

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

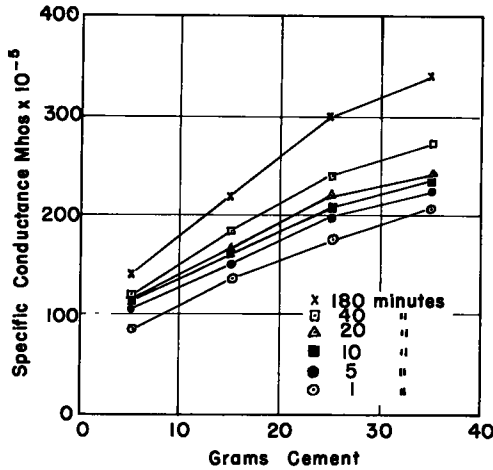


Figure 1. Typical curves showing effects of varying the dilution period.

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.

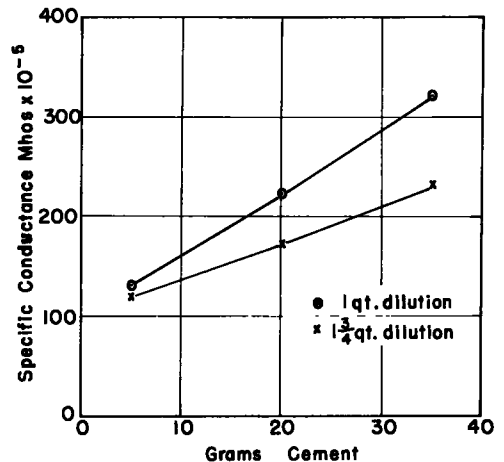


Figure 2. Typical curves showing effect of varying the dilution quantities.

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

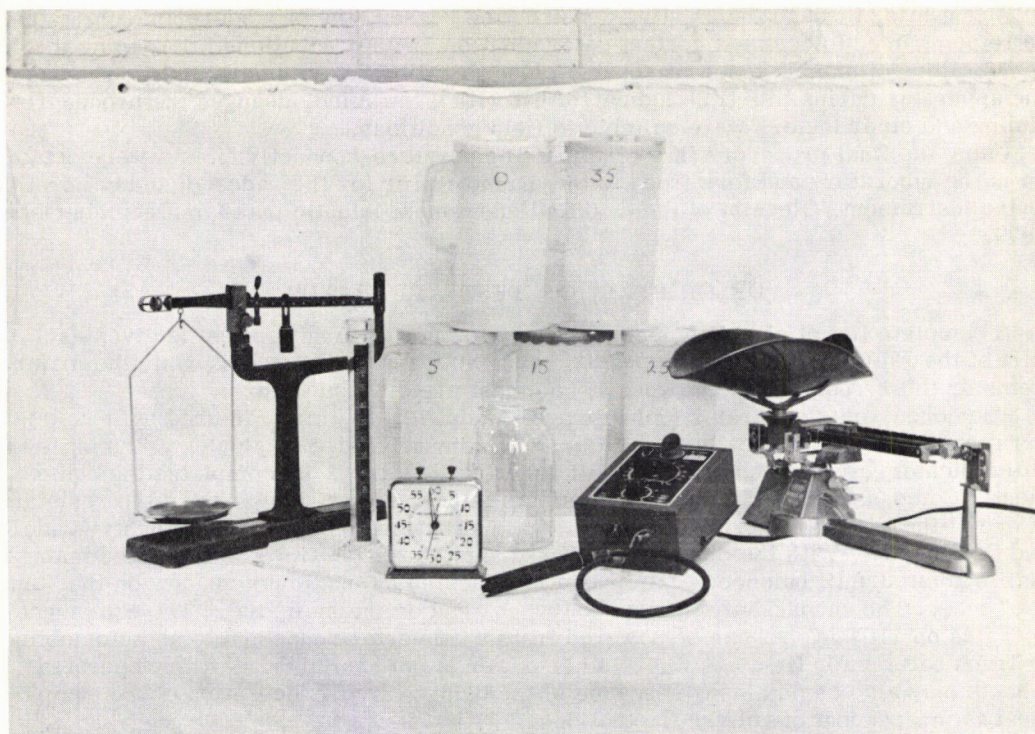


Figure 3. Electrical conductivity test apparatus for CTB.

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 300×10^{-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

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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.

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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 ₂ O to "0" and mix
	1	- - - - - " " " " "5" " "
	2	- - - - - " " " " "15" " "
	3	- - - - - " " " " "25" " "
	4	- - - - - " " " " "35" " "
Tempering	10	- - - - - " 1 qt. H ₂ 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 H₂O 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% H₂O 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.