International Journal of the Physical Sciences Vol. 5(7), pp. 1034-1039, July 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Compressional and shear-wave velocity measurements in unconsolidated top-soil and comparison of the results

Osman Uyanik

Department of Geophysics Engineering, Faculty of Engineering and Architecture, Suleyman Demirel University, Isparta 32260, Turkey. E-mail: uyanik@mmf.sdu.edu.tr. Tel: +90 246 211 13 59. Fax: +90 246 237 08 59.

Accepted 30 April, 2010

Seismic compressional, P- and shear, S-wave measurements were done on the unconsolidated top-soil with depth of 1 m at the different locations of the study area. In case of working with metallic P-wave source, the effect of the air-filled zone and disturbance of the air-wave are received by geophones located near the source (short offset). It is possible to reduce the effect of the disturbance of air-wave and to obtain correct P- and S-wave velocities by using source equipment consisting plastic hammer and wooden cone for very short offsets. In this study, a 12-channel seismograph with signal stacking ability was used together with high frequency (100 Hz) geophones on the top-soil. The geophone intervals were set to 20 cm at the all locations. Two dimensional models were constructed by applying two dimensional inversions to the first arrival time of direct and refracted waves. It was seen that compressional wave velocity (Vp) values of very-near-surface soils are lower than the velocity of the P-wave in air (330 m/s). Additionally, it should be noted that the ratio between P and S wave velocity is about 1.5 in the dry unconsolidated top-soils.

Key words: Near surface seismic, top-soil, shear and compressional waves, air-velocity, Vp/Vs ratio.

INTRODUCTION

Many studies have shown that compressional (P) wave velocity (Vp) is below the 330 m/s in the near surface soil. Even more, Bachrach et al. (1998) found that the P wave velocity of beach sand is lower than 100 m/s. Bachrach and Nur (1998) suggested a quantitative explanation for low P wave velocities for the near surface ground. Baker et al. (1999) also observed P wave velocities in the near surface ground lower than the velocity in the air.

The seismic velocity ratio (compressional and shear wave velocity ratio, Vp/Vs) is especially sensitive to the fluid in the pores existing in the sedimentary rocks. Particularly, the Vp/Vs ratio in the gas saturated environments is much lower than liquid saturated environments (Tatham, 1982). Pickett (1963) studied on the porous environment for the Vp/Vs ratios, and found about 1.9, 1.8 and 1.6 to 1.75 for limestone, dolomite and sandstones, respectively. According to Gregory (1977), Poisson's ratio is about 0.1 for most of the dry rocks and unconsolidated sands.

In this paper, the results obtained for P-waves are similar to previous studies mentioned above. But exceptionally, this study has shown that Vp/Vs, Poisson's, E/G and K/G ratios in the unconsolidated clayey sand between the depths from 0 - 0.2 m are lower than 1.5, 0.1, 2.2 and 1, respectively. Additionally, it has also shown that 2D models of Vp/Vs with K/G and Poisson's with E/G ratios are almost identical.

MATERIALS AND METHODS

Seismic refraction method is widely utilized in delineation of the deep earth layers, determination of the physical properties of ground and in solution of the engineering problems - such as selection of a dumping and settling areas and designation of the bearing capacity for engineering structures (Grand and West, 1965; Sarma and Iossifelis, 1990; Budhu and Al-Karni, 1993; Richards et al., 1993; Dormieux and Pecker, 1995; Paolucci and Pecker, 1997; Soubra, 1997; Reynolds, 1997; Kumar and Rao, 2002; Kumar and Kumar, 2003; Turker, 2004; Coudhury and Subba , 2005; Othman, 2005; Tezcan et al., 2006; Ulugergerli and Uyanik, 2007). The seismic refraction method provides the elastic properties of subsurface layers for engineering applications (Grant and West, 1965). The usage fields are easily extended to various

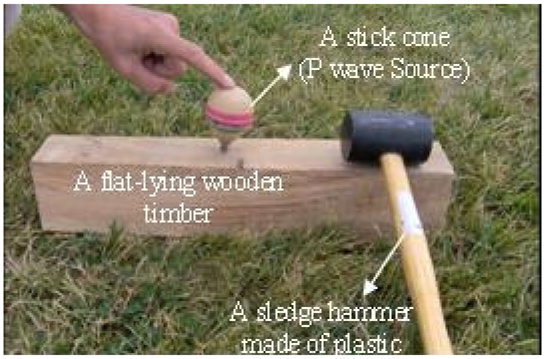

Figure 1. P and S wave sources.

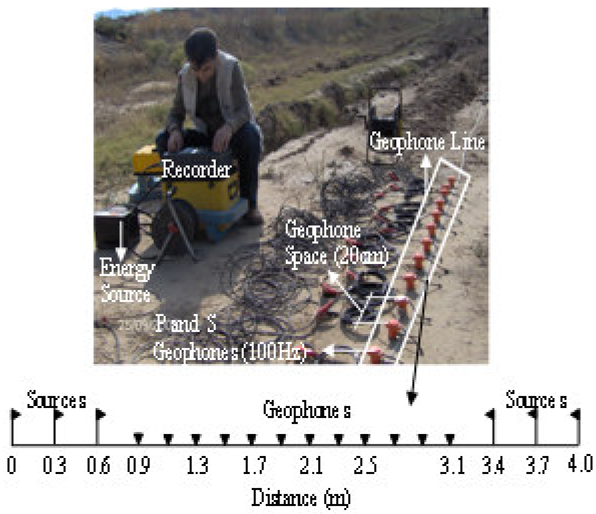

Figure 2. Very shallow /high resolution seismic refraction survey.

interdisciplinary problems, as quality control of ground before and after compaction and determination of the degree of compaction and compaction efficiency (Uyanık and Ulugergerli, 2008).

Delineation of alteration zones, investigation of cavities, establishing the occurrence, locations and apertures of structural discontinuities, determination of zones of structural weakness in the basement, and stability analysis of the ground together with the determination of mechanical properties of the rocks, may also be obtained via evaluation of seismic velocities Vp and Vs.

In this context, any independent elastic constant can be related to the Vp/Vs ratio. In considering a homogeneous and isotropic solid material, only three elastic constants are required to describe the mechanical properties of the system. These are the income-pressibility (bulk modulus K), the elasticity (Young modulus E) and the rigidity (Shear modulus G). As in the case of Poisson's ratio, there is a correspondence between the ratio K/G (the ratio of incompressibility and rigidity) and the velocity ratio Vp/Vs. There is also same correspondence between the ratio E/G (the ratio of elasticity and rigidity) and the velocity ratio Vp/Vs.

The universal relations among K, Poisson's ratio (μ) and G and among E, Poisson's ratio and G are given in equation 1 and equation 2, respectively (Dobrin and Savit, 1988):

$$K = 2G [(1+\mu)/3(1-2\mu)], \tag{1}$$

$$E = 2G [1+\mu]. \tag{2}$$

If the Poisson's ratio is written with an equivalent equation based on Vp/Vs ratio

$$\mu = [(Vp/Vs)^2-2]/ [2(Vp/Vs)^2-2] \tag{3}$$

The relations between seismic velocities and elastic parameters are given below. Since all of elastic parameters were deduced using compressional wave velocity (Vp) and shear wave velocity (Vs) values, all will be termed elastic parameters in the rest of the text. After Dobrin and Savit (1988) one can write. If in equations 1 and 2 is written as equation 3 in place of μ, Equations 1 and 2 could be rewritten to give K/G and E/G ratios as they are shown in equation 4 and 5, respectively:

$$K/G = [(Vp/Vs)^2-(4/3)], \tag{4}$$

$$E/G = 3 [(Vp/Vs)^2-(4/3)] / [(Vp/Vs)^2-1]. \tag{5}$$

Additionally, the existing relation between G and Vs is given in the equation 6.

$$G = \rho\, Vs^2 \tag{6}$$

Where, ρ is the density of soil. There is a direct correlation between seismic velocity and the density and ripability of subsurface materials. Thus, ρ may be calculated from Vp (Gardner et al., 1974; Hawkins and Whitely, 1979; McMahon, 1980; Tezcan et al., 2006). According to Tezcan et al. (2006)'s approximation, the bulk density (ρ) can be given as:

$$\rho = 16 + 0.002Vp \tag{7}$$

Seismic data and soil sample collection

Seismic refraction data

Field study was performed in the grassy garden of Suleyman Demirel University campus located in Isparta in the South of Turkey. The seismic study was based on recording the travel time of an elastic wave traveled through the ground, refracted from a subsurface, and received via geophones on the surface (Figure 1). In this study, seismic P- and S-waves were recorded using vertical and horizontal components geophones (100 Hz), respectively, connected to a 12-channel digital recorder. Geophones were laid along a line with 20 cm spacing (Figure 2). Shot points were at both ends of the line, with a 30, 60 and 90 cm offset along the line. The required energy for P-wave measurement was created by a 1 kg plastic hammer hitting the wooden cone at the shot points (Figure 1). The S-wave was created by hitting the ends of a flat-lying wooden timber (5 × 10 × 50 cm) loaded by a person, the weight of which increases thee friction and the contact area of the timber with the ground surface (Figure 1).

The first arrivals to each geophone are marked and extracted from the data (Figure 3). A commercial software package, SeisOPT® (Pullammanappallil and Louie, 1993), was used to evaluate the data, and the results of the 2D inversion of the first arrivals for each profile were obtained. Geo-seismic sections illustrate the variations in velocities with respect to distance (horizontal axis) and depth (vertical axis) (Figures 4 and 5). P and S velocity variations versus depth were obtained from inverse solution and illustrated in cross-sectional manner in the Figures 4 and 5. Variations of the elasticity parameters against depth were calculated by substituting the obtained P and S velocity values to equations 3, 4, 5, 6 and 7. The cross-sectional illustrations of the Vp/Vs, μ, E/G and K/G ratios-depth models can also be seen in the

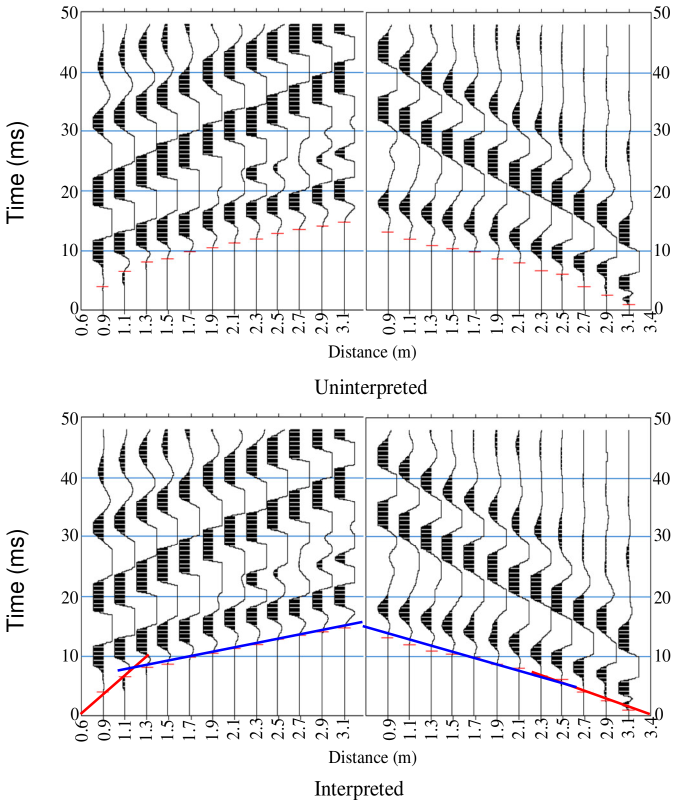

Figure 3. Raw and interpreted field data (P wave pulse) generated by stacking the four- plastic hammer hitting created.

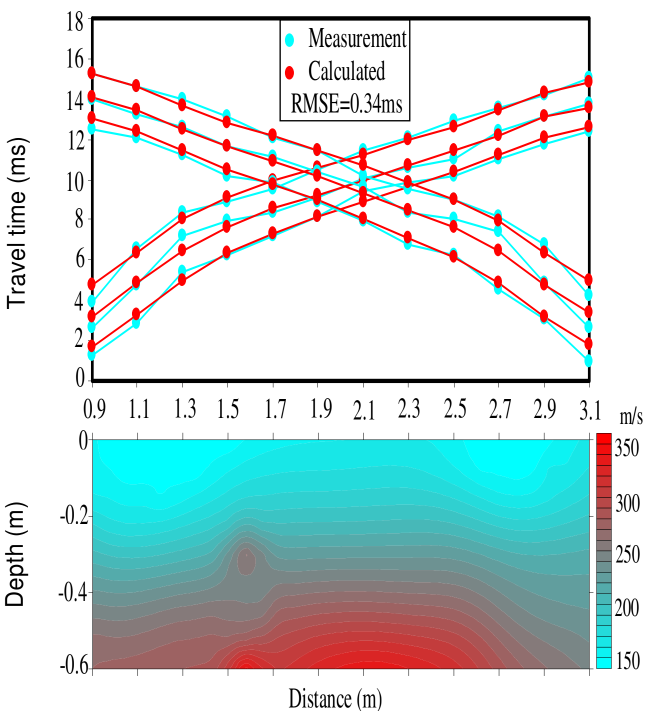

Figure 4. 2D solution to the two-layer problem from the first arrivals picket in P-wave measurements.

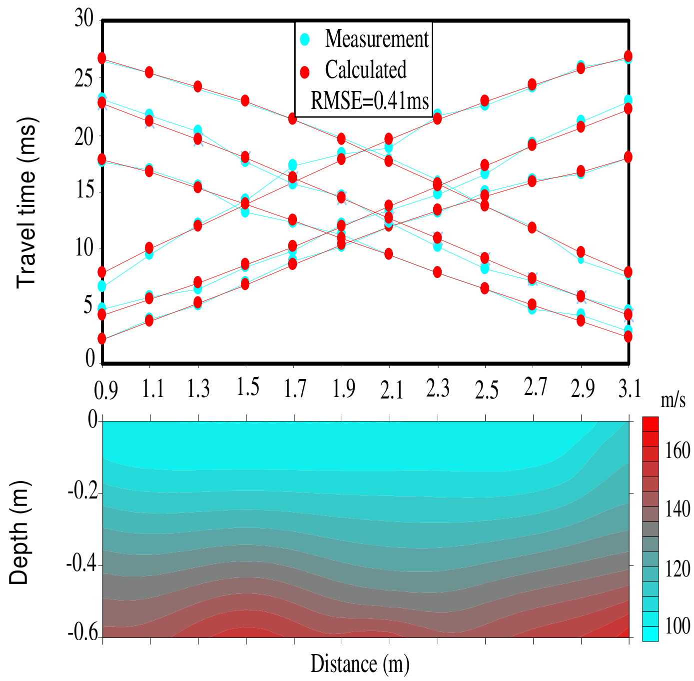

Figure 5. 2D solution to the two-layer problem from the first arrivals picket in S-wave measurements.

Figures 6 and 7. The Figure 8 showing the relations between μ, E/G, K/G and Vp/Vs was prepared by using the data in Table 1. If the values of Vp/Vs in Table 1 are written in place of Vp/Vs in equation 3, 4 and 5, the values of μ, E/G and K/G can be calculated and Figure 8 can be plotted from the values in Table 1. In addition, average velocities of P and S wave determined for depths 0 -0.3 and 0.3 - 0.6 m in Figures 4 and 5. The average elasticity parameters in Table 2 were calculated to depths 0 - 0.3 and 0.3 - 0.6 m using the average velocities (Table 2).

Top-soil sampling

Top-soil data were collected at the depth intervals of 0.0 - 0.3 and 0.3 - 0.6 m, at the same location where seismic data were collected. The undisturbed samples were taken in cylinders of 5 cm diameter and 5 cm height and measured natural unit weight *in-situ*. Thereafter, the samples were analyzed in laboratory and determined consistency Atterberg limits (Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI)), and soil types to sieve analysis (Table 3). Table 3 contains depth of top-soil samples (z), natural (γ_n), dry (γ_d) and grain (γ_s) densities, water content (w), porosity (n), void ratio (e) and degree of saturation (S) as well. Laboratory studies suggest that soil is clayey sand. It can be inferred that soil is porous (for n = 0.41) and dry (for s < 0.5).

DISPLAY OF THE RESULTS

Figure 3 shows raw data and the result of interpretation of seismic records. The geo-seismic models prepared from P and S waves are correlated very well and illustrated in Figures 4 and 5. The P wave velocities in the unconsolidated top-soil were found to be lower than the

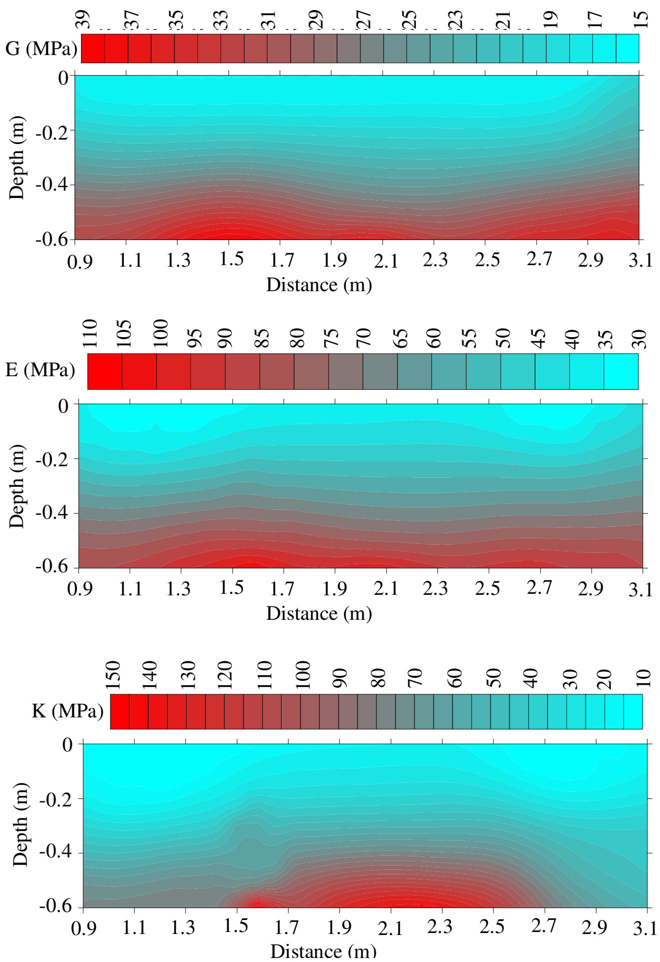

Figure 6. 2D models of the elasticity parameters (G: rigidity module, E: elasticity module, K: incompressibility module) calculated from seismic velocities in same depth.

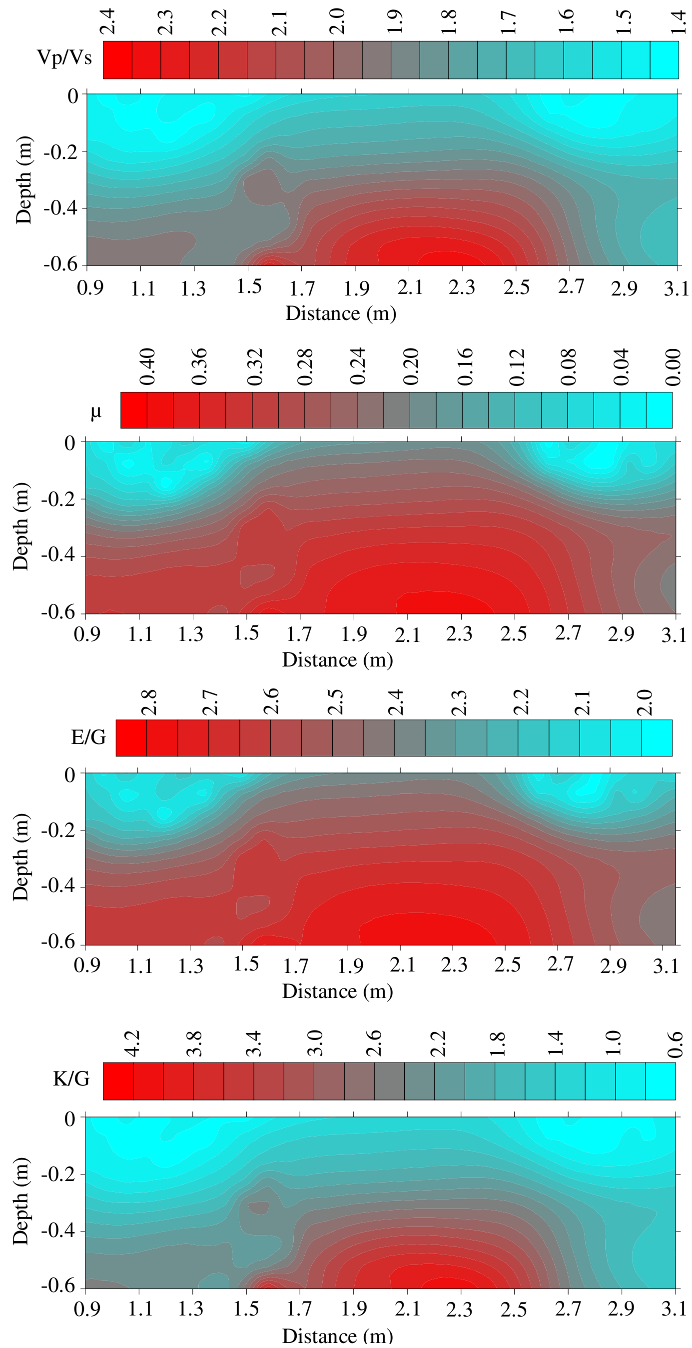

Figure 7. 2D models of Vp/Vs (the ratio of P and S-wave velocities), µ (Poisson's ratio), E/G (the ratio of elasticity and rigidity) and K/G (the ratio of incompressibility and rigidity) in same depth.

velocity of the P-wave in air (330 m/s). Softness of the top-soil caused the decrease in the S-wave velocities lower than 200 m/s (Figure 5). 2D models of elasticity parameters in Figure 6 indicates that the top-soil is very unresisting versus shear, worse of elastic properties and very unresisting versus pressure. 2D models of µ with E/G and Vp/Vs with K/G illustrated in Figure 7 are almost identical. Additionally, the top section of 2D model of Vp/Vs ratio is about 1.5 and K/G ratio is lower than 1. Furthermore, the ratio of average P and S wave velocities illustrated in the Table 2 is also about 1.5 for the depths of 0.0 -0.3 m of the top-soil. These results indicate that the top-soil of the ground has an air-filled porous structure. As it is seen in the Table 3, porosity of the top-soil is about 0.41. It is well known that P wave propagates in every kind of medium while S wave can only propagate in hard grounds. If the porous medium contains water, Vp value increases while Vs value declines, and consequently, Vp/Vs ration increases (Vp/Vs > 3.5). On the other hand, if the porous media is saturated by air, then Vp declines and Vp/Vs ratio decreases (-1.5).

Relative variations between any three independent elastic constants, however, can be related to variations of Vp/Vs. The plot in the Figure 8 shows the Poisson's ratio, K/G (the ratio incompressibility and rigidity) and E/G (the ratio elasticity and rigidity) variations against the Vp/Vs ratio variations was prepared by using the equations 3, 4

Table 1. The values of Ratio Vp/Vs, poisson's, E/G and K/G, used to plot Figure 8.

Vp/Vs	µ	E/G	K/G	Vp/Vs	µ	E/G	K/G
1.3	-0.225	1.551	0.357	2.6	0.413	2.826	5.427
1.4	-0.021	1.958	0.627	2.7	0.421	2.841	5.957
1.4142	0.000	2.000	0.667	2.8	0.427	2.854	6.507
1.5	0.100	2.200	0.917	2.9	0.433	2.865	7.077
1.6	0.179	2.359	1.227	3	0.438	2.875	7.667
1.7	0.235	2.471	1.557	3.1	0.442	2.884	8.277
1.732	0.250	2.500	1.666	3.2	0.446	2.892	8.907
1.8	0.277	2.554	1.907	3.3	0.449	2.899	9.557
1.9	0.308	2.617	2.277	3.4	0.453	2.905	10.227
2	0.333	2.667	2.667	3.5	0.456	2.911	10.917
2.1	0.353	2.707	3.077	3.6	0.458	2.916	11.627
2.2	0.370	2.740	3.507	3.7	0.461	2.921	12.357
2.3	0.383	2.767	3.957	3.8	0.463	2.926	13.107
2.4	0.395	2.790	4.427	3.9	0.465	2.930	13.877
2.5	0.405	2.810	4.917	4	0.467	2.933	14.667

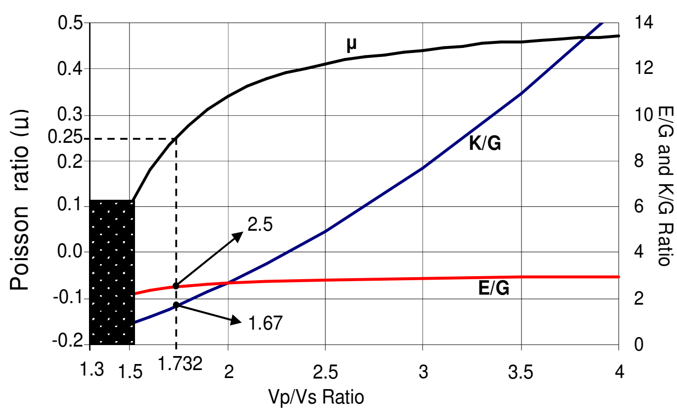

Figure 8. E/G (the ratio of elasticity and rigidity), K/G (the ratio of incompressibility and rigidity) and µ (Poisson's ratio) changes versus Vp/Vs (the velocity ratio). Note the relatively linear relation between Vp/Vs and three other parameters, especially for larger values of Vp/Vs.

and 5. For a solid material, Poisson's ratio µ, Vp/Vs, K/G and E/G are 0.25, √3 (1.732), 5/3 (1.67) and 5/2 (2.5), respectively. Figure 8 shows the range of Vp/Vs varies from 1.3 - 4. A Vp/Vs ratio less than √2=1.414213 involves a negative Poisson's ratio which can occur only in the anisotropic materials (Love, 1927). In the Figure 8, shaded area can be considered to be air saturated soil. Therefore, K/G, E/G and µ are less than 0.95, 2.22 and 0.11, respectively.

K (bulk modulus) value is less than G (shear modulus) value in the air saturated soils. It should be additionally noted that; if the Vp/Vs ratio is equal to 2, the value of E/G ratio is equal to the value of K/G ratio, and if the Vp/Vs ratio is lower than 2, value of the E/G ratio is higher than the value of K/G ratio. Finally, if the Vp/Vs ratio is higher than 2, the value of E/G ratio is lower than the value of K/G ratio (Table 1 and Figure 8).

Conclusions

In this study, P and S wave velocities were determined for the top-soil of the weathering zone by carrying out seismic refraction survey. Additionally, soil samples collected from the depth intervals of 0.0 - 0.3 and 0.3 - 0.6 m were subjected to the some tests in order to determine the natural, dry and grain densities, water content, porosity, void ratio and degree of saturation. At the end of this study, it is verified once more that the P wave velocity can be lower than its value in air. Most importantly, it should be emphasized that Vp/Vs ratio was found to be about 1.5 for top-soil (about 0.6 m). It implies that top-soil is also porous and air-filled environment.

On the other hand, the study introduced that plastic hammer, wooden cone with metallic end, and wooden beam can be considered adequate to investigate P and S wave propagation in very shallow refraction surveys.

The results of this study can be benefited in near surface constructional operations by removing the organic layer of top-soil of the ground until finding Vp/Vs ratio is more than 1.5.

ACKNOWLEDGEMENTS

Author is grateful to Dr. Ibrahim AYDIN and Dr Emin U. Ulugergerli for their constructive and clarifying comments.

Table 2. Average elastic parameters and their ratios obtained from average seismic velocities.

z (m)	Vp (m/s)	Vs (m/s)	ρ (kN/m^3)	Vp/Vs	μ	G (MPa)	K (MPa)	E (MPa)	K/G	E/G
0.0-0.3	176	119	16.352	1.48	0.079	23.156	19.777	49.967	0.854	2.158
0.3-0.6	269	137	16.538	1.96	0.325	31.040	78.284	82.250	2.522	2.650

Table 3. Properties of alluvial soil at two depths (NS: name of sample).

NS	z (m)	Consistency limits			Sieve analysis (%)				USCS group name
		LL	PL	PI	4+	4-200	200-	symbol	
A	0.0-0.3	34	5	29	2	70	28	SC	Clayey sand
B	0.3-0.6	30	4	26	4	66	30	SC	Clayey sand
NS	**z (m)**	**γ_n (kN/m^3)**	**γ_d (kN/m^3)**	**γ_s (kN/m^3)**	**w**	**n**	**e**	**S**	
A	0.0-0.3	15.794	13.852	23.544	0.14	0.412	0.7	0.47	
B	0.3-0.6	16.598	15.889	23.965	0.05	0.337	0.508	0.21	

REFERENCES

Baker GS, Steeples DW, Schmeissner C (1999). In-situ, high-frequency P wave velocity measurements within 1 m of the earth's surface, Geophysics, 64: 323-325.

Bachrach R, Nur A (1998). High-resolution shallow seismic experiments in sand, Part I: Water table, fluid flow, and saturation, Geophysics, 63: 1225-1233.

Bachrach R, Dvorkin J, Nur A (1998). High-resolution shallow seismic experiments in sand, Part II: Velocities in shallow unconsolidated sand, Geophysics, 63: 1234-1240.

Budhu M, Al-Karni A (1993). Seismic bearing capacity of soils, Geotechnique, 43(1): 181-187.

Coudhury D., Subba RKS (2005). Seismic bearing capacity of shallow strip footings, J. Manuf. Syst., 24(1): 117-127.

Dobrin MB, Savit CH (1988). Introduction to Geophysical Prospecting, 4th edn. McGraw-Hill.

Dormieux L, Pecker A (1995). Seismic bearing capacity of foundation on cohesionless soil, J. Geotechnical Eng., 121(3): 300-303.

Gardner GHF, Gardner LW, Gregory AR (1974). Formation velocity and density–the diagnostic basic for stratigraphic traps, Geophysics, 39: 770-780.

Grant FS, West GF (1965). Interpretation Theory in Applied Geophysics, New York: McGraw Hill, p. 583.

Gregory AR (1977). Fluid saturation effects on dynamic elastic properties of sedimentary rocks, Geophysics, 41: 895-921.

Hawkins LV, Whiteley RJ (1979). Estimation of rippability and excavation conditions in calcrete deposits with seismic refraction methods, 1st Geophysical Conference Australian Society of Exploration Geophysicists, 10: 223-224.

Kumar J, Rao VBKM (2002). Seismic bearing capacity factors for spread foundations, Geotechnique, 52(2): 79-88.

Kumar, J., Kumar, N. (2003). Seismic bearing capacity of rough footings on slopes using limit equilibrium, Geotechnique, 53(3): 363-369.

Love AEH (1927). A treatise on the mathematical theory of clasticity, Cambridge, Cambridge Univ. Press, p. 104.

McMahon BK (1980). Engineering seismic refraction surveys over Elura, Exploration Geophys., 11: 180-182.

Othman AAA (2005). Construed geotechnical characteristics of foundation beds by seismic measurements, J. Geophys. Eng., 2: 126-138.

Paolucci R, Pecker A (1997). Seismic bearing capacity of shallow strip foundations on dry soils, Soils Foundation, 37(3): 95-105.

Pickett GR (1963). Acoustic character logs and their application in formation evaluation, J. Petr. Tech., 659-667.

Pullammanappallil SK, Louie JN (1993). Inversion of seismic reflection travel times using a nonlinear optimization scheme, Geophysics, 58(11): 1607-1620.

Reynolds JM (1997). An Introduction to Applied Environmental Geophysics, New York: Wiley, p. 780.

Richards R, Elms DG, Budhu M (1993). Seismic bearing capacity and settlements of foundations, J. Geotechnical Eng. 119(4): 662-674.

Sarma SK, Iossifelis IS (1990). Seismic bearing capacity factors of shallow strip footings, Geotechnique, 40(2): 265-273.

Soubra AH (1997). Seismic bearing capacity of shallow strip footings in seismic conditions, Proceedings of the Institution of Civil Engineers - Geotechnical Eng., 125(4): 230-241.

Tatham RH (1982). Vp/Vs and Lithology, Geophysics, 47(3): 336-344.

Tezcan SS, Keceli A, Ozdemir Z (2006). Allowable Bearing Capacity of Shallow Foundations Based on Shear Wave Velocity. J. Geotechnical Geological Eng. 24: 203-218.

Turker E (2004). Computation of ground bearing capacity from shear wave velocity, In: Bergman, D. and Inan, E. (Ed.), Proceedings, Tenth International Symposium on Continuous Models and Discrete Systems 10: Kluwer, Netherlands, pp. 173-180.

Ulugergerli EU, Uyanık O (2007). Statistical Correlations between Seismic Wave Velocities and SPT Blow Counts and the Relative Density of Soils. J. Testing Evaluation, 35(2): 1-5.

Uyanık O, Ulugergerli EU (2008). Quality Control of Compacted Grounds Using Seismic Velocities, Near Surface Geophys., 6(5): 299-306.

White JE (1965). Seismic waves: Radiation, transmission and attenuation, McGraw-Hill Book Co.