# VARIATION IN LABORATORY AND FIELD STRENGTHS OF SOIL CEMENT MIXTURES

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This report evaluates the variability in compressive strengths of stabilized in-place soil cement mixtures from the standpoint of design and actual field conditions. The findings are based on 15 projects with soils ranging from high silt to high sand content and 8 to 14 percent cement by volume. The data indicate considerable variation in the laboratory and field-molded specimens. In general, under the present construction techniques of cement application and density and moisture control, the product is within 75 percent of the 28-day design strength (225 psi or 1550 kPa). The data also indicate a need for pug mill mixing of soil and cement to reduce cement content variation.

•THIS report, which is an abridgment of a comprehensive study (1), evaluates the variability in compressive strengths of stabilized in-place soil cement mixtures from the standpoint of design and actual field conditions. The evaluation is based on 15 projects with soils ranging from high silt to high sand content and plasticity indexes of up to 15. The cement content varied from 8 to 14 percent by volume.

## PROCEDURE

For strength evaluation, specimens were prepared and cured both in the laboratory and in the field. The strengths of these specimens were compared to the 7- and 28-day strengths of roadway cores. The variability of the laboratory design was studied in four phases. Each phase was designed to provide data on the variability among and within laboratories.

## TEST RESULTS

Figure 1 shows the mean percentage of all tests that achieved specified compressive strengths in each mode of sampling and curing.

The means for the first bar chart (laboratory-molded and laboratory-cured, 7 day) include compressive strength results of materials in which the cement quantity recommendations were originally based on the wet-dry brush test, as well as those actually based on 300 psi (2070 kPa). The projects in which compressive strength was used for cement recommendations show substantial verification of the materials laboratory design, with only one of these projects having soil types in which less than 300 psi was obtained at the recommended cement percentage.

### Variability of Cement Content of Bases

Cement contents of field-molded specimens and cores were determined on all 15 projects.

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**Figure 1. Mean percentages of specimen compressive strengths.**

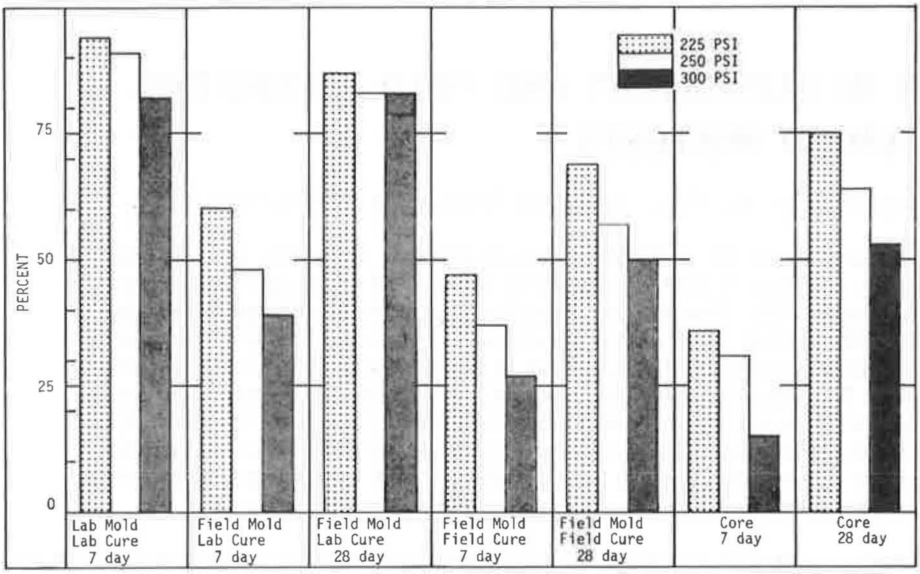
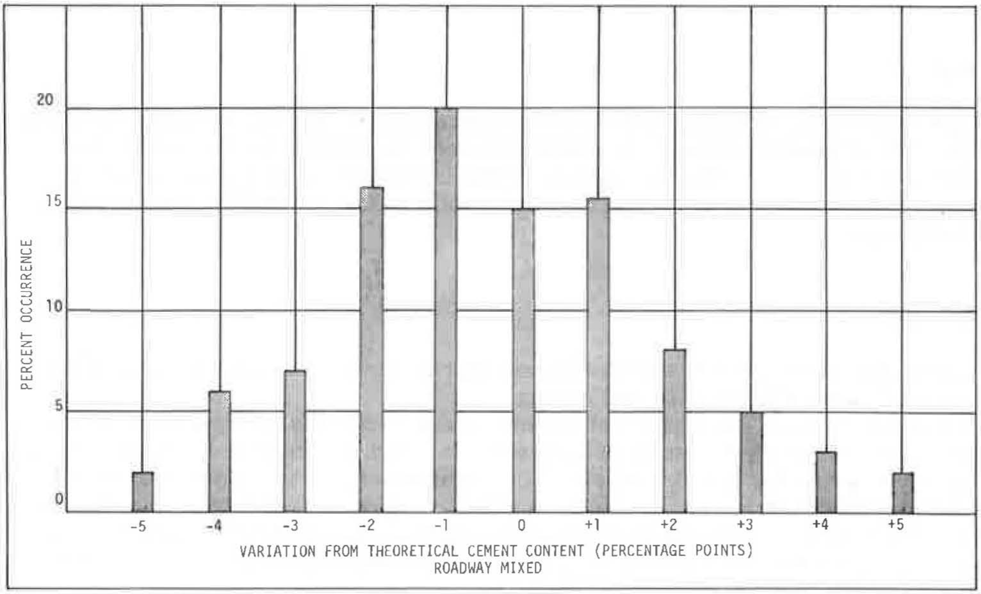



**Figure 2. Frequency of occurrence of actual and theoretical cement contents.**



An attempt was made to correlate the cement content of field specimens with strength; however, a definite trend could not be established because of the variation in specimen density and curing. These test results, however, did show the wide variation of cement within the soil cement bases as a result of in-place mixing. This is shown in Figure 2, which is a composite of all test runs (311 observations) and shows the percentage of observations in which the roadway-mixed cement content varied from the theoretical cement content.

## Variability in Laboratory Design

In the process of obtaining the laboratory data, it was discovered that the laboratory design procedure for soil cement, based on compressive strength, exhibited a greater amount of variability than was previously acknowledged. At first, procedural errors were blamed, but repeated tests under strictly controlled circumstances confirmed the degree of variability. It was found that a difference of 100 psi (6890 kPa) between identical specimens could occur.

To evaluate the variability of the test procedure, interlaboratory tests were conducted. Such test procedures are used to ascertain whether a product meets the specifications set down for the products, or they may be performed for design purposes as was the case here. Regardless of the purpose, the information desired is whether the test procedure as set forth is capable of yielding acceptable agreement among results from different laboratories.

Table 1 gives the statistical parameters for the first phase of the cooperative test. Laboratory designations used in Table 1 are as follows:

| Designation | Laboratory |
| --- | --- |
| 1 | Research |
| 2 | Materials |
| 3 | District 07 |

The variation for each series of soil cement data is expressed by the standard deviation. In the comparison of variability among laboratory-soil cement series data, the relative measure of the dispersion is given in the table as the coefficient of variation, which is the ratio of standard deviation to the mean of a given series. This measure is particularly useful when widely differing means are encountered.

The magnitude of the coefficient of variation for the district laboratories was considerably higher than that indicated by the research or materials laboratories. This was because they were unfamiliar with the test procedure. Furthermore, the magnitude of this variation was considerably higher than would be expected because of chance alone. Therefore, an effort was made to isolate the causes of variation before the second round of cooperative testing commenced.

It was found that the temperature of the three components—soil, cement, and water—varied widely within and among the three laboratories. The soil and the cement were stored, in some instances, in areas where temperatures were not controlled. That is, the temperature of the storage area fluctuated with the season: high in summer and low in winter. This could result in the use of hot cement and soil for some specimens molded in the summer.

Tap water was used in the molding of all specimens. This in itself did not seem to cause any problems; however, the temperature of one laboratory's tap water was close to 100 F (38 C) because its pipes were adjacent to the building's steam lines.

A check of specimens immediately after molding revealed many dry particles. The existing procedure required the full incorporation of water and cement immediately

**Table 1. Statistical evaluation of laboratory data before standardization.**

| Soil | Cement Content (percent) | Mean | | | Standard Deviation | | | Coefficient of Variation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| A | 6 | 289.33 | 220.00 | 254.13 | 14.36 | 9.26 | 21.72 | 0.05 | 0.04 | 0.08 |
| | 8 | 414.00 | 344.25 | 344.88 | 26.41 | 34.31 | 22.63 | 0.06 | 0.10 | 0.07 |
| | 10 | 548.67 | 439.13 | 492.88 | 20.13 | 19.06 | 25.09 | 0.04 | 0.04 | 0.05 |
| | 12 | 678.33 | 698.25 | 647.00 | 59.80 | 36.62 | 65.42 | 0.09 | 0.05 | 0.10 |
| | 14 | 789.25 | 830.78 | 871.88 | 60.29 | 60.33 | 136.43 | 0.08 | 0.07 | 0.16 |
| | 16 | | | | | | | | | |
| B | 6 | 211.63 | – | – | 10.41 | – | – | 0.05 | – | – |
| | 8 | 278.38 | 207.88 | 208.00 | 14.60 | 14.20 | 29.39 | 0.05 | 0.07 | 0.14 |
| | 10 | 315.88 | 219.63 | 289.25 | 8.87 | 5.90 | 25.19 | 0.03 | 0.03 | 0.09 |
| | 12 | 387.25 | 303.63 | 304.00 | 17.19 | 17.53 | 24.91 | 0.04 | 0.06 | 0.08 |
| | 14 | 442.88 | 335.88 | 357.25 | 30.76 | 28.82 | 28.85 | 0.07 | 0.09 | 0.08 |
| | 16 | 465.63 | 411.88 | 427.38 | 11.06 | 16.47 | 46.49 | 0.02 | 0.04 | 0.11 |
| C | 6 | 277.75 | 206.00 | 231.38 | 12.12 | 15.55 | 26.75 | 0.04 | 0.08 | 0.12 |
| | 8 | 344.38 | 279.13 | 283.75 | 23.65 | 14.37 | 30.65 | 0.07 | 0.05 | 0.11 |
| | 10 | 398.25 | 309.25 | 349.63 | 15.94 | 13.11 | 53.03 | 0.04 | 0.04 | 0.15 |
| | 12 | 445.00 | 356.50 | 479.55 | 24.04 | 23.40 | 55.75 | 0.05 | 0.07 | 0.12 |
| | 14 | 535.63 | 399.65 | 469.50 | 49.51 | 37.40 | 36.15 | 0.09 | 0.09 | 0.08 |

Note: 1 psi = 6.9 kPa.

**Table 2. Statistical evaluation of laboratory data after standardization.**

| Soil | Cement Content (percent) | Mean | | | Standard Deviation | | | Coefficient of Variation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Sandy loam | 6 | 353.00 | 237.25 | 219.00 | 17.98 | 8.61 | 18.40 | 0.05 | 0.04 | 0.08 |
| | 8 | 476.50 | 302.50 | 281.75 | 45.54 | 15.69 | 2.36 | 0.10 | 0.05 | 0.01 |
| | 10 | 538.00 | 345.75 | 322.00 | 47.22 | 5.12 | 20.49 | 0.09 | 0.01 | 0.06 |
| | 12 | 654.25 | 445.75 | 440.25 | 22.31 | 29.68 | 27.40 | 0.03 | 0.07 | 0.09 |
| | 14 | 820.25 | 506.75 | 556.75 | 48.04 | 8.83 | 52.71 | 0.06 | 0.02 | 0.09 |
| | 16 | 899.00 | 557.00 | 540.25 | 24.22 | 30.60 | 25.32 | 0.03 | 0.05 | 0.05 |
| Clay loam | 6 | 254.25 | 149.75 | 181.25 | 15.73 | 6.65 | 5.19 | 0.06 | 0.04 | 0.03 |
| | 8 | 333.00 | 192.25 | 220.50 | 8.60 | 13.40 | 16.38 | 0.03 | 0.07 | 0.07 |
| | 10 | 359.50 | 220.00 | 227.00 | 16.10 | 8.83 | 12.06 | 0.04 | 0.04 | 0.05 |
| | 12 | 391.00 | 234.50 | 224.75 | 19.04 | 17.06 | 16.03 | 0.06 | 0.05 | 0.07 |
| | 14 | 440.50 | 276.50 | 273.75 | 19.33 | 9.25 | 17.04 | 0.04 | 0.03 | 0.06 |
| | 16 | 510.00 | 275.50 | 322.75 | 4.81 | 21.13 | 27.29 | 0.01 | 0.08 | 0.08 |
| Silty loam | 6 | 189.50 | 136.75 | 140.75 | 5.67 | 5.91 | 16.50 | 0.03 | 0.04 | 0.12 |
| | 8 | 214.00 | 167.00 | 159.50 | 18.78 | 12.83 | 14.11 | 0.09 | 0.08 | 0.09 |
| | 10 | 271.50 | 199.50 | 195.50 | 15.46 | 12.37 | 37.12 | 0.06 | 0.06 | 0.19 |
| | 12 | 329.00 | 218.00 | 216.50 | 13.29 | 11.52 | 6.35 | 0.04 | 0.05 | 0.03 |
| | 14 | 403.00 | 265.00 | 266.00 | 12.38 | 12.73 | 27.64 | 0.03 | 0.05 | 0.10 |
| | 16 | 429.75 | 310.00 | 292.25 | 13.33 | 16.79 | 15.31 | 0.03 | 0.05 | 0.05 |

Note: 1 psi = 6.9 kPa.

prior to mixing. The soil particles did not adequately absorb the water immediately, causing density variations. Later, during the curing process, these soil particles possibly competed with the cement for the available water.

Another possible cause of variation was the cement itself. The cement used by the three laboratories came from different sources. Seven-day compressive strength (AASHO T-106) varied from 2,100 to 4,500 psi (14 480 to 31 030 kPa).

To alleviate these possible causes of variation the following steps were taken:

1. Each component in the fabrication of soil cement specimens was brought to the same temperature, 75 ± 5 F (24 ± 3 C), before the specimens were molded;
2. Water was added to the raw soils, and the mixture was allowed to slake overnight before addition of cement;
3. Cement from the same manufactured batch was used; and
4. The time involved in fabrication of specimens was held uniform.

The densities and moisture contents of the specimens were closely controlled among the three laboratories by using the same density and optimum moisture for specimen design for each material tested.

On the basis of standardization, a second set of soil samples was distributed to the same laboratories. The soils belonged to the same classification group. The same experimental design as the first one was used in this phase except that there were four replications instead of the previous eight. The improvement in the variability is clearly evident from data given in Table 2. With the exception of two series of data, the relative dispersion was 0.10 or 10 percent or less. Overall there was a decrease in the variability of the test procedure as a result of standardization.

The effect of soil samples stored for some period of time and then mixed for cement content determination was another aspect studied. To test whether there is a difference due to time in the strength property of specimens mixed and compacted at different times by the same laboratory, the statistical t-test for unpaired data was run. The mean for each soil group data obtained at time A was compared to the mean of the same soil data obtained at time B. On the basis of the calculated t-values, none of the differences in the means was significant at the 0.05 level.

## CONCLUSIONS

The primary conclusions on the basis of this study are as follows:

1. The inconsistency in laboratory design can be minimized if factors such as molding, temperatures, slaking, and fabrication time are closely adhered to.
2. Under the present construction techniques of cement application and density and moisture control, a fair product is produced with 75 percent of the stations having achieved 75 percent (225 psi or 1550 kPa) of the design strength at 28 days. The compressive strength of cores taken on eight projects after 3 months or more was well over 300 psi (2070 kPa).
3. For those projects in which the laboratory design criteria were based on compressive strength, the raw soils sampled and tested in the laboratory showed substantial verification of the materials laboratory design. Only one project had soil types in which the 7-day strength was less than 300 psi (2070 kPa) at the recommended cement percentages.
4. In-place mixing of cement with soil appears to be somewhat undesirable. Results of 311 observations show a variation of ±5 percent from the theoretical cement content in the soil cement bases studied.

ACKNOWLEDGMENT

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REFERENCE

1. Soil-Cement Study. Louisiana Department of Highways, Research Rept. 72, Nov. 1973.