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SEISMIC MICROZONATION OF HISTORICAL PENINSULA (İSTANBUL) WITH RESPECT TO LIQUEFACTION SUSCEPTIBILITY

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ABSTRACT

In this study the geologic and geotechnical conditions of old Istanbul (Fatih and Eminönü Provinces) were investigated in detail and a seismic microzonation study was performed with respect to liquefaction potential for probabilities of exceedance of 10% and 40% in 50 years. The geologic and tectonic features of the study area were determined utilizing the findings of soil investigation borings drilled in the past for various construction activities and the borings drilled within the framework of JICA project.

The microzonation maps regarding liquefaction potential are prepared based on the simplified procedure (Seed et al.,1984, 1985) for the coast lines of Haliç, Yenikapı and Kumkapı and in the areas around Vatan street where liquefaction is thought to be likely to take place. In order to be able to evaluate and analyze the liquefaction susceptibility of the region, the study area is divided into 250m x 250m grids. For each grid representative soil profiles are determined and simulated earthquake time histories are obtained from the spectral acceleration values at 0.2 and 1.0 seconds resulting from the probabilistic seismic hazard analysis for 10% and 40% probabilities of exceedance in 50 years. Dynamic site response analyses are performed using EERA (Bardet et.al., 2000) and the simulated earthquake time histories (Papageorgiou et.al.,2000) to obtain maximum ground surface acceleration values. The results of simplified analyses for liquefaction assessment are processed by GIS techniques to produce microzonation maps in terms liquefaction susceptibility with respect to probabilities of exceedance of 10% and 40% in 50 years.

Keywords: liquefaction, microzonation, dynamic site response analysis

INTRODUCTION

Some of the most devastating effects of earthquakes on structures are due to liquefaction of foundation soils which may cause lateral spreading, bearing capacity loss and settlements. Therefore, regions which are prone to liquefaction have to be determined and evaluated in detail for the planning of new residential areas and assessment of the seismic vulnerability of the already built up areas during a probable earthquake. For this purpose, nowadays microzonation maps (Ansal et.al., 2003; Ansal et.al., 2005; Kilic et.al.,2005; Kilic et.al., 2006) with respect to liquefaction hazard are prepared for seismic safety planning of residental areas in order to mitigate earthquake induced liquefaction damages. Since liquefaction phenomenon is closely related with the geologic conditions, the liquefaction hazard maps should be based on geological maps.

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In this study, seismic microzonation with respect to liquefaction susceptibility is carried out based on the procedure recommended in the Microzonation Manual (MERM, 2004) by considering the effects of earthquakes with probabilities of exceedance of 40% and 10% in 50 years and the results are compared with each other. In the assessment of the study area for liquefaction hazard, areas which are covered with artificial fill and alluvium such as Vatan street (Yenibahçe brook) and Haliç coast, as well as Kumkapı and Yenikapı coast line along Marmara Sea are chosen for investigation. Other areas which are covered with Bakırköy formation, Gürpınar formation and Thrace formation comprise soils of low sand and silt content which are free of liquefaction risk. Liquefaction assessment is carried out in 108 cells which are identified as potential risk areas considering the top 20m of the soil profile, and liquefaction potential index is determined for each cell based on the procedure developed by Iwasaki et al. (1982).

GEOLOGY OF THE HISTORICAL PENINSULA

For the assessment of the earthquake hazard level of historical peninsula region, a total of 10.6 km^2 area was investigated through geological and geotechnical studies.The geology and soil profile of the historical peninsula have been studied through surface geological investigations, 125 borings drilled for various purposes, and several trial pits opened in and around the area. Two distinct formations are outcropping on the historical peninsula and they are covered with layers of alluvium and artificial fill. The older of the two formations is Lower Carboniferous “Trakya” formation, which constitutes the bedrock in the area and is composed of interbedded sandstone (graywacke), siltstone and claystone (Kaya, 1971; Vardar and Bayraktar, 1993). The other group comprise of units seated unconformably on “Trakya”, and represented by Upper Oligocene – Upper Miocene deposits composed of interbedded sand, clay and carbonates. The Upper Oligocene – Upper Miocene deposits cover extensive areas both on the historical peninsula and on other parts of the European Istanbul, starting in depositional sequence with interbedded clay and sand, later continuing with intercalations of gravelly sand, and, in the upper levels, interbedded marl and limestone due to increased carbonate content (Gürpınar, Çukurçeşme, Güngören, Bakırköy, Belgrad formations, from bottom to top).
The engineering geology map of the study area is shown in Figure 1.

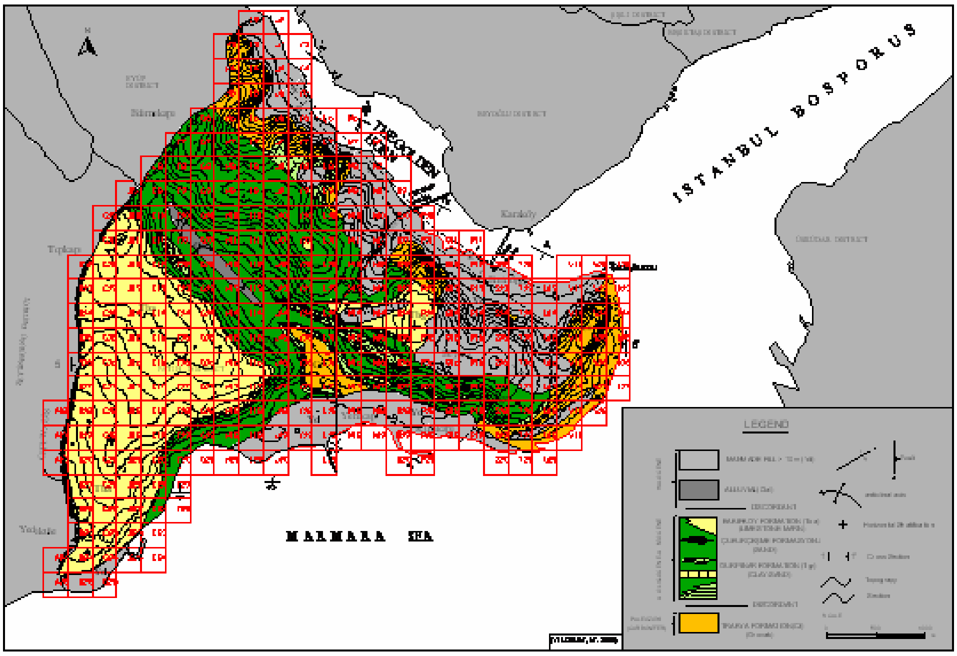

Figure 1 Engineering Geology Map of the Historical Peninsula(Ince,2005)

SITE CLASSIFICATION

The site classification of the region with respect to local soil conditions was performed by utilizing the data from 125 soil borings drilled by different agencies and companies. The soil boring logs included

the description and thickness of soil layers and SPT results. The results of PS logging tests which were carried out in four deep borings drilled in Fatih and Eminönü provinces and two borings drilled in the vicinity of the study area within the scope of the project " The Study on a Disaster Prevention/Mitigation Basic Plan in Istanbul including Seismic Microzonation in the Republic of Turkey" carried out in 2001-2002 (JICA and IMM) were also utilized in site soil classification.
The site soil classification at each cell is determined according to both Turkish Earthquake Code (TEC,1998) and NEHRP (BSSC, 2001) by taking into consideration the soil profile and soil properties defined for each cell. The site classification maps according to each method are shown in Figure 2 and Figure 3.

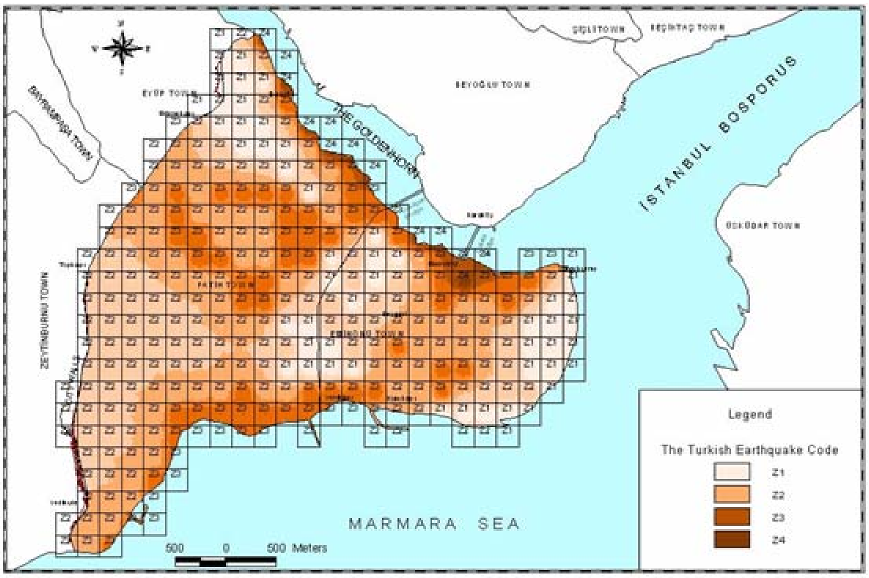

Figure 2 Soil classification according to Turkish Earthquake Code (TEC,1998)

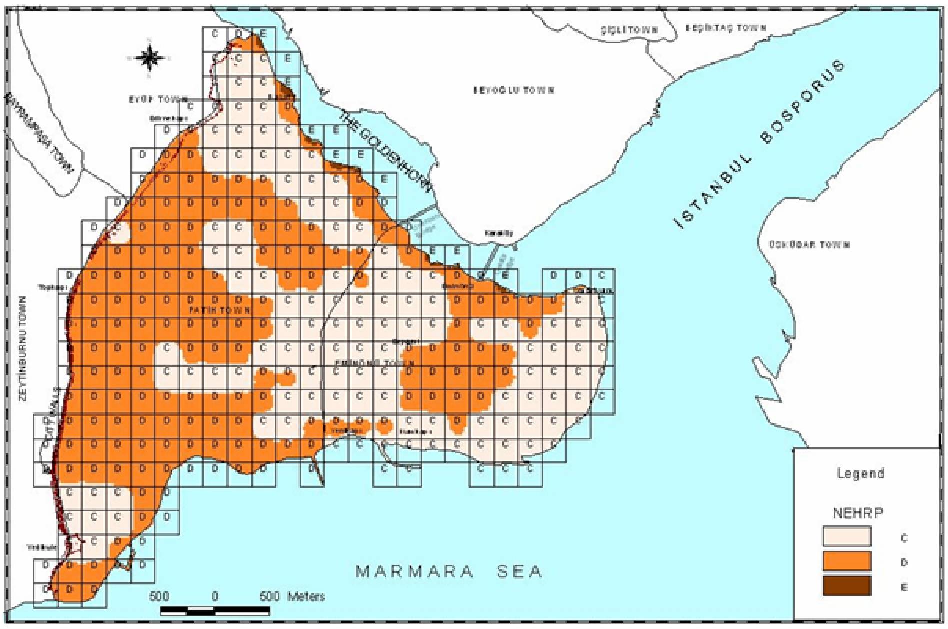

Figure 3 Soil classification according to NEHRP (BSSC, 2001)

The site classification mappings have shown that the areas where Trakya Formation is outcropping can be classified as Z1-Z2/C, and zones of Z2/C-D appear in regions where Bakırköy formation are outcropping. The areas where Gürpınar formation outcrops are classified as Z2-Z3/C-D and the coastal areas which are covered with alluvial deposits and artificial fill are classified as Z3-Z4/D-E.

SITE RESPONSE ANALYSIS

In this study, site response analyses are conducted for historical peninsula by using the computer code EERA (Bardet et al., 1998) using the defined soil profiles and the simulated earthquake time histories (Papageorgiou et.al.,2000) obtained from the regional probabilistic earthquake hazard study (Erdik et.al., 2004) for each cell. From the results of one-dimensional (1-D) site response analysis, peak ground acceleration (PGA) values are determined for probabilities of exceedance of 10% and 40% in 50 years. The variation of peak ground surface accelerations in the region for probabilities of 10% and 40% in 50 years are shown in Figure 4 and Figure 5, respectively.

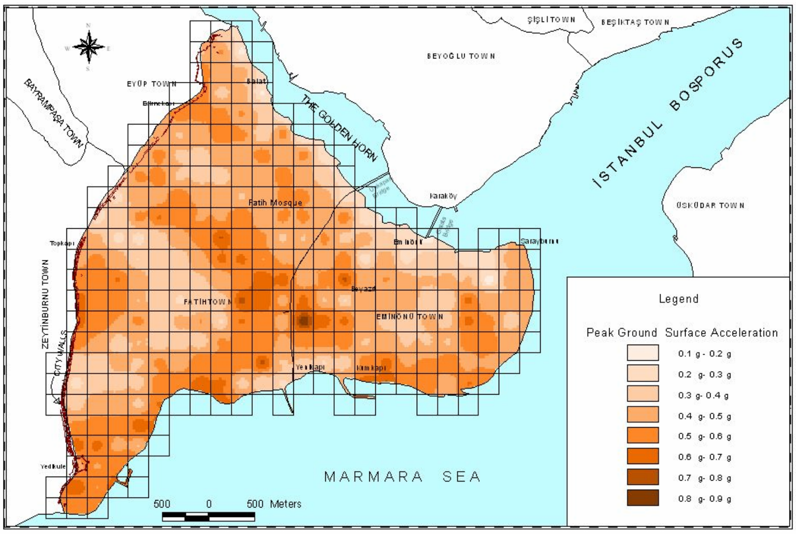

Figure 4 The variation of peak ground surface accelerations in the region for probability of exceedance of 10% in 50 years (Ince, 2005)

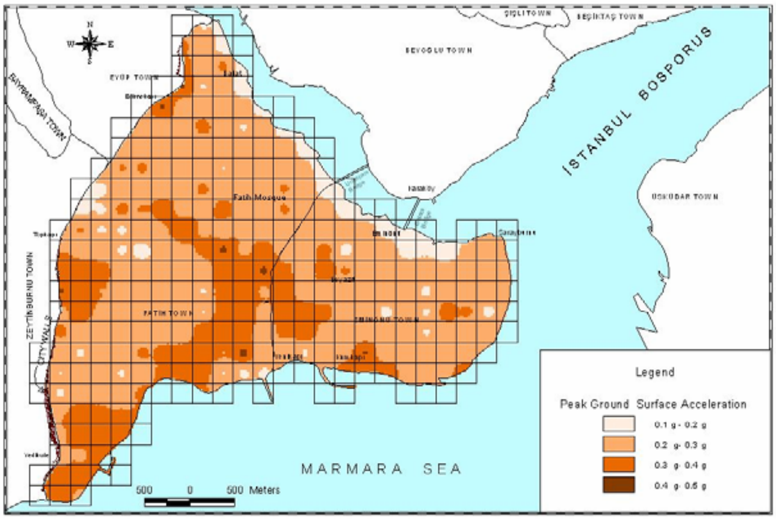

Figure 5 The variation of peak ground surface accelerations in the region for probability of exceedance of 40% in 50 years (Ince, 2005)

ASSESSMENT OF LIQUEFACTION POTENTIAL

In this study, the microzonation maps in terms of liquefaction susceptibility are developed for the regions covered with artificial fill and alluvial deposits in the peninsula based on the method developed by Youd et al.(2001) and Iwasaki et al. (1982) as recommended in the Microzonation

Manual Part 2II (MERM, 2004). This widely accepted procedure is an extended version of SPT-based method proposed by Seed et al. (1984, 1985).

Procedure for evaluation of liquefaction susceptibility

In the method proposed by Youd et al.(2001), the cyclic stress ratio (CSR) which represents the dynamic loading effects during an earthquake is determined by using the peak ground surface acceleration values determined from the site response analysis performed, as defined by the equation developed by Seed and Idriss (1971),

$$CSR = \left(\frac{\tau_{av}}{\sigma'_{v0}}\right) = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right) r_d \tag{1}$$

where,

a_{max} = the peak ground acceleration

σ_{v0} = total vertical stress (kN/m^2)

σ'_{v0} = effective vertical stress (kN/m^2)

g = the acceleration due to gravity (m/s^2)

τ_{av} = average cyclic shear stress (kN/m^2)

r_d = shear stress reduction factor

The shear stress reduction factor r_d is determined with the following equation (Youd et al., 2001),

$$r_d = \frac{\left(1.00 - 0.4113 z^{0.5} + 0.04052 z + 0.001753 z^{1.5}\right)}{\left(1.00 - 0.4177 z^{0.5} + 0.05729 z - 0.006205 z^{1.5} + 0.001210 z^2\right)} \tag{2}$$

where

z = depth beneath ground surface in meters

The liquefaction resistance of soil is estimated with the following equation (Youd et al., 2001),

$$CSR_L = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{\left[10(N_1)_{60} + 45\right]^2} - \frac{1}{200} \tag{3}$$

where $(N_1)_{60}$ is the SPT-N values corrected for energy, equipment, and procedural effects (Youd et al., 2001), as below

$$(N_1)_{60} = N\, C_N\, C_R\, C_S\, C_B\, C_E \tag{4}$$

Here,

N = Standart Penetration Test blow count number (blows/30 cm)

C_N = correction factor for overburden effects which is taken as (Liao and Whitman,1986)

$$C_N = (P_a/\sigma'_{v0})^{0.5} \tag{5}$$

C_R = correction for "short" rod length,

C_S = correction for non-standardized sampler configuration,

C_B = correction for borehole diameter, and

C_E = correction for hammer energy ratio

For the correction factors, taking into consideration the common borehole drilling practice in Turkey, it is assumed that C_E=0.5, C_B= 1, C_s=1.1 and C_R is taken as suggested by Youd et al. (2001) with respect to the depth of each individual testing location (C_R=0.75 for d<3 m, C_R=0.8, for d=3-4 m, C_R=0.85 for d=4-6 m, C_R=0.95 for d=6-10m, C_R=1 for d=10-30m).

Since fines content has a great influence on the liquefaction resistance of soils, $(N_1)_{60}$ values are further corrected for fines content as (Youd et al., 2001),

$$(N_1)_{60cs} = (N_1)_{60} C_{FINES} \tag{6}$$

where C_{FINES} is determined by the following equation (MERM, 2004),

$$C_{FINES}=(1+0.004\ FC)+0.05\left(\frac{FC}{N_{1,60}}\right) \quad \text{lim: } FC \geq 5\% \text{ and } FC \leq 35\% \tag{7}$$

where FC= percent of fines

Since the liquefaction resistance curves expressed with eq.(3) is given for a magnitude 7.5 earthquake, a magnitude scaling factor (MSF) is needed for the other earthquake magnitudes, and the factor of safety with respect to liquefaction may be calculated from (Youd et al., 2001),

$$FS=\left(\frac{CRR_{7.5}}{CSR}\right)MSF \tag{8}$$

where MSF factor is chosen from a range of recommended values given by Youd et al. (2001). For this study MSF is taken to be 1 and 1.32, for the probabilities of exceedance of 10% and 40%, respectively.

The safety factors against liquefaction are calculated along the total depth of the soil profile for the soil layers which are determined to be liquefiable. Then, the liquefaction potential for each bore hole location is computed by the procedure developed by Iwasaki et al. (1982) using the safety factor values calculated at various depths. The procedure by Iwasaki et al. (1982) predicts the liquefaction performance of the soil profile at a specific site down to a depth of 20 m by employing a liquefaction potential index, LPI ,which is defined as

$$LPI=\int_0^{20} F(z)w(z)dz \tag{9}$$

where z is the depth below the ground water surface in meters,

$$F(z)=1-FS \qquad FS \leq 1 \tag{10}$$

$$F(z)=0 \qquad FS>1 \tag{11}$$

$$w_z=10-0,5z \tag{12}$$

The liquefaction potential assessment based on LPI values are given in Table 1.

Table 1. Liquefaction potential according to Liquefaction Potential Index (LPI)

Liquefaction Potential	LPI
None	0
Low	0 < LPI <5
Medium	5<LPI <15
High	LPI > 15

EVALUATION OF THE RESULTS

The microzonation maps for the liquefaction susceptibility developed for the region with respect to probabilities of exceedance 10% and 40%, are shown in Figure 6 and Figure 7, respectively. As can be seen from these maps, the shores of Marmara Sea and Golden Horn and a narrow band along the Vatan street are the liquefaction susceptible areas in the historical peninsula due to the presence of thick alluvial deposits and near surface groundwater table. It is also observed that liquefaction susceptibility is very high, even though the peak accelerations are in the level of 0.1-0.2g range, along the Golden Horn coast line. This is due to the presence of thick very weak alluvial deposits with low SPT-N values and near surface ground water table. The liquefaction potential risk appears to be slightly higher with respect to the probability of exceedance of 10%, compared to that of 40%.

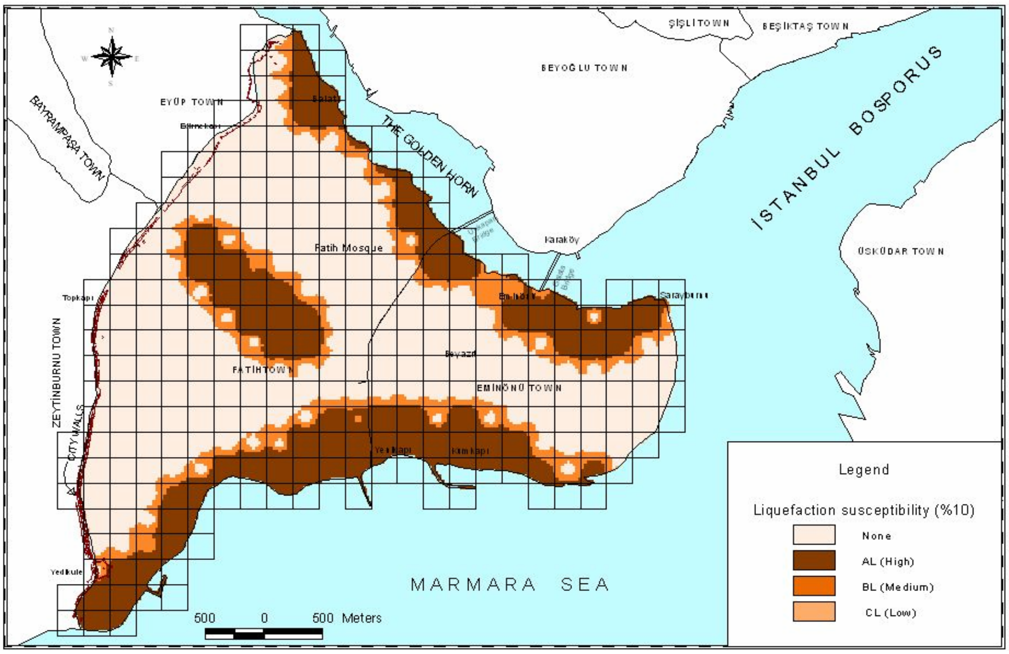

Figure 6 Microzonation map for liquefaction hazard in historical peninsula for probability of exceedance of 10% in 50 years, (Ince,2005)

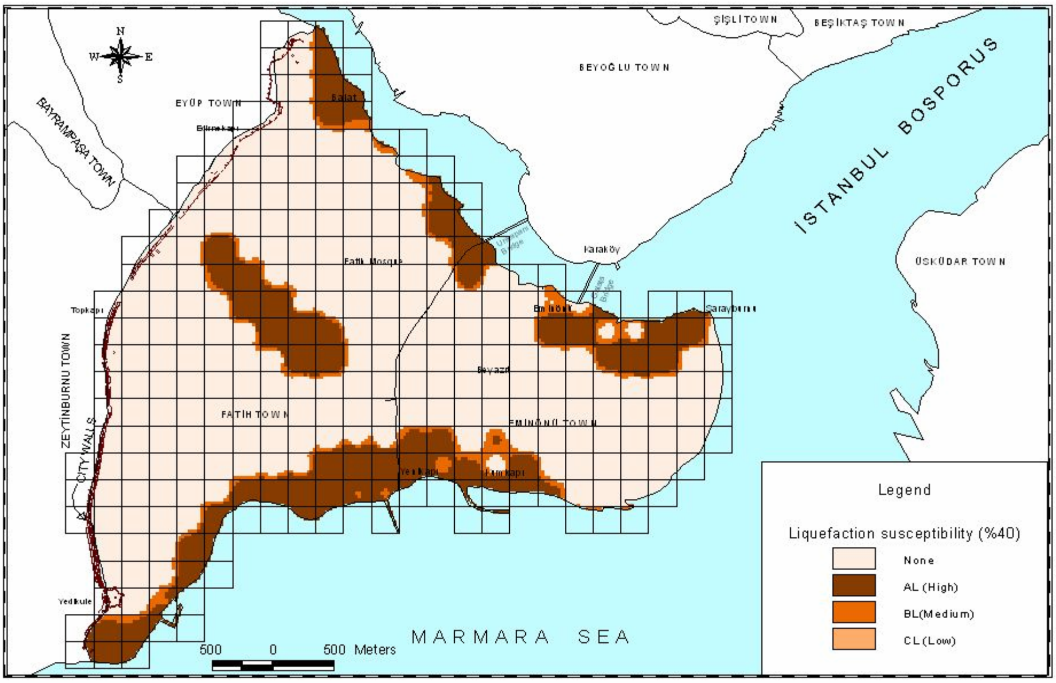

Figure 7 Microzonation map for liquefaction hazard in historical peninsula for probability of exceedance of 40% in 50 years (Ince,2005)

CONCLUSIONS

In this study, the microzonation maps in terms of liquefaction susceptibility are developed for the historical peninsula in Istanbul in accordance with the procedure recommended in the Microzonation Manual (MERM, 2004). In order to be able to assess the liquefaction susceptibility of the region, the effects of two different earthquakes with probabilities of exceedance of 10% and 40% in 50 years are investigated and the results are compared with each other. As a consequence of the study, the liquefaction susceptibility is seen to be high for the areas which are covered with artificial fill and alluvium such as Vatan street (Yenibahçe brook) and Haliç coast, as well as Kumkapı and Yenikapı coast line along Marmara Sea and the liquefaction susceptibility is determined to be higher for an earthquake with probability of exceedance of 10% than probability of exceedance of 40%. It is recommended that in seismic vulnerability assessment of the existing buildings in the region as well as in the design and construction of new buildings, liquefaction risk is seriously taken into account.

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