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ORIGINAL PAPER

Investigation of the soil behaviour of Fethiye District, Mesudiye, Muğla, by one-dimensional equivalent linear analysis method

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Abstract

Soil behaviour during earthquakes is just as important as the prediction of earthquakes. Seismic waves alter the soil strata that they traverse during earthquakes, and the strata may also change the properties of seismic waves. Conditions such as the type, stratification status, and combinations of the strata can also create different effects in the seismic wave. With dynamic soil behaviour analysis, the effects of earthquake ground motion and ground performance on general performance can be obtained by the change in acceleration parameters. In this study, one-dimensional dynamic analysis was carried out using the EERA (Bardet et al., EERA: A computer program for equivalentlinear earthquake site response analyses of layered soil deposits, University of Southern California, Los Angeles, 2000) program by using the drilling information of the Karaböğürtlen formation, which consists of alluvium, coastal sediment and siltstone, claystone, and sandstone units in the selected region. For this purpose, idealised soil profiles were created by using the drilling information from the region of Mesudiye in the province of Muğla, district of Datça. Acceleration values, which varied in depth and surface acceleration values, were obtained as a result of one-dimensional analysis using national and international characteristic earthquake acceleration records selected from the literature. Since the dynamic and kinematic structure related to the deformation in the region is extremely complex and there is no generally accepted model, different mechanism situations have been examined using the characteristic earthquake records that have happened in the world. According to the results, similar results were obtained in earthquakes with the same mechanism; it was observed that the acceleration values which were occurred in the earthquake records with different mechanisms had been changed. Moreover, it was calculated that the greatest amplification is in beach sediments composed of sand and clay units, and the highest amplification value was in the Parkfield earthquake, which increased the peak acceleration value by six times.

Keywords One-dimensional dynamic soil behaviour analysis · EERA · Amplification · Peak acceleration · Different Earthquake records · Muğla

Introduction

In engineering, one of the problems that play an important role in structural damage distribution is the prediction of ground response. Soil behaviour analyses are used in estimating surface motions necessary for developing design response spectra; evaluating liquefaction hazard, necessary dynamic stress, and unit strain; and determining forces caused by earthquakes which render ground supporting walls unstable.

The seismic waves caused by the energy released during earthquakes are altered by geological and local conditions through propagation (Haşal 2009). In a complete soil behaviour analysis, the breaking mechanism in the earthquake source and stretching waves spreading in the ground, reaching the top of the bedrock under a certain area, are modelled and the impact of this on the surface is predicted. Since this mechanism contains many uncertainties, empirical methods produced mostly from recorded earthquakes are used. At the same time, these relations are used in seismic hazard analyses to estimate bedrock motion features. Given the fact

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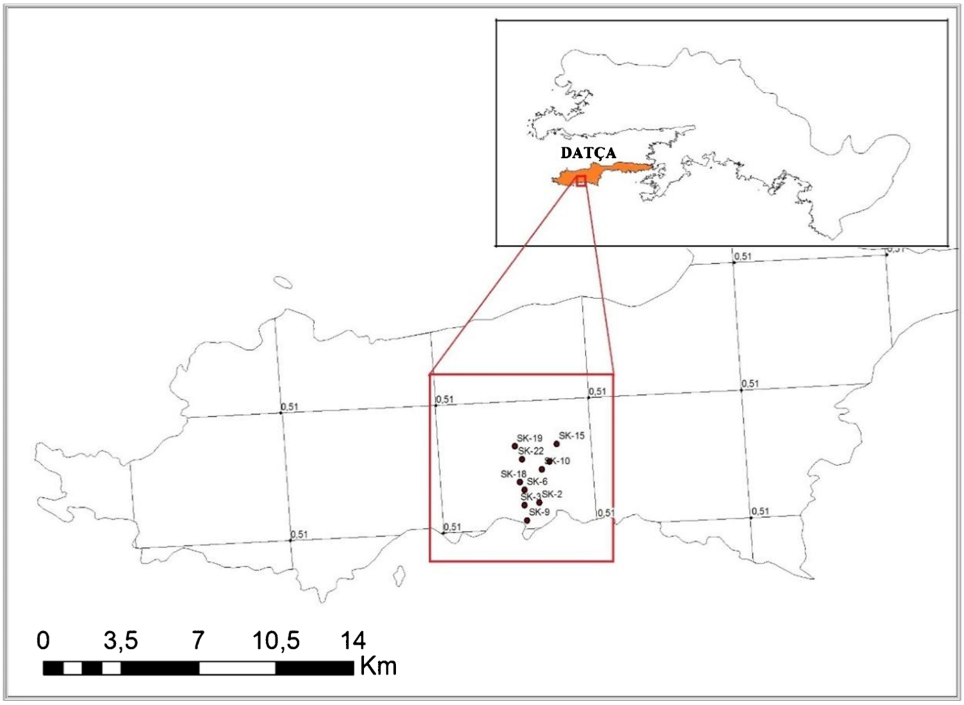

Fig. 1 Drilling locations in Mesudiye region of Muğla province

that seismic waves can travel for hundreds of kilometres in rock environments but mostly travel less than 100 m in the ground, it is seen that the strata play a very important role in determining motion characteristics on the surface (Kramer 1996).

In order to estimate the effects of the design earthquake on the surface, all local ground conditions, including topographic features, should be taken into account in the soil behaviour analysis. Calculation methods for analysis of soil behaviour are grouped as one, two, and three dimensional. Since two- and three-dimensional geometry of soil strata and bedrock are required in two- and three-dimensional approaches, mostly one-dimensional soil behaviour analysis is preferred. When performing a one-dimensional analysis, it is neglected that the strata have a limited dimension horizontally (İyisan and Haşal 2007).

Mohamedzeın et al. (2004) studied the Khartoum region of Sudan in detail from seismic, geotechnical, and geological perspectives. The ideal soil profile of the region was created, and a new design spectral acceleration spectrum was created for the one-dimensional soil analysis made with the EERA program, using internationally important earthquake records.

In the study conducted by Yalçın et al. (2008) in the southeast coastal region of İzmir Bay, the region was investigated in terms of seismotechnics and the critical earthquake

Table 1 Nationally and internationally important earthquakes used in the analysis

Earthquakes		Date	Location	Fault type	Magnitude	Depth (km)	Epicentre
1	Chi-Chi	21 September 1999	Chi Chi/Taiwan	North–South-trending fault	Mw = 7.6	25.4	23.772°N, 120.982°E
2	Coyote	8 April 1968	California/ABD	Strike-slip	Ms = 7.0	6.6	33.180°N, 116.103°W
3	Imperial Valley	19 May 1940	California/ABD	Strike-slip	Ms = 6.9	10	32.733°N, 115.5°W
4	Kobe	16 January 1995	Kakogawa	Strike-slip	Mw = 6.9	18.4	34.59°N, 135.07°E
5	Kocaeli	17 August 1999	İzmit /Turkey	Strike-slip	Mw = 7.5	16.3	40.748°K, 29.864°D
6	Loma Gilroy-1	18 October 1985	California/ABD	Strike-slip	Mw = 6.9	18	36.973°N, 121.572°W
7	Loma Gilroy-2	18 October 1985	California/ABD	Strike-slip	Mw = 6.1	18	37.009°N, 121.569°W
8	Mammoht Lake	25 May 1980	California/ABD	Normal Oblique	Mw = 6.0	15.2	37.688°N, – 118.802°W
9	Nahanni	23 December 1985	Canada	Reverse	Mw = 6.7	13.6	62.11°N, 124.27°W
11	Northridge-1	17 January 1994	Beverly Hills	Reverse Slip	Mw = 6.6	18.3	34.213°N, 118.537°W
13	Northridge-2	17 January 1994	Beverly Hills	Blind Trust	Mw = 6.7	18.2	34.213°N, 118.537°W
14	Parkfield	28 September 2004	California/ABD	Strike-slip	Mw = 6.0	11	35.815 N, 120.374 W
15	Whittier Narrows	4 October 1987	California/ABD	Blind Trust	Mw = 5.9	17.7	34.06°N, 118.08°W

fault was determined as İzmir Fault. The seismic hazard of the region was calculated deterministically, and the obtained bedrock accelerograms were included in the equivalent linear analysis in the EERA programme, using the ideal soil profiles created. Thus, surface acceleration and average shear stress were calculated (M_s). The liquefaction risk of the region was revealed by using the obtained values.

In the study conducted by Kılıç et al. (2006), field response analyses were carried out with the EERA computer code, using the findings of field and laboratory research, in order to investigate the effects of local ground conditions on dynamic behaviour. The behaviour of the region during a possible earthquake was investigated with one-dimensional response analyses.

In Kirikit et al. (2010), the behaviour of clay soil layers on rigid rock ground during earthquake was analysed using a linear and equivalent linear approach. For linear analysis, the records of the 1992 Landers earthquake were analysed in the programme created by writing a Matlab code, and surface ground motions were found. For the equivalent linear soil analysis, the Shake 2000 (Ordonez, GA 2000) programme was used, and the results obtained in both approaches were compared and differences were revealed.

Ansal et al. (2011) aimed to create a model for soil amplification and determination of site-specific design earthquake characteristics. In the study, the 1999 Kocaeli earthquake spectral accelerograms for the repetition periods of 475 and 2475 years, spectral accelerations created in the program (Shake91 1992) and NEHRP (2003) acceleration spectrum values were compared.

In Unutmaz et al. (2011), the seismic hazard of an area with an alluvial ground in the district of Karsiyaka in Izmir province was calculated. In the study, ideal soil profiles were created by using the drilling data obtained from the region. In the Shake 2000 (Ordonez, GA 2000) programme, one-dimensional soil behavioural analysis of the study area was performed using 12 ground movements selected in accordance with the seismotectonic structure of the field. In addition, the region is modelled in the FLAC-3D (2009) program, which performs nonlinear analysis using the three-dimensional finite difference method, and the results obtained in the two approaches are compared with the same inputs.

In the study carried out by Çokar (2012), the degree to which location, combinations, and stratifications of soil impacts earthquake ground motion properties and the parameters that affect these were investigated. For this purpose, the

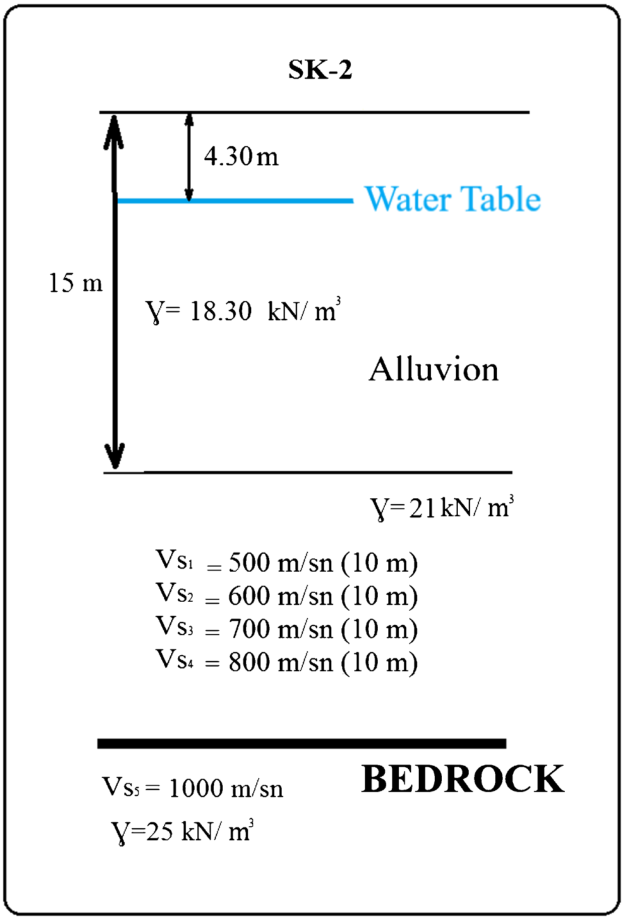

Fig. 2 Sk-2 ideal soil profile (Yılmazoğlu 2015)

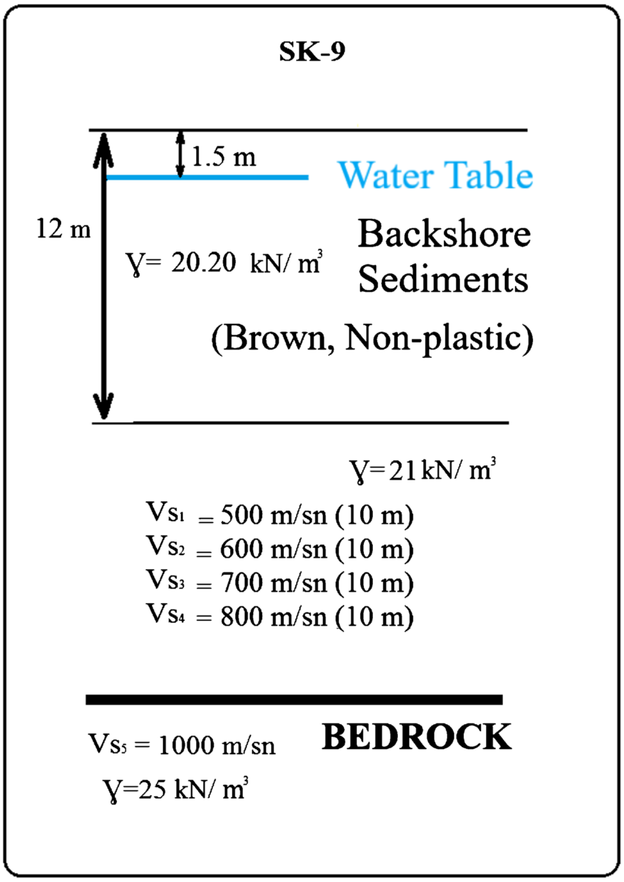

Fig. 3 Sk-9 ideal soil profile (Yılmazoğlu 2015)

equivalent linear analysis method was examined in detail, and the SHAKE 2000 software, which uses this method for one-dimensional soil response analysis, was used. Idealised soil profiles have been created by using the drilling results and ground survey report for the construction of the new building of Gebze High Technology Institute Materials Science and Engineering, various earthquake motions were applied to determine ground sections by using the Shake 2000 (Ordonez, GA 2000) programme, and soil behaviour was investigated. The accelerations of the same earthquake record on the bedrock and the surface were compared, and it was observed that the current soil profile amplified the earthquake effect approximately three times on the surface.

In the study by Civelekler et al. (2018), one-dimensional dynamic analysis was performed using Kocaeli-Yarimca ground motion data to examine the effect of local soil conditions on soil amplification. For this purpose, local soil properties were determined for 40 different soundings in the region. Equivalent linear models were run using Deepsoil software to examine the effect of specified local soil properties on dynamic behaviour. As a result of the analysis, different magnification values were obtained for each borehole. These magnification values were mapped using Geographic Information Systems (GIS).

In the study conducted by Özyazıcıoğlu et al. (2019), the data of the boreholes, which were drilled by the General Directorate of State Hydraulic Works (DSİ) between 1960 and 1980, and whose depths were up to 275 m, were used to determine the soil profiles. Equivalent-linear amplification analyses were performed using the EduShake/ProShake program. In the profiles created at the well points, using 8 different bedrock movements, the acceleration-time history of the average movement on the ground surface and the average PSA (apparent spectral acceleration) graphs were created and the design spectrum given in the Turkish Earthquake Code (TEC 2007) and the bedrock exposure were compared with the PSA. For certain periods, magnification ratios in terms of spectral acceleration (relative to bedrock outcrop movement) were calculated.

The work by Falcone et al. (2021) proposes maps of amplification factors obtained through numerical simulations of the local seismic response related to one-dimensional underground models based on site-specific data. It is stated that it is functional in the creation of damage scenarios on infrastructures.

One-dimensional dynamic behaviour analysis

When a fault is broken under the surface of the ground, body waves spread from the source in all directions. When they reach the limits of different geological units, they are reflected and broken. As the wave transmit velocities of superficial units are generally lower than the deeper units, the inclined rays (body waves) hitting the horizontal layer boundary usually break into a more vertical position (Kramer 1996). One-dimensional soil behaviour analysis is based on the assumption that all boundaries are horizontal and caused by SH waves radiating from the bedrock in the vertical direction, dominating the response of the ground. In one-dimensional ground response analyses, ground and bedrock surfaces are considered to be infinitely longitudinally horizontal (Kramer 1996; Çokar 2012).

Linear approach

The one-dimensional linear approach method, also known as the one-dimensional equivalent linear approach method, is based on soil behaviour analysis transfer functions. Transfer functions are used in identifying various response parameters of an input movement, such as bedrock acceleration in soil behaviour problem; for instance, shift, velocity,

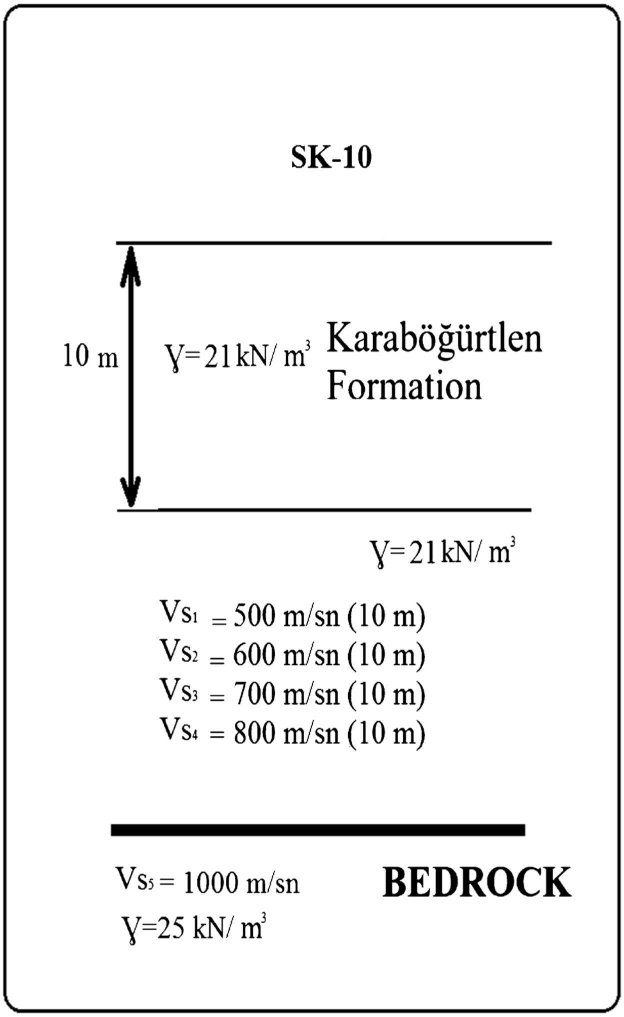

Fig. 4 Sk-10 ideal soil profile (Yılmazoğlu 2015)

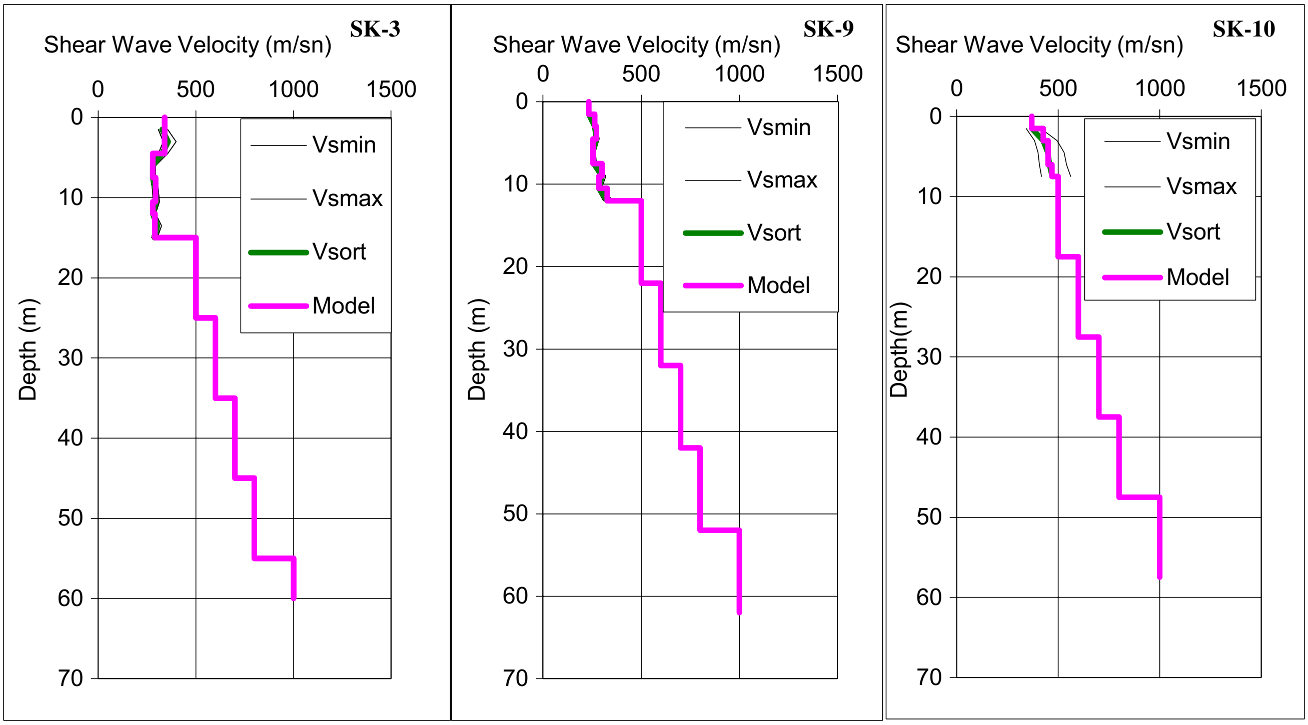

Fig. 5 Depth-shear wave velocity profiles of SK-3, SK-, and SK-10 drillings

acceleration, shear stress, and shear unit strain. The analysis of lineal systems is limited as this approach is based on the projection principle. (Kramer 1996; Çokar 2012).

The time-dependent variation of a bedrock movement known as input can often be represented as a Fourier series using the fast Fourier transform (FFT) Method. In other words, the output, that is, the Fourier series of the ground surface motion, is obtained by multiplying each term in the Fourier series of the input, the bedrock motion, by the transfer function. Output obtained as ground surface movement can then be expressed in the time domain using inverted FFT. The transfer function thus indicates how each frequency in the bedrock movement used as input is magnified or damped by the soil (Kramer 1996).

Parameters affecting soil amplification in one-dimensional models

Local ground conditions are one of the important parameters in the earthquake-resistant design phase of buildings or facilities since they affect the damage to the structure or facilities during earthquakes. Like strata affect the amplitude, frequency content, and duration of the strong motion; earthquake waves affect the strata's qualifications that they pass through (Haşal, 2009). The most important effect on strata is soil amplification. However, strata act as strainers for seismic waves, and they damp some while magnifying others (Kramer 1996; Haşal 2009; Çokar 2012).

Table 2 G/Gmax and damping ratios selected for soil layers (Yılmazoğlu 2015)

No	Formation	γn (kN/m^3)	Type	Depending on the value received
1	Alluvion	18.30	Mat 1	G/G max: Vucetic and Dobry (1991), Ip = %25 Damping ratio: Vucetic and Dobry (1991), Ip = %25
2	Backshore Sediments	20.20	Mat 2	G/G max: Vucetic and Dobry (1991), Ip = %30 Damping ratio: Vucetic and Dobry (1991), Ip = %30
3	Karaböğürtlen Formation	21	Mat 8	The average value of damping ratio and attenuation relations for rock (Idriss 1990)
4	Bedrock-1	21	-	Idriss (1990)
5	Bedrock -2	21	-	Idriss (1990)
6	Bedrock -3	21	-	Idriss (1990)
7	Bedrock -4	21	-	Idriss (1990)
8	Bedrock -5	25	-	Idriss (1990)

The main reason for the increase in the amplitude of earthquake motion in soft soils is the seismic impedance (self-resistance) difference between the ground and the bedrock beneath it (Haşal 2009; Çokar 2012). When seismic impedance is considered as a measure of the ambient resistance to grain motion, the seismic impedance (Z) for the vertical S wave expanding within the strata is the multiplication of the density (ρ) and the speed of S wave (V_s)

$$Z = \rho \times V_s \tag{1}$$

If the scattering and damping are neglected, the seismic wave energy formed due to the conservation of energy principle should be preserved up to the surface.

$$E(t) = \frac{1}{2}(\rho * V_s)V^2(t) \tag{2}$$

Here, $E(t)$ represents the seismic energy generated, $(\rho \times V_s)$ represents the resistivity of the strata, and $V^2(t)$ represents the particle speed. When approaching the surface, ambient density (ρ) and the S-wave velocity (V_s) are reduced, so the grain speed (V (t)) increases to preserve the energy (Kramer 1996; Hasal and Iyisan 2004; Haşal 2009; Çokar 2012).

If the seismic impedance difference between the bedrock and the strata, which is above it, is large, the seismic waves are covered in the upper strata. In the horizontally layered one-dimensional ground model where physical qualifications change in one direction, this occlusion only affects the up and down matter waves in the stratum. If the stratum contains two- or three-dimensional discontinuities, it also affects surface waves. Interferences between these occluded waves create resonance peaks, and the frequency of resonance peaks is related to the thickness of the stratum on the bedrock and the S-wave speed (Çokar 2012).

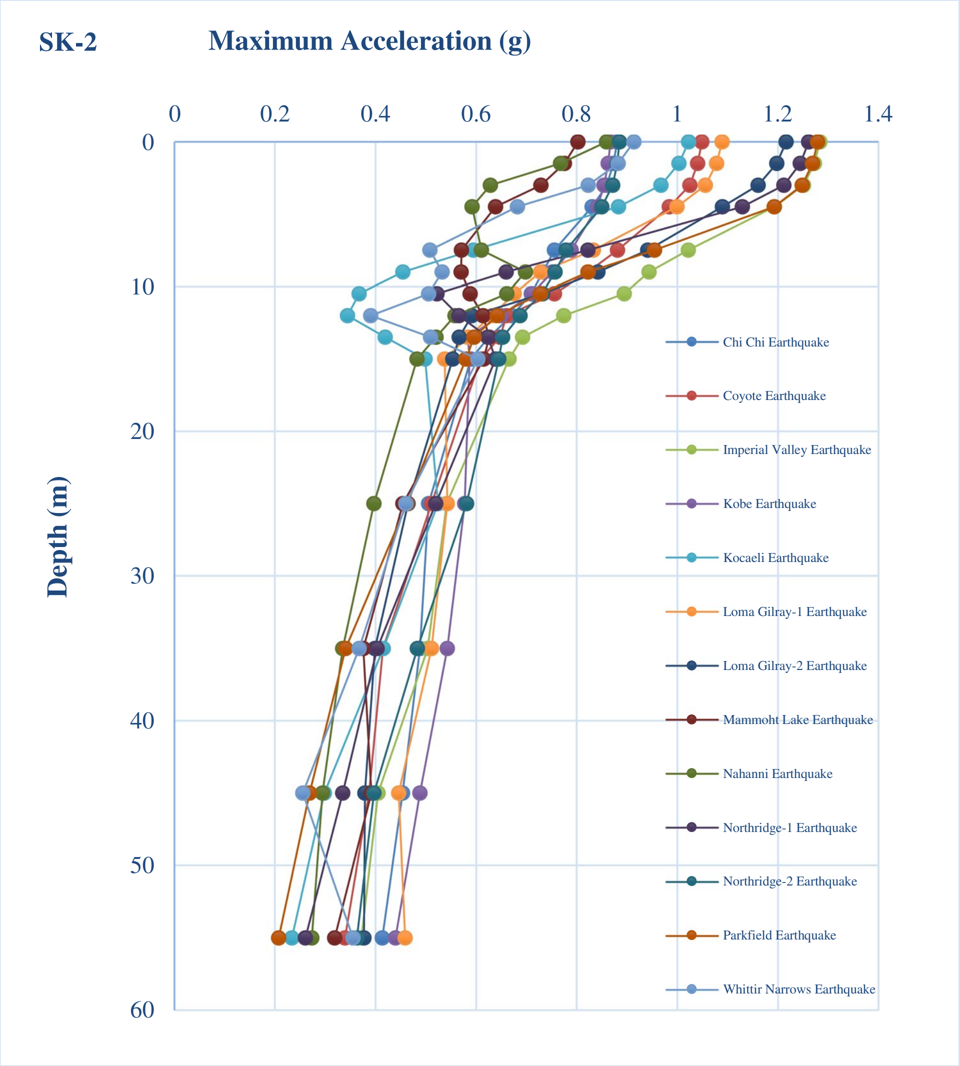

Fig. 6 Depth-acceleration results for Sk-2 (Yılmazoğlu 2015)

If it is necessary to list the parameters that affect the soil amplification in one-dimensional models, it can be listed as:

- Theoretical soil amplification functions,
- Topographic features of the strata,
- Bedrock depth, the thickness of strata on the bedrock, and soil dynamic qualifications (such as shear modulus and damping ratio),

and *S*-wave speed and incidence angle.

Introducing the area of examination

The province of Muğla, within which the study area is located, is a city rich in history and tourism, and has many natural attractions. The region, which is a leading city in terms of tourism income in Turkey, is also one of the regions where the risk of seismic activity is high. A province known to have many grabens, gulfs, and faults, Muğla, experienced many earthquakes in the past that caused loss of life and property. The investigation area, Mesudiye region, is in

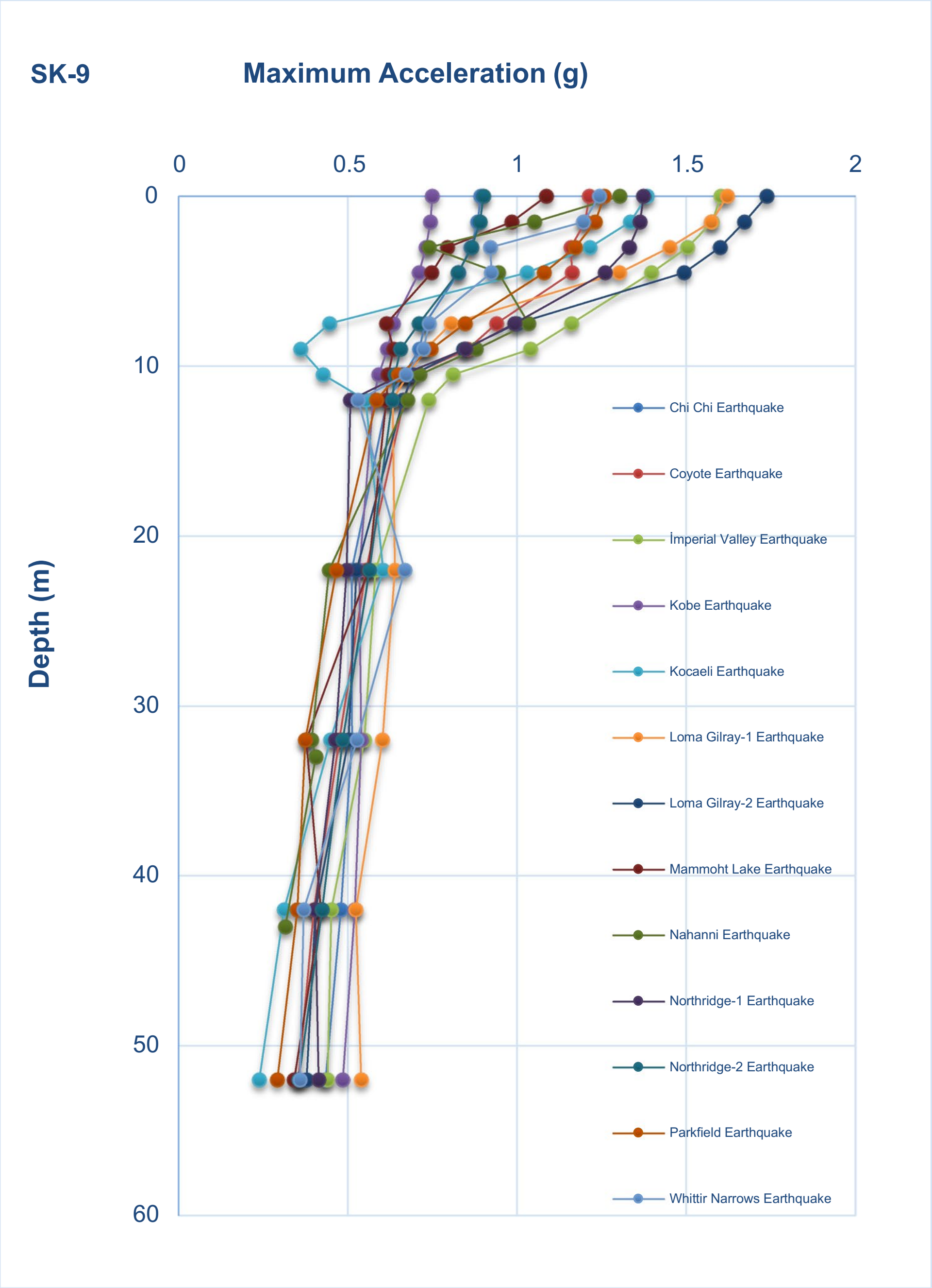

Fig. 7 Depth-acceleration results for Sk-9 (Yılmazoğlu 2015)

an area located in the boundaries of Datça district in the south of Muğla. Figure 1 shows the drilling locations of the Mesudiye region of Muğla province used in the analyses.

General geology of the region

The units and structures reflecting the basic geological features of the Western Taurus Mountains are outcropped in the region. It has been known for many years that Palaeozoic-Mesozoic and Tertiary aged rock units of different origin outcropped in the region as autochthonous and allochthonous units (Bozcu et al. 2007). The Lycian nappes among the allochthonous units are located between the Menderes Massif in the north and the Beydağları autochthon in the south. Units defined as Tavas nappe, Bodrum nappe, and Marmaris ophiolite nappe as allochthonous units belonging to the Lycian nappes outcrop. These nappes are tectonically located on the Eocene aged Elmalı formation in the region. Allochthonous units in the study area are unconformably covered by Plio-Quaternary sediments (Şenel et al. 1991, 1996; Bozcu et al. 2007). They form a light metamorphic unit in the Bodrum Peninsula, the basis of which is composed of the Paleozoic aged conglomerate-sandstone-shale alternation. Mesozoic aged units are prominent with Triassic-Liassic dolomitic limestones, Liassic-Marnic aged silty-marly limestones, and Upper Cretaceous-Paleocene aged wild film overlying all these sediments. Cenozoic rock units begin with Oligocene aged sediments. After Oligocene, a violent magmatism in the peninsula formed plutonic and volcanic rocks at various stages (Şenel et al. 1991, 1996). A widespread calcalkaline volcanism was active in the region, and tuff-agglomerate deposits; andesite-trachyandesite-latit-dacite-type lavas were formed. This calcalkaline volcanism formed by the crustal material gradually turned into alkaline olivine basaltic formations made up of the mantle. Thus, the second volcanic phase begun; this time alkali type

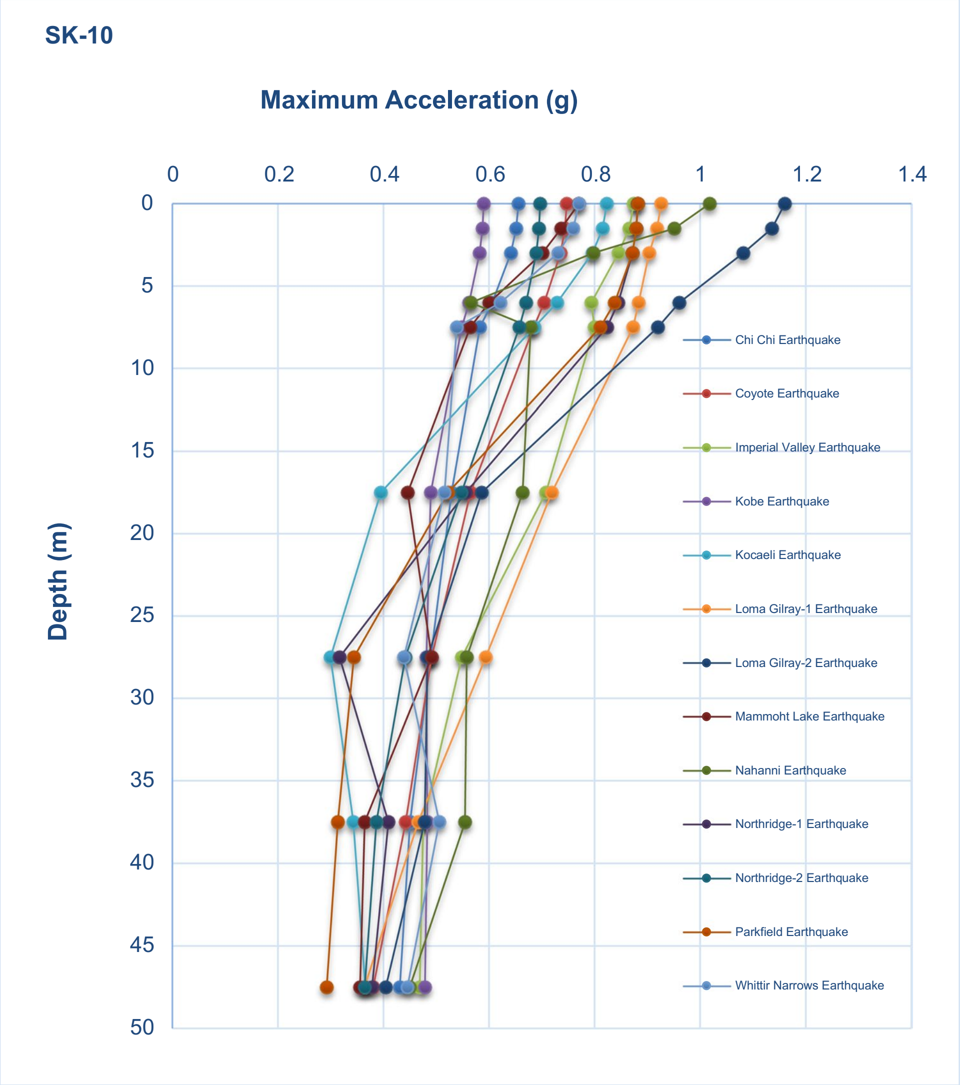

Fig. 8 Depth-acceleration results for Sk-10 (Yılmazoğlu 2015)

basalt-trachybasalt-trachyte-like lavas were formed in the form of dykes. Limestones formed in the Lower Pliocene are observed after the end of the Volcanism in the Upper Miocene. Then, the Quaternary includes travertines, slope debris, alluviums, and possibly pumice stones and tuffs from neighbouring Kos Island (Şenel et al. 1991, 1996).

One-dimensional dynamic behavioural analysis of the survey area using different earthquake records

Earthquake properties used in analysis

The Aegean Region (Western Anatolia), where the study area is located, is one of the regions with the greatest dynamics where intense earthquake movements are observed, although it is outside the North Anatolian Fault system, which is the largest fault system in Turkey. In this region, ground movements, that is, escape mechanism and subduction relations, have a very complex structure both kinematically and dynamically. Many tectonic and seismo-tectonic models have been proposed to explain the seismological structure of Western Anatolia (Dewey and Şengör 1979; Şengör 1987; Seyitoğlu and Scott 1992, 1996; Koçyiğit et al. 1999). There are many studies on seismic activity and earthquake hazard in the region (Barka and Reilinger 1997; Şalk et al. 2000, Kahraman et al. 2008, 2011). However, since the dynamic and kinematic structure of the deformation in the region is extremely complex, there are no generally accepted models. For these reasons, national and international characteristic earthquake records were selected and their effects on the region were examined. National and international earthquakes, normalised according to the acceleration values calculated according to the 10% probability of exceedance in 50 years, were used as bedrock input (İnce and Yılmazoğlu 2021). The fault type, magnitude, depth, location, and distance of the Strong motion station for the selected earthquakes are given in Table 1.

Soil profiles created for analysis

In the drillings selected for use in the analysis of soil dynamic behaviour, 3 formations attract attention. These are alluvium, beach sediments, and the Karaböğürtlen Formation. Alluvium: The alluvial sediments located on the coastal plains between Nergizli hill and Adatepe consist of loose and water-saturated brown gravel, sand and mud. Beach sediments: Beach sediments consist of brown sand and clayey units. Karaböğürtlen Formation: The Upper Senonian aged Karaböğürtlen formation, which is represented as a blocky flysch that outcrops in a wide area between Nergizli hill and Ürküntülük hill, is thin-medium-thick layered sandstone, claystone, and silt stones in grey, blackish grey, greenish grey, black, light brown, yellowish brown, dirty yellow, red, and other colours. It includes surfaces such as sandy-clayey limestone, micrite, chert micrite, calciturbidite, marl, and also serpentinite, basic vulcanite, limestone, and similar blocks occasionally. It shows a chaotic structure in general and displays frequent rock type changes in lateral and vertical directions (Demirtaş et al. 2012). Idealised one-dimensional soil profiles were prepared using drilling data conducted in the Mesudiye region and are shown in Figs. 2, 3, and 4. The sliding module, damping ratio values, and material types defined depending on the plasticity index from the literature for the ideal soil profiles prepared are given collectively in Table 2. Suitable damping relations for alluvium, beach deposits, Karaböğürtlen Formation, and bedrock were selected and classified according to their specific weight. The transition from bedrock to ground layers was made in 5 stages according to the shear wave velocity (Bedrock-1,V_s = 500m/sn; Bedrock-2,V_s = 600m/sn; Bedrock-3,V_s = 700m/sn; Bedrock-4,V_s = 800m/sn; Bedrock-5, V_s = 1000m/sn). In addition, groundwater was taken into account in each ideal soil profile and introduced to the EERA program.

Shear wave velocity profiles (vs depth)

Correlations between the number of SPT N pulses and shear wave velocity were used to generate shear wave velocity profiles. Shear wave velocities were found from SPT-N values by benefiting from the studies of İyisan (1996), Ohsaki and Iwasaki (1973), İmai (1977), Ohta and Goto (1978), and Seed and Idriss (1970) and taking the average of all of them. Mean shear wave values were found. In dynamic soil analysis, shear wave velocity must be defined for each soil layer. Therefore, shear wave velocities and shear wave velocity profiles for each layer were defined from the values obtained by correlation from the SPT-N results for each cell (Fig. 5).

Analysis results

Peak acceleration-depth change charts

Using the earthquake accelerograms in Table 1, the depth-acceleration results of the soil profiles for Sk-2, Sk-9, and Sk-10 drillings were obtained and shown in Figs. 6, 7, and 8.

Maximum acceleration values in SK-2 drilling with alluvial stratum increased by 0.48–0.66 g at the 15th meter, while it was 0.20–0.46 g at the 55th meter. The acceleration values on the surface formed by the waves proceeded from the strata reached the values of 0.80–1.28 g. The acceleration value has increased approximately 3–4 times on the surface according to this.

While the rock’s acceleration values varied between 0.24 and 0.54 g at the 52nd meter in the SK-9 drilling where the coastal sediments were found, it reached the values of 0.53–0.74 g 12th meter when the rock ended and the strata started. According to the changing earthquakes, when the waves reached the surface, the peak acceleration values reached 0.75–1.74 g. It was seen that the acceleration value increased approximately 3–3.5 times on the surface according to this.

In SK-10 drilling, where the Karaböğürtlen formation (consisting of claystone, siltstone, and sandstone) is located, the peak acceleration values vary between 0.29 and 0.48 g at the 50th meter, while it reached the values of 0.54–0.92 g at the 7.5th meter and reached the values of 0.59–1.16 g on the surface. It is seen that the acceleration value increases about 2–2.5 times on the surface according to this.

When the peak acceleration values of the three drillings were evaluated, it was seen that the highest increase in peak acceleration occurred in the SK-2 drilling, where the alluvial stratum was found. The lowest increase occurred in Karaböğürtlen formation, which is a rock.

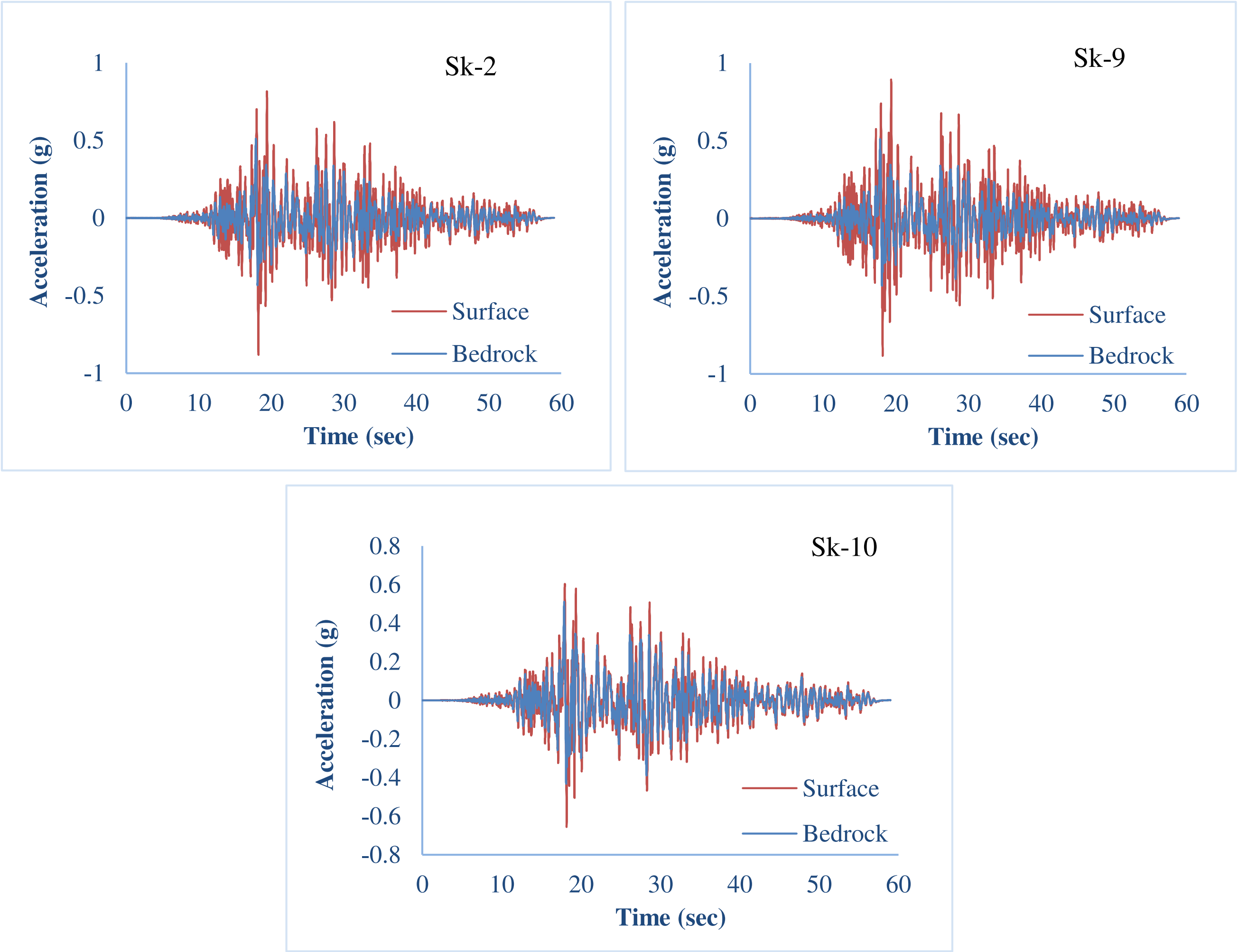

Fig. 9 Comparison of bedrock-surface acceleration values for Sk-2, Sk-9, and Sk-10 drillings using Chi Chi earthquake (Yılmazoğlu 2015)

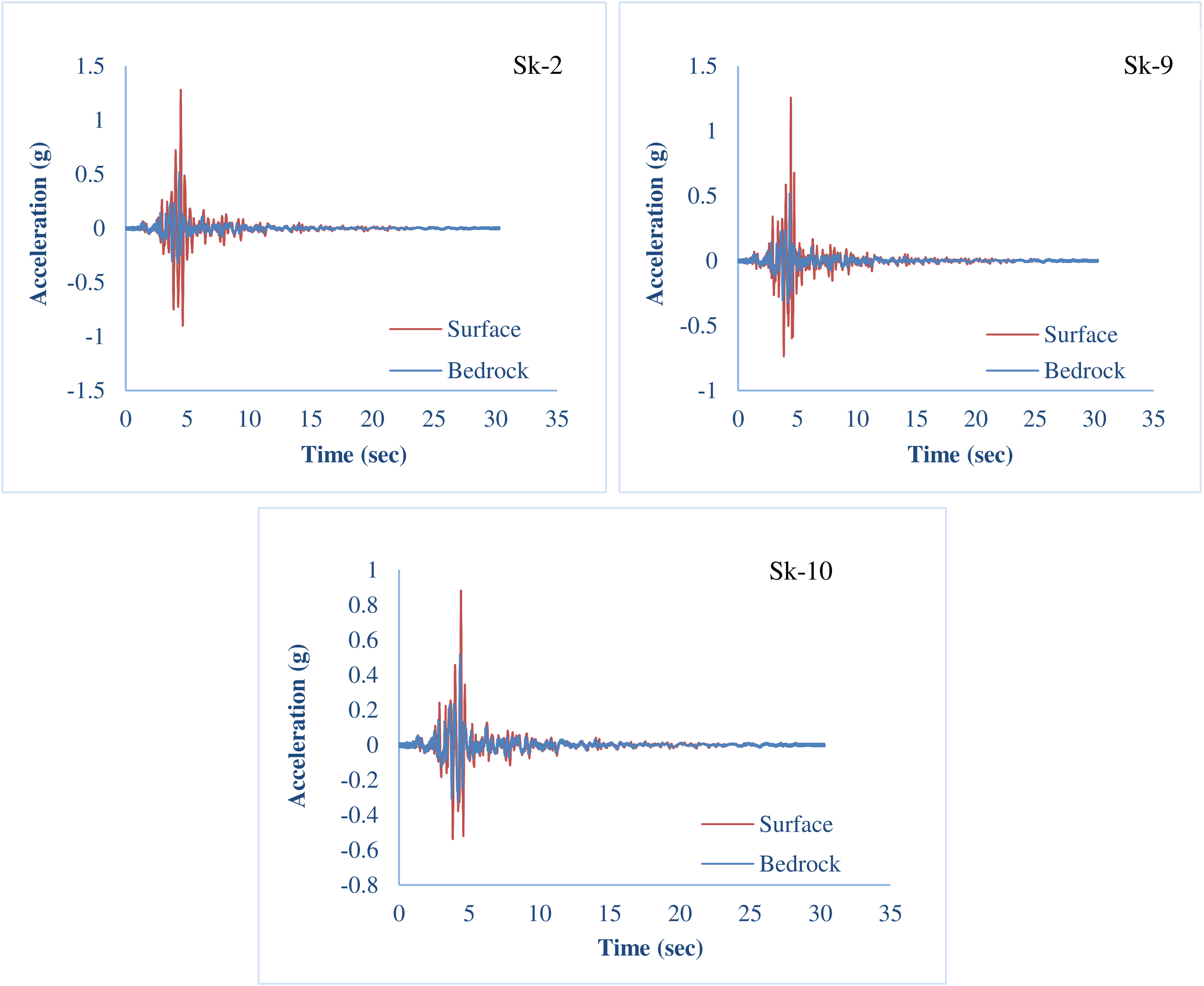

Fig. 10 Comparison of bedrock-surface acceleration values for Sk-2, Sk-9, and Sk-10 drillings using Parkfield earthquake (Yılmazoğlu 2015)

Bedrock-surface acceleration-time change charts

The EERA program can create the acceleration-time record of the accelerations occurring on the surface, as well as carrying the acceleration of the main bedrock to the surface. Thus, it enables easier comparison between the bedrock and the surface. In the analysis, bedrock and surface acceleration-time graphs obtained for soil profiles were compared and shown separately for three selected earthquakes with different fault mechanisms (Figs. 9, 10, and 11). In addition, peak acceleration values and amplification rates obtained for bedrock and surface in all drillings are shown in Table 3 and Fig. 12.

Results and conclusions

In this study, peak acceleration-depth and bedrock-surface acceleration time graphs were obtained for 3 types of drilling data selected as a result of one-dimensional dynamic analysis. When the depth-acceleration graphics are examined, it can be said that the maximum magnification is

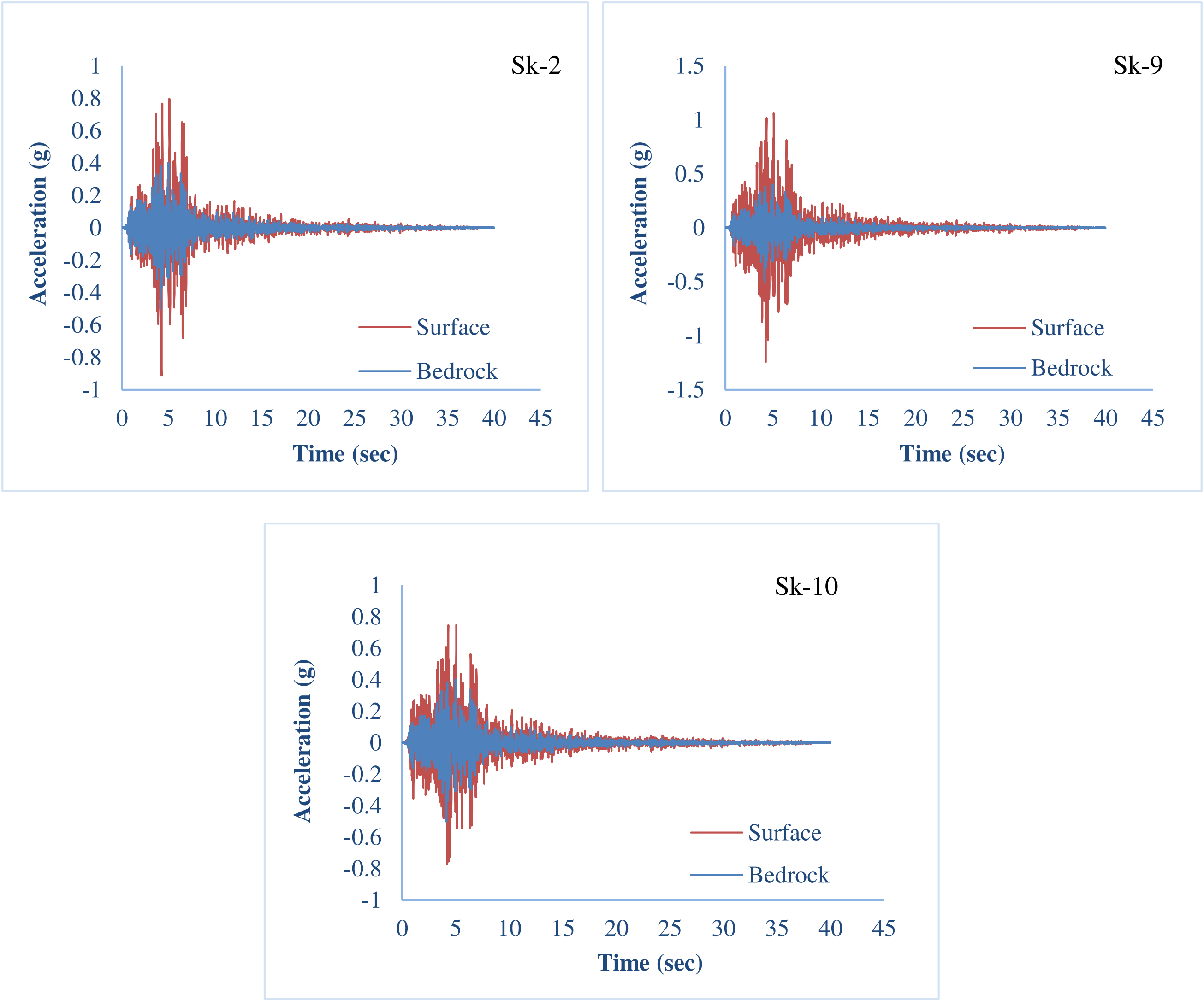

Fig. 11 Comparison of bedrock-surface acceleration values for Sk-2, Sk-9, and Sk-10 drillings using Whittir Narrows earthquake (Yılmazoğlu 2015)

Table 3 Amplification ratios for Sk-2, Sk-9, and SK-10 (Yılmazoğlu 2015)

Earthquakes	SK-2 (Alluvion)			SK-9 (beach sediment)			SK-10 (Karaböğürtlen formation)		
	Bedrock	Surface	Amplification Ratio	Bedrock	Surface	Amplification Rate	Bedrock	Surface	Amplification Ratio
Chi Chi (Tayvan)	0.41357	0.88045	2.129	0.43432	0.89230	2.054	0.43099	0.65589	1.522
Coyote	0.33902	1.04900	3.094	0.35360	1.21377	3.433	0.38044	0.74723	1.964
Imperial Valley	0.37162	1.28320	3.453	0.44001	1.60279	3.643	0.46875	0.87419	1.865
Kobe	0.43961	0.86686	1.972	0.41970	0.74963	3.173	0.47866	0.58981	1.232
Kocaeli	0.23340	1.02278	4.382	0.23807	1.38491	5.817	0.36587	0.82327	2.250
Loma Gilroy-1	0.45872	1.08913	2.374	0.53985	1.62209	3.005	0.36422	0.92628	2.543
Loma Gilroy-2	0.37714	1.21601	3.224	0.37847	1.73848	4.593	0.40421	1.16015	2.870
Mammoht Lake	0.31902	0.80252	2.516	0.34119	1.08655	3.185	0.35576	0.77022	2.165
Nahanni	0.27337	0.85928	3.143	0.31525	1.30408	4.137	0.44964	1.01826	2.265
Northridge-1	0.26078	1.26136	4.837	0.41379	1.37409	3.321	0.37840	0.88182	2.330
Northridge-2	0.36311	0.88484	2.437	0.35483	0.90122	2.540	0.36445	0.69663	1.911
Parkfield	0.20755	1.27903	6.163	0.29228	1.25785	4.304	0.29256	0.88214	3.015
Whittir Narrows	0.35489	0.91378	2.575	0.35869	1.24342	3.467	0.44556	0.77056	1.729
Mean			3.254	**Mean**		2.898	**Mean**		2.128

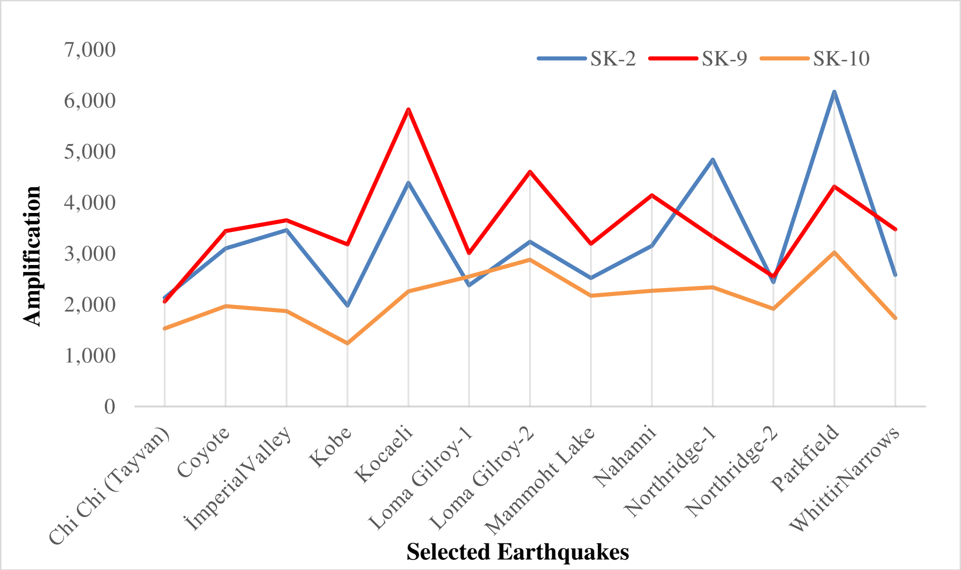

Fig. 12 The relationship between selected earthquakes and amplification ratio for selected drilling

occurred by 3.0–4.0 times in the alluvial layer (Sk-2) with water-saturated gravel, sand, and mud units, then 3.0–3.5 times in beach sediments which consists of loose sand and clay units (Sk-9), and the least change occurred in the Karaböğürtlen formation (Sk-10) which consists of sandstone, siltstone, and claystone with 2.0–2.5 layers. In addition, it has been observed that the characteristic of the earthquake accelerations used as input in one-dimensional dynamic soil analysis affects the acceleration values that occur. For example, while similar results are obtained in Coyote, Imperial Valley, Loma Gilroy-1, Loma Gilroy-2 Mammoth Lake, Parkfield, and Whittier Narrows earthquakes on the San Andreas fault in California, it is observed that the acceleration values occurring in different mechanism earthquake records changed. When the bedrock and surface peak acceleration-time values are examined, the highest value was obtained as 6163 for Sk-9 drilling with the Parkfield earthquake record on the San Andreas fault.

Declarations

Conflict of interest The authors declare no competing interests.

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