Study on Seismic Waves' Speed Changes under Different Conditions and Determination of Soil Parameters by Using Them

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Abstract:
The measurement of seismic waves speed, particularly shear waves, takes a key and determinative role in classification of land type, carrying out special site studies in terms of earthquake risk and dynamic design of underground structures. The speed of shear wave in soil layers is one of the fundamental components in geotechnical calculations and dynamic analyses, particularly determination of dynamic shear module, elastic module, hardness level, Poisson's ratio, soil bearing capacity and so on. In view of wave speed changes in different formations of land, which is a function of kind, density, porousness, water content and elastic qualities of those formations, this paper first studies the amount of speed changes of seismic waves in different environments and different conditions of soil. The results of studies indicate that waves speed has considerable changes in different conditions. Then, the required parameters which can be determined through the speed of shear and longitudinal waves such as elastic module, shear module, poisson's ratio, foundation bearing capacity, bed reaction coefficient, soil unit weight, etc., have been studied.

Keywords: shear wave, longitudinal wave, seismic waves speed, soil parameters.

1. Preface:

Seismic waves are called elastic waves of materials, as these waves cause elastic transformation of materials. When passing through the objects, these waves cause molecular transformation in them and the speed of transformation process varies in different objects depending on their elastic properties and density of materials. Shear waves cause shearing, but don't change the volume of materials; whereas longitudinal waves cause volumetric changes of molecules and don't cause any shearing.

In earthquake engineering and geotechnical sciences, the speed of waves in soil environment is one of the significant and influential parameters in the classification of soil type. The speed of shear wave is considered to be the most accurate method for classification of land type and the measurement of seismic waves speed, particularly shear waves, has a determinative role in classification of land type, carrying out special site studies in terms of earthquake risk and dynamic design of underground structures.

Among the factors influencing the speed of wave circulation, we can mention the following:

Lithological properties of soil: grain size, shape, type, distribution, quantity, density, stability, etc.

Physical properties of soil: porosity, impenetrability, density, anisotropy, saturation level, solidity or liquidity percentage, pressure and temperature.

Elastic properties of soil: shear module (G), bulk module (K), yang module €, poisson's ratio (μ) and lame constant (λ).

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In view of the fact that different parameters influences the speed of seismic waves circulation whether separately or collectively, and considering that the speed of seismic waves varies in different formations of land and is a function of kind, depth, density, porosity, water content and elastic properties of land, so the assessment of changes of waves speed based on each of these factors may help us identify the type and properties of soils more accurately. In line with this objective, the manner of changes of waves speed under influence of a number of fundamental factors has been studied in the following parts.

2. Parameters Influential in the Speed of Seismic Waves Circulation

2.1 The Effect of Depth Increase:

In view of changes of soil parameters such as elasticity coefficient and Poisson's ratio, the more we move towards land depth, the more the value of elasticity coefficient and soil density increases and the more its Poisson's ratio decreases. Changes of elasticity coefficient as the result of depth is more than other influential parameters such as changes of Poisson's ratio and density and consequently the speed of shear and longitudinal waves increases as the result of depth increase.

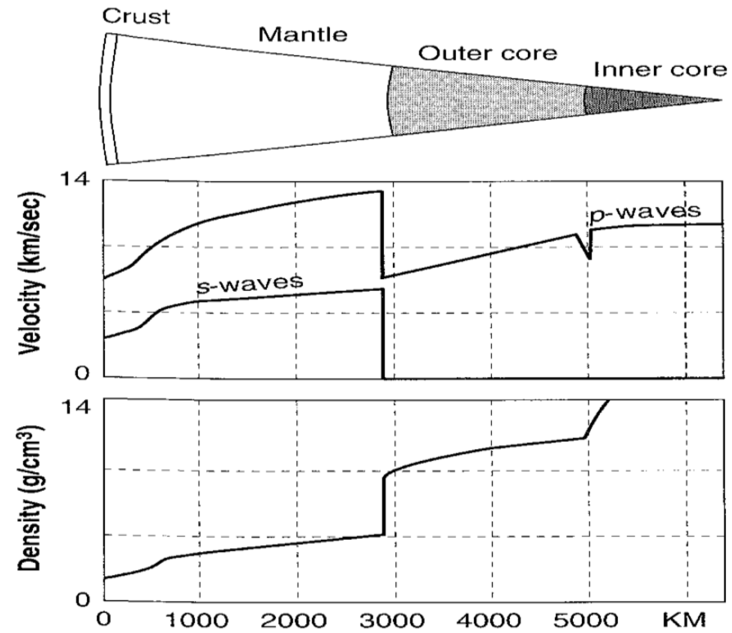


Figure 1: changes of speed and density of longitudinal and latitudinal waves inside the ground

2.2 The Effect of Hardness and Density

Hardness and density of soil influences the speed of transmission of longitudinal and shear waves as well. Circulation of waves in saturation soils depends on soil skeleton and water content in its empty spaces. In the investigation of Turkey regions' soil, changes of such parameters as the amount of porosity, water content percentage, soil density and changes in the speed of shear and longitudinal waves in relation to depth were studied. The results indicated that longitudinal wave showed more speed changes than shear waves did and soil density increased as well and the amount of porosity reduced with depth increase (pressure increase, density increase).

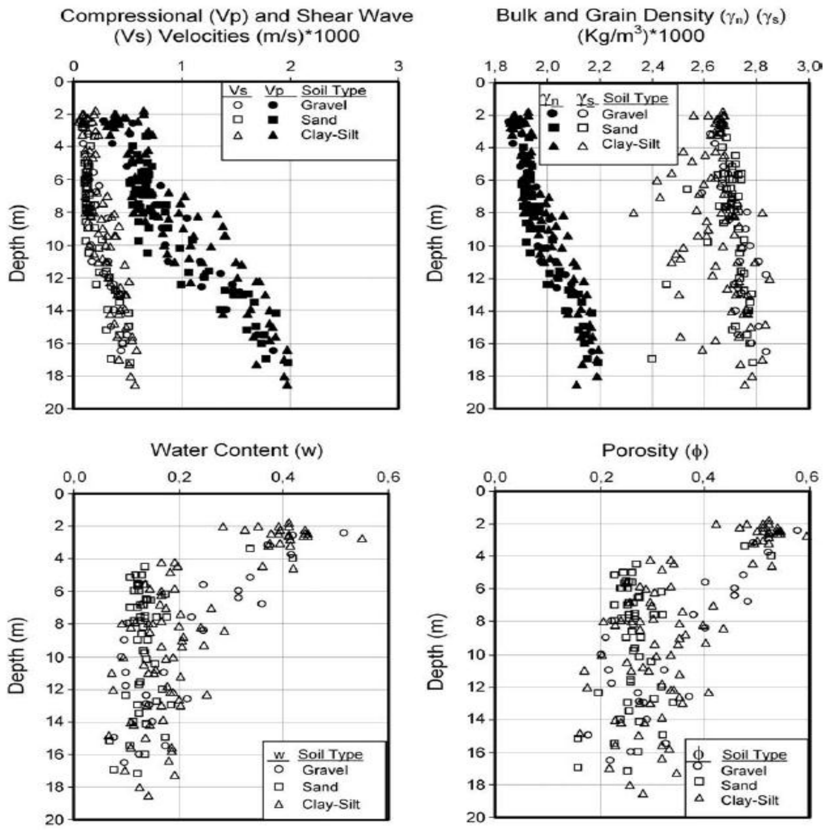


Figure 2: The manner of changes in soil parameters such as w, ys, Vs and Vp in relation to depth

2.3 The Effect of Porosity

If we name the difference between longitudinal wave in dry stone and saturation stone as ∇p, based on the performed tests we can see its changes resulting from the amount of porosity in Figure 3. As we can see, reduction of porosity results in increase of seismic waves speed. Soil saturation influences the speed of shear waves more than the amount of porosity does. The speed of waves in very porous and fully saturated stones is less than the speed of waves in less porous and less saturated stones. The reason is that longitudinal wave speed in water is less than its speed in stones' skeleton.

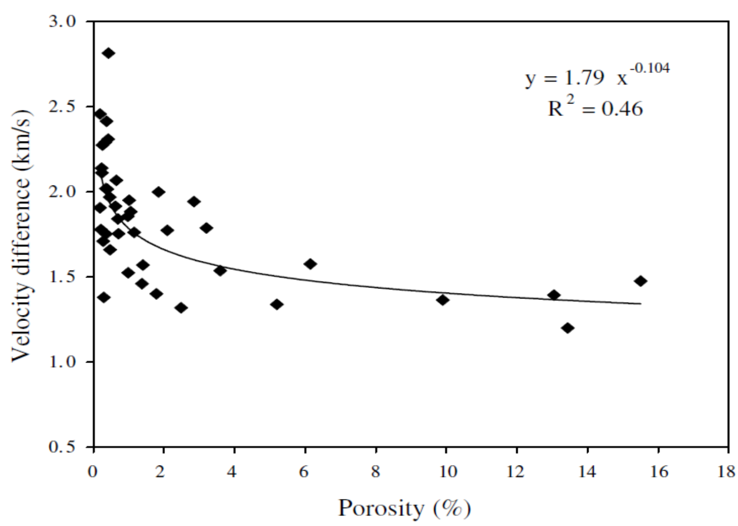
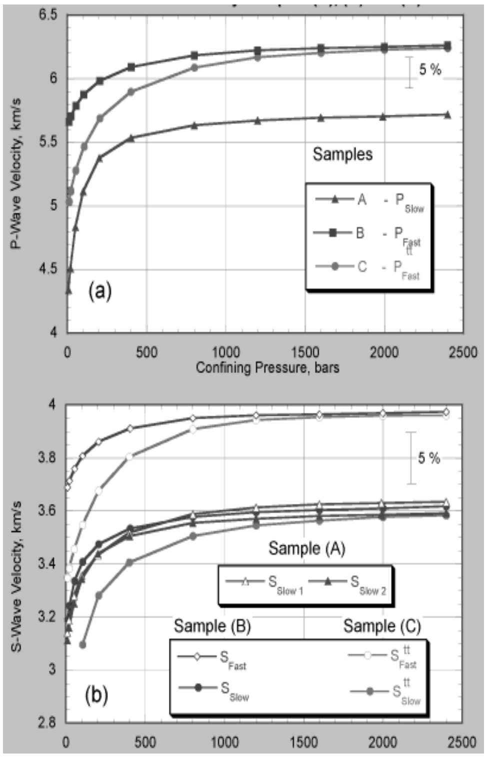


Figure 3: The relation between the difference of longitudinal wave speed (in dry and saturation stone)

2.4 The Effect of Density
Soil density is the most important influential factor in the speed of shear wave and is shown by the ratio of holes. The history of static tension is important in sticky soils, but is of less importance in grain soils. Form, size and structure of grains have small effect on the speed of waves, as their effect has been seen in the ratio of holes before. The speed of shear wave is the most accurate way to determine the type of land and according to classification specified in directive 2800, based on the speed of shear wave, the more compressed the soil the higher the speed of waves in it, and the more compressed the soil and the less holes in it, the faster the transmission of waves in it.

2.5 The Effect of Surrounding Tension and Overall Pressure
In view of the fact that the more we move from the surface of ground towards the center the more the amount of pressure increases, so according to Figure 4 we can see the changes in waves speed and changes of shear module and bulk module with changes of pressure. We can see that increase of shear and bulk modules results in increase of waves speed. In addition to surrounding tension which influences speed changes, as the result of depth, as you see in Figure 5, the speed of longitudinal and shear wave increases as the result of overall pressure as well.



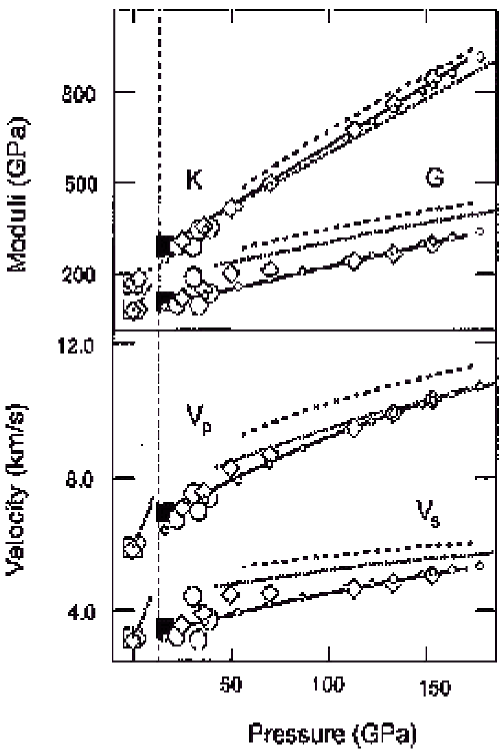


Figure 4: the manner of changes in shear module and bulk module
Figure 5: speed changes of shear wave and longitudinal wave as speed of shear and longitudinal wave in comparison with pressure increase

2.6 The Effect of Saturation Degree and Underground Water Level

As with soils, wave speed in saturation stones is dependent distinctly on wave speed in the stone itself and wave speed in water itself. The speed of longitudinal wave is based on a function of variable saturation degree. Figure 6 presents a relation based on regression between longitudinal wave in dry and saturation conditions. In the regions where the level of underground water is high or the soil is saturated, the speed of waves can be determined through estimation of longitudinal wave speed in dry soil by formula 1, based upon which the speed of longitudinal wave in wet soil can be calculated.

$V_p^w = 0.94 V_p^d + 2.1 \qquad R^2 = 0.74$

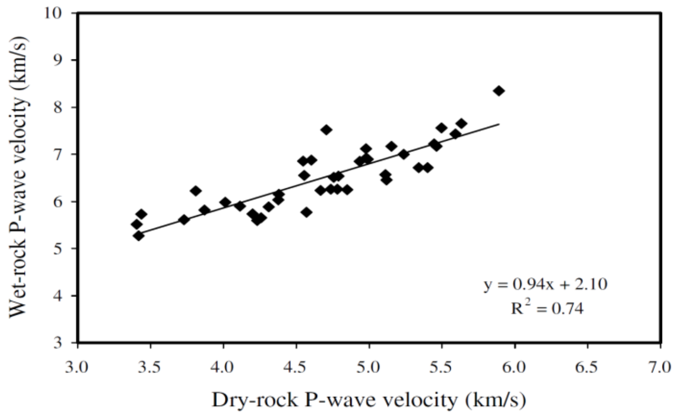


Figure 6: The relation between speed of wave p in dry stone and speed of wave p in saturation stone

Based on tests carried out by researchers, the amount of water in stone influences the speed of longitudinal wave and the more the saturation degree decreases from 100% to 70%, the more the speed of longitudinal wave decreases and between saturation degree 70% and 10% it remains almost constant and unchanged. In saturation degree below 10%, there are a lot of changes in the speed of longitudinal wave.

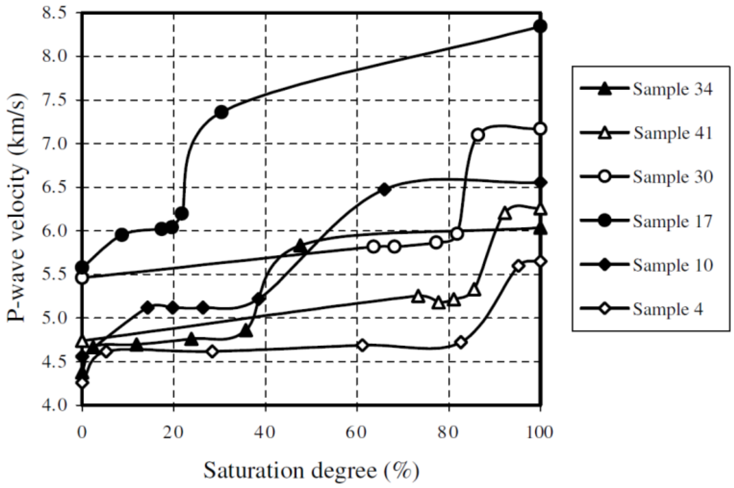


Figure 7: Speed of longitudinal wave as a function of saturation degree

2.7 The Effect of Water Content and Humidity

Most of researchers such as Biot points to two types of waves: pressure waves which pass through liquids and solids and shear waves which pass only through soil skeleton (water cannot be sheared). When the saturating liquid present in soil is replaced with another fluid such as a gas, longitudinal wave shows considerable speed reduction in soil. The speed of longitudinal wave in liquids is more than in gases and since liquid and gas cannot tolerate transformations, shear wave cannot be circulated in all liquids and gases.

Accuracy in the measurement of underground water level conditions is necessary for carrying out geophysical tests. Maximum speed of longitudinal wave in soil occurs when the soil is saturated. In this case, speed of longitudinal wave in underground water level even reaches 5000 foot per second and this depends on the amount of salinity and water temperature. Longitudinal and shear waves can be determined by seismic tests in saturated and non-saturated soils. Based on the past studies, only the amount of speeds used to be calculated separately for saturated and non-saturated soils, based upon which the speed of shear or longitudinal wave in relation to each other can be obtained and then underground water level depth can be determined by using the essays and formulas which have recently been presented.

3. Parameters resulting from Seismic Waves

3.1 Soil Hardness and Bearing Capacity

The speed of shear waves is used to determine soil hardness degree as well. Since it is very costly to obtain such information by non-geophysical methods, seismic methods are considered to be the most appropriate way. Nevertheless, as you can see in figure 8, the results achieved by shear strains resulting from the measurement of shear wave speed show a good adaptability with the issues of allowed bearing capacity presented by Tarzaghi & Pek.

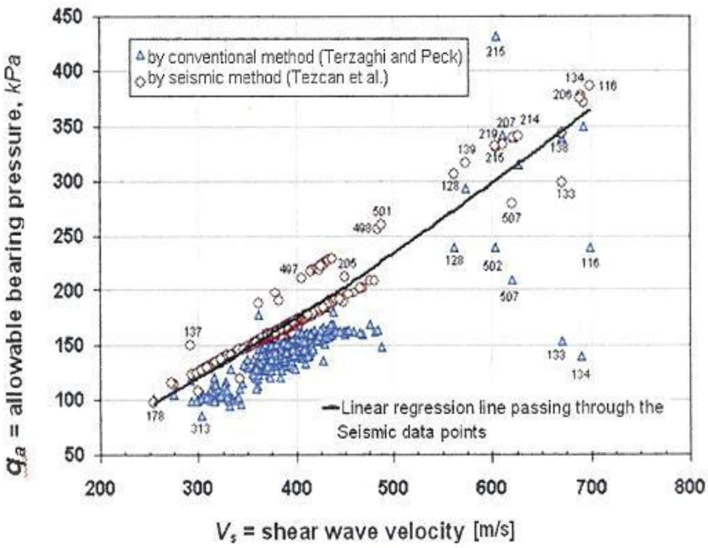


Figure 8: Comparison between seismic and ordinary methods in determination of bearing capacity (based on data obtained from 373 case studies in Turkey)

3.2 Soil Unit Weight

To determine soil unit weight, we can use laboratorial methods and, if the results of shear wave exist, one of the following two formulas:

$$\gamma=3.2V_p^{0.25}$$

$$\gamma=\gamma_0+0.002V_p$$

Where, γ is soil volume unit weight and γ_0 is the amount of soil volume unit weight in original conditions and is obtained from table 1 depending on soil type.

Table 1: original unit weight values depending on soil type

Soil type	Clay and silt soils and loose sand	Compressed sand and grit	Mudstone and limestone soils	Sand soil with sandstone	Hard stones
γ_0	16	17	18	20	24

3.3 Determination of Soil Hardness based on Speed of Shear Wave

Hardness is a variable which attributes partial increase of tension ($\Delta\tau$ or $\Delta\sigma$) to partial increase of relative transformation or strain ($\Delta\gamma$ or $\Delta\varepsilon$). Hardness of an element of soil changes with the amount of strain, in a way that when strain is small, the highest hardness is obtained and when strain increases, hardness reduces. The use of speed of shear wave has been considered to be the most reliable method for determining maximum shear hardness of soils (G_{max}). The amount of (G_{max}) is usually dependent on average effective tension and soil density. To determine shear hardness as well as elasticity module of soil based on shear wave speed, density and Poisson's ratio of soil, we can use the following formula.

$$G=\rho V_s^2 \qquad E=G/2(1+\nu)$$

When shear strain increases, the speed of shear wave and shear module reduces. Determination of soil hardness is one of the fundamental steps in solving geotechnical engineering issues in both static and dynamic areas. In-situ seismic tests are tests which apply very small strains in intended materials. These tests have been paid a great attention as they determine soil behavior in the area of linear elastic transformations. After investigation of different seismic methods, we can conclude that in problematic lands, such as comminuted weak stones, except the test of loading near land surface, the use of geophysical technics is the only appropriate way to determine the transformability of soils.

3.4 Determination of Elasticity Module and Poisson's Ratio

Assuming that homogenous stone is isotropic and elastic, we can use the following formulas to calculate yang elasticity module (E) and Poisson's ratio (v) by using elastic waves speed and stone density (p):

$$E=\rho V_s^2 \frac{(3V_p^2-4V_s^2)}{V_p^2-V_s^2}$$

$$\nu=\frac{(V_p^2-2V_s^2)}{2(V_p^2-V_s^2)}$$

The above modules are known as dynamic elastic modules because they have been achieved by using the speed of wave which is a dynamic phenomenon. But if obtained by means of static tests such as plate or uniaxial pressure loading, they are called static elastic modules because loading process is very slow.

10. Conclusion

In this research, we studied such factors as density, saturation degree, porosity, pressure, etc., in connection with seismic waves and the amount of speed changes of seismic waves under different conditions. The more we move from the surface of land toward its center, the more the amount of density, hardness, overall pressure, elasticity module and shear module increases and, in contrary, reduction of porosity and empty space between molecules of soil and stone results in increase of cohesion and connection of molecules and, consequently, increase of seismic waves speed. Nowadays, considering the ever-increasing use of seismic waves speed in estimation and calculation of dynamic and static parameters of soil and stone, it is very important to consider all factors and parameters influential in the speed of seismic waves. In this research we attempted to briefly study the effect of each of these factors.

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