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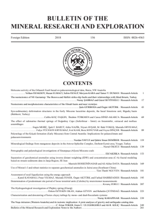

Determination of predominant site period of loose terrestrial units (Caliche) by microtremor measurements

Kıvanç ZORLU[a]*

[a]*Mersin University, Faculty of Engineering, Department of Geological Engineering, Çiftlikköy Campus, Mersin orcid.org/0000-0002-2086-7379.*

Research Article

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ABSTRACT

The caliche profiles that have been observed in arid-semi arid climate regions can be described as terrestrial formations which are vertical succession and composed predominantly of calcium carbonate. At the top of the caliche profile, there is hard pan leyer as a weak rock and soft pan layer characterized by loose soil is existed. Caliche is formed by the displacement and/or cementation of soil, rock, and weathered material, and is usually found in unsaturated zones. In the study area, consist of caliche units located in Adana. It is noteworthy that the caliches of Quaternary is widely crop out throughout the region, exhibited a flat topography in the region locate at this unit. The paleosolic deposits in the Adana Basin, which is characterized by climate oscillations in the Pleistocene and surface waters rich in carbonate, following draining, capillarity and weathering, initially formed as a result of sedimentological and followed by pedological processes. Adana is located in the I. and II. degree seismic zone, where many earthquakes have been observed in historical and instrumental periods. It was found that the greatest structural damage sustained by the earthquakes that occurred in Adana especially in 1998, was seen in the buildings located on caliche ; it is believed that the damage caused to the buildings located on chalice can be attributed to the of morphologically distinct layers or horizons. This study determines the sediment amplification characteristics and horizontal to vertical spectral ratio (H/V) within the borders. Accordingly, to demonstrate H/V between the hard pan and the soft pan horizon of the caliche, 24 microtremor measurements were performed on locations with soft pan, on locations with no hard pan, and on locations where the profile directly begins with the soft pan.

1. Introduction

The increase in damage rates during earthquakes is directly related to the lithological characteristics of the ground built on, in addition to the structural characteristics of the building. Rock or soil sites display different behaviours during earthquakes, with the effects of earthquakes observed more in soil. According to Terzaghi and Peck (1967), hard soils are those with a single axis compression resistance of over 400 kPa. Clayton and Serratrice (1977) stated that materials called hard soil and weak rock were located at the boundary between soil and rock. According to these researchers, in spite of determining the resistance of hard soil and weak rock with a variety of laboratory experiments, there was still uncertainty in defining these types of material. While the engineering characteristics of these types of materials were ignored in previous years, currently more detailed investigation of the characteristics of these materials have begun due to the rapidly increasing construction and resulting engineering problems experienced (Clayton and Serratrice, 1977). One of the most important studies on classification of hard soils and weak rocks belongs to Johsonston and Novello (1993). These types of material are found in the centre of a broad span ranging from soft clay and loose sand to hard rock. Accordingly, weak rocks have single axis compression resistance values between 0.5 MPa and 25 MPa. Researchers have defined material with single axis compression resistance values smaller than 0.5 MPa as being “soil” and material with values above 25 MPa as “hard rock”. Caliche types display a profile with transition from weak rock to loosely-structured sandy, silty, clayey soil. The levels in the

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* *Corresponding author: Kıvanç ZORLU, kivancgeo@mersin.edu.tr*
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caliche profile in the study area are accepted as C (soft rock) and E (soft ground) in the site classification of the National Earthquake Hazard Reduction Program (NEHRP). According to NEHRP, these classes have S-wave velocity values (V_{s30} m/s) of >1500 m/s and >180 m/s, respectively. According to Eurocode 8 site class criteria, the caliche profile levels may be assessed as A (rock and rock or geologic formation containing at least 5 m weak material at surface) and D (loose to moderate-low cohesion layers or dominantly soft to hard cohesive). According to this classification system, the S-wave velocities are <800 m/s and >180 m/s, respectively (Halaç, 2016).

Goudie and Pye (1983) defined caliches as continental formations dominated by calcium carbonate with zoning in the vertical direction and horizontal or nearly horizontal placement, with transition from loose state to very compressed states. Caliche, mainly in unsaturated zones, indicates substitution and/or cementation of soil, rock and weathered material. When mechanical and structural characteristics are noted, caliche type units may be called collapsible soils (soils with potential for collapse) (Popescu, 1986; Rollins et al., 1993, Zorlu and Kasapoğlu, 2009). In the literature soils with potential for collapse are generally stated to be residual granitic material, tuffs, alluvial fans, loess and carbonate rocks (Rogers, 1995). These types of soils generally contain very small amounts of clay, with silt and fine sand grain size material. Clay content between 10 to 20% is ideal in terms of collapse. If the clay amount exceeds these proportions, the material typically displays plastic clay behaviour and collapse mechanisms do not occur. Very low amounts of clay content and insufficient bonds between particles provides the unstable structure necessary for collapse (Steven, 1998). Collapsible soils are characterised by large volume changes (reduction in volume) under fixed stress when they become saturated. These types of material display higher stability in dry situations, have very low density porous structure and are material that loses stability when wet.

This study aims to assess some dynamic properties of caliche outcropping in the I and II degree earthquake region of Adana and surroundings with buildings damaged in the 27 June 1998 Adana-Ceyhan earthquake (Aydan et al., 1998) and with this aim microtremor studies were performed. Microtremor measurements were used to assess the predominant site period and the relative ground amplification effect.

2. Geology of the Study Area

The study area is located in the Eastern Mediterranean region between Adana province and Ceyhan county (Figure 1). One of the most rapidly urbanizing areas in Turkey, Adana is the most important city in the Mediterranean region in terms of trade and industry. Generally the study area contains Late Cretaceous, Oligo-Miocene, Miocene, Pliocene and Quaternary rocks and again caliches of the same age (Figure 2).

Upper Cretaceous: As seen on the simplified geology map given in figure 2, Upper Cretaceous-aged rocks are observed as large blocks along Haramidağ, Mount Cebel-i Nur and Kürt Dağı (Kürt Mountain) near the study area. These units with volcanosedimentary character are represented by tuff containing manganese limestone, volcanic sandstone, clayey limestone and agglomerates. In terms of topography, Upper Cretaceous rocks are observed in areas with high slope and generally have tectonic contacts. In units observed as blocks, limestones have many fractures and fragile structure (Kozlu, 1987).

Oligo-Miocene: Oligo-Miocene-aged units have olistostromal character and form by the combination of different blocks. The matrix of the unit is turbiditic with abundant plankton fossils and clastic structure. Generally large olistostrome blocks are surrounded by conglomerates found scattered through different levels of the sequence. The unit is observed in topographic areas with moderate slopes and was formed by rapid deposition of erosion products from different sedimentary and ophiolitic rocks in the area in a narrow and long basin transported by rivers (Kozlu, 1987).

Miocene: Of Miocene-aged units, the Güvenç formation is observed in northwest sections of the study area near Alihoca village. The Güvenç formation has moderate-thick layers and occasional cross-bedding and was deposited in the Burdigalian-Serravallian according to results in Yetiş (1987). Comprising gray conglomerate and sandstone, the unit is observed in areas with high-slope topography. Miocene-aged units that occur in the stratigraphic sequence of the region but do not outcrop in the study area include the Karaisalı, Köpekli, Cingöz and Kuzgun formations (Kozlu, 1987).

Pliocene: Pliocene-aged units in the study area are called the Handere formation. The Handere formation

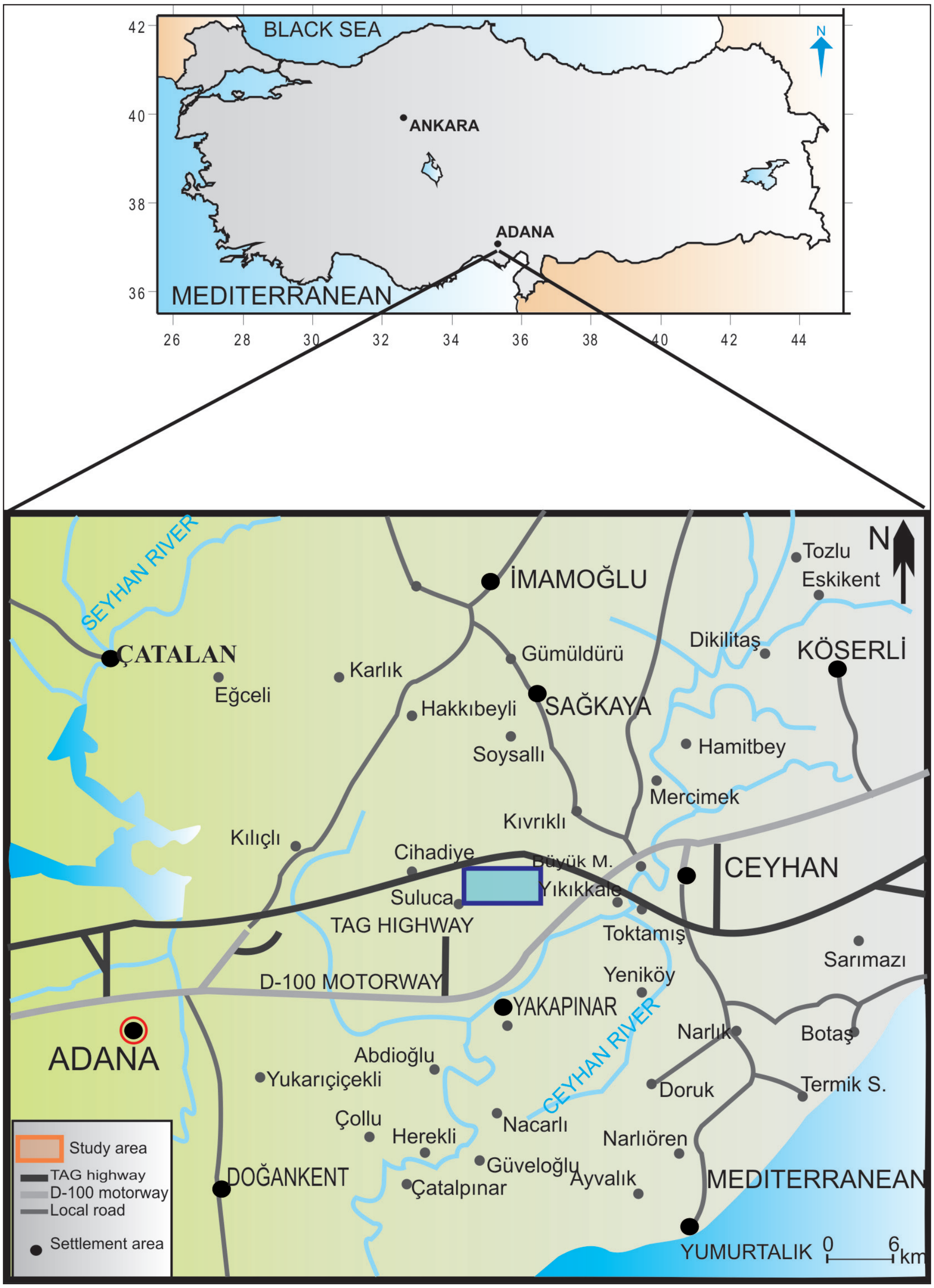


Figure 1- Location map of the study area.

outcrops north of Adana and Misis, generally in areas with moderate slope topography. The sandstone, siltstone, marl, mudstone and pebble sandstone comprising this formation generally have light brown to light gray colour with total thickness of nearly 700 m (Yetiş, 1978). The formation has moderately thick layers, with occasional cross-bedding observed in the units. These units were formed by erosion of high elevation areas after orogenesis of the Tauride Mountains, followed by transportation and deposition at lower elevations. Conglomerates are very common in this sedimentary sequence. The upper contact of the Handere formation is covered by caliche commonly observed in the Adana Basin and occasionally by young alluvium.

Quaternary: Caliche and alluvium sequences comprise Quaternary-aged sediments. Quaternary-

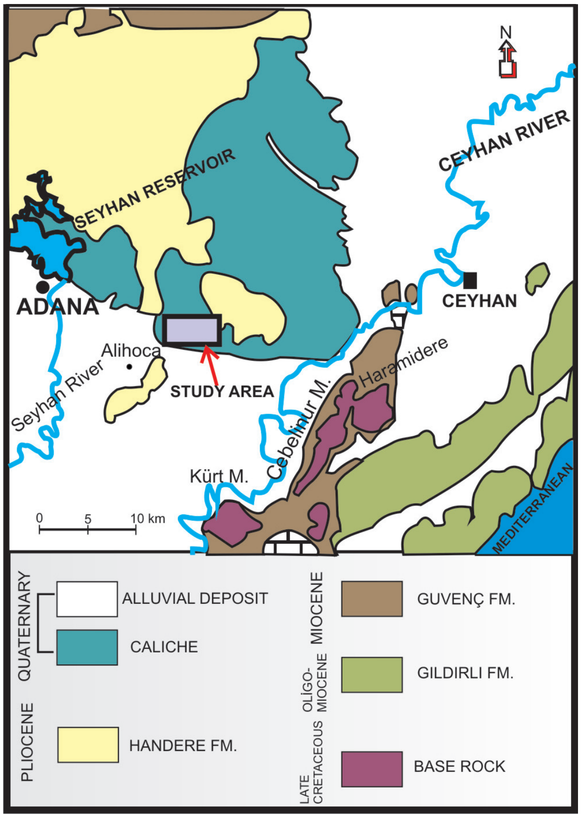


Figure 2- Geology map of the study area.

aged caliche has very large distribution in the region between Adana-Ceyhan and is noted in settlement areas, especially with low slope. When assessed in these terms, it appears that caliches have a significant spatial distribution in the region. Within the 400 km^2 area covered by caliche, 81% of the area has topographic slope of less than 10^o with 16% having slope of 10^o-20^o, and only 3% with slope above 20^o. The area where Adana Organised Industrial Zone is located generally has topography with slope less than 10^o and is completely covered with caliche.

Palaeosolic caliches in the Adana Basin formed as a result of firstly sedimentalogic and then pedological mechanisms after climate oscillations in the Pleistocene and with filtration, capillarity and decomposition events together with carbonate-rich surface waters. The age of these caliches is accepted as Quaternary (Şenol, 1989).

One of the most important elements in caliche formation is basement rock, which is the Pliocene-aged Handere formation in this region. Differences in the lithological properties of the basement rock may cause changes in the caliche prolife formed at local scale (Şenol, 1989).

Caliches in the study area have a profile formed of hard caliche with soft rock quality and soft caliche (formed of pebble-sandy and silty-clayey levels) with soil quality. These levels generally display variations over short distances in the region, with some levels not observed in some areas or thicknesses varying significantly.

Alluvium: In the study area, there is ancient alluvium forming the Adana and Misis-Andırın basins and young alluvium observed along rivers. The ancient alluvium generally are covered by plant soil. Young alluvium developed along rivers, and generally is poorly sorted, cemented pebble, sand and silt and clay size material.

3. Determination of Predominant Site Period and Investigation of Effect of Sediment Amplification

In line with the aim of the study, 24 microtremor (micro vibration) records were obtained to determine the predominant site period and ground amplification for caliche observed in Adana province, Ceyhan county (Figure 3). The Nakamura (1989) method was used to interpret microtremor records. In addition to microtremor measurements for the study area in general, measurements were completed around structures damaged during the 1998 Adana-Ceyhan earthquake. To determine the amplification difference between hard pan and soft caliche, records obtained in areas with hard caliche and in areas where the profile began directly with soft caliche had the traditional spectral ratio and Nakamura (1989) techniques applied to research the effect on relative ground amplification of hard caliche.

3.1. Microtremor Measurement Methods

Microtremors are low amplitude (1-10 micron) vibrations that may occur anywhere and anytime caused by oceanic, atmospheric or artificial sources (traffic, industrial machinery). Microtremors may be known seismic wave types (S, P, surface wave, etc.) or a combination of several (Udwadia and Trifunac 1973).

The vibration of the ground under a structure during an earthquake, in other words shaking, exposes the engineering structure to vibrations. When the period of the engineering structure and the ground it sits on are close to each other, resonance occurs and linked to this the damage may be greater than

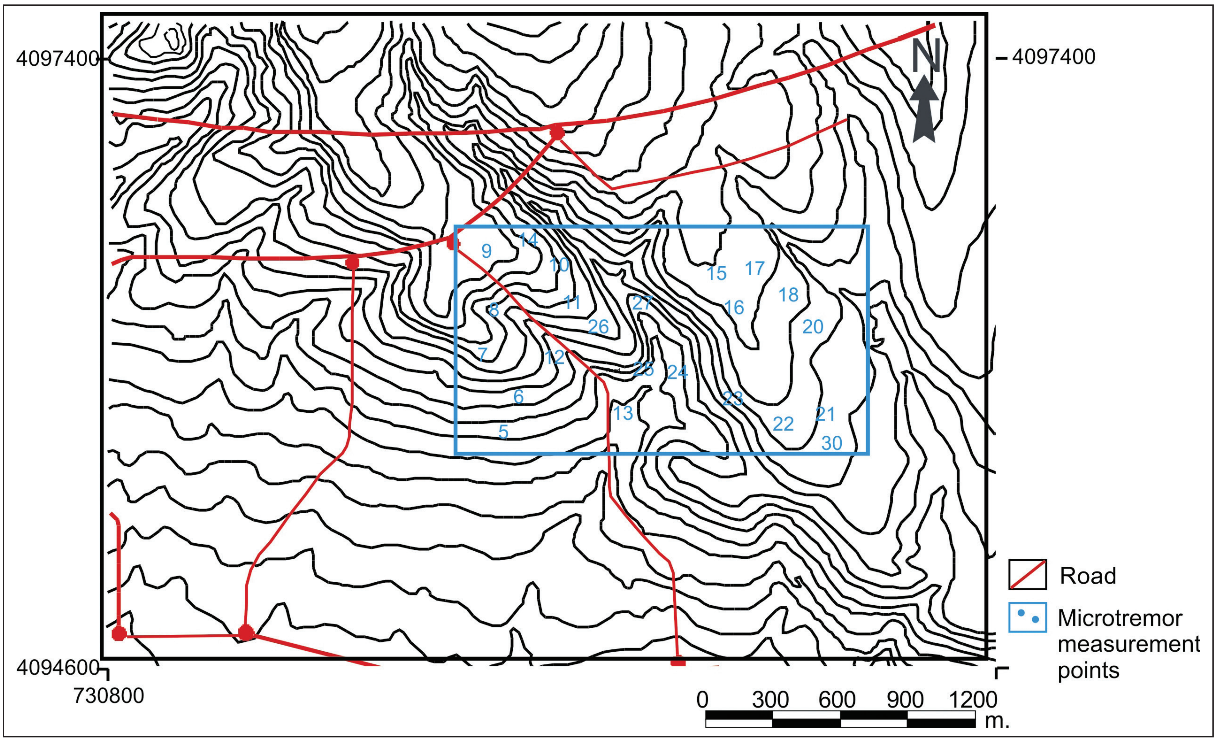


Figure 3- Location of microtremor measurements with the aim of determining predominant site period and relative ground amplification.

expected. Currently investigations after earthquakes have observed the structure-site resonance effect as an effect that increases damage (Wenk et al., 1998). Wenk et al. (1998) stated that after the 1998 Adana-Ceyhan earthquake, studies of 65 damaged buildings found that the most damaged buildings mainly had five and seven floors and the building frequencies varied from 1.5-2 Hz. Additionally, Çelebi (1998) used the Nakamura method based on acceleration records from Ceyhan station and stated that the transfer function obtained peaked at 1-1.5 Hz.

3.2. Methods Used and Data Processing

Microtremor measurements performed during the study used an Akashi brand JEP-6A3 model, and 3 component flat receptors with frequency band from 0.2-20 Hz. The acceleration data recorded by these receptors were stored in a Datamark LS-8000WD data recorder. Locations where microtremor records were taken were determined based on the size of the study area by applying a grid system with measurements taken nearby for points coinciding with buildings or roads. Measurements were taken as 3 minute records. The microtremor records were drawn with zero axis off-set correction and 1-10 Hz band transition Butterworth-type filter applied (Figure 4).

In the next stage, the Fourier amplitude spectra were obtained for each component in the frequency environment (Figure 5), with 0.4 band interval Parzen window applied while obtaining these spectra. After microtremor records were processed as above and made ready for evaluation, the Nakamura spectrum and traditional spectral ratio methods were applied.

3.3. Traditional Spectral Ratio Technique

In this method, the ratio of spectra from the location where data obtained from microtremor records are assessed is obtained with the spectrum obtained from a certain reference point. To apply this technique, the record has zero axis off-set correction and 1-10 Hz ban transition Butterworth type filter applied. Later the spectra for each component in the frequency environment are obtained. The ratio of spectra obtained from hard pan and soft caliche were obtained in the amplitude environment depending on components and recalculated with source and road effects removed. Additionally, spectrum smoothing was completed with the 0.5 Hz band width Parzen window (Figures 6 and 7).

3.4. Nakamura Method

The Nakamura method (Nakamura, 1989) is based on microtremor measurements and finding the ratio of

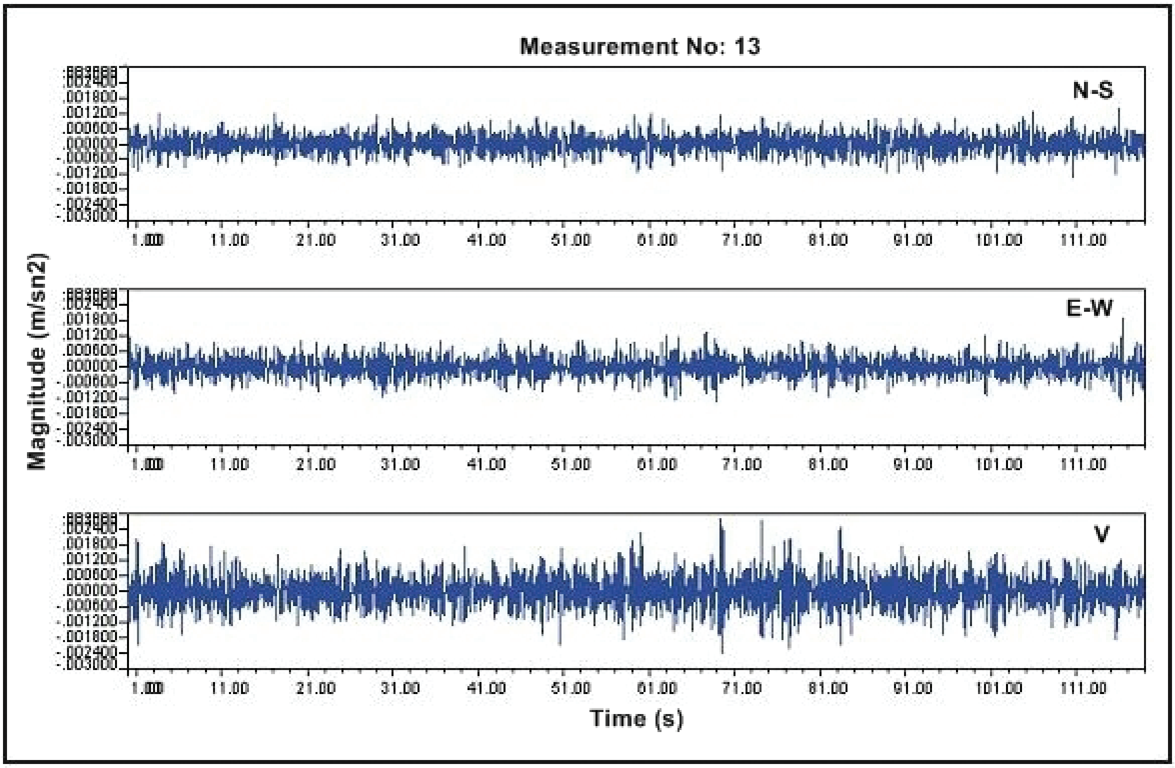


Figure 4- Three components from measurement point 11 in the study area, 3 minute microtremor record showing N-S (north-south), E-W (east-west) and UD (vertical) components.

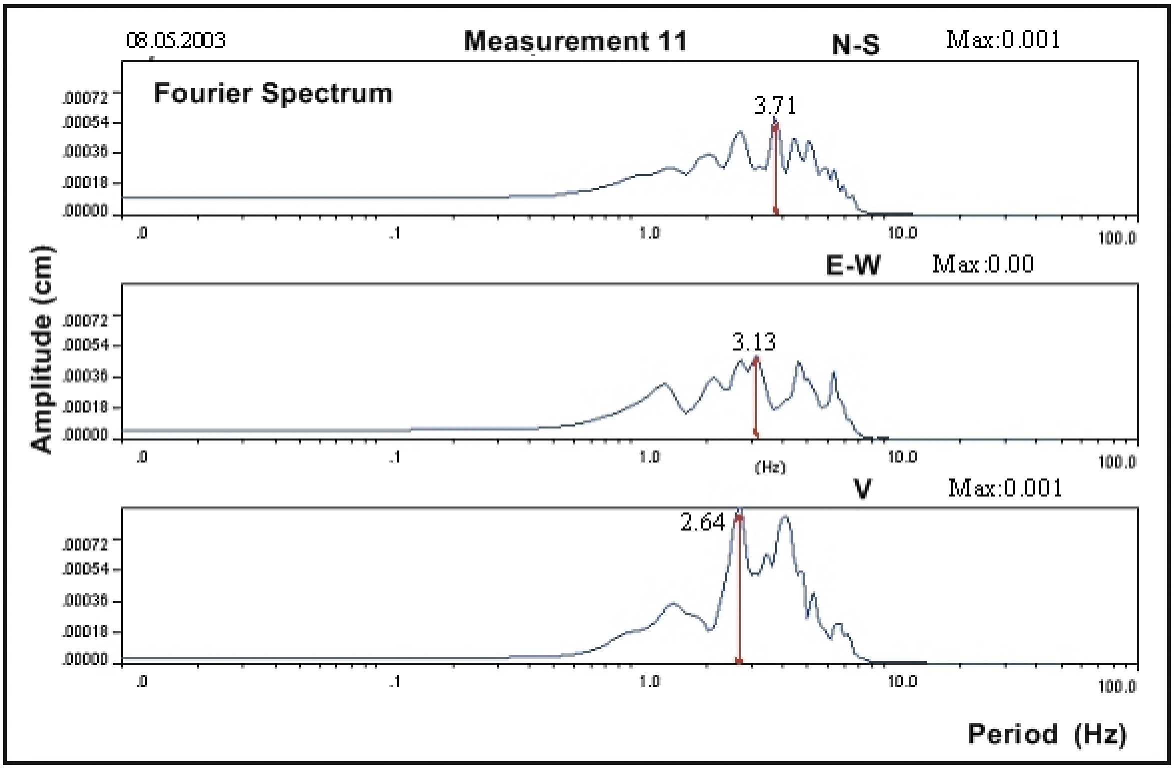


Figure 5- Three components from measurement point 11 in the study area, Fourier amplitude spectra of microtremor record showing N-S (north-south), E-W (east-west) and UD (vertical) components.

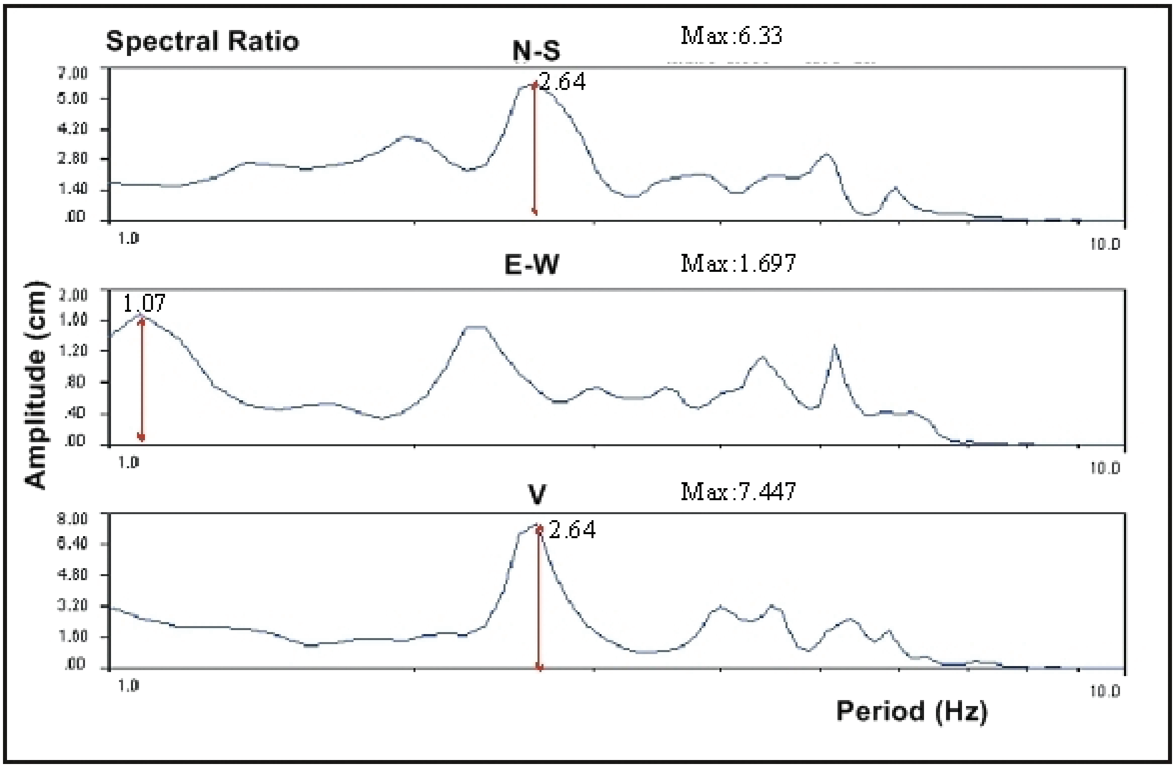


Figure 6- Spectra calculated from records obtained from pebble-block layer and hard pan layer using "traditional spectral ratio technique" and amplitude and amplification difference between hard pan caliche and soft pan levels (coarse grained level).

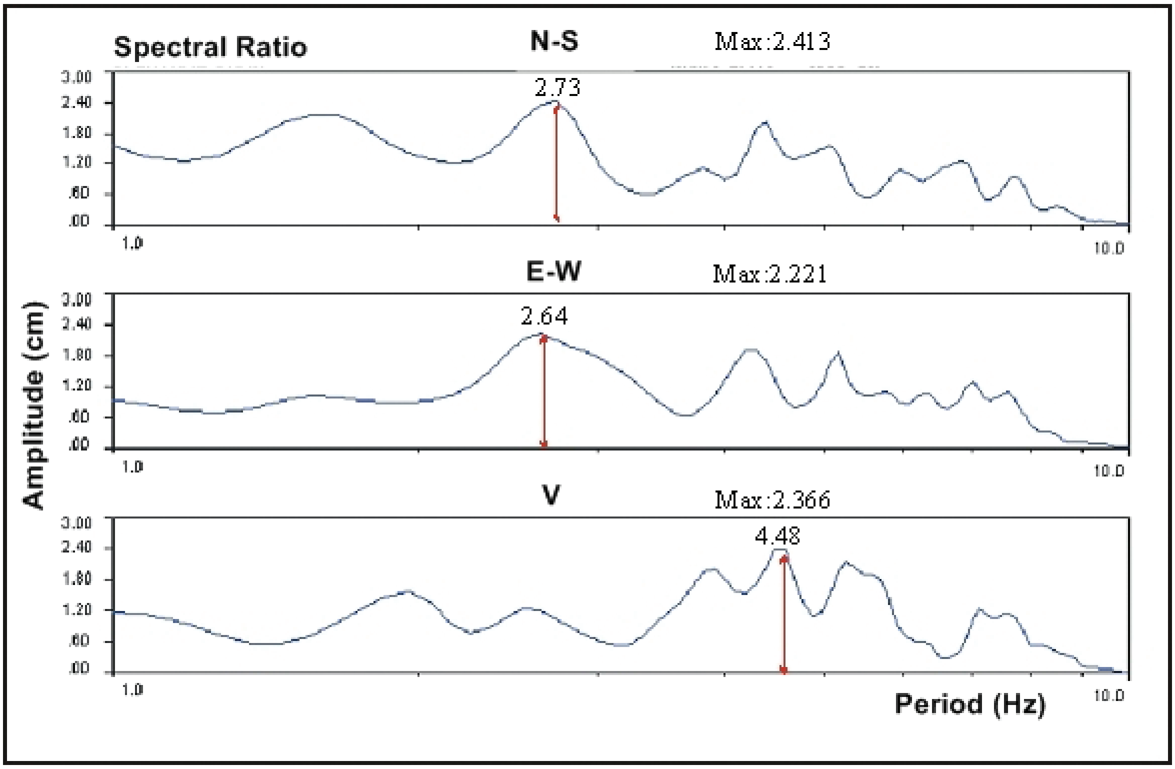


Figure 7- Spectra calculated from records obtained from hard pan and silty-sandy levels using "traditional spectral ratio technique" and amplitude and amplification difference between hard pan caliche and soft pan levels (coarse grained level).

horizontal and vertical spectra (H/V). Vertical motion is mainly dominant in artificial vibration sources and causes Rayleigh waves. The Rayleigh wave effect is clearly observed in the vertical component. As a result, Rayleigh waves are assumed to be the noise of microtremors and an attempt is made to remove the effect.

In this method, the effect of Rayleigh waves accepted as noise is reduced to a minimum. As a result, studies are performed in the early hours of the morning from 02:00-04:00 to prevent measurements being affected by traffic noise or other artificial external noises.

Additionally, continuous measurements of the basement rock and the caliche profile above it may display differences in H/V ratios. By taking the Fourier amplitude spectra of time data obtained from microtremor measurements, studies can separately obtain spectra for each component in the frequency environment. In the next stage, the ratio of horizontal spectra with vertical spectra in each frequency interval is obtained with Eq. 1 used during this process. H/V calculations were completed with GEODAS Data Acquisition System 1.14. Additionally, the ratio of the geometric mean of the amplitude of the horizontal component is taken with the vertical component, with spectrum smoothing performed with a 0.5 Hz band width Parzen window (Figure 8).

$$H/V = \sqrt{S_{NS}^{2} + S_{EW}^{2}} \,/\, S_{UD} \tag{1}$$

H/V : Horizontal and vertical spectral ratio

S_{NS} : North-south component

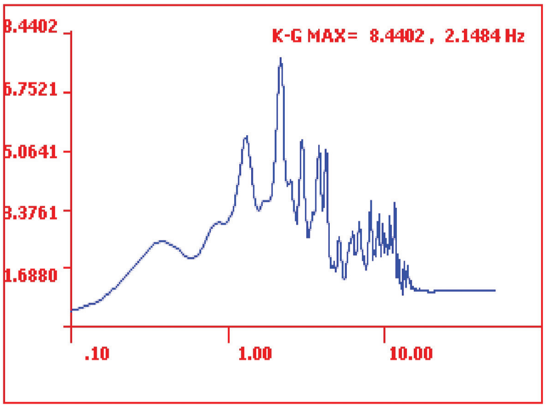
S_{EW} : East-west component

S_{UD} : Vertical component

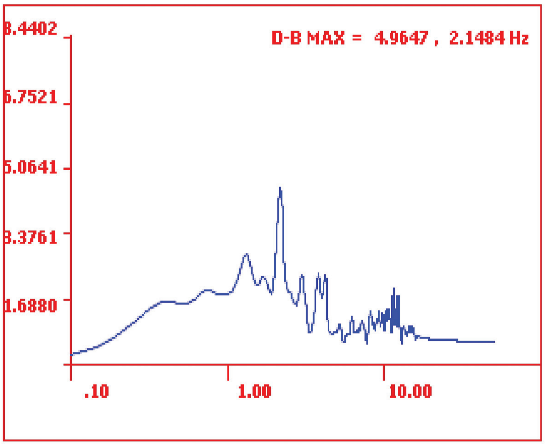
3.5. Assessment of Data and Results

In this study research into the effect of relative ground amplification on hard pan and soft caliche levels found the following results.

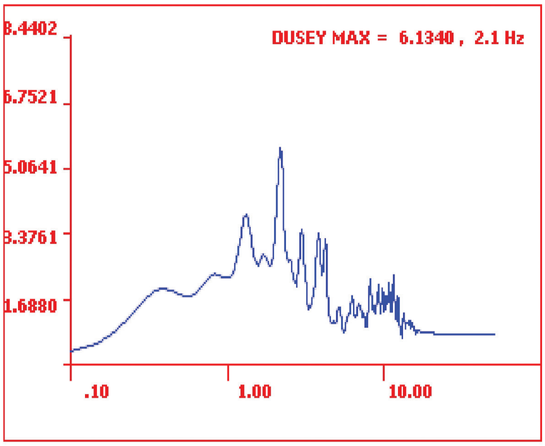
a) When the Fourier spectra of data obtained from microtremor measurements are examined, it is not possible to state a single predominant mode. When the spectra are generally examined, this situation is clearly observed.



a) X(f)/Z(f)



e) Y(f)/Z(f)



e) $(X(f) * Y(f))^{0.5} / Z(f)$

Figure 8- Typical H/V spectra obtained using the Nakamura (1989) technique on the microtremor record (horizontal axis : period, vertical axis : amplitude).

b) There are three modes that appear predominant; in other words it is possible to mention three frequency intervals. The first mode on the spectra is 5.7 Hz interval (0.2-0.1 s period) hard pan effect, the second mode is for soft caliche levels with 2-3 Hz interval (0.5-0.3 s period) for pebble-block level and silty-sandy level and finally there is a 1-2 Hz interval (0.9-0.5 s period) where the effect of the underlying clay unit that is generally not observed in the field is noted.

c) Measurements of hard pan determined the predominant site period from Fourier spectrum as 7 Hz (0.14 s) (Figure 9b). When the Nakamura spectrum is obtained, the predominant amplitude is 5.5 Hz (0.18 s) and it appears to provide 1.5 times relative ground amplification (Figure 9c).

d) When measurements are investigated from pebble-block levels at the surface in areas without a hard pan level, or where it has been removed, the Nakamura spectrum has 2.8 Hz (0.37 s) predominant site period (Figure 10b) providing 1.25 times relative ground amplification (Figure 10c).

e) Measurements taken in the silty-sandy level where there is no hard pan or pebble-blocky layer of soft caliche had 1.75 Hz (0.57 s) predominant site period and provided 1.8 times amplification (Figure 11c).

f) When the traditional spectral ratio method is applied to hard pan and soft caliche levels, the pebble-block layer of soft caliche was observed to have 1.79 Hz (0.56 s) with 6-7 times relative ground amplification compared to hard pan. For the silty-sandy level, at 2.5 Hz (0.4 s) period there was 2.4 times maximum amplification compared to hard pan.

These data were taken from a trench where hard pan, and the pebble-blocky layer and silty-sandy layer of soft caliche are found together, which makes it possible to state that all three records are affected by the same source. As a result, the variations in amplification and periods is due to the variation within the geologic units.

Though the site period values determined with the traditional spectral ratio method are in the same interval compared to the Nakamura spectrum, the difference in amplification values is due to the hard pan acting like a high-pass filter and thus it is natural that it exaggerates amplitudes in its own natural period (10-4 Hz) and suppresses the others. Similarly the pebble-blocky and silty-sandy layers of soft caliche tend to exaggerate signals in their own predominant period intervals (3.3-1.6 Hz). In conclusion, when the ratio of the hard pan spectrum to the others is obtained, as the ratio increases for the same frequency values, the amplification will be different. Additionally, the pebble-block level period and amplification value is larger than the silty-sandy level and this is a topic that needs to be emphasised for structures with many floors or high period built on the pebble-block level.

Two microtremor measurements were made in the front and back garden of the Organised Industrial Zone Administration building that was severely damaged by the Adana-Ceyhan earthquake. When the Nakamura spectrum of the first record in the front garden is examined (Figure 12), there is 0.23 s (4.3 Hz) site period with 3.1 times relative ground amplification, while the second record had 0.27 s (0.37 Hz) site period with 2.7 times relative ground amplification (Figure 13). When the traditional spectral ratio technique, accepted as a measurement reference, is obtained from the soft caliche and hard pan in the area where the administration building is located, there is 0.23 s (4.3 Hz) site period in N-S direction with 11 times ground amplification, 0.2 s (5.2 Hz) in E-W direction with 8 times amplification and 0.17 s (5.9 Hz) vertical period with 6.7 times amplification, as observed on figure 14. These results show the site of the administration building had 0.23-0.3 s (4.3-3.3 Hz) predominant period interval with mean 3 times amplification. According to the approach in Eq. 2 recommended for structures in Turkey by Bayülke (1978), assuming the administration building is a 3-floor reinforced concrete building with 0.2-0.3 s (5-3.3 Hz) period, it is in the same period interval as the site. The damage was most probably the result of the structure resonating with the ground.

$$T_a = 0.1 \times N \qquad (2)$$

Here; T_a, building period (s) and N is the number of floors in the building.

Coordinates of the measurement points, predominant site period and relative ground amplification values are presented in Table 1. The spatial distribution of the predominant site period obtained from Nakamura spectra and the ground

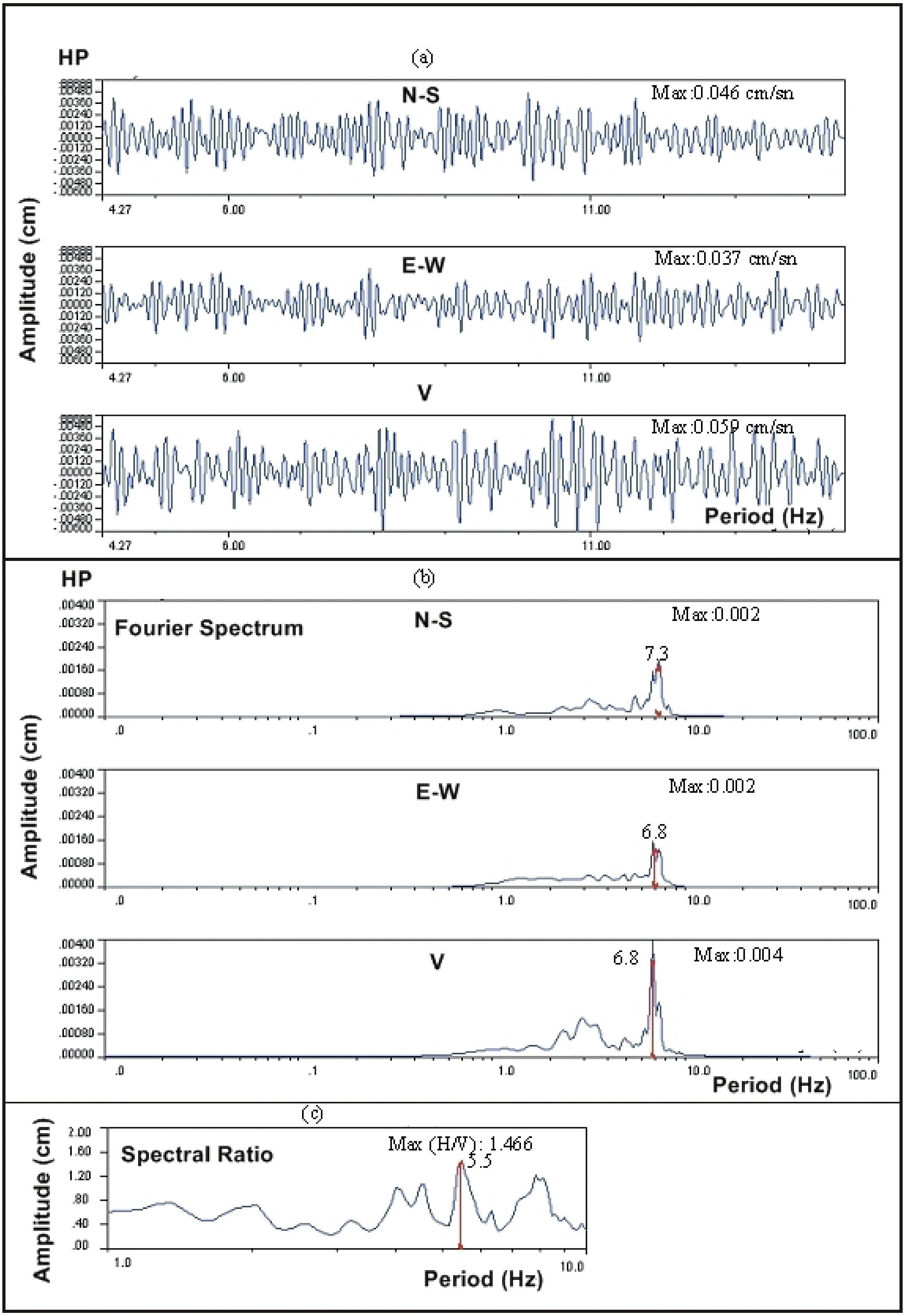


Figure 9- Fourier spectra and H/V spectra obtained with Nakamura (1989) method for hard pan records.

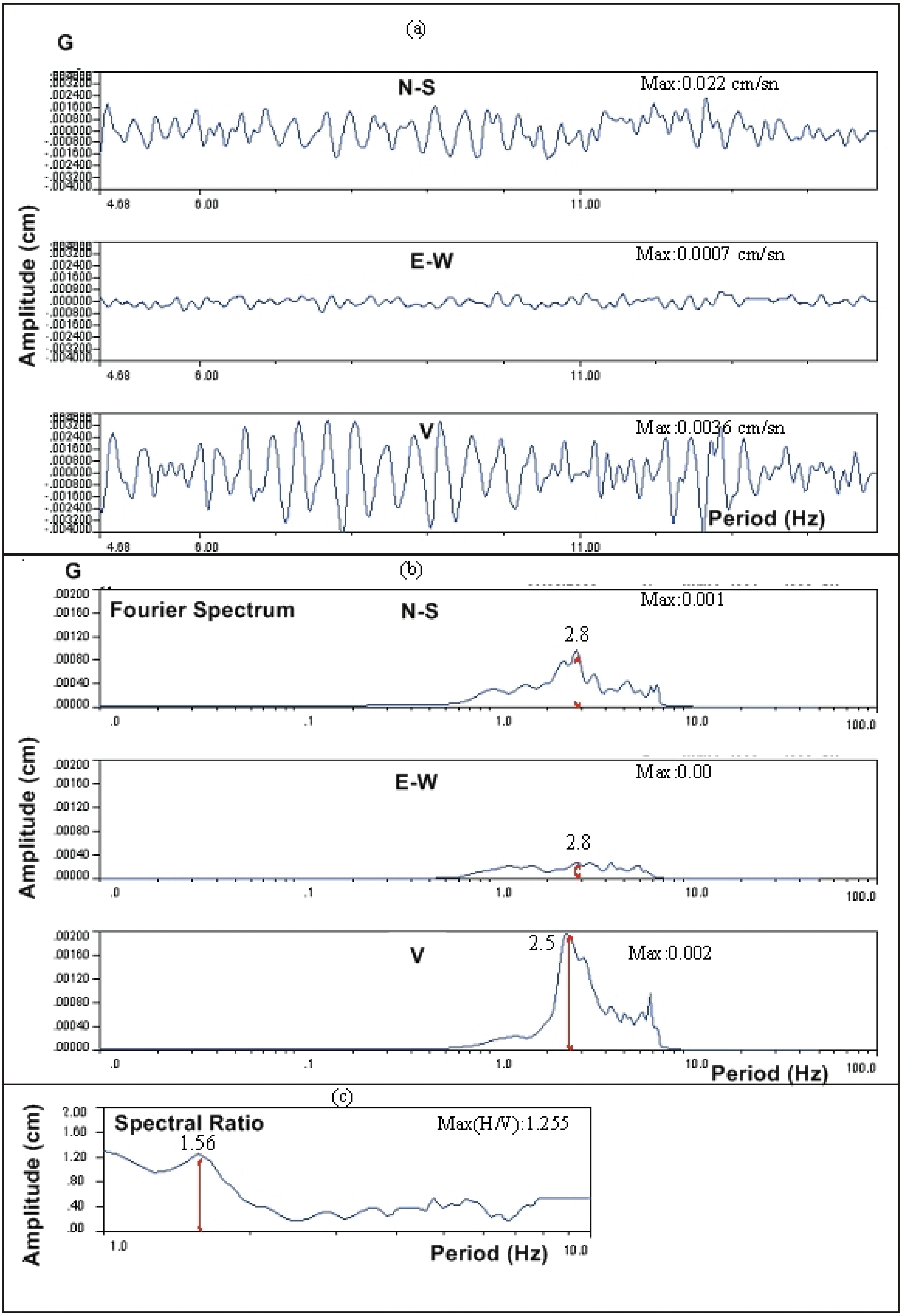


Figure 10- Fourier spectra and H/V spectra obtained with Nakamura (1989) method for soft pan (pebble-block layers) records.

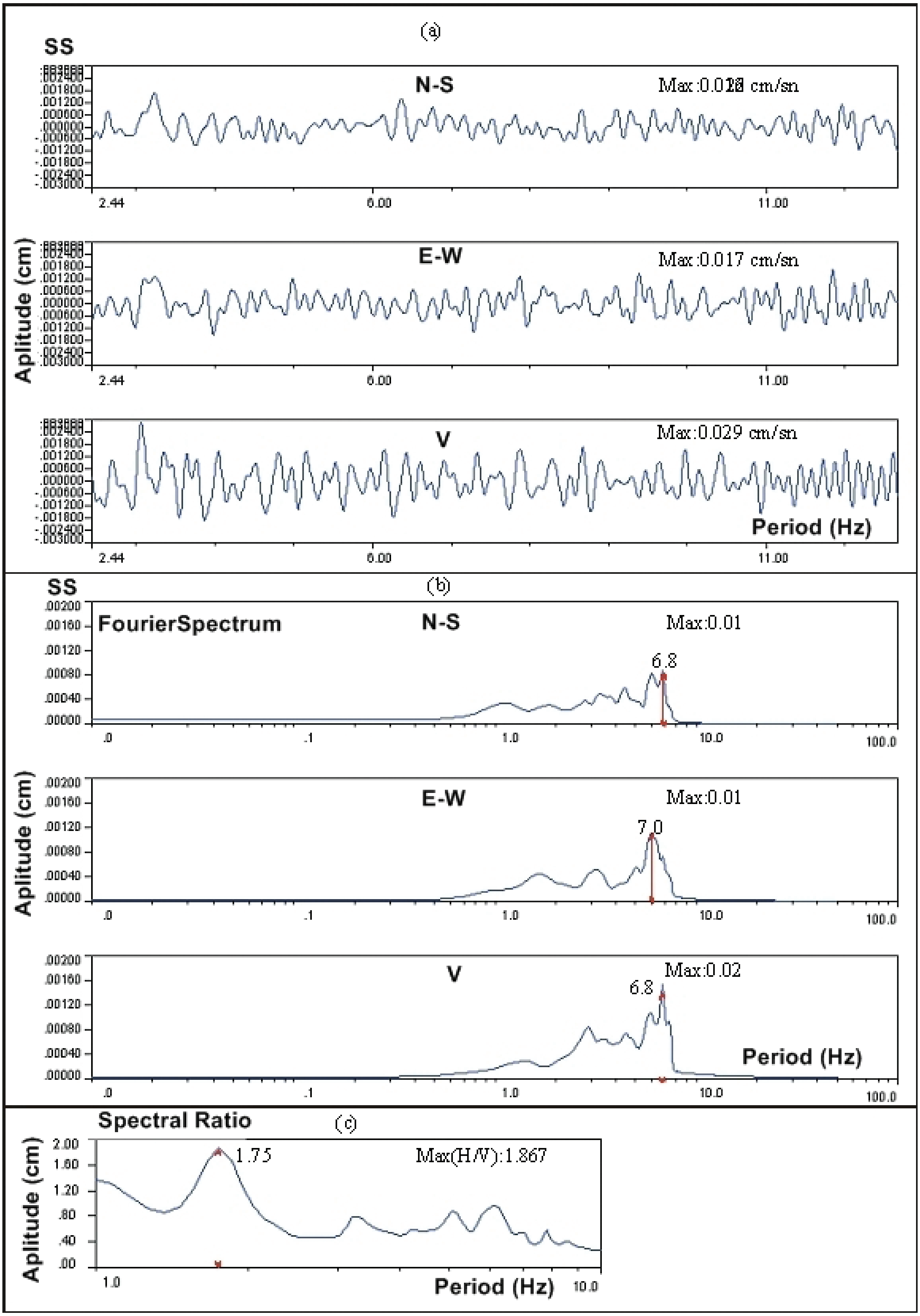


Figure 11- Fourier spectra and H/V spectra obtained with Nakamura (1989) method for soft pan (silty-sandy layer)

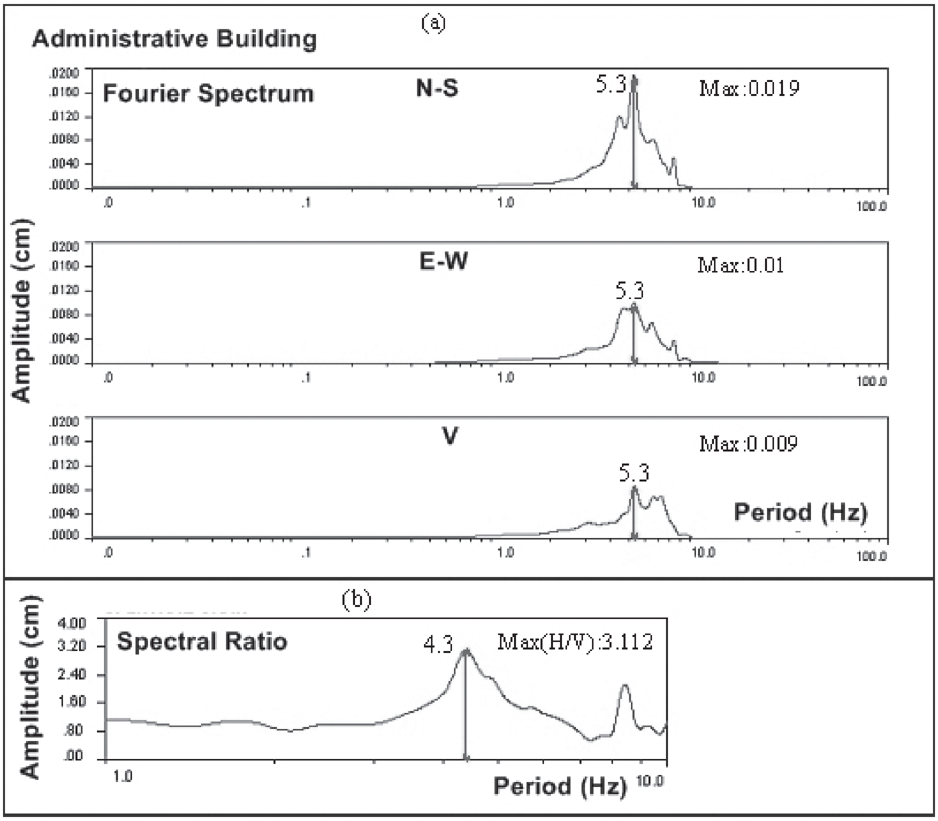


Figure 12- First record from garden of the Adana Organised Industrial Zone Administration building (N-S direction parallel to long axis of building).

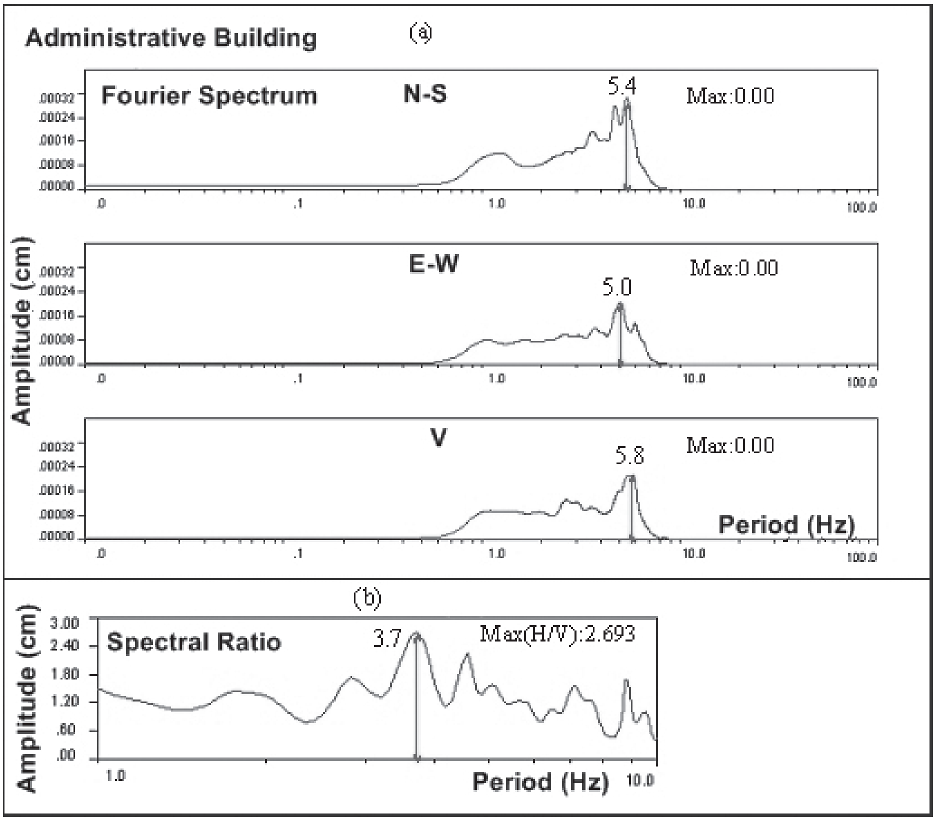


Figure 13- Second record from garden of Adana Organised Industrial Zone Administration building (N-S direction parallel to long axis of building).

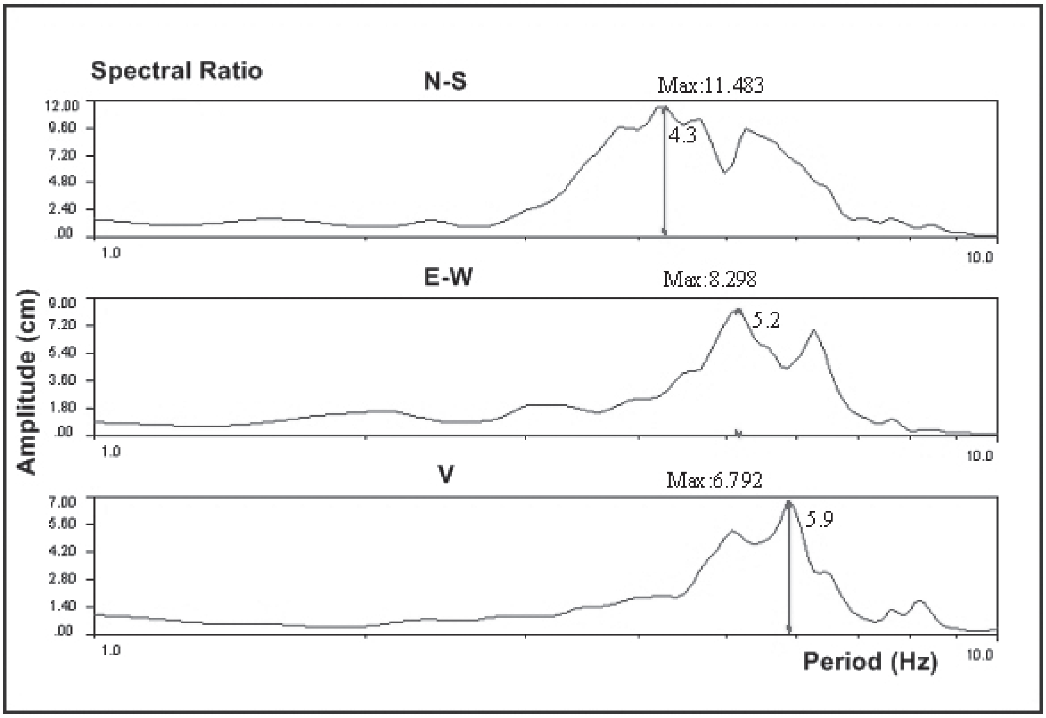


Figure 14- Amplification formed when traditional spectral ratio technique is applied to soft pan level compared to hard pan level for ground at the damaged administration building.

amplification at these periods are shown on maps in figure 15 and 16. For estimation of values from points that could not be measured, a zone map was not created considering errors due to the lack of sufficient measurement points and it was considered more appropriate to give values as points.

In addition to microtremor measurements completed in the study area, measurements were obtained beside damaged buildings, including the administration building severely damaged in the 1998 Adana-Ceyhan earthquake. In these areas the predominant site period and the ground amplification values for these periods

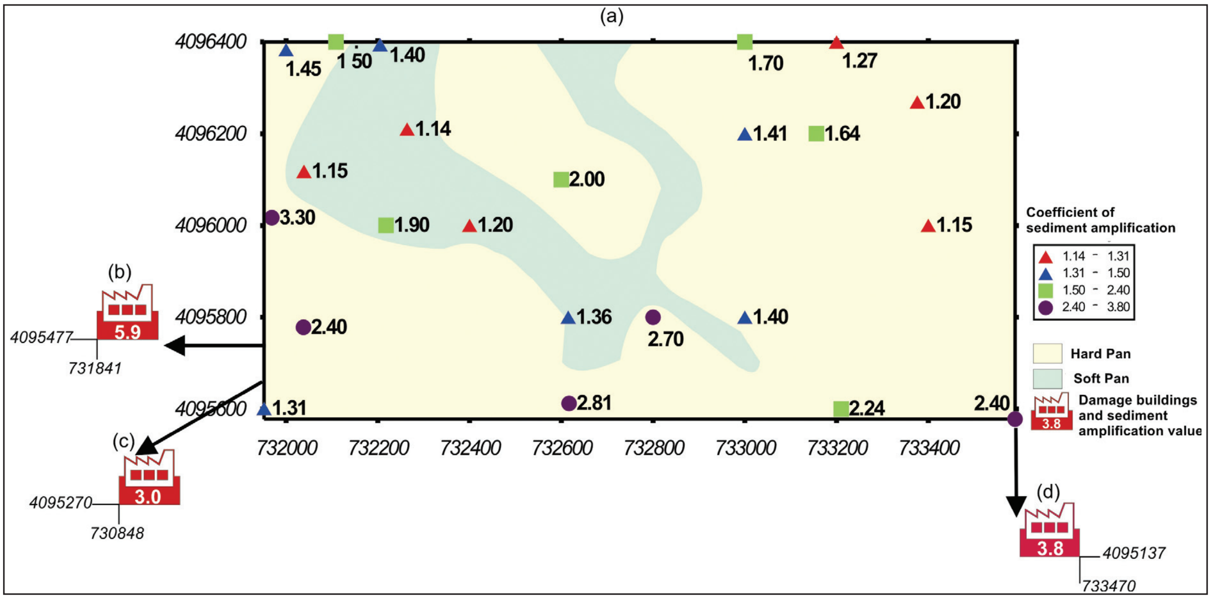


Figure 15- Relative amplification values obtained from Nakamura spectra (a) spatial distribution in the study area and (b, c, d) amplification values found from some damaged buildings outside the measurement area.

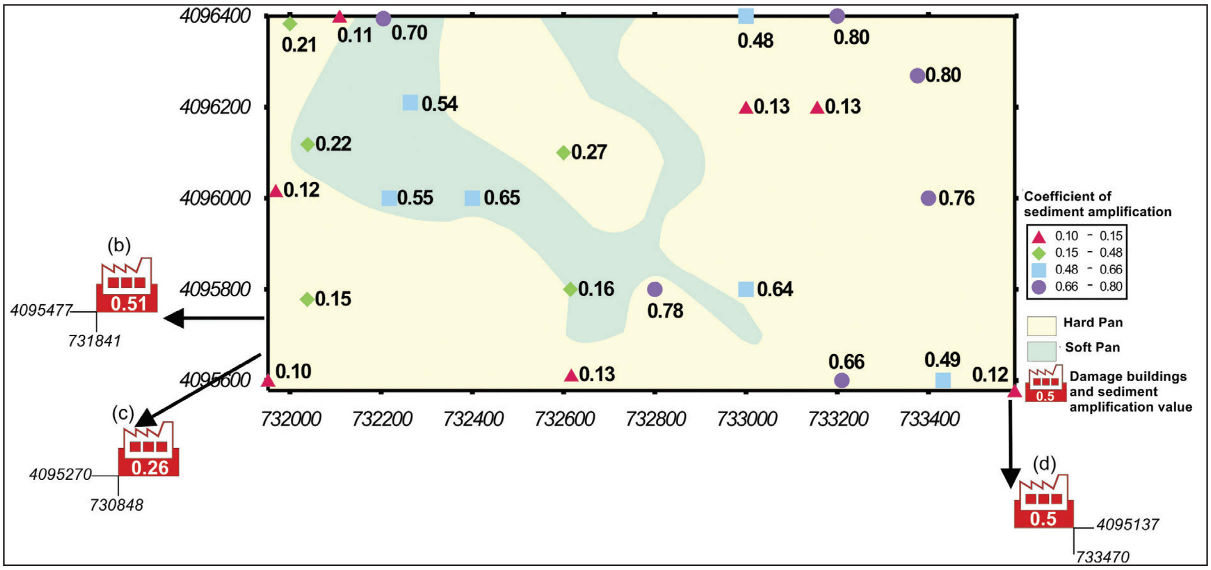


Figure 16- Predominant site periods obtained from Nakamura spectra (a) spatial distribution in the study area and (b, c, d) predominant site periods from some damaged buildings outside the measurement area.

Table 1- Predominant site period and data and coordinates used to create maps for amplification at these periods.

Measurement point	Ground Type	Longitude	Latitude	Amplification	Dominant Period (s)
1	HPC	731952	4095601	1.3	0.1
2	HPC	732038	4095778	2.4	0.2
3	HPC	731969	4096017	3.3	0.1
4	HPC	732039	4096118	1.2	0.2
5	HPC	732000	4096383	1.5	0.2
6	SPC	732205	4096394	1.4	0.7
7	P	732264	4096210	1.1	0.5
8	P	732218	4096000	1.9	0.6
9	HPC	732617	4095612	2.8	0.1
10	HPC	732109	4096400	1.5	0.1
11	SC (HPC)	733000	4096400	1.7	0.5
12	SC (HPC)	733000	4096200	1.4	0.1
13	SC (HPC)	733200	4096400	1.3	0.8
14	SC (HPC)	733376	4096269	1.2	0.8
15	HPC	733156	4096200	1.6	0.1
16	SC (HPC)	733400	4096000	1.2	0.8
17	HPC	733432	4095600	3.8	0.5
18	HPC	733210	4095600	2.2	0.7
19	HPC	733000	4095800	1.4	0.6
20	HPC	732800	4095800	2.7	0.8
21	SPC	732615	4095800	1.4	0.2
22	P	732400	4096000	1.2	0.7
23	HPC	732600	4096100	2.0	0.3
24	HPC	733589	4095578	2.4	0.1

HPC: Hard pan caliche, SPC: Soft pan caliche, SC: Soil cover, P: Pebble-block level were determined. The severely-damaged buildings are 3- and 4-floor reinforced concrete buildings, with the building period and site period in the same interval and damage occurred due to the buildings resonating with the ground. The predominant site periods and ground amplification values for these periods for the locations of damaged buildings outside the area chosen for microtremor measurements are shown on figures 15 and 16 along with the building coordinates.

In conclusion, it was determined from these maps that the predominant site periods vary from 0.1-0.8 s with ground amplification varying from 1.14-3.8 times. The relative amplification values from measurements taken on hard pan have higher values compared to those obtained from soft caliche with the hard pan having an increasing effect on relative ground amplification. The cause of the amplification on hard pan may be shown as the interaction of wave amplitudes due to repeated reflections and wave scatter between the hard pan and the underlying discontinuities (transitions between different levels within the caliche profile). Wave phases overlap increasing the amplitudes and reaching the surface which is considered to be the true cause of amplification.

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