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Investigation of soil structure in Uzungöl settlement area by Shallow Seismic Methods

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Abstract

This study was performed to relase the soil structure of Uzungöl district of Trabzon city, a vocational area, where had been formed by a historical landslide and lake deposits and to evaluate its geotechnical characters by using seismic methods which are noninvasive, rapidly applicable and provide substantial information about the structure of investigated ground in a short time. For this purpose, seismic refraction, active-passive surface waves and seismic reflections in 16 profiles were gathered on four sub-areas and and evaluated by current favorable numerical methods. Although it considerably varies between profiles, the depth of basement, depositional base of deposits, was averagely obtained as 13.5-15m at upper elevation and 25-50m at lower elevation of the study area. Dynamic elastic parameters and average shear wave velocity of the upper 30m (V_{S30}) of soil in the area were calculated. The soil classification of study area was interpreted as locally Z1 and Z2 class for TEC, B and C class for EC-8 code, C and D class for NERHP. According to V_{S30} (394-530m/s), ground amplification and predominant vibration period of the study area are respectively obtained as 1.5-2.1 and 0.23-0.30sec. On the other hand, all deposits are characterized by stiffness-solid soil, excluding arable soil from surface to a few meters depth. In addition, the first meters of bedrock shows weathered character, but deeper parts are very compact and hard. Therefore, a scientific infrastructure has been formed to carry out the engineering projects to be planned for Uzungöl settlement safely and without damaging the environment.

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Introduction

Investigation of soil (or ground) structure and characterization is a vital to a proper design and lifelong performance of buildings in settlement areas (Coutinho and Mayne, 2012) and necessary to prevent from possible natural hazards. Various methods such detailed engineering geological studies, geotechnical investigations, and geophysical studies (Boominathan et al., 2007) have been used in recent years. In this scope, using seismic methods among the noninvasive geophysical techniques for near surface characterization of geotechnical sites has grown rapidly during the last few decades since information derived from drillings has become time consuming and costly. Seismic methods which are commonly used for geotechnical site investigation include seismic reflection and refraction (Cook, 1965), seismic surface waves (Park et al., 1999). These seismic techniques provide precisely to map a buried bedrock topography, sediments and strata, and frequently employed to study of dynamic behavior of soil properties at geotechnical sites, laterally and vertically (Poormirzaee and Moghadam, 2014; Rehman et al., 2016).

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Seismic methods are based on recording the elastic waves propagating in layered subsurface which were formed on the surface or in a hole by means of a source and these waves are recorded as the function of time at receivers placed on the surface. A seismic data includes reflection, refraction, surface waves and other seismic events such as environmental noises, multiples and diffractions. From the analysis of these records layered subsurface and seismic velocity (V_p for P-wave and V_s for S-wave) of each layer can be obtained as 1D, 2D and 3D as the function of the distance and the depth. Benefiting from this velocity information all dynamic elastic parameters of the target depth can be calculated, so geotechnical properties can be explained. When these operations are compared to drilling studies, they are quite advantageous owing to their properties of scanning a large area in a short time, quickly surveying, and not damaging the environment. Therefore, seismic methods are essential methods which have a wide application use in imaging the near-surface in detail, determining the soil characteristics for engineering purposes, geotechnical assessments, environmental studies, hydrogeological investigations, seismic hazard estimations and archaeological investigations. In recent 30 years, as well as traditional seismic refraction technique, some other techniques such as refraction microtremor (ReMi) with which passive sources are used, active sourced multichannel analysis of surface wave (MASW) based on surface wave analysis, and P-wave first arrival tomography from seismic refraction data have especially been used widely to determine geotechnical profile of the ground. While, especially, MASW and ReMi techniques are commonly used to obtain 1D and 2D shear wave (S-wave) velocity structure of the ground safely and to determine the stiffness-hardness profile of the ground (Xia et al., 1999), P-wave first arrival tomography is extremely beneficial for both vertical and lateral P-wave velocity variation and basement topography of the ground (Azwin et al., 2013). In addition to this, shallow seismic reflection technique is frequently used to map structural properties of the ground such as lateral discontinuities and shallow-stratigraphy (Steeples and Miller, 1990).

This is the first geophysical study carried out in the area of Trabzon-Uzungöl settlement, a vocational area, formed by a historical landslide and deposited by alluviums transported by rivers and extremely steep mountain slopes (Alkan, 1996) to determine underground tomography, structural properties, dynamic-elastic parameters, the thickness of the material and to interpret them geotechnical properties. In this scope, in 16 profiles, seismic refraction data, active and passive surface wave data and also seismic reflection data in 3 of those profiles were gathered. P-wave velocity tomographic sections and migrated reflection sections to image subsurface geometry and structure of the study area and 1D S-wave velocity depth profiles to soil classification were obtained for all profiles. In addition to 2D S-wave velocity sections were obtained by inverting the surface wave fields of reflection data for the 3 profiles. All the obtained outputs were comparatively interpreted in terms of the ground structure of the study area and geotechnical characteristics by taking general geology of the area into consideration.

Material and Methods

The location and geology of the study area

Uzungöl takes place in a deep valley surrounded by high mountains where Soğanlı and Kaçkar mount ranges are combined in East Pontid Tectonic Belt, where there are rainforests of Turkey, 1100m from sea level and 99 km from Trabzon (Figure 1).

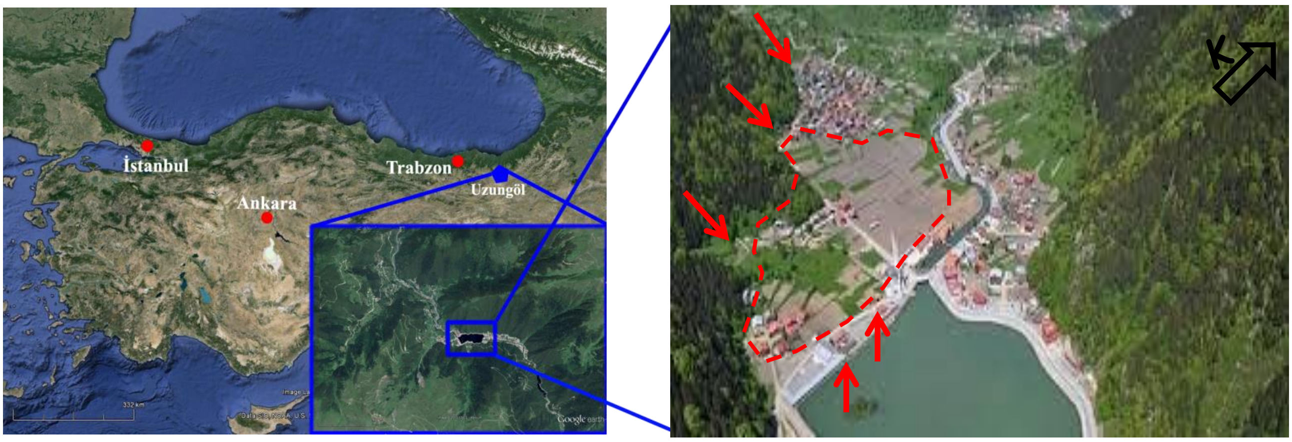

Figure 1. Location map of Uzungöl settlement including the investigated site (Google Earth). Data gathered area (red dashed line). Arrows shows directions of transportation of the materials composed of river-lake sediments and landslides

Geology map including the study area is given in Figure 2. According to this the oldest rocks observed in the region belongs to Mesozoic era, and there are a lot of around from Tertiary era. Jura-sub cretaceous aged andesite, basalt lava and Pyroclasts have a wide range in close vicinity of Uzungöl, and also while the basalts outcrop around Uzungöl are stiff-hard and durable, alluvial units in the study area consist of partly 10-15m thick and gravelly-sandy units including large blocks (Yeşilyurt, 2002). Simplified lithological column by Bulut (1989) in the study area was modified and it is given in Figure 3.

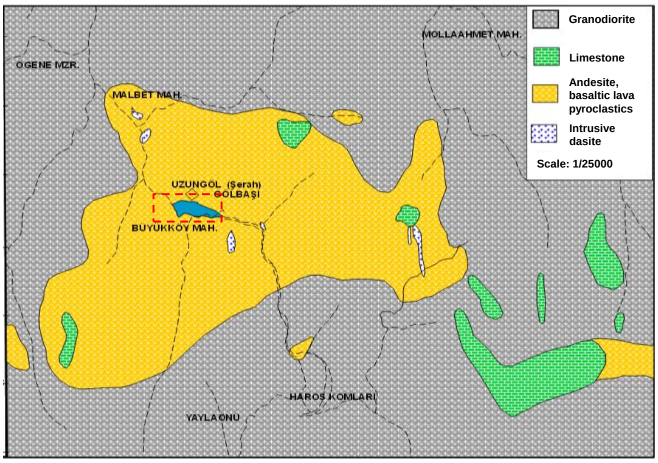

Figure 2. Geologic map of Trabzon- Çaykara- Uzungöl (Şerah) (MTA, 1985)

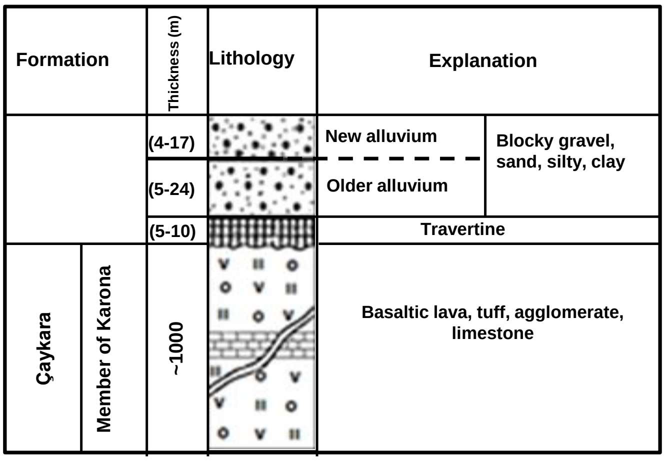

Figure 3. Simplified lithostratigraphy (modified from Bulut, 1989)

Also, the lithological column regarding drillings done in 5 different locations by DSİ (1982) and A-A' cross-section referring to S3-S5 drilling locations are given in Figure 4a and 4b. According to well inform, the ground is generally consist of sandy-silty clayey with the thicknesses of 10-15m according to S3 and S5 wells, while it is clearly seen that the bedrock is consist of basalts.

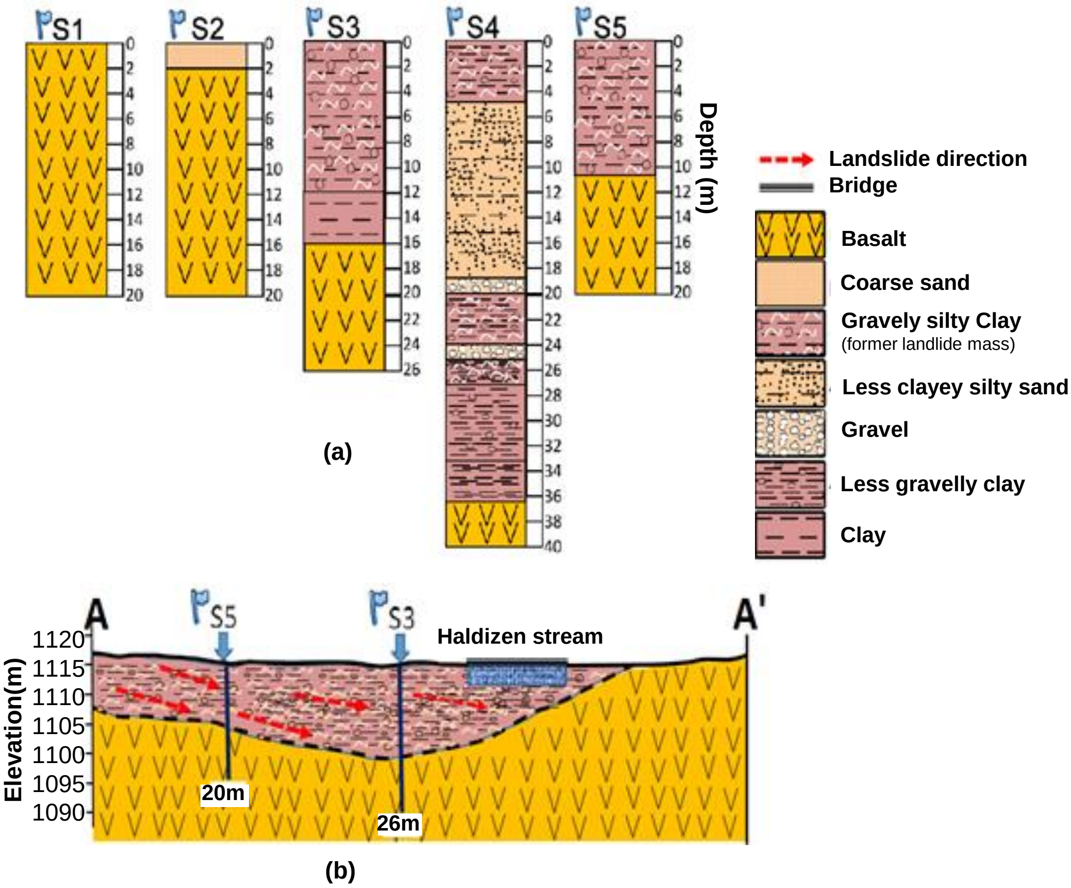

Figure 4. (a) Lithological column from drilling logs at coastal of Lake and (b) geological cross-section of A-A' (modified from DSİ, 1982)

Results and Discussion

Data set and assessment

All data were gathered on the suitable profiles which are determined by preliminary studies carried out in the study area and the interviews with residents. In data acquisition vertical component geophones with 4.5 (for refraction, MASW and ReMi) and 40 Hz (for reflection) and 24 channel exploration seismography were used. The location of 16 profiles is shown in Figure 5. 11 of the profiles were situated in the west of the lake where there are especially agricultural areas, while 4 other profiles were situated in the south part of the lake, which is very near to shore of the lake. As the north of the lake is used as a car park, there were no available places to collect data. However, some sample data were collected in the area which was suitable for a short spread and formed by filling the lake. Profiles were divided into 4 groups: Group 1 represents the area which was partly opened to settlement and where the structuring is considered to proceed rapidly. Group 2 presents an area where the construction is relatively low because of arable. Group 3 represents slope topography and any construction is not allowed there as it is in a location because of landslide hazard. Group 4 represents the profiles which were the nearest areas to the lake, and also structuring is proceeding at the present time. During data acquisition, 10kg sledge hammer and 30 cm radius 5 cm thick solid plastic panel was used in all profiles. To improve signal/noise rate of MASW and refraction records vertical stacking were used as 3 for each shot point and as 10 for ReMi records. The data acquisition parameters for all profiles are listed in Table 1.

Figure 5. The location of measurement profiles in the study area

Table 1. Summary of seismic data acquisition parameters

SURVEYING/PROFILES		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	16
REFRACTION	NS	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	ΔX (m)	3	2	2	2.5	2	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	T (s)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MASW	X_0(m)	12	10	10	10	6	12	8	8	8	6	6	8	12	12	18	8
	ΔX(m)	3	2	2	2.5	1.5	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T(s)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ReMi	ΔX (m)	3	2	2	2.5	2	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T(s)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
REFLECTION	X_0(m)	2		2			2										
	ΔX(m)	2		2			2										
	Δt(ms)	0.5		0.5			0.5										
	T(s)	1		1			1										
	NS	25		16			19										
	ΔS(m)	1		1			1										

NS: number of shots within profile, Δx: geophone interval, Δt: time sampling interval, T: record time, X_0: first offset, ΔS: shot interval. m: meters, s: second and ms:milisecond

In addition to MASW data, ReMi records were collected with 4.5 Hz receivers with using automatically triggering property of recording device. Data samples from recorded data are given in Figure 6. Except for ReMi records, the differences between the other data are basically related with the purposive data acquisition parameters such as record time and sampling time.

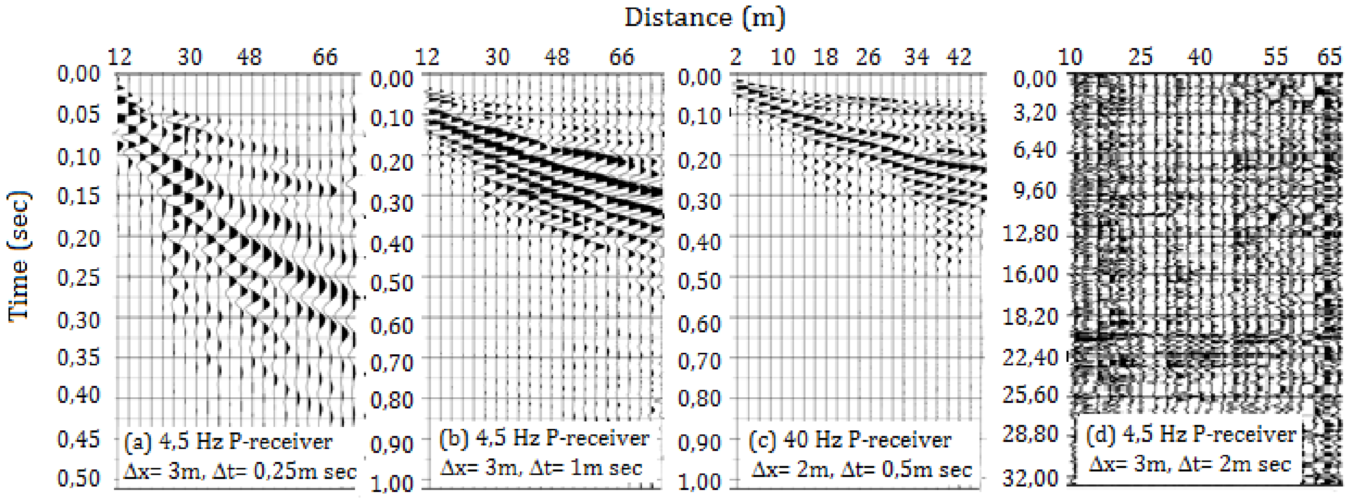

Figure 6. Field data samples gathered according to our purpose. (a) seismic refraction (b) MASW (c) seismic reflection and (d) ReMi data

To increase the reliability and the accuracy of first arrival tomographic inversion of seismic refraction data and therefore, to obtain high resolution P-wave velocity structure of the ground, more shots as possible were done. Number of these shots varies between seven and twelve and shots were organized as follow: two far offset shots, forward and reverse shots and inner-shot between geophones as possible. Thus, tomographic solutions produced more reliable and detailed results to determine both velocity model and bedrock topography when compared to traditional delay time methods. On the other hand, individual and combined analysis of MASW and ReMi data ensured to obtain 1D S-wave velocity-depth profile. Even though the data acquisition and dispersion curve (represents the phase velocity versus frequency of surface wave) extracting practices for the two methods differ, the inversion analysis is the same in both methods. In application, firstly dispersion curves from both data are separately extracted and then combined. The dispersion curve of ReMi data represents lower frequency information (generally 2-20Hz) or longer wavelength leading to obtain V_s values at deeper part of the ground, while the MASW data represents higher frequency (generally 5-70Hz) or short wavelength leading to obtain V_s values at shallow part of the ground. So the combination of both dispersion curves provides reliable and accuracy information about S-wave velocity-depth variation in the inversion. This strategy was demonstrated with Figure 2 in the paper of Uyanık et al. (2013). Therefore, when not reached to 30m by inversion of the MASW dispersion curve, it was utilized from dispersion curve of ReMi data. As seismic reflection data were gathered along the layouts forwarded to the directions of the receivers, 2D S-wave velocity sections for the measurement profile were formed by placing and combining 1D S-wave velocity profiles obtained from surface waves of these data into the middle of each layout. On the other hand, geometry and shot number of seismic reflection data were formed according to obtaining the most common midpoint (CMP) stacking number (folding) as soon as possible. First arrival tomographic inversion of seismic refraction data and the inversion of ReMi dispersion curve were evaluated with using SeisOpt software (Pullammanappallil and Louie, 1997), while MASW data were inverted with KriSis (Kritakis and Vafidis, 2011) code written in MatLab language. On the other hand, in the assessment of seismic reflection data, Promax (URL-1) software was used.

All of P-wave velocity sections obtained from first arrival tomographic inversion is illustrated in Figure 7 according to their surveying locations in UTM (Universal Transversal Mercator) coordinates. It is clear that P-wave velocity sections generally refer to the existing landslide materials, the thicknesses of which vary between 15-20m. At the same time, they explain that the depth of bedrock is quite variable between profiles. Accordingly, the thickness of the material on the bedrock increases towards the lake. As seen on sections, the stratigraphy has three units: (1) the unit (shown by purple and deeper part by blue color) is mostly composed of landslide materials and is available for agriculture. The P-wave velocity of the unit is nearly

V_p=~110-1600m/sec, and its thickness varies between the profiles. Especially the thickness of the unit is more for P7, P8 and P10 profiles since the locations of these profiles are on landslide-prone area. So that bedrock topography was not imaged for P7 profile because of very thick material deposition. (2) The unit is represented by dominantly green colors for all sections. P-wave velocity interval of the unit is mostly V_p=~1600-2800m/sec respectively. The unit is characterized by landslide deposits, but it is harder and the other (unit by purple color). (3) Units illustrated by yellow and red colors represent the bedrock consisting of basalts (Vp>~2800m/sec).

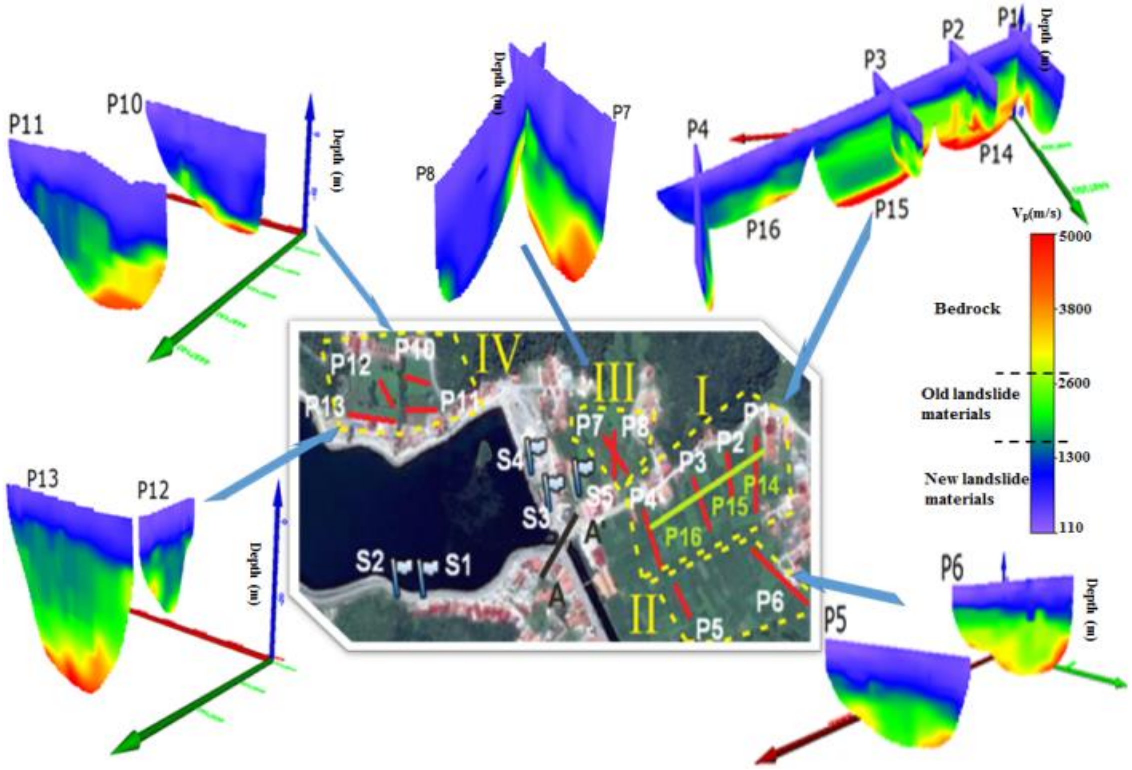

Figure 7. P-wave first arrival tomography sections obtained for profiles 1,2,3,4 and 1D S wave velocity-depth profiles

The dispersion curves were extracted from all MASW and ReMi records and 1D S-wave velocity-depth profiles for 30m depth are obtained by either individual or combined inversion of those curves. Here, the 1D-Vs profiles for Group I and III are shown in Figure 8. Aforementioned, in the area including Group I data, structuring activity is currently on going and if it continues like this, this area will be completely filled with buildings as soon as possible. On the other hand, despite the area of Group III is restricted area as landslide-prone area, structuring is moving to this area. So, S-wave velocity-depth profiles of these areas are given here. The results for Group I show similarly that the velocity increases gradually with depth. This means that the ground consolidates to depth. It is note that although P7 and P8 profiles are intersecting profiles, they show the similarity up to 16m but significant difference below 16m depth (see arrow). This is because the thickness of the deposited materials along the P8 profile is more, that is, the bedrock is deeper at this point. These velocity-depth profiles are quietly accordance with the tomographic results, and S-wave velocity meaningfully raises in the levels corresponding to P-wave velocity changes shows that stiffness-hardness of the material increases from the surface to the depth.

Reflection data gathered in profiles 1,3,6 were made ready to be interpreted by a sequential data processing techniques including data loading, geometry definition, editing-muting, bandpass filtering (15-90Hz), common midpoint sorting, velocity analysis, normal moveout correction, CMP stacking and Kirchoff depth migration. Produced seismic sections are comparatively presented with P-wave velocity tomographic sections in Figure 9 (right column). Possible interface between landslide material and bedrock was indicated by benefitting from amplitude and phase changes in the sections (red dotted line). Especially, bedrock level in tomography section for profile 6 could not be clearly determined, whereas this level was determined in the reflection section of the same profile. On the other hand, remarkable velocity drop in the tomography section of profile 3 was interpreted as lateral reflection discontinuity in the reflection section. It is obviously seen that landslide material, depending on bedrock topography variety, has different thicknesses between profiles in both tomographic and reflection sections.

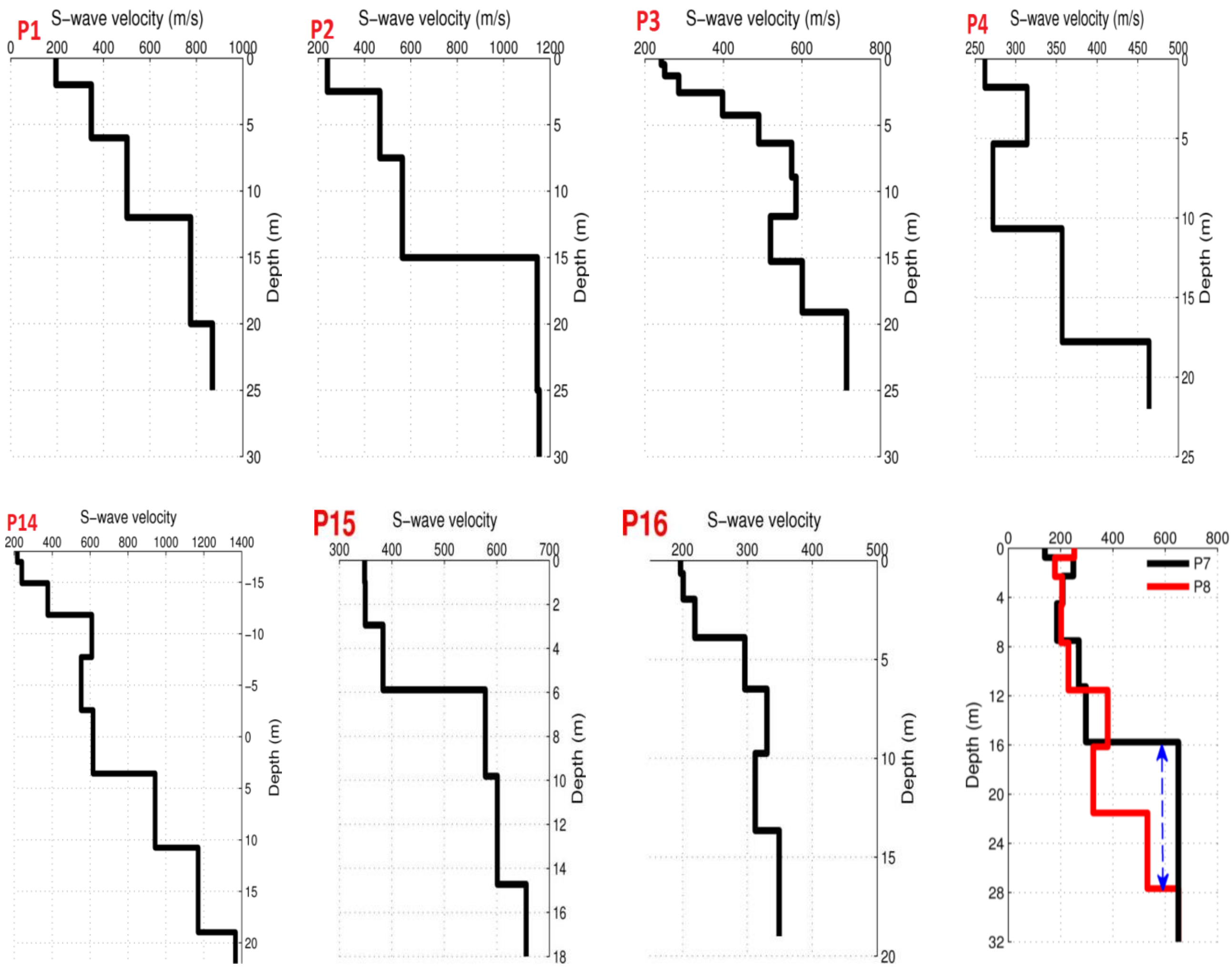

Figure 8. 1D S-wave velocity-depth profiles for Group I (except for P7 and P8) and III

1D S-wave velocity-depth profiles obtained by using surface waves of each consecutive reflection shot were placed into the middle point of each spread for profiles 1,3,6 and they were combined by interpolation. Thus, 2D S-wave velocity-depth sections were obtained and the soil character of the study area was determined (Figure 10). The vertical bar in middle of 2D-V_s section (right) is the inversion of MASW data of profile 1. This shows that 1D-V_s and 2D-V_s results are purely compatible. Therefore, landslide material thicknesses (V_s<600m/s), and accordingly, bedrock topography vary even though 2D S-wave velocity and tomographic sections supported each other. According to S-wave velocity variation, soil stiffness profile is shown on velocity scale with color bar in Figure 10.

The thickness, lateral and vertical variation, stiffness-hardness profile of the soil and the depth of bedrock and topography in the study area were determined with P- and S- wave velocity and reflection sections. Besides, elastic-dynamic parameters of the material were calculated for the first 30m by using this velocity information. S-wave velocity-depth sections in Figure 10 show to mostly 20-23m depth information as they are derived from the reflection data acquisited with 40Hz receivers. ReMi records of these profiles were benefitted for 30m and deeper parts. Therefore, for all profiles, the value of average S-wave velocity (V_{S30}) in the first 30m depth, necessary for national Turk Earthquake Codes (TEC, 2007) and international EURO Code 8 (EC-8) (CEN, 2004) and NEHRP (BSSC, 1997) ground classifications. Also, geotechnical information was obtained by calculating other parameters correlated with V_{S30} such as ground predominant vibration period, soil amplification, and stiffness-hardness, weathering and softness of the soil.

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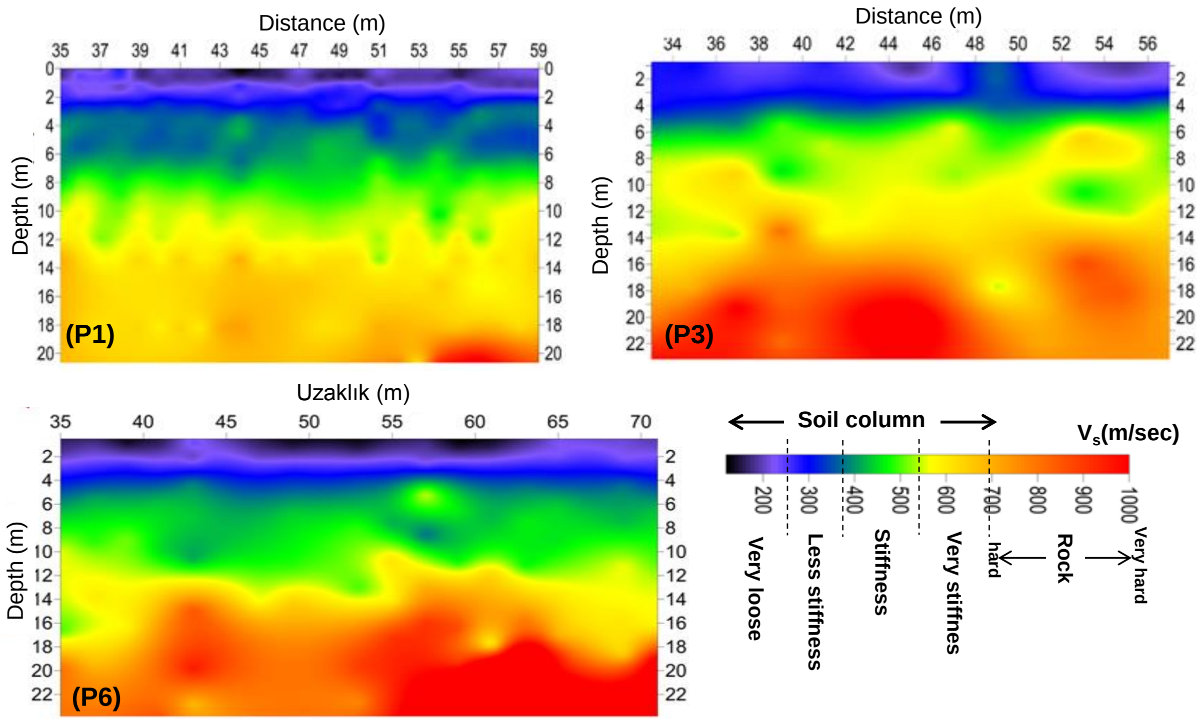

Figure 9: The comparison of P-wave velocity tomographic and reflection sections in profiles 1, 3, 6

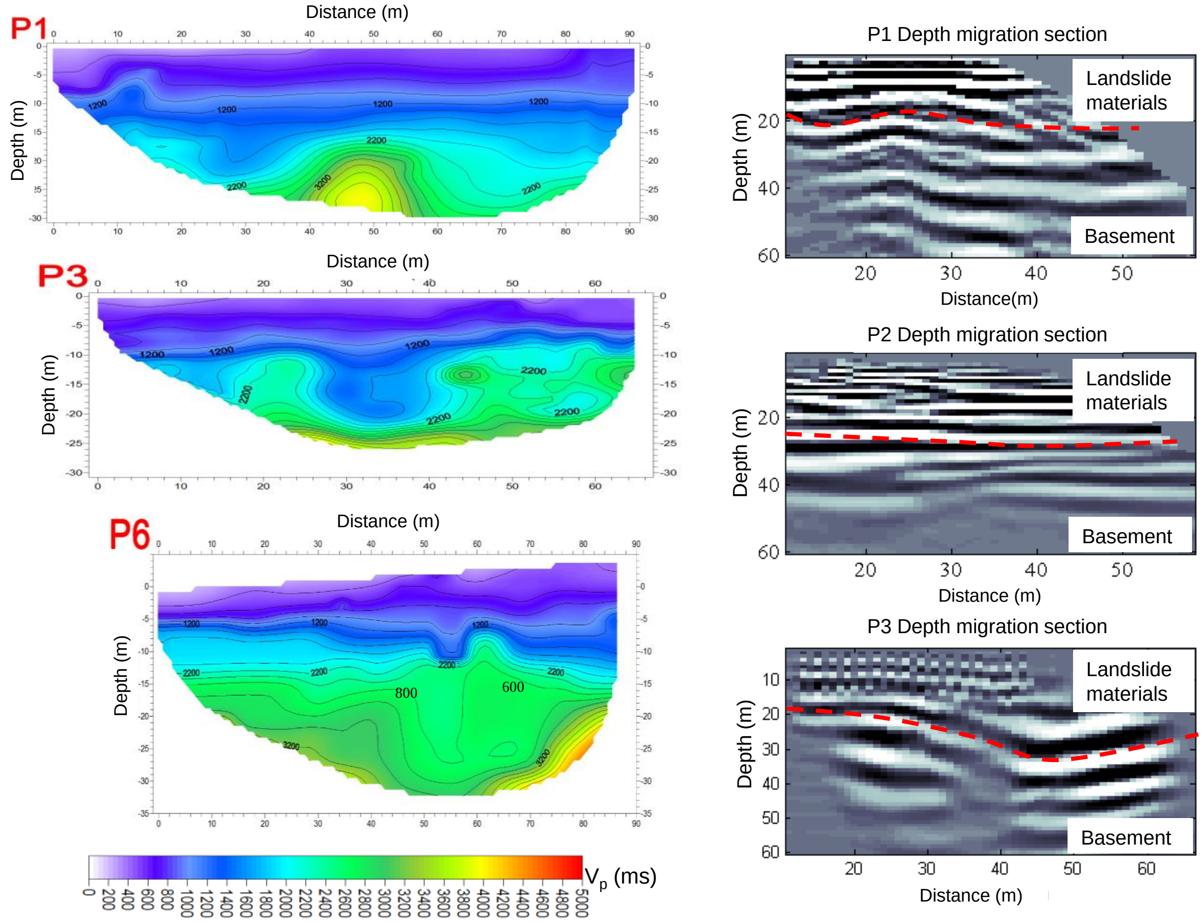

Figure 10. 2D S-wave velocity-depth sections obtained for profiles 1, 3, and 6. The geotechnical character of the ground is shown on color bar

Besides, elastic-dynamic parameters of the material were calculated for the first 30m by using this velocity information. S-wave velocity-depth sections in Figure 10 show to mostly 20-23m depth information as they are derived from the reflection data acquisited with 40Hz receivers. ReMi records of these profiles were benefitted for 30m and deeper parts. Therefore, for all profiles, the value of average S-wave velocity (V_{S30}) in the first 30m depth, necessary for national Turk Earthquake Codes (TEC, 2007) and international EURO Code 8 (EC-8) (CEN, 2004) and NEHRP (BSSC, 1997) ground classifications. Also, geotechnical information was obtained by calculating other parameters correlated with V_{S30} such as ground predominant vibration period, soil amplification, and stiffness-hardness, weathering and softness of the soil.

Conclusion

In this study, the structure and geotechnical properties of Uzungöl settlement area formed by a historical landslide materials and lake sediments were investigated with shallow seismic methods. On the other hand, the use of integrated seismic methods and the assessment of data in different analysis were proved to be extremely beneficial to discover ground structures and properties in high accuracy and reliability. The thickness of the soil in the study area is very irregular up to the bedrock. While thicknesses are 15-20m in the west of the study area, they are displayed ≥30m in the south and lake nearby. Thus, it is seen that the thickness of the soil in the study area increases towards the lake and it reaches the highest level in the areas near the lake. All lithological units were defined by taking the same coloring scale into consideration, depending on P- and S-wave velocity sections changing along the depth, and they are shown on the sections obtained for profile 1 in Figure 11. Generally 3 main geological units which were formed by; (1) arable, landslide materials whose the stiffness and hardness vary in different degrees and basalt from the surface and those units are divided into subunits in itself each. Therefore, soil profile is separated into 5 lithological and geotechnical subunits : (1) very loose gravelly-silty-clayey arable between 0-2.5m (V_p=300–480 m/sec, V_s=180–250 m/sec, (2) less stiffness silty-gravelly clay (V_p=480-1100m/sec, V_s=250-380 m/sec) between 2.5-7m, (3) stiffneess gravelly-clay (V_p=1100-2000 m/s, V_s=380-550 m/sec) between 7-15m, (4) very stiffness gravelly-clay or softness bedrock (V_p=2000-3200 m/sec, V_s=550-700 m/sec) and between 15-20m, (5) hard-very hard bedrock formed from basalt rock (V_p> 3200m/s, V_s >700 m/s) larger than ~20m depth.

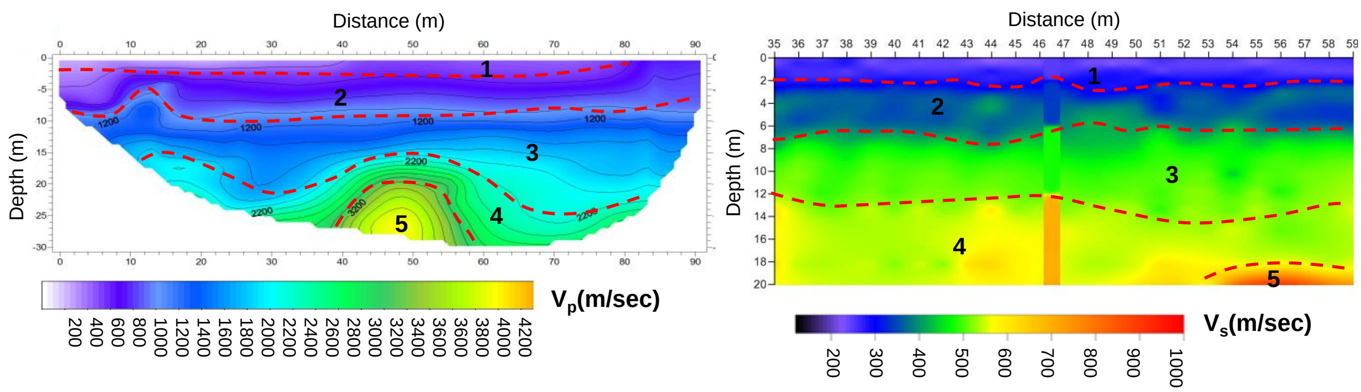

Figure 11: The lithological correlation between units from drillings and P-wave (left), S-wave (right) velocities for profile 1: (1) arable soil (2) silty-gravelly clay (3) medium-stiffness gravelly clay (4) very stiffness-solid gravelly clay (5) bedrock (basalt)

It was seen that P-wave velocity decreased until less than 2000 m/s because there is a transition level between the weathering in a few meters of bedrock and overlying very stiff-solid landslide material. Geotechnical assessment explaining the ground profile and its properties of the study area was done owing to the dynamic-elastic parameters calculated for each profile and V_{S30} values. Thus, the site classification of the study area is summarized in Table 2. Consequently, we suggest that the information will make an important contribute to make the development planning of Uzungöl settlement.

Acknowledgements

This study was supported by Karadeniz Technical University Scientific Research Projects Unit (Project no: 11512). We thank Municipality of Uzungöl and Çaykara and landowners for their permission to enable us to collect data during the project. We would like to special thank Dr. Satish Pullammanappallil and Dr. George Kritakis for contributions in tomographic, ReMi and MSW solutions of data.

Table 2. The site classification of the study area according to V_{S30}, which was calculated as an average value for each group shown in Figure 5 and 7.

Site classification according to V_{s30}, the eighted average value of S-wave velocity up to 30m								
Area No	V_{s30} (m/s)	$A_0=68*(V_{s30})^{-0.6}$ (Midrokowa, 1987)	$T_0=4*H/V_{s30}$ (s) (H=30m)	T_A (s)	T_B(s)	TEC (Turkish Earthquake Code)	EC-8 (Eurocode-8)	NEHRP (National Earthquake Hazard Reduction Program)
I	530	1.56	0.23	0.15	0.35	B and C class	B and C class	C and D class
II	474	1.69	0.25	0.17	0.38			
III	336	2.10	0.36	0.24	0.54	Local soils class:	(Hard soil)	(Stiff-hard soil or soft
IV	394	1.89	0.30	0.20	0.45	Z2-Z3		rock)
						(moderate stiff-hard soil)		

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