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Mert Grit and Ali Ismet Kanli*

Integrated Seismic Survey for Detecting Landslide Effects on High Speed Rail Line at Istanbul–Turkey

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Abstract: In this study, Multichannel Analysis of Surface Waves Method (MASW), seismic refraction tomography and seismic reflection methods are used together at Silivri district in Istanbul – a district with a landslide problem because of the high speed rail line project crossing through the area. The landslide structure, border and depth of the slip plane are investigated and correlated within the local geology. According to the obtained 2D seismic sections, the landslide occurs through the East-West direction in the study area and the landslide slip plane with its border are clearly obtained under the subsurface. The results prove that the study area is suitable enough for the landslide development and this evolution also affects the high speed rail line project.

Keywords: Seismic Reflection; Refraction tomography; MASW; Landslide; Railway

1 Introduction

The landslide research is one of the most important application area of near surface geophysical engineering studies. In parallel with the developments of geophysical equipments and softwares, seismic tomography and high resolution seismic reflection methods are widely used in the determination of soil properties and geological structures of the near surface materials. Furthermore, surface wave methods are also commonly used in the determination of S wave velocities. Since the ground properties can easily change even in short distances, it is important to research these properties for the engineering applications. Using engineering parameters that are obtained from geophysical studies for the construction designs may reduce the damage of natural disasters like the earthquakes [1].

Conventional analyses of seismic refraction data sets produce simple assumptions about the velocity structure that is in conflict with the observed heterogeneity, lateral discontinuities, and gradients. However, refraction tomography is designed to resolve velocity gradients and lateral velocity changes enabling it to be applied in settings where the delay time techniques fail, such as the areas of compaction, karst, and fault zones [2]. Seismic tomography involves the inversion of the first arrival traveltimes from many sources and geophones in order to create a seismic wave velocity distribution within the subsurface [3, 4]. Seismic refraction tomography is able to give the image of the landslides that have complex velocity structures [5]. This method has been widely used to model the landslides [e.g. 6–8]. It is observed that lateral velocity changes can be imaged competently by the use of the seismic tomography method [9] and [10] the utilized seismic tomography. These two methods also become functional in conjunction with the Surface Wave Method (SWM) in the characterization of landslides areas.

The success of the seismic reflection techniques depends on the existence of the discrete velocity and/or density changes within the subsurface. Discrete changes in the seismic velocity or the mass density are known as the acoustical contrasts. Generally, the acoustical contrast occurs at the boundaries of the geologic layers or formations. The classical use of seismic reflection involves identification of the boundaries and the layers of the geologic units. This technique is becoming more cost effective since it provides new applications for the resolution improvements [11]. Reflection seismic profiling is commonly used as a geophysical tool in a wide range of areas in order to image the subsurface [12]. Additionally, imaging the shallow landslides can become increasingly successful as a result of the recent developments in the shallow seismic reflection method [13]. It is known that the compressional and shear wave velocities are generally lower within landslide bodies than they are in the undisturbed rocks due to the weathered and fractured nature of the landslide mass [14].

Mert Grit: Istanbul University, Graduate School of Science and Engineering, Department of Geophysical Engineering, 34320, Avcilar Campus, Istanbul, Turkey
***Corresponding Author: Ali Ismet Kanli:** Istanbul University, Faculty of Engineering, Department of Geophysical Engineering, Avcilar Campus, Istanbul, Turkey; Email: kanli@istanbul.edu.tr; Tel.: +90 212 4737070 ext. 17565; Fax: +90 212 4737180

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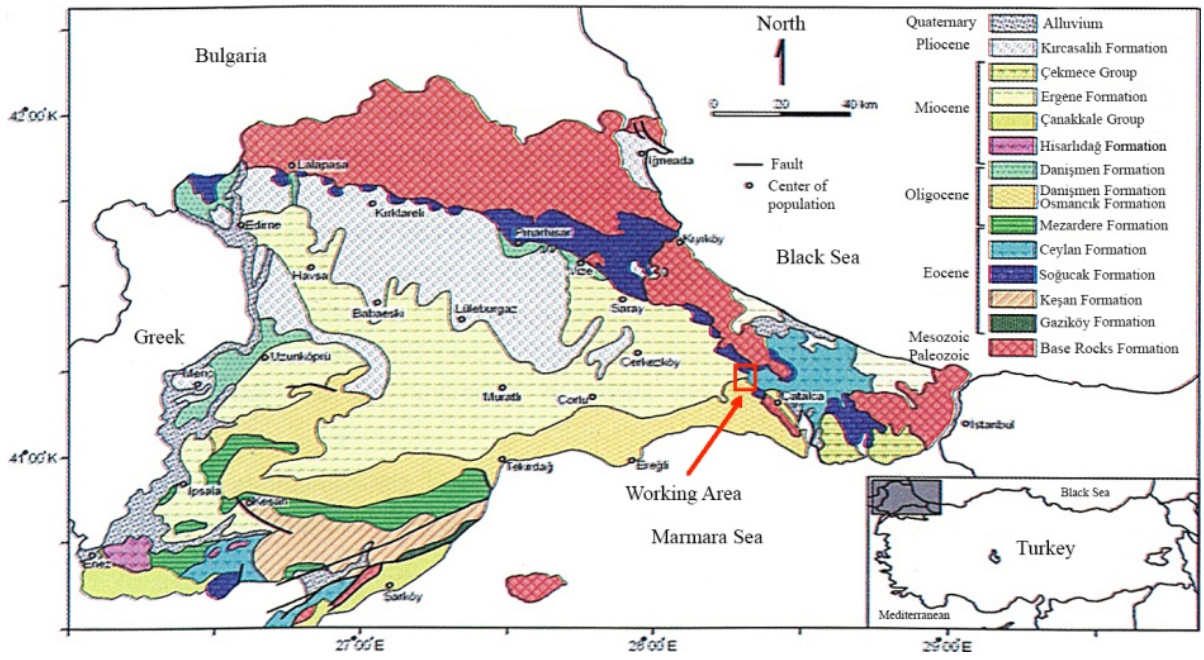


Figure 1: Geological map of the study area (from [18]).

Although the ground roll is considered as a noise in the conventional body wave surveys, its dispersive properties can be used to obtain information from the near-surface elastic properties. Among various seismic waves, the surface waves have the strongest energy as a result of their high signal-to-noise ratio (S/N), making it a powerful tool in the near surface characterization. In layered media, the propagation velocity of a surface wave depends on the frequency (or wavelength) of the wave because of its geometric dispersion. Shear wave velocity can be derived by inverting the phase velocity of the surface (Rayleigh and/or Love) waves. Surface Wave Methods use Rayleigh-wave data recorded on data acquisition instrument to determine the phase-velocity dispersion curve, and then the shear wave velocity is estimated with respect to depth from the dispersion relation by performing a geophysical inversion procedure [15].

In this study, MASW, seismic refraction tomography and seismic reflection methods are used together on two separate profiles at Bekirli village in Silivri district of Istanbul which has a landslide problem crossing through the high speed railway project. The Landslide structure, border and depth of slip plane are investigated and correlated within the local geology by using three important seismic methods. In conclusion, the landslide problem and its effects on the construction of the high speed rail line are discussed.

2 The study area and the geology of the region

The study area takes place at the northern part of the Marmara Sea, near Bekirli village at Silivri district in Istanbul. Thrace basin which includes the study area takes place in the geographic borders lie through Greek from west, Saros Gulf from southwest and Aegean sea [16, 17]. Ergene and Danişmen formations occur in the study area. The geological map of the study area is given in Figure 1.

Danişmen formation takes place between Osmancık formation and Ergene Group at a deep zone of the Thrace Basin. The formation's age is upper oligocene and it's thickness is about 200–300 meters. Due to its' incompetent lithological properties, it forms the plains and it appears at incisions and coil furnaces. It consists of coily shales that rarely include milestone and sandstone interval layers. It often has unfirmed pattern. The clastics of Ergene Group – that are stored at the upper delta distribution-channels irregularly and they come upon with Danişmen formation.The top layer of the study area has an unconsolidated structure. Beneath this layer, we have Ergene group which contains conglomerate, sandstone, clay and clayed limestone. At the bottom, there is the Danişmen formation which contains shale and siltstone. The evolution of the landslide occurs between Danişmen and Ergene formations. Ergene formation takes place upon Danişmen for-

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Table 1: Data acquisition parameters of Profile 1 and Profile 2.

Profile No	Profile Lenght	Geophone Interval	Shot Interval	Recording Lenght	Sampling Interval
Profile 1 and 2	87 meter	3 meter	1.5 meter	2048 ms	0.25 ms

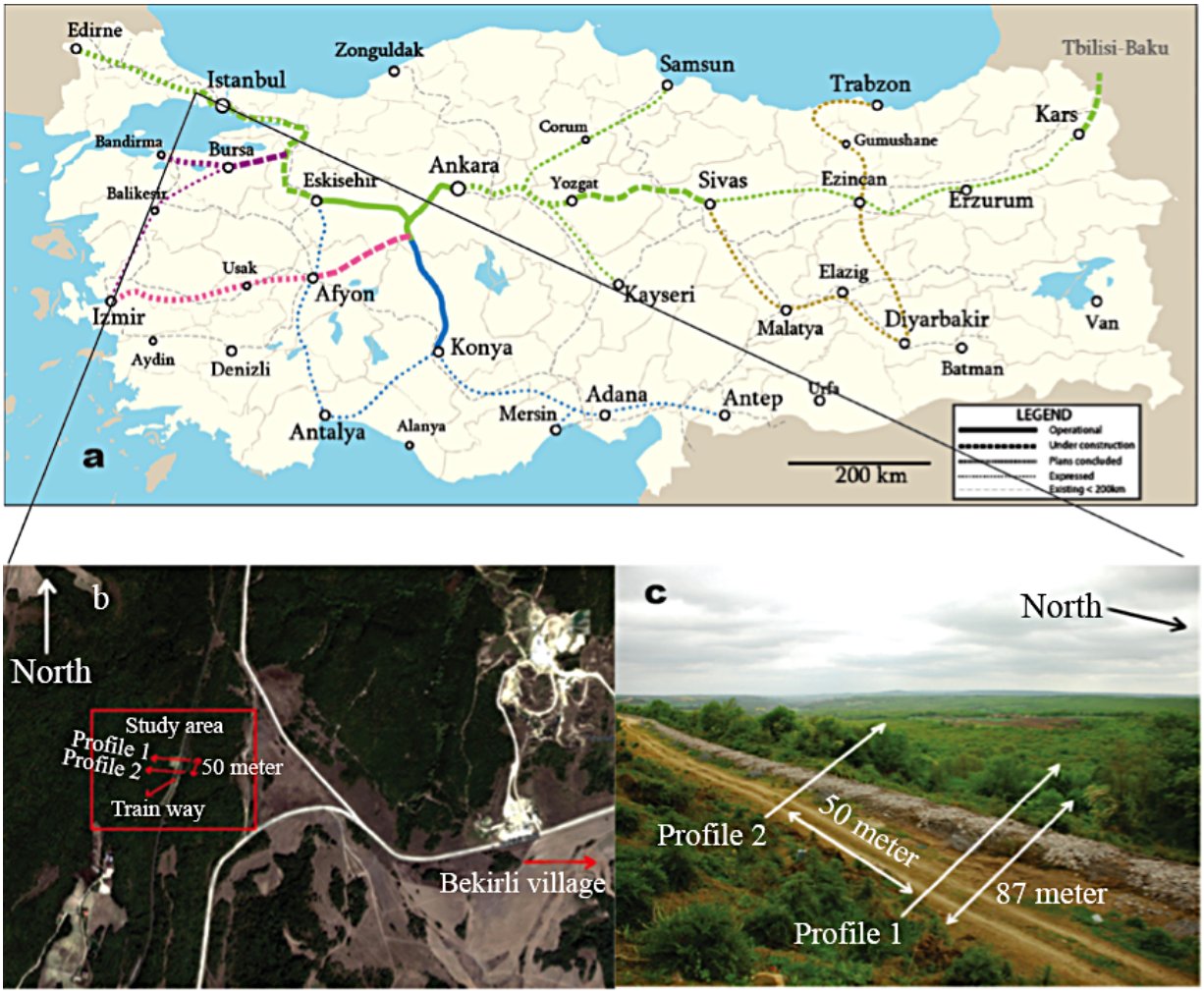


Figure 2: a) High Speed Rail Line Project of Turkey is given in the picture. b) Study area and the locations of Profile 1 and Profile 2. c) Picture from the field showing the rail line and the profiles.

mation and it is structured as a fractured rock. The underground water generates an impermeable zone between these two formations and it causes the evolution of the landslide.

3 Methodology

In the study, seismic survey was carried out through the Halkalı-Çerkezköy High Speed Rail Way that is in Bekirli village, Silivri district of Istanbul. Data are gathered from the two separate profiles. The distance between Profile 1 and Profile 2 is 50 meters and the length of each profile is 87 meters. Profile locations and study area can be seen in Figure 2. PASI 16SG-24N 24 channel seismograph is used for gathering seismic data and 7 kg of sledgehammer source with 10 Hz geophones were used for seismic measurement. Shot intervals are taken as 1.5 meter and, 59 shots with 3 folds are carried out during the field study. Data acquisition parameters that are used in the study is given in Table 1. The total lenght of each profile is 87 meters and the offset is taken as 9 meters. Each profile was

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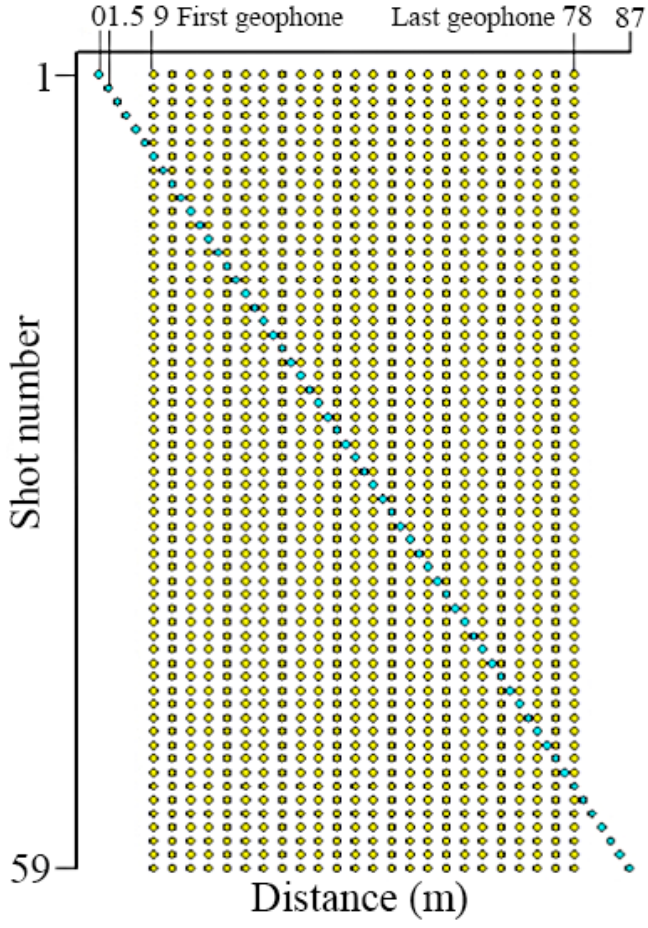


Figure 3: Field geometry of Profile 1 and Profile 2. Yellow dots represent the geophone locations and grey dots represent the shot locations.

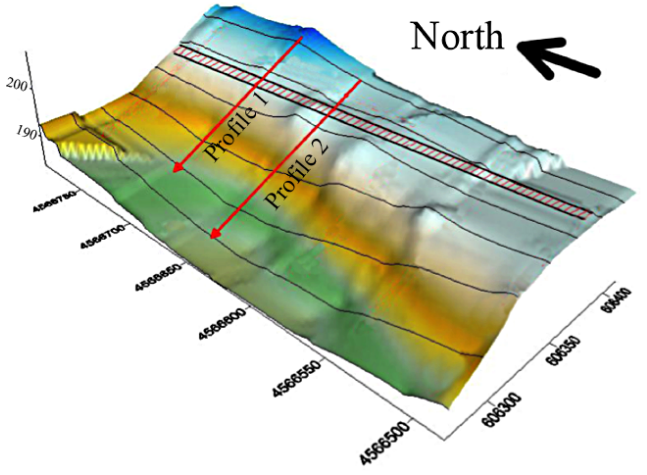


Figure 4: Topographic image of the study area with the location of the profiles.

stable and shot locations were shifted during the stage of data gathering. The geometry of the field used in the study can be seen in Figure 3. The data gathered in this geometry are used throughout all the analysis process. The local topography data of the study area are recorded by GPS. The topographic map is plotted as seen in Figure 4.

Before beginning the data process, geometry setups are checked in order to eliminate the probable mistakes that could appear at the field. Before the initiation of the MASW and the seismic refraction tomography analyses, bad traces and noises should be eliminated from the seismic data.

Geometrics Seisimager software and modules are used for MASW and seismic refraction tomography data analysis. In the seismic reflection data process, VisualSUNT 6 software is used.

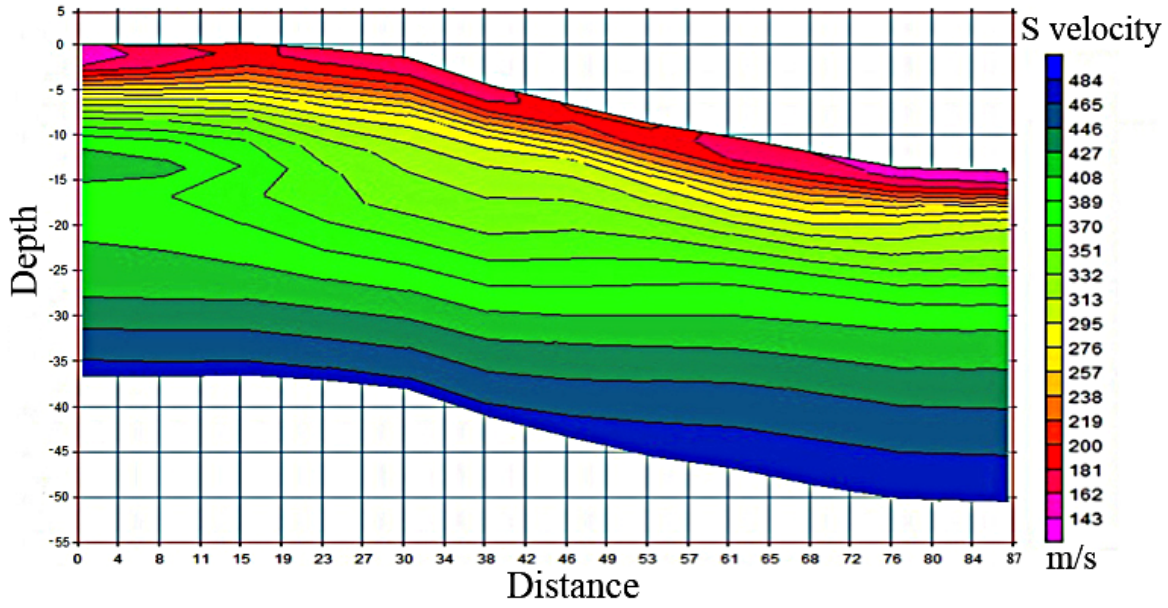
3.1 MASW analysis

S-wave velocity model of the Profile 1 and Profile 2 are obtained by making use of the MASW method. First of all, Common Mid Point Cross Correlation (CMPCC) gathering process is applied to all the data in each profile. In this way, traces with common mid point are grouped. This stage is essential for the two dimensional analysis. As a result of this process, seismic record numbers are reduced from 59 to 12 and then, these records are used for the frequency spectrum analysis.

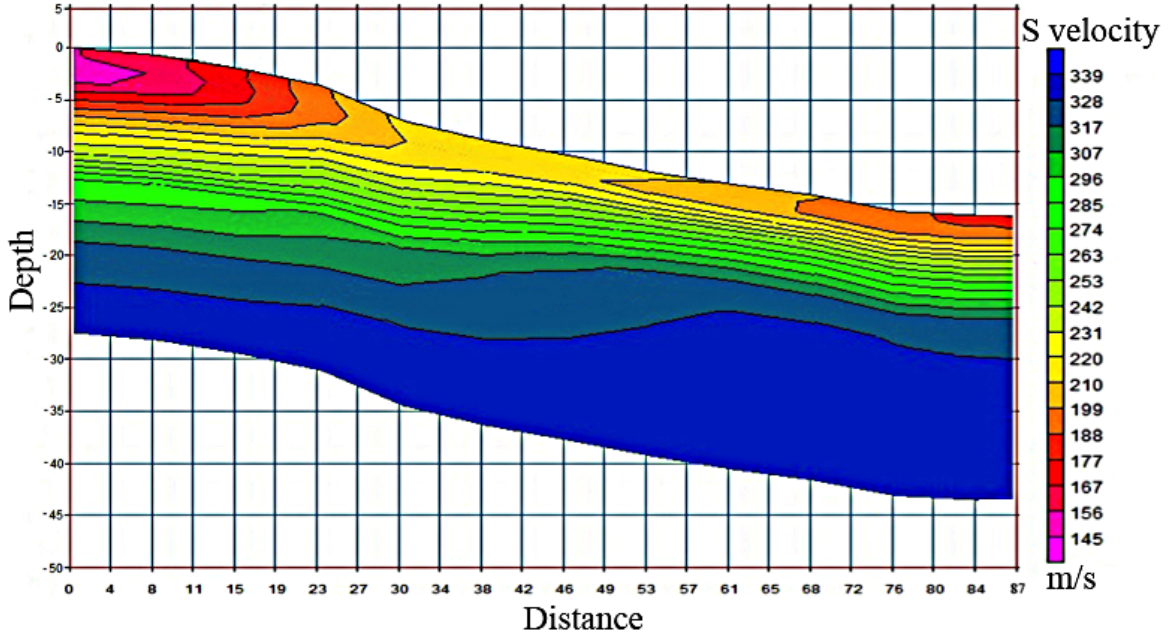
After CMPCC gathering, time domain seismic records are transformed into the frequency domain by making use of the phase shift method. Maximum amplitudes of each frequency are selected on the frequency spectrum in order to create the dispersion curve. This stage is the most important part of the data process in order to get proper S-wave velocity results at the end of the process. After determining the dispersion curves, initial models are created in order to initiate the inversion process. In this stage, two dimensional S-wave velocity model is created by depending on the depth and layer numbers. In the inversion stage, the damped least square method [19, 20] is used and thus, S-wave velocity models are obtained for profile 1 and profile 2. Finally, GPS records (locations and elevations) are imported and added into models to arrive at the S-wave models with a topography information. In Figure 5 (a and b) two dimensional S-wave velocity models that are obtained can be seen.

As seen in the Figure 6 (a and b), one dimensional analysis results of profile 1 and profile 2 can be observed respectively in the middle of the profiles (39th meter of each profile).

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(a)



(b)

Figure 5: Obtained 2D S-wave velocity models for Profile 1 (a) and for Profile 2 (b).

3.2 Seismic refraction tomography

P-wave velocity models of profile 1 and profile 2 are obtained by making use of the seismic refraction tomography method. In this technique, travel time differences between the observed and the theoretical data results are tried to be minimized. After picking the first breaks, initial velocity model is created and travel times are calculated by making use of the ray tracing technique. The differences of the travel time between the results of the field study and the calculated travel times of each ray are determined. Eventually, travel time differences are found in each iteration during the inversion process and the models are updated by making use of the Simultaneous Iterative Reconstruction Technique (SIRT) [21, 22].

In the study, after the picking stage of data analysis, the 13 time-distance curves are chosen for each profile. Afterwards, the conventional refraction data analysis is ex-

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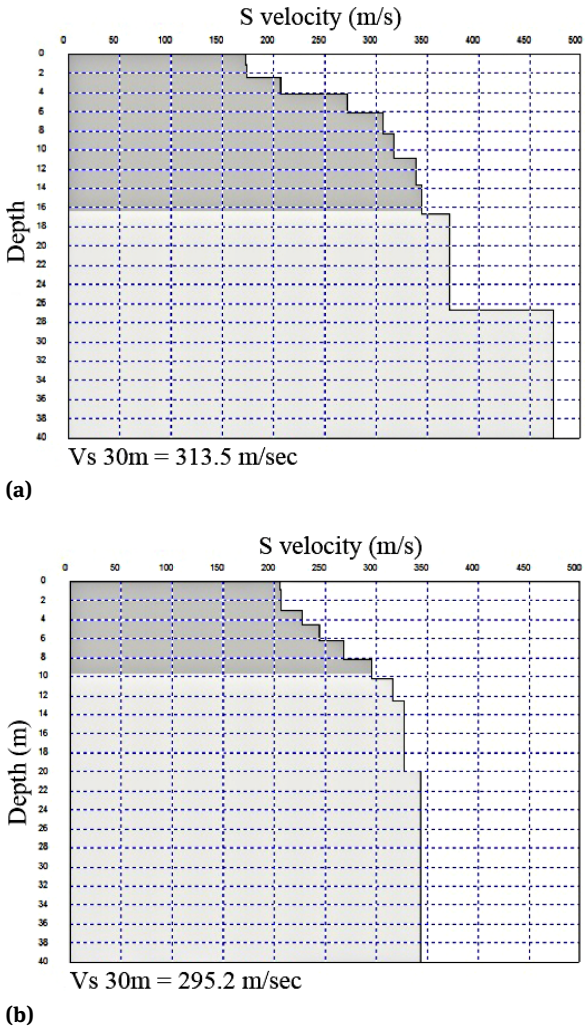


Figure 6: One dimensional velocity model in the middle of profile 1 (a) and profile 2 (b).

ecuted in order to create the initial layer model which is a crucial step in the determination of the minimum and maximum velocities and the top of the deepest layer. In the creation of the initial model stage, GPS data are also imported and they are added into the models. And at last, the inversion process is executed to obtain the P-wave tomograms. The tomograms that are obtained and the ray tracing process of profile 1 and profile 2 can be seen in Figure 7 and 8 respectively.

3.3 Seismic reflection

The visualSunt 6 software is used for the seismic reflection data analysis. Before beginnning the analysis, all data are converted into the SU (Seismic Unix) file type and the geometry setup is adjusted. The geometry adjustment is an important part of the data analysis in order to arrive at the proper results at the end of the process. The geometry configurations that are used for the seismic reflection data analysis of each profile can be seen in Figure 9.

In the edition stage, data are controlled and bad traces with the noisy data are eliminated from the seismic records. Frequency filters are applied to the seismic data by evaluating the frequency-amplitude spectrums. The automatic gain control is applied to correct amplitudes and then, the data is resampled and record lengths are optimized. After finalizing the pre-editing process, data sets become ready for the sorting process.

In this stage, the shot gathered data are transformed into the common depth point gathers. Afterwards, the velocity analysis is performed to determine the layer models and the stack process is executed. Then, the deconvolution and second filtering processes are applied. The time domain data are transformed into depth domain in order to arrive at the reflection depth cross-sections. Eventually, the elevation data are added to cross-sections and the final reflection depth cross-section results are obtained (Figure 10).

4 Interpretation and results

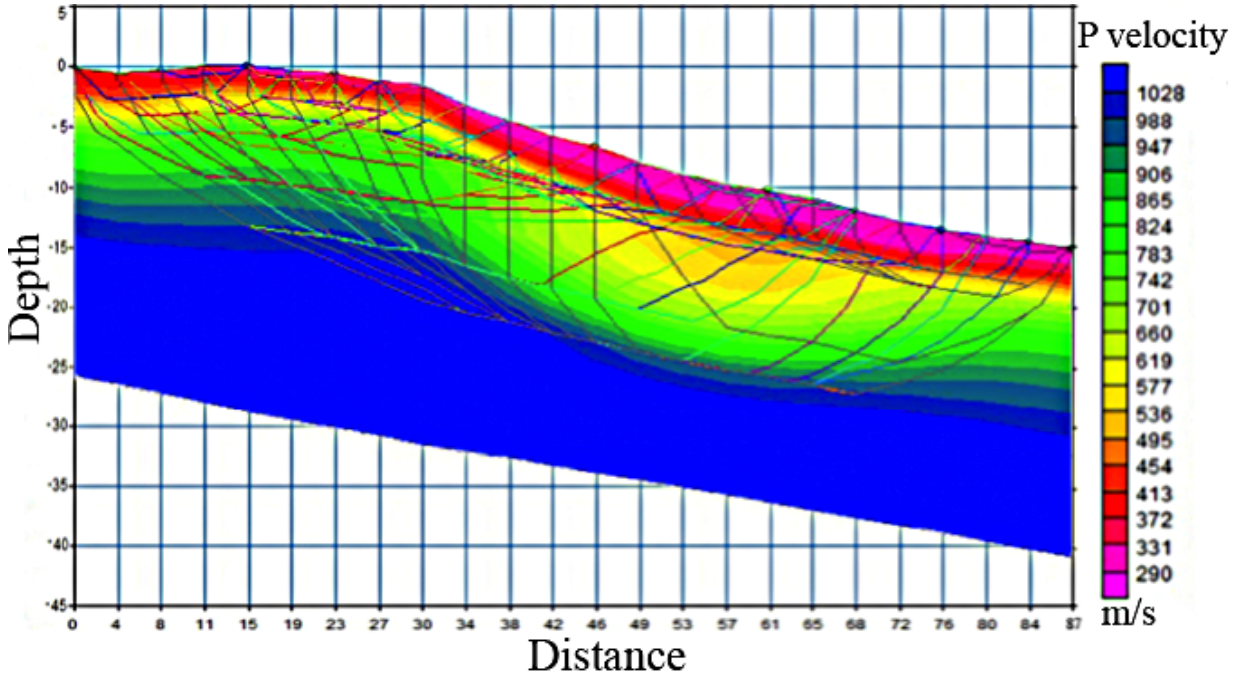
By making use of MASW, seismic refraction tomography and seismic reflection methods, the two-dimensional P and S wave velocity models and the reflection depth cross-sections are obtained for profile 1 and profile 2 which are crossing through the Railway project. The landslide effects on the railway are determined as a result of evaluating the geology of the province and the subsurface landslide properties. In Figures 11 and 12, the 2D seismic interpretation of the profiles crossing through the railway project can be seen.

The length of the profile 1 is 87 meters and the profile is perpendicular to the railway which cuts the profile 1 at the 32nd meter. (Figure 11). According to the GPS data, the elevation of profile 1 is 201.56 meters at the beginning and 185.38 meters at the end. Therefore, it is obvious that there is 16.18 meters elevation difference between the beginning and the ending points.

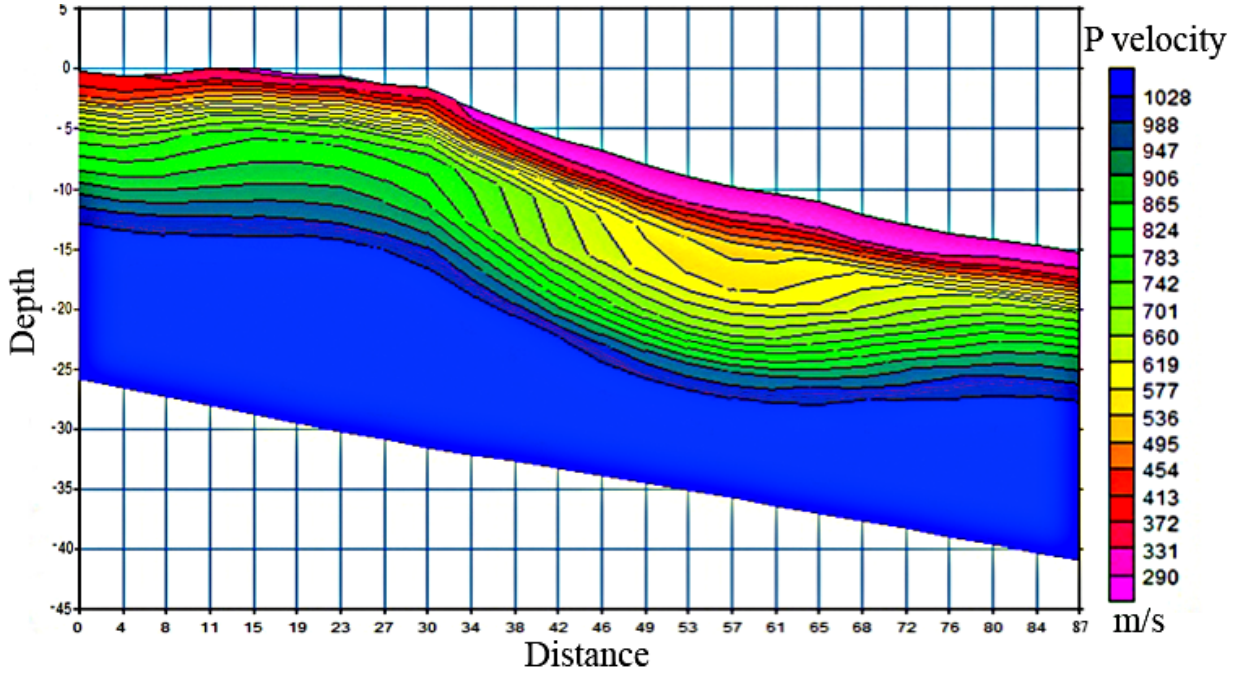
According to the seismic reflection result, the beginning of the landslide slip plane (red line) cuts the profile 1 at the 18th meter. The deepest point of the landslide slip plane reaches to 30 meters of depth (Figure 11c). Some fractures and faults are also detected.

The landslide slip plane can also be found in 2D MASW and 2D seismic refraction tomography sections that can be

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(a)



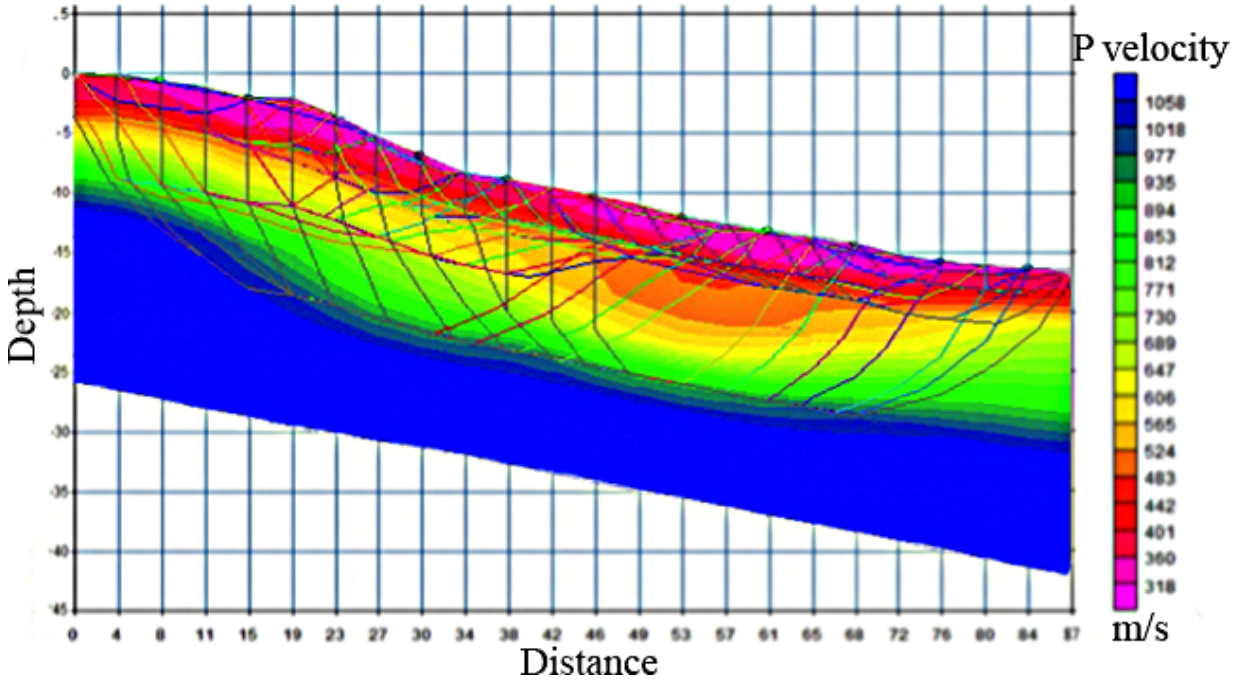
(b)

Figure 7: Ray tracing process (a) and obtained P-wave velocity tomogram (b) for profile 1.

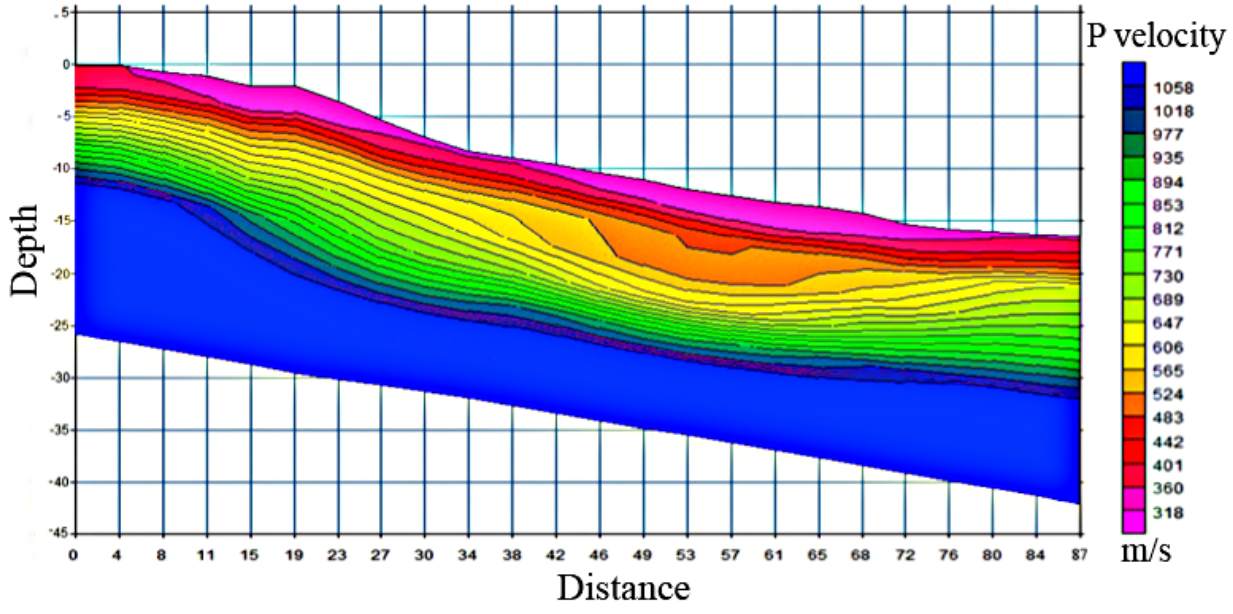
observed in Figure 11a and Figure 11b respectively. This result is congruent with the seismic reflection depth cross-section given in Figure 11c. However, because of penetration problem, the seismic refraction tomography results could not reach resolution of the same depth as they are observed in the seismic reflection method.

According to MASW results given in Figure 11a, there is a layer which has 446–484 m/s S-wave velocity under the landslide slip plane. Upon this plane there is a layer that has 238–427 m/s S-wave velocity and, at the top of this zone there is a layer that has 143–219 m/s S-wave velocity

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(a)



(b)

Figure 8: Ray tracing process (a) and obtained P-wave velocity tomogram (b) for profile 2.

which can be thought as an alluvium supported by the geology of the area.

According to the seismic refraction tomography results given in Figure 11b, there is a layer that has 1000 m/s P-wave velocity beneath the landslide slip plane. Upon this plane there is a layer that has 495–906 m/s P-wave velocity and at the top of this zone there is a layer that has 290–454 m/s P-wave velocity.

The length of the profile 2 is also 87 meters and the profile is perpendicular to the railway that cuts the profile 2 at the 11st meter (Figure 12). According to the GPS data, the elevation of the profile 2 is 201.71 meters at the beginning and 184.178 meters at the end. There is a 17.54 meters elevation difference between the beginning and the ending points.

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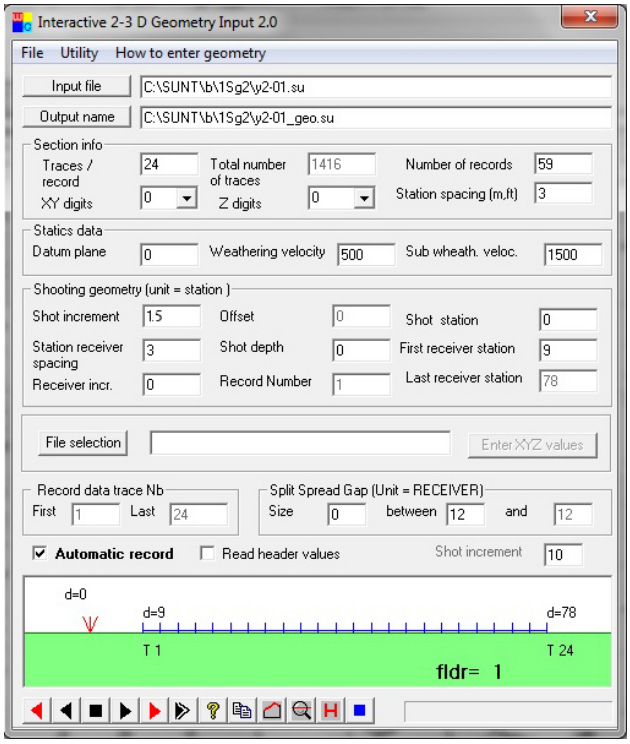


Figure 9: Adjustment of field geometry in reflection analysis.

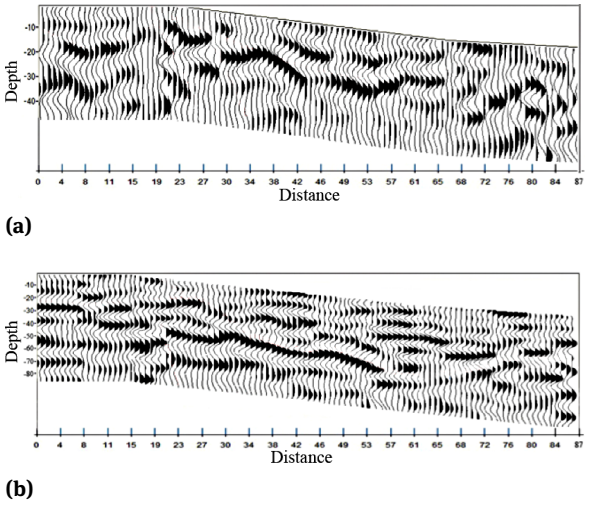


Figure 10: Depth cross-sections obtained from seismic reflection data for (for) profile 1 (a). and profile 2 (b).

According to the seismic reflection results, the beginning of the landslide slip plane (red line) cuts the profile 2 at the 20th meter. The deepest point of the landslide slip plane reaches to 80 meters of depth (Figure 12c). Some fractures and faults are also detected. Landslide slip plane is deeper in the profile 2 than it is in the profile 1 since the profile 2 is closer to the deeper parts of the landslide area.

The landslide slip plane and layer structures can be clearly observed on 2D MASW (Figure 12a) and seismic refraction tomography sections (Figure 12b). However, MASW and seismic refraction tomography methods cannot reach the depth resolution of the seismic reflection technique as seen in profile 1.

According to MASW results in Figure 12a, there is a layer beneath the landslide slip plane which has 330 m/s S-wave velocity, upon this plane there is a layer that has 210–300 m/s S-wave velocity and at the top of this zone there is a layer that has 145–200 m/s S-wave velocity which can be thought as an alluvium supported by the geology of the area.

According to the seismic refraction tomography results given in Figure 12b, there is a layer under the landslide slip plane that has 1000 m/s P-wave velocity, upon this plane there is a layer that has 524–935 m/s P-wave velocity and at the top of this zone there is a layer that has 318–483 m/s P-wave velocity. With regards to all the seismic results, it can be said that the landslide appears trough East-West direction (Figure 13).

5 Conclusions

In this study, three important seismic methods are carried out in order to detect the landslide continuation beneath the subsurface at Halkalı-Çerkezköy high speed rail line project that is in Bekirli village, Silivri district of Istanbul. MASW, seismic refraction tomography and seismic reflection methods are used together to obtain the 2 dimensional P, S velocity models and reflection depth cross-sections of each profile.

According to the seismic reflection result given in Figure 11c, the beginning of the landslide slip plane cuts the profile 1 at the 18th meter. The deepest point of the landslide slip plane reaches to 30 meters. Some fractures and faults are detected beneath the landslide slip plane. The landslide slip plane exists also on MASW and seismic refraction tomography sections that can be seen in Figure 11a and Figure 11b respectively. This result is congruent with the seismic reflection depth cross-section as seen in Figure 11c. However, the seismic refraction tomography section has not reached the depth resolution as seen in the seismic reflection method due to the penetration problem.

According to seismic reflection result given in Figure 12c, the beginning of the landslide slip plane cuts the profile 2 at the 20th meter. The deepest point of the landslide slip plane reaches to 80 meters depth. Since the profile 2 takes place at the deepest point of the landslide, there

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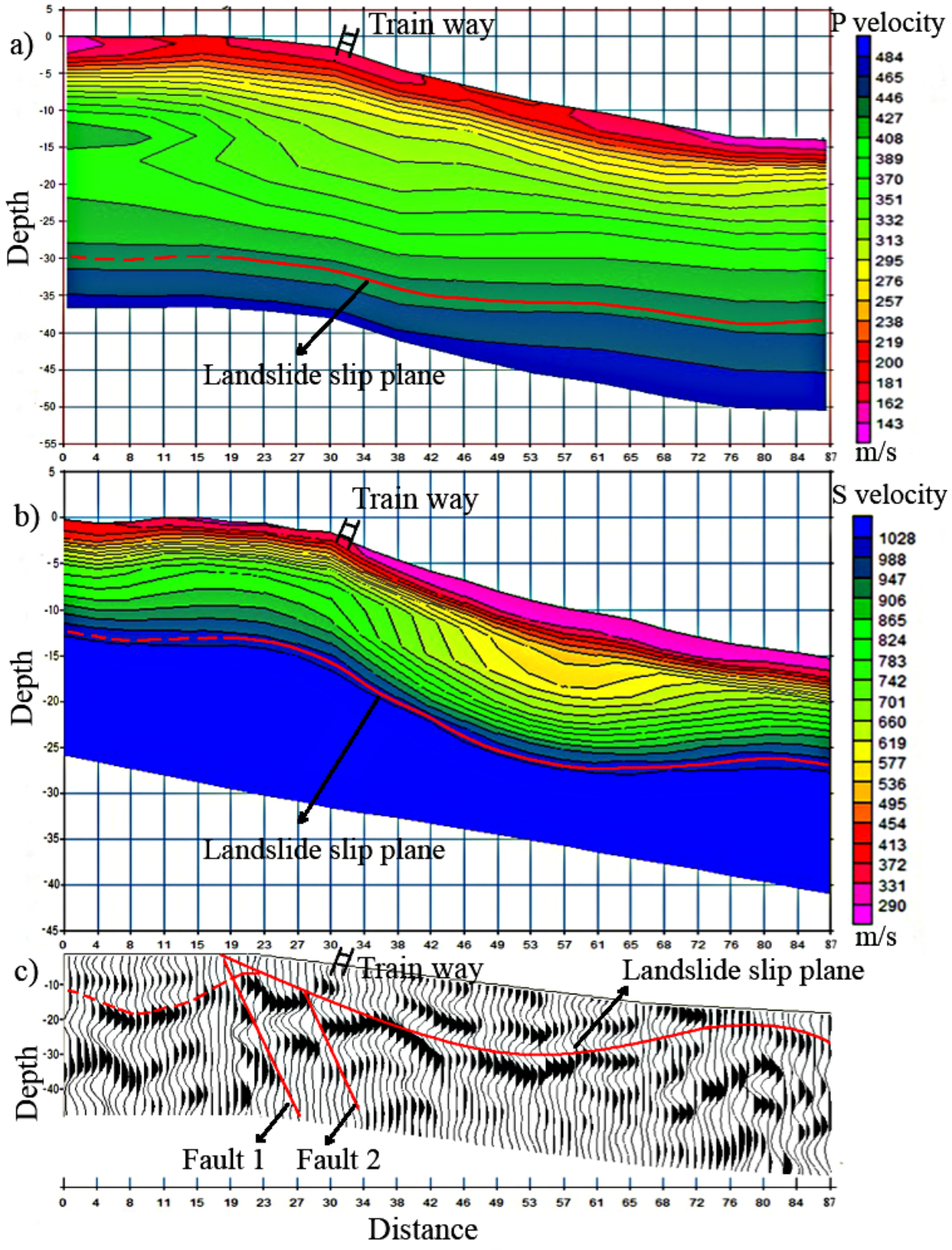


Figure 11: Interpretation results for profile 1 a) Multichannel Analysis of Surface Waves (MASW) b) Seismic refraction tomography c) Seismic reflection depth cross- section.

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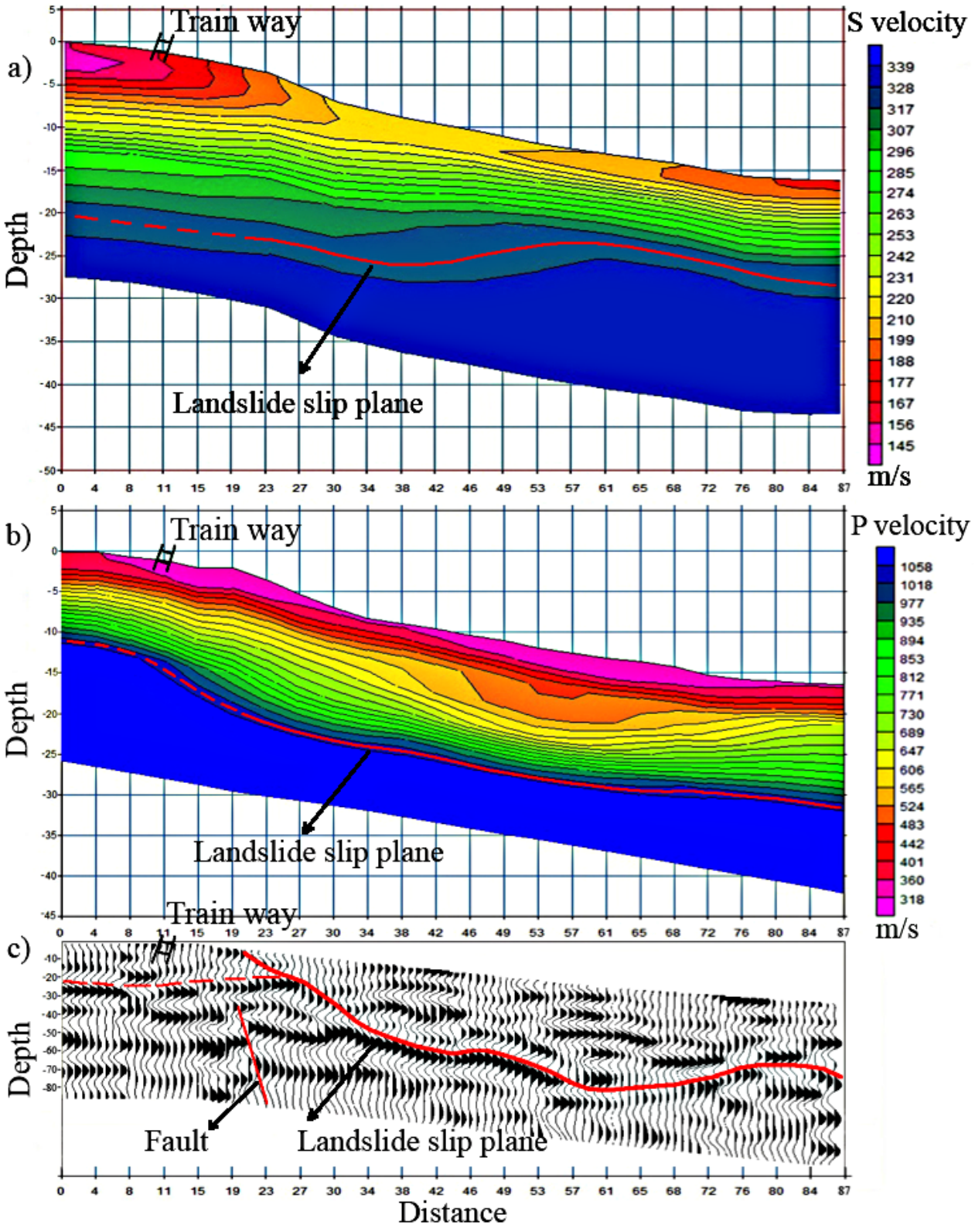


Figure 12: Interpretation results for profile 2 a) Multichannel Analysis of Surface Waves (MASW) b) Seismic refraction tomography c) Seismic reflection depth cross- section.

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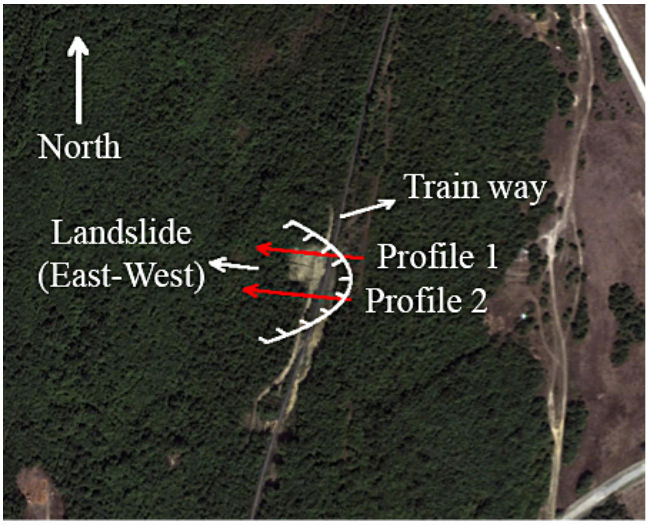


Figure 13: Location and direction of landslide in the study area.

is a difference in depth between the profile 1 and the profile 2 when compared with landslide slip plane. The landslide slip plane and the layer structures can be clearly seen on 2D MASW (Figure 12a) and 2D seismic refraction tomography sections (Figure 12b). However, MASW and seismic refraction tomography methods have not reached the depth resolution as seen in the seismic reflection technique of profile 2 as well.

It is observed that the highest layer of the study area has an unconsolidated structure when the detailed geology of the this study area is correlated with the velocity model results and the seismic sections. Beneath this layer, Ergene Group takes place which contains conglomerate, sandstone, clay, clayed limestone. At the bottom, Danişmen Formation takes place that contains shale and siltstone. The landslide occurs through the East-West direction of the study area (Figure 13).

The evolution of the landslide occurs between Danişmen and Ergene formations. Ergene formation takes place upon Danişmen formation and it is structured in the form of fractured rocks. The underground water generates an impermeable zone between these two formations and it is the reason of the landslide evolution.

Detailed seismic studies prove that the landslide slip plane and its' borders are clearly observed and seismic velocities are congruent with the local geology of the study area. When the seismic results, slope of the study area and the geological conditions are considered, it is obvious that the study area is suitable for the development of landslide and, this evolution will also affect the high speed rail line project. Consequently, precautions are needed to be performed in order to protect the rail line from the probable landslide risks in the study area.

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