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A pilot seismic microzonation study for Istanbul

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ABSTRACT: In urban centers the earthquake hazard is usually quantified and portrayed in terms of microzonation maps. The microzonation maps and the land use requlations are important long-term tools in the mitigation of earthquake risk. The paper reviews the past microzontion studies in Turkey, covers a summary of the current understanding of the issues involved and provides a pilot study for the microzonation in Istanbul.

1 EARTHQUAKE MICROZONATION STUDIES IN TURKEY

The first comprehensive applications of the earthquake hazard microzonation in Turkey were conducted in connection with the UNDP/ UNESCO Project on the Survey of the Seismicity of the Balkan Region (UNDP, 1974). In this context, applications involving the Medvedev's method and the Kanai's method were utilized.

The microzonation studies conducted at Eskel, Turkey (Ergunay and Bayulke, 1974) utilized the Medvedev's method. Medvedev (1965) attempted to relate the increments of seismic intensity to seismic site rigidity (P-wave velocity times the density) and to the elevation of the water table. The intensity increments for the basic categories of the ground with respect to bedrock (granite) is found to vary from 1 (moderately firm ground) to 3 (loose fill) with an additional increase of 1 unit for cases where the water table is at the foundation level. The experience with the direct application of the Medvedev's method were not always favorable. In this respect it is worth mentioning that, the microzonation of Bucharest, Romania (UNDP, 1974), which is based Medvedev's method, was tested by the 1977 (M=7.2) Vrancea earthquake (Balan et al., 1982) with rather unsatisfactory correlations between the predicted and the observed results (Erdik et. al,1991).

The microzoning studies conducted at Izmit, Turkey (Gencoglu and Ayhan, 1974) involved the measurement of the microtremors and the site classification on basis of the Kanai's method. From analyses of microtremor records obtained at over 1000 locations in a wide variety of soil conditions, Kanai (1961, 1966) discovered that the time and frequency domain wave shapes of microtremors are distinctly different in different soil conditions ranging from hard rock to loose fill. On the basis of these findings Kanai proposed two methods for the purpose of microzoning. One method attempts to delineate the four soil zones on the basis of the largest period and the mean period of the microtremors. The other one does the same using the largest amplitude and the predominant period of the microtremor measurements. The critics of this method claim that the micro-tremors originate at shallower depths and follow different propagation paths compared to earthquakes. In certain cases the microtremor measurements may be nonstationary over different periods of the day and yield more information about the excitation than the transfer characteristics of the media. Furthermore, the microtremor data can provide information only on the low-strain behavior of the medium, and require careful interpretation in assessing the strong motion response characteristics of the site.

2 CONTEMPORARY UNDERSTANDING IN MICROZONATION

Seismic microzonation maps can be defined as maps providing estimates of parameters needed for the siting and the earthquake resistant design of civil engineering structures and systems. A seismic zonation map uses empirical and observational data in connection with a physical model to provide these estimates. Microzonation for earthquake hazards has the potential to serve as guides for safer land use and construction. The microzonation procedures should combine a multitude of information to achieve an optimum solution to the problem of mitigating earthquake hazards. Microzonation studies, as such, involve the determination of pertinent site characteristics and their incorporation in the design of structures and systems. The necessary information that should be conveyed by an earthquake hazard based microzonation map are: modification of the strong ground motion by site conditions, earthquake induced soil failures and terrain movement, and tectonic surface ruptures.

The incorporation of the "Modification of the Ground Motion by Ground Conditions" in the microzonation maps in a quantitative manner is a controversial issue. In this regard there have been analytical, empirical and experimental (observational) approaches. Earthquake engineering has documented that the damage distribution is generally site-dependent. The structures founded on unconsolidated material frequently receive greater damage. The immediate vicinity of lateral discontinuities, contact zones between highly contrasting formations, top of isolated hills, elongated crests, edges of plateaus and cliffs are usually the zones of amplification. Several researchers have shown that, the relative shaking response will be greatest where the surface geologic units have the lowest impedance values and where the impedance contrast between the surface layer and the underlying one is the greatest. Joyner and Fumal (1985) have incorporated the local S-wave velocity the assessment of site effects on PGA and PGV. Thus, the maps that characterize the local S-wave velocities should provide a first approximation to the relative shaking response. By use of microtremor data the relative response of different points in the region can be assessed. Nuclear explosions and micro-earthquakes can beneficially replace the microtremor data (Roger et al., 1985). Analytical procedures can also be used for the determination of the site response. These methods range from simple one-dimensional calculations to three-dimensional, linear/non-linear, time/frequency domain and finite difference/element computations. Several micro-zonation maps have been prepared using one-dimensional non-linear analytical procedures, especially in Japan. These maps provide the predominant periods and PGA's for given reference accelerations. The success of these analytical procedures should await for the collection of an adequate sample of strong motion data.

The earthquake induced soil failures are liquefaction, loss of strength and densification. Techniques to evaluate the liquefaction potential involve the preparation liquefaction susceptibility and shaking opportunity maps. These two maps are merged to depict the liquefaction potential. Landslides, rockfalls, and subsidence are earthquake induced terrain movements. Materials that are most susceptible to earthquake induced landslides are: weakly cemented, weathered and/or fractured rocks; loose unsaturated sands; and sand and gravel with layers sensitive clay. The probability that a landslide will occur on a particular slope during a particular earthquake is a function of both the pre-earthquake stability of the slope and the severity of the earthquake ground motion. The surface expressions of Quaternary faults should be included in the microzonation maps to avoid (or to accommodate) their effects.

3 EARTHQUAKE HAZARD IN ISTANBUL

A rational earthquake hazard assessment methodology for any urban area should provide for the uncertainties associated with the input parameters and be based on appropriate stochastic models. The probabilistic hazard assessment methodology that will be employed for Istanbul will be an updated version of the one incorporated in Erdik et al.(1985). Subsequent to the acquisition of pertinent geo-tectonic and seismologic data and seismic source modeling, the methodology can be described on the basis of the following key steps and parameters:

1. Source seismicity information step involves the construction of recurrence relationships. Log-linear recurrence relationships will be developed after an artificial homogenization process to account for the deficient data.

2. Development of intensity-based local attenuation relationships. Careful evaluation, identification and adoption of world-wide strong motion data-based ground motion attenuation relationships.

3. Use of a proper stochastic model for recurrence forecasting.

For the last step homogeneous Poisson process will be used. The pro's and con's of this process and its comparison with others are documented in Erdik et al.(1983 and 1985).

Figure 1 shows the active tectonic elements to be considered for the earthquake hazard assessment for Istanbul. The epicentral distribution of earthquakes with magnitudes grater than 5 are indicated in Figure 2. For the intensity based hazard assessment a regional intensity attenuation relationships developed by Erdik et al.(1983 and 1985) will be used. For the peak ground acceleration (PGA) based hazard assessment the PGA attenuation relationships developed by Campbell (1981) are found to be appropriate on the basis of the comparisons with the available Turkish data (Erdik et al., 1985).

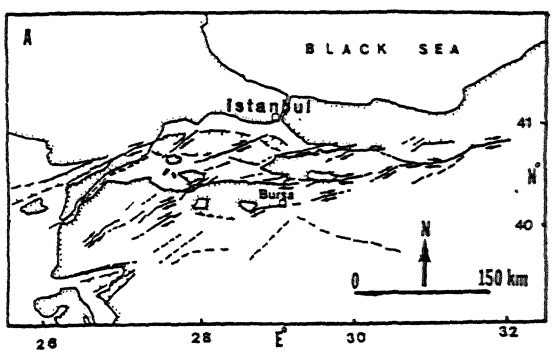

Figure 1. Distribution of active fault segments of the North Anatolian fault zone in the Marmara region, south of Istanbul.

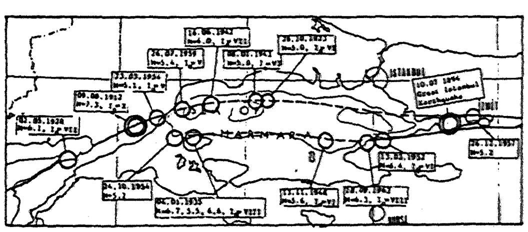

Figure 2. Seismicity of the Marmara region for the period of 1900-1992. Only eartquakes with magnitude greater than 5 are considered.

Figures 3 illustrates the variation of MSK Intensity and the PGA (at competent rock outcrop) in Istanbul for different annual probabilities of exceedance.

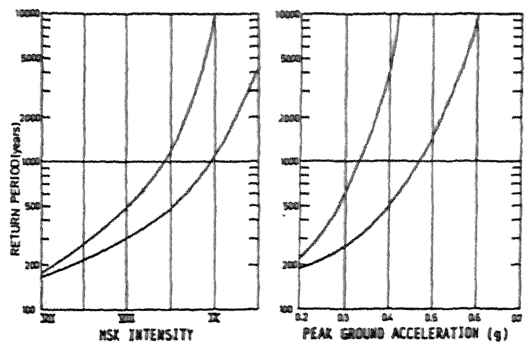

Figure 3. Variation of MSK Intensity and PGA (in g's) at competent rock outcrop in Istanbul for different annual probabilities of exceedence.

4 A PILOT STUDY OF MICROZONATION FOR ISTANBUL

As a pilot study, the microzonation of the Istanbul Peninsula within the city-walls, will be considered. Istanbul, with a population of over 8 million people and hosting the largest industrial and economic activity in Turkey, has been frequently subjected to destructive earthquakes. Ambraseys (1971) indicated that the recurrence interval of damaging earthquakes for Istanbul over 2000 years is about 55 years. Furthermore, the region to about 20km south of the city has been identified as a seismic gap (Barka and Toksoz, 1989).

The peninsula is made up of three ridges (Figure 4): two of which trend NW-SE with a maximum elevation of 60-70m, and the third one (Sarayburnu) trends NE-SW with an elevation of about 40m. Old landslides, which were interpreted from areal photographs, occur along the Marmara Sea coast and along the cliffs of the Golden Horn. The oldest geological rock unit is the intensely fractured and folded early Carboniferious sandstone-shale (Figure 5) with a 2-18m thick weathering zone (Aksoy 1982). It is overlain by the late Miocene age continental-shallow marine deposits. Lower part of this sequence comprises of sand and gravel and its thickness varies from a few meters to over 20m. A clay-Marl formation overlies this unit. The thicknesses of these deposits decrease from West to the East from 120m to 6m (Sayar and Sayar, 1962). Mactra limestones, interbedded with clay and sand, is the upper unit of the late Miocene and crop out between Yedikule and Topkapi. Main Ouaternary deposition, fine grained sand and silt, and artificial fills reach 60-70m thicknesses along the Golden Horn, dropping down to 10m along the coast. 3-7m thick artificial fills have also been observed from the well-logs and excavations on the ridges between Beyazit and Sultanahmet (Figure 6). From aerial photographs two probable NE-SW trending faults within the Carboniferious rocks can be interpreted at each side of Topkapi Palace. S-wave velocities of these formations are 365þ100 m/s for Quaternary deposits, 750m/s for the Mactra limestone, 365 þ50m/s for clay and marl and 330þ75m/s for sand/gravel (Ercan and Is,1991).

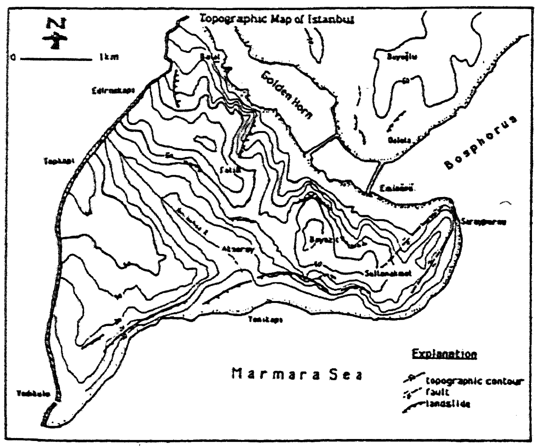

Figure 4. Morphological map of Istanbul, Contours are in 10 meter interval.

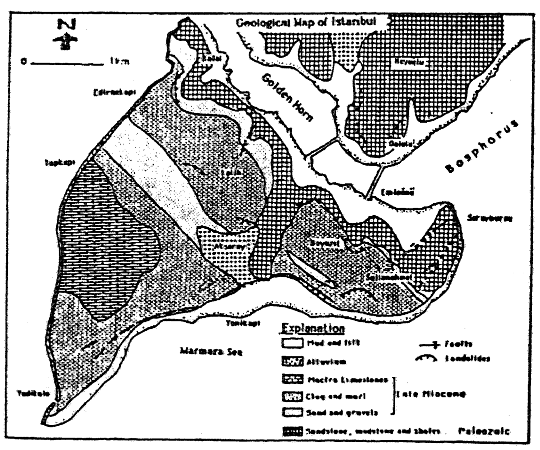

Figure 5. Simplified geological map of Istanbul.

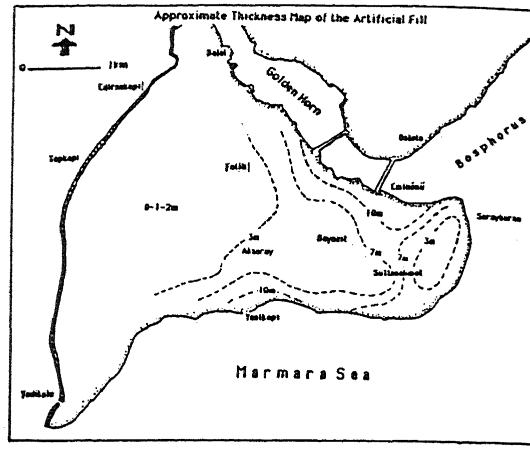

Figure 6. Aproximate thickness map of the artificial fills in Istanbul.

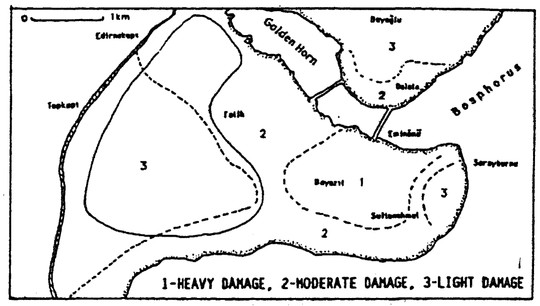

Figure 7. Approximate damage zonation map for the 1509 and 1894 earthquakes in Istanbul. (Solid contours are for the 1509, solid contours are for the 1894).

Two preliminary damage zone maps for the 1509 and 1894 earthquakes, based on the damage information in Ambraseys and Finkel (1990), are presented in Figure 7. The damage zoning for the 1509 earthquake can be misleading due to the biased concentration of buildings and in the walled area. The 1509 earthquake was one of the largest earthquakes (M·7.4) in Istanbul, killing about 5000 and injuring 10.000. Every single house had some degree of damage, in some places the ground opened up and sand ejected and a 6m high sea wave occurred. In the 1894 earthquake (M=6.7, I=VIII) most damage took place on the Fatih-Beyazit ridge and slumping observed in Eminonu. The Grand Bazaar had heavy damage due to its "loose fill" type ground condition. Both earthquakes were in the Marmara Sea and related to the movement of the North Anatolian fault zone.

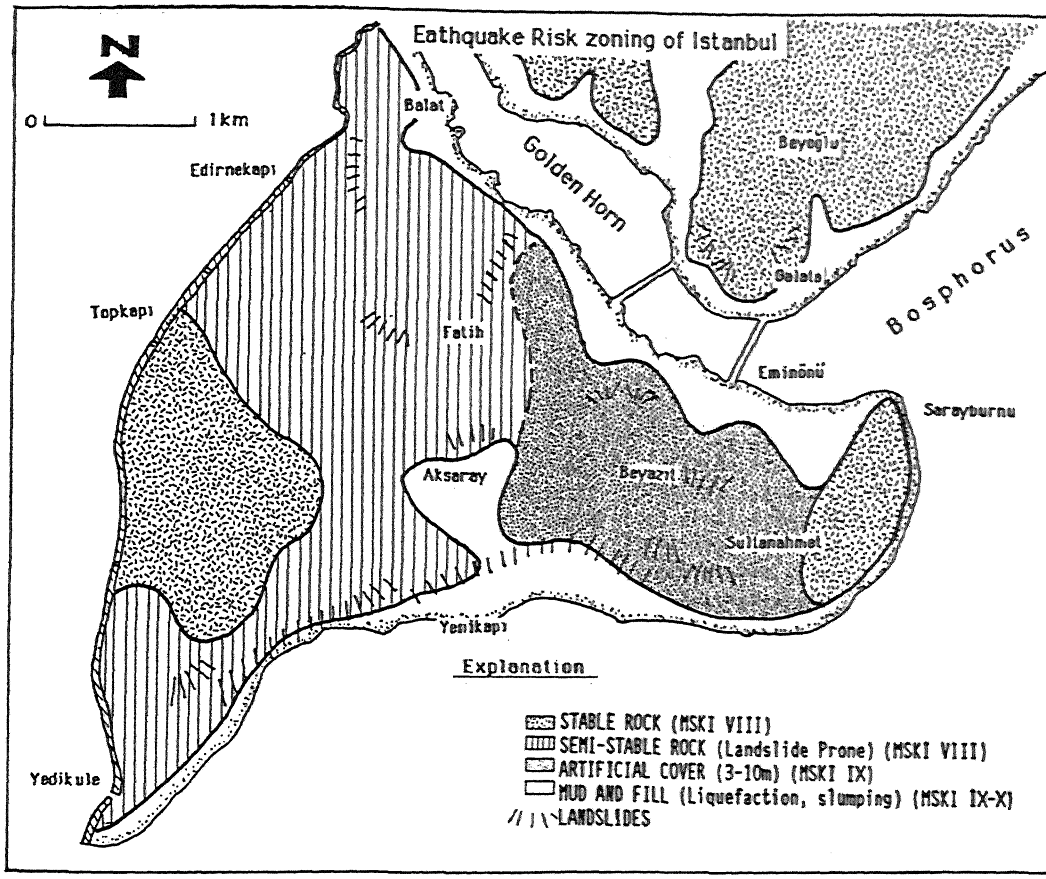

Figure 8. Preliminary microzoning map of Istanbul.

The preliminary microzonation effort covered in this study will be based on morphology (Figure 4), geology (Figure 5), distribution of artificial fills (Figure 6), damage distribution in significant historical earthquakes (Figure 7), and some limited geophysical and geotechnical data. Figure 8 illustrates our interpretation of four earthquake hazard zones. The stable rock zone defines some part of the Carboniferious rock (where the artificial cover is little or none) and the late Miocene Mactra Limestone. The semi-stable zone represents mostly late Miocene sand and gravel, and clay and marl. In this zone ground shaking hazard is somewhat increased and slopes are prone to land sliding. The zone encompassing the thick artificial cover will be subjected to increase in the ground shaking. The zone of mud and fill delineates potential of ground failures such as liquefactions, fissuring and slumping. In Figure 8 the locations of potential earthquake induced landslides are also illustrated. It should be noted that, in the stable rock zone there might be local problems due to fracture planes versus slopes (e.g. fault and joints) and ground shaking may increase depending on the thickness of the weathering zone.

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