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Inter-Relationship between Shear Strength and Acoustical Properties of Silt-Clay Matrices

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Introduction

A saturated silt-clay matrix can be regarded as a homogeneous medium consisting of two phases viz; solid phase and liquid phase. The solid phase consists of soil skeleton with pore spaces and the liquid phase consists of water in the pores. Each pore is considered to be interlinked and any infinitesimal soil element is supposed to contain both the phases. Above definition of the saturated soil media was given by Biot (1956) while developing the theory of propagation of elastic waves in a fluid saturated porous solid. In further extension of the Biot's work Ishihara (1968) proved theoretically that the wave propagation velocity through saturated soil media depends upon the type of soil, void ratio, stress history, nature of pore fluid and the structural arrangement of soil particles within the soil mass.

On the other hand the experimental and theoretical works done by the various research workers in the field of geotechnical engineering such as Lambe (1951), Henkel (1959), Abbot (1965), Whitman (1960) have also confirmed that geotechnical properties of soil viz; liquid limit, plastic limit, cohesive strength and angle of internal friction etc. depend upon the same parameters such as soil type, void ratio, degree of saturation, soil structure and nature of pore fluid. Therefore a case exists for attempting correlation between the acoustical and various geotechnical properties of soils. However, it requires a very systematic approach. Nomograms and charts will have to be prepared for predicting the geotechnical properties of soil under different

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stress conditions. The change in the degree of saturation cannot be attempted fruitfully because in that case the soil media turns into a three phase medium and the analysis of wave propagation in three phase medium is a bit complicated and hence its practical utility will be highly limited. On the other hand a saturated soil mass can be visualized as a soil sample obtained from sea/river bed materials. Even with this limitation the proposed correlation between the acoustical and geotechnical properties of soils will have a lot of utility in predicting the shear strength and other properties of soil under riverine and marine conditions, with the help of geo-physical (acoustical) data, which are collected during the routine geophysical surveys of river and sea bed materials by geophysicists.

The present paper gives the results of an attempt made in above direction of research by the authors. Some laboratory tests on different types of saturated silt-clay matrices containing varying percentages of kaolonite in the sample were conducted in Ultrasonic Monitoring Triaxial Apparatus (UMTA) for soil testing. This apparatus facilitates the simultaneous measurement of acoustical velocity and shear strength parameters under stress controlled conditions. The test results were then used to calculate the shear strength of the soil samples under different all round pressure, and a nomogram was prepared for predicting the shear strength of soil with the help of its acoustical velocity and octahedral principal stress condition for different types of silt-clay matrices.

Apparatus

Ultrasonic Monitoring Triaxial Apparatus for soil testing is a stress controlled apparatus for correlating the acoustical and geotechnical properties of triaxially loaded soil samples. Complete schematic details of the apparatus have been given by Jakhanwal and Singh (1991). The apparatus has the facility of measuring the ultrasonic time delay, changes in the height and volume of samples during the application of the stress. The deviatoric stress can be increased in steps, while the lateral stress can be kept constant during the shear testing of the sample. The full saturation of the sample is ensured by the application of the back pressure in the sample through self compensating mercury control system.

Test Procedure

The test procedure starting right from the preparation of laboratory controlled silt-clay matrices to the determination of shear and acoustical properties are given below :

Preparation of Silt-Clay Matrix Samples

The local soil was dried and then sieved to get the silt fractions. A known weight of kaolinite clay was added and dry mixed in the known amount of silt and their matrices are given in Table 1. The numerical prefix attached to the SCM designation represents the percentage of clay by weight in the silt-clay matrix.

Water was added in the amount twice that of the liquid limit of the soil to get the slurry of the sample. All care was taken to remove as much air from the sample as possible. The slurry was then transferred to modified "CBR" mould. The load on the sample was increased in steps upto 1.5 Kg/cm^2. The loading pattern followed conforms to I.S. specification for consolidation testing. The soil was allowed to consolidated under each load for twenty four hours. Three dimensional drainage was allowed during consolidation. This process gave a block sample. The standard triaxial soil samples of 38.0 mm dia. for one series of tests were extracted from this block sample in the sampling tubes.

Test Procedure for Determining Shear and Acoustical Properties with UMTA.

The sample collected in the tube as described in the above section was taken out and trimmed to the standard size (38 mm dia and 75.0 mm height) and thereafter was transferred to UMTA. Initially the back and the cell pressures were increased simultaneously upto a value of 1.5 Kg/cm^2 to achieve full saturation of the sample. The full saturation was indicated ultrasonically by the stabilization of time-lag value of the transmission of acoustical waves through the soil sample. After this the cell pressure was increased to 2.0 Kg/cm^2, while the back pressure remained constant so as to give an all round effective pressure of 0.5 Kg/cm^2. The soil was allowed to

TABLE 1 : Basic Properties of Various Silt-Clay Matrices

SCM Designation	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Specific Gravity	Soil Type
100 SCM	62	32	30	2.62	CH
60 SCM	43	27	16	2.68	CL
40 SCM	35	24	11	2.69	MI
20 SCM	22	20	2	2.72	ML
0 SCM	–	–	–	2.73	ML

consolidate under this effective pressure. The final dial gauge and time-lag readings were taken. The acoustical velocity corresponding to the stage was calculated. The deviatoric load was increased in steps till the sample failed. Under each deviatoric load the sample was allowed to deform for 24 hrs. The above test procedure was repeated with another samples of the same test block under different effective cell pressures of 1.0 Kg/cm^2, 2.0 Kg/cm^2, and 3.0 Kg/cm^2. The initial time lag reading under each effective all round pressure gave the acoustical velocity. The method of calculating the acoustical velocity with the help of the time lag value and dial gauge measurements are given by Singh and Jakhanwal (1989).

The above mentioned test procedure was repeated for 0 SCM, 20 SCM, 40 SCM, 60 SCM and 100 SCM soil matrix samples.

The shear strength was calculated by using Mohr's diagrams given in Figs. 1 to 5.

Test Results and Discussion

The test results have been presented in the form of a final nomogram in Fig. 6. It represents the variation of acoustical velocity, shear strength and effective cell pressure for different types of soils designated as 0 SCM, 20 SCM,

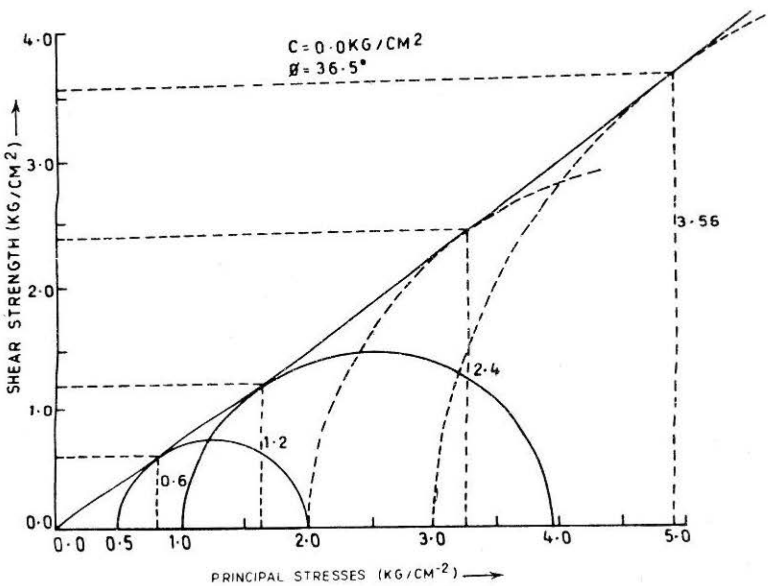

FIGURE 1 : Mohr's Circle for 0 SCM

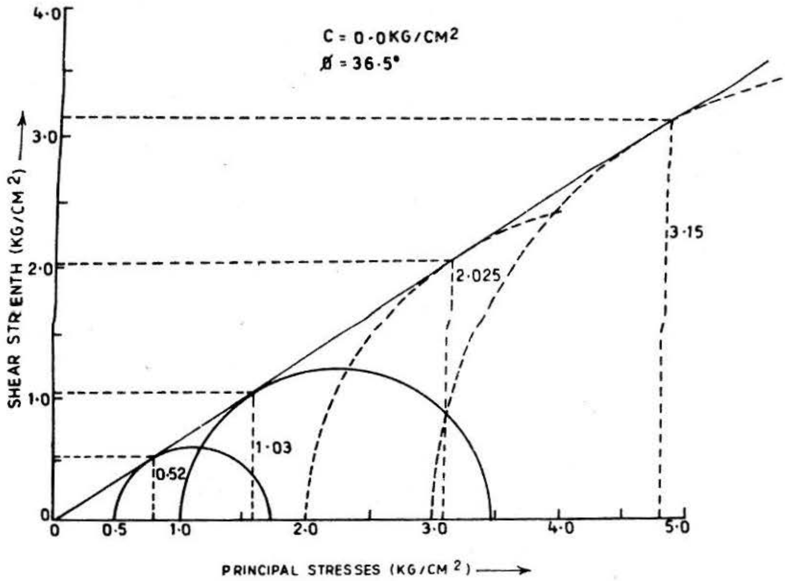

FIGURE 2 : Mohr's Circle for 20 SCM

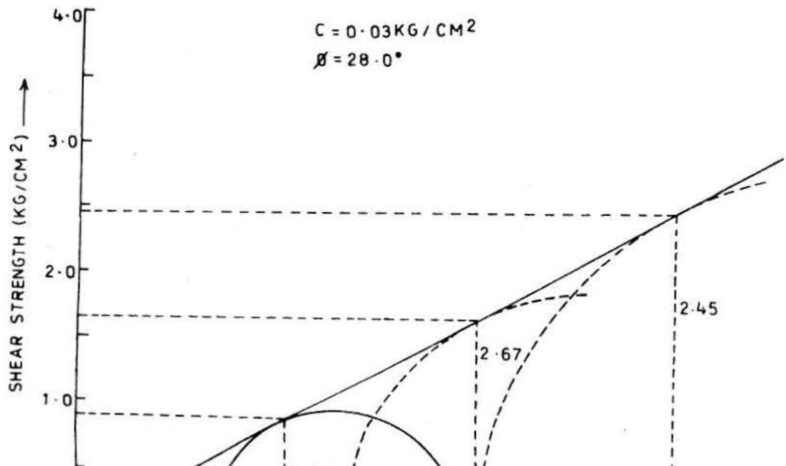

FIGURE 3 : Mohr's Circle for 40 SCM

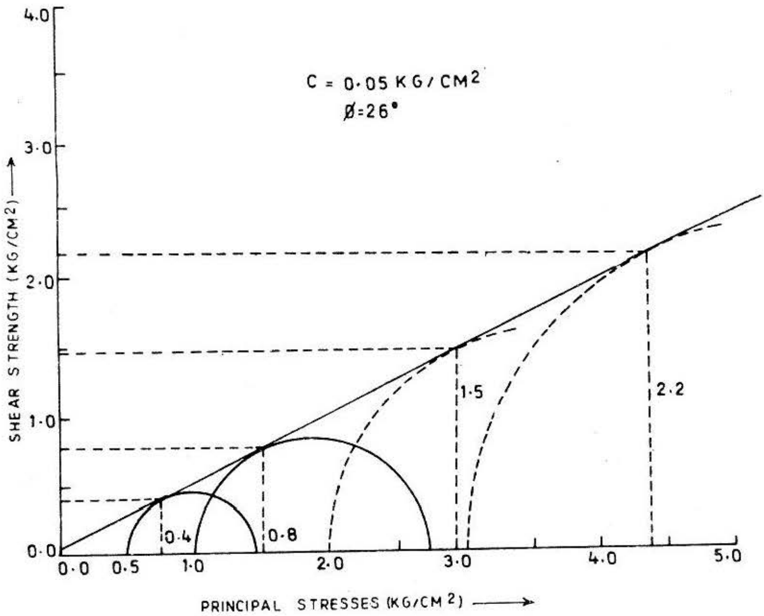

FIGURE 4 : Mohr's Circle for 60 SCM

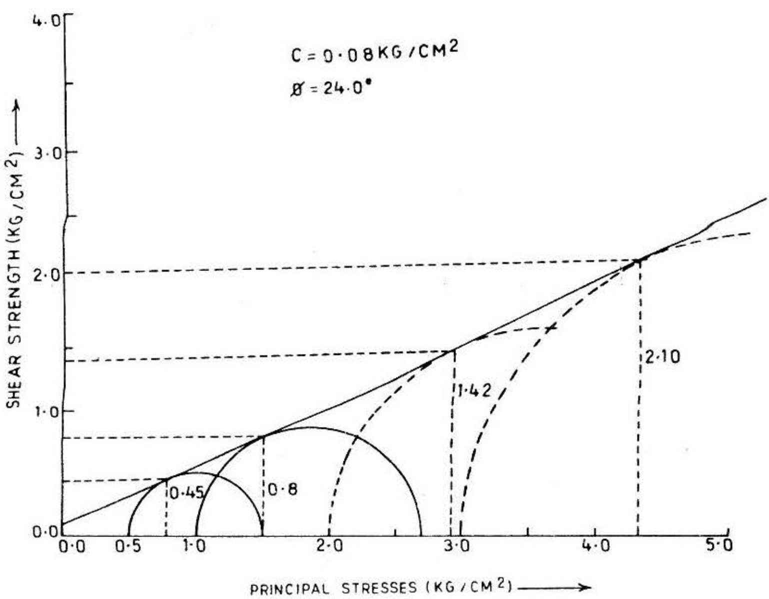

FIGURE 5 : Mohr's Circle for 60 SCM

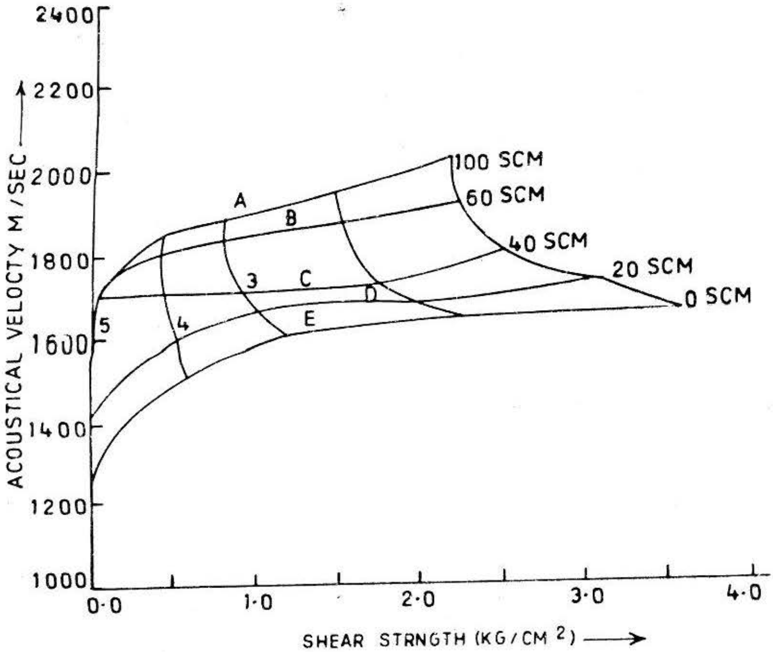

FIGURE 6 : Nomogram for Ultrasonic Velocity, Shear Strength, Effective Cell Pressure and % Clay Content in Silt Clay Matrix
(1) 3.0 kg/cm², (2) 2.0 kg/cm², (3) 1.0 kg/cm², (4) 0.5 kg/cm², (5) 0.0 kg/cm²
(A) 100 SCM, (B) 60 SCM, (C) 40 SCM, (D) 40 SCM, (E) 20 SCM, (E) 0 SCM

40 SCM, 60 SCM and 100 SCM. The numerical prefix to SCM denotes percentage of clay in matrix. Figures 1 to 5 show respectively the Mohr's Circle for 0 SCM, 20 SCM, 40 SCM, 60 SCM to 100 SCM respectively.

From the nomogram it is seen that only with the help of either of the two sets of information i.e. acoustical velocity and stress history, or acoustical velocity and the soil type, the shear strength of the saturated soil can be predicted.

For example :

A value of shear strength of 0.38 Kg/cm^2 is easily obtained from the nomogram for 60 SCM soil type and a measured acoustical velocity of 1800 m/sec.

Likewise, a shear strength value of 0.8 Kg/cm^2 is found out from the nomogram for an effective pressure of 1.0 Kg/cm^2 and measured acoustical velocity of 1700 m/sec.

Thus the test results though limited in number amply show that for the different types of saturated soils the nomogram can be prepared with the help of similar tests. Such nomograms will be of direct help in the prediction of shear strength of river/sea bed deposits with the help of their acoustical properties. Similarly other geotechnical properties of soils can as be tried for. This approach is expected to save time and money of soil investigation work conducted on sea/river deposits for civil engineering constructions.

Conclusion

The Ultrasonic Monitoring Triaxial Apparatus (UMTA) can be used successfully for the establishment of correlation between acoustical velocity and shear strength of saturated soils. The nomograms prepared with the help of such tests on different types of soils can be used in the prediction of shear strength of sea/river bed deposits non-destructively without resorting to conventional geotechnical tests which may save cost and time of geotechnical investigations.

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References

ABBOT, M.B. (1960) : "One Dimensional Consolidation of Multilayered Soils" Geotechnique, Vol. 10, No. 4, p. 151.

BIOT, M.A. (1956) : "Theory of Propagation of Elastic Waves in a Fluid Saturated Porous Solid" Journal of Acoustical Society of America, Vol. 28, pp. 168-191.

DENNESS, B., McCANN, D.M. and FAIRLIC, A. (1974) : "Geotechnical Studies of Sea Floor Sediments Around Arrane" Proc. Conference on Off-shore Structure, London, pp. 21-26.

HENKEL, D.J. (1959) : "The Relationship Between Pore Water Pressure and Volume Change Characteristics of Saturated Clays" Geotechnique, Vol. 9, No. 3, pp. 119-135.

ISHIHARA, K. (1968) : "Propagation of Compressional Waves in a Saturated Soil" Proc. International Symposium of Wave Propagation and Dynamic Properties of Earth Materials, Univ. of New Mexico Press, pp. 195-206.

JAKHANWAL, M.P. (1983) : "Instrumentation and Application of Ultrasonics in Geotechnical Studies of Soils" Ph.D. Thesis, Banaras Hindu University, Varanasi-221005 (India).

JAKHANWAL, M.P. and SINGH, U.P. (1991) : "Effect of $CaCO_3$ on Acoustico-geotechnical Properties of Silty Soils" Indian Geotechnical Journal, Vol. 21, No. 3, July 1991, pp. 256-270.

LAMBE, T.W. (1951) : "Soil Testing for Engineers" John Wiley, New York.

PENMAN, A.D.M. (1952) : Shear Characteristics of a Saturated Silt Measured in *Triaxial Compression" Geotechnique, Vol. 3, pp. 312-328.*

SINGH, R.B. and JAKHANWAL, M.P. (1980) : Ultrasonic Monitoring Consolidometer for Soil Testing" Proc. International Conference & Exhibition on Ultrasonics, held at National Physical Laboratory, New Delhi, pp. 81-85.

SINGH, R.B. and JAKHANWAL, M.P. (1982) : "Ultrasonic Monitoring Triaxial Apparatus for Soil Testing" Journal of Pure and Applied Ultrasonics, Vol. 4, pp. 8-11.

SINGH, R.B. and JAKHANWAL, M.P. (1982) : "Acoustical and Engineering Properties of Triaxially Loaded Off-shore Soils from Bombay High" Proc. IVth International Congress, International Association of Engineering Geology, New Delhi, Vol. VII, pp. 275-283.

SCHULTZE, E. and HORN, A. (1965) : "The Shear Strength of Silt" Proc. VIth International Conference on Soil Mechanics and Foundation Engineering, Vol. I, pp. 350-353.

WHITMAN, R.V. (1960) : "Some Considerations and Data Regarding the Shear Strength of Cohesive Soils" Boulder, Colorado, pp. 581-614.