SITE CHARACTERIZATION AND SITE AMPLIFICATION FOR A SEISMIC MICROZONATION STUDY IN TURKEY

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Abstract— **The pilot areas were divided into cells by a grid system of 500 m × 500 m for estimating the effects of site conditions at a scale of 1:5000 by assigning representative soil profiles at the centre of each grid. These soil profiles were classified according to the Turkish Earthquake Code, NEHRP site classification, equivalent shear wave velocity and used for site response analyses. The zonation maps involve the division of the area into three zones as (A, B, and C). In all cases, the variations of the calculated parameters are considered separately and their frequency distributions were determined. Thus the zone A shows the most unsuitable 33 percentile, zone B the medium 34 percentile and zone C shows the most favorable 33 percentile. A suitable parameter is considered to be the average spectral acceleration between 0.5-1.5 sec periods obtained from site response analysis. Even though more empirical, the spectral amplifications calculated using equivalent shear wave velocities gave consistent values that appear to be realistic when compared with the selected soil profiles. Thus microzonation maps with respect to ground shaking were based on the average of spectral accelerations and spectral amplifications obtained from equivalent shear wave velocities.**

Keywords—**Microzonation, site characterization, site response analysis, soil amplification**

INTRODUCTION

Seismic microzonation requires multi-disciplinary contributions as well as comprehensive understanding of the effects of earthquake generated ground motions on man-made structures. It can be considered as the process for estimating the response of soil layers under earthquake excitations and thus the variation of earthquake ground motion characteristics on the ground surface. The key issue affecting the applicability and thus feasibility of any microzonation study is the suitability and reliability of the parameters selected for zonation.

Microzonation studies were conducted in two pilot areas (1) Adapazarı and (2) Gölcük for testing the applicability of the proposed procedure developed mainly for land use and urban planning in Turkey [1, 2]. Researchers from Bogaziçi, Middle East Technical, and Sakarya Universities and Directorate of Disaster Affairs from Turkey, Institute of Geophysics and Institute of Geotechnical Engineering (IGT) of the Swiss Federal Institute of Technology in Zurich, Structural Engineering Institute of the Swiss Federal Institute of Technology in Lausanne, Studer Engineering from Switzerland, and World Institute of Disaster Risk Management participated in the project that was carried out in several partly simultaneous and partly consecutive phases.

The first phase involved the compilation of the available seismological, geological and geotechnical data that was previously obtained for different purposes.

The second phase of the study was the evaluation of the earthquake hazard for the microzonation study [3]. Both pilot areas were divided into 0.005° × 0.005° grid system to evaluate earthquake hazard parameters for each grid in terms of spectral acceleration ordinates. Since the major purpose for the microzonation study is to provide input for land use and urban planning it was decided to determine the required earthquake hazard parameters based on the Poisson model for a return period of 100 years that corresponds approximately to 40% probability of exceedance in 50 years.

The third phase of the study involved microtremor measurements in the pilot areas and interpretation of the results obtained [4].

The fourth phase of the study was the evaluation and analysis of the available geotechnical data to determine the necessary parameters for conducting the microzonation study. Both pilot areas were divided into grids to evaluate the representative soil profiles for each grid. Site response analyses were conducted for each grid using the acceleration spectra compatible simulated earthquake time histories obtained for each grid separately based on the seismic hazard study [5].

The fifth phase involved the evaluation of the liquefaction susceptibility [6] and landslide hazard [7] based on the results obtained in the fourth phase of the study.

The last phase involved the final evaluation of all the findings obtained from the studies conducted for specifying the microzonation maps with respect to ground shaking, liquefaction susceptibility and landslide hazard.

SITE CHARACTERIZATION

Both pilot areas were divided into 500 m × 500 m grids to evaluate the representative parameters for each grid by defining hypothetical boreholes located at the centre of the grids. A hypothetical borehole should be an idealized borehole, which will be the most representative for the soil conditions in the specific grid. In an ideal project, new site investigations might be conducted, almost in the centre of each of the grids.

Available existing data were taken into account for the identification of the local site conditions. Data were available from different sources for the two project areas, with varying degrees of reliability and quality. Thus this information should be treated with great care and a plausibility check of the available data is essential prior to carrying out the microzonation procedure. Nonetheless data from different sources should be taken into account if the quality appears to be acceptable so that it is possible to benefit from an independent view of the soil conditions in overall terms.

Several resources of site investigations were available. Additionally, some site investigations, mainly conducted after the earthquake of 1999, are reported in the literature or are published [8, 9, 10] or are available on the Internet [11]. The use of these data in terms of a definition of the representative boreholes, however promising, has not been possible because significant necessary information such as exact coordinates of the location of the site investigations, topographical conditions, depth of ground water table, information about the site investigation techniques, etc. has not been available. These data have already been interpreted, and only the essence of the results of the original soundings is given in the publications. Thus, they can be used for comparison and for checking plausibility only but they cannot be used as basic data for the microzonation study.

Mainly two sources of data have been used for the pilot study. The first, the most reliable source were data sheets of existing and new boreholes based on drilling work, SPT and CPT data, and some additional laboratory tests summarized by Prof. A.Önalp from Sakarya University. The second source was the data files of the General Directorate of Disaster Affairs (GDDA), which were transformed into a database at the DRM local office by Dr. Köksal. The second source included some of the data available from the first source, but also soundings, which have been used as a base for other publications, and of other origins. The reliability, the density and the quality of the information when compared with the first source were somewhat variable. Thus the overall quality of this database was difficult to judge and sometimes it would have been easier to conduct new soundings.

In total there were 120 sets of data for Adapazarı and 97 sets for Gölcük, which were available from Sakarya University. Additionally 22 (Adapazarı) and 6 (Gölcük) CPT loggings were available, but without further drilling information. Not all of these data sets cover a single 500m x 500m grid point.

Locations of all the boreholes are shown on the geological map in Fig. 1 for the Adapazarı region. Almost all of the area was classified as an alluvium deposit. As can be observed from this figure in some cases, there is more than one borehole available for each grid. Other grids of the original pilot study area were not covered.

306 data sets were available in the database of GDDA in total for Adapazarı, while 66 turned out to be similar sets of boreholes, which already have been received from Sakarya University but with reduced information. 260 sets were included for the Gölcük area. The variation of the information was crucial. For some of the boreholes, a similar amount of data to that given by Sakarya University was available. For other locations, only limited and very simplified information was given.

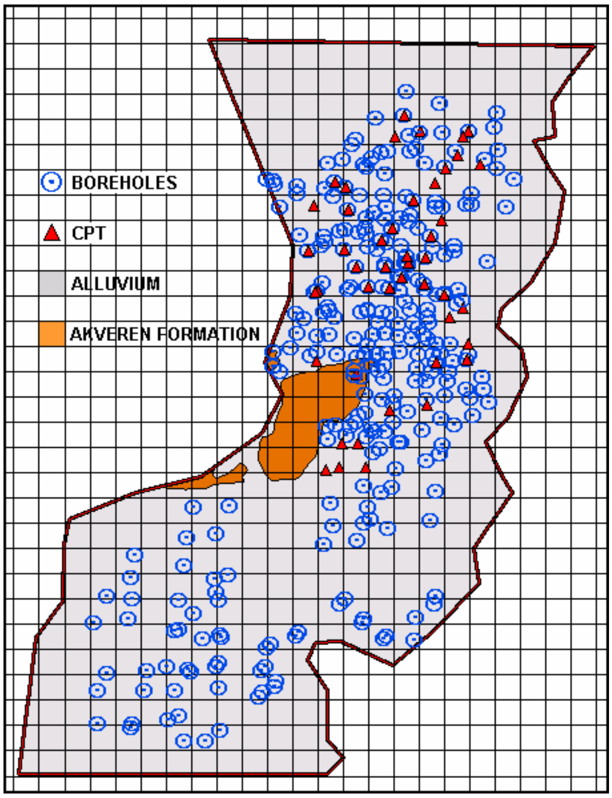

Fig. 1: Locations of available boreholes in Adapazari

Data consistency and choice of representative boreholes

All of the available data about the borehole information available for each location has been checked first for consistency. Secondly data from each grid has been compared. Thirdly, a representative borehole has been chosen.

Representative boreholes have been chosen for each grid close to the available existing data. Layer simplification and choice of the representative borehole has been carried out based on engineering judgment. It should not be forgotten that these representative boreholes have been chosen for the microzonation study and not for any other purpose (e.g. replacing site investigation for new buildings).

All representative data has been transmitted in graphical format, which can be transferred into the database. The graphical format allows an easy overview of the data to be used in the next steps of the microzonation project. In addition, a graphical sheet forces further users to be confronted with comments on reliability and the details of the background of data. Also, further users of the hypothetical boreholes are directed to the original borehole numbers and the respective database.

Fig. 2 shows an example where good correlation could be found among the existing boreholes and Fig. 3

shows the opposite. Here, three different boreholes could be established within one grid. A river valley could be identified crossing the grid. The slopes on both sides show different topsoil layers. In such cases, the representative borehole has been chosen by means of topographic maps as well as the distribution of soils in the neighboring grids.

Using existing data offers a good opportunity to start a microzonation project without spending too much money on additional data derivation. Nevertheless, this has to be done with great care and knowledge of the local soil conditions. Thus some of the decisions taken by IGT for the two project areas, in terms of the choice of the hypothetical boreholes and their interpretation, might be questionable for local geotechnical engineers, but will be exact enough to fit the purpose of the microzonation study for the project areas and to give examples for future users.

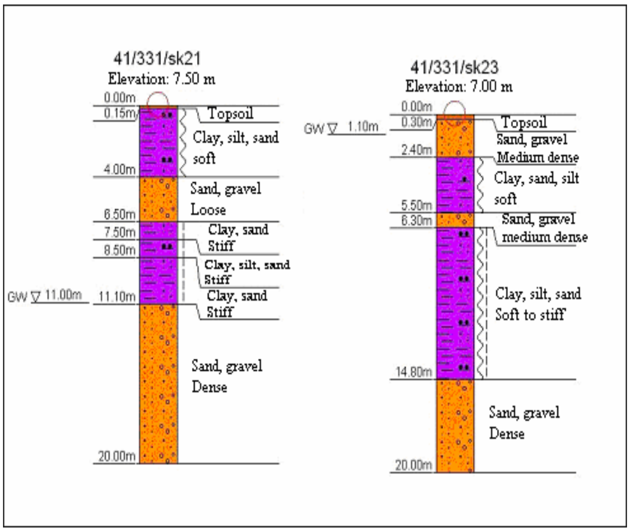

Fig. 2: Two different available boreholes for grid P4 Gölcük

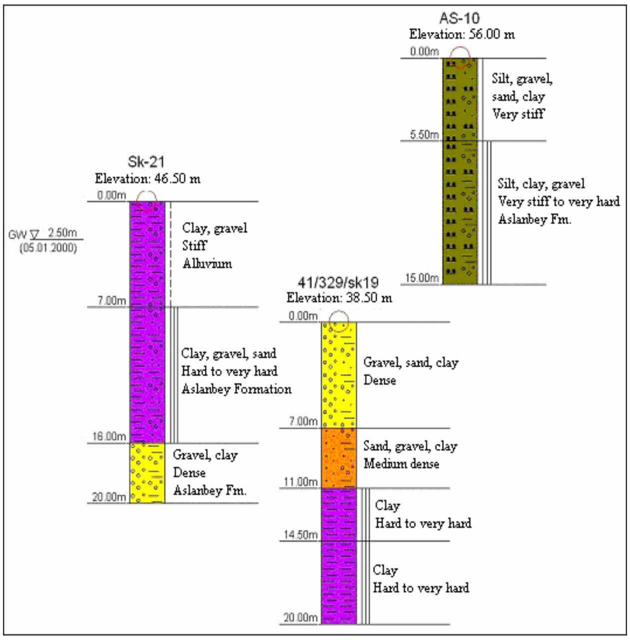

Fig. 3: Three different boreholes for grid J6 in Gölcük

Site Classification

The site classification is based on the use of the Turkish Code [12] and the NEHRP [13] approach. The boundary information needed for both procedures are the local soil conditions and, in particular the distribution of shear wave velocities in the topmost 30m. To conduct this part in a structured manner, firstly the shear wave distribution in the upper layers has been established.

Several procedures can be used to establish the shear wave velocity (v_S) distribution with depth. Aside from measurements in the borehole, which were only available very rarely, several empirical correlations between SPT and CPT data and shear wave velocity can be used. Different methods have been studied in comparison. This comparison included mainly correlation with CPT results, measured data from, linear extrapolation of known data, and SPT correlations [14]. As a result, the correlation of the shear wave velocity with the SPT values seemed to offer the best fit and it has been decided to choose one of these methods. The results of this comparison are not shown and nor are they discussed here in detail due to space restrictions. Fig. 4 gives an example of the differences in the resulting velocities. The Iyisan method [14], developed based on local data sets and local testing methods, was used for the pilot study. This relationship is valid for all soil types to estimate shear wave velocity from SPT tests:

$$v_S = 51.5\, N^{0.516} \qquad (1)$$

where N is uncorrected SPT blow counts for 30 cm.

The shear wave velocity profiles for the hypothetical boreholes were estimated from borehole measurements for shear wave velocity (Seismic Profile or SCPTU) if available. If no shear wave measurements were available, Eq. (1) is used to estimate the shear wave velocities based on SPT blow counts. Usually, the test results were available only for the upper layers so that the deeper layers had to be correlated with the SPT values.

As further procedure requires constant shear wave velocity for layer of predefined thickness, a medium value has been chosen for each layer. Idealizations and assumption have to be made for certain situations.

If the SPT profile is not available for the last layer, it was linearly extrapolated for this last layer up to a depth of 30m below surface. In most cases, this extrapolation was constant for fine-grained soils. A slightly increasing shear wave velocity distribution was chosen for coarse-grained material. The soil type of the unknown layer was adopted from the last known layer of the borehole profile.

If the SPT profile is not available for the top layer (i.e. fill or topsoil layer), an assumption of the shear wave velocity of 100 m/s was made.

If no SPT results were available only in one intermediate layer, a correlation with the existing measurement data seemed appropriate.

If no SPT test results are available, which is always the case for interpolated boreholes, a correlation between the soil type and the existing v_S measurements with depth was used. This correlation works well for the soil types clay, silt and sand. No measurements have been available for gravel so that an assumption has to be made.

The shear wave distribution has to be determined for the topmost 30m or up to bedrock or competent layer. The value of the shear wave velocity for the competent layer was chosen to be v_S = 700 m/s. Therefore shear wave velocities were interpolated to define the depth of the competent layer.

Site classification according to the Turkish Code is based on a two-step procedure. The Code subdivides the classification in two areas. Initially the soil group A-D has to be determined so that a local site class can be derived. It is clear that there are 4 different possibilities for identifying the soil group, which are all equivalent. In terms of comparability of the results of the classification, it has to be decided before the beginning of the classification to follow a certain sequence of decisions. For the pilot studies, it has been decided to focus on SPT – values first and use the shear wave velocities only if there are no SPT values available. The second classification of the Turkish Code "site class" correlates the soil group with the expansion of the different layers in the topmost 30m.

Site Response Analysis

The site response analysis determines the main frequencies and amplification that the surface of the ground will experience. There are several ways of achieving this, including simple empirical methods using analogies given in Codes. A more sophisticated method has been chosen for this project, based on a one dimensional analysis, in which an earthquake input motion is introduced at a competent soil or rock outcrop from where the waves are permitted to travel vertically up through the soil column [16].

Some assumptions have to be made for the analysis. As described previously, only a few of the grids show a competent layer in the topmost 30m. Thus, data from the literature had to be taken into account to derive the soil strata up to the competent layer. It was only necessary to represent the soil profile between 30 m and the competent layer with the selected shear wave velocity distribution.

When no site-specific soundings are available to identify the competent layers, geophysical methods have to be used. Results of array measurements conducted and described in [17] were used here where average shear wave velocities over larger areas of soil up to bedrock were given. Two stations reported for both of the pilot areas are in the area of interest. In Gölcük, the stations GLF and GLH are the stations located in the pilot area, where the stations are ADC and ADU in Adapazarı. The shear wave velocities were given in average value for these stations. After the depth at which a value of v_S = 700 m/s has been reached, a linear increase of v_S was assumed in order to derive the depth of the competent layer, so that the shear wave velocity profile with depth could be linearly interpolated between two layers to reach the competent layer.

The allocation of the two stations to each grid in the pilot areas has been done based on the results of the microtremor measurements [5].

The zones determined where relatively constant fundamental frequencies may be found, could be correlated with one of the stations previously described by [17], so that each grid could be related to one of the stations. Thus a shear wave velocity profile could be established up to the competent layer.

Spectrum compatible simulated acceleration time histories that were generated for each grid [3] based the procedure suggested by [18, 19] were used for conducting site response analysis. The Microzonation Manual [2] is recommending using a minimum of three different simulated acceleration time histories for each grid for site response analyses so that the average of the calculated response parameters can be used for microzonation. Since the main purpose of the study was to demonstrate the proposed procedure, only one simulated acceleration time history calculated separately for each grid was used for site response analyses.

The hypothetical borehole was introduced for each grid as the soil profile, including the extension up to competent layer. In case of mixed layers, the softer layer has been chosen as the representative one.

The shear wave velocity distribution has to be included for each of the materials. In addition, the strain dependency of the material properties has to be allocated to each soil. 8 different material types were used in the site response analysis with different dynamic shear modulus and damping ratio degradation with the shear strain amplitude as given by [20, 21].

Seismic Microzonation for Ground Shaking

The final stage of the microzonation involved interpretation and assessment of all the available results obtained from the different phases of the study to finalize the microzonation maps in the selected pilot areas. There were basically two reasons behind the grid approach adopted for evaluating and interpreting the effects of site conditions on the ground motion at the free field. (1) to utilize all the available data in each grid in order to have more comprehensive and reliable information about the soil profile; (2) to eliminate the effects of different distances among boreholes or site investigation points during the GIS mapping. The results obtained were mapped using GIS techniques by applying linear interpolation among the grid points, thus enabling a smooth transition of the selected parameters. Soft transition boundaries are preferred to show the variation of the mapped parameters. More defined clear boundaries were not used and are not recommended due to the accuracy of the study. This allows some flexibility to the urban planners and avoids misinterpretation by the end users that may consider the clear boundaries as accurate estimations of the different zones.

The initial boundaries of the pilot areas were the official boundaries of the cities considered in the pilot areas.

However, since there were no boreholes or in-situ tests mostly in the outer grids, it was decided to modify the boundaries of the both regions as shown in the following maps for microzonation study to avoid the need for additional extrapolation that may not be very reliable.

The zonation map for site conditions with respect to Turkish Earthquake Code is shown in Fig. 4. The majority of the area is classified as Z3 or Z4 indicating the dominance of loose and soft alluvial deposits in the area.

The approach adopted in the assessment of the calculated zonation maps involves the division of the area into three zones as (A, B, and C). Since the site characterizations, as well as all the analysis performed, require various approximations and assumptions, it was preferred not to present the numerical values for any parameter. In all cases, the variations of the calculated parameters are considered for each area separately and their frequency distributions were calculated. Thus the zone A shows the most unsuitable 33 percentile (e.g. low equivalent (average) shear wave velocities, high spectral accelerations or high spectral amplification), zone B the medium 34 percentile and zone C shows the most favorable 33 percentile (e.g. high average shear wave velocities, low spectral accelerations or low spectral amplifications).

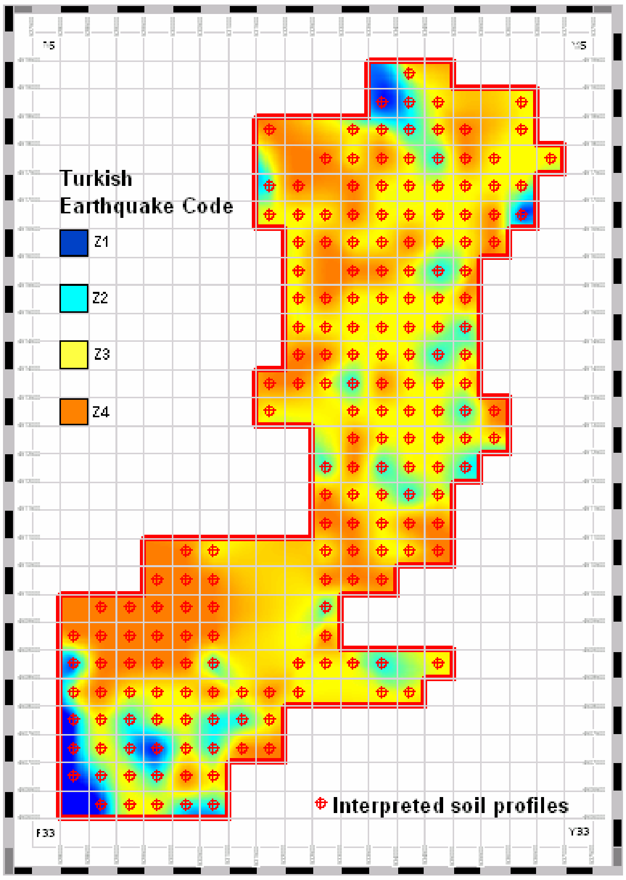

Fig. 4: Site Classification according to the Turkish Earthquake Code for Adapazarı

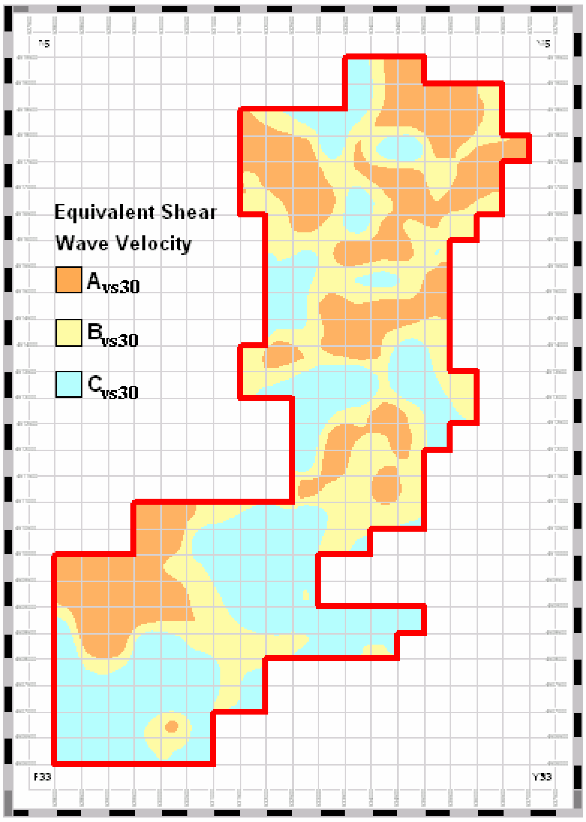

Fig. 5: Zonation with respect to equivalent shear wave velocity for Adapazari

One alternative to determine the effects of soil layers is to use the equivalent shear wave velocity that is defined as the weighted average of shear wave velocities of soil and rock layers in the upper 30 meters. Equivalent shear wave velocities are being used in earthquake codes for the purpose of evaluating the earthquake characteristics on the ground surface [22, 23, 24].

The variation of equivalent shear wave velocity for the Adapazarı region is shown in Fig. 5 as described above in terms of three zones. The zone A_{vs30} shows the lower 33, zone B_{vs30} shows the medium 34, and zone C_{vs30} shows the higher 33 percentiles with respect to equivalent shear wave velocities.

The basic intention in assessing the ground shaking intensity is to estimate the effects of local site conditions. Thus it would be logical to base this decision on all the available results from site identifications based on equivalent shear wave velocity, site response analysis as well as from microtremor measurements conducted in the region. In the case of site response analysis, a suitable parameter is considered to be the average spectral acceleration between 0.5-1.5 second periods based on the consensus reached among the project participants.

The zonation with respect to average spectral accelerations was mapped in accordance with the relative mapping in terms of three zones. A_s shows the regions with higher 33, B_s shows the regions with medium 34, and C_s shows the regions with lower 33 percentiles with respect to average spectral accelerations (Fig. 6).

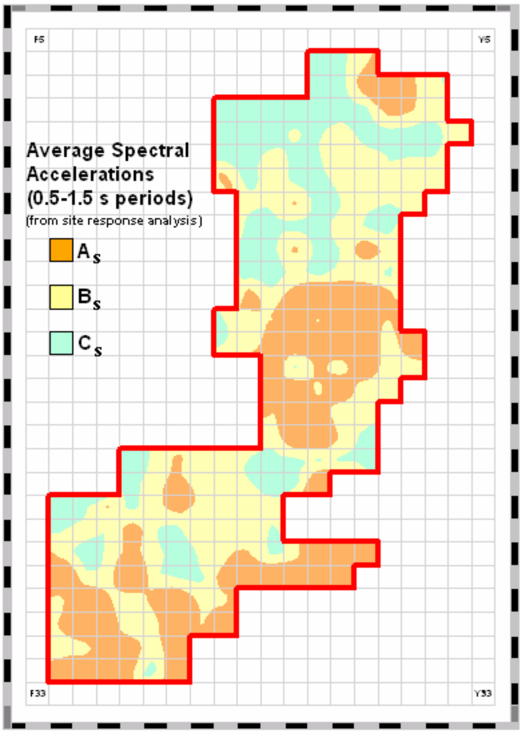

Fig. 6: Zonation with respect to average spectral accelerations calculated by site response analysis for Adapazari

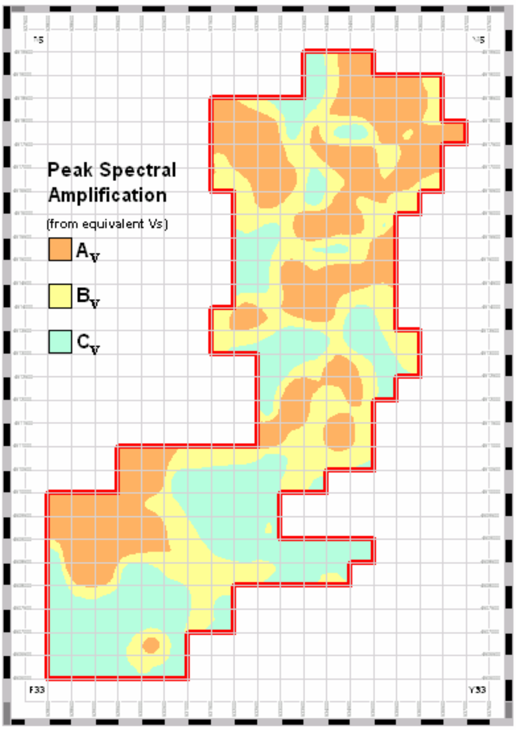

Fig. 7: Zonation with respect to spectral amplification calculated from equivalent shear wave velocity for Adapazarı

The peak spectral amplifications based on equivalent shear wave velocity were calculated using the empirical relationship given by [25];

$$A_K=68\ v_S^{-0.6} \qquad (2)$$

where A_K is the spectral amplification and v_S is the equivalent shear wave velocity. The peak spectral amplifications calculated from Eq. (2) were evaluated and the variations were also mapped, as in the case of average spectral accelerations obtained by site response analyses.

The zonation with respect to peak spectral amplifications calculated using equivalent shear wave velocities, was mapped in accordance with the relative mapping in terms of three zones. A_v shows the regions with higher 33, B_v shows the regions with medium 34, and C_v shows the regions with lower 33 percentiles with respect to peak spectral amplifications (Fig. 7).

Even though it is generally accepted that H/V ratios obtained from microtremor records would not lead to very reliable spectral amplification values [26, 27], they can still be taken into consideration when finalising the microzonation with respect to site amplification. Therefore, the results obtained from the microtremor study were utilised to map the variation of the spectral amplifications only for Adapazarı region, since the number of microtremor measurements were very limited in the Gölcük pilot area. The results of the microtremor studies are plotted only for comparison purposes, original measurement locations were used at the mapping stage, neglecting the effects of the spacing between the measurement points.

The zonation with respect to peak spectral amplifications calculated from H/V ratios obtained from the microtremor study was mapped in accordance with the relative mapping in terms of three zones. A_m shows the regions with higher 33, B_m shows the regions with medium 34, and C_m shows the regions with lower 33 percentiles with respect to peak spectral amplifications as given in Fig. 8.

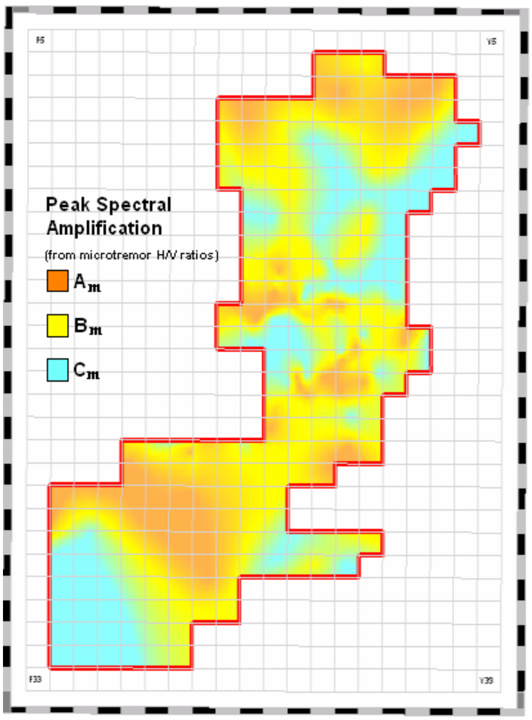

Fig. 8: Zonation with respect to spectral amplification from microtremor H/V ratios for Adapazarı

The final mapping with respect to ground shaking can be accomplished by comparing the average spectral accelerations obtained by site response analyses with the peak spectral amplifications calculated using equivalent shear wave velocity. In order to make this comparison, the results obtained from both approaches are shown in a consecutive order for Adapazari area.

As can be seen from these maps, there are similarities and differences. After studying the soil profiles and site classifications, it was observed that the site amplifications were relatively high and at others the peak ground accelerations were very low based on the site response analyses. The site response analysis, whether it is conducted by EERA [16] or Shake [28], would sometimes give unrealistically high spectral amplifications or very low peak ground acceleration values depending on the thickness of the deposit, estimated initial shear moduli, and also on the characteristics of the input acceleration time histories. On the other hand, even though they are more empirical, the spectral amplifications calculated using equivalent shear wave velocities tend to give more consistent values that appear to be more realistic when compared with the selected soil profiles.

It was decided to establish the ground shaking microzonation map taking into consideration both average spectral accelerations obtained from site response analyses and peak spectral amplifications calculated from equivalent shear wave velocities.

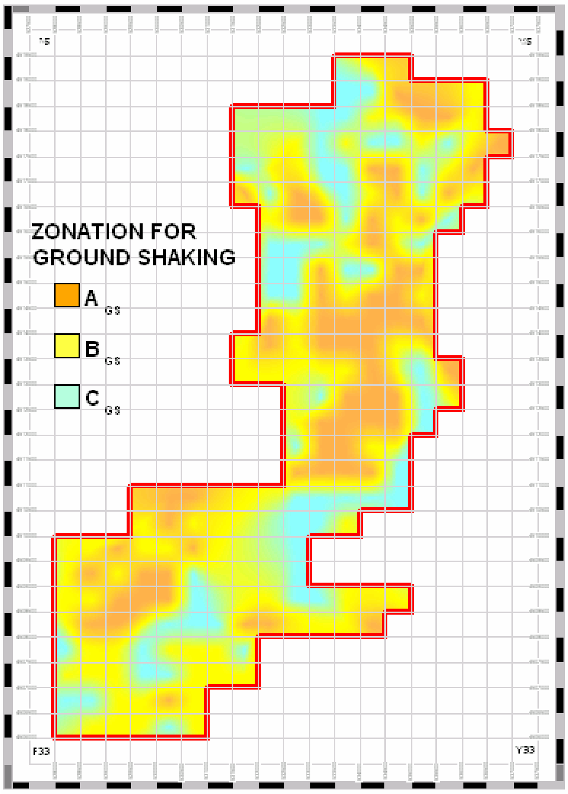

Fig. 9: Ground shaking microzonation map for Adapazarı when overlapping zones are determined for each grid from average spectral acceleration map obtained from site response analysis and peak spectral amplification map calculated from equivalent shear wave velocity

Since both zonation maps (Fig. 6 and Fig.7) were divided in to three zones, it was also essential to have three zones again in the final ground shaking microzonation map where A_{GS} shows the areas with higher ground shaking and C_{GS} shows the areas with lower ground shaking potential. The zone A_{GS} corresponds to overlapping zones of A_S and A_V or A_S and B_V or B_S and A_V. The zone B_{GS} corresponds to overlapping zones of A_S and C_V or C_S and A_V or B_S and B_V. The zone C_{GS} corresponds to overlapping zones of B_S and C_V or C_S and B_V or C_S and C_V obtained from both approaches.

The assessment for each grid was performed numerically by adopting the above criteria to determine the three zones and then perform the mapping using the new data. The resulting map obtained is shown in Fig. 9.

CONCLUSIONS

In seismic microzonation the variation of earthquake ground motion is studied taking into account the earthquake source and path characteristics as well as geological and geotechnical site conditions in a probabilistic manner. Due to the damage distributions observed during past earthquakes, it became evident that earthquake zonation maps prepared at small scales do not yield the necessary information for risk mitigation at a city level. With the increase in the analytical, in-situ and laboratory investigation capabilities, there has been significant increase in the accumulated databases concerning the regional geological formations, earthquake source mechanisms, seismic activity and earthquake ground motion records. In the light of these scientific and technical advances, it became possible and feasible to conduct seismic zonation studies at regional and microzonation at local levels with continuously increasing scales [29, 30]. The main objective is to estimate more accurately the ground motion characteristics during possible earthquakes taking into account all the main controlling factors.

Within the framework of the pilot microzonation studies conducted for Adapazar and Golcuk regions, a methodology is developed for adoption as a guideline for seismic microzonation investigations in Turkey [30]. The proposed methodology is based on the regional estimation of the earthquake hazard, detailed investigation of geological and geotechnical site conditions and analysis of the ground motion characteristics based on a grid layout.

The seismic microzonation for ground shaking was conducted as a part of the case study for Adapazarı region based on the average of average spectral accelerations and peak spectral amplifications calculated from site response analyses and equivalent shear wave velocities. Even though the peak spectral amplifications calculated from microtremor H/V ratios are not considered very reliable, they seem to agree with the ground shaking zonation map in the case of Adapazarı, thus supporting the decision to use the average of average spectral accelerations and peak spectral amplifications as the zonation criteria for the ground shaking microzonation maps.

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REFERENCES

[1] A.Ansal, S.Springman, J.Studer, E.Demirbaş, A.Önalp, M.Erdik, D.Giardini, K.Şeşetyan, M.Demircioğlu, H.Akman, D.Fäh, A.Christen, J.Laue, J.Buchheister, Ö.Çetin, B.Siyahi, Y.Fahjan, P.Gülkan, S.Bakir, P.Lestuzzi, M.Elmas, D.Köksal1, and O.Gökçe, "Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere", Research Task Group Report, World Institute for Disaster Risk Management project on Microzonation for Earthquake Risk Mitigation, 2003.

[2] J. Studer and A. Ansal "Seismic Microzonation for Municipalities, Manual" Research Report for Republic of Turkey, Ministry of Public Works and Settlement, General Directorate of Disaster Affairs prepared by World Institute for Disaster Risk Management, Inc., 2003.

[3] M.Erdik, K.Şeşetyan, M.Demircioğlu, B.Siyahi and H.Akman, "Assessment of the Seismic Hazards in Adapazarı, Gölcük, Değirmendere and İhsaniye Provinces in Northwestern Turkey", in *Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere*, Ch. 3, 2003.

[4] D.Fäh, A.Christen, Ü.Gülerce, and C.Greifenhagen, "Single-station ambient vibration measurements and interpretation for the cities of Adapazarı and Gölcük, Turkey", in *Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere*, Ch. 4, 2003.

[5] J.Laue, J.Buchheister, and S.M.Springman, "Geotechnical Site Characterisation" and "Site Response Analyses", in *Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere*, Ch. 5 and 6, 2003.

[6] K.Ö.Cetin, "Seismic Soil Liquefaction Assessment Methodologies", in *Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere*, Ch. 7, 2003.

[7] B.Siyahi and Y.Fahjan, "Landslide Hazard", in *Part 2C-Case Studies, Microzonation of Pilot Areas, Adapazarı, Gölcük, İhsaniye and Değirmendere*, Ch. 8, 2003.

[8] T.L.Youd, J.P.Bardet, and J.D.Bray, Eds, *Earthquake Spectra*, Supplement A to Vol. 16, 1999 Kocaeli, Turkey Earthquake Reconnaissance Report, 2000.

[9] A.Ansal, Ed. *Lessons Learned from Recent Strong Earthquakes,* Proceedings of Earthquake Geotechnical Engineering Satellite Conf., Chamber of Civil Engineers, Istanbul Section, 2001.

[10] M.N.Toksoz, Ed. *The Izmit Earthquake of 17 August 1999*, Bulletin of Seismological Society of America, Vol. 92, No. 1, 2002.

[11] *Documenting Incidents of Ground Failure Resulting from the August 17, 1999 Kocaeli, Turkey Earthquake*, http://peer.berkeley.edu/

[12] *1997 Turkish Earthquake Resistant Design Code*, Ministry of Public Works and Settlement, Government of Republic Turkey "Specification for Structures to be Built in Disaster Areas" English Translation, Kandilli Observatory and Earthquake Research Institute http://www.koeri.boun.edu.tr/depremmuh/.

[13] BSSC-Building Seismic Safety Council, "NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for Seismic Regulations for new buildings and other structures", 2000 Edition, Part 1: Provisions (FEMA 368), Ch. 4, BSSC Washington, D.C., 2001.

[14] B.S.Bakır, H.Sucuoğlu, and T.Yılmaz, "An Overview of Local Site Effects and the Associated Building Damage in Adapazarı during the 17 August 1999 İzmit Earthquake", *Bulletin of the Seismological Society of America*, Vol. 92, No.1, pp.509-526, 2002.

[15] R.Iyisan (1996) "Correlations Between Shear Wave Velocity and In-situ Penetration Test Results". *Technical Journal of Turkish Chamber of Civil Engineers*; Vol. 7 No. 2, pp.1187-1199 (in Turkish).

[16] J.P.Bardet, K.Ichii, and C.H.Lin, (2000) "EERA, A computer program for Equivalent linear Earthquake site Response Analysis of layered soils deposits", University of Southern California, Los Angeles, 2000.

[17] K.Kudo, T.Kanno, H.Okada, O.Özel, M.Erdik, T.Sasatani, S.Higashi, M.Takahashi, K.Yoshida, (2002) "Site-specific issues for strong ground motions during the Kocaeli, Turkey, earthquake of 17 August 1999, as inferred from array observations of microtremors and aftershocks", *Bulletin of Seismological Society of America*, Vol. 92, pp. 448-465, 2002.

[18] G.Deodatis, "Non-stationary Stochastic Vector Processes: Seismic Ground Motion Applications", *Probabilistic Engineering Mechanics* Vol.11, pp.145-168, 1996.

[19] A.Papageorgiou, B.Halldorsson and G.Dong, "Target Acceleration Spectra Compatible Time Histories", University of Buffalo, Dept. of Civil, Structural and Environmental Engrg., NY, 2000, http://civil.eng.buffalo.edu/engseislab/.

[20] H.B.Seed and I.M.Idriss, "Soil Moduli and Damping Factors for Dynamic Response Analyses", Report No: EERC 70-10, EERC, University of California, Berkley, 1970.

[21] M.Vucetic, and R.Dobry, "Effect of soil plasticity on cyclic response", *Journal of Geotechnical Engineering, ASCE*, Vol.117, No.1, pp.89-107, 1991.

[22] I.A.Beresnev and G.M.Atkinson, "Shear Wave Velocity Survey of Seismographic Sites in Eastern Canada: Calibration of Empirical Regression Method of Estimating Site Response", *Seismological Research Letters*, vol. 68, pp.981-987, 1997.

[23] R.D.Borcherdt, "Estimates of Site Dependent Response Spectra For Design (Methodology And Justification)" *Earthquake Spectra*, Vol. 10, No. 4, pp. 617-654, 1994.

[24] W.B.Joyner and T.Fumal, "Use of Measured Shear-Wave Velocity For Predictive Geological Site Effects On Strong Motion", *Proceedings of the 8th World Conf. on Earthquake Engineering*, Vol. 2: pp.777-783, 1984.

[25] S.Midorikawa, "Prediction of Isoseismal Map in the Kanto Plain due to Hypothetical Earthquake", *Journal of Structural Eng*. 33B, 43-48, 1987.

[26] Bard P.Y. "Microtremor Measurements: A tool for site effect estimation?" *Proceedings of 2nd Int. Symp. on the Effect of Surface Geology on Seismic Motion*, Japan, 1998.

[27] C.Lachet, and P.Y.Bard, "Numerical and Theoretical Investigations on the Possibilities and Limitations of Nakamura's Technique", *Journal of Phys. Earth*, Vol. 42, pp.377-397, 1994.

[28] P.B.Schnabel, J.Lysmer, and H.B.Seed, "SHAKE – A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites", Report No. EERC 72-12, UC Berkeley, 1972.

[29] C.Lachet, Hatzfeld, D., Bard, P.Y., Theodulidis, N., Papaioannou, C. & Savvaidis, A. (1996) "Site Effects and Microzonation in the City of Thessaloniki-Comparison of Different Approaches", *BSSA*, (86)6:1692-1703.

[30] A.Marcellini, Bard, P.Y., Iannaccone, G., Meneroud, J.P., Mouroux, P., Romeo, R.W., Silvestri, F., Duval, A.M., Martin, C. & Tento, "The Benevento Seismic Risk Project. II- The microzonation", *Proc. 5th International Conference on Seismic Zonation,* Nice, France, Vol. 1, pp.810-817, 1995.