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Evaluation of Küçükçekmece Region with respect to soil amplification

L'évaluation de la région de Küçükçekmece conformément à l'amplification du sol

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ABSTRACT
In this study, the local soil conditions at Küçükçekmece-Sefaköy regions in Istanbul are investigated and a microzonation study is carried out with respect to soil amplification in accordance with the new Microzonation Manual (MERM, 2003). Within the framework of a project implemented for investigation of the region with respect to suitability for settlement, the geological and tectonic characteristics of the region were investigated with the aid of soil exploration borings. In order to be able to investigate the effects of local soil conditions on the dynamic behavior, one dimensional site response analysis are performed with the computer code EERA by utilizing the findings of field and laboratory investigations. The outcomes of the numerical analyses and emprical equations are processed by GIS techniques in order to produce microzonation maps in terms of soil amplification.

RÉSUMÉ
Dans cette étude les conditions de sol local de Küçükçekmece-Sefaköy à İstanbul sont analysées et l'étude de microzonation est focalisée conformément à l'accordance à l'emplification du sol avec la nouvelle Microzonation Manuel (MERM, 2003). Dans le cadre d'un projet implémenté pour la recherche de la région, les caractéristiques techtonique et géologique de l'installation de la région sont étudiées à l'aide d' un sondage du sol. Pour la faisabilité de la recherche des effects dynamiques des conditions du sol local, une analyse de variabilité de dimension du site est effectuée avec un code informatique EERA en utilisant les résultats de terrain et des analyses de laboratoires. Les résultats des analyses numériques et une équation sont effectuées avec la technique GIS pour la production de la carte de microzonation dans le cas de l'amplification du sol.

1 INTRODUCTION

Seismic microzonation studies involve defining the parameters which are used for land use and city planning and their variation in the investigated region. During the last decade, both the increase in the availability of experimental and instrumental data and the developments in the seismic ground amplification analysis methods have led to significant developments in microzoning studies. Study of the damage distribution and strong motion records after the recent major earthquakes have shown that seismic source and local site conditions (proximity to the fault, rupture direction, duration, surface and subsurface topography, nonlinear soil behavior, etc.) are very important. On the other hand, in the assessment of the earthquake hazard in a specific site or region, the use of probabilistic methods which account for all the uncertainties in earthquake occurrences that may arise due to different earthquake source mechanisms, is considered to be a more realistic approach.

In this study, a seismic microzonation study was carried out for Küçükçekmece and Sefaköy regions in İstanbul, Turkey, with respect to soil amplification, in accordance with the Seismic Microzonation Manual prepared by World Institute for Disaster Risk Management (DRM) in order to evaluate and assess the probable effects of an expected Marmara earthquake in the Küçükçekmece and Sefaköy regions in western Istanbul. The stages of the seismic microzonation study performed can be summarized as the following:

1. Within the framework of a project implemented for the investigation of Küçükçekmece region with respect to suitabilitiy for settlement, the geological and tectonic characteristics of the area are determined and the geotechnical properties of the local soil conditions were investigated through a large number of soil exploration borings and laboratory testing. Additionally, the findings of geophysical surveys and microtemor measurements were also utilized for the assessment of seismic behavior of soil profiles encountered in the study area.
2. The earthquake hazard is evaluated in regional scale and regional earthquake hazard parameters are determined by KOERI (Kandilli Observatory and Earthquake Research Institute) for the return period of 475 years which correspond to 10% probability of exceedance in 50 years.
3. In order to be able to evaluate and analyze the available geotechnical data, the research area is divided into approximately 250mx250m grids. For each grid representative soil profiles are determined and site classifications according to Turkish Earthquake Code, NEHRP (BSSC, 2001) and equivalent shear wave velocities are assigned.
4. Simulated earthquake time histories compatible with the so called " Uniform Hazard Response Spectrum" (NEHRP, 1997) are obtained by utilizing TARSCHTS (2000) computer code for each grid from the spectral acceleration values at 0.2 seconds and 1.0 second resulting from the probabilistic seismic hazard analysis for return period of 475 years.
5. One dimensional (1-D) dynamic site response analyses are performed by using the computer code EERA (2000), and the simulated earthquake time histories. As a result of the site response analyses, peak ground accelerations, spectral accelerations and soil amplifications at the ground surface are determined for each grid.
6. Zonation maps with respect to soil amplification are produced using GIS mapping procedure with the overall evaluation of the outcomes determined from the study.

2 THE GEOLOGY OF THE REGION

Within the scope of investigations carried out at Küçükçekmece and Sefaköy districts for their suitability for settlement, geological maps of the area at 1:5000 and 1:1000 scales were prepared. The geological map of the study area (Yıldırım ve Savaşkan, 2002) and a general geological cross-section through the area are shown in Figure 1 and Figure 2, respectively. The formations outcropping in the area start with the lithologies belonging to Middle Eocene Kırklareli formation. This formation rests unconformably on the "graywacke" sequences of Trakya formation (Carboniferous) and is composed of limestone and argillaceous limestone. The formation is relatively strong and thus may form steep valley slopes. At its base, it starts with a cream–white, locally loosely cemented, sometimes carbonaceous basal conglomerate, and continues upward with thinly to medium bedded, occasionally thickly bedded, karstic, compact limestone. Further upward, the sequence, which is horizontal to slightly dipping, becomes argillaceous limestone and marl with gradually increasing clay content. Kırklareli formation is overlain by younger deposits of Upper Oligocene–Upper Miocene, which are quite widespread in the area. These start with sand and gravel, gray–cream in color, and continue upward uninterruptedly with green, thinly to medium bedded, horizontal to slightly dipping, overconsolidated clay, and interbedded clay and sand layers (Yıldırım and Savaşkan, 2002 and 2003). In the upper levels (Upper Miocene) of the sequence, granular lenses, and organic, soft to medium stiff clay lenses respectively named Çukurçeşme and Güngören formations are encountered. The uppermost level of the deposition, called Bakırköy formation, is characterized by mactra-bearing, argillaceous limestone interbedded with clay and fine sand.

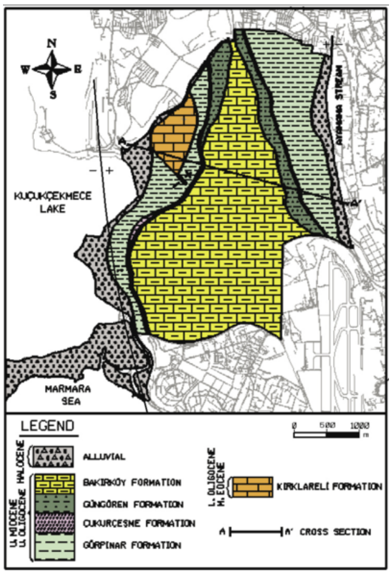

Figure 1. The geological map of the region

2.1 *Geotechnical parameters*

The variation of soil parameters which were determined through the soil investigations undertaken in the area and the laboratory tests carried out on the samples recovered from the site are summarized in Table 1. The nature of the fill and alluvial deposits appear to change locally. While the fill and alluvial soils near Küçükçekmece Lake on the West are classified as GM-GC and SM-SC, the fill and alluvial deposits near Ayamama River on the East are classified as CL. The undrained shear strength (c_u) values determined from the unconfined compression tests and UU triaxial compression tests conducted on undisturbed samples recovered from Güngören and Gürpınar formations, uniaxial compressive strength values (q_c) determined from point load tests and compressive strength values (q_t) obtained from uniaxial compression tests executed on samples recovered from Kırklareli and Bakırköy rock formations are given Table 2.

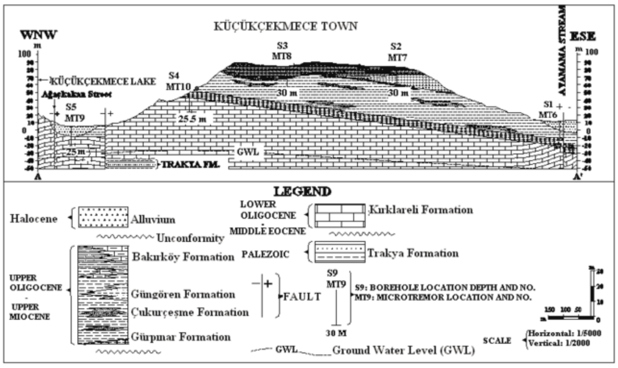

Figure 2. The geological cross-section (A-A′) of the region

2.2 *Site classification*

The site classification at each grid was performed according to both Turkish Earthquake Code (TEC, 1998) and NEHRP (BSSC,2001). The region is determined to include Z1, Z2, and Z3 site classes according to Turkish Earthquake Code and C,D and F site classes according to NEHRP. The site classification maps with respect to Turkish Earthquake Code and NEHRP are shown in Figure 3 and Figure 4, respectively. Site soil classification maps indicate that the zones of Z1/C appear in regions where Kırklaereli and Bakırköy formations are outcropping, and the zones of Z2/D dominate the areas covered with other formations (except the alluvial deposits). The site class Z3/D is observed to exist in scattered areas covered with Çukurçeşme, Güngören and Gürpınar formations and in small portion of alluvial site. The majority of the alluvial sites are classified as Z4/F, indicating the risk of liquefaction.

Table 1. Natural water content, consistency limits , natural unit weight and SPT-N Blow counts of the soil formations encountered at the study area

Soil Description	w_n (%)	w_L (%)	w_P (%)	γ_n (kN/m3)	Gravel (%)	Sand (%)	Silt-Clay (%)	Soil Class	SPT N Blow counts
Alluvial Deposit	21-55	26-65	21-33	17-18	3-22	56-95	4-74	SM-SC or CL	10-40
Fill	29-33	42-57	21-31	17-18	0-43	28-34	7-23	GM-GC or CL	6-27
Bakırköy Formation*	28-75	40-114	21-74	18-19	0-6	16-97	1-84	CH or MH	In the upper 5m 22-28 after>30
Güngören Formation	27-66	46-113	25-48	17-20	-	-	-	CH	At near surface12-20, at deeper >22
Gürpınar Formation[1]	18-55	38-99	23-48	19-21	-	-	-	CH	13-18
Gürpınar Formation[2]	18-55	38-99	23-48	19-21	-	-	-	CH	22-28
Gürpınar Formation[3]	18-55	38-99	23-48	19-21	-	-	-	CH	>Refusal
Kırklareli Formation*	20-25	38-42	22-26	18-19	-	-	-		>26
Çukurçeşme Formation	-	-	-	19-20	0-41	48-85	11-23	SM-SC	Refusal
Gürpınar Formation[4]	-	-	-	20-21	0-14	47-83	16-48	SM-SC	Refusal
Gürpınar Formation[5]	-	-	-	21-22	14-39	40-66	15-20	SM-SC	Refusal

*Clay levels [1] (4.0 -7.50 m depth) [2] (7.50 -10.50 m depth) [3] (>10.50 m) [4](sand levels) [5](gravel levels)

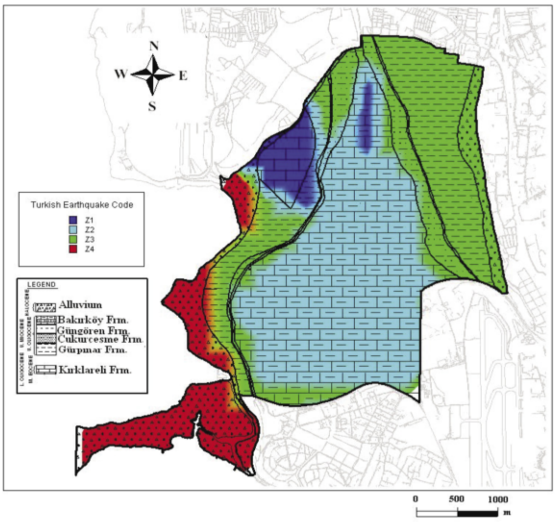

Figure 3. The site soil classification according to Turkish Earthquake Code (1998)

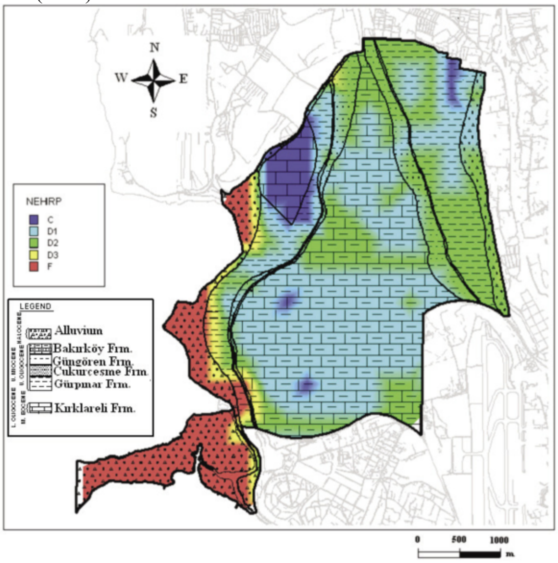

Figure 4. The site soil classification according to NEHRP (BSSC, 2001)

Table2. Strength parameters for soil and rock formations encountered at the study area

Soil and Rock Description	c_u (kPa)	q_c (kPa)	qt (kPa)
Gürpınar Formation	30-80	-	-
Güngören Formation	18-77	-	-
Bakırköy Formation	-	1100-55000	5000-50000
Kırklareli Formation	-	2700-75000	3900-60000

2.3 *Shear wave velocity distribution*

The shear wave velocities measured from PS logging tests performed in the study area are observed to vary between the maximum weighted shear velocity (V_{smax}) and minimum weighted shear wave velocity (V_{smin}) values computed from empirical relationships utilizing SPT blow count numbers recommended by Ohta and Goto (1978), Seed and Idriss (1981) and İyisan (1996). Therefore, the shear wave velocity distributions with depth to be used in the analyses are derived from the average shear wave velocities (Vs_{ave}) which are determined from empirical relationships.

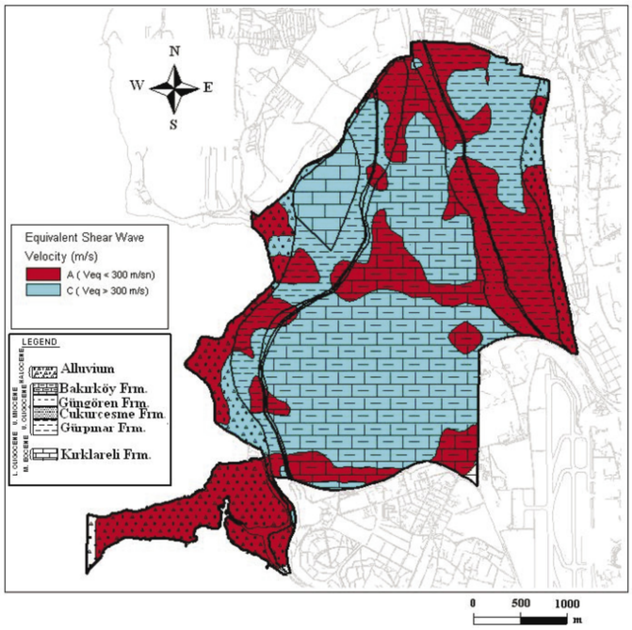

Figure 5. The variation of equivalent shear wave velocity

Equivalent shear wave velocities are computed for the upper most 30 meters and they are determined to vary between 216 m/s and 464 m/s for the study area, whereas the measured shear wave velocities for the top 30 meters from the PS logging tests are observed to vary between 250 m/s and 450 m/s. The variation of equivalent shear wave velocity in the study area is shown in Figure 5, where Zone A shows the areas where equivalent shear wave velocities are less than 300 m/s and Zone C shows the areas where equivalent shear wave velocities are more than 300 m/s. The soil profiles near Küçükçekmece Lake on the west , along Marmara sea coast on the south, and along the Ayamama River on the east comprise of thick alluvial deposits that have SPT-N values varying in a wide range (3-Refusal) and correspondingly the computed shear wave velocities have shown large variation in the alluvial regions.

3 SITE RESPONSE ANALYSIS

In this study, dynamic site response analyses are performed using the computer code, EERA (Bardet et al. 1998) which provides a procedure to define inputs and outputs in Excel-routines based on equivalent linear analysis program SHAKE 91 (Idriss and Sun, 1992).

3.1 *Earthquake input file*

For simulation of time domain ground motion compatible with the response spectra, the procedure developed by Deodatis (1996) and coded by Papageorgiou et al. (2000) was utilized. The TARCHTS(target acceleration spectra compatible time history) is a ground motion simulation program generating a synthetic time history of ground acceleration. The time domain simulations are non-stationary with random phase.

3.2 *Soil profile and material parameters*

In order to be able to carry out site response analysis for the region, representative soil profiles were defined for a total of 279 (250mx250m) grids. For each soil layer in the soil profiles, total unit weight, thickness, shear wave velocity and variation of G/G_{max} and damping with strain level are provided as inputs.

For clay type soils the G/G_{max} and damping curves proposed by Vucetic and Dobry (1991) which takes the effect of plasticity into consideration, and for alluvial sites as well as for Çukurçeşme and Gürpınar sandy deposits, the curves of Seed and Idriss (1970) and Idriss (1990) were utilized. For Bakırköy formation, the curves recommended in EERA as Attenuation of Rock average and Damping in Rock were used.

3.3 *Seismic microzonation with respect to ground motion*

Site response analyses were conducted for Küçükçekmece region using the selected soil profiles and the input time histories obtained for each grid from the regional probabilistic earthquake hazard study. The basic intention of the site response analysis is to estimate the effect of local site conditions in assessing the site amplification with respect to ground shaking.

From the results of one-dimensional (1-D) site response analysis performed with respect to the earthquake parameters for probabilities of exceedance of 10% , peak ground acceleration (PGA), maximum spectral acceleration and soil amplification values were determined. In the evaluation of maximum spectral accelerations, the average spectral acceleration between 0.5 and 1.5 second periods was defined and mapping procedure was carried out according to the average spectral acceleration $(S_a)_{ave}$. In order to perform a zonation map with respect to spectral acceleration, the cumulative frequency distribution of these calculated values were evaluated as defined in Microzonation Manual (MERM, 2003) and the study area was divided into two zones as A and C. The variation of average spectral acceleration in Küçükçekmece for probability of exceedance of 10% are shown in Figure 6. In Figure 6, average spectral accelerations for probability of exceedance of 10% are observed to vary between 0.37g and 1.42g and the areas with average spectral accelerations greater than 0.61g were defined as Zone A_S and the areas with less than 0.61 g were defined as C_S. From the mapping given in Figure 6, it may be observed that the distribution of two zones A_S and C_S are approximately equal in the study area.

The peak spectral amplifications were also computed from equivalent shear wave velocities using the empirical relationship given by Midorikawa (1987),

$$A_k = 68V_s^{-0.6} \qquad (1)$$

where A_k is the spectral amplification and V_s is the equivalent shear wave velocity for the uppermost 30 m's in the soil profile.

The variation of spectral amplifications computed from equivalent shear wave velocity based on Midorikawa (1987) are shown in Figure 7. Here, the spectral amplifications are seen to vary between 1.71 and 2.70. The areas with greater than 2.04 amplification are assigned as Zone A_V and the areas which show amplification less than 2.24 are as C_V with respect to cumulative frequency distribution.

In Figure 8, the final seismic zonation map with respect to ground shaking for probability of exceedance of 10% is shown. The final seismic zonation for ground shaking was accomplished based on the evaluation of average spectral accelerations obtained by site response analysis and by peak spectral amplifications calculated using equivalent shear wave velocity. Here, The zone A_{GS} corresponds to overlapping zones of As and Av, the zone B_{GS} corresponds to overlapping zones of As and Cv or Cs and Av and the zone C_{GS} corresponds to overlapping zones of Cs and Cv. Here, the zone A_{GS} represents relatively high shaking level, higher than average, B_{GS} represents relatively medium shaking level, slightly above average and C_{GS} is defined as relative low shaking level, slightly below average.

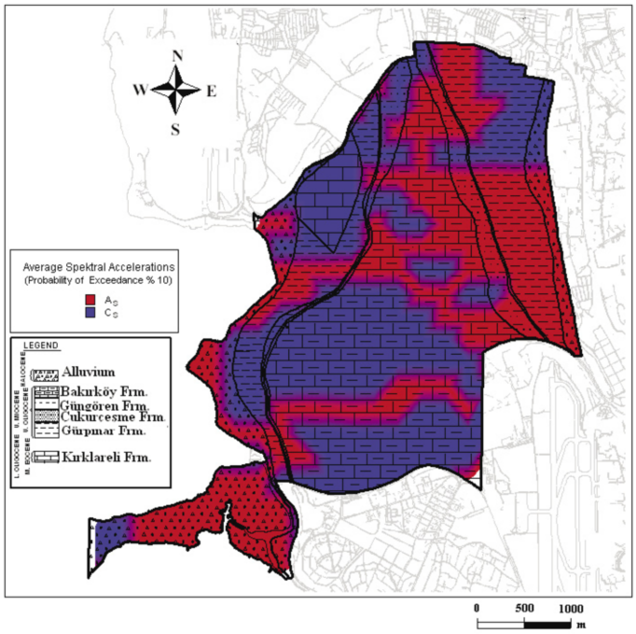

Figure 6. The variation of average spectral acceleration in Küçükçekmece for probability of exceedance of 10%

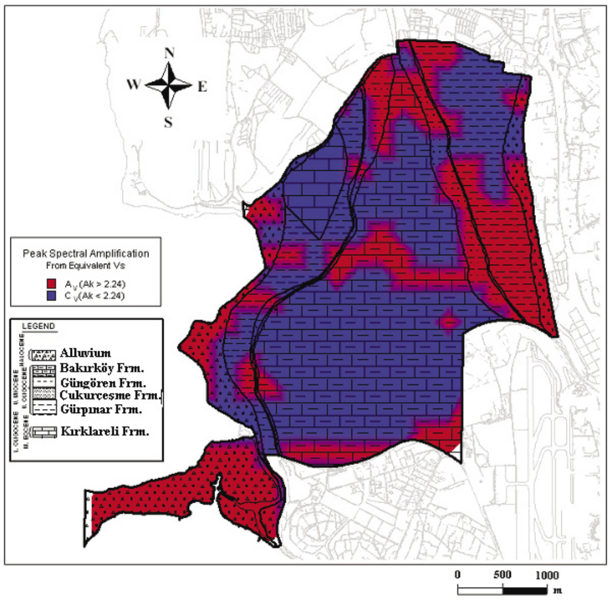

Figure 7. The variation of spectral amplifications computed from equivalent shear wave velocity based on Midorikawa (1987)

As can be seen from the comparison of Figures 1, 3 and 4 with Figure 8**,** there are similarities and some differences with the soil profiles and site classifications, and seismic zones. It was observed that at some grid points the site amplifications were relatively high and at some grid points the peak ground accelerations were very low based on the site response analyses. This is due to the fact that, the site response analysis would sometimes give unrealistically high spectral amplification 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. Additionally, for thick soil columns subjected to large motions, an equivalent linear (EQL) analysis may underestimate the ground motions at short periods (Joyner et al., 1981) (As a result, the EQL approach may not be able to converge due to nonlinear behavior at large strains). Therefore, especially in the area lying between Küçükçekmece Lake and Marmara Sea consisting of thick alluvial deposits where the ground water table is almost on the ground surface and the depth of bedrock varies between 180m and 200m, the site response analysis is believed to yield unrealistic results and, this Zone C designation for this area in Figure 8, probably underestimates the seismic hazard level.

In Figure 8, it is observed that the plateau in the central parts of the study area where marl and agrillaceous limestone of Bakırköy formation outcrops, the western slopes where limestone of Kırklareli formation comprising the bedrock is outcropping and the northwestern corner of the study area where bedrock is at shallow depths constitute the more favorable zones B and C. On the other hand, the eastern slopes overlooking the Ayamama River which are covered with clay layers of Güngören and Gürpınar formation, together with the areas along the stream bed, and the areas along the western shores of Küçükçekmece Lake which are covered with alluvial deposits constitute the more risky Zone A where site specific detailed investigations are required.

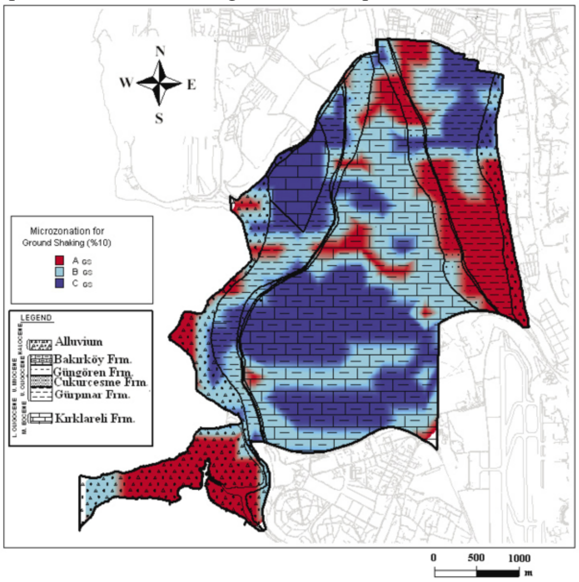

Figure 8. The seismic zonation map with respect to ground shaking for probability of exceedance of 10%

4 SUMMARY AND CONCLUSION

In this study, the dynamic behavior of soil conditions of Küçükçekmece-Sefaköy region are investigated and a seismic microzonation study was carried out with respect to soil amplification in accordance with the procedure recommended in Microzonation Manual (MERM, 2003) prepared by World Institute for Disaster Risk Management (DRM). The dynamic site response analyses were performed based on site specific earthquake hazard parameters derived for probabilities of exceedance of 10% in 50 years.

The microzonation map with respect to ground shaking map is generally seen to be compatible with the geological map and local site classification maps. The regions which are covered with alluvial deposits are generally classified as Z4 and F according to Turkish Earthquake Code and NEHRP, respectively and mapped as A_{GS}. However, zoning of the alluvial areas at the western parts of the Küçükçekmece region, where the bedrock is very deep and the groundwater level is close to the ground surface, as C_{GS} with respect to ground shaking intensity is considered to be unrealistic and is concluded to be closely related to the fact that 1-D equivalent linear site response analysis would sometimes give unrealistically high spectral amplification 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.

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