Study the Inter-Relationship between Index and Engineering Property of Clayey Soil by Ultrasonic Pulse Velocity Test

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Abstract- *This paper aims at investigating the ultrasonic and properties of clay soil like dry density, water content and bulk density, compressive strength by adopting the direct transmission method Cylindrical soil specimens (50 mm diameter and 100 mm height) were produced to perform a series of uniaxial compressive strength test. The ultrasonic waves were transmitted and received by P-wave and the ultrasonic travel time and amplitude were recorded by an ultrasonic detector during the whole deformation process. Unconfined compressive tests were also conducted on compacted samples of 38 mm diameter to establish the relation between compressive strength and pulse velocity. Soil tested and exhibited an increasing pulse velocity with increase in dry density until the optimum water content. A rapid drop in pulse velocity was observed subsequently with decrease in density. This observation is in conformity with the findings of earlier various investigators.*

Keywords- Ultrasonic pulse velocity test, dry density, water content, bulk density, compressive strength.

I. INTRODUCTION

Soil is supposed to be most complex material regarding the various civil engineering projects. For determination of its index and engineering properties, particularly on field, we commonly use direct methods which are destructive tests as well. For ex. in situ density is determined by sand replacement method, core cutter method which are destructive tests. However these methods are time consuming and frequently halt the construction. So, for quicker assessment, non-destructive methods are used. In this method some properties can be correlated with the parameter, which can be measured easily. Non-destructive methods most commonly include nuclear density test, electrical resistivity and cone penetration test. However these methods are not as popular as conventional testing methods among the practicing engineers because of their less accuracy and practical difficulty in using them. Soils are compacted in situ for various engineering activities such as the construction of embankments, pavements, hydraulic barriers, etc., In the constructed structure, the Stress-strain and strength properties of the compacted soil are very important. Since these properties are functions of dry density and water content, specifications laid for the construction require, that each layer of soil to be compacted to some stated density at a particular moisture content. The minimum density and water content at which the soil is to be compacted at field is normally decided through the laboratory compaction test. But verifying the same at field is an important task. This is commonly carried out by direct measurement of in situ density through destructive tests such as sand cone replacement method, rubber balloon method, core cutter method and drive cylinder test. These tests are carried out in various layers of the compacted soils. However, these methods are time consuming and frequently halt the construction activities. For the quicker assessment, non-destructive methods are used. In the non-destructive methods, density and water content are correlated to a third parameter, which can be measured easily. Non-destructive methods that are most common include nuclear density test, electrical resistivity method and cone penetration test. These methods correlate soil density with nuclear absorption, electrical resistivity and penetrometer resistance respectively. However these methods are not as popular as the conventional testing methods among the practicing engineers because of less accuracy and practical difficulty in using them. Ultrasonic Pulse Velocity method hitherto used to assess the quality of concrete, asphalt, metals, etc., is being tried to predict some of the physical and engineering properties of soils by geotechnical researchers. Though the conceptual relation between these parameters has been assessed, the correlation among them is not established. Further, the studies on strength and elastic properties of compacted soil with pulse velocity are very limited. Hence the study aims to correlate velocity with compaction parameters, strength and elastic property of soil. Tests were conducted on laboratory compacted clayey soils having different plasticity. The variables investigated are compaction energy, method of compaction and size of samples.

II. LITERATURE REVIEW

An extensive literature review has been conducted in line with the titled research plan to find out the current level of research and identify the gaps in study .the salient feature of the most relevant works are presented in following text.

David M. Weidinger, Louis Ge, and Richard W. Stephenson[1] studied The analysis of ultrasonic pulse velocity tests on compacted soil is attributed to Weidinger D.M et, al. The material is classified by the Unified Soil Classification System as an ML. The standard proctor compaction curve for this particular soil is shown in Figure1. The calculated Poisson's ratio was compared to an assumed range of values. The actual Poisson's ratio of the silt is unknown, but an appropriate range can be assumed. Typically, Poisson's ratios for sands range from 0.2 for loose sands to 0.4 for dense sands. Poisson's ratios for clays range from 0.4 to 0.5 for saturated clays (Holtz and Kovacs, 1981). The soil used for these tests is a densely compacted low plastic slit with 17% clay content. This places the Poisson's ratio in the range of 0.35 to 0.40, depending on the moisture content .The Poisson's ratio ranged from 0.41 in the stiff, low moisture content samples to 0.34 for the softer samples at higher moisture contents and lower dry density. The average Poisson's ratio for all tests was 0.38 with a standard deviation of 0.02 which confirmed the assumed range of the Poisson's Ratio was between 0.35 and 0.40. P wave velocities obtained from ultrasonic pulse velocity measurements were ranging from 260 m/s to 390 m/s while the S-wave velocities were ranging from 110 m/s to 180 m/s. The maximum shear wave velocities occurred in the soil samples prepared dry of the optimum moisture content and decreased with increasing moisture content and saturation. Finally, presenting plots in bulk density versus wave velocity gives a clearer trend than dry density versus wave velocity.

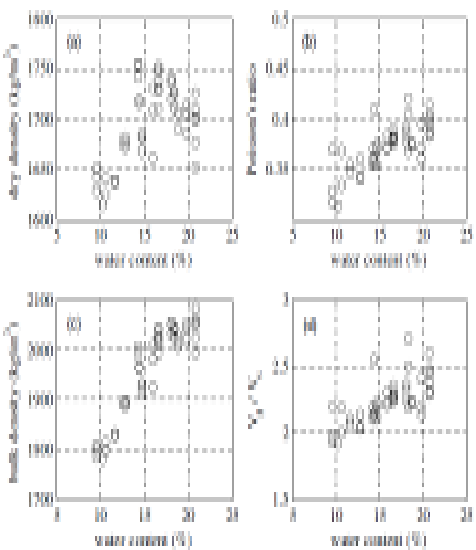


Fig 1: Density, Poisson's ratio and wave velocity ratio versus water content.

Desislava z. slavova, david m. weidinger, adam f. sevi, and louis ge.[2] Evaluation of Compacted Silt Characteristics By Ultrasonic Pulse Velocity Testing is attributed Soil sample low plasticity silt,

With a yellow colour. The liquid limit of the material is 30, and the plastic limit is 24. The material contains 17.0 % natural clay. The silt was classified using the USCS Class System as ML. Ultrasonic pulse velocity testing is a relatively easy to perform test that investigates the p wave and s-wave velocity of a given soil. The two major components to determine the wave velocities were the sample height and the wave arrival time. The wave data was filtered to exclude noise allowing the wave arrival time was determined. In this study two different compaction molds were used for compacting a single silt soil. Specimens were prepared in the Proctor compaction mold, and in a smaller 71.1 mm (2.8-inch) diameter compaction mold. Two different compaction efforts were used when preparing soil in the two molds. Namely, the standard and modified Proctor compactive efforts. Specimens prepared in the 152.4-mm (6-in) diameter Proctor mold were trimmed to 2.8-inch diameter before testing. In this manner all test specimens were tested using the same diameter. Generally, slightly higher wave velocities were found for samples of higher dry unit weight. The smaller compaction mold could be used for compacted specimens in place of the larger mold, but care and experience are needed in order to match target values on a given compaction curve. Lower wave velocities were observed at higher moisture contents; however, regardless of compaction mold sizes and compactive effort, the wave velocities show the strongest correlation with variations in moisture content.

K. Kumar [3] studied was the Study of Relative density and ultrasonic pulse velocity inter-relation of pilani sandy and silty clay soil. Calibration curve has been developed to estimate maximum and minimum dry density for soil samples by knowing ultrasonic pulse velocity through them. Objective of their study was to estimate dry density of soil in loosest as well as in the densest state, using some simple technique. Determination of ultrasonic pulse velocity through soil sample has been used for this purpose. Based on observed variation of maximum and minimum dry density and ultrasonic pulse velocity with silty clay content, calibration curve has been developed to estimate maximum and minimum dry density for soil samples of the region of study. Calibration curves developed in the study cover a wide range of silty clay content. Most of the soil samples in the region of study is sandy and will have silty clay content in the range as used to develop calibration curves in present study. Consequently, calibration curves developed in present study can be used for most of the soils collected from the region of study. Calibration curve has been developed to estimate maximum and minimum dry density of soil samples by knowing ultrasonic pulse velocity through them. Determination of ultrasonic pulse velocity requires relatively small amount of soil as well as relatively simple experimental set-up, consequently calibration curves of present study are of great significance. Same principle can be used for soil samples of other region also. Similar calibration curves can be developed to estimate maximum and minimum dry density by knowing ultrasonic pulse velocity through these soil samples as well. Once dry density of soil in the loosest as well as in the densest state is estimated through ultrasonics, relative density of soil can be estimated if in-situ dry density of soil is known. Consequently, estimation of relative density using technique suggested in this paper is quite useful.

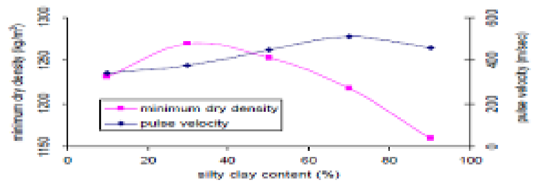


Figure 1 Ultrasonic pulse velocity, minimum dry density interrelation

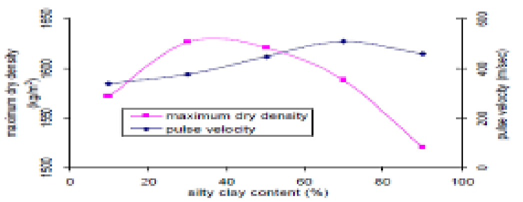


Figure 2 Ultrasonic pulse velocity, maximum dry density interrelation

Fig2: Ultrasonic pulse velocity, maximum dry density interrelation

T.Senthilmurugan et, al. [4] studied on Compaction Characteristics and Strength through Ultrasonic Method Soil sample: 130 clayey soil samples. They took soil samples of three particular regions, name it as soil1, 2and 3. Various index properties are calculated and soil 1 and 2 are classified a clays of high plastic whereas the soil3 falls in CL group. Investigated properties compaction energy, method of compaction, soil type, specimen size and water content.Conclusions are drawn. Irrespective of the type of soil, method of compaction and energy of compaction, the relation between velocity and water content established an identical relation to that of a typical compaction characteristic curve of Proctor (1933) and is also in comparison with the observations reported by Yesiller et al (2000). Peak velocities and maximum densities were within ± 1% water content for the two clay types tested. These observations were similar to that reported by Sheeran et al (1967) and Yesiller et al (2000).The pulse velocity increased with compaction energy and decreased with plasticity. The relation between velocity and density is linear for the soils tested. Unconfined compressive strength and secant modulus of compacted soils were correlated with velocity and are found to vary exponentially with velocity. The validation of empirical equations proposed in this study for predicting density, water content, compressive strength and secant moduli, through a fresh set of data of another soil of Chennai (Minjur village) is encouraging. Though the findings of this study are encouraging and support the use of ultrasonic pulse velocity technique as another method to assess the quality of compaction, strength and elastic property of soils, it has the following limitations. The equations proposed in this study need field investigations. Direct transmission adopted in this study cannot be extended to the field compacted soils without sampling. The effect of microstructure variation of compacted soil on velocity is not considered in this study. Conclusions drawn are valid for the two types of soils tested. The quality of compaction can be assessed reasonably only on the samples compacted at dry side of OMC and OMC. Density can be monitored better than the water content, because two values of water content are possible for a given P wave velocity. The evaluation of moisture content for the dry and wet side of compaction needs two independent relations among the parameters. Despite the limitations brought out in this study, this technique can be continued to assess the adequacy as an auxiliary method to investigate the compaction and mechanical properties of soils.

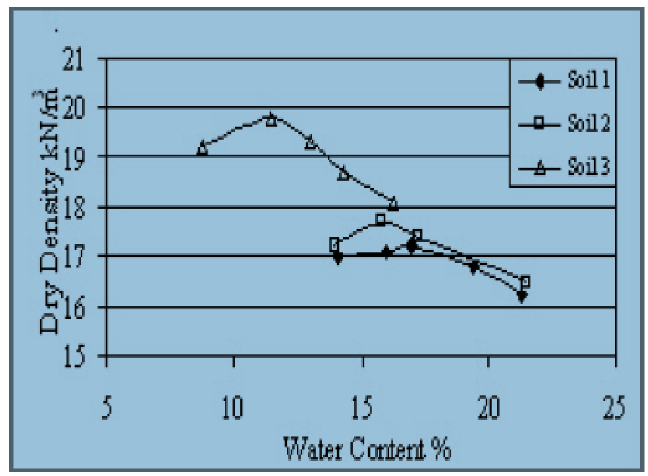


Fig3.Compaction Characteristics: Modified Dynamic Compaction

III. METHODOLOGY

Present study is focused on the relation between ultrasonic pulse velocity, engineering and index properties of soil.

- Certain relation between pulse velocity and compaction density can be obtained.
- Velocity and compressive strength can be correlated.
- Interrelationship between relative density of soil and ultrasonic pulse velocity can also be established.

1. Working of ultrasonic pulse velocity

At a construction site, a technician tests a pipeline weld for defects using an ultrasonic phased array instrument. The scanner, which consists of a frame with magnetic wheels, holds the probe in contact with the pipe by a spring. The wet area is the ultrasonic couplant that allows the sound to pass into the pipe wall. In ultrasonic testing, an ultrasound transducer connected to a diagnostic machine is passed over the object being inspected. The transducer is typically separated from the test object by a couplant (such as oil) or by water, as in immersion testing. However, when ultrasonic testing is conducted with an Electromagnetic Acoustic Transducer (EMAT) the use of couplant is not required.

There are two methods of receiving the ultrasound waveform: reflection and attenuation. In reflection (or pulse-echo) mode, the transducer performs both the sending and the receiving of the pulsed waves as the "sound" is reflected back to the device. Reflected ultrasound comes from an interface, such as the back wall of the object or from an imperfection within the object. The diagnostic machine displays these results in the form of a signal with an amplitude representing the intensity of the reflection and the distance, representing the arrival time of the reflection. In attenuation (or through-transmission) mode, a transmitter sends ultrasound through one surface, and a separate receiver detects the amount that has reached it on another surface after traveling through the medium. Imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

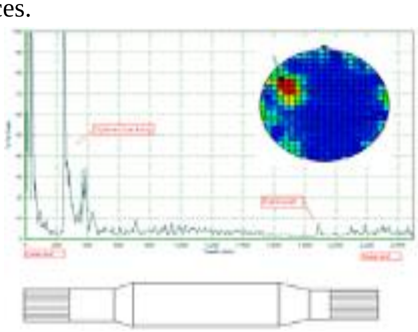
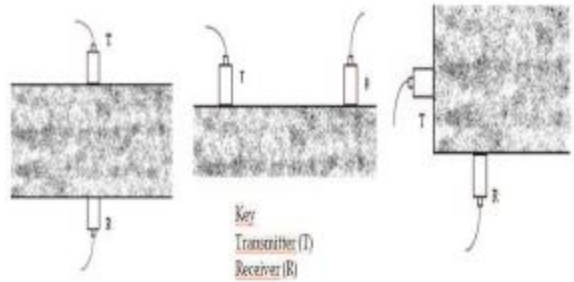


Fig 4: Non-destructive testing of a swing shaft

1.1 Direct method of Pulse velocity Determination

The direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer; however, it is possible to detect pulses travelling through sample in some other direction. In other words it is possible, to make measurements of pulse velocity (BS 12504-4, 2004) by placing the two transducers on either:

a. opposite faces - direct transmission ,
b. adjacent faces - semi-direct transmission ;
c. the same face - indirect or surface transmission .



(a) Direct Transmission (b) Indirect or surface Transmission (c) Semi-direct Transmission

Direct transmission is the most sensitive than indirect transmission which is least sensitive. Direct transmission is possible to apply when two faces of the sample are available for testing. The velocity V, is calculated from the distance between the two transducers and the electronically measured transit time t of the pulse as:

Velocity =Length/Time

Properties of the soil selected for test are determined and which are as follows:

Table no 1: Properties of soil selected for test

SN	Description	Properties
1	Liquid limit	41
2	Plastic limit	15
3	Plasticity index	26
4	Classification	CL
5	OMC	16.5%
6	MDD	17.52kN/m^2

1.2 Specimen preparation and testing

- The soil material was first pulverized then passed through a 425 mm sieve. Water was added to the dry soil to prepare at various moisture content samples.
- The moisture content between the samples varied from 10 % to 19 %
- Soil specimen were compacted in a proctor mould (capacity 2250cc, internal diameter 150mm, effective height 127.3mm) and a rammer for compaction (face diameter 50mm mass of 2.6 kg free drop 310mm)
- After achieving the desired compaction, the mould was trimmed down. The top and bottom surface s of the specimen were smoothed in order to allow better

transition of the ultrasonic waves. Then that compacted soil sample has been extracted from the mould.

- Smoothing of the top and bottom surfaces to allow transition of the ultrasonic waves was not simple. Then the ultrasonic test system was used and the time was recorded.
- After the velocity determination, with the help of sampling tubes samples has been extracted in a split mould of diameter 100mm.
- Unconfined compressive strengths were calculated for those samples.
- Bulk Density of those individual samples were also determined

In this manner the wave velocity, bulk density, and compressive strength of the samples were found.

III. RESULT AND DISCUSSION

The test was conducted on selected soil samples and the obtained results are:

Length of sample= 0.133m, diameter of sample= 0.1m

Table no. 02: Ultrasonic pulse velocity on soil samples

Sample	Time (sec)	velocity	Sample	Time	velocity
1	876.03	151.82	10	360	369.44
2	620	214.51	11	355	374.64
3	508	261.81	12	352	377.84
4	449	296.21	13	350	380
5	442	300.9	14	342	388.88
6	441.42	301.3	15	351.26	378.63
7	406	327.58	16	355.76	373.84
8	390	341.02	17	361.88	367.52
9	372	357.52	18	378	351.82

Table no. 03: Density of clayey soil samples

Sam -ple	Wt. of cylindrical soil specimen (kg)	Bulk density (kN/m²)	Sam -ple	Wt. of cylindrical soil specimen (kg)	Bulk density (kN/m²)
1	876.03	151.82	10	360	369.44
2	620	214.51	11	355	374.64
3	508	261.81	12	352	377.84
4	449	296.21	13	350	380
5	442	300.9	14	342	388.88
6	441.42	301.3	15	351.26	378.63
7	406	327.58	16	355.76	373.84
8	390	341.02	17	361.88	367.52
9	372	357.52	18	378	351.82

Table 4: Compressive strength of soil samples

Sample	Compressive strength (kN/m²)	Sample	Compressive strength (kN/m²)
1	55.02	10	101.42
2	61.73	11	105.22
3	81.13	12	105.89
4	91.71	13	107.15
5	91.79	14	109.89
6	97	15	109.89
7	98.56	16	112.35
8	98.58	17	112.95
9	100.52	18	120

The above results were calculated and the calibration curve was developed between velocity, bulk density and compressive strength. The observations of the curve can see and discussed accordingly.

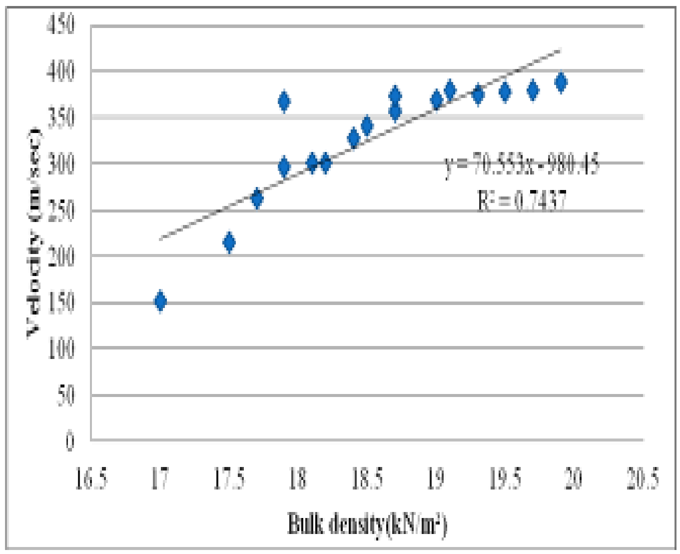


Fig 5: Velocity vs. Bulk density

- The relation between the density and velocity are analyzed
- For a given soil, the velocity increased with increase in density.
- The linear relation obtained through regression analysis between velocity and density is given in following equation, $y = 126.84\ x - 1745.3$ $R^2 = 0.7257$
- The correlation coefficient ($R^2 = 0.7257$) for the above equation which shows reasonable association between the two parameters investigated

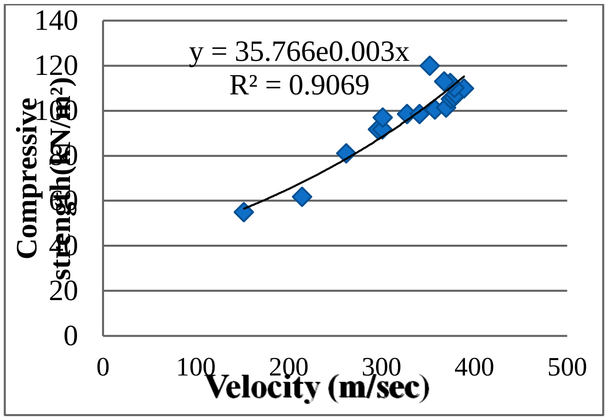


Fig 6: Variation of velocity with compressive strength

- Unconfined compressive strength measured on the soil samples are related with velocity of propagation of ultrasonic waves as both of them are functions of density and moisture content independently.
- The compressive strength increases exponentially with increase in velocity.
- Exponential curve fitting resulted in the following equation, $y = 35.766\ e\ \hat{}(0.003\ x)$ $R^2 = 0.9069$

IV. CONCLUSION

In this study soil specimen were tested and pulse velocities were measured by direct transmission method The parameters investigated were soil type, bulk density, compressive Strength. Based on the results following conclusions are drawn.

- The relation between velocity and density is linear for the soils tested.
- Unconfined compressive strength of the soil sample was correlated with velocity and is found to vary polynomial with velocity.
- The empirical equations proposed in this study for predicting density, Compressive strength is encouraging.

This technique can be used to assess the adequacy as an auxiliary.
method to investigate the compaction and density of soil

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