DYNAMIC BEHAVIOR OF WEAK SOILS TREATED WITH ADDITIVES

by

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SYNOPSIS

An experimental study was conducted to evaluate the dynamic response of two weak soils, a uniform loose sand and a silty clay, treated with cement, lime, and a combination of lime and fly ash. Dynamic properties in terms of dynamic shear modulus and damping were determined by resonant column technique. The test parameters studied were confining pressure, shear strain amplitude, moisture content, and treatment level. A total of 80 specimens were analyzed. With various combinations of the test parameters considered, a total of approximately 1,800 tests were conducted. The results show the use of additives to stabilize weak soils subjected to earthquake or other forms of vibratory loads is very effective for it increases the rigidity and energy dissipation characteristics of the soils.

INTRODUCTION

Design procedures and criteria for a foundation-structure system for earthquake loading have greatly advanced over the last decade. With all these advances in analytical treatment of the problems, however, local near surface geological and soil conditions have been found to have profound effects on the dynamic response of structure-foundation systems, and that earthquake damages to structures can be reduced to a considerable extent by improving (rigidifying) the underlying weak soil.

Application of soil stabilization techniques for foundations subjected to vibratory loadings have been suggested in the past; however, in treating weak clay soils and structurally unstable granular soils to support such foundations, advantages of using soils treated with additives have not been fully utilized due mainly to the lack of knowledge and understanding of the behavior of chemically treated soils under dynamic loading. The purpose of this study was, therefore, to provide some of the much needed information on the dynamic behavior (wave propagation and damping characteristics) of some weak soils treated with additives.

EXPERIMENTAL INVESTIGATION

The materials used for this study were a uniform sand and a fine silty clay. The major independent test variables considered were moisture content and treatment level of additives for the soils, and confining pressure and shear strain amplitude for the testing apparatus. Based on strength criteria, treatment levels for both sand and clay were chosen at 2, 4 and 6% for cement; 1, 3 and 5% for lime, 1/10, 3/10 and

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5/10% for lime/fly ash. The specimens were tested at confining pressures of 3, 10, 20 and 35 psi. At a given confining pressure, the dynamic shear modulus and damping were determined at five different strain levels ranging from 1.4×10^{-5} to 1.5×10^{-4}. Moisture content was varied over a wide range on both sides of the optimum. Altogether, a total of 88 specimens were tested. With the various combinations of test parameters considered, a total of approximately 1,800 tests were conducted.

The dynamic shear modulus and damping were determined by means of the "resonant column" technique in torsion on remolded specimens prepared by a miniature compactor designed specially for this study. A detailed discussion of the test apparatus, test procedure and the theoritical concept of torsional resonant column technique used may be found in the article by Chiang (1). Immediately following the dynamic tests, the specimens were tested in a static triaxial compression apparatus for the evaluation of static properties of the soils for correlation.

ANALYSIS AND DISCUSSION OF TEST RESULTS

A detailed analysis, discussion of the test results and findings therefrom are presented in the reference by Chiang (1). The essential findings from this study are herein summarized.

Dynamic Shear Modulus - Dynamic shear modulus for both sand and clay increases with increasing confining pressure, and their relationship is linear on a log-log scale. Treatment of both soils with additives results in an increase in the dynamic shear modulus with cement-treatment being the most effective of the three additives used. Empirical equations for dynamic shear modulus of cement-treated sand and clay at small shear-strain amplitude are derived as functions of confining pressure, void ratio and cement content. Dynamic shear modulus for both materials decreases with increasing shear-strain amplitude. The maximum dynamic shear modulus for cohesive soils can be obtained at a strain amplitude of 3×10^{-5}, while for cohesionless soils, especially at higher confining pressure and greater treatment level, the maximum dynamic shear modulus must be extrapolated at zero strain amplitude. Treatment with additives increases the rate of change of the dynamic shear modulus with strain amplitude for cohesionless soils, while the opposite is true for cohesive soils.

At a given confining pressure and treatment level, the dynamic shear modulus of cohesionless soils can be assumed for practical purposes to be unaffected by the moisture content, but for cohesive soils, the modulus decreases rapidly when the moisture content of the clay specimen is increased beyond its optimum, with the maximum value occurring near the optimum moisture content.

Dynamic shear modulus can be predicted from the static shear strength of the soils as shown in Figs. 1 and 2. It is observed that a linear relationship exists between the static strength and dynamic shear modulus regardless of the type of additives treatment level and moisture content. Similar relationships are obtained at other strain amplitudes. This linear relationship between the dynamic shear modulus (G) and the static deviatoric stress (σ_d) may be expressed empirically as

$$G = 13.87 + 0.42\ \sigma_d \quad \text{for sand,}$$

and

$$G = 7.51 + 0.60\ \sigma_d \quad \text{for clay.}$$

The dynamic shear modulus for sand is found to be essentially independent of frequency at small strain amplitudes as evidenced by very small changes in the modulus values at the first few normal modes of vibration.

Damping - Logarithmic decrement decreases with increasing confining pressure for both treated and untreated soils, and for sand a linear relationship exists between the two parameters. Logarithmic decrement of both treated and untreated soils increases continuously with the strain amplitude and no peak value appears within the strain amplitude studied. The rate of increase of logarithmic decrement is more pronounced at lower confining pressure for sand specimens. For cohesionless soils, treated or untreated, the logarithmic decrement is independent of the moisture content, but for cohesive soils, a minimum logarithmic decrement occurs at the optimum moisture content. Logarithmic decrement of cohesive soils at moisture increases gradually.

The effect of treatment level is to increase the damping capacity of the soils especially those treated with cement. The degree of influence of additives diminishes at higher confining pressures. Relationships between logarithmic decrement at small amplitude and the static deviatoric stress at 1% longitudinal strain, both at a confining pressure of 20 psi, are shown in Figs. 3 and 4. It is observed that logarithmic decrement increases over low-strength range but stays practically constant over high-strength range. No such an apparent relationship exists, however, between damping and static strength for cohesive soils. Scattering of data points may be attributed to the effects of other parameters, most probably the moisture condition.

CONCLUSIONS

The investigation has shown that the use of additives to stabilize weak soils subjected to earthquake or other forms of vibratory loads is very effective for it increases the rigidity and energy dissipation characteristics of the soils. The aspect of designing a foundation on a weak soil based on the dynamic characteristics of the treated soil appears very promising.

REFERENCES

1. Chiang, Y. C. "Dynamic Response of Soils Treated with Additives", Ph.D. Thesis, Rutgers University, May, 1972.

2. Chiang, Y. C. and Chae, Y. S. "Dynamic Properties of Cement Treated Soils", Bull. 369, Highway Research Board, National Academy of Science, 1972.

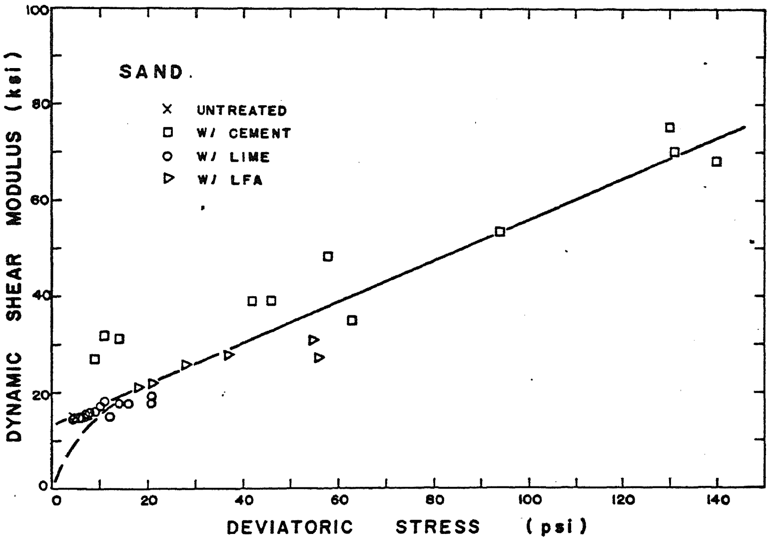

FIG. 1 DYNAMIC SHEAR MODULUS VS. STATIC STRENGTH

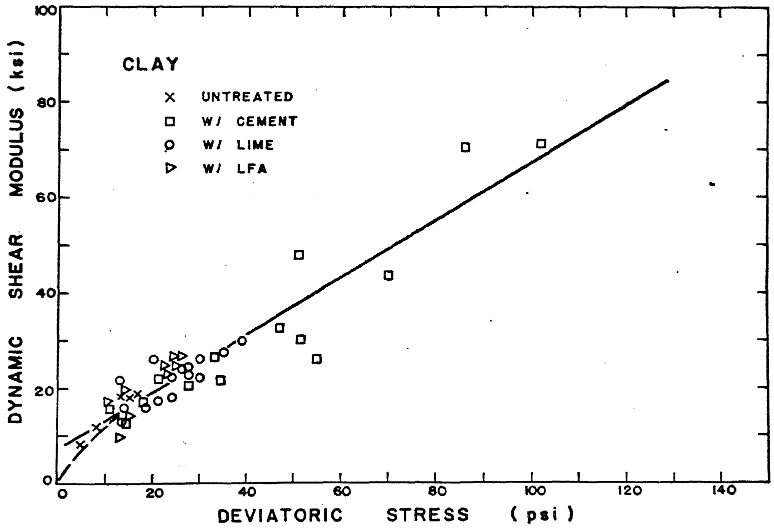

FIG. 2 DYNAMIC SHEAR MODULUS VS. STATIC STRENGTH

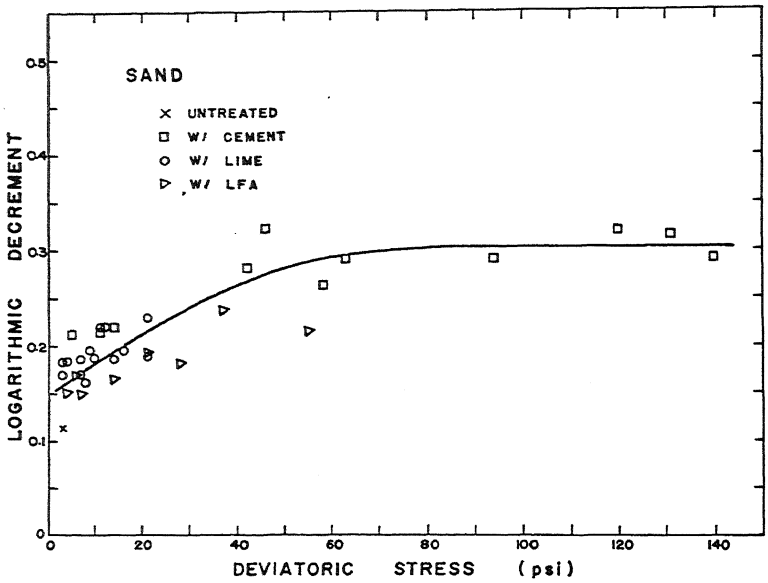

FIG. 3 DAMPING VS. STATIC STRENGTH (SAND)

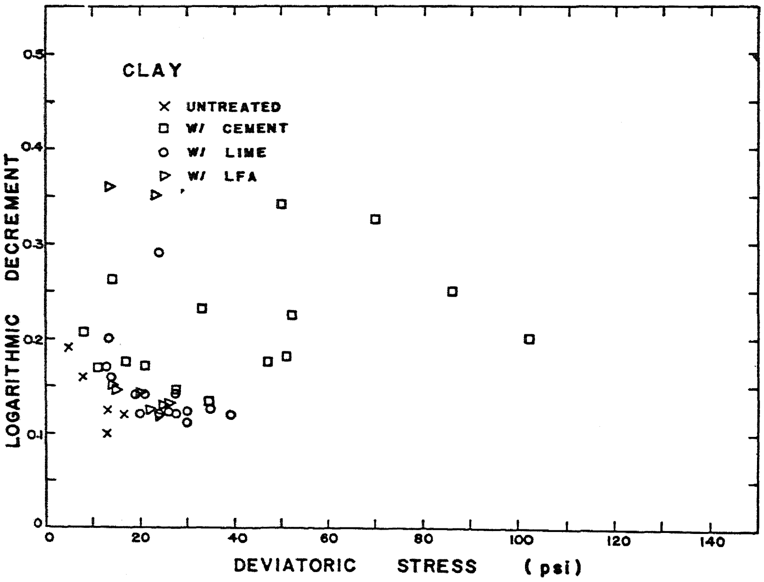

FIG. 4 DAMPING VS. STATIC STRENGTH (CLAY)