Indian Geotechnical Journal, 21 (3), 1991

Effect of $CaCO_3$ on Acoustico-Geotechnical Properties of Silty Soils

by

M. P. Jakhanwal*

U. P. Singh**

Introduction

A saturated soil mass of silt—$CaCO_3$ matrice can be regarded as a homogeneous saturated soil mass consisting of two phase medium, viz., solid and liquid phases. The solid phase consists of soil skeleton and the liquid phase consists of brine water present in the pores of the soil mass, Biot (1956). It has been proved theoretically by Ishihara (1968) that the wave propagation velocity through saturated soil media depends upon the type of soil, void ratio, stress history, nature of pore fluid and structural arrangement of the soil particles. On the other hand the experimental and theoretical works done by the various geotechnical research workers such as Lambe (1951), Henkel (1959), Abbot (1960), Penman (1952), Schultze, E. and Horn, A. (1965), Whitman (1960) have also confirmed that the geotechnical properties of soils such as liquid limit, plastic limit, cohesive strength, angle of internal friction, bulk compressibility etc. depend upon the soil type, void ratio, degree of saturation, soil structure, stress history and nature of pore fluid. Hence if the degree of saturation is made equal to one the factors affecting the geotechnical properties will be same as that for the wave propagation velocity through the saturated soil mass. Under this theoretical background the research work for correlating the acoustical velocity of saturated silt $CaCO_3$ soil matrices with their various geotechnical properties has been taken up. The previous work done by Jakhanwal and Singh (1983), showed that the acoustico-geotechnical properties of off-shore soils (received from oil and Natural Gas Commission, Bombay High) get affected by the presence of carbonate in the saturated soil mass. It was then recommended that a systematic study is required to study the effect of carbonate on the acoustico-geotechnical properties of soils.

---

*Associate Professor of Civil Engineering, Muzaffarpur Institute of Technology, Muzaffarpur-842003 (India.).

**Department of Physics, Bihar University, Muzaffarpur (India).

(*The modified manuscript of this paper was received in March, 91 and is open for discussion till end of February, 1992*).

Accordingly a systematic study has been conducted to study the effect of variation of $CaCO_3$ in the brine saturated soil mass on its acoustical and geotechnical properties. The acoustical property has been determined in the special apparatus viz. ultrasonic monitoring triaxial apparatus for soil testing (UMTA) designed and fabricated by Singh and Jakhanwal (1982), and the geotechnical properties have been determined as per Indian standard code of practice given for respective tests.

The test results indicate that the acoustical velocity increases with the increase in percentage of $CaCO_3$ in the soil sample. The liquid limit, plasticity index, bulk compressibility and angle of internal friction can be empirically related with the *p*—wave acoustical velocity of the brine saturated silt—$CaCO_3$ matrices determined under an effective alround cell pressure of 0.5 kg/cm^2 in ultrasonic monitoring triaxial apparatus (UMTA).

The finding of the present research points towards the possibility of predicting the geotechnical properties of general marine soils by using non-destructive ultrasonic test techniques in future. However, due to the limited work done till now intensive experimental and theoretical work is needed before coming to the above conclusion in a final way. A check on the effect of mineralogical composition of marine soil on its acoustico—geotechnical properties is also required to be made.

Test Procedure

In this section the method of sample preparation and a brief resume of test procedure adopted are given.

Preparation of Sample

In order to make the results comparable it became necessary to prepare samples under uniform conditions in which only the percentage of $CaCO_3$ varied from sample to sample. To achieve this the following procedure for laboratory preparation of soil sample was adopted.

The locally available soil whose properties are listed below was air dried and then sieved through Indian Standard sieve No. 36.

Some basic properties of the local silt soil used are:

Specific gravity — 2.69
Liquid Limit % —22.45
Plastic Limit % —20.20
Plasticity Index — 2.25
Group classification —ML

The required percentages of $CaCO_3$ were added to the local soil. The value of liquid limit of this soil $CaCO_3$ mixture was determined separately by taking out small amount of sample from the bulk. The artificially prepared marine water (Gross, 1976) [refer Table-1] equal to twice the value of liquid limit was gradually added to the Soil—$CaCO_3$ mixture so as to get an uniform slurry. This uniform slurry was transferred to a modified C.B.R. mould (shown in Fig. 1). The load on the slurry was increased in small steps upto 1.5 kg/cm^2, starting from the seating load of 0.05 kg/cm^2. The sample was kept saturated during the entire process of consolidation.

TABLE 1

Composition of the marine water (after Gross, 1976) per 1000 gm of solution.

Nacl	— 23.48 gm	$NaHCO_3$	— 0.192 gm
$MgCl_2$	— 4.98 gm	KBr	— 0.096 gm
Na_2SO_4	— 3.92 gm	H_3BO_3	— 0.026 gm
$CaCl_2$	— 1.10 gm	$SrCl_2$	— 0.24 gm
KCl	— 0.66 gm	NaF	— 0.003 gm

When the sample became finally consolidated under this load of 1.5 kg/cm^2, the C.B.R. mould was taken out from the loading frame and the soil samples were extracted in the sampling tubes for triaxial soil testing.

The above procedure was repeated for soil samples containing different percentages (viz. 0%, 5%, 10%, 20%, 30% and 40%) of $CaCO_3$.

Determination of Acoustical Properties

The determination of acoustical property (p—wave velocity) was done in a special apparatus called ultrasonic monitoring triaxial apparatus for soil testing (UMTA). The schematic diagram of the apparatus is given in Fig. 2. The samples collected in the sampling tubes were extracted and trimmed to the standard size. Then it was placed in the UMTA as shown in the figure. Initially the cell pressure and the back pressure were increased simultaneously upto 1.5kg/cm^2. A back pressure of 1.5kg/cm^2 was found to be sufficient for completely saturating the sample under the application of back pressure by disolving the air present in the pores of the soil (Jakhanwal, 1983). Thereafter the back pressure was kept constant and the alround pressure was increased to 2.0kg/cm^2 so as to give an effective cell pressure of 0.5kg/cm^2. The sample was allowed to drain under this effective cell

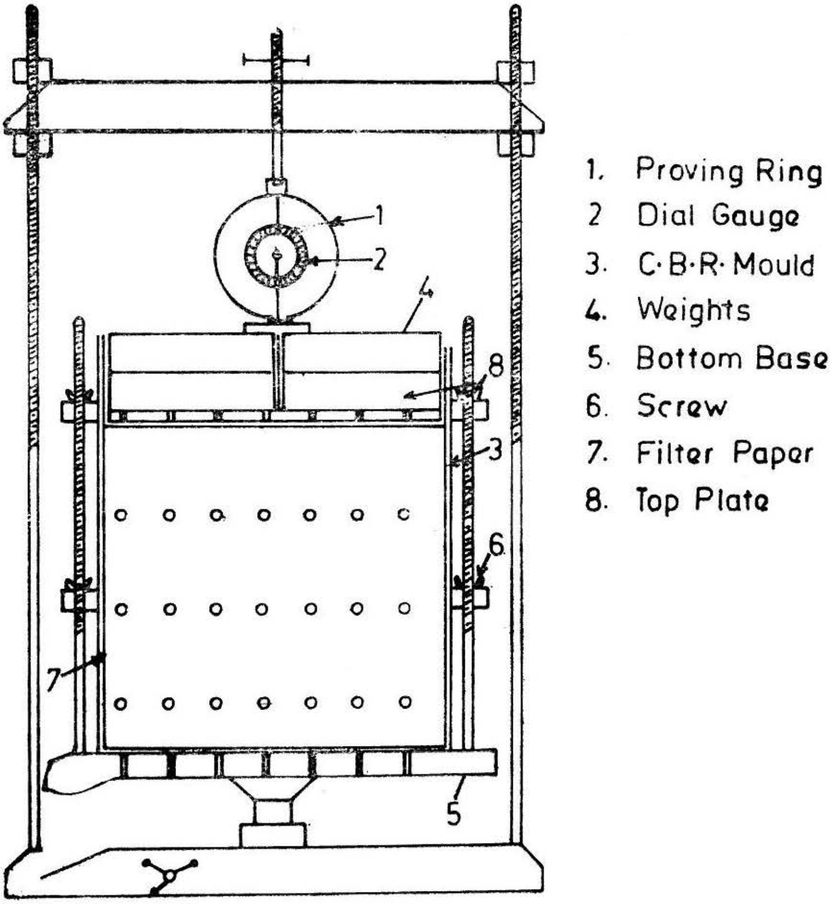

FIGURE 1 Loading Frame with C.B.R. Mould

pressure. When the sample got consolidated under this cell pressure completely, the time—lag between the transmitted ultrasonic pulse through the bottom probe and the received ultrasonic pulse through the top probe were determined. Calibration time—lag, which is the time taken by ultrasonic wave to travel between the transmitting probe and the receiving probe (without sample) was deducted from the total time—lag to get the time of travel of wave through the soil sample only. The length of the sample divided by the time of travel of the above wave through the soil sample gave the value of acoustical velocity through the soil sample.

Determination of Geotechnical Properties

The liquid limit, plastic limit, bulk compressibility, cohesive strength and angle of internal friction were determined in the laboratory in case of each

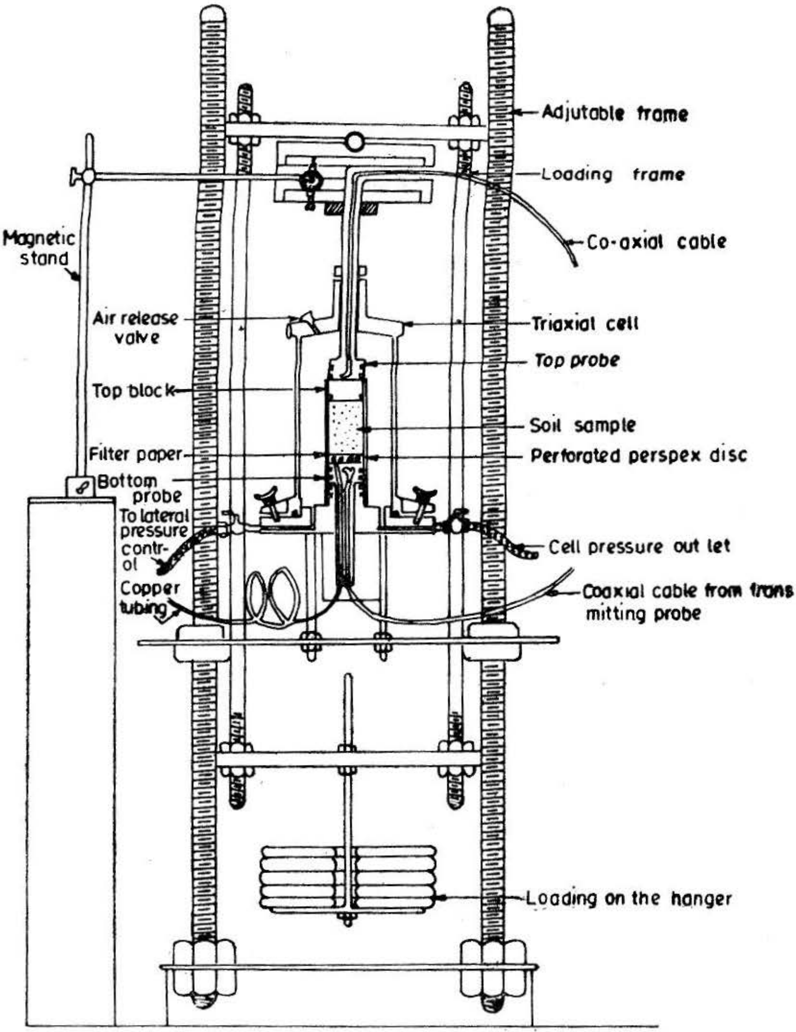

FIGURE 2 Ultrasonic Monitoring Triaxial Appratus 'UMTA'

sample as per the recommendations of Bureau of Indian standard for the various tests. The soil classification test results of the various $CaCO_3$—silt matrices used in the test are given in Table-2.

Test Results

The observed test results have been presented in the following figures.

Fig. 3 represents the variation of liquid limit (*L.L.*) with the variation of percentage of $CaCO_3$ in the soil sample.

TABLE 2

Soil classification test results.

% of $CaCO_3$	specific gravity	liquid limit	plastic limit	plasticity index	soil type
0	2.69	22.45	20.20	2.25	ML
5	2.67	27.50	21.64	5.86	ML
10	2.66	29.84	24.00	5.84	ML
15	2.65	32.22	26.10	6.12	ML
20	2.60	36.20	28.00	8.20	MI
30	2.58	42.10	32.10	10.00	MI
40	2.57	48.00	36.00	12.00	MI

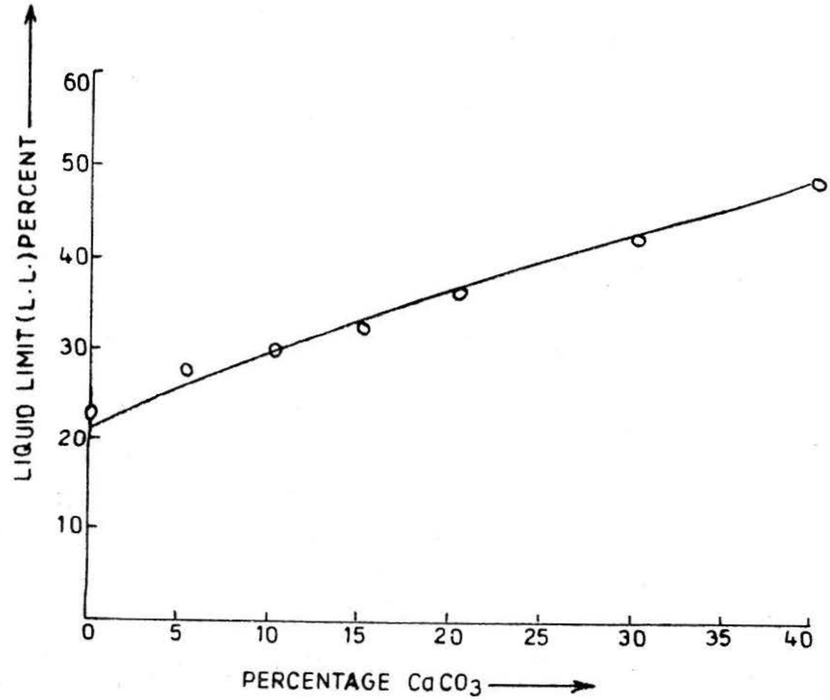

FIGURE 3 Variation of Liquid Limit with % $CaCO_3$

Fig. 4 represents the variation of plasticity index (*P.I.*) with the variation of percentage of $CaCO_3$ in the soil sample.

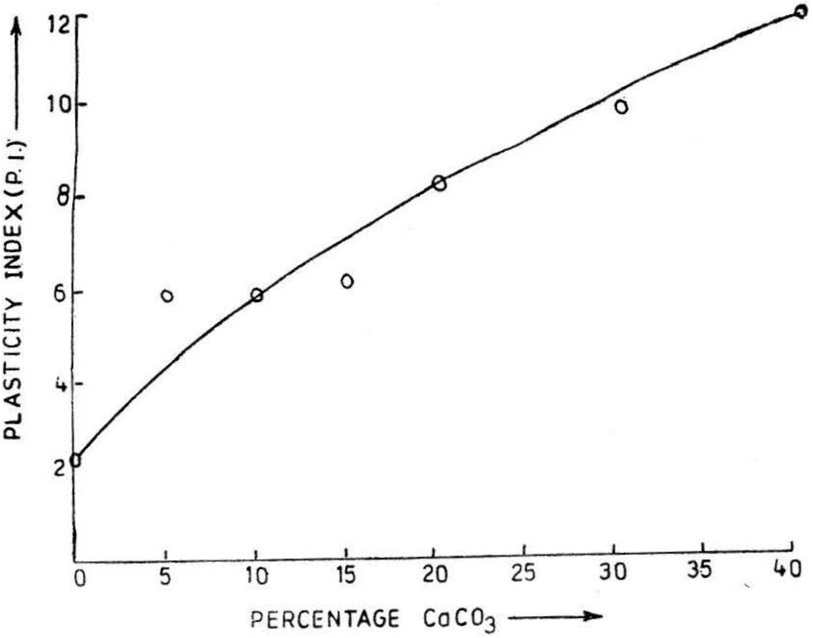

FIGURE 4 Variation of Plasticity Index with % $CaCO_3$

Fig. 5 represents the variation of Bulk compressibility (C_b) with the variation of percentage of $CaCO_3$ in the soil sample.

Fig. 6 represents the variation of cohesive strength (c) with the variation of percentage of $CaCO_3$ in the soil sample.

Fig. 7 represents the variation of Angle of internal friction (ϕ) with the percentage of $CaCO_3$ in the soil sample.

Fg. 8 represents the variation of Acoustical velocity (V_n) with the percentage of $CaCO_3$ in the soil sample.

With the help of the test results mentioned above the following graphs are deduced for correlating the acoustical properties of brine saturated carbonate soils with their corresponding geotechnical properties.

Fig. 9 represents the variation of liquid limit (L.L.) with acoustical velocity of the soils containing different percentages of $CaCO_3$. The nature of the curve indicates that with the help of acoustical velocity the liquid limit of the soil can be predicted. An empirical equation governing the relationship between the acoustical velocity and liquid limit has been obtained, which is given below.

$$V_n = 1000 \log (L.L.) + 318 \tag{1}$$

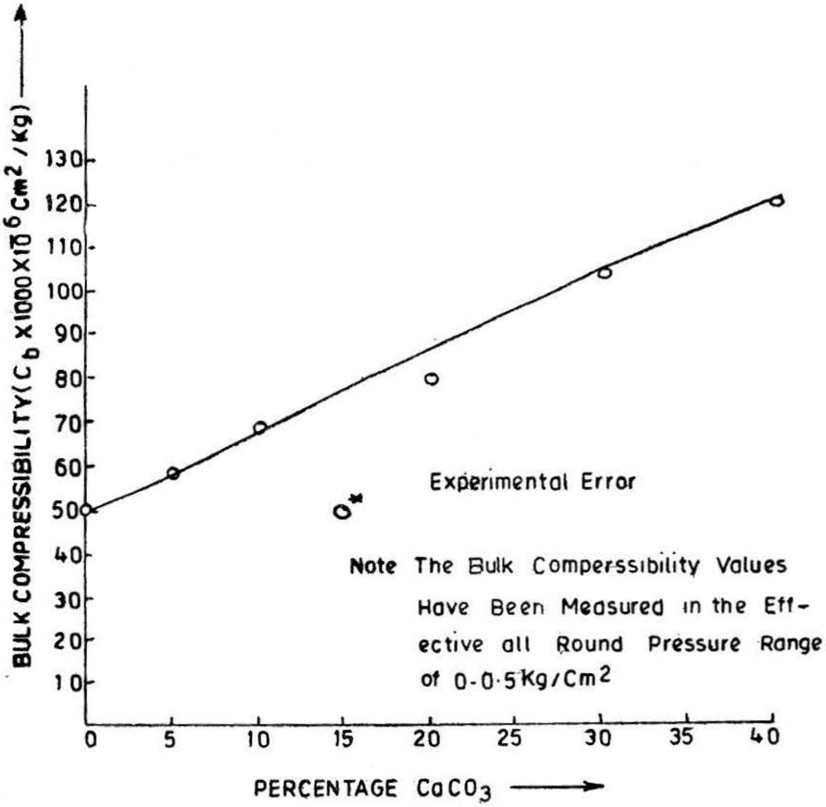

FIGURE 5 Variation of Bulk Compressibility with % $CaCO_3$

Fig. 10 can be used for predicting the plasticity index (*P.I.*) of the soils tested with the help of acoustical velocity. An empirical equation for correlating the acoustical velocity with the plasticity index of the soil has been derived. The derived relationship is as follows

$$V_n = 777.78 \log (\text{P.I.}) + 748.9 \qquad (2)$$

Fig. 11 represents the correlation curve obtained for predicting the bulk *compressibility* (C_b) *of soil with the help of* acoustical velocity data.

Fig. 12 represents the correlation curve between the cohesive strength (c) and the acoustical velocity of the soil.

Fig. 13 represents the variation of Angle of internal friction (ϕ) with the acoustical velocity of the soil. The empirical relationship derived for correlating angle of internal friction with the acoustical velocity is given below.

$$\phi^\circ = -0.03V_n + 82.5 \qquad (3)$$

Fig. 14 represents the variation of Acoustical velocity (V_n) with the increase in percentage of $CaCO_3$ in the soil sample. The nature of the curve indicates that the acoustical velocity increases with the increase in percentage of $CaCO_3$ in the sample. However the rate of increase in acoustical velocity

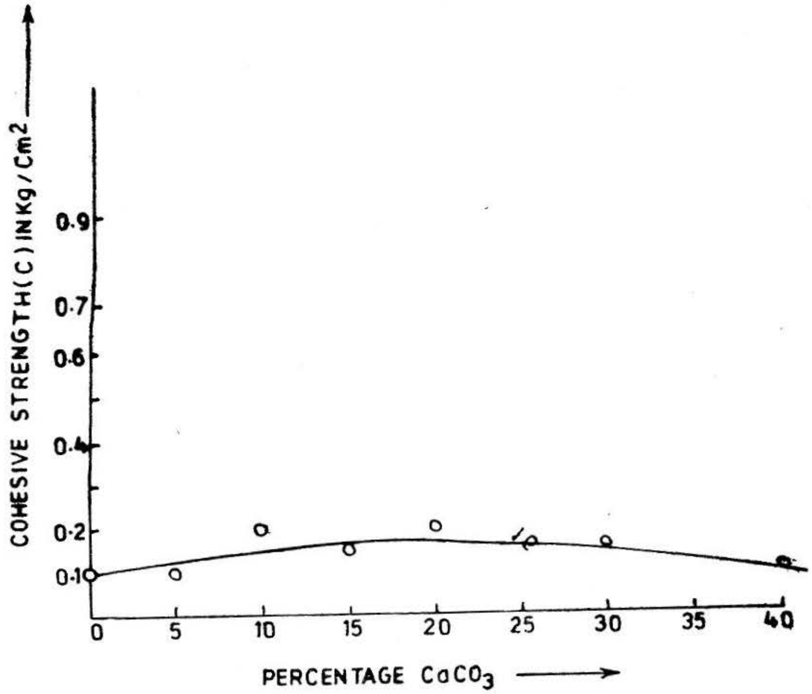

FIGURE 6 Variation of Cohesive Strength with $CaCO_3$

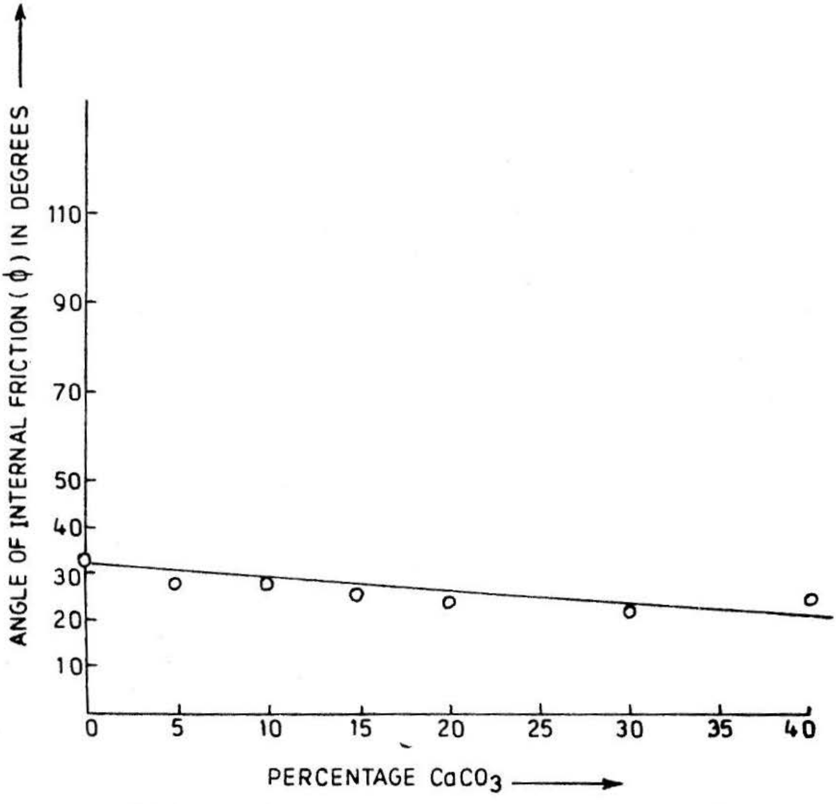

FIGURE 7 Variation of Angle of Internal Friction with % $CaCO_3$

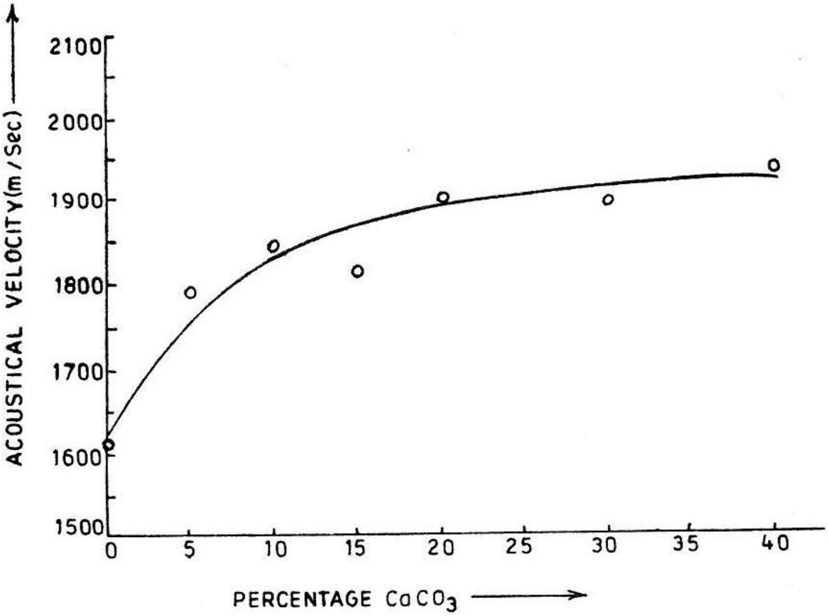

FIGURE 8 Variation of Acoustical Velocity with % $CaCO_3$

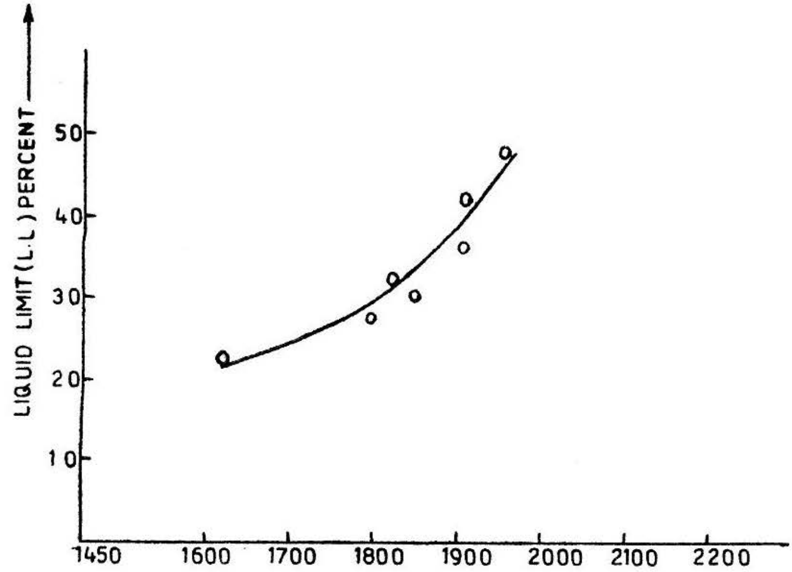

FIGURE 9 Variation of Liquid Limit With Acoustical Velocity

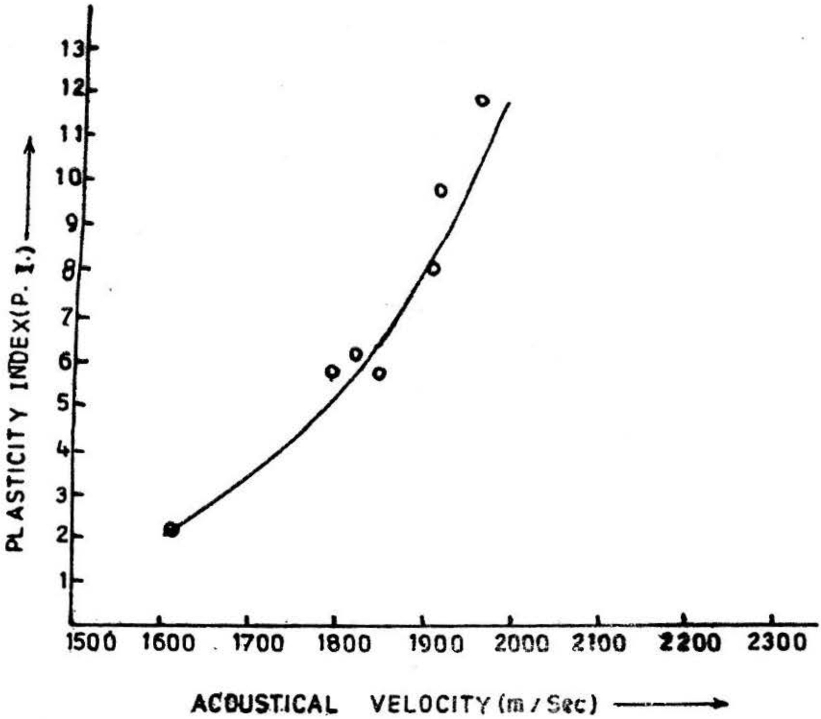

FIGURE 10 Variation of Plasticity Index with Acoustical Velocity

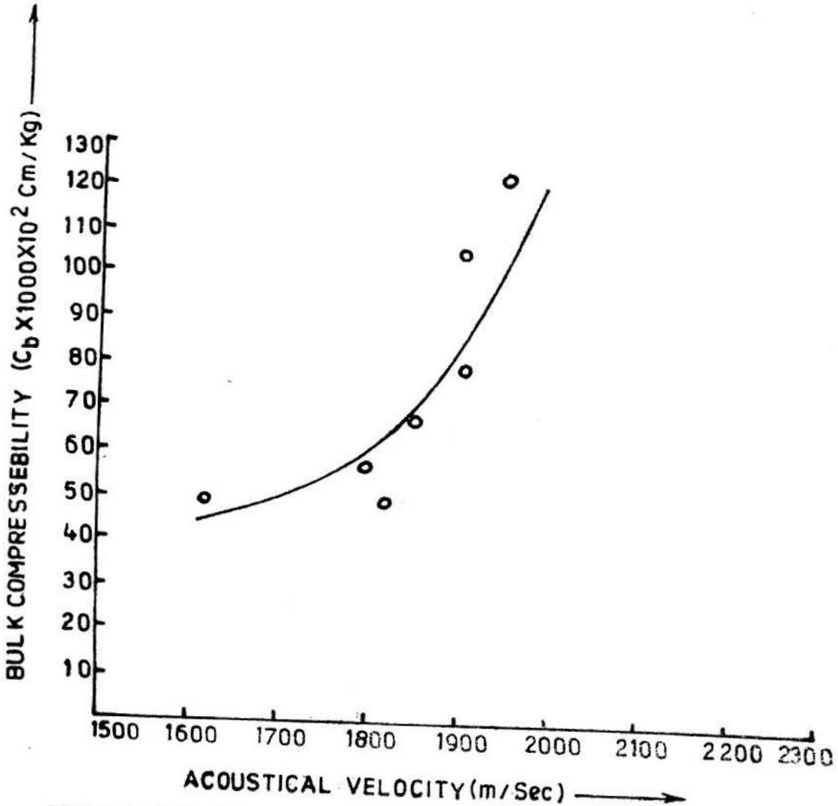

FIGURE 11 Variation of Bulk Compressebility with Acoustical-Velocity

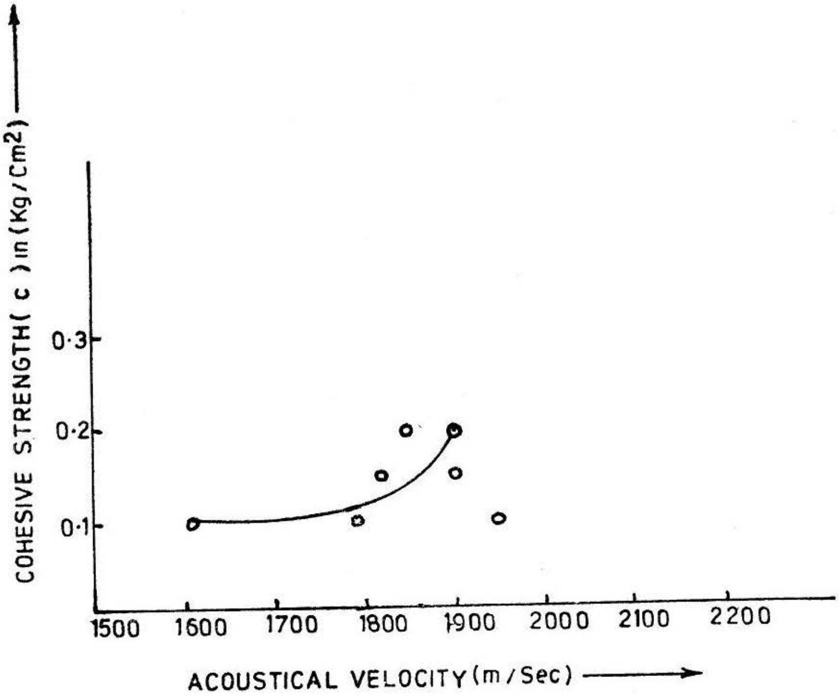

FIGURE 12 Variation of Cohesive Strength with Acoustical Velocity

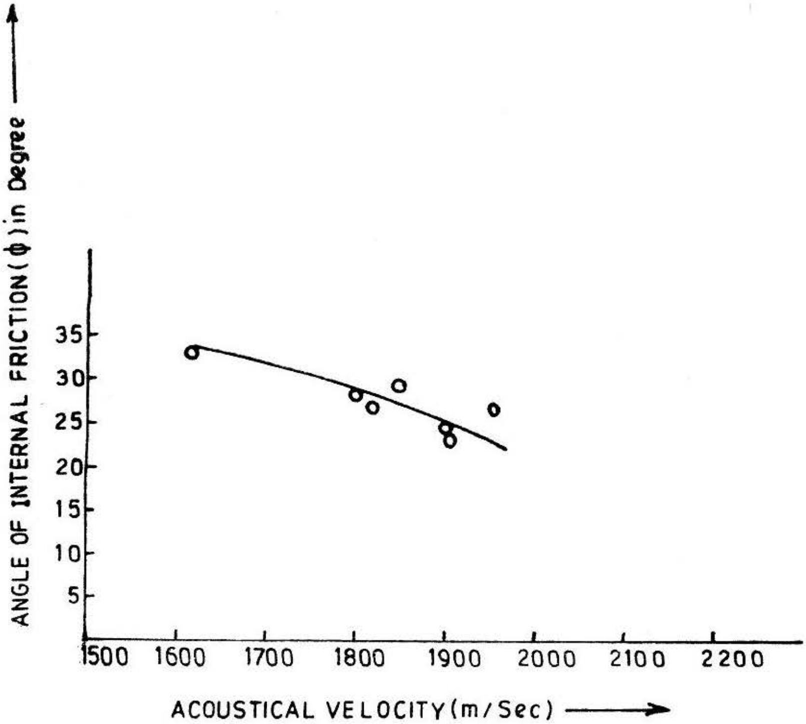

FIGURE 13 Variation of Angle of Internal Friction with Acoustical Velocity

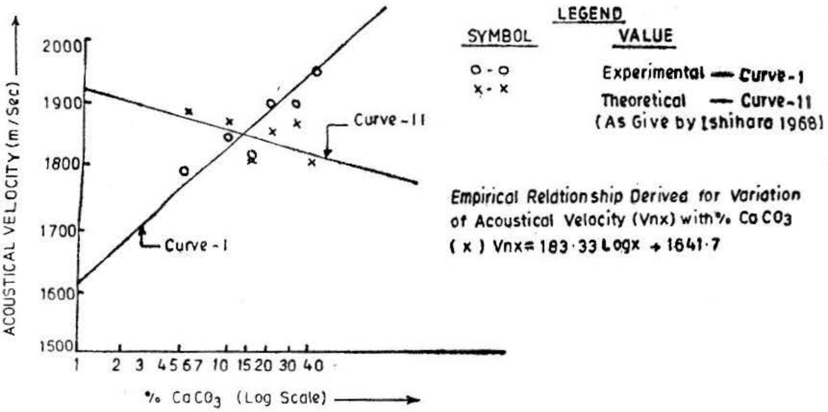

FIGURE 14 Variation of Acoustical Velocity with % $CaCO_3$

values with the increase in percentage of $CaCO_3$ decreases after following a steep rising trend during the initial stages of increase in the percentage of $CaCO_3$ (*i.e.* 15% $CaCO_3$). The acoustical velocity values measured during the tests conform to the value ranges obtained by Hamilton *et. al.* (1956), Murty and Muni (1957). The theoretical curve drawn by using equation given by Ishihara (1968) has also been presented in this figure as curve II. It may be noted that curve II pertains to non carbonate soils only, and the curve I has been obtained experimentally for the marine simulated carbonate soils.

Discussion of Test Results

The curves given in figures 3 and 7 indicate that the geotechnical properties of brine saturated soils (such as: liquid limit, plasticity index, bulk compressibility, cohesive strength and angle of internal friction) depend upon the carbonate content in the soil. A definite trend of variation is observed in case of all the geotechnical properties mentioned above except that for the cohesive strength. The reason for this particular exception in case of cohesive strength only could not be ascertained during the course of the present research.

However, the colloidal properties of the $CaCO_3$ particles used may have to be investigated.

Figure 8 indicates that the acoustical velocity of carbonate soils also depend upon the carbonate content in the soil. The increase in acoustical velocity with the increase in the percentage of $CaCO_3$ in the sample is in conformity with the earlier findings of Jakhanwal and Singh (1983). Figure 9 indicates that the acoustical velocity increases with the liquid limit and hence it can be said that for carbonate soils the liquid limit and the acoustical velocity both increase with the carbonate content in the soil. The empirical relationship derived between the acoustical velocity and the liquid limit points towards the possibility of developing non destructive test parameters in future for the prediction of liquid limit with the help of *P*-wave acoustical velocity of the soil samples determined under standard test conditions described in the text of the paper. Similar findings are made in case of prediction of plasticity index and angle of internal friction with the help of *P*-wave acoustical velocity (Refer Figs. 10 and 13). Figures 11 and 12, which represent the variations of bulk compressibility and cohesive strength with acoustical velocity have got poor coefficient of correlativity. Fig. 14 gives the variation of acoustical velocity with the carbonate content in the soil. The curve I gives the strainght line variation of the same with good coefficient of correlativity. Except for figures 11 and 12 the coefficient of correlativity for all the correlation curve varies in the range 0.78—0.99.

Although the number of test results are limited, they indicate towards an emerging field of research in the areas comprising of geotechnical engineering and non destructive testing of soils under full saturation conditions, which are similar to that of marine conditions. However, detailed investigations are required to verify the results further. Further research work is recommended in this direction.

Conclusion

The limited research work conducted on brine saturated carbonate silty soils under full saturation conditions indicate that the acoustical and geotechnical properties of such type of soils depend upon the percentage of $CaCO_3$ in the soil sample. The trend of the test results indicate the liquid limit, plasticity index, bulk compressibility, angle of internal friction and acoustical velocity have a straight line variation with the percentage of $CaCO_3$ in the soil sample on a semi-log scale. However the trend of variation of cohesive strength with $CaCO_3$ is not a straight line, the reason for this variation needs further investigations.

Special empirical relationships have been developed for predicting the values of liquid limit, plasticity index and angle of internal friction of the soils with the help of the acoustical velocity determined undeı the alround pressure of $0.5 kg/cm^2$ using a special apparatus called ultrasonic mointoring triaxial apparatus (UMTA) which was designed and fabricated by the first author. These results also indicate that there exists some possibility of predicting the geotechnical properties of soils non-destructively. However, extensive research work is suggested to be undertaken by different agencies in order to consider all the aspects, such as stress history, type of soil, minaral composition etc. A much closure study of the variation of *P*-wave acoustical velocity with the change in percentages of $CaCO_3$ is also recommended.

References

ABBOTT, 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". *Jr. of Acoustical Society of America,* Vol. 28. p. 168-191.

GROSS, M. and Grant., (1976), "Oceanography". Charles E. M Grawhill Publishing Co. Columbus, p. 52.

HAMILTON, E.L. and et. at., (1956). "Acoustic and other Physical properties of Shallow water Sediments off San Diego". *Jr. of Acoustical Society of America,* Vol. 28, No. 1, p. 1-15.

HENKEL, D.J. (1959) : "The Relationship between Pure-Water pressure and Volume Change characteristics of Saturated Clays." *Geotechnique,* Vol. 9. No. 3, p. 119-135.

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

JAKHANWAL, M.P. and SINGH R.B, (1983): "UMTA and SEM Studies of Some Off-shore Soils from Bombay High." *Proc. Second Indian Conf. in Ocean Engineering* (*INCOE*-83), Central Water and Power Research Station, Pune-1359-63.

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

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

MURTY, G.R.K. and MUNI, M.M., (1987) :"A study of some Physical properties of Sediments of the Back waters and Adjoining Continental Shelf off Cochin, India, Marine Geology, p. 121-128.

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

SCHULTZE, E. and HORN, A., (1965) : "The Shear Strength of Silt." *Proc. VI Int. Conf. Soil Mech. and Foundation Engg.* Vol I, p. 350-353.

SADANA, M.L., (1978): "Consolidation and Shear Strength characteristics of Normally consolidated Silty-Clay Matrices and Related Microstructures," Ph. D. Thesis, Banaras Hindu University, Varanasi-221005 (India).

SINGH, R.B. and JAKHANWAL, M.P., (1982): "Ultrasonic Monitoring Triaxial Apparatus for Soil Testing." *Journal of Pure and Applied Ultrasonics,* Vol. No. 1, P.B.-11.

SHITMAN, R.V., (1960): "Some consideration and Data Regarding the Shear Strength of Clays, "*Proc. A.S.C.E. Res. Conf.* Shear Strength of Cohesive Soils, Boulder, Colorado, P. 581-614.