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LIQUEFACTION CRITERIA FOR THE WESTERN ANATOLIA-TURKISH AEGEAN REGION

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ABSTRACT

The western Anatolia including the Aegean coastline of Turkey with highly populated commercial, agricultural, industrial and touristic centers is one of the seismically most active and vulnerable regions in the world. The study proposes a range of design earthquakes, M=6.5 - 7.5 and a_h(max)=0.4 - 0.5g for the subregions of the region with probability of 90% not being exceeded in 50 years based on the recently reported works by others (Erdik *et al.*, 1985; Gulkan *et al.*, 1993). For these design earthquakes, liquefaction criteria have been developed for the geotechnical engineer for saturated clean sands as well as silty sands. It is disclosed that for the particular high magnitude and acceleration ranges liquefaction criteria are insensitive to "minor" variations in these parameters, and thus a rigorous determination of the design earthquake for the subregions is not warranted for this objective.

KEYWORDS

Liquefaction, design earthquake, western Anatolia

INTRODUCTION

Seismically the western "edge" of Anatolia including the Turkish Aegean coastline in the eastern Mediterranean has been one of the most active and vulnerable areas in the world. This may be observed from Fig. 1 which depicts the recent (1968-1983) seismic events in Turkey. The same region on the other hand contains the greater portion of population centers in Turkey and is associated with a fast developing industrial and commercial economy. With the increasing tourism industry along the Aegean coastline, construction of multi-story buildings and infrastructure including highways, bridges, airports, waterfront structures, etc., have also grown at an accelerating pace during the last decade. Through a continuing process, structural engineering aspects of earthquake-resistant design requirements are being incorporated in the State Building Code. It is the intent of this paper to provide parallel input on the most relevant geotechnical-earthquake engineering design component, namely liquefaction.

For the purpose of this study, the western Anatolia-Turkish Aegean region is defined as that land area bounded between longitudes 26E and 30E, and latitudes 36N and 41N degrees as depicted in Fig. 1. In the region, natural deposits of very loose to medium dense, saturated sand and silty sands, as well as man-made fill soils of similar gradation which would be classified as liquefaction susceptible, are abundantly present. The paper provides criteria for the geotechnical engineer to determine liquefaction susceptibility of sand/

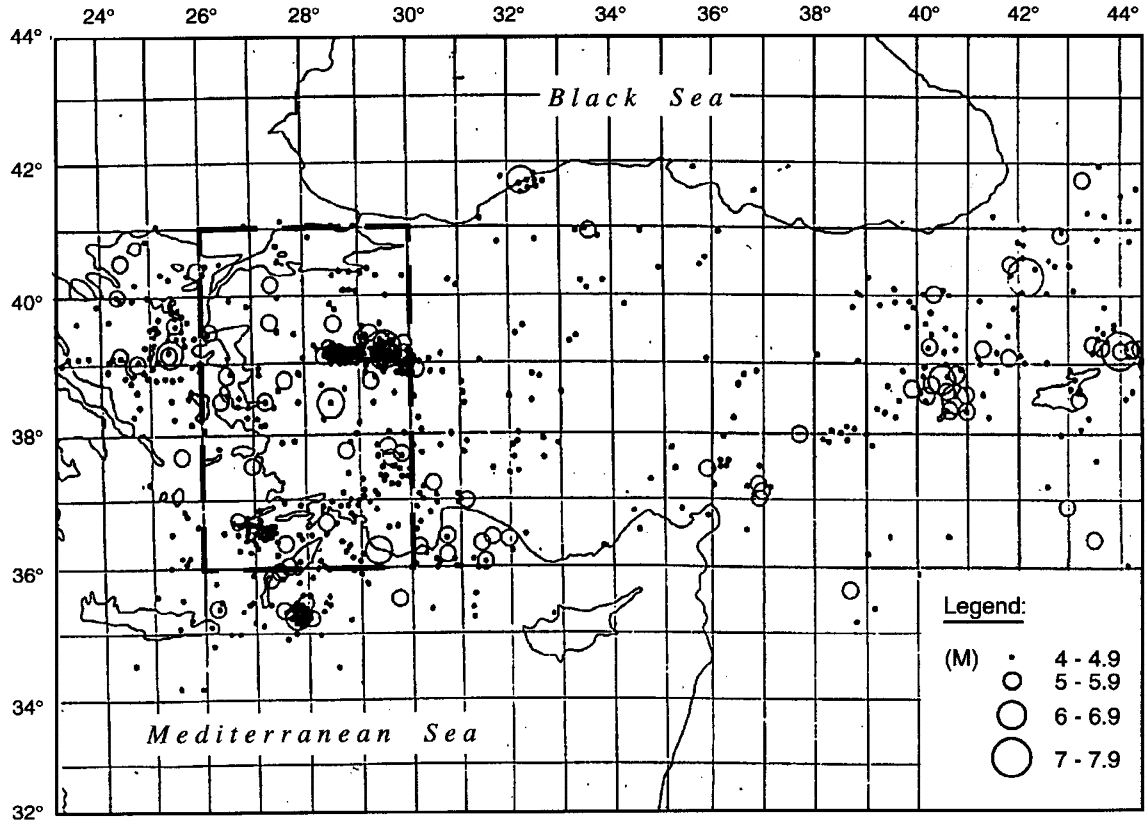

Fig. 1. Seismic events in Turkey during 1968-1983. (after Erdik *et al.*, 1985)

silty sand deposits and fill soils relative to the regional seismicity. Utilization of the criteria for a project site requires simply representative test boring data, including Standard Penetration Test (SPT) records (i.e., blow counts or N-values) and the groundwater level relative to the ground surface, which are routinely obtained during the course of a subsurface exploration program for foundation engineering evaluation. The criteria developed are based on the principles and methodology established by Prof. H.B. Seed and his co-workers (Seed and Idriss, 1971; Seed *et al.*, 1985) progressively at the University of California-Berkeley during the period of 1965 - 1985.

REGIONAL SEISMICITY

General

In the "larger" picture, Turkey lies within the Mediterranean segment of the Alpine-Himalayan orogenic system. Three primary plates affect the tectonics of the Mediterranean region, namely: The African plate, the Eurasian plate, and the Arabian plate. In the "smaller" picture of the eastern Mediterranean, the seismotectonics is more complex and the existence of secondary but rapidly moving micro-plates has been introduced in the various models proposed for the region (Erdik *et al.*, 1985). These micro-plates, depending on the particular model, include the Aegean (or Peloponnisian) and the Turkish (or Anatolian) plates with a poorly defined boundary, and even smaller plates in the Aegean, including from north to south the Rhodopean, Olympus, Saros, northern Anatolian, western Turkey, and Taurus as depicted in Fig. 2 (Papazachos, 1974).

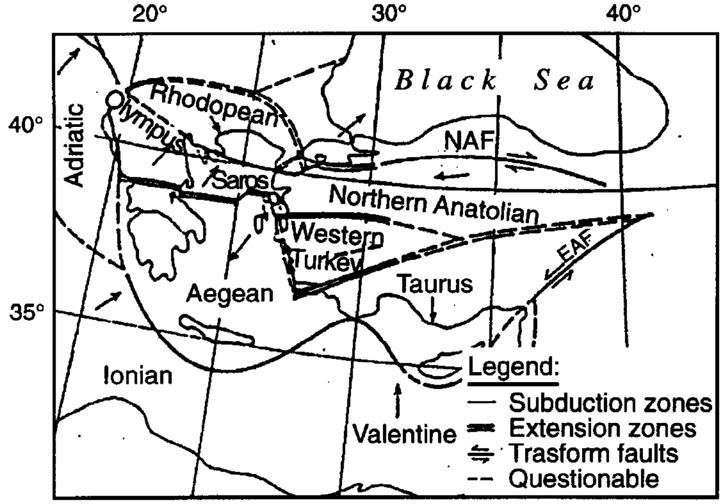

Fig. 2. Plate tectonic model for the eastern Mediterranean. (after Papazachos, 1974)

Seismic Sources

Erdik *et al.* (1985) proposed the seismic source model reproduced in Fig. 3 for the western Anatolia-Turkish Aegean. These source zones from north to south are reviewed very briefly below.

No. 1 - Anatolian Through is the western extension of the very active North Anatolian Fault. It also includes the Izmit-Sapanca and Gemlik-Iznik grabens. No. 5 - Chios and Lesbos zone extending from Gulf of Edremit to the south of the Izmir peninsula is associated with numerous small grabens and other tectonic structures. Nos. 6, 7, and 8 - West Anatolian graben complex which has exhibited intense seismic activity historically, consists of the east-west trending grabens bounded by high angle normal faults. While some models suggest that the grabens terminate shortly beyond the Aegean coastline, other models suggest that they extend beneath the Aegean as troughs. No. 9 and No. 10 - Cyclades and Fethiye source zones are associated with a Tertiary-Quaternary volcanic arc extending from west (Thebes) to east into southwestern Anatolia and terminating at the stress concentration area around Fethiye (Erdik *et al.*, 1985).

In Fig. 4, large earthquakes with M≥6.0 which occurred during the period from 1904 through 1983 in the region under study are presented.

DESIGN EARTHQUAKE FOR THE REGION

Geotechnical earthquake engineering evaluation of a seismically active region requires an assessment of liquefaction susceptibility of the natural deposits of relatively loose saturated sands, silty sands as well as the man-made cohesionless fill soils. Manifestation of liquefaction could be loss of bearing support for shallow foundations, seismically induced settlements, lateral spreading and flow slides affecting deep as well as shallow foundations, or a combination of the above, depending on the site topography, subsurface profile and natural or constructed physical boundaries. In all of the above described phenomena liquefaction is the triggering element.

In evaluation of liquefaction susceptibility the earthquake induced ground shaking (driving mechanism) is defined relative to its intensity and duration. Intensity is represented by the magnitude of the horizontal peak ground acceleration, and the duration or the number of the significant cycles of the shear stresses

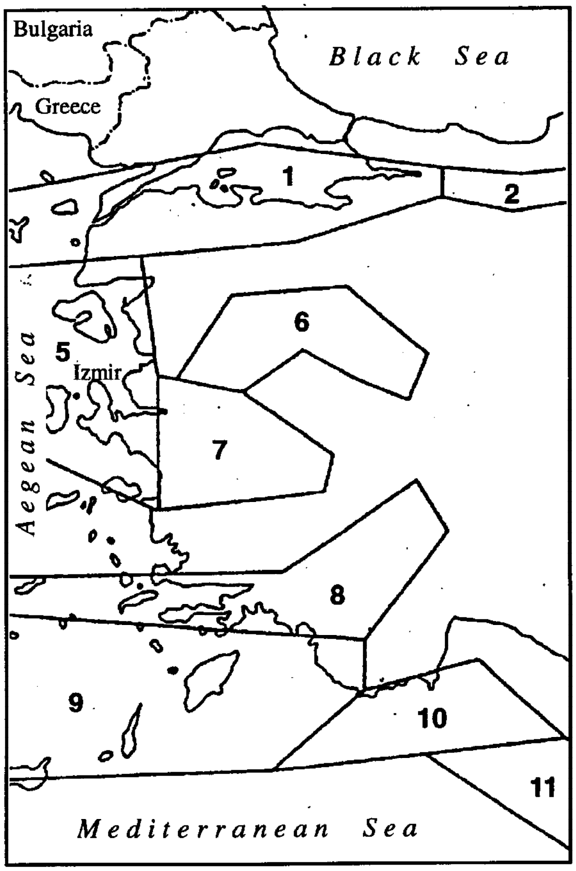

Fig. 3. Seismic sources for the western Turkey-Turkish Aegean. (after Erdik *et al.*, 1985)

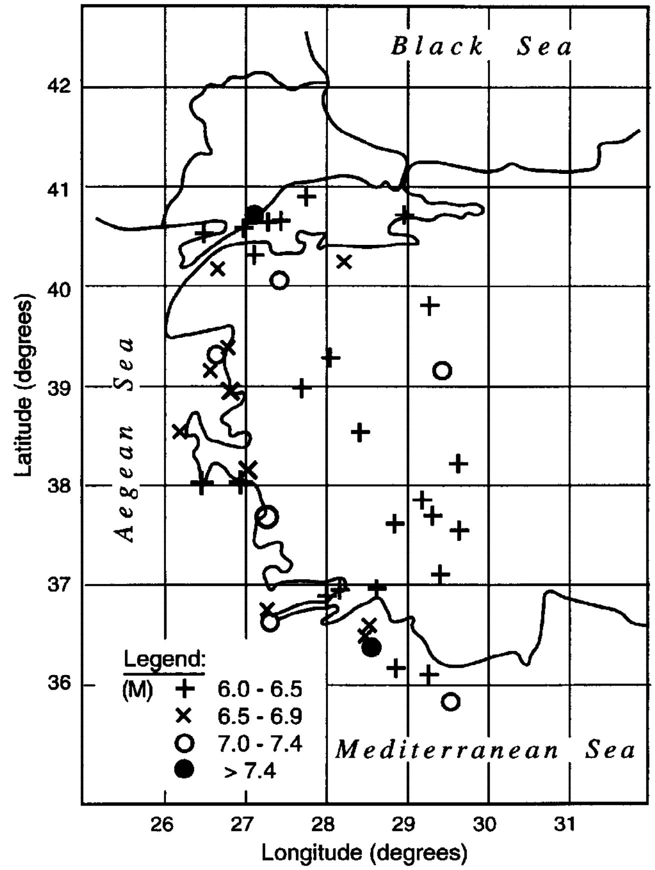

Fig. 4. Large (M≥6.0) earthquakes affecting the western Anatolia-Turkish Agean (1904-1983). (data after Erdik *et al.*, 1985)

generated by the vertically propagating shear waves is related to the magnitude of the earthquake (Seed and Idriss, 1982).

In establishing the peak horizontal ground acceleration and magnitude of the design earthquakes for the region, the probabilistic approach was adopted. Following the generally accepted criteria in current practice for earthquake resistant design of buildings and infrastructure (NEHRP, 1994), the "design earthquake" was selected to be one having a peak horizontal ground acceleration whose probability of not being exceeded is 90% during a design life of 50 years. This is also referenced as the 50-year earthquake, and probabilistically it has a return period of 475 years.

Recently, Gulkan *et al.* (1993) developed probabilistic peak horizontal ground acceleration (seismic hazard) maps for Turkey. In developing these maps, they synthesized all available geologic, tectonic, and historical seismicity data to identify the seismic source zones in Turkey, which are in close agreement with those proposed by Erdik *et al.* (1985) earlier (see Fig. 3). Gulkan *et al.* (1993) used the attenuation relationship proposed by Joyner and Boore (1981) developed for the western U.S.A., suggesting that the seismo-tectonics of the western U.S.A. and Turkey are generally similar. The portion of the map by Gulkan *et al.* (1993) pertinent to this study is reproduced in Fig. 5, depicting the peak horizontal ground acceleration contours with a probability of 90% not being exceeded in 50 years. It may be observed that the particular acceleration contours range between 0.4 g and 0.5g in the region.

Erdik *et al.* (1985) developed probabilistic maximum intensity (I_o) maps for Turkey using the Medvedev, Sponheuer and Karnik (MSK) intensity scale, which is nearly identical to the Modified Mercalli scale and more widely used around the world. The maximum intensity (MSK) map with a probability of 90% not being exceeded in 50 years developed by Erdik *et al.* (1985), is reproduced in Fig. 6 for the region under study. Again, it may be observed that maximum intensity contours (MSK) range between Io=8 and 8.5. In descriptive terms, the physical consequences associated with these levels of intensity include among others "sand and mud ejection, ground settlement, breaking of underground pipes, changes in well waters" (Krinitzsky *et al.*, 1993), which indicate the occurrence of liquefaction.

Erdik *et al.* (1985) also established a correlation between the Richter Magnitude (M) and the Maximum Intensity (I_o) in the form:

$$M = a_1 + a_2 I_o \tag{1}$$

and estimated the regression coefficients a1 and a2 for the individual seismic source zones identified in Fig. 3. Applying these coefficients to Eq. 1 yields M values ranging from M=6.4 to 7.8. Based on this observation and the data presented in Fig. 4, it is proposed that a range of M=6.5 to 7.5 would be representative for the region under study with a probability of 90% not being exceeded in 50 years.

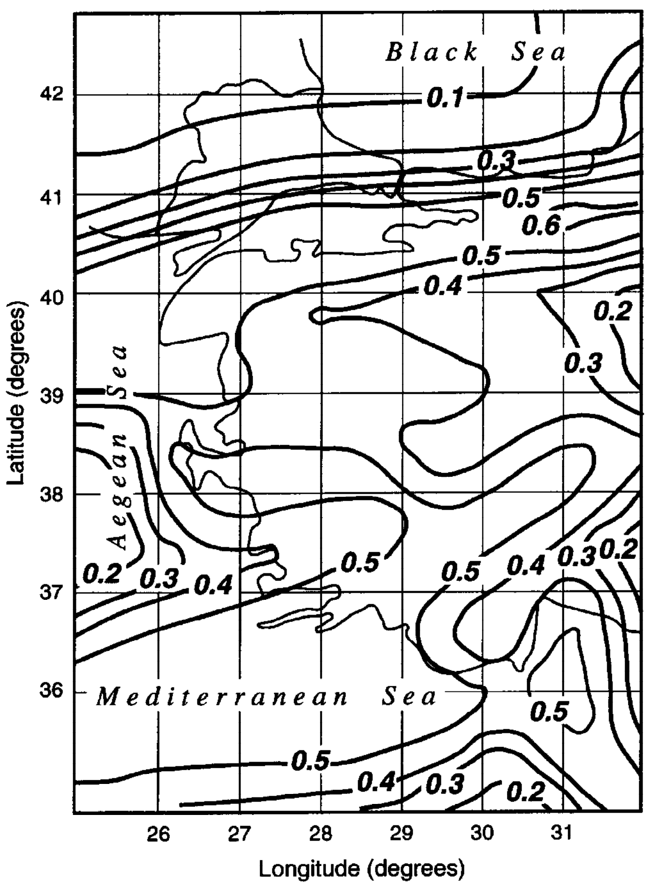

Fig. 5. Peak horizontal ground acceleration contours with probability of not being exceeded 90% in 50 years. (after Gulkan *et al.*, 1993)

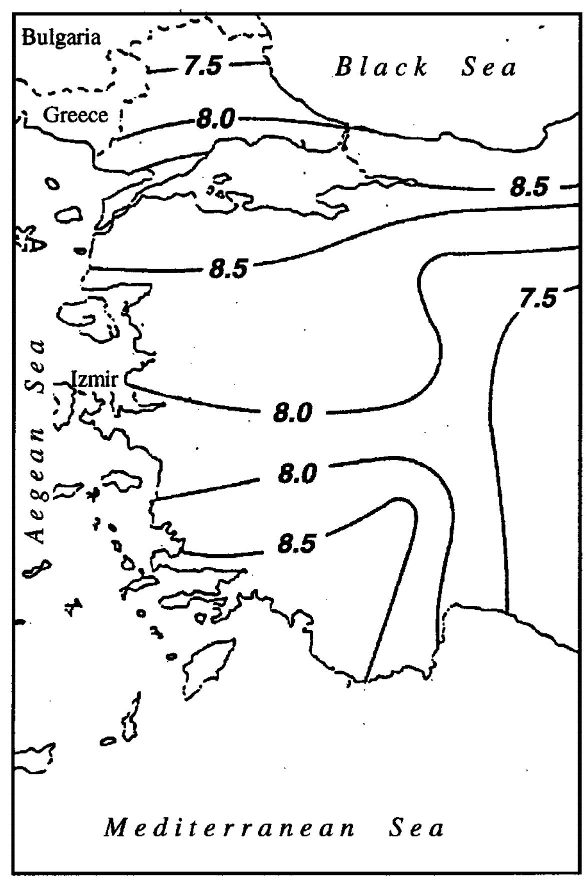

Fig. 6. Maximum intensity (MSK) contours with probability of not being exceeded 90% in 50 years. (after Erdik *et al.*, 1985)

In conclusion, the following "design earthquakes" were adopted to be representative of the subregions of the region for liquefaction assessment:

$$M = 6.5,\ a_h(\max) = 0.4\ g \text{ and } 0.5\ g;$$
$$M = 7.5,\ a_h\max) = 0.4\ g \text{ and } 0.5\ g.$$

The "design earthquake" for a particular project site in the region for liquefaction evaluation may be determined by the geotechnical engineer utilizing Figs. 5 and 6 and other location specific historical seismic information.

LIQUEFACTION CRITERIA FOR THE REGION

Basic mechanism of liquefaction in loose saturated sands/silty sands subjected to earthquake-induced ground shaking has been the subject of intense study by researchers predominantly in the United States and Japan following the devastating 1964 Niigata and Alaska earthquakes. During the subsequent two decades, Prof. H.B. Seed and his co-workers at the University of California have developed with progressive improvements (Seed and Idriss, 1971, 1982; Seed *et al.*, 1985) a methodology to determine the conditions for initial (threshold) liquefaction relative to a specified design earthquake and particular project subsurface conditions. The methodology takes into account the in-situ relative density (in terms of Standard Penetration Test-Blow Count; SPT-N) and the fines content (percent by weight passing the No. 200 sieve) of the saturated sand/silty sand deposits or fill soils. This approach which has been widely adopted in current practice was utilized in this study to develop the respective liquefaction criteria for the design earthquakes established in the previous section. These criteria are presented in Figs. 7 through 10. Each criterion includes conditions of groundwater level at ground surface and 3 m below as well as fines content of 35, 15, and 5 percent or less.

The use of Figs. 7 through 10 by the geotechnical engineer requires only the basic subsurface data for a project site, which are commonly determined for foundation evaluation/design, including test borings with SPT-N profiles, groundwater level, and adequate grain size distribution test data. If a potential liquefaction condition is indicated from the figures, that is, where none, a few, some or a great portion of the SPT-N data fall to the left of the respective liquefaction envelopes, the anticipated end effects for the particular condition is to be further evaluated, including potential loss of bearing support, seismically induced settlements (Tokimatsu and Seed, 1987), and/or lateral spreading (Bartlett and Youd, 1995), and in parallel mitigating countermeasures are to be developed.

A close review of Figs. 7 through 10 provides a significant observation; that is, the liquefaction envelopes (criteria) for the four design earthquakes considered are nearly identical. The explanation for this phenomenon lies in the fact that the cyclic shear stress ratio versus normalized SPT-N blow count, (N1)60, relationships (Seed *et al.*, 1985) are "nonlinear," and beyond a level of horizontal ground acceleration (or the corresponding cyclic stress ratio) there is no additional demand on the SPT-N value to maintain a stable, non-liquefiable condition. In other words, if a saturated sand/silty sand deposit is at or above a certain relative density, then it will not be subject to liquefaction regardless of the intensity and duration of the earthquake-induced ground shaking. The horizontal ground acceleration levels of 0.4 - 0.5 g, and the magnitudes of M= 6.5 - 7.5, characterizing the seismicity of the particular region represent such "high" intensities and "long" durations of ground shaking. This observation in turn indicates that for the particular region, a rigorous determination of the design earthquake relative to its subregions (Fig. 3) is not necessarily warranted for potential liquefaction evaluation.

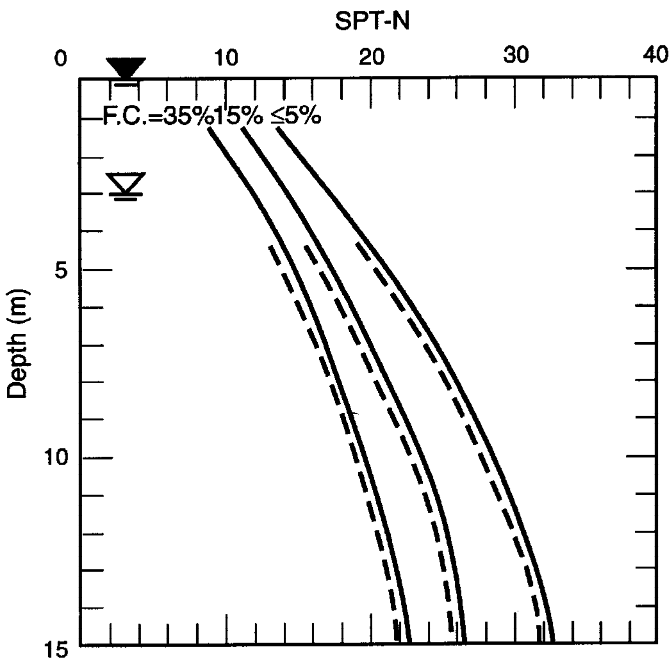

Fig. 7. Liquefaction criteria for design earthquake: M=6.5, $a_h(max)$=0.4g.

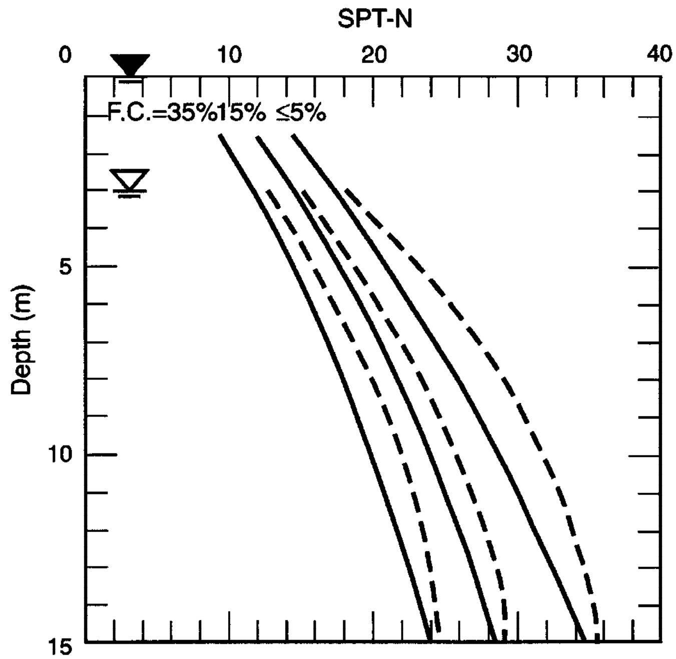

Fig. 8. Liquefaction criteria for design earthquake: M=6.5, $a_h(max)$=0.5g.

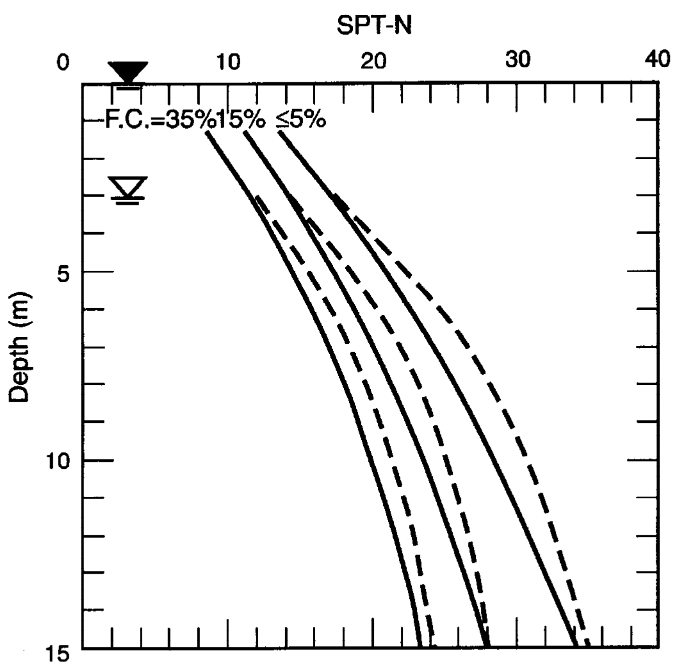

Fig. 9. Liquefaction criteria for design earthquake: M=7.5, $a_h(max)$=0.4g.

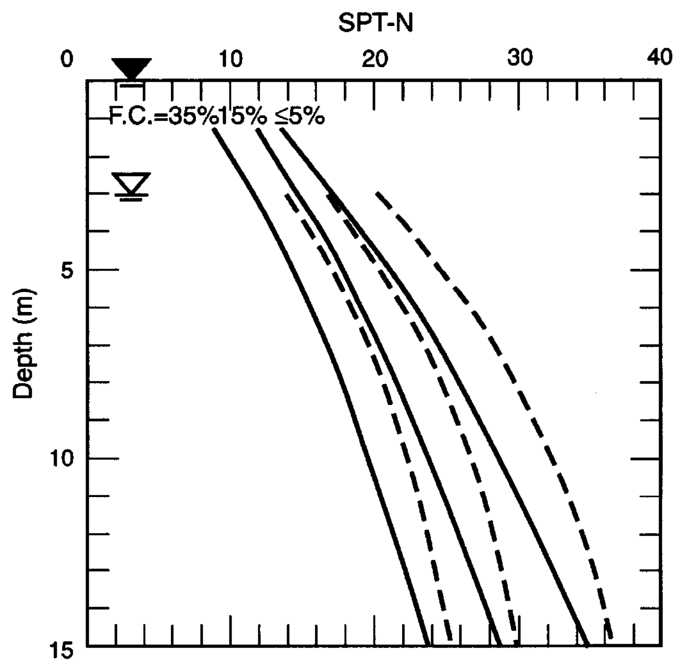

Fig. 10. Liquefaction criteria for design earthquake: M=7.5, $a_h(max)$=0.5g.

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