DYNAMIC PROPERTIES OF EXPANSIVE SOILS TREATED WITH ADDITIVES

by

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SYNOPSIS

An experimental study was conducted to evaluate the dynamic response of expansive clay soils treated with lime, salt, and a lime-salt combination. 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, type of treatment and treatment level. A total of 74 specimens were tested. With various combinations of the test parameters considered, a total of approximately 1,500 tests were conducted. The results show that the use of additives to stabilize expansive soils subjected to earthquake or other forms of vibratory loading is very effective for it increases the rigidity and energy dissipation characteristics of the soils.

INTRODUCTION

Problems associated with expansive clay soils have been recognized world wide including such regions as Africa, Australia, Canada, India, South America and the United States. Damages caused by expansive soils have been found in all kinds of structures such as buildings, highways, hydraulic structures, underground utilities and services, and landslides. Annually, expansive soils inflict billions of dollars in damages all over the world. Furthermore, expansive soils, found in most states, cover some of the earthquake prone areas, especially the Western part of the United States.

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

There are a number of remedial measures which can be utilized to minimize or eliminate damages associated with expansive soils. These may include pre-loading, compaction control, pre-wetting, dewatering, replacement by select

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material, and chemical and electro-osmotic stabilization. The use of lime additive has proven to be an effective and economical way of stabilization. Sodium chloride used as a chemical admixture in conjunction with lime has also been found to accelerate and enhance lime-clay reaction. However, whether soil stabilization technique can be as effectively utilized for expansive soils under dynamic loading as under static loading has yet to be proved. The purpose of this study was, therefore, to provide some information on the dynamic properties (wave propagation and damping characteristics) of an expansive clay treated with additives.

EXPERIMENTAL INVESTIGATION

The material used for this study was a commercial Western Bentonite (montmorillonite) clay mined at Black Hill, North Dakota. It constituted mostly of silica and alumina (84% by weight) and the remaining 16% was of minute fragments of other minerals. The untreated soil had the optimum moisture content of 24.3% and the maximum dry density of 80 pcf. The major independent test parameters considered were moisture content and treatment level of additives for the soil, and confining pressure and shear strain amplitude for the testing apparatus. The soil was treated either with salt, lime, or a lime-salt combination. Treatment levels were chosen at 4, 6, 8 and 10%. Moisture contents were varied over a wide range on both sides of the optimum. 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 shear strain levels ranging from 2.80×10^{-5} to 2.80×10^{-4}. Altogether, a total of 74 specimens were tested. With various combinations of the test parameters considered, a total of approximately 1500 tests were conducted.

The dynamic shear modulus and damping were determined by means of "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 theoretical concept of torsional resonant column technique used in this study may be found in the reference by Au (1). Immediately following a dynamic test, the specimen was tested in a static triaxial compression apparatus to evaluate the static properties of the soil for the purpose of correlating with dynamic properties.

ANALYSIS AND DISCUSSION OF TEST RESULTS

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

Dynamic Shear Modulus - Dynamic shear modulus for both treated and untreated soils increases with increasing confining pressure, and their relationship is linear on a log-log scale as shown, typically, in Fig. 1. Treatment of soil with additives result in an increase in dynamic shear modulus with the lime-salt combination being the most effective of the three additives used. It should be noted that the rate of increase with confining pressure also increases with higher level of treatment. Empirical equations for dynamic shear modulus of both treated and untreated expansive clay at small shear-strain amplitude are derived as functions of confining pressure, void ratio and treatment level.

At a given treatment level and confining pressure the dynamic shear modulus decreases with shear-strain amplitude for both the treated and untreated soils as shown, typically, in Fig. 2. The maximum dynamic shear modulus for both soils is obtained at the shear strain amplitude of 2.8×10^{-5} for the present investigation. A previous study (2) indicates that for cohesionless soils, especially at higher confining pressure, the maximum dynamic shear modulus must be extrapolated at zero strain amplitude. The rate of decrease of dynamic shear modulus with strain amplitude is dependent upon the treatment level.

At a given confining pressure and treatment level the dynamic shear modulus for lime-treated soils increases with moisture content up to a value beyond the optimum as shown in Fig. 3. The rate of increase with moisture content is much lower for treated soils than for untreated soils. It is of interest to note that the dynamic shear modulus of the soil treated with salt solution alone decreases slightly with increasing moisture content. For the clays treated with lime-salt combination the dynamic shear modulus can be assumed for practical purposes to be unaffected by the change in moisture content.

Dynamic shear modulus can be predicted from the static shear strength of the soils as shown in Fig. 4. It is observed that a linear relationship exists between the static strength and dynamic modulus at a given confining pressure and strain amplitude, regardless of the type of additives, treatment level and moisture content. Similar relationships are obtained at other strain amplitudes and confining pressures. The relationship between the dynamic shear modulus G in ksi and the static deviatoric stress σ_d in psi may be derived empirically which would allow the calculation of dynamic shear modulus based on the triaxial compression test results:

$$G = 17.65 + 0.108\ \sigma_d \qquad (1)$$

<u>Damping</u> - Damping decreases with increasing confining pressure for both treated and untreated soils. The effect of treatment diminishes at higher confining pressure, and the rate of decrease of damping is much greater with greater level of treatment within the range of cinfining pressure studied. In general, damping of both treated and untreated soils increases continuously with increasing strain amplitude and no peak value appears within the range of strain amplitude studied.

Presumably, damping approaches zero as strain amplitude approaches zero.

The effect of moisture content on damping appears to be minimal for all levels of treatment and strain amplitude. However, the damping capacity can be increased by the addition of additives regardless of its moisture condition. The increase in damping with treatment level is more pronounced at higher strain amplitudes and at lower confining pressures. Of the three different additives used, the soil with lime-salt combination shows the greatest damping capacity.

There is no apparent correlation between damping at small amplitude and the static deviatoric stress when plotted in the same manner as in Fig. 4. Data points are scattered which 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 expansive soils subjected to earthquake or other forms of vibratory loading is very effective for it increases the rigidity and energy dissipation characteristics.

REFERENCES

1. Au, W. C., "Dynamic Properties of Treated Expansive Soils with Additives," Ph.D. Thesis, Rutgers University, October, 1976.

2. Chae, Y. S. and Chiang, Y. C., "Dynamic Behavior of Weak Soils Treated with Additives," Proc. 5th World Conference on Earthquake Engineering, Rome, June, 1973.

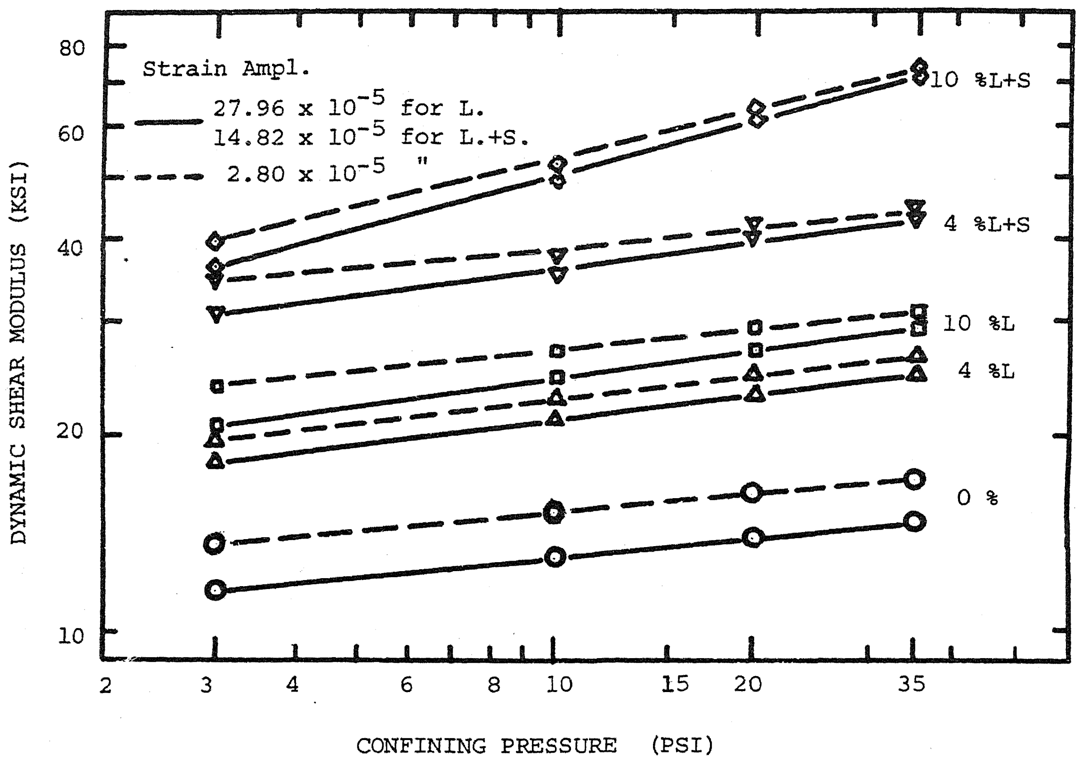

Fig. 1 Effect of Confining Pressure on Dynamic Shear modulus

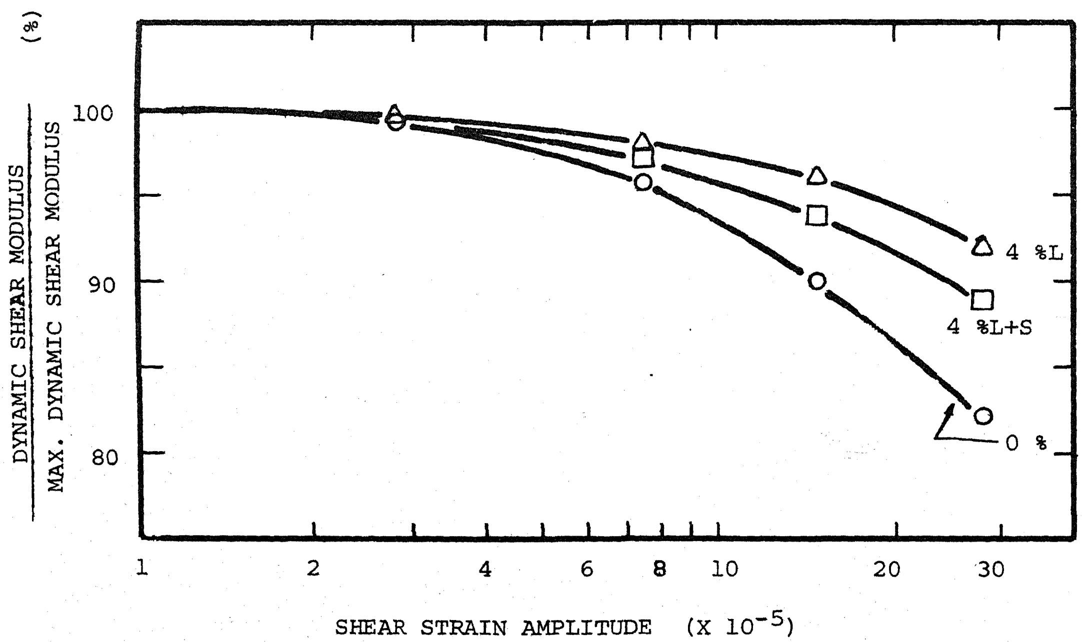

Fig. 2 Effect of Shear Strain Amplitude

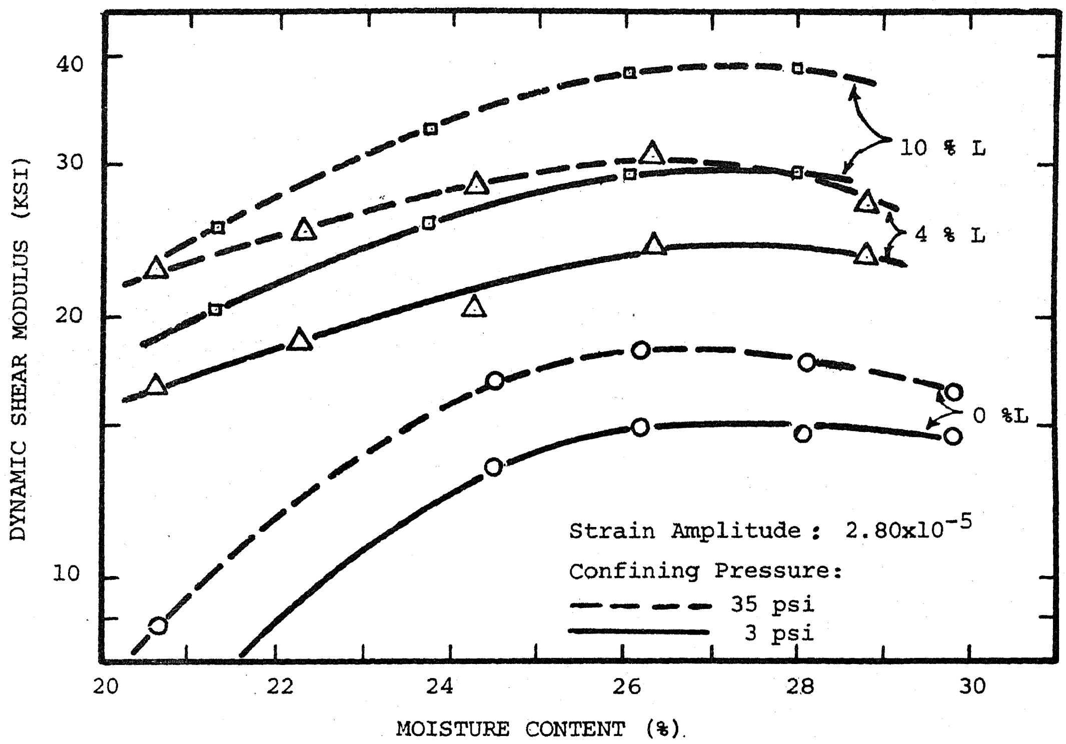

Fig. 3 Effect of Moisture Content on Dynamic Shear Modulus

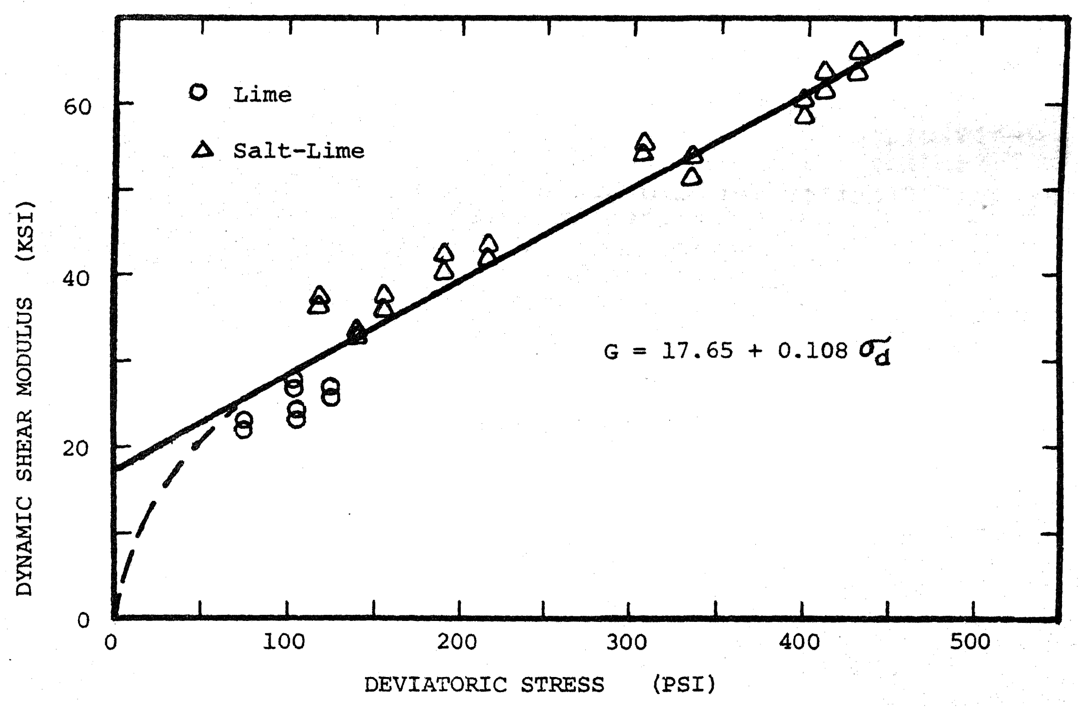

Fig. 4 Dynamic Shear Modulus vs. Static Deviatoric Stress