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Full Length Research Paper

Variations of soil liquefaction safety factors depending on several design earthquakes in the city of Yalova (Turkey)

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The 1999 earthquakes (which had magnitudes Mw of 7.4 and 7.2) in Turkey caused great destruction and damage for Yalova (Turkey) sites in the Marmara Region. In the investigation area, the mainly reason for destruction is the liquefaction. As it is known, liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. In the frame of this research, probabilistic and deterministic analyses were used to determine the safety factors for several parameters. For the study area, the probabilistic seismic hazard analysis showed very high seismic activity. By using deterministic seismic hazard analysis, the magnitudes were estimated for the three rupture (with four different fault lengths, 109, 120 and 174 km) model of North Anatolian Fault Zone in the Marmara Region. By using analysis (deterministic and probabilistic), estimated magnitudes and accelerations of earthquake were taken as alternatively 6.5, 7.0 and 7.5 for magnitudes and from 0.2 - 0.50 g for accelerations. For several design earthquake parameters, cyclic stress analysis of liquefaction were applied to the field data (both SPT (N) and S wave data), obtained in the Yalova region. In the first phase of the study of liquefaction, the cyclic stress ratio approach was applied for all data to analysis of soil liquefaction. Then FS (factor of safety) values of liquefaction were estimated with this approach.

Key words: Problematic soils, soil liquefaction, earthquakes, Yalova (Turkey).

INTRODUCTION

Earthquake occurrences on the North Anatolian Fault (Turkey) are well documented in historical and modern periods. The 1999 Duzce and Golcuk (had magnitudes Mw of 7.4 and 7.2), earthquakes caused great destruct-tion and damage for the Yalova (Turkey) sites. One of the causes for the heavy damage to buildings is the liquefaction induced settlements. Therefore, evaluation of soil liquefaction potential has become one of the most important topics of interest.

The current simplified methods for assessing soil liquefaction potential use a deterministic safety factor to judge whether liquefaction will occur or not. Engineers usually use a factor of safety (FS) to evaluate the safeness of a soil structure. The safety factor is defined as the strength of a member divided by the load applied to it.

Liquefaction resistance can be estimated by in situ test or laboratory test. Standard Penetration (SPT), cone penetration (CPT) and shear wave tests are the most used for the estimation of liquefaction susceptibility. Methods based on the SPT were developed by Seed and Idriss (1971); Seed et al. (2001); Iwasaki et al. (1978); Tokimatsu and Yoshimi (1983); Youd and Idriss (1997). Methods by using the CPT include those developed by Seed and Alba (1986); Robertson and Campanella (1985). For engineering purposes, data obtained from site investigation including boring, laboratory test need to be used besides methods based on SPT and CPT (Finn, 1993; Ansal, 1991). Methods by using the shear waves developed by Stokoe et al, 1988¸ Andrus and Stokoe, (1996), (1997), (1999); Dobry et al. (1981). State of art of liquefaction analysis is evaluated by Youd et al. (2001). Main goal of this study is to investigate the variations of

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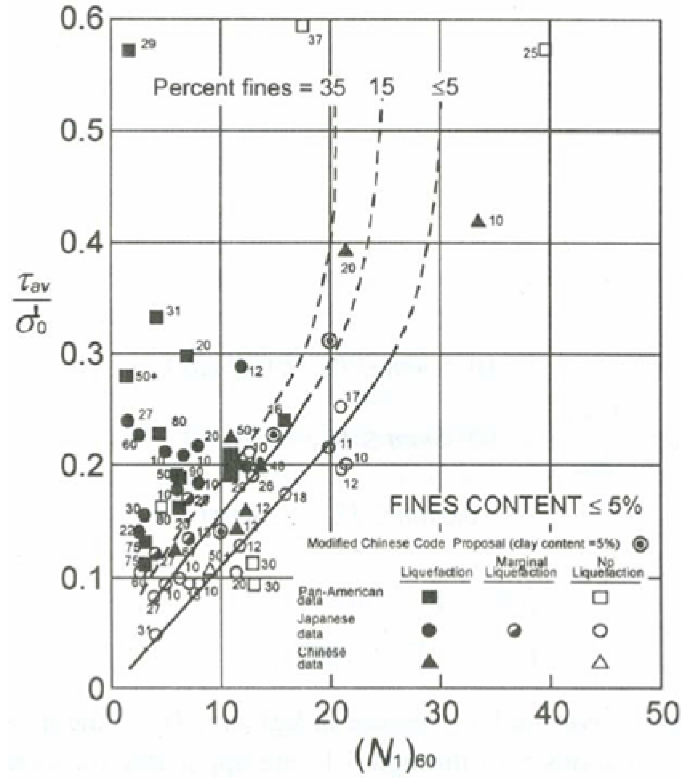

Figure 1. Correlation between equivalent uniform cyclic stress ratio and SPT N1, 60 value for events of magnitude Mw = 7.5 for varying fines contents (After Seed et al., 2001)

safety factors depending on several design earthquakes for soil liquefaction in the city of Yalova (Turkey)

THEORY FOR LIQUEFACTION ANALYSIS AND LIQUEFACTION INDUCED SETTLEMENTS

In this study, a practical reliability-based method is developed for assessing the soil liquefaction potential of the Yalova (Turkey) Region. Our approach, based on conventional theory, enables the earthquake-induced cyclic stress ratio (CSR) and soil cyclic resistance ratio (CRR).

The most widely used simplified SPT-N method is proposed by Seed et al. (2001). This method calculates the earthquake-induced cyclic stress ratio in a soil layer via the simplified equation below:

CSR (cyclic stress ratio) = 0.65 (Amax /g) (σo / σo') rd (z) / MSF (M) (1)

where σo' and σo are the effective and total vertical overburden pressures at some specified depth; Amax is the peak horizontal ground acceleration; rd (z) is the stress reduction factor at depth z, MSF (M) is a magnitude scaling factor that considers the duration effect of different earthquake magnitudes. In equation (1), σo' and σo are directly computed from boring log and laboratory test data, and can therefore be regarded as deterministic values with no variance; The rd (z) and MSF (M) vary with the depth and the earthquake magnitude. The safety factor for liquefaction can be calculated by the simple equation below:

SF = CSR /CRR (1)

Criteria for evaluation liquefaction resistance based on SPT, CPT or Shear wave data are largely embodied in the *CRR* versus *N1, 60* plots (Youd, et al. 2001). This procedure is based on the relationship of SPT *N*- values, corrected for both effective overburden stress and energy, equipment and procedural factors affecting SPT testing (for *N1, 60*-values) versus intensity of cyclic loading, expressed as magnitude-weighted equivalent uniform cyclic stress ratio (*CSReq*). The correlation between corrected *N1, 60*-values and the intensity of cycling required to trigger liquefaction is also a function of fines content as shown in Figure 1 (Seed et al., 2001).

Earthquake hazard analysis of Yalova region

Seismic hazard analysis is the computation of probabilities of occurrence per unit time of certain levels of ground shaking caused by earthquakes. This analysis is often summarized with a seismic hazard curve, which shows annual probability of exceedence versus ground motion amplitude. Deterministic and Probabilistic seismic hazard analysis was used to evaluate the seismic hazard dered the North Anatolian Fault in Marmara Sea.

Deterministic Seismic Hazard Analysis: Required input for deterministic hazard analysis is a designation of active faults or earthquake sources in the region. For the Marmara Region, it was assumed tree model (A, B and C) for seismic hazard. Model A: approximately 120 km rupture length; Model B: approximately 109km rupture length; Model C: approximately 174 km rupture length. For these models, magnitudes were estimated (Table 1a and b).

Probabilistic Seismic Hazard Analysis of Region: The westward motion of Turkey relative to Eurasia is related to the collision between Arabia and Eurasia in the Caucasus and Eastern Turkey, which is thought to have of region. Potential earthquake source area was consistarted about 12 M years ago in the Mid-Miocene. The thickened crust in Eastern Turkey provides the gravitational potential energy, or buoyancy force, driving Turkey. westwards; most of this motion being accommodated along the North and East Anatolian strike slips fault systems (Ketin, 1948; McKenzie 1972, 1978; Sengor, 1979a, 1979b; Oral, 1994; Oral et al 1995; Taymaz, 2000). The neotectonic related geodynamic evolution of the Mediterranean started during and after the collision of Africa with Arabia. In northern Anatolia, total consumption of the Tethian Ocean between the Sakarya continent and the

Table 1a. Equations for rupture length and magnitude estimations.

Researcher	M (magnitude)	Magnitude Type
Abraseys and Zatopek (1968)	M = (0,881 LOG(L))+5,62	Ms
Douglas and Ryall (1975)	M = (LOG(L)+4,673)/0,9	Ms
Patwardan et al. (1980)	M = (LOG(L) 1,1)+5,13	Ms
Toksöz et al (1979)	M = (LOG(L)+3,62)/0,78	Ms
Wells and Coppersmith (1994)	M = 5,16+(1,12 LOG(L))	Mw

Table 1b. Model A: approximately 120km rupture length; Model B: approximately 109km rupture length; Model C: approximately 174km rupture length. Magnitude estimations for these models.

Researcher	M (magnitude) Ranges for A Model	M (magnitude) Ranges for B Model	M (magnitude) Ranges for C Model
Abraseys and Zatopek (1969)	7,4	7,4	7,6
Douglas and Ryall (1975)	7,5	7,5	7,7
Patwardan et al. (1980)	7,4	7,4	7,6
Toksöz et al. (1979)	7,3	7,2	7,5
Wells and Coppersmith (1994)	7,5	7,4	7,7

Table 2a. Some Important Earthquakes in Marmara region (Gündogdu et al., 2002; Sayin et al., 2002).

Year	Location	Magnitude
1912	Sarköy – Mürefte	Ms = 7.3
1935	Marmara Adasi	Ms = 6.3
1953	Yenice – Gönen	Ms = 7.4
1957	Abant	Ms = 6.9
1963	Cinarcik	Ms = 6.3
1964	Manyas	Ms = 6.8
1967	Adapazari-Mudurnusuyu	Ms = 7.0
1975	Çanakkale	Ms = 6.7
1999	Gölcük	Mw = 7.6

Taurides created a compressional system which affects the region since Late Cretaceous. The Eastern Anatolia transferred to the N-S compression toward the west from Late Miocene onward. In this escape regime the North and East Anatolian strike-slip fault systems have played important roles. The N-S shortening deformation regime was replaced by an N-S extensional system in the western part of the Anatolian plate as a result of the escape tectonism. In this period, the crust reached excessive degrees of thickening which was generated from the Upper Mantle. The Marmara Region is located in North West Turkey and connects the Aegean Sea with the Black Sea. The sea of Marmara includes a series of tectonically active basins at the western end of the right-lateral North Anatolian Fault (Taymaz, 2000). It is 275 km long and 80 km wide with a broad shallow shelf to the south and a series of deep (up to 1250 m) sub-basins to the North (Taymaz, 2000). The most frequent and destructive earthquakes occurred in Turkey. Historical records show that the Anatolian Peninsula has experienced many major shocks that have damaged and destroyed urban centers. The Marmara Sea earthquake on September 10, 1509 destroyed Istanbul and was one of the largest earthquakes in the last 5 centuries. In the 20th century the most devastating earthquakes were: the magnitude 8 Erzican-Refahiye earthquake of December 26, 1939; the magnitude 7.1 earthquake 13 on March 13, 1992 near Erzincan which ruptured the same segment of the North Anatolian fault that broke in 1939 (500 dead, 2,000 injured, 60,000 homeless); the Golcuk earthquake of 17 August 1999 with a magnitude (Mw = 7.6 that caused more than 15,000 dead and 40,000 injured people and economic losses of about 16 billion USD (7% of GDP). The combined toll of these earthquakes, concentrated on the North Anatolian fault zone, is for the century 58.000 deaths, 116.000 injuries, and excessive building damages and monetary losses. Some important earthquakes in Marmara region are given in Table 2a.

In Table 2b, earthquakes were given in our area within 150km radius. Gutenberg-Richter recurrence relationships was determined as:

$$\text{Log}(N) = 2.55 - 0.58\,M \quad (2)$$

Earthquake occurrence probability were given in Table 2c by using $Rm = 1 - e^{-(N(M).D)}$ (3)

Where Rm = Risk value (%); D, duration; N (M) for M magnitude (2) equation value.

Attenuation relationship was defined by two attenuation models. From a set of attenuation relationships, the design acceleration values of the city was calculated as 0.43 g (for Joyner and Boore (1981) model) and 0.47 g

Table 2b. Earthquakes in the study area about 100km radius.

Magnitudes	4.5 ≤ M <5.0	5.0 ≤ M < 5.5	5.5 ≤ M <6.0	6.0 ≤ M <6.5	7.0≤ M <7.5
Numbers	54	15	9	2	1

Table 2c. Earthquake occurrence probability for region.

Magnitude	For D = 10 (Years) Probability (%)	For D = 50 (Years) Probability (%)	For D = 75 (Years) Probability (%)	For D = 100 (Years) Probability (%)
5	98.5	100.0	100.0	100.0
5.5	82.0	100.0	100.0	100.0
6	50.4	97.0	99.5	99.9
6.5	24.9	76.2	88.4	94.3
7	11.1	44.4	58.5	69.0
7.5	4.7	21.3	30.2	38.1

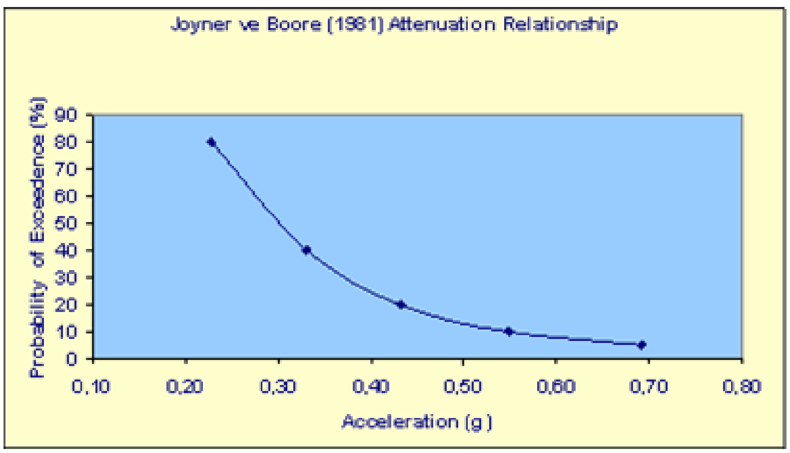

Figure 2. Hazard Curve for region by using Joyner and Bore (1981) attenuation model.

(for Campbell (1997) model) with exceeding probability of 20% in 50 years. Finally, a hazard curve for region was estimated (Figure 2). Estimated acceleration values for 7.6 magnitude and several epicentral distances was given in Table 2b.

GEOLOGY AND LOCAL SOIL CONDITIONS OF REGION

The geology and boring sites (200+) are shown in Figure 3. The geological information of region based on the detailed evaluation of existing geological maps and literature on the Northern Anatolia, Yalova and Sea of Marmara regions.

Geomorphologic information in the form of 1:25,000 scales topographic maps, stereo aerial photography and satellite imagery taken after the earthquake, were examined and evaluated. The most recent geological maps published by the General Directorate of Mineral Research and Exploration (MTA) in 1999 were constructed in digital format. These maps were used as a base to present study. The soil classification of the area is divided in to different type of site classes (A, B, C, D) according to the Eurocode. This information provides a summary of the ground conditions in the Yalova Province. All the superficial geology were considered to be either site class D (Quaternary deposits), whilst other sites was considered to be site class C, B and A (for example Yalakdere and Kilic formation).

Study area is characterized by very large Quaternary deposits, Tertiary Yalakdere and Kilic formation. Quarternary deposits consist of stratified materials having varied grain sizes, and derived from the various geological units in the vicinity (Yilmaz and Yavuzer, 2005). Flood plain sediments comprise fine sand, silt and clay, of Holocene age. Holocene marine swamp sediments overlie the marine marginal plain, and contain saturated clay and organic mud. Marine marginal plain sediments are f ormed of

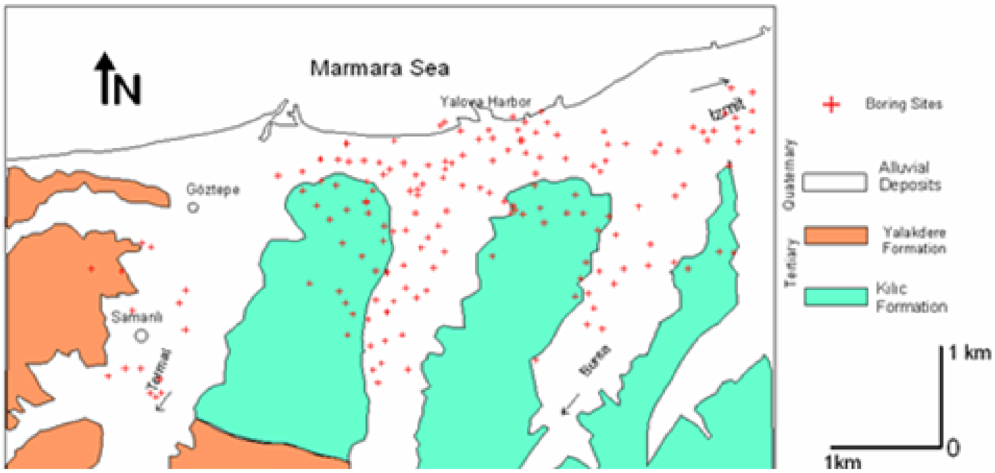

Figure 3. Geology of Yalova region and boring sites.

Table 3. Safety Factor (SF) and Risk Levels.

Risk level	Safety factor
Risky	>1,2
Critical Risk	0,8 < SF < 1,2
No Risk	0,8 <

of sand, silt and clay-size materials. These deposits were also widespreadly observed near to the sea. Holocene beach sediments were observed overlying all the other units near to the Marmara Sea, and contain gravel, sand and silt materials.

Partly well-bedded and thin-bedded, the yellowish and brown-grey colored Kilic formation crops out widely in the study area (Yilmaz and Yavuzer, 2005). This formation occurs as an alternation of claystone, siltstone, conglomerate and marl.

The age of this unit is Miocene, and located in the south of the study area. The Kilic formation forms the high topography trending S-N such as ridges cut by the valley perpendicular to the sea coast, in the study area (Yilmaz and Yavuzer, 2005).The Kilic formation is located in the south of the study area and shows a consisting of claystone, sandstone, siltstone, conglomerate and marl. This formation forms the ridges which are perpendicular to the Marmara Sea. Quaternary deposits overlie the Kilic¸ formation with a disconformity (Yilmaz and Yavuzer, 2005).

From the available records of the boreholes drilled in different locations throughout the study area, it is evident that the groundwater table is generally very shallow. The ground water level generally fluctuates between 0.5 and 3.0 m below the surface as seen in static groundwater depth map (Yilmaz and Yavuzer, 2005). Groundwater table map of region is in Figure 4.

VARIATIONS OF LIQUEFACTION SAFETY FACTORS DEPENDING ON SEVERAL DESIGN EARTHQUAKES

In this study safety factors are classified as shown Table 3. Variations of liquefaction safety factors depending on several design earthquakes are shown in Figure 5a - j.

RESULTS AND DISCUSSION

Earthquake hazard analysis of region with field (SPT and groundwater depth) and laboratory (index properties) data and analysis were integrated to evaluate the liquefaction resistance of the saturated soils in the city of Yalova. Because groundwater levels in the region (Figure 4) are shallow in the locations near to the Marmara Sea, these levels may effect to as one of the main trigger factor of the occurrence of liquefaction during an earthquake.

A simple and practical approach which is called as liquefaction safety factor has been presented for the evaluation of liquefaction hazard in saturated sandy soils of Yalova (Turkey) region. The proposed approach requires variations of safety factors depending on several design earthquakes parameters. By the present approach it may be possible to characterize the liquefaction boundary line that separates liquefaction from non- liquefaction regions.

The magnitudes and acceleration values of the earthquakes in hazard analysis were respectively chosen as 6.5, 7.0 and 7.5 (magnitudes), and as 0.25, 0.30, 0.35, 0.40, 0.45 and 0.50 g (accelerations). When the magnitudes and the acceleration values were exceed 7.5 and 0.3 g values, shore sides of the study area will be under the liquefaction risk (as shown in Figure 5 a-j).

When the saturated soil conditions, geologic and geomorphologic features were considered together with liquefaction analysis (Figure 3, 4 and 5a-j), it conclude

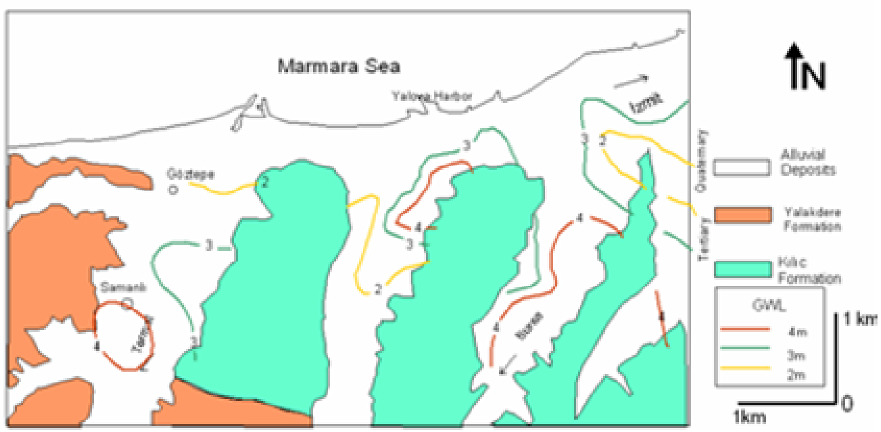

Figure 4. Ground water level map (from the surface) of Yalova region.

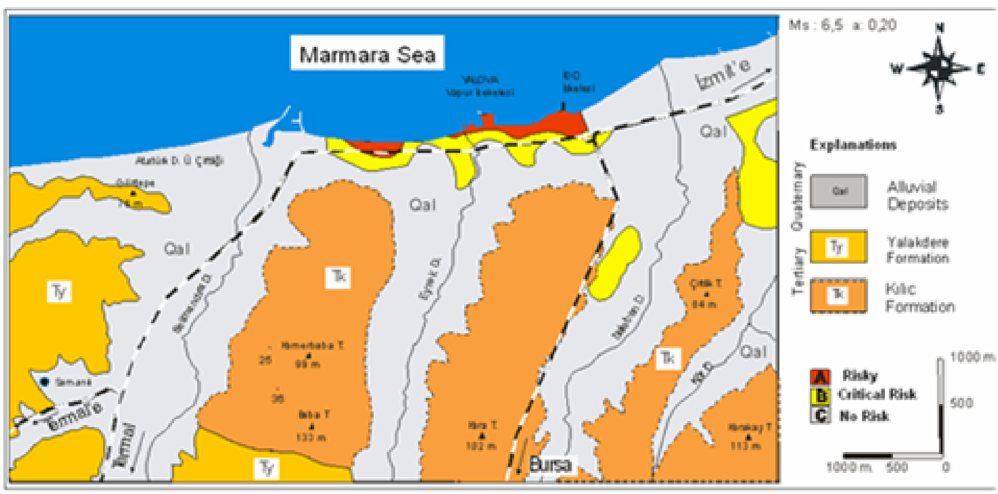

Figure 5a. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 6.5 and acceleration (a):0.2 g.

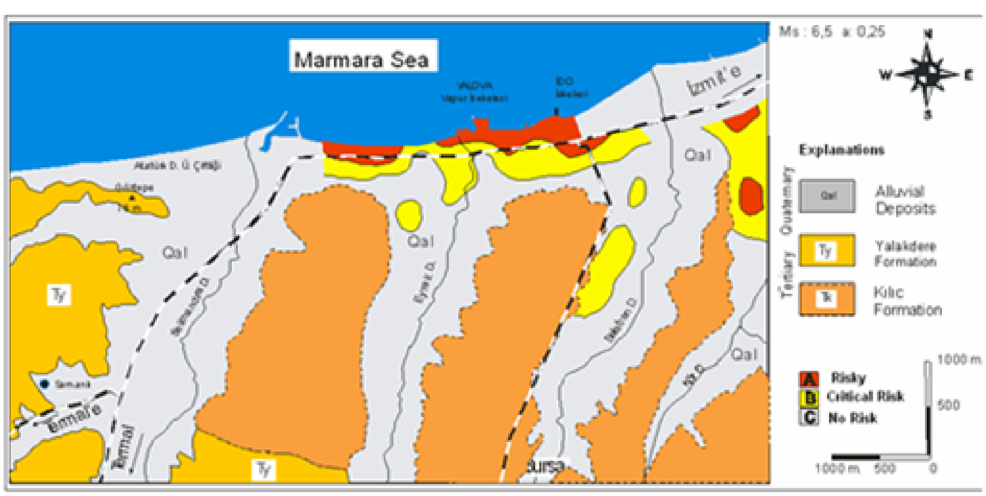

Figure 5b. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 6.5 and acceleration (a):0.25 g.

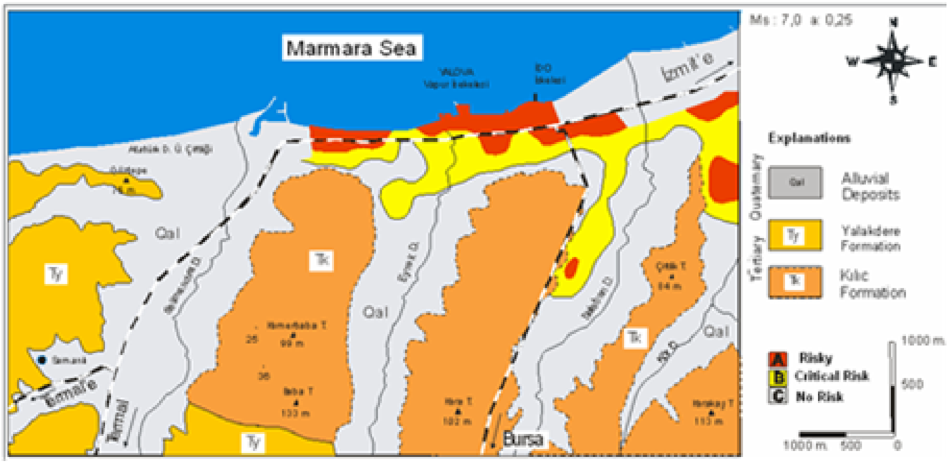

Figure 5c. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.0 and acceleration (a):0.25 g.

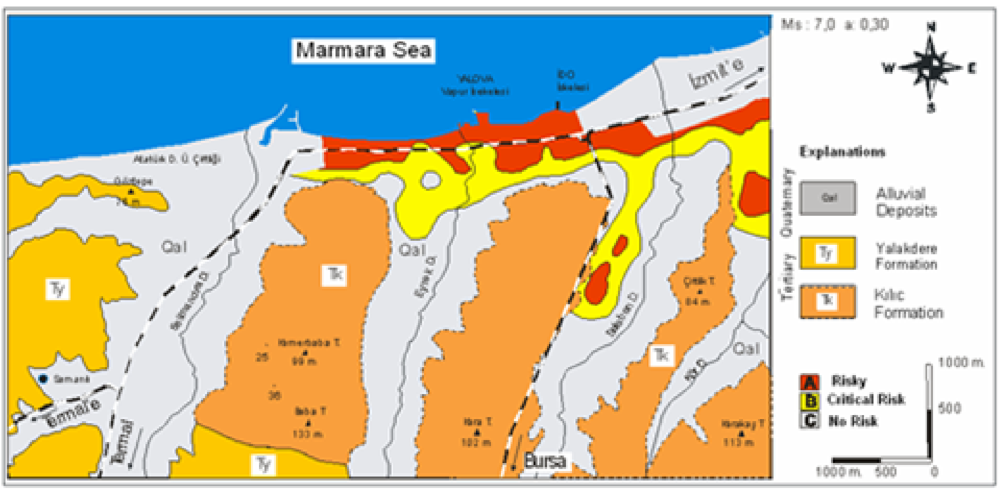

Figure 5d. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.0 and acceleration (a):0.3 g.

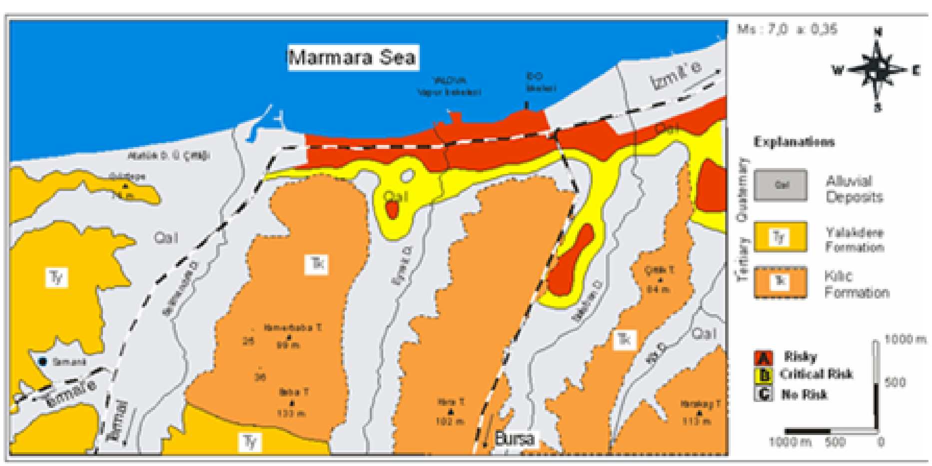

Figure 5e. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.0 and acceleration (a):0.35 g

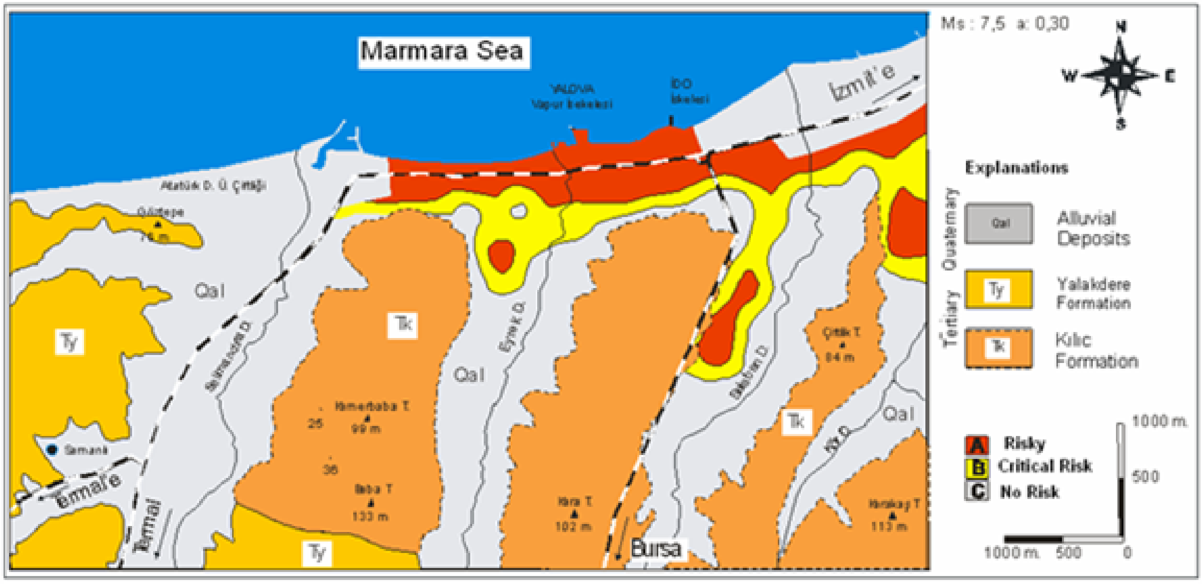

Figure 5f. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.5 and acceleration (a):0.3 g.

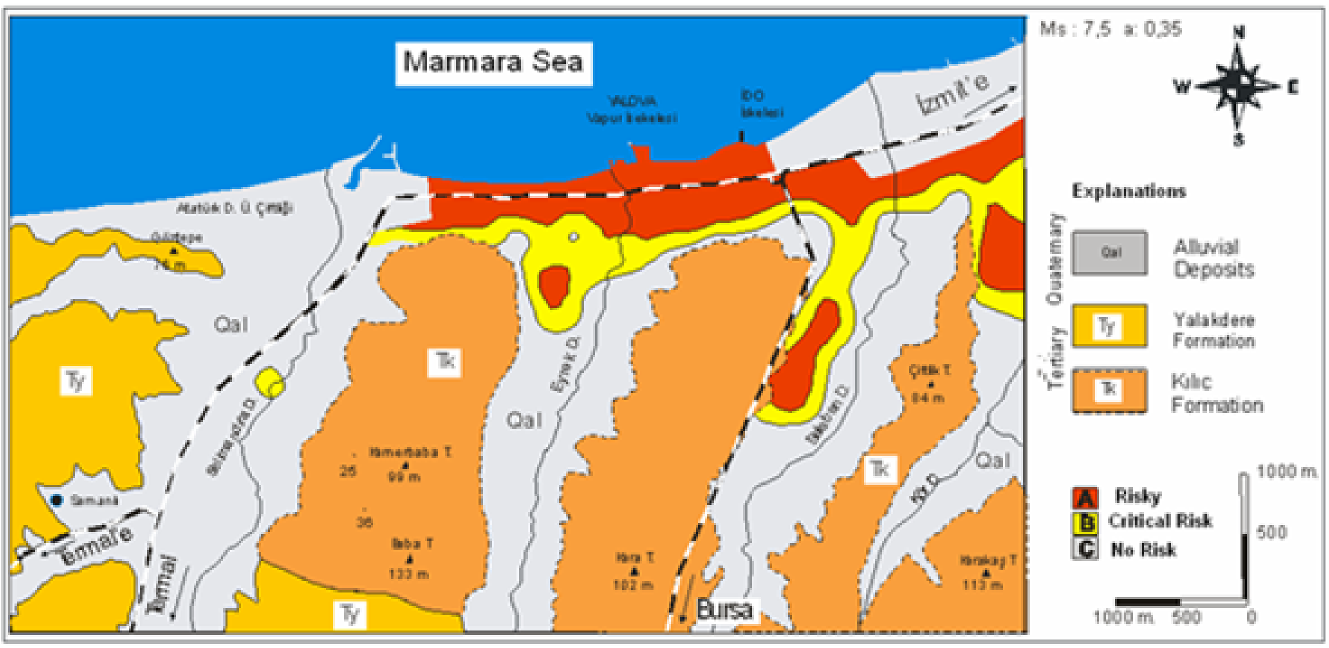

Figure 5g. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.5 and acceleration (a):0.35 g.

that some part of Quaternary deposits of the study area is having from critical risk to risky liquefaction levels (criteria according to Table 3) with increased design earthquake values.

As Lubkowski et al. (2002) and Yilmaz and Yavuzer (2005) point out, the highest risk is in the recent superficial Quaternary deposits, such as beach, coastal, delta, levee and flood plane deposits, whilst the lowest risk is in older Quaternary deposits (example, upper and lower terrace deposits) and the solid geology inland. In addition to this, the size of earthquake magnitude and acceleration is also important factor to occurrence or to realize the liquefaction event.

Estimation of the liquefaction-induced ground settlements, local site effect (by different kind of geophysical data) and its relation to the earthquake damage for Ya-

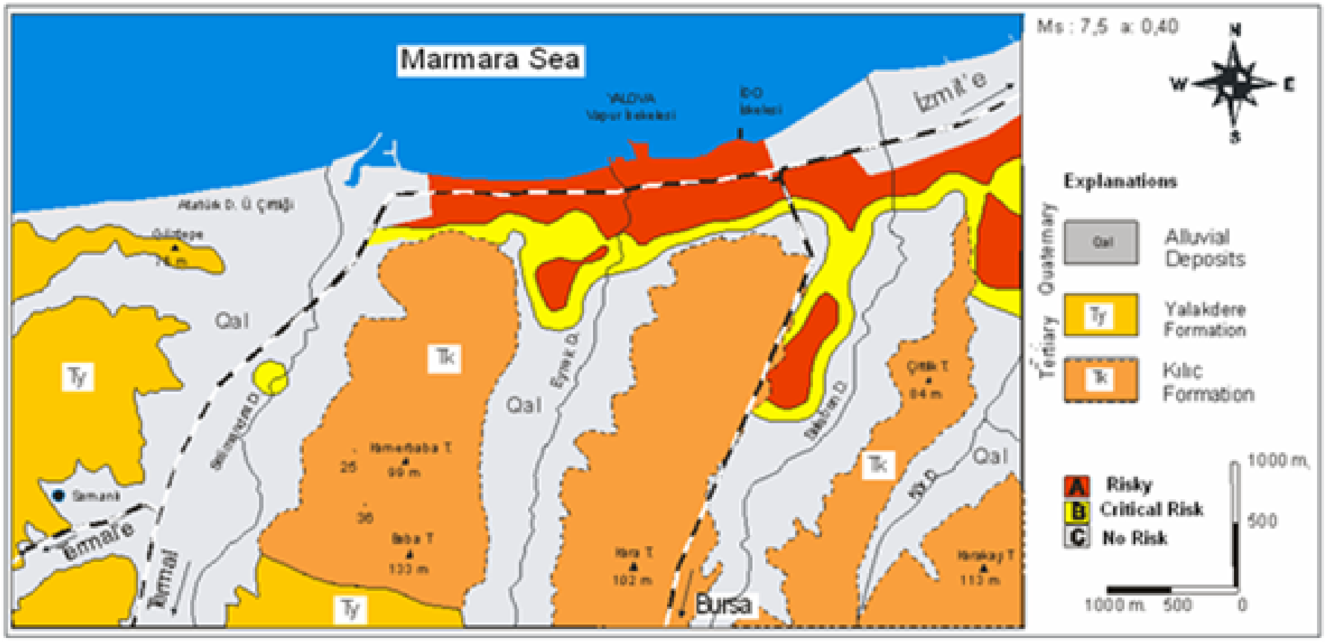

Figure 5h. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.5 and acceleration (a):0.4 g.

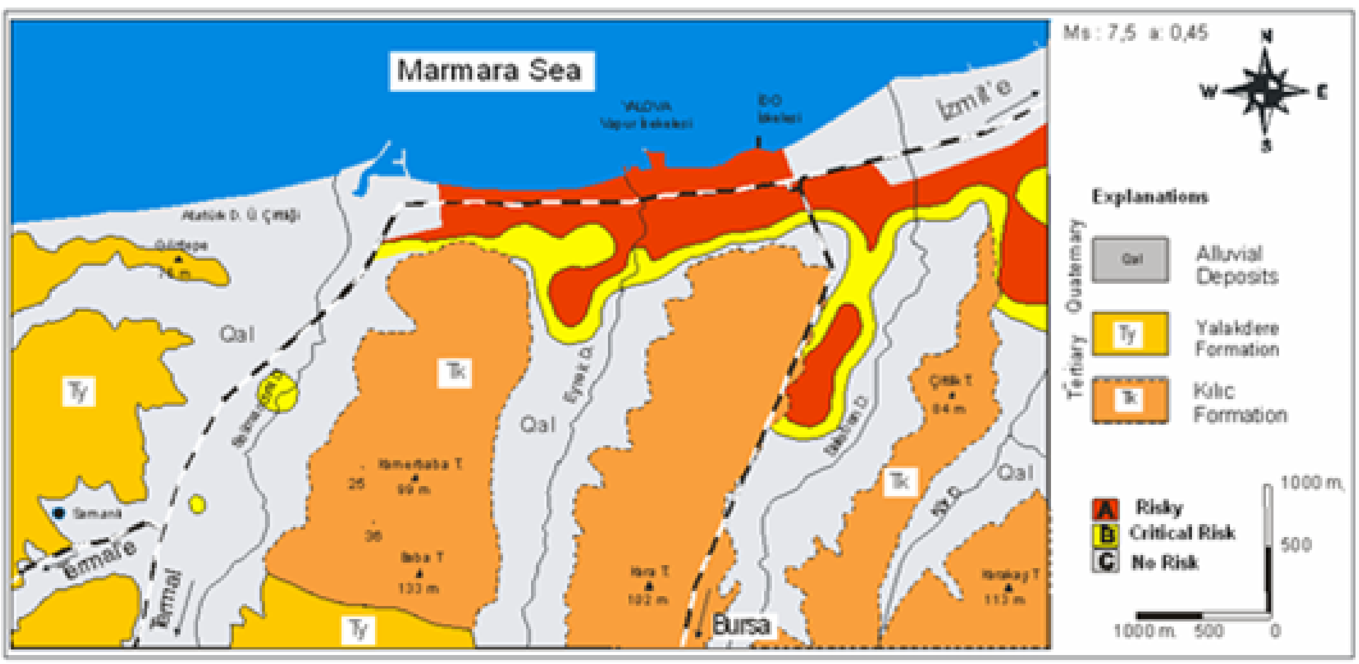

Figure 5i. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.5 and acceleration (a):0.45 g.

lova city must also be carried out in detail in order to prevent the occurrence of soil problems of engineering structures in the future.

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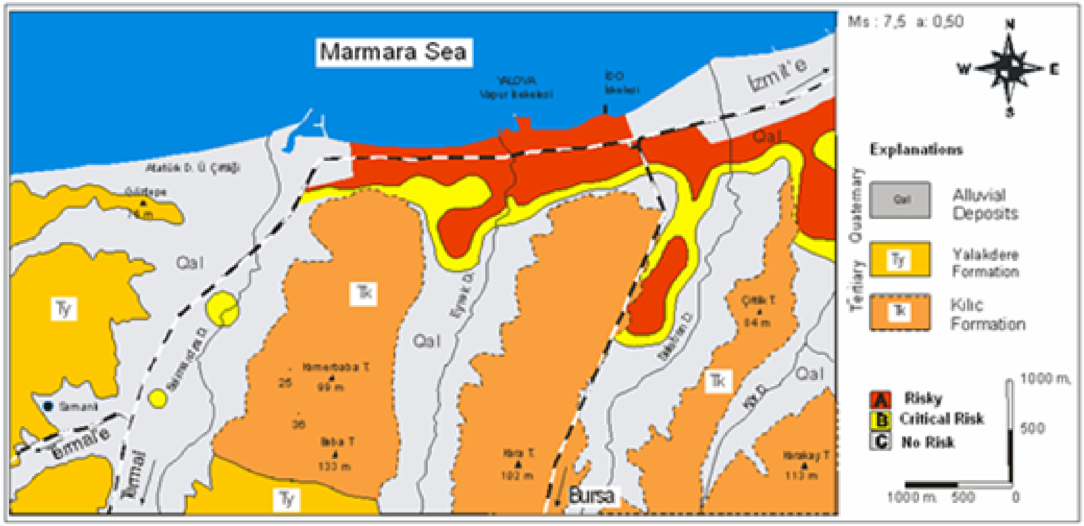

Figure 5j. Variations of liquefaction safety factors depending on earthquake magnitude (Ms): 7.5 and acceleration (a):0.5 g.

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