Shear and P-Wave Velocity Interrelation of Pilani Region Soil

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Abstract- According to elastic rebound theory, earth's crust behaves like an elastic medium. Due to earthquake, aerial bombardment or bomb-blast ground motion occurs resulting in stress waves. Shear wave as well as P-wave are two different type of stress waves. They are also called body waves because they travel through the earth. The propagation velocities of shear waves as well as P-waves are determined by the modulus of elasticity of the propagation medium like soil. Shear waves are quite damaging to geotechnical construction. Standard field based and lab based methods are available for shear wave velocity determination as well as estimation. All of them require complicated experimental set-up. Laboratory based P-wave through soil determination is very simple on the other hand. In the present study, interrelation between shear wave velocity and P-wave velocity based on laboratory set-up has been studied for Pilani region. Exponential curve of best fit equation to obtain estimated value of shear wave velocity has been obtained knowing the P-wave velocity. Study is for Pilani region soil. Similar study can be undertaken at similar other regions also.

Keywords – Stress Waves, P-Wave, Shear Wave, Exponential Curve, Pilani Region

I. INTRODUCTION

In the geotechnical domain, soil is generally assumed to be isotropic and linearly elastic so that its properties can be described using only two parameters. In most of the solutions it will be convenient to use Young's modulus as one of the parameters and Poisson's ratio as the other. The elastic body under sudden loading impulse does not experience disturbance in the entire body instantly. Only the part of elastic body which is in close contact with external force agency is affected first. Deformations produced subsequently spreads throughout closely in the form of waves. In the propagation process, elasticity and inertia of the body play important roles. Wave is essentially a form of disturbance, which travels from one part of elastic body to the other through the oscillatory motion of particles of the elastic medium.

From earthquake engineering perspective, seismic waves are classified as P-wave and shear wave. P-wave is first to reach earth's surface. P-wave arrives longitudinally at short distances and is also called a longitudinal wave. Physically P-wave is compressive in nature and propagates generating vibrations parallel to the direction of propagation. They are analogous to sound waves, the motion of an individual particle that a P-wave travels through is parallel to the direction of travel. P-waves involve no rotation of the material they pass through. Shear wave reaches after P-wave and is physically shear or torsion wave. Shear wave vibrates in a direction normal to the direction of propagation. At short distances its motion is primarily transverse. Shear wave is also called transverse wave. They cause shearing deformations as they travel through a medium. Shear waves involve no volume change. The velocities of shear and P-wave depends on the stiffness of the solid with respect to the type of deformation induced by each wave. The P-wave velocity exceeds the shear wave velocity by an amount that depends on the compressibility of the body. It is reflected in its Poisson's ratio.

The elastic rebound theory is an explanation for how energy is spread during earthquakes. As rocks on opposite sides of a fault are subjected to force and shift, they accumulate energy and slowly deform until their internal strength is exceeded. At that time, a sudden movement occurs along the fault, releasing the accumulated energy, and the rocks snap back to their original un-deformed shape. In geology, the elastic rebound theory was the first theory to satisfactorily explain earthquakes. Previously it was thought that ruptures of the surface were the result of strong ground shaking rather than the converse suggested by this theory.

According to elastic rebound theory, earth's crust behaves like an elastic medium. Soil or rock can be deformed and will return to its original shape after the stresses are released. Soil or rock under pressure accumulates strain energy until pressure becomes greater than friction and movement occurs. After sudden movement, earthquake produces ground motion generating stress waves. They may also be generated by artificial means like bomb-blast or aerial bombardment.

P-waves are first to arrive at seismograph. They are fastest and can move through solid, liquid or gas. They leave behind a trail of compressions and rarefactions on the medium they move through. Certain animals can feel P-waves much before an earthquake hits crust. Humans only feel the ramifications it has on the crust. They can be used for calibration purposes. Shear waves are second to arrive during an earthquake. They are much slower than P-waves and can travel only through solids.

Shear wave velocity is an important dynamic soil measurement. It is used for assigning site soil profiles to seismic site classes that govern geotechnical as well as structural design. It is also used to calculate the small strain shear modulus of the soil. This is an essential parameter for geotechnical and earthquake engineering design. Various methods exist to measure the shear wave velocity in the field as well as lab. The seismic cone penetration test (SCPT) is a common method used to determine the shear wave velocity in the field. During a SCPT, arrival times of shear waves generated at the ground surface are determined after halting the cone penetration at discrete depths and taking measurements. In this way, average shear wave velocity between SCPT measurement depths can be determined. In the laboratory, bender elements are commonly used to measure the shear wave velocity of samples from discrete depths [1]. These field and lab based methods are complicated.

In the present study, interrelation between shear wave velocity and P-wave velocity has been studied for Pilani region soil. This interrelation can be used to obtain estimated value of shear wave velocity, knowing P-wave velocity for Pilani region soil. As P-wave velocity determination is much simple, suggested technique in present study has lot of advantages.

II. EXPERIMENTAL DETAILS

Soil samples investigated in the present study has been collected from 15 different locations located close to Birla Institute of Technology & Science, Pilani campus. At all the locations design test pits were excavated upto a depth of 2meters below ground level [2]. Samples of soil were collected from this depth to determine its design cohesion and angle of internal friction under in-situ conditions using drained direct shear testing. Drained direct shear testing was used because soil at all 15 locations was freely draining type. All samples were found to be cohesion-less. Their design angle of internal friction in degrees has been shown in Table 1.

Equation relating angle of internal friction, ϕ in degrees and SPT N value for cohesion-less soil is available in literature [3]. It is as follows.

$$\phi = 7N \text{ (for } \phi \leq 28) \quad (1)$$

$$\phi = 27.12 + 0.2857N \text{ (for } \phi > 28 \text{ till } \phi = 41.405) \quad (2)$$

Cohesion-less soils have close to zero cohesion (less than 5kPa). SPT N value listed in Table 1 has been obtained from equations 1 & 2.

This equation is also available in literature to obtain estimated value of shear wave velocity V_s in m/s based on SPT N value of loose granular soil for SPT N range 0-20 [3].

$$V_s = 130 + 7.5N \quad (3)$$

Equation 3 has been used to obtain estimated value of shear wave velocity V_s in m/s listed in Table 1.

Table 1 Angle of internal friction, SPT N, V_p & V_s values of Pilani region soil

Angle of internal friction (degrees)	SPT N value	V_p (m/s)	V_s (m/s)
23.62	3.37	303.4	155.275
26.32	3.76	320.5	158.2
27.27	3.89	310.2	159.175
26.83	3.83	315.3	158.725
27.18	3.88	335.3	159.1
27.55	3.93	325.3	159.475
26.95	3.85	342.1	158.875
27.43	3.91	345.5	159.325
27.69	3.95	348.8	159.625
29.24	7.42	389.8	185.65
29.49	8.29	384.3	192.175
29.13	7.03	392.5	182.725
29.6	8.68	398.5	195.1
29.11	6.96	404.2	182.2
30.89	13.19	420.3	228.925

Ultrasonic pulse velocity testing is a long established non-destructive testing method. It involves determination of velocity of longitudinal waves (P-waves) through the sample. In the present study, use of ultrasonic technique has been made for the testing of soils. Method involves P-wave velocity determination by measuring time taken by a pulse to travel a measured distance in the sample. Transducers are placed in contact with the sample and low frequency transducers are used for this purpose. Frequency used was 150kHz. Through transmission technique was used. Transmitting and receiving transducers were placed on the opposite faces of the sample. Axes of the transducers were aligned.

All the 15 soil samples tested were from locations located within radius of 100km of Birla Institute of Technology and Science, Pilani campus. At all the locations, test pits were excavated upto a depth of 2meters from ground surface. Soil samples were collected from that depth. For all 15 soil samples, dry sample was taken. Required amount of water was added to get in-situ water content in it. Tap water available in the laboratory was used for this purpose. This soil water mixture was statically compacted in a wooden frame. Density of soil compact in the wooden frame was 1.45gm cm^{-3}. Inner plan area of wooden frame was 6cm x 6cm. Thickness of wooden frame was 1.7cm.

Testing was done using ultrasonic materials tester (Model: Emefco type UCT3). This ultrasonic materials tester is a low ultrasonic frequency (150kHz) tester for civil engineering purposes. Coarse grained samples like soils can conveniently be tested with this ultrasonic materials tester. Transmission time of P-wave was determined through soil sample of 1.7cm thickness using through transmission technique. P-wave velocity is thus determined.

Transmitting and receiving transducers having diameter 3.6cm each were placed on the opposite faces of the soil sample such that their axes remain collinear. Grease was used as coupling agent between transducer face and the soil sample. P-waves passes through the soil sample from transmitting to receiving transducer. P-wave velocity V_p thus obtained in m/s for all 15 soil samples is also listed in Table 1.

III. SHEAR AND P-WAVE VELOCITY INTERRELATION

Data points for shear and P-wave velocities obtained for all 15 soil samples shown in Table 1 have been plotted in Figure 1. P-wave velocity, V_p in m/s has been taken in linear X-axis. Shear wave velocity, V_s in m/s has been taken in linear Y-axis.

Exponential curve of best fit also has been drawn for this set of data along with its equation. $R^2 = 0.817$ for the equation. This indicates good correlation between data points. Estimated value of shear wave velocity in m/s thus can be obtained using equation given in Figure 1 knowing P-wave velocity in m/s for Pilani region soil. Shear waves are quite damaging to geotechnical structures. Their convenient estimation is always desirable for safe geotechnical design.

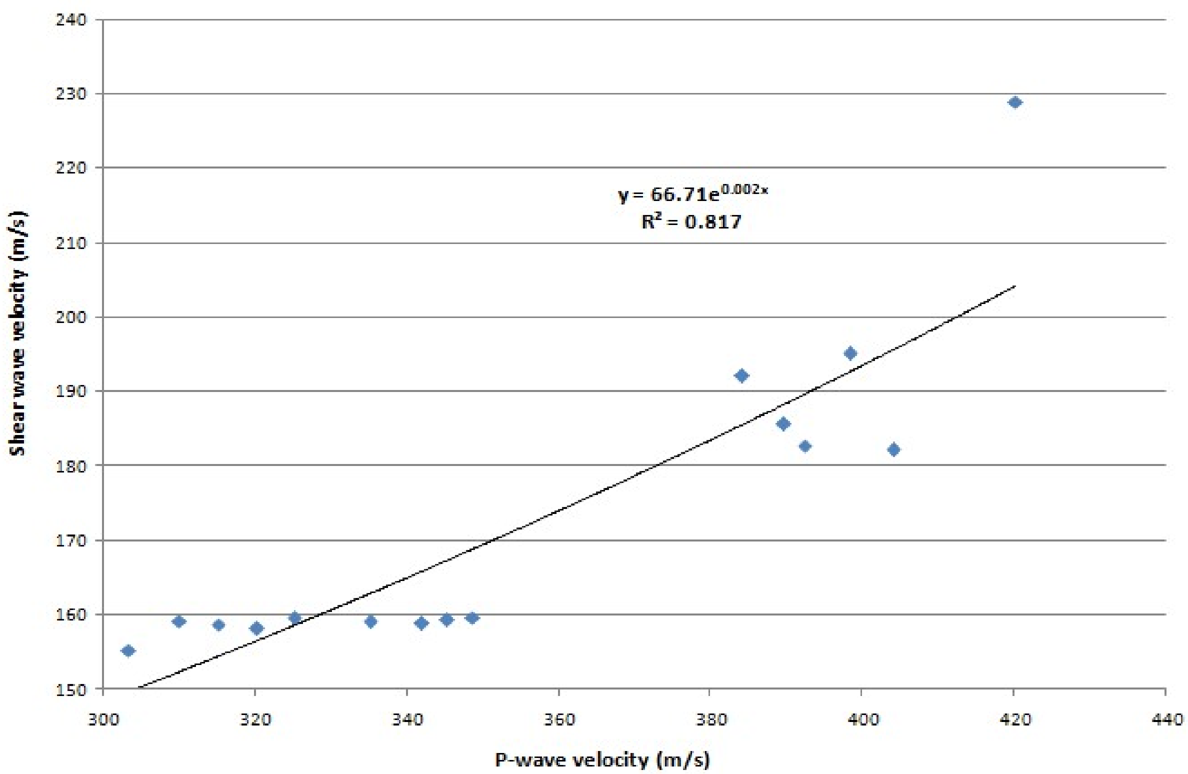

Figure 1. P-wave velocity and shear wave velocity interrelation of Pilani region soil

IV. CONCLUSIONS

Geophysical methods have been used increasingly over the past few decades as part of geotechnical site investigations. These methods are generally non-invasive or minimally invasive, and can provide extremely valuable additional data to conventional site investigation techniques which may involve 2 borehole drilling and sampling, various forms of penetration testing, and testing involving pressure meter or dilatometer [4].

Of particular relevance to foundation engineering is the shear wave velocity, Vs, which can be related directly to the in-situ stiffness of the ground through which the shear waves travel. Vs can be measured directly via in-situ geophysical methods [5]. They identified three broad approaches to in-situ measurement:

1. Via surface waves, using techniques such as Multi-channel Analysis of Surface Waves (MASW), Spectral Analysis of Surface Waves (SASW) and Continuous Surface Wave System (CSWS).
2. Via boreholes, using down-hole, cross-hole or up-hole techniques, or P-S suspension logging.
3. Via soundings, such as the seismic CPT (cone penetrometer test) or the seismic DMT (dilatometer) test.

Nowadays equations are also available to obtain estimated value of shear wave velocity based on SPT N value of soil.

In the present study, interrelation between shear wave velocity and P-wave velocity has been studied for Pilani region soil. It is based on 15 soil samples collected from 15 different locations located within a radius of 100km from Birla Institute of Technology & Science, Pilani campus from a depth of 2meters from ground surface. Foundation depth for most of the structures is around 2meters in this region.

Using the exponential curve of best fit equation obtained in present study, estimated value of shear wave velocity can be obtained knowing P-wave velocity for Pilani region soil with $R^2 = 0.817$. P-wave velocity determination as explained in present study is very simple. Suggested technique thus has lot of advantages. Similar study can be undertaken in other similar regions also.

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