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Influence of Different Parameters on Shear Wave Velocity

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Abstract: Subsurface conditions play a major role in the damage potential of earthquakes. Local geological conditions generate significant amplification of the ground motion. The simple way to characterize the site condition is by estimating the shear wave velocity. The main objective of this paper is to evaluate the influence of silt content, density and confining pressure in the shear wave velocity. Soil samples were collected from different locations of College of Engineering, Guindy campus for conducting the bender element (BE) test. The shear wave velocity(V_s) determined from bender element test for the respective field density were compared with shear wave velocity obtained from Multichannel Analysis of Surface Wave (MASW) test. For understanding the influence of above mentioned parameters the bender element tests were carried out. The important conclusions arrived through the studies are increase in density and confining pressure increases the shear wave velocity but increase in silt content decreases the shear wave velocity. The maximum variation in the shear wave velocity determined from laboratory and field are in the range of 11.62% to 18.5%.

Keywords : BE test, MASW test, Shear wave velocity (V_s) , Shear modulus (G).

I. INTRODUCTION

Shear wave velocity (V_s) is one of the important factors in site characterization since it travels only through the soil media when earthquake occurs. The shear wave disturbances map out the dilatational and rotational strains when they travel through the soil. Shear modulus(G) is related to the stiffness of the material, and which is one of the most engineering parameters. The shear modulus can be find out easily if the shear wave velocity and density of the soil are known [1]. Commonly, the laboratory tests used to measure shear wave velocity are Resonant Column (RC) test, Torsion Shear (TS) test and Bender Element(BE) test. In that, the piezo-electric bender element test is relatively simple and non-destructive test [2]. Bender elements has piezoelectric property, which converts the electrical energy into mechanical energy and vice-versa. In the testing system two bender elements one as a transmitter and the other as a receiver will be there. When the electric input reaches the transmitter element, which will create shear disturbances(mechanical energy) in the soil.

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The receiver element receives the shear disturbances and convert as electrical output [3].The shear waves in BE test interferes with P-waves that reflect from the cell walls. Therefore, the specimen radius to height ratio must be accounted for in experimental design [4]. The qualities of the signals received from BE test are good in saturated soil than in the dry soil [5].

The various method to determine shear wave arrival times in time domain are visual picking, first major peak to peak and cross correlation. In that visual picking method is easiest and more reliable [6] . The near field effect and attenuation can be minimized by maintaining the ratio between tip to tip distance and wavelength is in the range of 2 to 9 [7].Shibuya et al. conducted down-hole seismic surveys at nine-sites worldwide, together with comparative results of BE tests on reconstituted clay samples, and were examined in an attempt to quantify the shear modulus of normally consolidated clays at very small strains of the order of 0.0001%[8]. Maheswari et al. performed comparative study on shear wave velocity values obtained from BE tests and MASW tests for soft and stiff clays [9]. There is no major study on the shear wave velocity values in soil with silt content and also how the behavior of shear wave velocity with respect to few soil parameters such as soil density, water content, confining pressure and the percentage of silt content in sand. Section II in this paper gives the details about the locations selected for the present study. Section III and IV describes about the principles, testing procedures and how to get output from BE and MASW tests respectively. The results of BE and MASW tests are compared and given in section V. The behavior of Vs with various parameters are presented in section VI. In section VII the conclusion of the present study is summarized and given.

II. LOCATIONS SELECTED FOR THE PRESENT STUDY

In College of Engineering Guindy (CEG) campus, Anna University, Chennai five locations are selected for the present study and is listed as follows;

Location 1 - Space right to the Division of Soil Mechanics and Foundation Engineering (DSM and FE) [13.0107^0 N, 80.234^0 E]

Location 2 - Space opposite to Marutham hostel [13.0143^0 N, 80.238^0 E]

Location 3 - Space opposite to Staff Quarters [13.0144^0 N, 80.237^0 E]

Location 4 - Ground next to Lavender hostel [13.0142^0 N, 80.236^0 E]

Location 5 - Location near to Sewage Treatment Plant [13.0174^0 N, 80.237^0 E]

Fig. 1 shows the selected locations for the study in map. In the above mentioned five locations soil samples are collected at a depth of 2m below the ground level for Bender Element testing. For all the locations the field density was determined by sand replacement method and water content was obtained by oven drying method. For the collected soil samples the index properties and compaction characteristics also found out and listed in Table I.

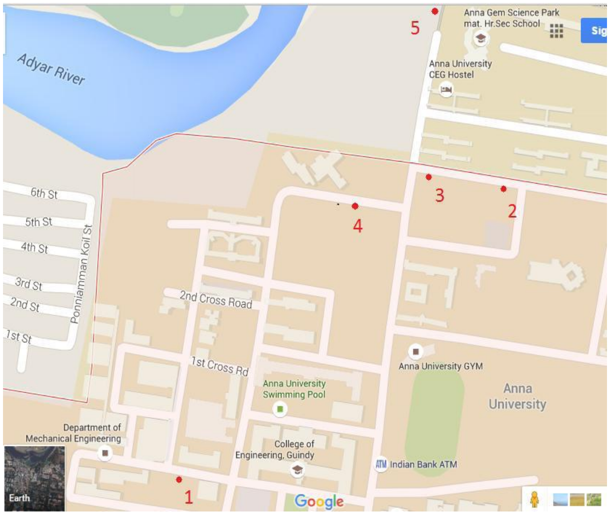

Fig. 1. Selected locations for the study.

Table -I: Properties of testing media

Properties	Location 1	2	3	4	5
Field density (g/cc)	1.56	1.46	1.43	1.64	1.41
Field water content (%)	7.37	2.01	1.88	6.14	6.37
Specific gravity	2.64	2.66	2.65	2.74	2.7
Liquid Limit (%)	38	41	40	43	30
Plastic Limit (%)	27.5	29.5	28.5	31.5	14.4
Standard proctor compaction	9	9.84	9.38	9	9.78
i. Optimum Moisture content (%)					
ii. Maximum dry density (g/cc)	2.01	1.96	1.98	2.32	1.98
Angle of internal friction (ϕ)	360	370	36.5	380	380

III. BENDER ELEMENT TEST

Bender Element testing system (Fig. 2) is based on the piezoelectric property, which allows the generation detection of small shear waves travelling in a soil specimen [7]. The soil specimen taken for the study has dimensions of 50 mm in diameter and 100 mm in height. The electronic peripherals in the system permit the generation, acquisition, and storing of input and output signals. In that, function generator is used to generate wave by giving inputs as type of wave, amplitude, no of cycles, frequency and period of wave etc.

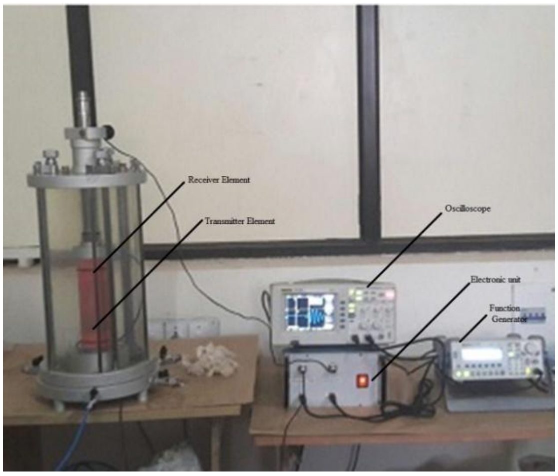

Fig. 2. Bender Element Test.

Oscilloscope acquire the input and output wave and store that. From the oscilloscope reading. we will be getting the time difference(Δx) between the input and output wave. A representation of oscilloscope reading is shown in Fig. 3. We know the tip to tip distance(L_{TT} = 70 mm) between two bender elements in the soil specimen [height of soil sample(100 mm) - total height of 2 elements(2x15 = 30mm)]. The tip to tip distance in meters (L_{TT}) divided by the time difference in seconds (Δx) between the input and output wave give the shear wave velocity of the soil specimen in m/s as shown in (1).

$$V_S = \frac{L_{TT}}{\Delta x} \qquad (1)$$

From the shear wave velocity (V_s), The shear modulus(G) can be calculated using (2). ρ is the density of the soil sample taken. The unit of ρ is in kg/m^3 and V_s is in m/sec.

$$G = \rho\,(V_S)^2 \qquad (2)$$

The near field effect has to be minimized by maintaining the L_{TT}/λ ratio between 2 and 9 [7]. The wavelength (λ) can be calculated by using (3). f_{in} is the input frequency in Hz.

$$\lambda = V_S/f_{in} \qquad (3)$$

A. Sample Preparation for BE test

A porous stone and then a filter paper has to be placed over the bottom pedestal and rubber membrane has to be slipped with the bottom pedestal and sealed with O-ring. The split mould of size 50 mm diameter and 100 mm height was fitted and tightened. Vacuum was applied such that the inner surface of the mould was fitted with rubber membrane. The calculated weight of soil samples to achieve desired density was divided into 5 portions. Soil was poured into mould in 5 layers and each layer was compacted by mild tamping method [10].

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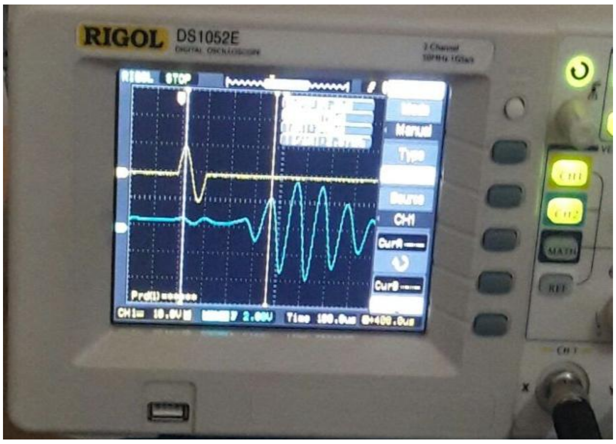
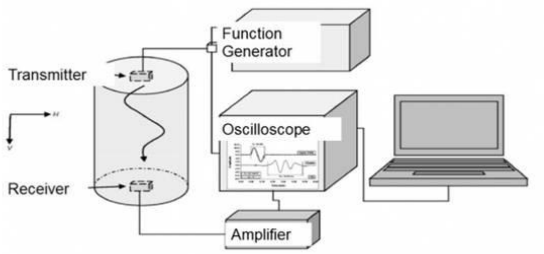


Fig. 3. Oscilloscope reading.

Filter paper and porous stone were placed and the rubber membrane was slipped with top pedestal and sealed with o-ring. The split mould was loosened and taken out. The vacuum was stopped and the chamber was filled with water to apply the confining pressure. For densities more than 1.56 g/cc samples were prepared separately in the laboratory by using 50 mm x 100 mm split mould and the prepared samples were pierced in the bender element carefully in order to avoid element damage while preparing higher density sample. Remaining procedures to prepare higher density sample are as mentioned above for testing.

B. BE test setup and connections

The transmitter and receiver elements connected with electronic unit (amplifier). Function generator also connected to electronic unit (amplifier).Both transmitter and receiver connection in the electronic unit has to be connected to the oscilloscope. The block diagram for BE test is shown in Fig.



4.

Fig. 4. Block diagram for BE test.

IV. MASW TEST

MASW test is used to map shear wave velocity variation of soil as a function of depth[11]. MASW analyses were performed using data slightly distorted by the mechanical response of the geophone. This test is one of the most widely used techniques in geotechnical engineering for the measurement of dynamic soil properties, identification of sub surface material boundaries and spatial variations of shear wave velocity [12]. Data was collected from the field by using an active seismic source as sledge hammer having the weight of 8 kg and a linear receiver (geophone) array. The maximum depth of investigation can vary with the site and type of active source used [13]. The schematic diagram of MASW test setup is shown in Fig. 5. SeisImager software is used in this study to get 1-D shear wave velocity profile. The standard procedure of surface wave methods involves three main steps: (1) Acquisition of field data, (2) Data processing and (3) Inversion analysis to obtain Vs profile.

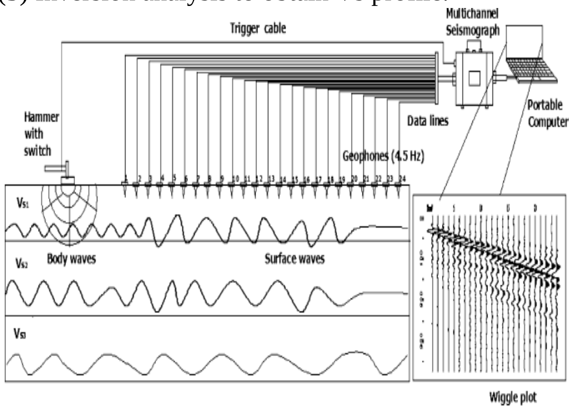


Fig. 5. Schematic of MASW test setup. (Source: www.masw.com)

For the present study the field records are collected from a research scholar at IITM institute. With that the dispersion and inversion analysis are performed. A representation of dispersion curve and 1-dimensional shear wave velocity profile are shown in Fig. 6 and Fig. 7 respectively. From the Fig. 6, it is shown that the obtained dispersion curve is matching with the theoretical dispersion curve. The obtained dispersion curve from the analysis is in red colour and the theoretical dispersion curve is in black colour.

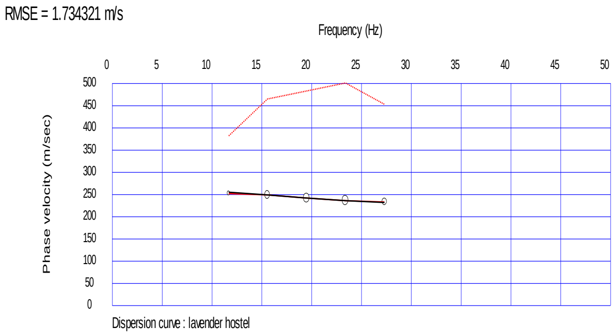


Fig. 6. Dispersion curve.

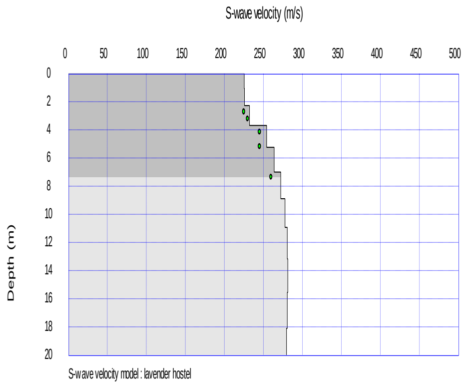


Fig. 7. One dimensional shear wave velocity profile.

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V. COMPARISON OF SHEAR WAVE VELOCITY (V_S) FROM MASW AND BENDER ELEMENT TEST

The variation in shear wave velocity values obtained from MASW and Bender Element test for the locations 2, 3, 4 and 5 is given in Table II. From the Table II, it is observed that the shear wave velocity obtained from bender element tests are 11 to 18 % lower than the MASW test. This variation is may be due to the following reasons.

a) Reconstituted specimens are used in BE tests for the present study.
b) chances of erroneous results in preparing the identical samples for all BE tests
c) Chances for small gaps in between the Bender Elements and the soil sample.

Table-II: Variation between MASW and Bender Element test results

Location	V_s from MASW test	V_s from BE test	Variation
Location 2	180 m/s	147.06 m/s	18.30%
Location 3	170 m/s	145.83 m/s	14.21%
Location 4	225 m/s	198.86 m/s	11.62%
Location 5	175 m/s	142.62 m/s	18.50%

VI. SHEAR WAVE VELOCITY(V_S) BEHAVIOR WITH VARIOUS PARAMETERS

Bender Element test is also conducted to get overview about the influences of density, water content, confining pressure and Percentage of silt content in sand variation. Researches which are useful and related to the current parametric study are reported in several literatures [14],[15],[16],[17],[18],[19]. The Location 1 soil samples are used for this analysis. The fourth series of test is conducted in river sand and silt. The details of series of test conducted to know about the V_s with various parameters are given in Table III.

Table- III: Details of test series

Series number	Constant Parameters	Variable Parameter
I	1) water content -OMC 2)confining pressure-100 kPa	<u>Density</u> 1.56 g/cc (Field density), 1.7g/cc, 1.8 g/cc, 1.9 g/cc, 2.01g/cc(maximum dry density)
II	1) Maximum dry density - 2.01 g/cc 2)confining pressure-100 kPa	<u>Water content</u> OMC - 9%, wet of OMC - 11% , dry of OMC - 7%
III	1) Field density-1.56 g/cc 2) water content - OMC	<u>Confining pressure</u> 100 kPa ,150 kPa, 200 kPa, 250 kPa, 300 kPa, 350 kPa and 400 kPa
IV	1) Density - 1.47 g/cc 2) water content - 10% 3)Confining pressure - 100 kPa	<u>Percentage of silt content in sand</u> 0%, 20%, 40%, 60%, 80% and 100%.

A. Influence of Density variation in Shear Wave Velocity

The behavior of shear wave velocity with respect to the density variation as given in Table II, series I is shown in Fig. 8. From the Fig. 8, it is observed that while increasing the density of the soil specimen the travel time decreases and hence the shear wave velocity and the shear modulus increase. This is due to the inter-particle contact increases as the density increases and hence the travel time decreases.

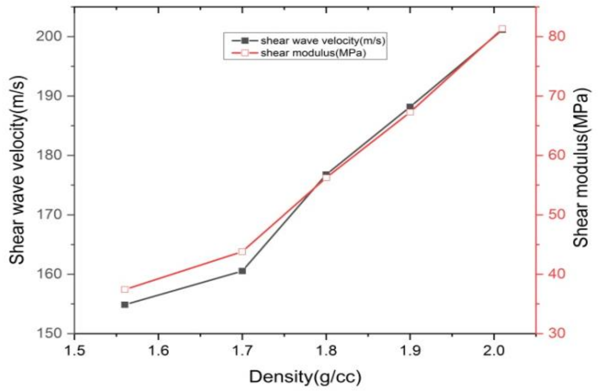

Fig. 8. Density versus Shear wave velocity.

B. Influence of water content variation in Shear Wave Velocity

Fig. 9 shows the variation of shear wave velocity and shear modulus with respect to different water contents. From the Fig. 9, it is observed that there are very minimal changes in shear wave velocity when we change the water content since the water has no shear strength. So that the shear wave velocity shows the properties of soil alone. The slight variation in shear wave velocity also may be due to the error in preparing identical soil specimens.

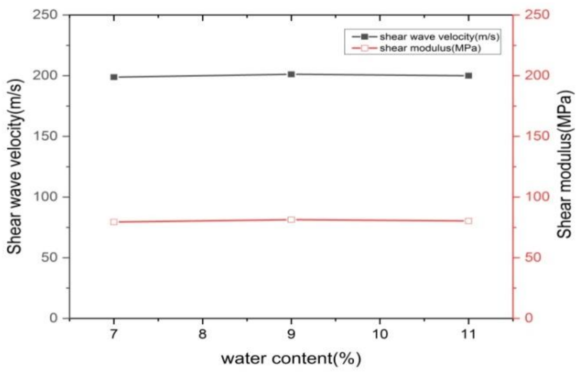

Fig. 9. Water content versus Shear wave velocity.

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C. Influence of Confining Pressure variation in Shear Wave Velocity

Fig. 10 shows the variation of shear wave velocity and shear modulus with respect to different confining pressures. From the Fig. 10, it is observed that the shear wave velocity and shear modulus increase as confining pressure increases.

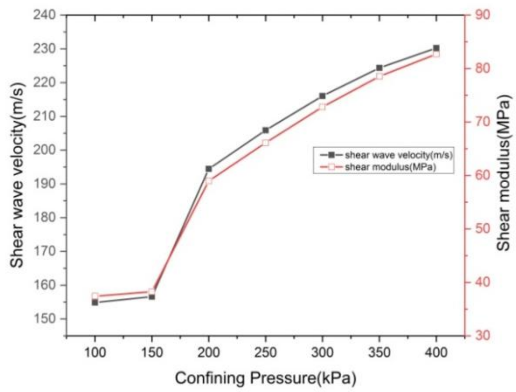

Fig. 10. Confining Pressure versus Shear wave velocity.

D. Influence of Percentage of silt content in sand variation in Shear wave velocity

Fig. 11 shows the variation of shear wave velocity and shear modulus with respect to different silt content. From the Fig. 11, it is clear that the shear wave velocity and shear modulus decrease as silt content increases.

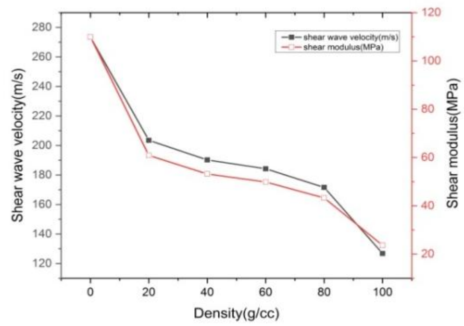

Fig. 11. Percentage of silt content in sand versus Shear wave velocity

Void ratio is calculated and given in Table IV by taking the density as 1.47 g/cc, specific gravity of sand as 2.65 and specific gravity of silt as 2.67. By using the Table IV, a graph is plotted in between void ratio and the percentage of silt content in sand and which is shown in Fig. 12. From the Fig. 12, it is observed that by increasing the percentage of silt content in sand, the void ratio increases and hence the travel dtime increases. So that by increasing the percentage of siltcontent in sand the shear wave velocity decreases.

Table -IV :Void ratio for the various percentage of silt content in sand

Description	Average Specific gravity (G)	Void ratio(e)
100% sand	2.65	0.802
80% sand and 20% silt	2.654	0.805
60% sand and 40% silt	2.658	0.808
40% sand and 60% silt	2.662	0.811
20% sand and 80% silt	2.666	0.814
100 % silt	2.67	0.816

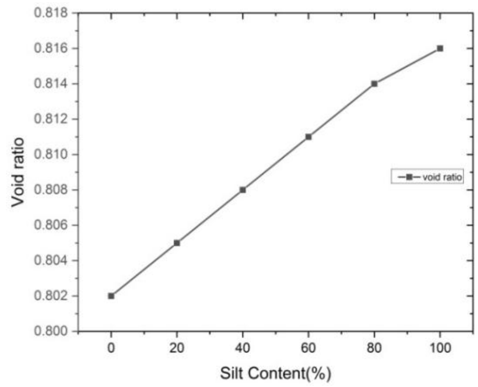

Fig. 12. Void ratio versus Silt content.

VII. CONCLUSION

This study is carried out to understand the influence of confining pressure, density and percentage of silt content in the shear wave velocity, which is being used to characterize the site condition for earthquake analysis. The laboratory determined shear wave velocities using bender element tests are also compared with field measured shear wave velocity using MASW. The conclusion made through this study are listed below.

a) Increase in confining pressure increases the shear wave velocity and the increase is maximum for the pressure range of 150kPa to 200kPa.
b) Increase in density increases the shear wave velocity and the increase is maximum for density higher than 1.7g/cc.
c) The shear wave velocity determined from MASW test is higher than the bender element test and the variation is in the range of 11.62% to 18.5%.
d) The change in the shear wave velocity is very minimal for the variation of water content in the range of 7% to 11%.
e) Increase in the percentage of silt content in sand decreases the shear wave velocity. This is due to the increase in void ratio (Refer Fig.11 and 12).

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