

Nondestructive Tests for Determining Compressive Strength of Cement-Stabilized Soils

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Nondestructive impact hammer tests were made on cement-stabilized noncohesive soils using a Clegg impact soil tester and a Proceq Type PT test hammer. Compressive strength of the stabilized soils varied from about 5 to 1,000 psi. Curves correlating impact hammer values with cement-stabilized soil compressive strength were developed for each of the test hammers. These curves can be used to correlate in situ nondestructive test values with the compressive strength of cement-stabilized soils.

Normally, tests for acceptance of the quality of soil-cement or cement-treated base course construction involve determination of cement content, compaction, and layer thickness.

In some areas, agencies have attempted to base acceptance on the compressive strength of drilled cores (see ASTM D1633-84 and ASTM C39-86). This procedure has led to difficulties, especially where relatively low-strength material is specified (300 to 400 psi). Often, it is not possible to obtain good core recovery from cement-stabilized bases at early ages; this difficulty can lead to unwarranted conclusions about the quality of construction. In addition, core drilling and testing of cores for compressive strength are both costly and time consuming. Thus, a need exists for a simple nondestructive testing device that can be used in the field to provide a more meaningful evaluation of the quality of cement-stabilized materials.

OBJECTIVE AND SCOPE

The investigation was undertaken to develop a nondestructive test method for determining the compressive strength of cement-stabilized soil. The objective was accomplished within the following scope:

1. Two commercially available impact hammers, a Clegg impact soil tester and a Proceq Type PT test hammer were selected to evaluate correlations between test hammer values and cement-stabilized soil compressive strength.
2. Six cohesionless soil materials were selected to evaluate impact hammer responses for a range of soil materials.
3. Each of the six soils was stabilized with different amounts of cement to develop a range of compressive strength.
4. Cement-stabilized soil test blocks were molded for impact hammer testing. Companion cylindrical specimens were

compacted to the same density as the test blocks to determine compressive strength.

5. Correlation curves of cement-stabilized soil compressive strength versus impact hammer test values were developed for each of the two instruments.

TEST EQUIPMENT AND SOILS

Two commercially available impact hammers were selected for the test program. Selection criteria included transportability, ease of operation, and cost. The Clegg impact soil tester

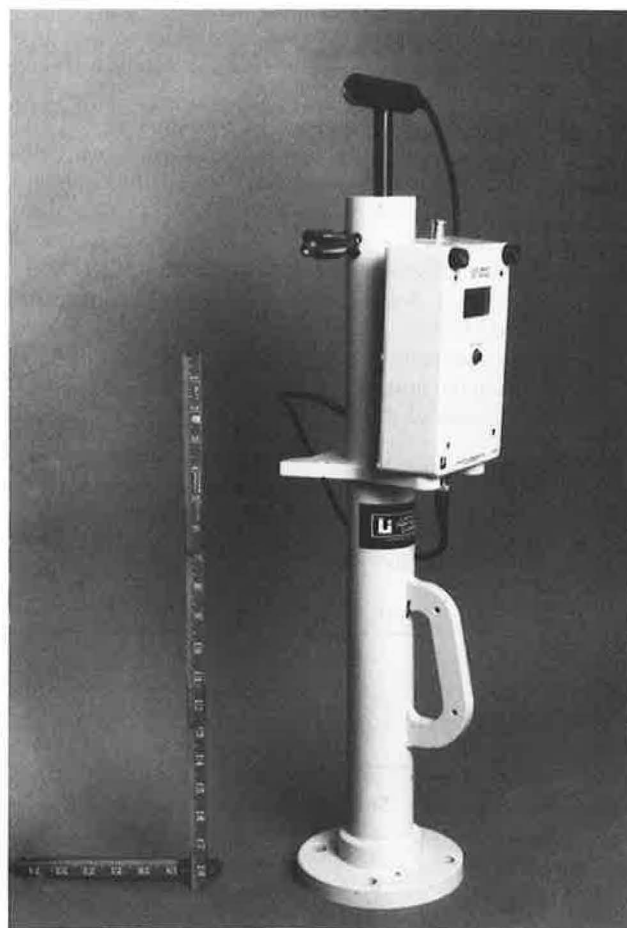


FIGURE 1 Clegg impact soil tester.

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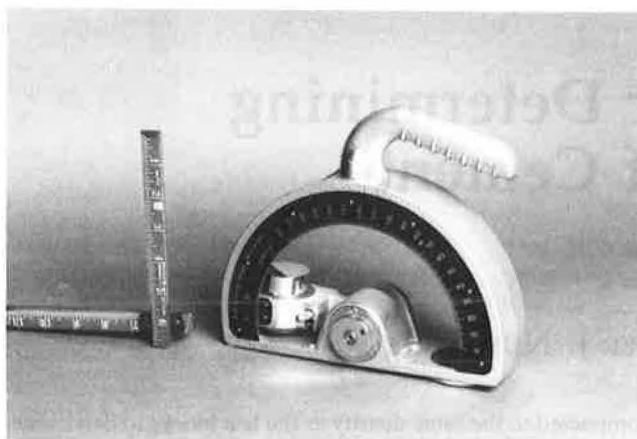


FIGURE 2 Proceq Type PT hammer.

including an approximately 10 × 10 × 31-in. carrying case weighs about 15 lb. The Proceq Type PT test hammer weighs about 5½ lb and is carried in an approximately 3 × 6 × 10-in. case. The test hammers are shown in Figures 1 and 2.

The Clegg impact soil tester consists of a 10-lb compaction hammer together with a guide tube and an electronic meter. The meter signal is provided by an accelerometer fastened to the hammer. Meter maximum deceleration readout is in digital form.

The Proceq Type PT hammer is a pendulum-type impact tester. Impact energy is 0.65 ft-lb with a hammer surface area of about 1.95 in.² Impact hammer rebound values are read from a scale on the instrument.

Six soils encompassing the range of cohesionless soil materials commonly used for soil-cement construction were obtained for this laboratory test program. Soil classifications and descriptions are presented in Table 1. AASHTO soil classifications vary from A-1-a to A-3(I). Standard density and optimum moisture determined in accordance with ASTM D558-82, *Moisture-Density Relations of Soil-Cement Mixtures*, varied from 106 to 142 lb/ft³ and from 6 to 13.5 percent by weight of dry soil plus cement, respectively. Moisture-density tests were made using the amount of cement estimated to produce soil-cement for each of the six soils.

TEST PROCEDURES

To evaluate the response of the impact hammers over a hardness range of compressive strength of about 5 to 1,000 psi,

TABLE 2 CEMENT CONTENTS AND DENSITIES

Soil No.	Cement Content, percent	Dry Density, pcf
1	2	86.3
	5	95.9
	8	101.4
	10	99.5
	12	99.5
	16	99.5
2	2	100.5
	5	100.5
	8	99.5
	10	100.5
	12	105.7
	16	105.7
3	5	108.2
	10	108.2
	15	106.2
4	5	104.1
	10	102.0
	15	102.0
5	8	117.4
	12	122.0
	16	122.0
6	4	128.3
	7	128.3
	10	118.5

cement-stabilized soil test blocks were molded with varying amounts of cement. Amounts of cement used for test blocks made with each of the six soils are presented in Table 2. The amount of water used for batching the cement-stabilized soil was equivalent to the optimum moisture content determined from the moisture-density tests.

The mix was placed in a 12 × 24 × 8-in. container and statically compacted to a thickness of about 6 in. On the basis of experience with both impact hammers, the boundary support of the container has an insignificant effect on surface hardness impact values when specimens are at least 6 in. deep and have

TABLE 1 SOIL CLASSIFICATION AND DESCRIPTION

Soil No.	AASHTO Class	Max. Dry Density, pcf	Optimum Moisture, percent	Sieve Analysis, percent passing				
				1/2 in.	no. 4	no. 10	no. 40	no. 200
1	A-1-b	118	11.0	100	96	75	38	11
2	A-3	106	11.5	100	100	100	96	0
3	A-1-b	128	9.5	100	96	78	44	10
4	A-2-4	118	13.5	100	99	89	61	15
5	A-1-b	127	8.5	100	97	76	28	1
6	A-1-a	142	6.0	83	60	49	24	4

a compressive strength of less than 1,000 psi. For specimens with compressive strengths in excess of approximately 1,000 psi, the within-test variability of impact values exceeds any differentiation of specimen support and boundary type.

Companion 2.8×5.6-in. cylindrical specimens were made in general compliance with ASTM D1632-87, *Making and Curing Soil-Cement Compression and Flexure Test Specimens in the laboratory*. However, the cylinders were compacted to the same density as the companion block specimens and curing was under wet burlap at 72°F.

Impact hammer tests on the cement-stabilized blocks were made after 1, 2, 3, 5, 7, 10, 14, and 17 days of curing under wet burlap. Three impact instrument readouts were averaged for each test to provide an impact value. The hammers were moved between each impact readout to prevent impact footprint superposition. Companion cylindrical specimens were tested each day that impact values were obtained according to ASTM D1633-84, *Compressive Strength of Molded Soil-Cement Cylinders*. A best-fit curve of compressive strength versus curing age was determined for each block's companion cylinders. Thus, normalized compressive strength data were available for each of the impact hammer values.

TEST RESULTS

Individual Soil Analysis

A linear regression of compressive strength on impact values for the Clegg impact soil tester and the Proceq Type PT test hammer was done for each of the six different soils. Outlier and leverage points identified in each linear regression were eliminated. The regression analysis for the six individual soils is presented in Table 3. The linear regression form for the compressive strength and impact value data is the log-log equation. For the six equations derived for the Clegg data, the coefficients of determination, R^2 , ranged from 0.75 to 0.94 and averaged 0.86. For the Proceq data, the values of R^2 ranged from 0.25 to 0.97 and averaged 0.75.

Combined Analysis

The analysis of individual soil data indicated that a single log-log relationship for all soils combined was feasible for both impact testers. Impact values versus compressive strength for the Clegg and Proceq testers are plotted in Figures 3 and 4, respectively. The values of R^2 for the Clegg and Proceq hammer log-log relationships are 0.90 and 0.84, respectively. The resulting equations are presented in Table 4.

Confidence Intervals of Strength Prediction

Confidence intervals at the 5 percent level of significance for the prediction of the actual value resulting from a given impact value were computed as shown in Figures 5 and 6 for the Clegg and Proceq hammers, respectively. The 95 percent confidence intervals represent the uncertainty of the probability density function about compressive strength, given an impact value. The conditional expectation, also computed for the two data sets, is presented in Table 5. The 95 percent confidence levels for the conditional expectation represent the uncertainty of the probability density function about the expected, or average, compressive strength for a given impact value. The conditional expectation confidence intervals are nonlinear functions of the impact values. The half-prediction interval as a percentage of compressive strength ranged from approximately 5 to 11 percent for both hammers.

Within-Test Variability

The within-test coefficient of variation, equal to the standard deviation divided by the mean, can be estimated from the within-test range of the three impact values (see ACI 214-77). The soil-cement specimen surface is assumed to be uniform in hardness and compressive or impact strength. Any impact value variation, therefore, follows from equipment and test method variability. The range in impact values cal-

TABLE 3 SUMMARY OF LINEAR REGRESSION ANALYSIS ON INDIVIDUAL SOILS

Impact Hammer	Soil No.	Soil Class	No. of Tests	Compressive Strength, psi			log (f'c) = "a" + "b" x log (Impact)		
				Minimum	Maximum	Average	"a"	"b"	R-sq.
Clegg	1	A-1-b	40	60	270	150	0.949	0.762	0.75
	2	A-3	39	40	770	300	0.015	1.372	0.90
	3	A-1-b	23	120	540	320	0.279	1.176	0.91
	4	A-2-4	24	100	490	230	0.326	1.173	0.94
	5	A-1-b	9	440	940	690	-0.263	1.522	0.75
	6	A-1-a	23	210	780	490	1.093	0.800	0.89
Proceq	1	A-1-b	25	90	270	190	0.952	0.857	0.86
	2	A-3	27	120	770	370	-2.327	2.742	0.97
	3	A-1-b	22	120	540	330	-0.960	1.981	0.94
	4	A-2-4	24	100	490	230	-1.024	2.049	0.93
	5	A-1-b	9	440	940	690	-0.304	1.703	0.25
	6	A-1-a	23	210	780	490	0.806	1.058	0.54

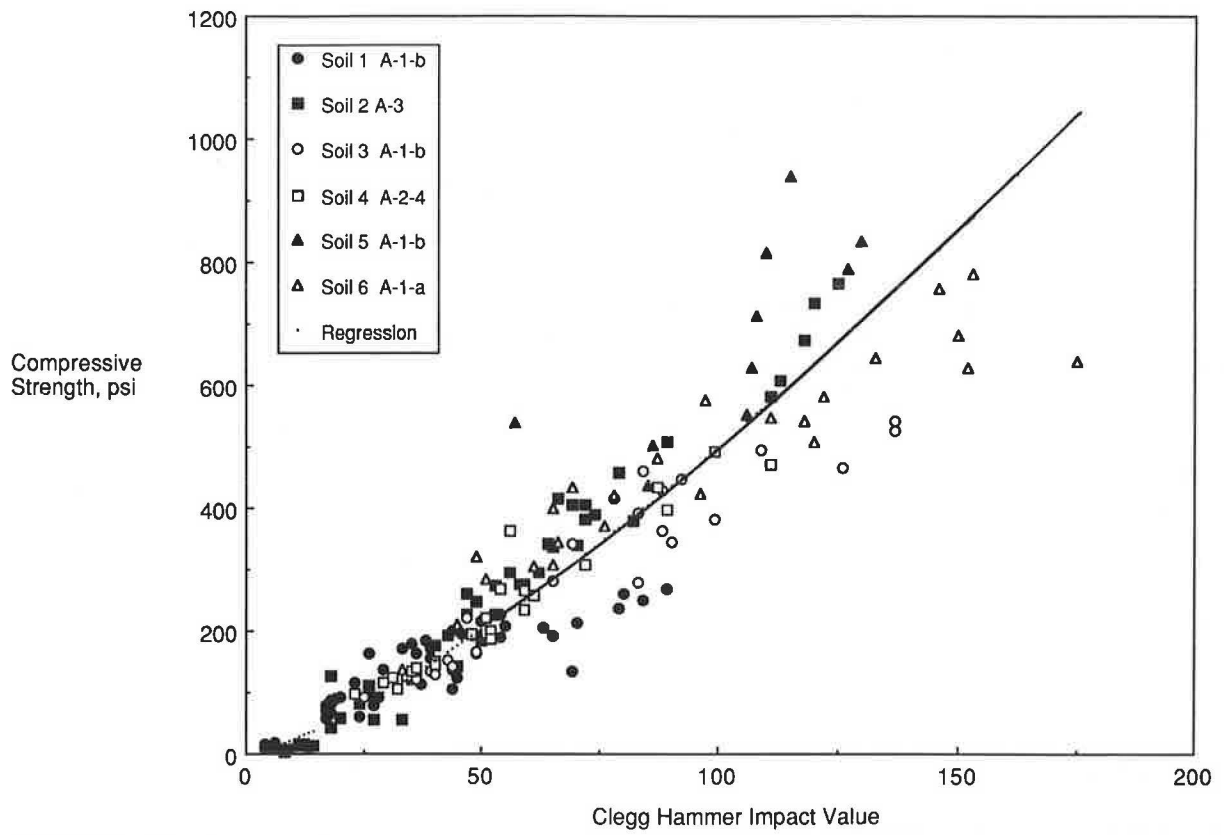


FIGURE 3 Clegg hammer data.

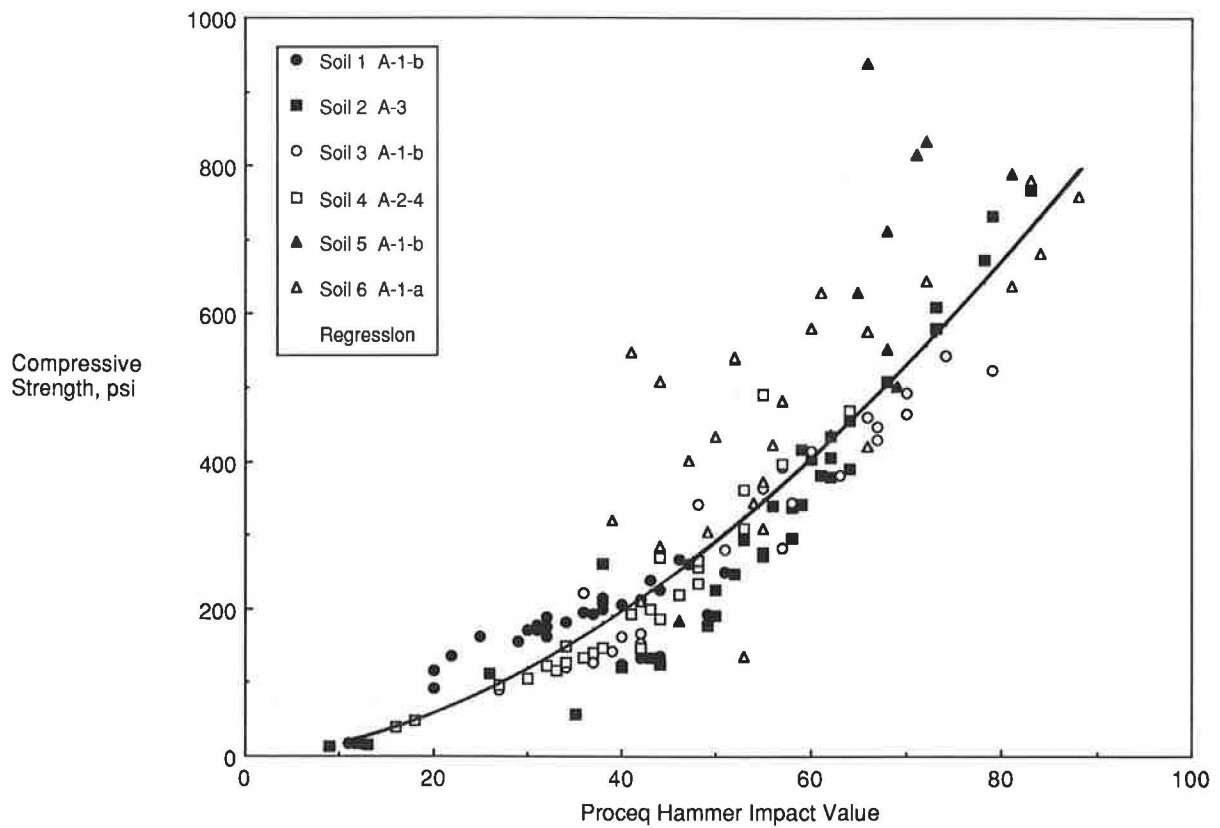


FIGURE 4 Proceq hammer data.

TABLE 4 SUMMARY OF LINEAR REGRESSION ANALYSIS

Impact Hammer	No. of Tests	Compressive Strength, psi			$\log(f'c) = "a" + "b" \times \log(\text{Impact})$				Standard Error	R-sq.
		Minimum	Maximum	Average	"a"	t-statistic	"b"	t-statistic		
Clegg	179	5	940	275	0.081	1.4	1.309	39.5	0.157	0.90
Proceq	145	15	940	325	-0.516	-4.8	1.757	27.1	0.133	0.84

culated for each soil, cement content, and test age were also assumed to represent the true ranges, because a single set of tests may be statistically insufficient.

The coefficient of variation calculated for the three impact values can be compared to that expected from compressive strength tests. The coefficient of variation of within-test compressive strength testing was calculated from published data of 115 sets of duplicate specimens molded from 35 different soil materials (2,3; ASTM D1633-84).

The resulting distributions of within-test coefficient of variation are shown in Figures 7 and 8. Average within-test coefficients of variation are 13.7, 9.7, and 10.5 percent for the Clegg hammer, Proceq hammer, and compressive strength tests, respectively. For coefficients of variation between 5 and 20 percent, the impact hammers exhibit a slightly larger variation than that expected from compressive strength testing. The percentages with coefficients of variation less than 20 percent are 80, 93, and 85 for the Clegg, Proceq, and com-

pressive strength data, respectively. The analysis indicates that similar within-test scatter of data exists between the impact hammers and compressive strength testing.

ADDITIONAL RESEARCH

The research program evaluated testing equipment to non-destructively determine compressive strength of soil-cement. Testing of the equipment in the field should be done to verify or modify the compressive strength versus impact value correlation developed from laboratory data. During field testing, the following issues should be addressed:

1. The number of impact tests averaged at a given test location may have to be increased to obtain similar coefficients of variation in the field as those expected from compressive strength testing.

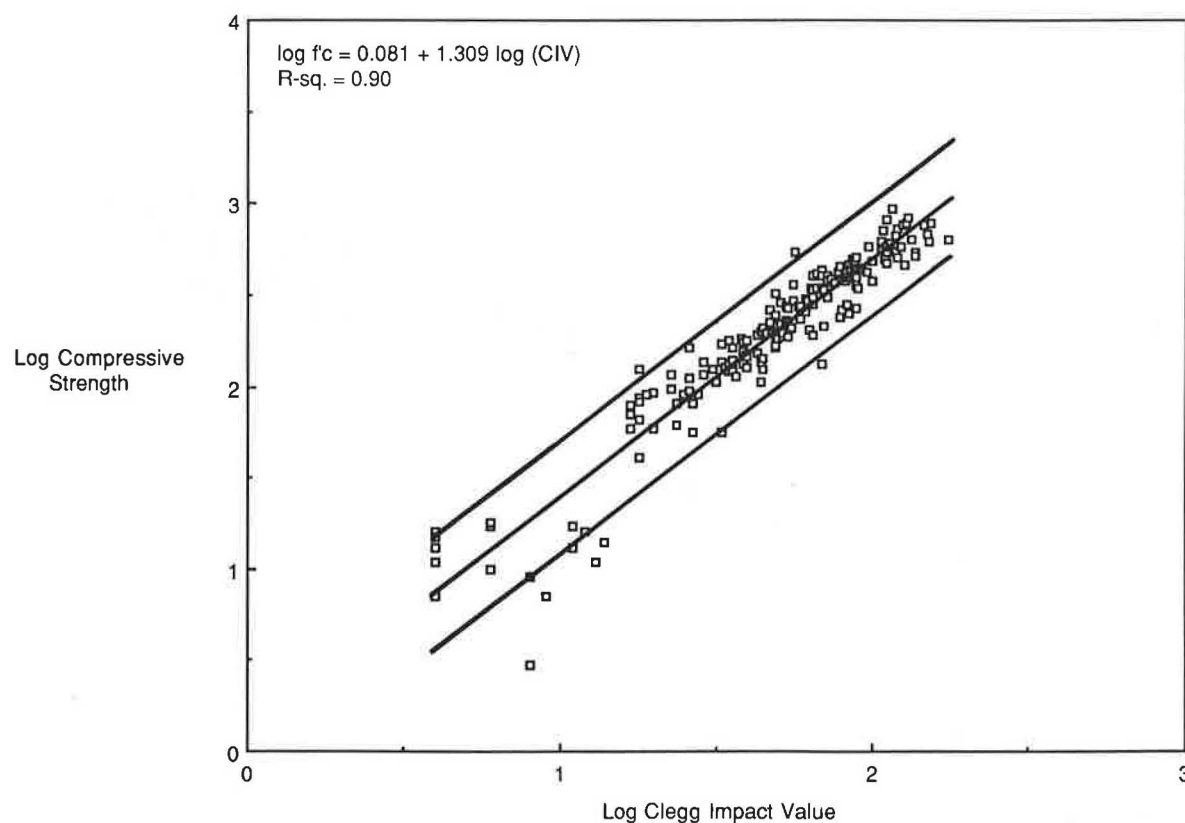


FIGURE 5 Clegg hammer 95 percent confidence intervals.

TABLE 5 CONFIDENCE INTERVALS FOR STRENGTH PREDICTION

f'c, psi	Clegg at 95% Level of Significance				Proceq at 95% Level of Significance			
	Low f'c, psi	High f'c, psi	Plus or minus, psi	Range, percent	Low f'c, psi	High f'c, psi	Plus or minus, psi	Range, percent
100	94	106	6	6.1	92	109	9	8.5
200	190	211	11	5.3	190	211	11	5.3
300	283	318	18	5.8	285	316	15	5.1
400	375	427	26	6.6	377	424	24	5.9
500	465	538	37	7.3	467	536	34	6.9
600	554	650	48	8.0	555	649	47	7.8
700	643	762	60	8.5	641	764	61	8.7
800	731	876	73	9.1	727	880	76	9.6
900	818	990	86	9.6	812	997	93	10.3
1000	905	1105	100	10.0	896	1116	110	11.0

NOTE: Prediction interval of the conditional expectation.

Range percent is one half the prediction interval as a percentage of compressive strength.

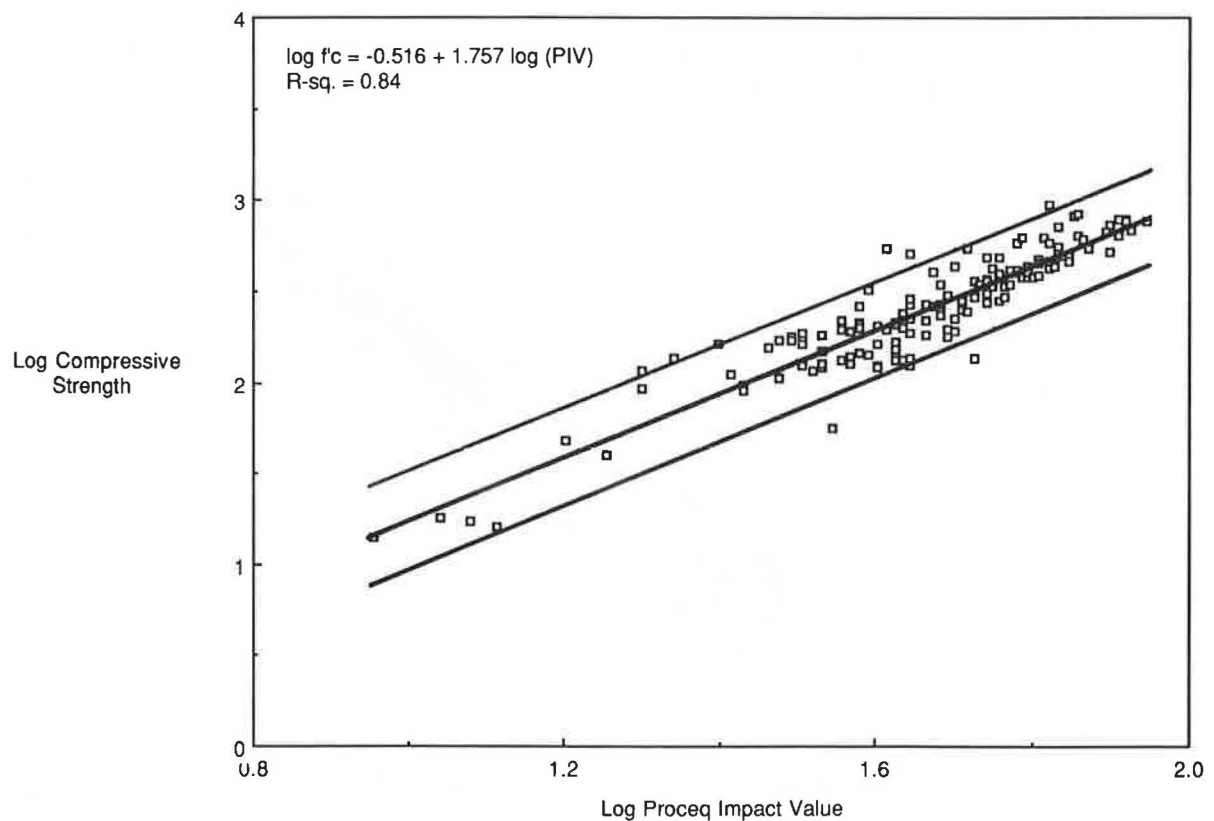


FIGURE 6 Proceq hammer 95 percent confidence intervals.

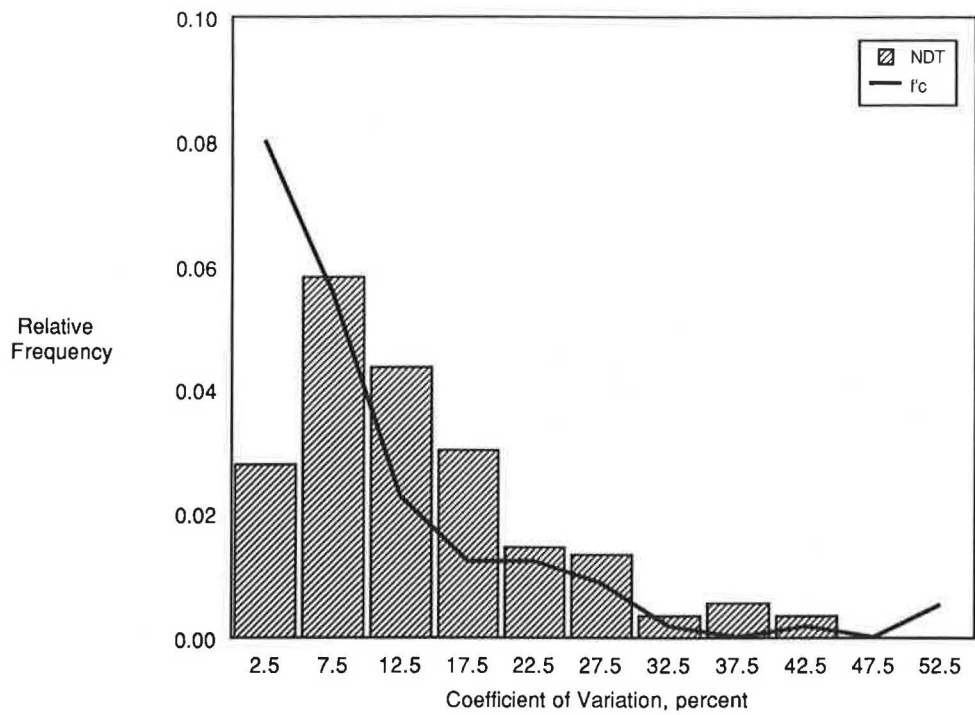


FIGURE 7 Relative frequency histogram for Clegg hammer impact values.

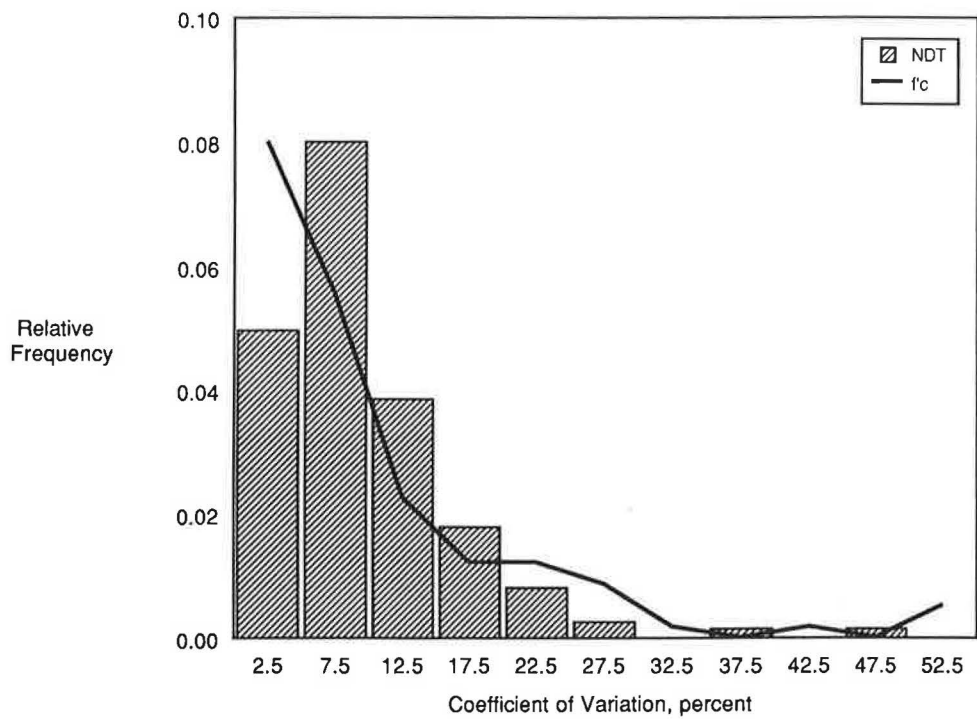


FIGURE 8 Relative frequency histogram for Proceq hammer impact values.

2. The effects of specimen damage during coring need to be established. Correlations between strength and impact value may need to be modified to incorporate specimen damage.

3. The study incorporated only six different cohesionless parent soils. Field testing should encompass a variety of soils (with differing degrees of cohesion) and cement contents.

CONCLUSIONS

Correlation curves were developed permitting the use of results from impact hammer nondestructive tests to determine the compressive strength and rate of strength gain of in situ cement-stabilized soil construction. This nondestructive method avoids the testing difficulties associated with drilling cores. It is recommended that five hammer readings, each on an untested area of the surface, be averaged.

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