20.2	99.4	19.5	20
	C	0	0.5	75.0	24.5	35.2	11.8	100.0	18.5	20
Monona XI	A	0	0.1	82.5	17.4	42.9	19.5	98.5	22.5	18
	B	0	0.4	88.7	30.9	45.8	23.5	98.7	22.0	16 <sup>1</sup>
	C <sub>1</sub>	0	0.4	73.2	26.4	39.9	17.0	105.0	18.0	> 20
	C	0	0.6	74.8	24.7	33.5	9.8	102.0	18.6	> 20
	C, Fe-rich	0	0.3	78.3	21.4	35.7	11.9	101.3	19.3	> 20
	C <sub>1</sub>	0	0.2	79.2	20.6	34.9	10.8	102.0	18.3	> 20
" IX	A	0	0.7	85.7	33.6	44.7	21.4	98.6	21.0	18
	B	0	0.5	88.3	31.2	41.8	20.3	103.2	18.3	16
	C <sub>1</sub>	0	0.5	70.1	29.4	41.2	19.7	103.3	19.0	16
	C	0	0.7	74.3	25.0	57.9	16.2	103.8	18.7	18
Marshall IV	A <sub>s</sub>	0	0.8	59.3	39.9	45.8	23.1	94.5	23.3	18
	B	0	0.4	65.2	34.4	46.0	25.9	102.3	18.8	14
	C <sub>1</sub>	0	0.3	68.2	31.5	41.7	21.0	103.0	18.8	18
	C	0	0.4	72.6	27.0	38.0	26.8	99.6	19.5	16
" V	A	0	0.5	64.7	34.8	42.6	19.7	98.3	21.5	18
	B	0	0.3	60.4	39.3	48.0	27.9	99.0	21.5	14
	C <sub>1</sub>	0	0.4	66.6	33.0	39.6	21.3	104.2	18.7	16
Marshall VIII	A	0	0.4	58.3	41.3	49.2	27.6	98.4	21.3	18.0
	B	0	0.4	54.8	44.8	56.3	33.2	98.8	22.0	16
	C <sub>1</sub>	0	0.4	63.6	36.0	43.6	22.5	103.3	18.7	16
	C, unoxidized	0	0.8	66.6	32.6	40.4	19.7	98.4	21.3	14
Sharpsburg, 500	A	0	2.0	57.0	41.0	46.1	21.9	96.0	21.0	12.5
	B	0	1.0	52.5	46.5	55.1	33.6	95.5	22.7	12
	C <sub>1</sub>	0	1.0	60.0	39.0	47.7	26.1	100.0	22.0	16.5
	Sandy loess	0	15.0	55.0	30.0	35.5	16.4	112.3	13.5	11
Ladoga 502	A	0	2.3	63.9	33.8	35.6	13.9	102.5	17.1	15
	B	0	1.0	50.0	49.0	37.4	21.0	99.3	19.7	21 <sup>1</sup>
	C <sub>1</sub>	0	2.4	60.4	37.2	51.7	31.2	100.2	19.7	15
(Paleosol on Loveland loess, 502)	A <sub>p</sub>	0	5.0	58.0	37.0	34.0	16.0	107.9	16.4	12
	B <sub>1p</sub>	0	6.1	56.5	37.4	39.1	22.1	107.2	17.0	11.5
	B <sub>2p</sub>	0	4.2	42.2	53.6	61.9	40.4	95.6	23.0	18 <sup>1</sup>

<sup>1</sup>Wet-dry losses exceed losses from freeze-thaw.

TABLE 5  
TEST RESULTS FROM EASTERN AND SOUTHERN IOWA LOESS SOILS

Series and Iowa No.	Horizon	Gradation				Consistency		Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content, (% by vol)
		Gravel, >2mm	Sand, 0.074-2mm	Silt, 5-74 $\mu$	Clay, <5 $\mu$	LL	PI			
Gray-Brown Podzolics:										
Fayette 100	A	0	2.1	62.6	35.4	41.0	17.7	102.7	19.3	13.5
	B	0	0.1	60.9	39.0	54.1	33.8	101.5	18.7	14.5
	C <sub>1</sub>	0	1.0	78.2	20.8	30.0	9.1	105.4	17.0	14.5
" 211	Sandy loess	0	8.3	79.4	12.3	25.5	6.3	109.2	15.3	9.5
	A	0	2.0	77.8	20.1	30.0	7.5	102.0	17.3	>20
	B	0	0.8	65.2	34.0	43.4	21.5	104.0	16.5	>19
	C <sub>1</sub>	0	0.5	67.8	31.7	45.8	23.9	104.3	17.8	17.5
	C	0	0.7	78.2	21.1	28.9	8.2	106.6	16.2	11.5
207	A	0	1.7	75.1	23.1	33.3	4.3	100.0	18.9	19.5
	B	0	0.4	68.9	30.7	38.0	15.0	102.7	19.2	16.5
	C <sub>1</sub>	0	0.5	64.3	35.2	41.7	19.3	101.9	18.1	20.5
	C	0	0.4	76.7	22.9	30.2	8.4	108.1	16.6	14
	C, unoxidized	0	0.3	77.5	22.2	28.6	6.7	109.6	15.8	13
Clinton 524	A	0	1.1	68.4	30.5	35.9	10.8	97.0	19.6	12
	B	0	0.7	61.8	37.4	43.9	22.4	98.8	20.0	12
	C <sub>1</sub>	0	0.3	69.7	30.0	36.2	15.9	103.7	19.0	14.5
" 119	A	0	1.2	64.8	34.0	36.9	12.9	96.1	22.1	17
	B	0	0.7	56.6	42.7	51.8	30.0	100.1	21.7	14.6
	C <sub>1</sub>	0	3.4	62.9	34.7	38.1	19.9	103.5	19.8	14.5
" 523	A	0	2.2	64.3	33.5	43.3	14.5	93.4	23.8	14
	B	0	2.8	58.0	39.5	48.5	24.1	98.3	19.5	16.5 <sup>1</sup>
	C <sub>1</sub>	0	4.6	58.9	36.5	36.8	18.8	105.3	18.5	10.5
Weller 530	A	0	4.7	65.3	30.0	32.4	11.9	97.0	19.5	13.5
	B	0	1.8	46.4	51.8	61.9	40.0	95.3	22.0	>20 <sup>1</sup>
	C <sub>1</sub>	0	4.8	55.2	40.0	39.1	21.4	104.3	19.6	10
Brunizems:										
Tama 122	A	0	2.3	71.5	26.2	32.9	8.9	102.8	18.4	17
	B	0	2.4	68.6	29.0	33.9	12.7	105.2	17.5	12
	C	0	5.0	77.6	17.4	25.4	1.8	107.8	16.0	12
" 212	A	0	3.4	71.6	25.0	35.7	11.7	99.8	19.2	17
	B	0	2.3	74.9	32.2	47.7	25.7	104.8	18.0	15
	C <sub>1</sub>	0	3.1	71.4	25.5	39.1	17.3	106.7	17.5	14.5
	C	0	1.2	66.6	22.8	32.8	10.7	106.0	17.3	13
	C, unoxidized	0	2.4	74.5	23.1	29.6	8.8	107.9	15.7	12.0
Muscatine 223	A	0	0.8	67.6	31.6	40.7	17.2	96.6	19.7	14
	B	0	0.7	63.9	35.4	45.5	25.5	100.1	18.5	14.5
	C <sub>1</sub>	0	0.3	69.0	30.7	37.4	15.9	105.1	18.0	14.5
	C	0	0.8	78.6	20.6	26.6	3.6	106.8	16.5	12
	C, Fe-rich	0	0.9	78.1	21.0	26.8	6.4	110.4	15.2	13.5
	C, unoxidized	0	1.4	76.3	22.3	28.2	9.1	107.6	17.3	12
" 111A	A	0	3.3	64.7	32.0	39.2	13.0	91.3	24.3	>21
	B	0	2.1	57.6	39.3	39.1	15.1	99.8	20.2	14.5
	C <sub>1</sub>	0	0.8	69.4	29.8	30.8	9.0	108.9	16.7	13.5
Mahaska 528	A	0	1.4	69.1	29.5	33.8	9.4	97.5	18.2	12.5
	B	0	0.7	57.8	42.5	49.5	26.2	102.0	20.5	13.5 <sup>1</sup>
	C <sub>1</sub>	0	1.6	61.4	37.0	46.0	25.1	101.5	19.5	11
Grundy 529	A	0	2.5	62.5	35.0	34.3	14.1	97.5	21.4	13
	B	0	0.7	54.5	44.8	50.5	31.2	96.3	23.4	14 <sup>1</sup>
	C <sub>1</sub>	0	0.5	65.8	33.6	38.0	20.2	104.0	17.8	12
" 525	A	0	2.7	63.3	34.0	38.4	11.5	97.5	21.3	17.5
	B	0	0.9	51.8	47.4	52.5	27.6	93.5	22.5	15.5
	C <sub>1</sub>	0	0.4	65.6	34.0	38.8	19.1	101.3	19.5	15 <sup>1</sup>
" 541A	A	0	3.6	57.4	39.0	41.5	15.2	96.7	20.0	18
	B	0	1.5	51.0	47.5	55.2	29.9	96.6	22.5	17 <sup>1</sup>
	C <sub>1</sub>	0	1.0	63.5	35.5	45.7	24.6	102.6	18.3	19 <sup>1</sup>

<sup>1</sup>Wet-dry losses exceed losses from freeze-thaw.

TABLE 6  
TEST RESULTS FROM KANSAN AND ILLINOIAN TILL SOILS

Series and Iowa No.	Horizon	Gradation				Consistency		Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content (% by vol)	
		Gravel, >2mm	Sand, 0.074-2mm	Silt, 5-74 $\mu$	Clay, <5 $\mu$	LL	PI				
Brunizems:											
Burchard 411	A	3.0	30.0	30.5	36.5	43.3	20.3	100.5	18.7	13	
	B	3.5	23.5	30.0	43.0	49.5	28.4	103.0	20.0	13	
	C <sub>Ca</sub>	1.5	24.5	29.0	45.0	45.4	30.2	108.6	18.3	13.5	
	C	3.0	24.5	28.5	44.0	41.1	25.7	108.1	16.0	17	
Shelby 415	A	0.8	31.6	39.6	28.0	35.6	15.1	99.3	21.0	14	
	B	2.7	29.2	30.9	37.2	47.4	29.4	103.0	19.3	15	
	C <sub>1</sub>	2.3	23.4	34.3	40.0	45.8	28.6	99.7	22.0	16	
	C	2.0	25.1	35.3	37.6	39.6	25.0	114.0	15.0	11	
" 416	A	8.0	36.5	29.5	26.0	36.4	14.6	104.6	17.3	12	
	B	3.5	32.2	25.1	39.2	44.2	23.1	109.7	15.5	14	
	C <sub>1</sub>	11.2	27.8	27.8	33.2	36.8	19.8	113.5	15.0	12	
	C	1.3	32.6	29.1	37.0	36.2	23.1	112.5	15.5	15 <sup>a</sup>	
" 425	C	2.5	35.6	30.9	31.0	29.0	12.0	117.8	13.0	11	
	Gray-Brown Podzolics:										
	Lindley 422	A	4.0	43.0	32.0	21.0	26.1	11.7	106.5	15.5	10.5
		B	1.2	37.1	25.2	36.5	39.3	23.0	108.3	15.7	13.5
C <sub>1</sub>		6.2	41.3	27.0	25.5	33.0	20.0	116.3	13.7	12.5	
C		1.0	40.8	31.7	26.5	28.9	14.8	118.4	11.0	13.5 <sup>a</sup>	
" 423	A	0	40.2	44.8	15.0	22.4	4.7	113.0	13.5	8	
	B	0.4	41.6	25.0	33.0	39.6	22.8	107.0	16.5	16.5 <sup>a</sup>	
	C <sub>1</sub>	2.0	40.0	27.0	31.0	36.2	21.4	111.0	15.5	12.5	
	C	0.8	28.7	35.0	35.5	40.9	22.6	113.1	14.2	12	
" 429A	B	1.2	30.7	17.7	50.4	35.6	18.5	101.0	21.0	15	
	C <sub>1</sub>	2.0	41.5	28.1	28.4	27.6	12.9	113.6	14.1	12.5	
	C	5.0	19.0	25.0	51.0	56.5	35.3	107.4	18.0	12.5	
" 436 (Illinoian till)	B	1.0	26.0	32.0	41.0	56.2	35.7	109.3	14.5	13.0	
	C <sub>1</sub>	1.0	26.0	32.0	41.0	56.2	35.7	109.3	14.5	13.0	
Paleosols:											
Gumbotil, 500-5C	B <sub>p</sub>	5.0	21.5	21.0	52.5	41.0	24.0	101.9	20.9	12	
Gumbotil, 528-4C	B <sub>p</sub>	0.3	16.1	13.1	70.5	85.0	53.3	99.3	21.4	18 <sup>a</sup>	

<sup>a</sup>Wet-dry losses exceed losses from freeze-thaw.

TABLE 7  
TEST RESULTS FOR EASTERN IOWA SANDS

Origin and Iowa No.	Horizon	Gradation				PI	Maximum Density (pcf)	Optimum Moisture (%)	Required Cement Content (% by vol)
		Coarse Sand, 2-0.42mm	Fine Sand, 0.42-0.74mm	Silt, 5-74 $\mu$	Clay, <5 $\mu$				
Fluvial <sup>1</sup>	C <sub>1</sub>	37.0	59.2	1.6	2.2	NP	117.0	8.8	7.5
S-31-1									
Eolian, local <sup>1</sup>	C <sub>1</sub>	24.4	74.4	0.2	1.0	NP	110.6	9.5	9.0
S-28-4									
Eolian <sup>1</sup>	C <sub>1</sub>	9.1	87.7	1.7	1.5	NP	113.6	9.1	8.5
S-6-2	B <sub>s</sub> (band)	13.9	81.5	1.6	4.0	NP	116.0	9.5	9.0
Eolian <sup>2</sup>	C <sub>1</sub>	1.7	86.9	8.6	2.8	NP	113.6	10.0	8.5
S-57-4									

<sup>1</sup>Old series name indicates Brunizem.

<sup>2</sup>Old series name indicates Gray-Brown Podzolic.



# Comparison of Type I and Type III Portland Cements for Soil Stabilization

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Test data are presented which indicate the possibility of significant economic and/or structural advantages in using Type III high-early-strength portland cement instead of Type I normal portland cement for soil-cement road construction. The data also indicate that high alkali content in Type I cement may be beneficial to the strength of cement-treated soil if the soil contains a relatively high proportion of clay-free quartz surfaces.

Test methods and criteria for evaluating the strength and durability of cement-treated fine-grained soils are presented and discussed. The minimum Type I and Type III cement requirements for soil-cement indicated by these methods, for the sandy, silty and clayey soils studied, were surprisingly low.

● **SOIL-CEMENT** is defined as a hardened material formed by curing a mechanically compacted intimate mixture of pulverized soil, portland cement and water. Durability and/or compressive strength are the common criteria for hardness. The standard for hardness varies (1). Soil-cement has an excellent record of successful field service in base courses of roads, airfields, parking lots and similar applications. It has some structural advantages over, and is often cheaper than, equivalent untreated granular base materials. An increase of these advantages would further increase the popularity of soil-cement.

## SOME POSSIBILITIES FOR IMPROVING SOIL-CEMENT

Two types of portland cement available on the market for general use in soil-cement are Type I normal cement and Type III high-early-strength cement, as described in ASTM Standard Specifications for Portland Cements, C 150-56 (2). Type I cement is usually used in soil-cement, probably because it is usually most readily available and is slightly lower priced than Type III cement. (The cost of Type III cement is currently about 13 percent higher than that of Type I cement.) However, if the cement requirement for soil-cement is significantly lower with Type III than with Type I, a possibility suggested by the work of Clare et al. (3, 4), Felt (5), and Leyder (6), there could be an economic advantage in using Type III cement.

Soil-cement requires a definite curing period prior to the construction of additional base or wearing courses. This curing period is normally seven days when Type I cement is used. Because curing time affects total construction time, a reduction in curing time made possible by use of Type III cement could be advantageous.

Recent work at Iowa State (7, 8, 9) and M. I. T. (10, 11) indicates that the use of small amounts of alkali additives in soil-cement may accelerate the rate of hardening. This suggests that the alkali content of portland cement may have a significant effect on the strength of soil-cement, a possibility which apparently has not been investigated previously.

## OBJECTIVES OF THE INVESTIGATION

This report presents the results of a laboratory investigation to obtain more information on the advantages of Type III cement over Type I cement for soil-cement road construction, particularly in Iowa. A second objective was to determine whether alkali content is an important compositional variable in portland cement used in soil-cement.

## PROPERTIES OF MATERIALS USED

## Soils

Properties of the three soils used in the investigation are given in Table 1. These sandy, silty and clayey soils are typical of widespread and readily available materials for stabilized road construction in Iowa. The sand-loess mix was sampled from the blended material used in the soil-cement base course of Primary System Highway Iowa 117, constructed in 1957.

TABLE 1  
PROPERTIES OF SOILS

Property	Sand-Loess (Colfax Mix) <sup>1</sup>	Friable Loess (20-2-VII) <sup>1</sup>	Kansan Till (409-12C) <sup>1</sup>
Geological description:	Mix of approximately 82% waste sand from hydraulic dredging operations and 18% Wisconsin-age loess, oxidized, calcareous, medium plastic	Wisconsin-age loess, oxidized, calcareous, friable	Kansan-age glacial till, oxidized, calcareous, plastic
Sampling location:	Jasper Co., Iowa	Harrison Co., Iowa	Ringgold Co., Iowa
Soil series:	Loess: Tama	Hamburg	Shelby (Burchard)
Horizon:	Loess: C	C	C
Sampling depth, ft:	Sand: Stock pile Loess: Borrow pit	35-36	4½-10½
Textural composition, <sup>2</sup> %:			
Gravel (> 2 mm)	0.0	0.0	0.0
Sand (2.0-0.074 mm)	70.7	0.4	31.5
Silt (0.074-0.005 mm)	22.3	80.0	30.0
Clay (< 0.005 mm)	7.0	19.6	38.5
Colloids (< 0.001 mm)	6.0	14.5	31.0
Atterberg limits <sup>3</sup> :			
Liquid limit, %	18.9	30.8	42.4
Plastic limit, %	16.4	24.6	20.5
Plasticity index, %	2.5	6.2	21.9
Classification:			
Textural <sup>4</sup>	Sandy loam	Silty loam	Clay
Engineering (AASHO) <sup>5</sup>	A-2-4	A-4(8)	A-7-6(12)
Chemical:			
Cation exchange capacity, <sup>6</sup> m. e./100g	11.0	13.4	29.5
Carbonates, <sup>7</sup> %	11.6	10.2	4.9
pH <sup>8</sup>	8.0	8.7	8.25
Organic matter, <sup>9</sup> %	0.16	0.17	0.17
Non-clay mineral composition, <sup>10</sup> %:			
Aggregates (silicious)	36.3	-	-
Quartz	50.5	56.0	60.2
Feldspars	9.0	21.1	21.1
Calcite	3.8	13.7	-
Others	0.3	9.2	18.7
Clay mineral composition:			
Predominant clay mineral <sup>11</sup>	Montmorillonite	Montmorillonite	Montmorillonite
Clay coatings on surfaces of grains > 0.005 mm <sup>12</sup>	Light to moderate (15-35%)	Moderate (20-80%)	Extensive (75-100%)

<sup>1</sup>Soil Research Laboratory sample designation.

<sup>2</sup>ASTM Method D 422-54T (2).

<sup>3</sup>ASTM Methods D 423-54T and D 424-54T (2).

<sup>4</sup>Triangular chart developed by U. S. Bureau of Public Roads (12).

<sup>5</sup>AASHO Method M 145-49 (13).

<sup>6</sup>Ammonium acetate (pH = 7) method on soil fraction < 0.42 mm (No. 40 sieve).

<sup>7</sup>Versenate method for total calcium.

<sup>8</sup>Glass electrode method using suspension of 15 g soil in 30 cc distilled water.

<sup>9</sup>Potassium bichromate method.

<sup>10</sup>Petrographic microscopical analysis.

<sup>11</sup>X-ray diffraction analysis.

<sup>12</sup>Estimated, based on microscopic examination of random grains > 0.005 mm.

## Portland Cements

The three Type I cements and two Type III cements used in the investigation were selected by William Lerch, Assistant to the Vice President for Research and Development, Portland Cement Association. The cements designated Ia, Ib and Ic in Table 2 meet the requirements for the ASTM specifications (C 150-56) for Type I portland cement; those designated IIIa and IIIb meet ASTM requirements for Type III portland cement (2).

The three Type I cements differed mainly in their total alkali content (as  $\text{Na}_2\text{O}$ ), which was the desired variable. Cement Ia had low alkali content, cement Ib had medium alkali content, and cement Ic had high alkali content. The 7- and 28-day com-

TABLE 2  
PROPERTIES OF THE TYPE I AND TYPE III PORTLAND CEMENTS<sup>1</sup>

Cement Designation Cement Type	Ia <sup>2</sup> (13) <sup>3</sup> I	Ib <sup>2</sup> (21) <sup>3</sup> I	Ic <sup>2</sup> (14) <sup>3</sup> I	IIIa <sup>2</sup> (31) <sup>3</sup> III	IIIb <sup>2</sup> (33) <sup>3</sup> III
Major oxide composition, %:					
Silicon dioxide ( $\text{SiO}_2$ )	22.18	23.71	22.17	20.36	20.03
Aluminum oxide ( $\text{Al}_2\text{O}_3$ )	4.70	3.97	4.62	4.96	5.08
Ferric oxide ( $\text{Fe}_2\text{O}_3$ )	2.12	3.21	3.03	2.11	2.52
Calcium oxide ( $\text{CaO}$ )	64.22	63.98	62.86	63.28	63.81
Magnesium oxide ( $\text{MgO}$ )	1.07	1.18	2.37	3.20	1.38
Sulphur trioxide ( $\text{SO}_3$ )	1.62	1.24	1.73	2.23	2.31
Sodium oxide ( $\text{Na}_2\text{O}$ )	0.04	0.22	0.06	0.23	0.21
Potassium oxide ( $\text{K}_2\text{O}$ )	0.19	0.40	1.30	0.22	0.44
Free calcium oxide ( $\text{CaO}$ )	1.61	0.65	0.19	1.45	1.83
Total equivalent alkali content as $\text{Na}_2\text{O}$	0.17	0.48	0.92	0.37	0.50
Calculated potential compound composition, %:					
Tricalcium silicate ( $\text{C}_3\text{S}$ )	53.6	45.4	47.1	60.1	63.2
Dicalcium silicate ( $\text{C}_2\text{S}$ )	23.2	33.7	28.1	13.0	9.8
Tricalcium aluminate ( $\text{C}_3\text{A}$ )	8.9	5.1	7.1	9.6	9.2
Tetracalcium aluminoferrite ( $\text{C}_4\text{AF}$ )	6.4	9.8	9.2	6.4	7.7
Physical properties:					
Fineness, turbidimeter (Wagner), sq cm/g	1660	1630	1880	2800	2530
Fineness, air permeability (Blaine), sq cm/g	3430	2890	3420	5800	5270
Compressive strength of 1-2.75 mortars, ASTM Method C 109					
1 day, psi	720	380	690	1820	2010
3 day, psi	1560	1390	1730	4000	4180
7 day, psi	2350	2450	2880	5630	5910
28 day, psi	4140	4330	4330	7010	6340

<sup>1</sup>Cements and property data furnished by Portland Cement Association.

<sup>2</sup>Designation used in this report.

<sup>3</sup>Portland Cement Association's designation.

pressive strengths obtained in 1-2.75 graded Ottawa sand mortars are similar. The difference in 1-day mortar strengths seems to correlate with small variations in fineness and calculated  $\text{C}_3\text{S}$  content.

The two Type III cements were quite similar and had medium alkali contents, although cement IIIa had a slightly lower alkali content than cement IIIb. They were much finer than the Type I cements and in mortars gave higher compressive strengths at ages up to 28 days. Type III cements had higher  $\text{C}_3\text{S}$  contents and lower  $\text{C}_2\text{S}$  contents than the Type I cements. Sulphur trioxide (gypsum) content was not considered a significant variable in this investigation, because the gypsum content of each cement was adjusted to about optimum for setting and strength properties of the cement paste.

## METHODS OF PREPARING AND TESTING SPECIMENS

### Mixing

The mixing of materials was done mainly with a Hobart Model C-100 Mixer. Proper proportions of cement and air-dry soil, based on the oven-dry weight of the soil, were placed in the mixing bowl, blended briefly by hand and then dry mixed by machine

for 1 min. The materials were mixed for another minute while a predetermined amount of distilled water was added. The mixing bowl was scraped and the materials hand mixed for approximately 1 min to break up any clods which might have formed. The mixture was given a final machine blending for 1 min.

### Molding

Test specimens were prepared by use of the molding apparatus shown in Figure 1. The specimens had a diameter of 2 in. and a height of  $2 \pm 0.005$  in. This specimen size also is used for compressive strengths tests by the Portland Cement Association when

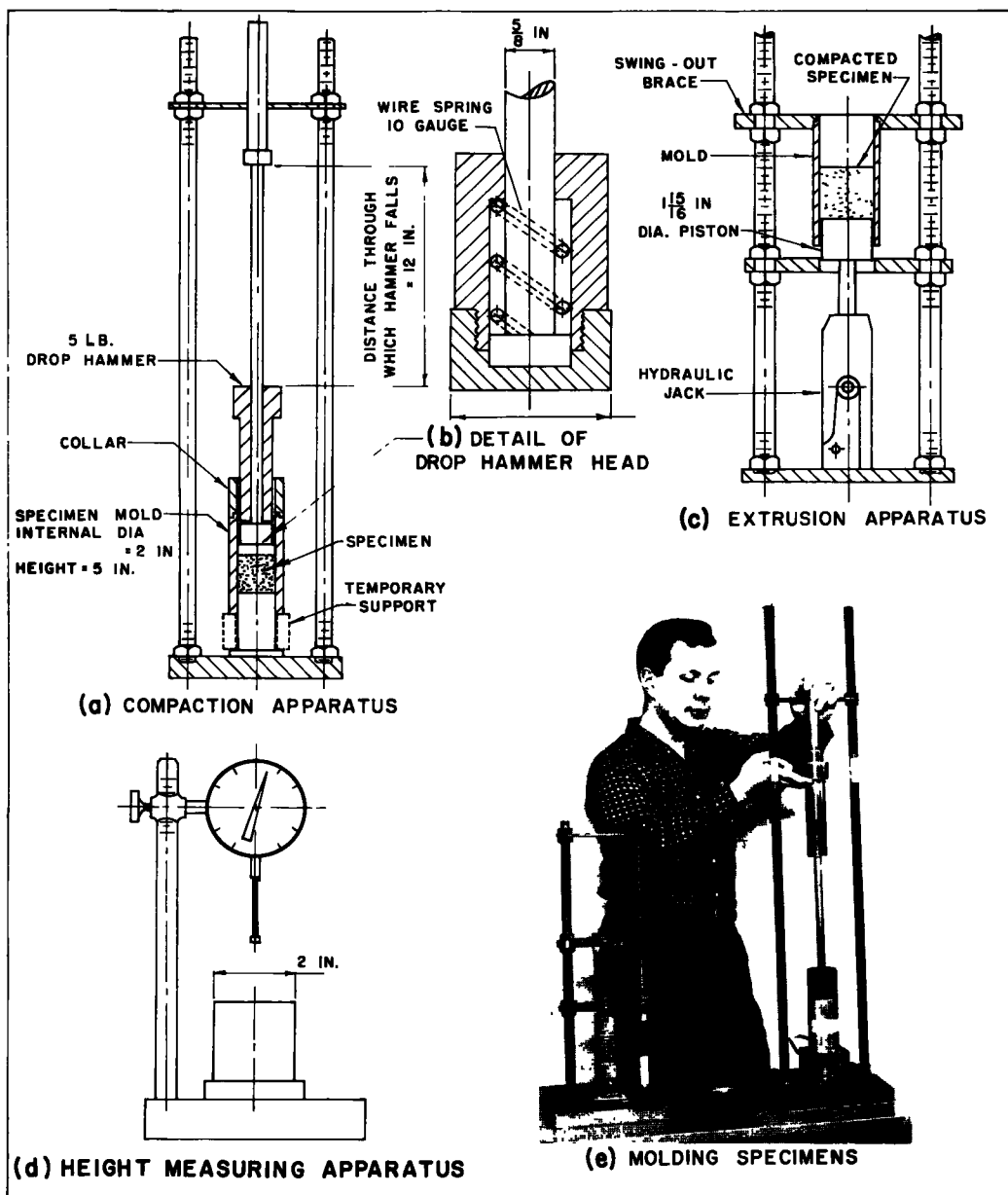


Figure 1. Apparatus used for molding 2-in. high by 2-in. diameter test specimens.

the soil contains no plus No. 4 material (14). A 2- by 2-in. specimen can be compacted to uniform density in one layer with no cleavage planes.

The amount of mixture needed for a specimen was placed in the calibrated cylinder supported by the temporary support. The mixture was given one blow with the 5-lb hammer, the temporary support was removed, and the mixture given an additional four blows. The molding cylinder was inverted and the specimen was given five additional blows. The resulting specimen was extruded, weighed to the nearest 0.1 gram and the height was measured to the nearest 0.001 in. When the molding is done on a wooden table, the ten blows with the 5-lb hammer dropping 12 in. gives a compactive effort approximately equal to standard ASTM (Proctor) compactive effort (ASTM Method D 558-57 (2)).

### Moisture-Density-Strength Relationships

The purpose of the moisture-density and moisture-strength relationship tests was to determine the optimum moisture contents for molding cement-treated soil specimens for subsequent immersed strength and freeze-thaw tests. The tests were performed with the three soils. Each cement in varying amounts was used with each soil.

Sufficient soil for ten specimens was dry mixed with the desired amount of portland cement. Enough of the mixture to mold two specimens was mixed with the required amount of water to obtain a moisture content on the dry side of optimum moisture. Two specimens were molded, measured and weighed, and two samples of the unmolded mixture were taken for moisture content determinations. The procedure was repeated four more times, with the moisture content of the mixture increased approximately 2 percent for each repetition.

The molded specimens of varying moisture content were cured for 7 days, immersed in water for 24 hours, and tested for unconfined compressive strength.

Average values of dry density (at time of molding) and immersed strength were calculated for each moisture content. These data enabled comparisons to be made of the optimum moisture requirements for maximum dry density and maximum immersed strength obtained from curves such as those for the cement-treated Kansan till mixtures in Figure 2. The optimum moisture contents for maximum dry density and maximum immersed strength were nearly identical for cement-treated sand-loess and friable-loess mixtures; therefore only typical moisture-density curves are shown in Figure 2. For cement-treated Kansan till mixtures, optimum moisture for maximum immersed strength was about  $1\frac{1}{2}$  percent greater, based on the oven-dry weight of the mixture, than optimum moisture for maximum dry density (Fig. 2). Leyder (6) reported similar results for clays. The type of portland cement did not significantly affect optimum moisture contents or maximum density, which agrees with the findings of Felt (5). Generally, an increase in cement content caused an increase of maximum density but only a slight decrease of optimum moisture contents. Therefore it was possible to select a single molding moisture content for each soil. The "optimum" moisture contents selected for use are indicated in Figure 2.

The moisture-density relations obtained by this method agree closely with those obtained by standard ASTM Method D 558-57 (2).

### Curing

Following molding, specimens for immersed strength or freeze-thaw resistance tests were wrapped in waxed paper sealed with cellophane tape and were placed in a moist curing room for designated periods. The desired constants for the curing room were a temperature of  $70 \pm 5$  F and a relative humidity of  $95 \pm 5$  percent. However, the temperature was known to deviate from the desired constant, particularly in the summer and winter, being higher in summer and lower in the winter.

### Immersed Strength and Freeze-Thaw Testing

Unconfined Compressive Strength After Curing and 24 Hours Immersion.—For each mixture, sufficient soil for nine specimens was dry mixed with the desired amount of

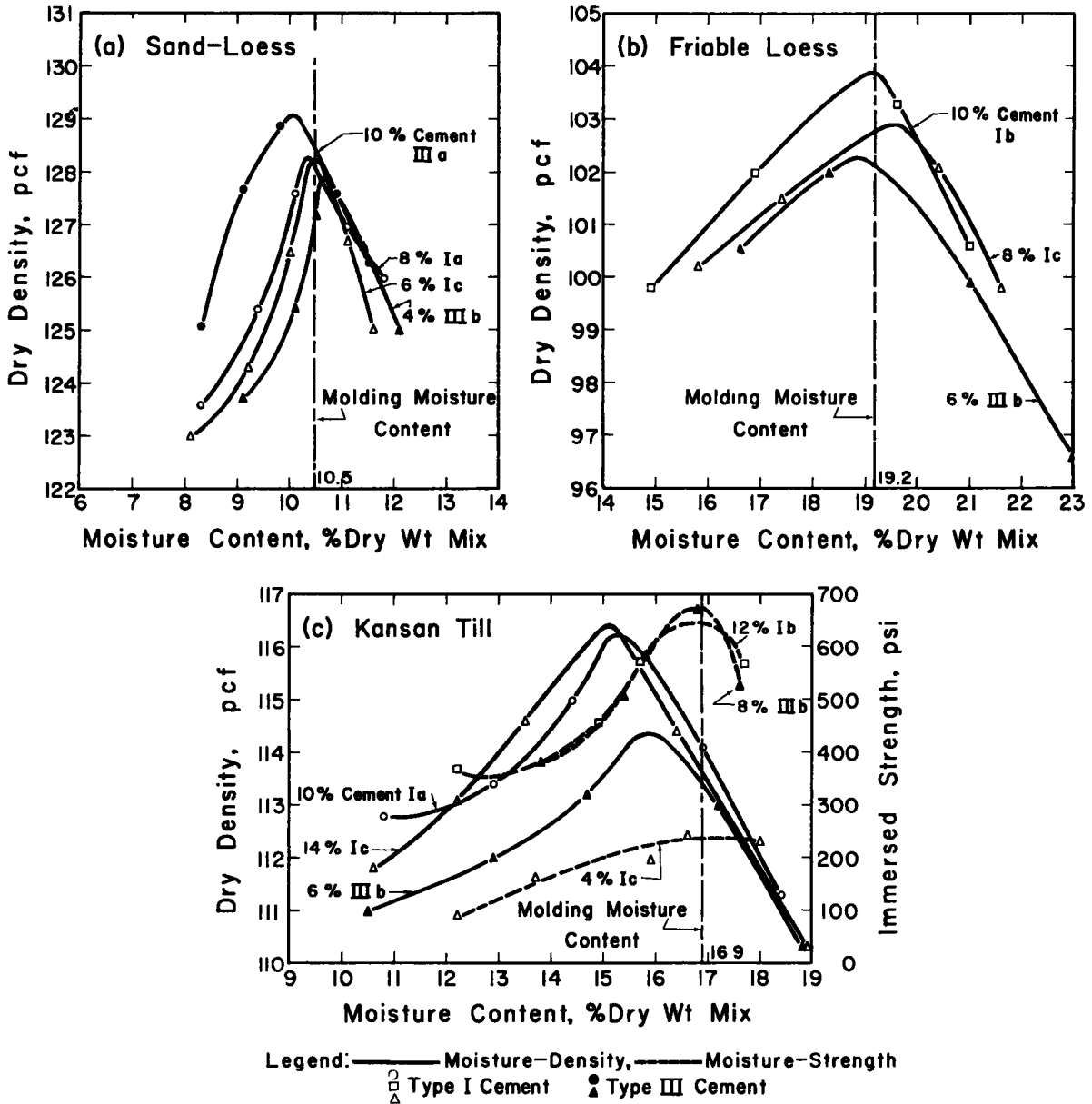


Figure 2. Typical moisture-density and moisture-strength curves for the Type I and Type III cement-treated soil mixtures studied. The molding moisture content indicated for each soil is the selected "optimum" for mixtures of the soil and Type I or Type III cement.

portland cement. Enough water to bring the mixture to optimum moisture was added. After moist mixing, nine specimens were molded, sealed in waxed paper (to reduce moisture loss and absorption of  $\text{CO}_2$  during curing) and placed in the humidity room.

Three specimens were cured for 2 days, three for 7 days and three for 28 days. At the end of each curing period, the specimens, with waxed paper removed, were immersed in distilled water, at room temperature, for 24 hr. Immediately after removal from the water bath, the specimens were tested for unconfined compressive strength. The maximum load to break a specimen, with a load travel rate of 0.1 in.

per min, was taken as the compressive strength. Average values, based on the three specimens, are reported. With very few exceptions, the difference between the individual values and the average value did not exceed 10 percent of the average value.

**Freeze-Thaw Resistance.**—The freeze-thaw test used to evaluate selected cement-treated soil mixtures is a modification of British Standard Test 1924:1957, "Determination of the Resistance of a Stabilized Soil Mixture to Damage by Frost (for fine-grained soils only)" (15). The modifications are as follows: using 2- by 2-in. instead of 2- by 4-in. test specimens, using waxed paper sealed with cellophane tape instead of paraffin to reduce moisture evaporation from specimens during curing, and using a resin-base paint (Plax) instead of tar as the seal coat on the tops of specimens. The freeze-thaw apparatus used is shown in the Appendix (Fig. 6), where the details of the modified British test are given.

Two identical specimens were molded for each mixture and curing period studied. (Specimens of cement-treated sand-loess were cured for 2 and 7 days, specimens of cement-treated friable loess and Kansan till were cured for 7 days only.) One specimen was designated the control specimen and the other the freeze-thaw specimen. After moist curing, the flat top surface of each specimen was sprayed with the resin-base paint to a thickness of approximately 1 mm. Then the control specimen was immersed for 15 days in distilled water at a temperature of  $77 \pm 4$  F; the freeze-thaw specimen was immersed for one day, then subjected to the 14 cycles of freeze-thaw (14 days) as described in the Appendix. The unconfined compressive strengths in psi of the control (immersed) specimen ( $p_c$ ) and the freeze-thaw specimen ( $p_f$ ) were then determined. The index of the resistance to the effect of freezing ( $R_f$ ) was calculated from the formula:

$$R_f = \frac{100p_f}{p_c} \quad (\text{percent})$$

The modified British freeze-thaw test is thought to simulate field freeze-thaw conditions better than the brushing test developed by the Portland Cement Association (14) and standardized by the American Society for Testing Materials (ASTM Method D 560-57 (2)). The modified British test is simpler, faster and requires less soil and additive materials than the ASTM test; these advantages are particularly important when a large number of specimens are to be evaluated. The use of the modified British test is limited to fine-grained soils which pass the No. 4 sieve.

## TEST RESULTS AND INTERPRETATIONS

### Unconfined Compressive Strength After Curing and 24 Hours Immersion

The purpose of these immersed strength tests was to obtain a comparison of the relative strength gain from the use of the Type I and Type III cements in mixtures with each of the three soils. Plots of immersed strength versus cement content, for each soil, cement type and curing period are shown in Figure 3. Plots of immersed strength versus curing time, for each soil, cement type and cement content are shown in Figure 4. Cement contents are expressed as percentages of the oven-dry weight of the soils.

**Sand-Loess.**—Type III cements gave higher strengths than Type I cements at all cement contents except 4 percent cement IIIb, which gave approximately the same strength as the same amount of the three Type I cements (Figs. 3a, b, c and 4a, b, c, d). Generally the rate of strength gain with increasing cement content was greater with Type III than with Type I cements, the strength difference being more pronounced after curing periods of 2 and 7 days than after 28 days.

The higher early strengths up to 28 days obtained with the Type III cements probably can be attributed to their fineness and  $C_3S$  contents. Being finer ground than Type I cement, Type III cement has a considerably larger surface area which serves to accelerate the hydration process and give a better distribution of gel. Furthermore  $C_3S$ , abundant in Type III cements, is the component of portland cement which contributes most to early strength (16). As expected, shown by the curves in Figure 3, the rate of strength gain of cement-treated soil generally increases with an increase in amount of Type III cement, and strengths are higher than with equal amounts of Type I.

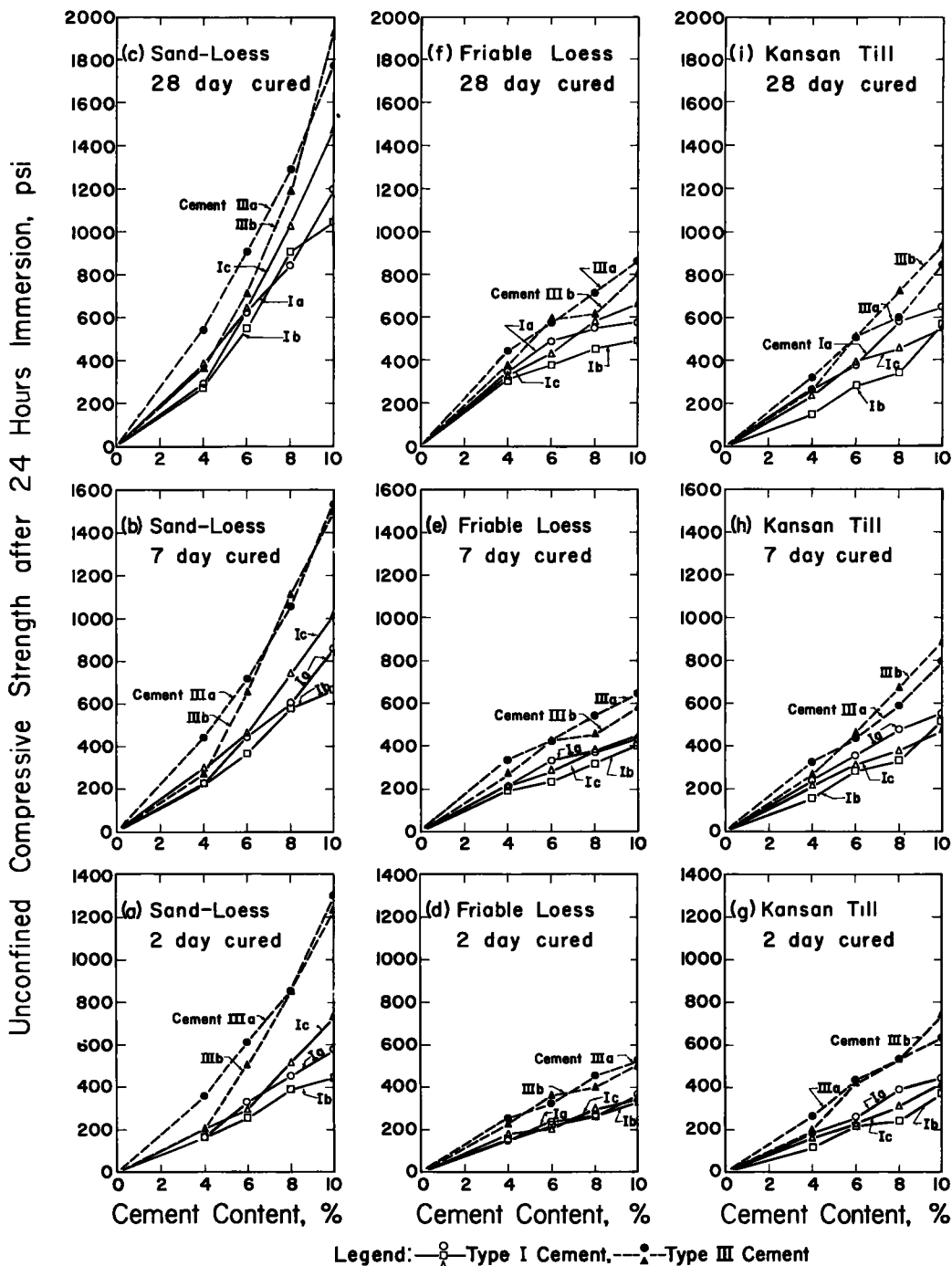
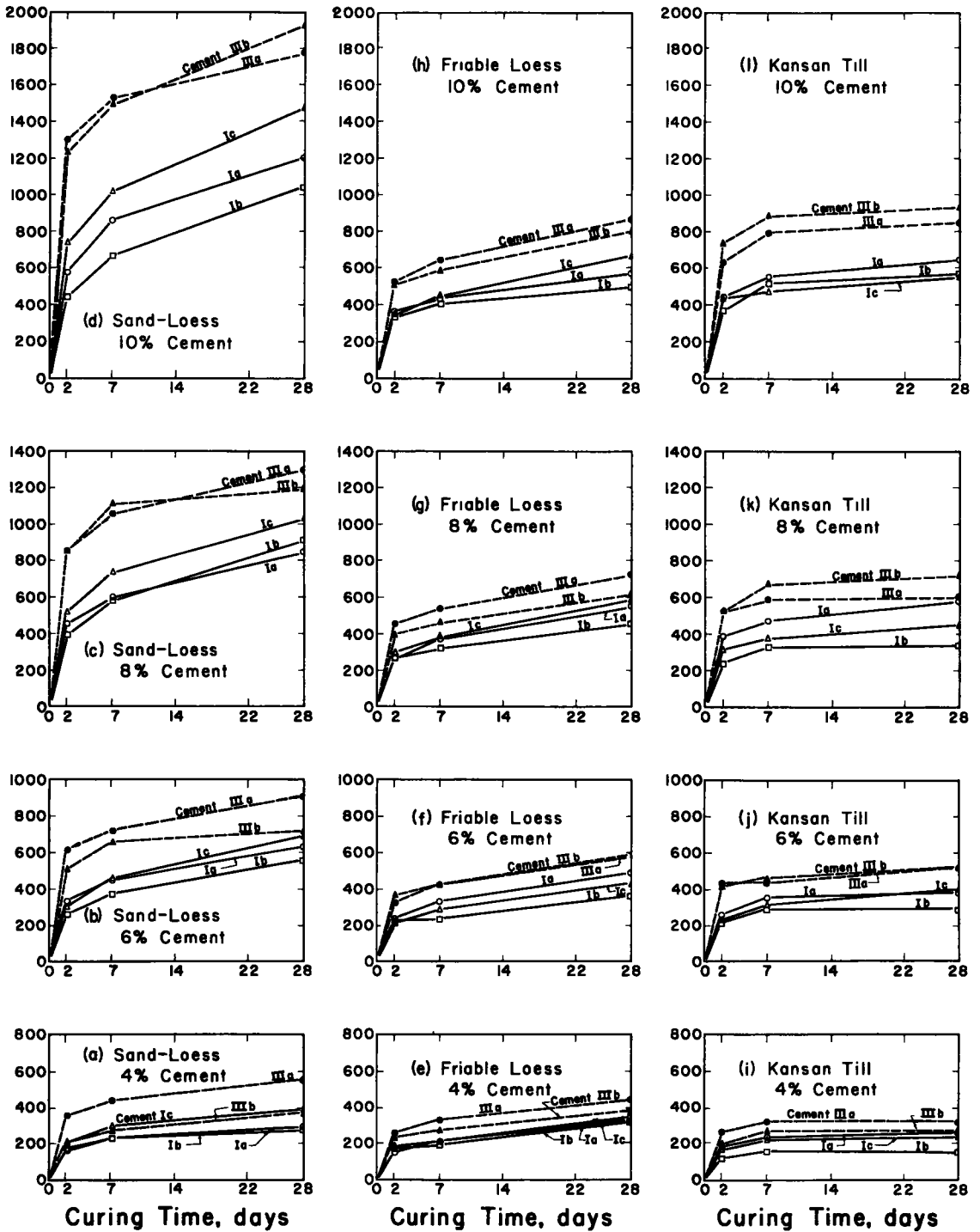


Figure 3. Immersed strength versus cement content, for each soil, cement type and curing period studied. Cement contents are percentages of the oven-dry weight of the soils.

Strength gain from  $C_3S$  begins to diminish after curing periods of 28 days, and  $C_2S$  becomes chiefly responsible for strength gain thereafter (16). Type I cement contains considerably more  $C_2S$  than Type III cement, and it seems probable that Type I strength curves would intercept Type III curves at some curing time beyond 28 days (Figure 4).



Unconfined Compressive Strength after 24 Hours Immersion, psi



Legend: —○— Type I Cement, - -△- - Type III Cement

Figure 4. Immersed strength versus curing time, for each soil, cement type and cement content studied. Cement contents are percentages of the oven-dry weight of the soils.

Among the three Type I cements, cement Ic produced highest strengths, this being particularly evident at 10 percent cement content after 28 days curing. Properties of the cement (Table 2) suggest the comparatively high alkali content may be the reason for the better performance, since the  $C_3S$  content was lower than and the cement fineness about the same as in cement Ia. Cement Ia, the low alkali cement, generally rated second best, but the medium alkali content Ib was coarser and contained less  $C_3S$  than cement Ia, which probably subtracted from the benefits derived from alkali reactions. The mineralogical properties of the sand-loess (Table 1) are considered conducive to benefits from alkali reactions, in that this soil contains a relatively large amount of quartz, and clay coatings on grain surfaces are comparatively light. Studies of the use of alkali additives to improve cement-treated soil have shown that greatest benefits to strength are obtained with soils having a relatively large proportion of uncoated quartz surfaces (8, 9, 11).

At the lower cement contents cement IIIa, the finest ground Type III cement, gave much higher strengths than cement IIIb, despite the fact that cement IIIb had slightly higher alkali and  $C_3S$  contents. However, its slightly higher alkali and  $C_3S$  contents may explain why the performance of cement IIIb improved as cement content increased. At 8 percent cement the two Type III cements gave similar strengths after 2 and 7 days curing. At 10 percent cement, cement IIIb gave higher strengths than cement IIIa, the difference being greatest (about 200 psi) after 28 days curing.

If an immersed strength of about 300 psi after 7 days curing is taken as indicative of satisfactory quality soil-cement prepared from the sand-loess (23), selection of cement contents that give this strength by interpolating from the curves of the best Type I and Type III cements in Figure 3b indicates that about 3 percent cement IIIa is equivalent to 4 percent cement Ic, making possible a 22 percent reduction in the cost of portland cement. If construction requirements necessitated an immersed strength of 300 psi after only 2 days curing (Figure 3a), about 3 percent cement IIIa is equivalent to about 6 percent cement Ic, cost-wise a 44 percent saving.

**Friable Loess.**—In mixtures with the friable loess, the Type III cements gave the highest immersed strengths after all curing periods (Figs. 3d, e, f and 4e, f, g, h). The occurrence previously noted with the sand-loess, greater strength differences between the Type III and Type I cements with increasing cement content, is evident although not as marked. In general the strengths obtained were considerably below those obtained with the sand-loess. This probably is largely due to the greater surface area of the friable loess. An increased soil surface area without a proportional increase of cement may result in a less perfect distribution and functioning of cement gel on grain surfaces, and consequently lower strengths.

Comparisons of strengths obtained with cements Ia and Ic, low and high alkali cements, respectively, show little evidence of alkali reactions benefiting strength. Generally these two cements gave similar strengths. Cement Ib gave the lowest strengths, except after 2 days curing, when all three Type I cements produced about the same strengths. The only indication of beneficial alkali reactions is that cement Ic gave appreciably higher strength than cement Ia at 10 percent cement content after 28 days curing. This suggests that due to a smaller amount of uncoated quartz surface (Table 1) the alkali reactions did not occur as readily as in sand-loess and that for the alkali reactions to have an appreciable effect required a relatively high concentration of alkalis and a fairly long curing period.

As with sand-loess, cement IIIa usually gave higher strengths than cement IIIb, presumably because fineness was the major cement property variable (Table 2) affecting strength.

Assuming that an immersed strength of 275 psi after 7 days curing is indicative of satisfactory quality soil-cement prepared from the friable loess, (tentative minimum value based on limited correlation tests by the Soil-Cement Bureau, PCA). Figure 3e shows that 3 percent cement IIIa could be used instead of 5 percent cement Ia with a 35 percent saving in the cost of cement. A similar comparison after 2 days curing (Figure 3d) indicates that for an immersed strength of 275 psi, 4 percent cement IIIa is about equivalent to 8 percent cement Ic, and 44 percent cheaper.

**Kansan Till.**—Kansan-age glacial till contains approximately equal amounts of sand,

silt, and clay sized particles (Table 1); hence it has a better gradation than friable loess which is approximately 80 percent silt and 20 percent clay. This may account for the higher immersed strengths obtained with some of the cement-treated Kansan till mixtures. The Type III cements again gave higher strengths than the Type I cements, the difference being greatest at the higher cement contents (Figs. 3g, h, i, and 4i, j, k, l).

Strengths obtained with the Type I cements do not correlate with the alkali contents of the cements, indicating no significant benefits to strength from alkali reactions. This seems reasonable in that quartz surfaces in Kansan till were heavily coated with clay particles. Cement Ia generally gave the highest strengths, possibly due to its relatively high  $C_3S$  and free CaO contents. The presence of an appreciable amount of free CaO in portland cement may improve the gel production process or provide additional cementation compounds by reacting with soil grain surfaces. The occurrence of the latter might also improve the chemical bonding of cement gel to grain surfaces. Previous work with Kansan till in soil-lime mixtures indicates that it contains minerals which are exceptionally reactive with  $Ca(OH)_2$  (17).

Cement IIIa gave higher strengths than cement IIIb when the cement content was 4 percent. At 6 percent cement the two Type III cements gave similar strengths; at higher cement contents, cement IIIb generally gave highest strengths. Cement IIIb had slightly higher free CaO, alkali and  $C_3S$  contents than cement IIIa, and the cumulative beneficial effects from the extra amounts of these components may account for the improved performance of cement IIIb at the higher cement contents.

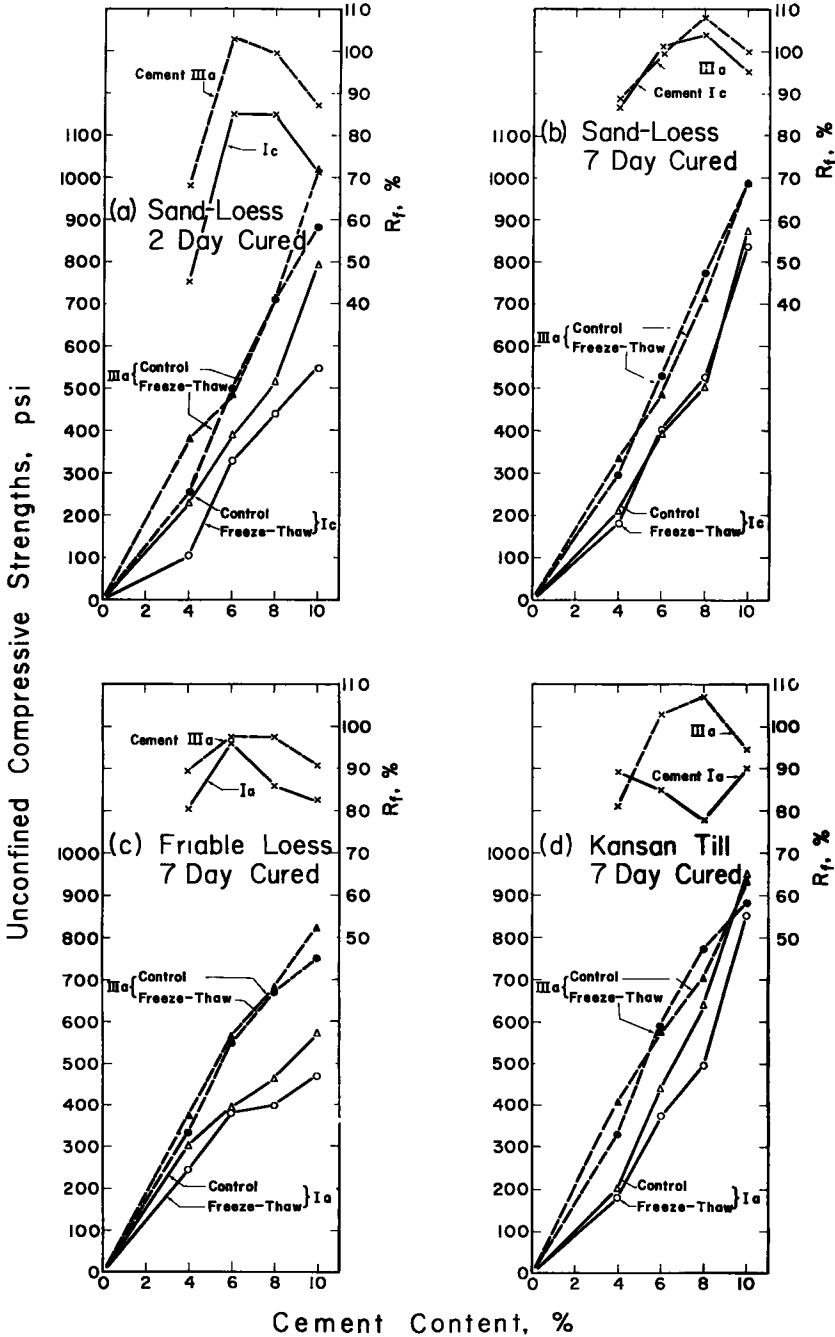
An immersed strength of 250 psi after 7 days curing may be indicative of satisfactory soil-cement prepared from the Kansan till (tentative minimum value based on limited correlation tests by the Soil-Cement Bureau, PCA). Use of this value and the curves in Figure 3h shows that 3 percent cement IIIa is equivalent to 4 percent cement Ia. The use of cement IIIa would reduce the cement cost by about 22 percent. Using the same strength criterion with the curves for 2 days curing (Fig. 3g) shows that either 4 percent cement IIIa or 6 percent Ia would produce satisfactory soil-cement. The use of the Type III cement would reduce the cement cost about 25 percent.

**Conclusion.**—The immersed strength test results for the cement-treated sandy, silty and clayey soils indicate the possibility of significant economic and/or structural advantages from using Type III high-early-strength portland cement instead of Type I normal portland cement for either normal or emergency soil-cement construction. A high alkali content in portland cement appears to be beneficial to the strength of cement-treated soil only when the soil has a relatively high proportion of quartz surface that is uncoated with clay minerals.

### Freeze-Thaw Resistance

The modified British test (Appendix) was used to determine whether the soils stabilized with Type III portland cement were as resistant to freeze-thaw deterioration as when stabilized with Type I portland cement. The Type I and Type III cements used with each soil were the ones that generally had given the best results in the study of unconfined compressive strengths after curing and 24 hr immersion. The results of the freeze-thaw study are graphed in Figure 5 to show the effect of increasing cement content (percent oven-dry weight of soil) on the unconfined compressive strengths of the control (cured + 15 days immersed) specimens and the freeze-thaw (cured + 1 day immersed + 14 cycles of freezing and thawing) specimens. Also shown is the effect of cement content on the index of the resistance to the effect of freezing ( $R_f$ ), the ratio of the freeze-thaw specimen strength ( $p_f$ ) to the control specimen strength ( $p_c$ ), expressed as a percentage.

**General Comparison of Type I and Type III Cements.**—Almost without exception mixtures with the Type III cement had much higher control and freeze-thaw specimen strengths than similarly proportioned mixtures with Type I cement. The strength differences were sometimes as much as 300 psi, clearly indicating the superior durability of the 2-day and 7-day cured specimens containing the Type III cement. The reason is probably the greater surface area of Type III cement as compared to Type I cement.



Legend ————Type I Cement,-----Type III Cement

Figure 5. Modified British freeze-thaw test results for selected Type I and Type III cement-treated soil mixtures, showing the effect of cement content on the unconfined compressive strengths of the control and freeze-thaw specimens, and on the index of the resistance to the effect of freezing ( $R_f$ ). Cement contents are percentages of the oven-dry weight of the soils.

## ACKNOWLEDGMENT

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## REFERENCES

1. "Definition of Terms Relating to Soil-Portland Cement Stabilization." Highway Research Abstracts, 29:28-29 (June 1959).
2. ASTM, "1958 Book of ASTM Standards, Part 4." Philadelphia, Pa. (1958).
3. Clare, K. E., and Pollard, A. E., "Relationship Between Compressive Strength and Age for Soils Stabilized with Four Types of Cement." Magazine of Concrete Research, 8:48 (Dec. 1951).
4. Clare, K. E., and Farrar, D. M., "The Use of Cements of Different Fineness in Soil-Cement Mixtures." Magazine of Concrete Research, 8:24, 137-144 (Nov. 1956).
5. Felt, E. J., "Factors Influencing Physical Properties of Soil-Cement Mixtures." HRB Bul. 108, pp. 138-162 (1955).
6. Leyder, J. P., "Stabilization du Sol au Ciment." Rapport de Recherche, pp. 1-164, Centre de Recherches Routieres, Brussels (Jan. 15, 1957).
7. Handy, R. L., "Stabilization of Iowa Loess with Portland Cement." Unpublished Ph.D. thesis, Iowa State Univ. Library, Ames (1956).
8. Handy, R. L., "Cementation of Soil Minerals with Portland Cement or Alkalis." HRB Bul. 198, pp. 55-64 (1958).
9. Tawes, R. H., "Improvement of Soil-Cement with Chemical Additives." Unpublished M.S. thesis, Iowa State Univ. Library, Ames (1959).
10. Lambe, T. W., and Moh, Z. C., "Improvement of Strength of Soil-Cement with Additives." HRB Bul. 183, pp. 38-47 (1957).
11. Lambe, T. W., Michaels, A. S., and Moh, Z. C., "Improvement of Soil-Cement with Alkali Metal Compounds." HRB Bul. 241, pp. 67-108 (1960).
12. Spangler, M. G., "Soil Engineering." Scranton, Pa., International Textbook Company (1951).
13. AASHTO, "Standard Specifications for Highway Materials and Methods of Sampling and Testing, Part I Specifications." Washington, D. C. (1950).
14. Portland Cement Association, "Soil-Cement Laboratory Handbook." Chicago (1959).
15. British Standards Institution, "1958 Yearbook." London (1958).
16. Blanks, R. F., and Kennedy, H. L., "The Technology of Cement and Concrete, Volume I Concrete Materials." John Wiley and Sons, Inc., New York, N. Y. (1955).
17. Davidson, D. T., Noguera, G., and Sheeler, J. B., "Powder Versus Slurry Application of Lime for Soil Stabilization." ASTM Proc. (1959).
18. Bruns, B. W., "Comparison of Type I and Type III Portland Cements in Soil-Cement Mixtures." Unpublished M.S. thesis, Iowa State Univ. Library, Ames (1959).
19. Hicks, L. D., "Design and Construction of Base Courses." HRB Bul. 129, pp. 1-9 (1956).
20. Portland Cement Association, "Concrete Paving Design." Chicago (1951).
21. Aldrich, H. P., Jr., "Frost Penetration Below Highway and Airfield Pavements." HRB Bul. 135, p. 131 (1956).

22. Davidson, D. T., Katti, R. K., and Handy, R. L., "Field Trials of Soil-Lime-Flyash Paving at the Detroit Edison Company, St. Clair Power Plant, St. Clair, Michigan." Detroit (1958).
23. Norling, L. T., and Packard, R. G., "Expanded Short-Cut Test Method for Determining Cement Factors for Sandy Soils." HRB Bul. 198, pp. 20-31 (1958).

## *Appendix*

### MODIFIED BRITISH (B.S. 1924:1957) FREEZE-THAW TEST

#### Scope

1. This method covers the determination of the change in the unconfined compressive strength of 2-in. high by 2-in. diameter specimens of stabilized fine-grained soil when subjected to cycles of freezing and thawing under specified conditions. The test specimens are prepared as described under Methods of Preparing and Testing Specimens in this paper or as described in the Portland Cement Association's Soil-Cement Laboratory Handbook (14, p. 32).

#### Apparatus

2. The apparatus required (Fig. 6) is as follows:

a. A commercial vacuum flask having a neck with an internal diameter of approximately  $2\frac{1}{2}$  in. and an internal depth of at least 4 in.

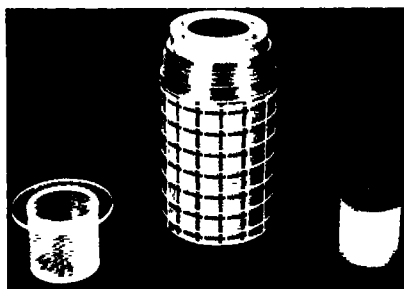
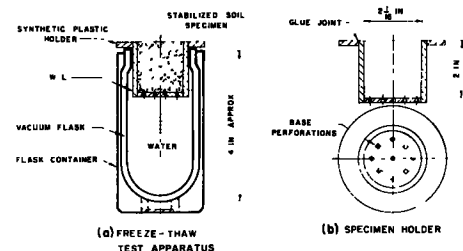
b. A specimen holder of low thermal conductivity and resistant to deformation under the test conditions, and capable of supporting a stabilized soil specimen 2 in. high and 2 in. in diameter within the vacuum flask, so that the upper flat surface of the specimen is flush with the top of the flask (Fig. 6). The base of the carrier shall be perforated to permit free access of water to the underside of the specimen.

c. A refrigerated space within which is maintained a temperature of  $-5 \pm 1$  C ( $23 \pm 2$  F), and which is large enough to contain the vacuum flask with its enclosed specimen. A thermometer mounted inside the refrigerated space.

d. A supply of asphalt or resin-base paint.

e. A supply of self-adhering membrane (the commercial product "Saran Wrap" was found very satisfactory).

f. About 100 ml of distilled water, cooled to  $8 \pm 2$  C ( $46 \pm 4$  F).



(c) VACUUM FLASK WITH MOUNTED SPECIMEN, SPECIMEN HOLDER, AND STABILIZED SOIL SPECIMEN

Figure 6. Apparatus used in the modified British freeze-thaw test.

#### Preparation of Specimens for Test

3. For each determination two identical specimens  $2 \pm 0.05$  in. high and 2 in. in diameter shall be prepared. (If greater accuracy is desired four or six identical specimens may be prepared for each determination.)

#### Test Procedure

4. a. After the desired curing period any covering material on the specimens

shall be removed and both specimens shall be weighed. The method and length of curing will depend on the method of stabilization. If either specimen has lost more than 2 g in weight during storage in a moist room maintained at a temperature of  $21 \pm 1.7 \text{ C}$  ( $70 \pm 3 \text{ F}$ ) and a relative humidity of at least 90 percent, both specimens shall be discarded. If dry curing is used to reduce the volatile content of specimens to a desired percentage of the original volatile content, the difference in weight between the specimens should not exceed 1 g.

b. After weighing, a coating of asphalt or resin-base paint, about 1 mm thick, shall be applied to the flat top surfaces of both specimens and allowed to dry. The specimens shall then be immersed in distilled water at  $25 \pm 2 \text{ C}$  ( $77 \pm 4 \text{ F}$ ).

c. After immersion for 24 hr one of the specimens shall be removed from the water and dried with blotting paper. A collar,  $1\frac{1}{2}$  in. deep, of a self-adhering membrane ("Saran Wrap") shall be placed around the top of the specimen.

d. Sufficient water at a temperature of  $8 \text{ C}$  ( $46 \text{ F}$ ) shall be poured into the vacuum flask so that when the specimen dealt with in (c) is inserted in the holder and the latter placed in the flask, the bottom  $\frac{1}{4}$  in. of the specimen is immersed in water. The vacuum flask and its contents shall then be placed in the refrigerated space maintained at  $-5 \pm 1 \text{ C}$  ( $23 \pm 2 \text{ F}$ ) for a period of 16 hr.

e. The flask and contents shall be removed and thawed for a period of 8 hr at a temperature of  $25 \pm 2 \text{ C}$  ( $77 \pm 4 \text{ F}$ ). If, after thawing, the level of the water inside the vacuum flask has dropped so that it is no longer in contact with the base of the specimen, water at  $8 \text{ C}$  ( $46 \text{ F}$ ) shall be added to restore the level.

f. The procedure described in (d) and (e) constitutes one cycle of freezing and thawing. Testing shall continue until the specimen has been subjected to 14 such cycles: the 8-hr thawing period may be extended to 66 hr for a maximum of 4 cycles of the total 14 cycles if this is required for experimental convenience. (The number of cycles of freezing and thawing in the test should approximate the number of cycles that the stabilized soil will be subjected to in the road each winter. Thus 14 cycles may not be appropriate in all climates or for all components (base, subbase, subgrade) of roads.)

g. At the conclusion of the freezing and thawing cycles the thawed specimen shall be removed from the holder and, together with the second (control) specimen which has been stored in water during the entire period (15 days), shall be allowed to drain for 15 min. The heights of both specimens shall be measured.

h. The unconfined compressive strengths of the two specimens shall then be determined. Each specimen shall be placed centrally on the lower platen of the compression testing machine, and the load shall be applied to the ends of the specimen. The load shall be applied so that the rate of deformation is uniform and approximately 0.10 in./min. The maximum load in pounds exerted by the testing machine shall be noted and recorded ( $p_f$  for the freeze-thaw specimen and  $p_c$  for the control specimen).

i. The moisture contents of representative samples of fragments taken from the interiors of the specimens shall be determined. In the case of soil stabilized with a fluid stabilizer, an additional representative sample of the fragments shall be set aside and their non-aqueous fluid stabilizer content(s) determined.

### Calculations

5. a. The unconfined compressive strengths ( $p_f$  and  $p_c$ ) of the two specimens shall be calculated from the formula:

$$p = 0.318 P \text{ (psi)}$$

in which

$P$  = the maximum load recorded in pounds.

b. The index of the resistance to the effect of freezing ( $R_f$ ) shall be calculated from the formula:

$$R_f = \frac{100p_f}{p_c} \text{ (\%)}$$

## Reporting of Results

6. a. The values of  $p_c$ ,  $p_f$ , and  $R_f$  shall be reported, the latter to the nearest 5 percent. The report shall also include relevant details of the composition of the stabilized soil mixture, the dry density at time of molding, and the moisture content and linear dimensional changes of specimens.

## *Discussion*

D. J. MACLEAN, Head of Soils Section, Road Research Laboratory, Harmondsworth, Middlesex, England. — The stabilization of soils with portland cement is today accepted in many parts of the world as one of the principal methods of road base construction. Its advantages are the low cost of construction and the ability almost invariably to make use of local materials especially where there is a lack of hard rock, the traditional road-building material. These advantages are obtained however, only at the price of closer scientific control in designing the composition of the material and in constructing the stabilized base. This paper is therefore particularly welcome as a valuable contribution to the development of sound laboratory techniques for evaluating the strength and durability of soil-cement as a road base material.

The approach adopted by the authors is the one favored in the United Kingdom; that is, the stabilized material is required to have a compressive strength exceeding a specified minimum value and to be subject to a loss in compressive strength, when subjected either to immersion in water or to alternate freezing and thawing, that does not exceed some specified maximum percentage of the compressive strength when cured at constant moisture content. It is believed that this approach has a number of advantages including the ability to select more reliably the appropriate design cement and moisture contents and the possibility of allowing for different traffic and climatic conditions.

In the United Kingdom a minimum compressive strength of 250 psi at 7 days has been used successfully to design soil-cement for bases of lightly-trafficked roads, but for heavily-trafficked roads, the results obtained from the performance of special experimental road sections indicate that a material with a minimum strength of the order of 400 psi at 7 days is probably required.

The indications from the present work that high-early-strength portland cement has economic and structural advantages over ordinary portland cement are in agreement with the findings of laboratory studies made by Clare, Pollard and Farrar at the Road Research Laboratory to which the authors refer in their paper, but road experiments are required to confirm whether there is a corresponding difference in the long-term performances of materials made with the two types of cement.

A result of particular interest in the present paper is that with cement-treated Kansan till the optimum moisture content for maximum immersed strength was  $1\frac{1}{2}$  percent higher than the optimum moisture content for maximum dry density. This suggests that where a cement-stabilized clay soil base is used in circumstances where it is likely to be affected by water after construction, there are advantages to be gained by compacting the material at the higher of the two optima.



# Development of a Test for Identifying Poorly Reacting Sandy Soils Encountered in Soil-Cement Construction

E. G. ROBBINS and P. E. MUELLER, respectively, Acting Manager; and Soils Engineer, Soil-Cement Bureau, Portland Cement Association, Chicago

In soil-cement construction, certain types of sandy soils are encountered that cannot be treated successfully with normal amounts of portland cement. While the use of additive soils, calcium chloride, and other chemicals, effectively neutralize this adverse reaction, it is impossible to detect the presence of this type of sandy soil until certain standard laboratory tests, which require approximately one week for completion, have been performed. The test method presented in this report provides a method of detecting this reaction in approximately one hour.

● SINCE THE ADVENT of soil-cement in the United States some 25 years ago, there have been encountered in some areas of the country certain sandy soils that require relatively high cement contents for successful treatment. Early research work by the Portland Cement Association (1) and others, resulted in the development of effective countermeasures that can be used when confronted with this type of material. These measures include the use of calcium chloride as an admixture, dilution with a normal acting soil, and under certain conditions, the use of salt water. Recent research has shown the addition of certain sodium compounds is very effective (2).

While this early work successfully gave a remedy to the situation, little was known of the chemical or physical cause of this poor reaction between the soil and cement. Until such research could be performed, little could be done to solve the rather vexing problem of identifying such soils during sampling operations in the field, or in the laboratory prior to running standardized soil-cement tests. This meant that in many cases valuable time was lost in testing a soil that could not be used for construction due to a high cement requirement. If it were possible to detect the poor reaction on the day sampling is performed, the use of borrow materials or other measures could be immediately decided on.

## INITIAL TRIALS AND CORRELATIONS

The acidity or alkalinity of a soil was long thought to have a bearing on the manner in which it reacted with cement. Early research (3) showed that organic matter of an acidic nature had an adverse effect on the soil-cement system, but this work was confined to fine-grained soil materials. Little data were available on the effects of organic content and acidity on sandy soils, and this became the first phase of the investigation.

Samples of 27 different sand soils from Florida and Michigan (two areas where poorly-reacting sands occur) were studied. Values of pH for each soil were determined using a Model G-Beckman pH meter, and organic contents were measured colorimetrically (4). Unconfined compressive strength was chosen as the "yardstick" by which cement reaction could most readily be measured, and 7-day strengths were obtained for each soil at the cement content indicated by the short-cut test procedure for sandy soils (5).

Correlations were then made using these three factors (pH, organic content and 7-day compressive strength) but a definite relationship was not obtained (Figs. 1 and 2). The results of the correlation showed a trend of decreasing strengths with increasing organic contents, although some very low strengths were obtained on soils having organic contents as low as 2,000 parts per million (ppm).

From this work it was indicated that neither the pH nor the organic content is a direct measure of the cement reaction, in a soil-cement system using poorly-reacting soils (6). However, the following general conclusions can be drawn from the data:

1. Unsatisfactory strengths were obtained on all sandy soils having organic contents greater than 20,000 ppm. It is noted however, that equally poor strengths were found in some soils having values as low as 2,000 ppm.

2. Unsatisfactory strengths were obtained on all soils having pH values lower than 5.3, although higher values did not necessarily correspond to higher compressive strengths.

### CONTRIBUTING RESEARCH

After analyzing these first unsuccessful correlations, it was apparent that efforts

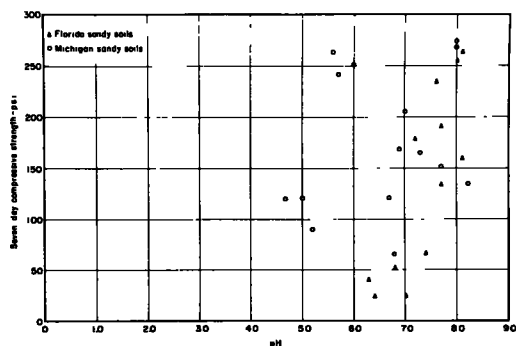


Figure 1. Effect of soil pH on the unconfined compressive strength of soil-cement mixtures.

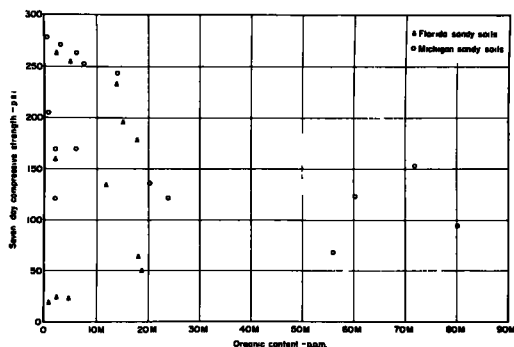


Figure 2. Effect of organic content of sandy soils on the unconfined compressive strength of soil-cement mixtures.

must be focused on the chemical process that was actually taking place when the cement came in contact with a poorly-reacting sand. A search for any published work on this subject drew attention to the extensive, and valuable, research conducted by the staff of D.J. Maclean of the Soil Section, Road Research Laboratory, Great Britain (7). The main finding of this work was that the compounds of a soil's organic matter that were most active in retarding the normal reaction of cement were of the hydroxy-quinone type; a type known to bind metal ions such as those of calcium, and in all probability a major cause in the activity of the soil toward cement. A test to measure this ability of the soil, to immobilize or absorb calcium, was therefore sought.

### DEVELOPMENT OF A TEST TO MEASURE CALCIUM ABSORBED BY A SOIL

In order that the absorption of calcium by a soil might be measured, calcium ions must be placed in contact with the soil grains. A standard saturated and carbonate-free solution of calcium hydroxide was selected as the agent for this.

When such a standard solution of calcium hydroxide is mixed with a predetermined amount of soil, the amount of calcium actually absorbed by the soil can be readily determined by titrating the calcium remaining in solution. This amount of calcium,

when compared with that available in the standard solution, provides a direct measure of the activity (or calcium absorbing ability) of the organic matter in the soil.

Titration were performed using the di-sodium salt of (ethylenedinitrilo) tetraacetate dihydrate, commonly referred to as EDTA (8). Due to the presence of magnesium in most soils, an indicator was selected that allowed the titration of calcium in the presence of magnesium. Fisher Scientific's Calcien and HHSNN were investigated, and the latter chosen for its clear and unmistakable color-change (9).

Using these ingredients and standard titration procedures, the following test method was formulated:

### CALCIUM ABSORPTION TEST METHOD

#### Reagents Used

**EDTA Solution:** Dissolve 3.72 grams of analytical reagent grade di-sodium (ethylenedinitrilo) tetraacetate dihydrate in distilled water and dilute to one (1) liter (0.01 M solution).

**Calcium Indicator:** Triturate 0.5 gram of 2-hydroxy-1-(2-hydroxy)-4-sulfo-1-naphthyl(azo)-3-naphthoic acid (referred to as HHSNN), and 50 grams of reagent grade sodium sulfate until the dye is thoroughly and evenly distributed.

**Calcium Hydroxide:** Dissolve 0.7408 grams of reagent grade calcium hydroxide in carbonate-free water and dilute to one (1) liter. Mix occasionally and allow to stand 24 hr.

**Potassium Hydroxide, 8 Normal:** Dissolve 448.8 grams reagent grade potassium hydroxide in distilled water and dilute to one (1) liter.

#### Procedure

Prepare soil on a No. 4 sieve and place 100 grams of dry Minus No. 4 material in a beaker. Add 150 ml of the standard calcium hydroxide solution. Allow to stand for 15 min with occasional swirling. Filter the resulting solution through Whatman No. 31 paper inside a Whatman No. 30 paper. Pipet 15.0 ml of the filtrate into a 125 ml Erlenmeyer flask and dilute with 30 ml of distilled water. Add 4ml of 8N potassium hydroxide to raise the pH of the solution to the required range of 12-14 (9), and allow to stand for 3 min with occasional swirling. Add 0.1 gram calcium indicator powder and titrate with the standard EDTA, the end point being attained when the wine color from the indicator turns to a vivid steel-like blue.

On rare occasion, a soil may be encountered that will cause the operator great difficulty in finding a clear end-point in the titration. This interference is usually caused by the presence of certain metals such as copper, iron, nickel, cobalt, and zinc. The addition of 30 mg each of potassium cyanide and hydroxylamine hydrochloride prior to the introduction of the calcium indicator powder will eliminate this interference.

Knowing that the standard solution of calcium hydroxide requires a certain amount of EDTA to satisfy the amount of calcium in it, the difference between this EDTA requirement and the amount needed to satisfy the soil- $\text{Ca}(\text{OH})_2$  aliquot, becomes a direct measure of the amount of calcium taken up by the soil. This is referred to as the calcium absorption factor.

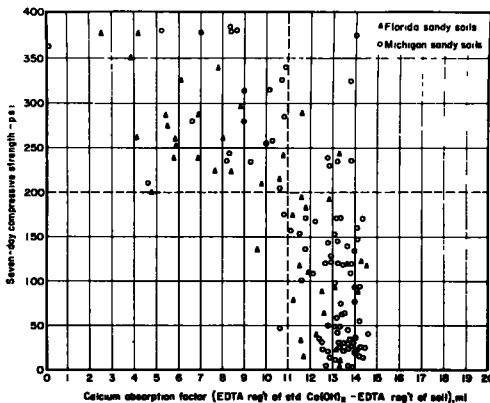


Figure 3. Unconfined compressive strengths of sandy soils with various calcium absorption factors.

### Application and Accuracy of Calcium Absorption Test Method

To show the application and accuracy of the calcium absorption test method, it was then performed on 68 samples from Florida and Michigan, and the results were correlated with the 7-day unconfined compressive strength of each soil-cement mixture. The results of this correlation were quite promising, and an additional 70 samples, mostly from Michigan, were procured to further expand the correlation. A plot of the total 138 tests (Fig. 3) showed that in almost every case those soils with low absorption factors had 7-day compressive strengths in excess of 200 psi. Conversely, the majority of the high absorption factors were associated with strengths less than 200 psi. This value was therefore selected as a criterion to distinguish between the normally acting and poorly-reacting sandy soils, and is in agreement with the experience of the Portland Cement Association's Soil-Cement Laboratory in testing these types of soils over the past 25 years.

A line was then drawn at a calcium absorption factor of 11 ml (the difference between the EDTA requirement of the standard  $\text{Ca}(\text{OH})_2$  solution and the EDTA requirement of the soil- $\text{Ca}(\text{OH})_2$  aliquot) and chosen as a dividing line; thus, those soils having calcium absorption factors less than 11 ml may be considered normal; those with factors greater than 11 ml, as poorly reacting.

By setting one value as the dividing line, the test is in no way quantitative; that is, it cannot predict just how "bad" a soil will react or how much additional cement will be needed to attain the hardness and durability required to pass the ASTM tests for soil-cement. Rather, in following this procedure, it is possible to determine, in advance of any routine soil-cement testing, only whether or not a soil will react normally with cement. If a soil is noted to be normal acting, tests must then be performed in order to establish a proper cement content for construction.

During the testing of these sandy soils it was noted that a few soils containing more than 15 percent silt and clay gave erroneous results. This was probably due to the much greater amount of surface area available for absorbing calcium. A maximum of 15 percent silt and clay was therefore set for soils to be tested by this procedure. This limitation will not detract from the usefulness of the test, however, for a great majority of the soils involved are always lacking in silt and clay material.

The accuracy of the test method was determined by plotting the calcium absorption values for the 138 soils against their 7-day compressive strength (Fig. 3) and determining the location of the points in regard to the 200 psi line and the 11.0 ml calcium absorption line.

The lower right-hand quadrant represents the area where the poorly-reacting soils should fall; normally-reacting soils should fall in the upper left-hand quadrant. Out of 138 soils tested, 127 or 92 percent of the samples fell in these quadrants and were thus successfully predicted as being either normally or poorly reacting. Of the remaining eight percent or eleven soils, three were predicted to be normal, inasmuch as they had low calcium absorption values, when actually they were poorly reacting because their strengths were below 200 psi. The poor reaction of these soils would be detected on testing using normal ASTM standard procedures for soil-cement. The other eight soils were predicted to be poorly reacting because they had high calcium absorption values; however, they were normally reacting because their strengths were more than 200 psi. These eight soils would have been eliminated without further testing consideration, but the elimination of these few soils is thought to be sufficiently small to make the test and results acceptable.

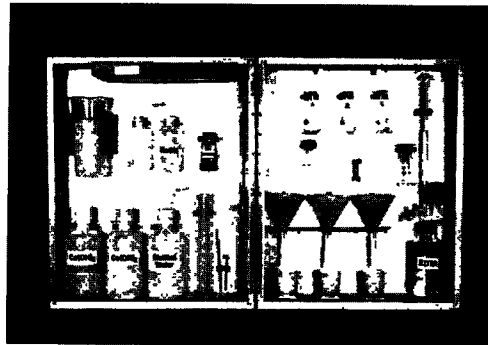


Figure 4. Equipment for calcium absorption test.

## CONCLUSIONS

1. Organic content and pH do not in themselves constitute an indication of a poorly-reacting sand. However, a sandy soil with an organic content greater than 20,000 ppm (2 percent) or having a pH lower than 5.3, will in all probability not react normally with cement.

2. The calcium absorption test provides a method of quickly determining, either in the laboratory or in the field, whether or not a sandy soil will react normally with cement in soil-cement construction. Thus, steps may be taken immediately to either (a) improve the reaction of the sandy soil with admixtures, or (b) to find locations of suitable borrow materials. The 92 percent accuracy of the test method is considered acceptable for this work.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Catton, Miles D., and Felt, E. J., "Effect of Soil and Calcium Chloride Admixtures on Soil-Cement Mixtures." HRB Proc. (1943).
2. Lambe, T. W., Michael, A. S., and Moh, Za-Chieh, "Improvement of Soil-Cement with Alkali Metal Compounds." HRB Bul. 241, pp. 67-108 (1960).
3. Winterkorn, H. F., et al., "Surface Chemical Factors of Importance in the Hardening of Soils by Means of Portland Cement." HRB Proc., 22:385 (1942).
4. A modification of ASTM Designation C40-48, "Standard Method of Test for Organic Impurities in Sand for Concrete." based on data contained in "Comparison of Standards for Colorimetric Test for Sand." ASTM Proc., 37th Annual Meeting, Vol. 34, Part I.
5. Norling, L. T., and Packard, R. G., "Expanded Short-Cut Test Procedures for Determining Cement Factors for Sand Soils." HRB Bul. 198, pp. 20-31 (1958).
6. Catton, M. D., "Research on Physical Relations of Soil and Soil-Cement Mixtures." HRB Proc. 20:821-855 (1940).
7. Arkley, V., "An Investigation of Soil Organic Matter on the Setting of Ordinary Portland Cement-Chemical Studies on the Active Fraction." Research Note No. RM/3193/VA, Dept. of Scientific and Industrial Research, Road Research Laboratory, Harmondsworth, Middlesex, England (Feb. 1958).
8. Welcher, F. J., "The Analytical Uses of Ethylenediamine Tetraacetic Acid." D. Van Norstrand Co., Inc., Princeton, N.J. (1957).
9. Patton, J., and Reeder, W., "Indicator for Titration of Calcium with (ethylenedinitrilo) Tetraacetate." Analytical Chemistry, 28:1026-8 (1956).

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The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

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