EFFECTS OF SILT CONTENT ON DYNAMIC PROPERTIES OF SANDY SOILS

H. Dezfulian (I)

Presenting Author: H. Dezfulian

SUMMARY

Undisturbed soil samples were recovered from a deposit of fine-grained alluvium consisting mainly of silty clay and clayey silt with silty sand, sand and silt materials occurring within the clay. The silty, sandy soils were tested in resonant column and cyclic triaxial tests to determine their dynamic loading characteristics at small to relatively large strains. The soils were also tested to determine their cyclic shear resistance and liquefaction potential. The paper includes a review of the literature on the dynamic properties of silty, sandy soils and presents the data obtained in the present study. The effects of confining pressure, silt contents, and grain size on the dynamic properties of such soils is discussed.

INTRODUCTION

Increasing fines content are known to lead to increasing cyclic shearing strength of granular soils. However, information on this form of behavior is apparently scarce in the literature possibly because of the difficulty in testing samples with the same relative density at different fines contents.

Most research efforts on the liquefaction potential of soils have been focused on reconstituted uniform, clean sands containing little or no fines. Case studies have revealed, however, that most liquefied soils are either silty sands or sandy silts (Ref. 1). Very few studies have been done on the effects of gradation characteristics of the silty sand and sandy silt on their cyclic strengths. Some of the more recent work on this subject include studies by Wei, et al (Ref. 2), Forrest, et al (Ref. 3), and Ishihara, et al (Ref. 4).

Iwasaki, et al (Ref. 5), examined sites of major Japanese earthquakes and developed an evaluation procedure for soil liquefaction potential. Zhou (Ref. 6) referred to laboratory cyclic shear test results by O. Masamitsu, et al (1979; in Japanese) performed on undisturbed samples of sand with various fines contents. Zhou noted that correlations between penetration resistance and liquefaction characteristics for sands must be modified for cases of silty sands. He proposed a preliminary approach in which the results of cone penetrometer resistance may be corrected for fines contents, thereby making it possible to evaluate the liquefaction potential of a silty sand site.

(I) Department of Civil Engineering, San Diego State University, San Diego, California, USA.

Chang, et al (Ref. 1), studied the effects of silt contents on liquefaction potential of sands by testing sixty-eight laboratory-made samples. The effect of silt content on the cyclic shear resistance and liquefaction potential of silty sand and sandy silt was evaluated. They found that the development of the greatest increase in cyclic shear strength upon addition of silty fines to a clean sand takes place in the area between 30 to 60 percent fines contents. They also concluded that the resistance to liquefaction of clean sands significantly increases with the mean grain diameter (D_{50}) and fine sands are more susceptible to liquefaction under cyclic loads than coarse sands.

Seed, et al (Ref. 7) have developed procedures for the evaluation of liquefaction potential using field penetration data. They have proposed that for silty sands and silts plotting below the A-line on the Casagrande plasticity chart and with $D_{50} < 0.15$ mm, the boundary established for liquefaction of sands based on standard penetration resistance can be used for silty sands, provided the standard penetration resistance for the silty sand site is increased by 7.5. This correction can have a very significant effect on liquefaction evaluations for silty sand deposits.

In the following sections, the results of a laboratory testing program performed on samples of silty, sandy materials obtained from granular zones within a fine-grained alluvial deposit are presented and the effects of silt contents and mean grain size on the dynamic characteristics of such soils are discussed.

DYNAMIC MODULUS TESTS

The primary trends of interest for modulus data are the manner in which shear modulus change with shearing strain amplitude. These trends, which are used for predicting the magnitude of shearing stresses induced by an earthquake, are not unique. They vary with soil type, confining conditions and previous stress history.

In the present study, dynamic tests were conducted on undisturbed soil samples taken from the granular zones at depths of 7 to 20 m by utilizing resonant column and cyclic triaxial test devices. Both devices were required to define dynamic response throughout the desired spectrum of shearing strains, i.e., 0.0001 to 1.0 percent.

Each set of resonant column and cyclic triaxial data was combined to define a shear modulus versus shearing strain relationship for a particular test material confined at a specific effective pressure. All cyclic triaxial test results were defined at the 13th, 14th or 15th cycle of loading. Modulus values from the resonant column-cyclic triaxial test set were then normalized by dividing values of moduli at different strain amplitudes by G_{max}, the modulus measured at the lowest strain amplitude during the resonant column tests. Values of G_{max} are plotted on Fig. 1.

Values of modulus ratio, G/G_{max}, and damping ratio were plotted as a function of the logarithm of the shearing strain amplitude, after which smooth curves were fitted through the data points. The plot was constructed by plotting all individual test results on a single figure. The average shear modulus was compared to curves presented by Seed and Idriss

(Ref. 8). Results of this comparative study are presented in Fig. 2. As can be observed in Fig. 2, the modulus ratio curve for the sands compares favorably, especially in the 0.01 to 0.1 percent range of shearing strain, to curves suggested by Seed and Idriss.

The effects of confining pressure on shear modulus for five strain levels (1.0, 0.10, 0.01, 0.001, and 0.0001 percent) were obtained. Straight lines were then fitted through the modulus-confining pressure data. A nearly linear relationship exists between the logarithm of shear modulus and the logarithm of confining pressure. The slope of the straight line drawn through the modulus-confining pressure data varies from about 0.90 at low shearing strain amplitudes to about 0.99 at higher strain levels.

The variation of the logarithm of maximum shear modulus G_{max} and the logarithm of confining pressure σ'_c indicates the following average linear relationship:

$$G_{max} = 650 \ (\sigma'_c)^{0.90}$$

LIQUEFACTION POTENTIAL TESTS

The dynamic strengths of the undisturbed granular soil samples were determined from stress-controlled cyclic triaxial compression tests. Samples were obtained by Pitcher barrel sampling equipment from the borings drilled. Only the results of samples taken from the granular zones occurring in the upper 7 to 20 m which were of main interest are discussed here. The mean grain diameter (D_{50}) ranged between 0.002 to 0.2 mm, with an average of 0.07 mm. Fines content (percent passing number 200 sieve) ranged between 7 and 100 percent with an average of 56 percent. In evaluating the cyclic strengths of the Pitcher samples, possible disturbance to samples was considered. Empirical evidence of this disturbance was indicated by the high standard penetration resistance obtained during drilling operations as contrasted to the low cyclic strengths determined in the same zone from laboratory testing. Sample disturbance could have occurred during the sampling operations, during transfer of the sample to field laboratory, during preparation of the sample for shipment, during transportation to the testing laboratory, or during laboratory preparation of the sample for testing.

The strength criterion of pore pressure equal to 5 percent double amplitude strain was used for analysis of liquefaction strength characteristics presented herein. The results plotted on Fig. 3 show relatively wide scatter. Some of this scatter can be attributed to the varying silt contents and confining pressure of the tested samples. Confining pressures varied from 0.70 to 12.3 kg/cm^2 and as stress ratios causing liquefaction decrease with increasing confining pressure, this effect contributes to the wide variation in results.

An attempt was made to separate the effects of silt content. As factors such as variations in sample disturbance and grain size will also contribute to data scatter, it is difficult to quantify the effects of silt content. In addition, tests with very high silt fractions could be influenced by the presence of significant clay fraction which would increase liquefaction resistance. In general, tests having lower silt contents, are seen to have lower liquefaction resistance than those with high silt contents. Also, considering the data points as a whole, and taking into account varying silt contents, it was noted that samples taken from depths of say 7 to 9 m have similar liquefaction characteristics to those taken from deeper zones. For the purpose of further analysis an average curve was drawn through the points to characterize the liquefaction resistance of cohesionless layers having depths less than 20 m, and is considered representative of material having a 50 percent silt content, as shown in Fig. 3.

To account for the observed trend of increasing liquefaction resistance with increasing silt content, measured stress ratios were adjusted in an approximate manner to be more representative of a 50 percent silt content. Measured stress ratios were increased 5 percent for silt fractions less than 20 percent and reduced 5 percent for silt fractions greater than 80 percent. Corrections for silt fractions between 20 percent and 80 percent followed a linear function. Results obtained by Chang, et al (Ref. 1) indicate a higher correction for silt contents.

The data presented in Fig. 3 was also studied on the basis of mean grain diameter, D_{50}, of each sample. The values of D_{50} varied from about 0.0017 to about 0.18. The results show no apparent trend in the cyclic strength of such materials with respect to basis of mean grain diameter. It may be noted that Chang, et al (Ref. 1) concluded that there is a tendency for increasing resistance to liquefaction of clean sands with increasing D_{50}.

CONCLUSIONS

Laboratory investigation of the dynamic properties of undisturbed samples of silty sand, sand and silt materials show that:

1. The following relation exists between G_{max} and confining pressure σ'_c:

$$G_{max} = 650\ (\sigma'_c)^{0.90}$$

2. Resistance to liquefaction is increased with increasing silt content.

3. The data show no apparent relation between resistance to liquefaction and mean grain diameter, D_{50}.

REFERENCES

1. Chang, N.-Y., S.-T. Yeh, and L.P. Kaufman. "Liquefaction Potential of Clean and Silty Sands," Proceedings, Third International Earthquake Microzonation Conference, Vol. II (June, 1982), Seattle, Washington, pp. 1017-1032.

2. Wei, R.L., T.L. Guo, and Y.M. Zuo. "Pore Pressure in Silty Sand Under Cyclic Shear." Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. I (1981), University of Missouri, Rolla, pp. 59-64.

3. Forrest, J.B., J.M. Ferritto, and G. Wu. "Site Analysis for Seismic Soil Liquefaction Potential." Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. I (1981), University of Missouri, Rolla, pp. 155-160.

4. Ishihara, K., S. Yasuda, and K. Yokota. "Cyclic Strength of Undisturbed Mine Tailings." Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. I (1981), University of Missouri, Rolla, pp. 53-58.

5. Iwasaki, T., K. Tokida, and F. Tatsuoka. "Soil Liquefaction Potential Evaluation with Use of the Simplified Procedure." Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. I (1981), University of Missouri, Rolla, pp. 209-214.

6. Zhou, S.G. "Influence of Fines on Evaluating Liquefaction of Sand by SPT," Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, Vol. II (1981), University of Missouri, Rolla, pp. 167-172.

7. Seed, H.B., I.M. Idriss, and I. Arango. "Evaluation of Liquefaction Potential Using Field Performance Data," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 3 (March, 1983), pp. 458-482.

8. Seed, H.B. and I.M. Idriss. "Soil Moduli and Dynamic Factors for Dynamic Response Analysis," Report No. EERC 70-10, Earthquake Engineering and Research Center, College of Engineering, University of California, Berkeley (December, 1970).

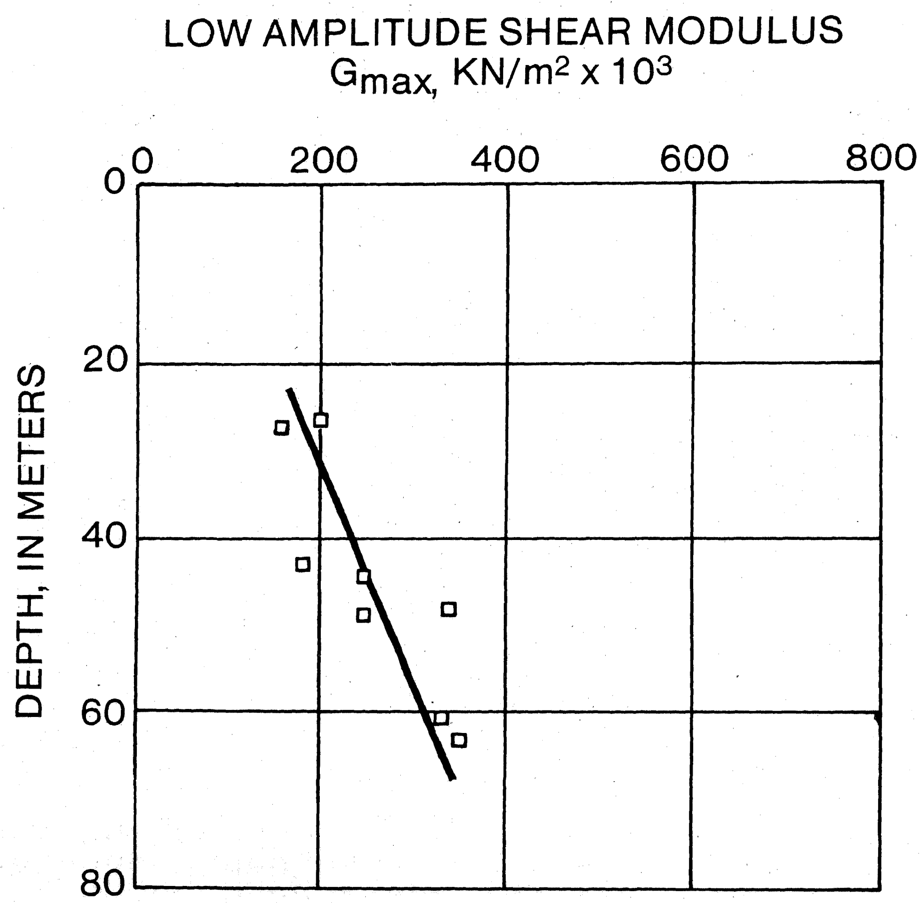

FIG. 1. - VARIATION OF G_{MAX} WITH DEPTH

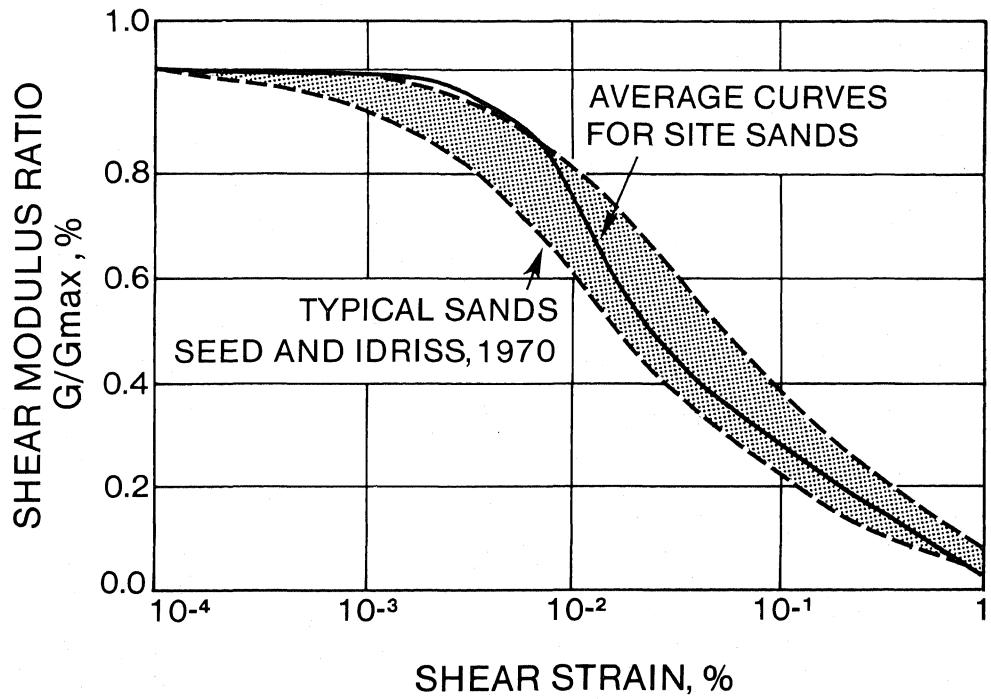

FIG. 2. - VARIATION OF G/G_{MAX} WITH SHEAR STRAIN

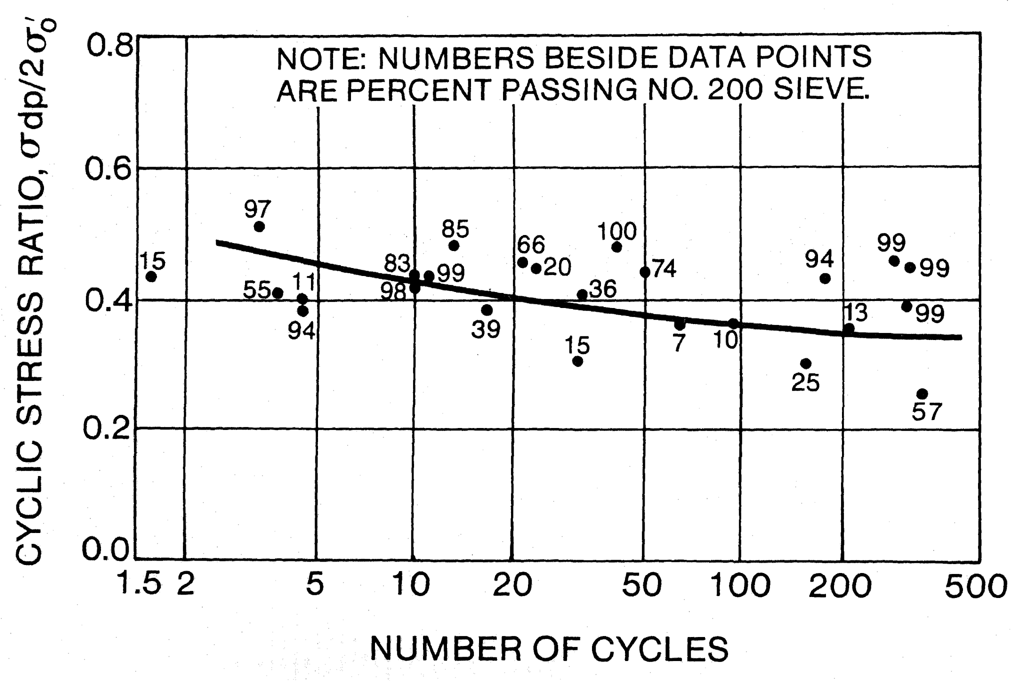

FIG. 3. - RESULTS OF CYCLIC TRIAXIAL TESTS