

The seismic microzonation map of Yenisehir-Bursa, NW of Turkey by means of ambient noise measurements

Ünal DİKMEN and Mete MİRZAOĞLU

General Directorate of Disaster Affairs, Earthquake Research Department, Ankara, Turkey

Abstract: *This paper describes the results of the study of seismic microzonation at Yenisehir-Bursa which is located at the Northwestern part of Turkey. Seismic noise measurements have been made at 151 sites. Short periods (less than 1 second) were taken into account at the main peak in the spectral ratio between the horizontal and the vertical components. At the investigated area, two maps were prepared that show the spatial variations of the predominant period and seismic amplification according to Nakamura's technique. The analysis shows that the north and south edges of the Yenisehir basin have relatively high predominant periods and high seismic amplification compared to the centre of the basin. This result is in line with the theory of topographic effects on seismic amplification and also confirmed the suitability of the H/V spectral ratio of ambient noise as a geophysical exploration tool in seismic hazard assessment.*

Key words: *microzonation, soil response, Nakamura's technique, H/V ratio, topographic effect*

INTRODUCTION

It has been well-documented that the effect of local geological conditions on ground shaking is an important factor in earthquake engineering. Particularly, soft sedimentary cover could strongly amplify the seismic motion. When amplifications take place at periods close to the fundamental periods of vibration of the buildings greater damages can be expected. Moreover, surface topography considerably affects the amplitude and frequency contents of ground vibrations (Faccioli 1991, Fin 1991). Meanwhile these topographic effects are low compared to soft soil amplification. At many destructive earthquakes it has been often reported that buildings located at hill tops suffered much more intensive damage than those located at the base. As justified by theoretical and numerical models there is also a systematic amplification of seismic motion at ridge crests and over convex topographies such as precipices. As opposed to this, there is de-amplification over concave topographic features, such as valleys and the base of hills. The amounts of these effects have been shown

by Pedersen et al. (1994) as being rather sensitive to the characteristics of the incident wave field (wave type, incidence and azimuth angles). Seismic hazard enables a description of potential seismic risk level that should be taken into account when designing new structures or upgrading existing ones. Estimation of the local response at a site is a key component of any analysis of local seismic hazard.

Experimental determination of site effects compared to numerical modeling has the advantages of avoiding the need of a great number of the geotechnical parameters of the soil. For that reason, nowadays experimental studies and techniques particularly microtremors and Nakamura's method in seismic hazard assessment have been useful.

Engineering applications of microtremors was initially proposed by Kanai and Tanaka (1961). Kanai and Tanaka (1961) classified the surface geological conditions at a site based on measurements of ambient noise with periods lower than 1 second. The measurement techniques and analysis methods of

microtremors have been studied for a long time. Nakamura's method is found to be suitable for the determination of the predominant periods of soils. Although discussion on seismic amplification computed by Nakamura's method has been continuing, a number of authors got meaningful results (Lachet 1996, Cornou 1998, Bard 1999). Nakamura's (1989) method is used in this study because it is easy to apply and requires neither local or regional seismic activity nor adequate reference site. In spite of the

problems related to their interpretation, microtremor measurements provide a very interesting approach to site effect evaluation by virtue of the low cost and rapidity of field operations and simplicity of analysis. An experimental study was made at Yenisehir, NW of Turkey (Figure 1) for several reasons: Yenisehir town is the first capital city of the Ottoman Empire hence the area is an important region on account of the historical and cultural influences.

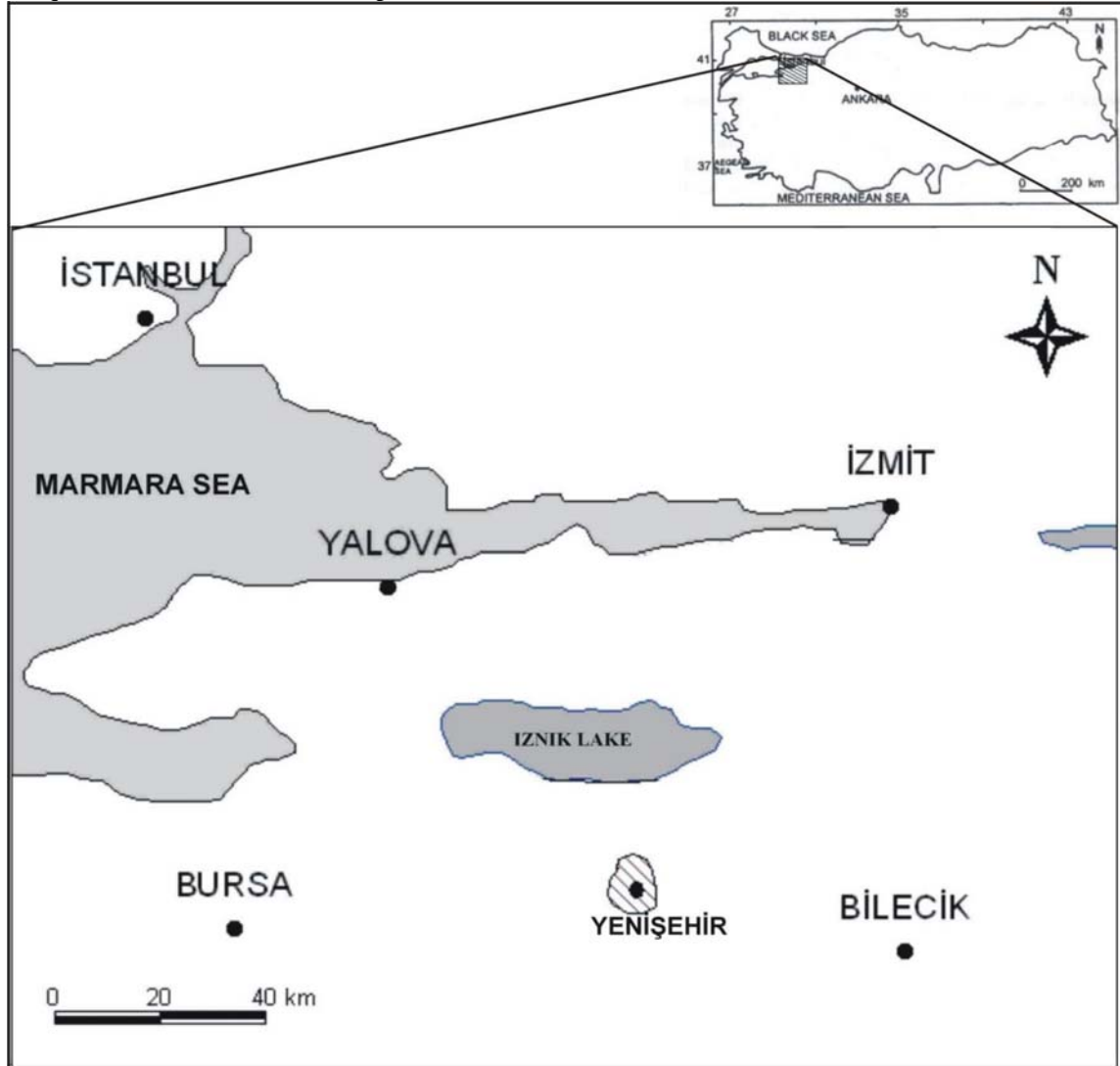


Figure 1. Location map

Recently the population of the town is growing up and therefore high rise buildings

are being under construction (Figure 2) without the knowledge of soil properties



Figure 2. A scene of the high rise buildings under construction in Yenisehir town

GEOLOGY, TECTONICS AND SEISMICITY OF THE REGION

The simplified geological map of the investigated area is given in Figure 3. This area named as “Yenisehir” basin has approximately EW elongation and its form resembles ellipsoid. It has about 35 km length and 12-13 km width. The basin is lying between Iznik basin from north and Inegol basin from south. These basins are the results of the activity of North Anatolian Fault, which is a major tectonic line in Turkey.

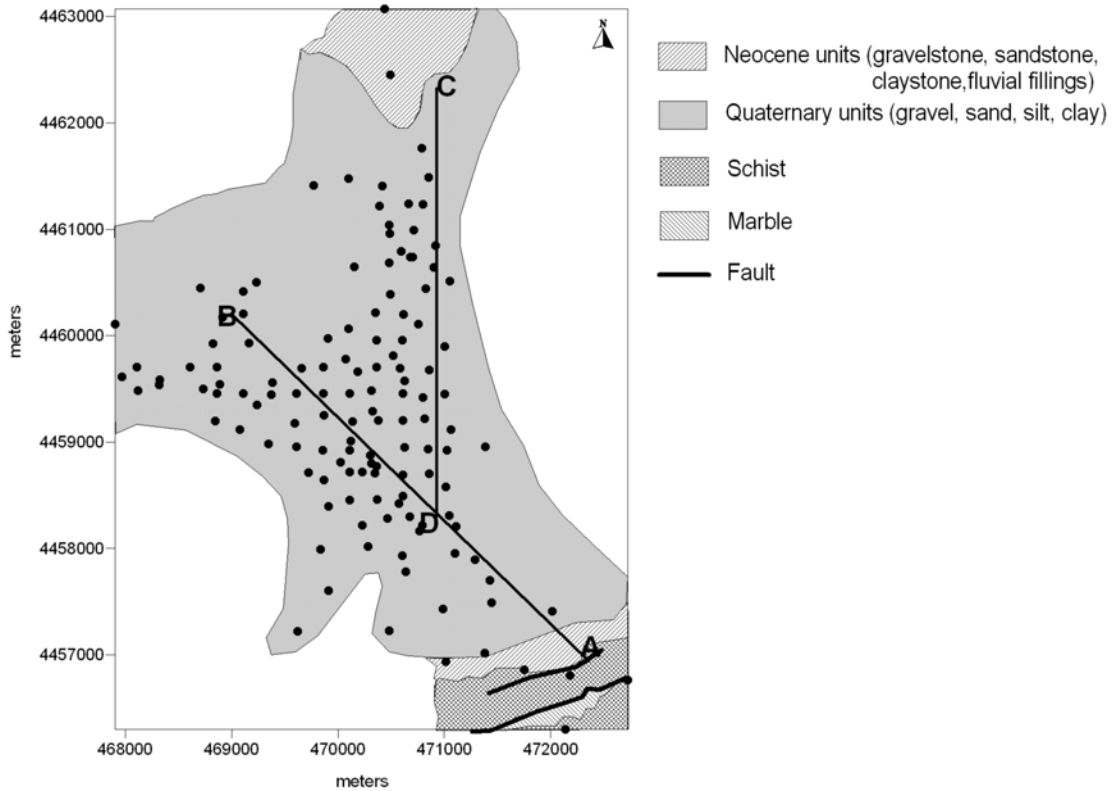


Figure 3. A simplified geological map of the investigated area, observation locations of microtremor measurements and electric sounding profiles

The investigated area has three distinct geological formations: (1) Quaternary series are primary composed of gravel, sand, silt and clay. These alluvial fillings are the most commonly observed units throughout the basin. (2) The lithological units of Neocene consist of gravelstone, sandstone and

claystone. These series are outcropping both at north and south margin of the basin. (3) Pre-Neocene age units composed of schist, marble, limestone, andesite and trachyte and observed both south and north crest of the basin. In order to get some insights about stratigraphical knowledge of the basin, two electrical sounding profiles (labeled as AB and CD)

were conducted in the area and showed in Figure 3. As can be seen from the cross-

sections (Figure 4) of which the resistivity decreases to depth of 250 meters.

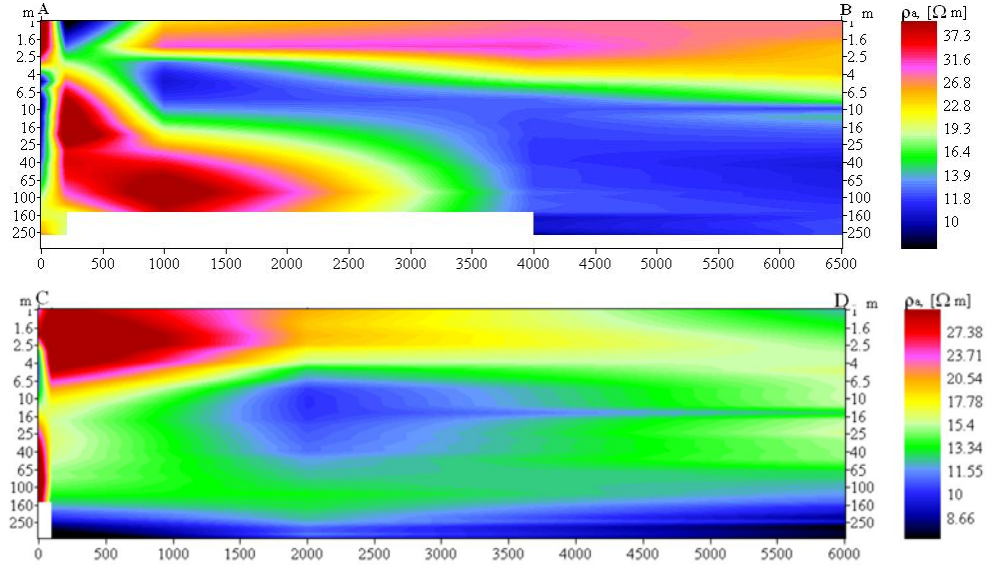


Figure 4. upper: Resistivity cross-section of AB profile, lower: Resistivity cross-section of CD profile (see Figure 3 for lines)

The region tectonically is being under strike slip fault regime. From the simplified tectonic map of the region, Yenisehir and surrounding area is controlled by right lateral strike slip

fault systems as Marmara region. Destructive earthquakes which have magnitudes greater than 5.0 occurred in that region (Figure 5).

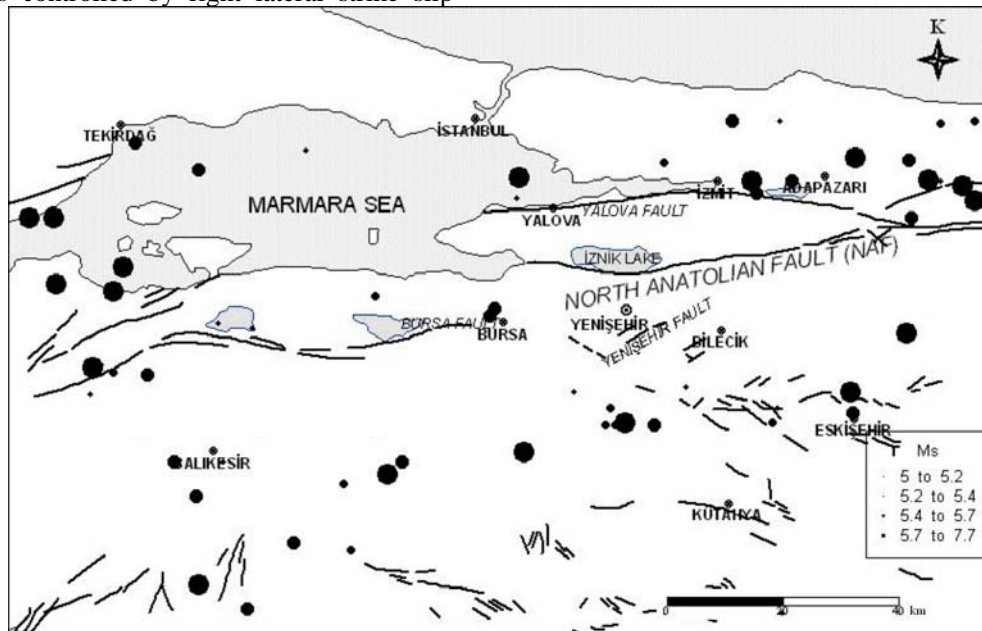


Figure 5. Map shows epicenter distribution of earthquakes occurred in the surrounding region of Marmara between 1900 and 2000 with magnitude greater than 5.0 and main fault systems

For instance, the earthquakes of 1999 Izmit and Duzce, affected Yenisehir and surrounding area. The fault, which has potential to produce destructive earthquakes in the region, is the west part of North Anatolian Fault. The frequency of occurrence of a destructive earthquake is about 180-250 years for Marmara region (Doyuran et al. 2003).

METHODOLOGY BASED ON RECORDINGS OF AMBIENT NOISE

Microtremors are ground vibrations with displacements amplitude about 0.1-1.0 micron and velocity amplitude about 0.001-0.01 cm s⁻¹ and they can be divided in two main groups according to their period ranges: periods less than 1 second named as “short period microtremor” which is related to shallow subsurface layers at depths several tens of meters and generated by near local surface sources such as traffic and industry machines. Periods greater than 1 second called as “long period microtremor” which is related to deeper soil layers down to a depth of hard rock and generated by winds, tides and teleseisms etc. Microtremors were studied since the early work of Omori (1908). Long period microtremors studied by Ohta et al. (1978) and Kagami et al. (1982). Application of short period microtremors to estimate site effects has been investigated for many years by Kanai and Tanaka (1954, 1961). The characteristics of microtremors were firstly described by Nakamura (1989). This technique as described by Nakamura’s (1989) based on the following assumptions for the fundamental characteristics of microtremors:

- Microtremors are essentially composed of Rayleigh waves propagating in the soft surface layers overlying a half space. Source effects might be removed from microtremors by taking the spectral ratios of the horizontal to vertical components of microtremor record at a single site.

- Only horizontal components of microtremors are influenced by soil while source spectral characteristics are maintained in vertical components as well as in horizontal components.
- Site effects due to surface geology are generally expressed as the spectral ratio (S_R) between the horizontal component of earthquake recordings at the surface of soft layer (H_s) and the ones at the outcropping bedrock, H_b (Figure 6).

$$S_R(w) = \frac{H_s(w)}{H_b(w)}$$

- The effect of Rayleigh wave (E_R) on noise motion is included in the vertical spectrum of the surface (V_s), but not at the base of the layer (V_b). Consequently, the effect of Rayleigh wave on the vertical motion should be represented as:

$$E_R(w) = \frac{V_s(w)}{V_b(w)}$$

- The effects of Rayleigh waves on both horizontal and vertical components are equal. It is assumed that for wide frequency range (0.2 – 20 Hz) the spectral ratio of the horizontal and vertical components of motion at the bottom of the layer is close to unity.

$$\frac{H_b(w)}{V_b(w)} = 1$$

- An estimation of the transfer function (S_E) of a surface layer is given by taking the spectral ratio of horizontal and vertical components of noise record at the surface site:

$$S_E(w) = \frac{S_R(w)}{E_R(w)} = \frac{H_s(w)}{V_s(w)}$$

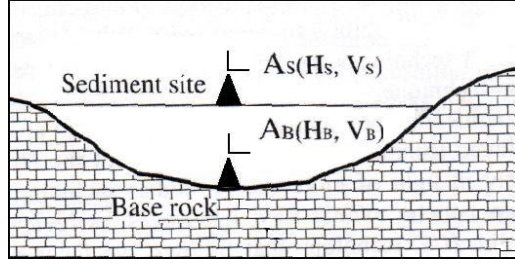


Figure 6. Simplified model assumed by Nakamura (1989) to interpret microtremor measurements

Observed amplitudes of earthquakes and H/V peak amplitudes were compared by Bard (1999) and found the latter always smaller than the former. Notwithstanding the theoretical and experimental investigations on seismic amplification using Nakamura technique are yet controversial. It is assumed that this technique could be useful for a lower bound estimation of seismic amplification of a site (Cornou 1998).

Experimental measurements and process

The experimental study was carried out over a region of about 30 km² at the area of Yenisehir. All the measurement points (151 in total) in the experiment are shown on Figure 3. The microtremor measurements were performed with a Datamark Ls-8000wd type recorder and Akashi-Jep6a3 type three components accelerometer with natural period of 1 second with flat acceleration response between 0.2 and 50 Hz. At each observation site a minimum of 180 second ambient noise, sampled at 100 Hz was recorded. And the following procedures were applied:

- Data were converted from binary to ASCII (for MicPlot),
- Waveforms were drawn by using MicPlot version 1.1 (for UNIX operation system),
- Windows including 2048 samples data were selected for analysis (it was advisable picking out 20 second data length for best quality of data in term of noise level),
- Cosines type window tapering on 5% of the signal were applied,
- Hanning type band-pass filter between 0.1 and 10 Hz were performed,
- Fourier spectra of the three component (NS, EW and UP) were calculated,
- Calculated Fourier spectra's of three components were smoothed with a Parzen window having 0.3 Hz bandwidth.
- H/V spectral ratios were calculated by

$$SR(w) = \frac{H_s(w)}{V_s(w)} = \frac{\sqrt{NS(w)^2 + EW(w)^2}}{UP(w)}$$

An example of microtremor record and calculated Fourier spectra and H/V spectral ratio were drawn in Figure 7.

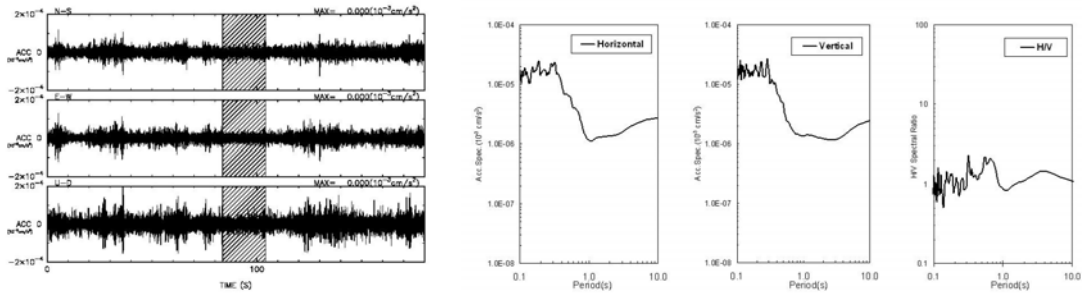


Figure 7. Left: an example of three components (EW, NS and UD) microtremor record measured in the area, right: The Fourier spectrum of horizontal and vertical components and calculated H/V ratio

SEISMIC MICROZONATION

Among several techniques for microzonation purposes, Nakamura's (1989) method was found suitable for the determination of the fundamental period and for the lower bound estimation of seismic amplification of a site (Bard 1999, Cornou 1998). Nakamura's method doesn't presently permit the amplitude level estimated by the H/V spectral ratio to be related to the amplification of a signal at the surface relative to that in the bedrock during a strong motion. Only the relative amplifications between two measurements points are assumed to be significant. On account of that, each measurement point provides a spectral ratio and enables us an estimation of the fundamental period and a lower bound estimation of the amplification at the site studied. Recently geotechnical investigation consists of drilling at 17 sites at maximum depth of 20 meters and laboratory experiments conducted by Doyuran et al. (2003). They produced a microzoning map (not displayed here) only according to drilling and laboratory results but without the knowledge of the fundamental characteristics of seismic wave motion and its effects on site response. By spatial interpolation between measured points, we draw a map of fundamental periods and a map of amplification observed at those fundamental periods over the investigated area. The fundamental period distribution map was divided mainly into four zones, which are: 0.2-0.4 s, 0.4-0.6 s, 0.6-0.8 s and periods greater than 0.8 second respectively in order to take into account both the height of a building and its fundamental period of vibration which can be expressed by the approximate formula:

$$T = \frac{(\text{number of storey})}{10.0}$$

From this point of view, in the period distribution map (Figure 10), each zone number (1, 2, 3 and 4) also corresponds to storey number which may be under high seismic risk when a destructive earthquake occurred at that region. High rise buildings,

which story's are changing from five to eight have been under construction in this area, showed on both map (Figure 10 and Figure 11) as rectangle with dashed line. The fundamental vibration periods of the buildings under construction and the fundamental periods of the enclosed site seems to be close to each other. Amplification map was divided into four zones as in the fundamental period distribution map according to their amplification values. As seen in the amplification map (Figure 11), hill-site at both north and south part of the basin amplifies the motion 5 to 9 times, while at the centre of the valley the amplifications change from 1.5 to 5.0. We believe that the topography of the basin significantly affects the amplitudes of the motion at the hill-site relative to the centre of the basin. On the amplification map, the fourth zone at both sites of the basin corresponds to a transition zone between Neocene units and alluvial deposits.

Topography effect on site amplification

Theoretical and experimental studies on topographical effects on ground motion have been made by Aki (1998) who showed the effects of topography using a simple structure of a triangle edge model. Facioli (1991) used Aki's model as ridge-valley topography and addressed the relative amplification at the crest of the ridge compared to the base and also the de-amplification in the valley. Amplification of the motion of the crest of ridge relative to the base is also pointed out by Brambati et al. (1980) dealing with damage patterns during the 1980 Friuli earthquake in Italy and in the Chilean earthquake of 1985 (Celebi 1987, Celebi 1991). In order to show topography effects on ground motion, a number of microtremor measurement locations covering all studied area (Figure 8), from north to south directions of the basin and their amplifications are shown in Figure 9.

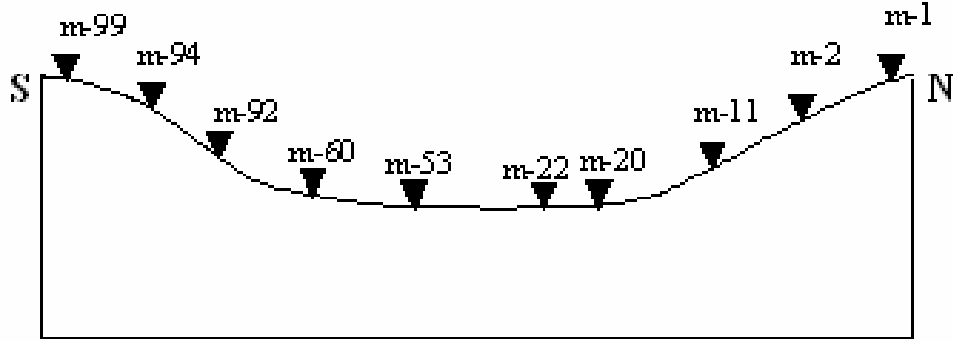


Figure 8. A sketch of microtremor locations situated at crest, hill site and base of the basin

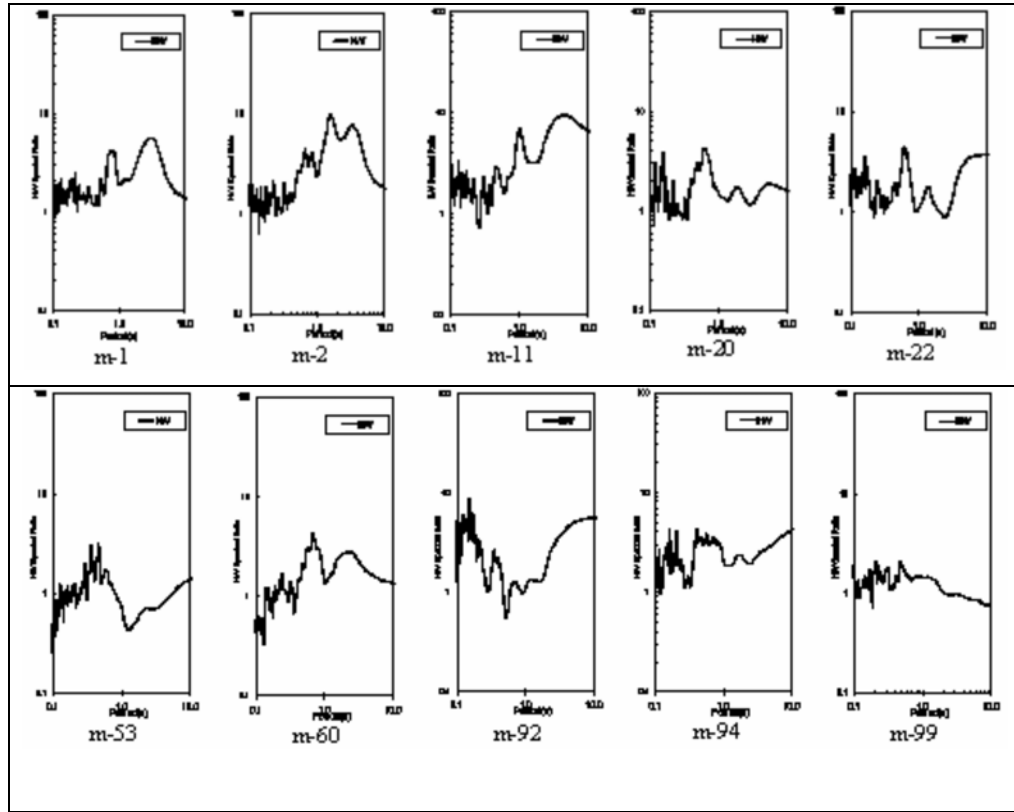


Figure 9. H/V ratios calculated at microtremor locations showed in Figure 8 to show topographic effect.

The points, m-1, m-2 and m-11 were located at crest and hill-site of north part of the basin. The points, m-20, m-22, m-53 and m-60 were located at the base. Lastly the points, m-92, m-94 and m-99 were located the crest and hill-site of south part of the basin (Figure 8). It can be easily seen that the amplifications at both sites are relatively higher than those at the base of the basin. This result is also significant at

the period distribution map (Figure 10) and in amplification map (Figure 11) given for microzoning proposes.

CONCLUSION

A number of ambient noise measurements conducted in the Yenisehir area were used to produce a fundamental period and an

amplification distribution map in the area. These maps allow to identify which buildings in this area could suffer more damages due to coincidence of the fundamental period of the soil and the fundamental period of vibration of the building. According to the amplification and period distribution maps, high rise buildings under construction at the area may suffer more when a destructive earthquake occurs at the surrounding region. Topography may play important role and amplify seismic motion much more relative to the base of a basin. It also has to be remembered that the results of such microzonation studies are intended for use by local authorities, city planners, and civil engineers whose technical background differ greatly. The H/V spectral ratio technique is very suitable when used in urban environment because of high noise level as suggested by Lachet et al. (1996) and it offers a fast, simple and economic method for seismic mitigation and earthquake planning especially at an urban environment or at a region with moderate or low seismicity.

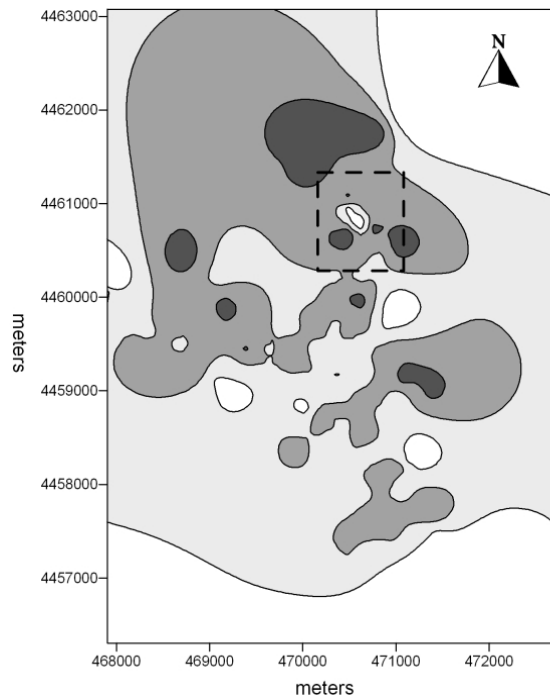


Figure 10. Short fundamental period distribution map

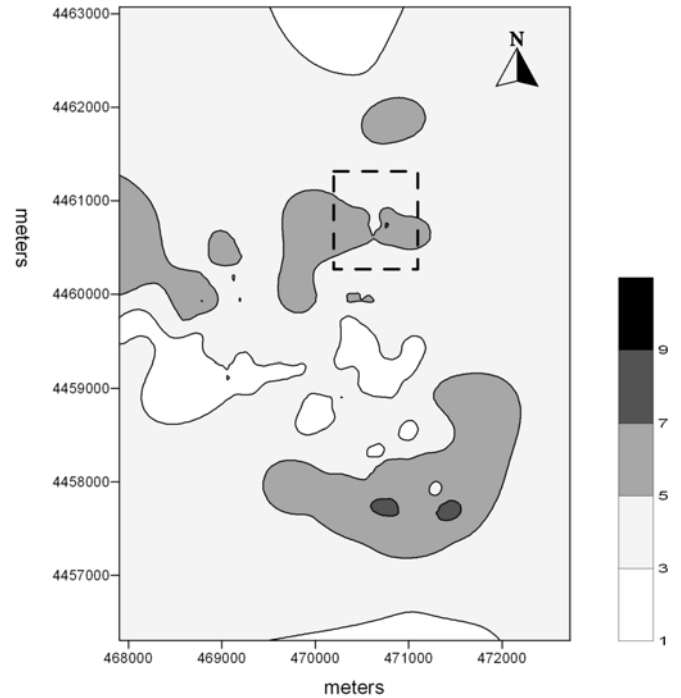


Figure 11. Map of amplification distribution at short fundamental periods

ACKNOWLEDGEMENTS

We thank to B. Hamdi Cingil, the mayor of Yenisehir and Sinan Süzgün from municipal department of technical service of Yenisehir for supports throughout the experimental work. We also thank to Dr. Murat Nurlu from Earthquake Research Department of General Directorate of Disaster Affairs for encouragement us during the study.

REFERENCES

- Aki K., 1988, Local site effects on ground motion, in *Earthquake Engineering and Soil Dynamics. II-Recent Advances in Ground Motion Evaluation*, J. L. Von Thun (editor), Geotechnical Special Publication no. 20, Am. Soc. Civil Eng., New York, 103-155
- Barambati E., Faccioli E., Carulli E., Culchi F., Onofri R., Stefanini R., Uloigrai F., 1980, *Studio de microzonizzazione sismica dell'are do Tarento (Friuli)*, Editio da Regione Autonoma Friuli-Venezia, Giulia
- Bard P. Y., 1999, Microtremor measurements: a tool for site effect estimation? State-of-the art paper, Second International Symposium on the

- effects of Surface geology on seismic motion, Yoklahama, December 1-3, 1998. Irikura, Kudo, Okada and Sasatani (Editors). Balkema 1999, 3, 1251-1279
- Celebi, M., 1987, Topographical and geological amplifications determined from strong motion and aftershock records of the 3 March 1985 Chile earthquakes, Bull. Seism. Soc. Am., 77, 4, pp 1147-1167
- Celebi M., 1991, Topographical and geological amplification case studies and engineering implications, Proceedings International Workshop on Spatial Variation of Earthquakes Ground Motion, Elsevier Science Publishers, B.V. Amsterdam.
- Cornou C., 1998, Etudes theoriques et numeriques sur la methode de Nakamura-Nogoshi. Memoire de Diplome d'Ingenieur, EOST Strasbourg-LGIT Grenoble, 132 pp (in French)
- Doyuran V., Kocyigit A., Yazicigil H., Karahanoglu N., Toprak V., Topal T., Suzen M. L., Yesilnacar E., Koray K. Y., 2000, Yenisehir Belediyesi yerlesim alani jeolojik-jeoteknik incelenmesi (in Turkish) (Proj no: 99-03-09-01-02), Orta Dogu Teknik Universitesi.
- Faccioli E., 1991, Seismic amplification in the presence of geological and topographic irregularities, Proceedings of the second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, St. Louis, Missouri, S, Prakash (editors), Univ. of Missouri-Rolla, 2, pp 1779-1797
- Finn, W.D., 1991, Geotechnical Engineering aspects of seismic microzonation, Proceedings of the Fourth International Conference on Seismic Zonation, August 25-29, Stanford, California, E.E.R.I. (editor), Oakland, I, pp 199-250
- Kagami, H., C.M. Duke, G.C. Liang and Y. Ohta, 1982, Observation of 1 to 5 second microtremors and their application to earthquake engineering. Part II. Evaluation of site effect upon seismic wave amplification due to extremely deep soil deposits, Bull. Seism. Soc. Am., No.72, pp.987-998.
- Kanai K., Tanaka T. 1954, On microtremors I, Bull. of the Earthquake Research Inst.32, 199-209
- Kanai K., Tanaka T. 1961, On microtremors VIII, Bull. of the Earthquake Research Inst. 39, 97-114
- Lachet C., Hatzfeld D., Bard P.Y., Theodulidis N., Papaioannou C., Savvaidis A., 1996, Site effects and microzonation in the city of Thessaloniki (Greece) comparison of different approaches, Bull. Seism. Soc. America (BSSA), 86\6\1692-1703
- Nakamura Y., 1989, A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface'' QR of RTRI, Vol. 30, No.
- Ohta Y., H. Kagami, N. Goto, and K. Sudo, 1978, Observation of 1 to 5 second microtremors and their application to earthquake engineering. Part I: Comparison with long-period accelerations at the Tokachi-Oki earthquake of 1968, Bull. Seism. Soc. Am., No.68.
- Omori F., 1908, On microtremors, Res. Imp. Earthq. Inv. Comm., Vol.6, pp.1-6.
- Pedersen H., LeBrun B., Hatzfeld M., Campillo M., Bard B.-Y., 1994, Ground motion amplitude across ridges, Bull. Seism. Soc. Am., 84, 1786-1800