# INTRODUCTION OF A MANUAL FOR A ZONATION ON SEISMIC GEOTECHNICAL HAZARDS PREPARED BY ISSMFE

## GEOTEKNİK OLAYLARDA DEPREM TEHLİKESİNİN BÖLGELENDİRİLMESİ İÇİN ISSMFE EL KİTABINA GİRİŞ

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## ABSTRACT

A new zonation manual entitled " Manual for Zonation on Seismic Geotechnical Hazards " has been produced by the Technical Committee 4 (Earthquake Geotechnical Engineering) of ISSMFE in conjunction with the current International Decade for Natural Disaster Reduction (IDNDR). The manual is a practice reference for working out zonation for seismic geotechnical hazards. The manual includes accepted approaches for assessing three kinds of geotechnical phenomena: local ground response, slope instability and liquefaction. For each of the three items, methodologies are arranged in three steps in terms of preciseness of the approach and their outcome. A brief outline of the Manual is introduced in this paper.


## 1 INTRODUCTION

The Technical Committee for "Earthquake Geotechnical Engineering", TC4, was authorized in 1985 by the International Society for Soil Mechanics and Foundation Engineering (ISSMFE) and initiated its activities in 1986. Its first term of tenure ended in 1989 at the time of the 12th ICSMFE in Rio de Janeiro with the publication of a special volume entitled "Earthquake Geotechnical Engineering" which was made possible by the financial assistance of the Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE).

The continuation of TC4 under the sponsorship of JSSMFE was endorsed in 1989 by the ISSMFE in Rio de Janeiro, and new undertakings were planned and executed for the term of office until the 13th ICSMFE in New Delhi in January, 1994. In the meantime, the International Decade for Natural Disaster Reduction (IDNDR) was authorized by UNESCO and came into effect in 1990. In support of IDNDR, the ISSMFE has taken an initiative to embark on some projects in concert with the intensions of IDNDR. One of these undertakings was to prepare and publish a manual containing guidelines and methodologies for performing zonation on geotechnical hazards caused by earthquakes. The items addressed in the manual pertain to ground motions, liquefaction and landsliding. A preliminary draft of the manual was prepared by a Task Committee established by JSSMFE. To ameliorate and furbish the draft, a workshop was held in July, 1992 in Lisbon in which pilot works on

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zonation by several key persons were presented and discussed. The outcome of the workshop was taken into consideration in amending the draft. The manual was published in January 1994 on the occasion of the 13th International Conference on Soil Mechanics and Foundation Engineering held in New Delhi, India.

## 2 FRAMEWORK OF THE MANUAL

This manual, prepared by the ISSMFE Technical Committee for Geotechnical Earthquake Engineering includes accepted approaches for assessing three kinds of geotechnical phenomena: local ground response, slope instability and liquefaction. For each kind of phenomenon, three grades of approach to zonation are described as below with reference to Table 1.

Table 1 Use of data for three levels of zonation

| | Grade-1 | Grade-2 | Grade-3 |
|---|---|---|---|
| Ground motions | • Historical earthquakes and existing information<br>• Geological maps<br>• Interviews with local residents | • Microtremor<br>• Simplified geotechnical study | • Geotechnical Investigation<br>• Ground response analysis |
| Slope instability | • Historical earthquakes and existing information<br>• Geological and Geomorphological maps | • Air photos and remote sensing<br>• Field studies<br>• Vegetation and precipitation data | • Geotechnical investigation<br>• Analyses |
| Liquefaction | • Historical earthquakes and existing information<br>• Geological and geomorphological maps | • Air photos and remote sensing<br>• Field studies<br>• Interview with local residents | • Geotechnical investigation<br>• Analysis |
| Scale of mapping | 1:1,000,000~1:50,000 | 1:100,000~1:10,000 | 1:25,000~1:5,000 |

**Grade-1: General Zonation**

The first level of zonation is based on compilation and interpretation of existing information available from historic documents, published reports and other available data bases. This is the crudest and lowest-cost approach, used for covering a wide region such as a country, state, province or prefecture, or local areas.

For the zoning of local ground motions, catalogues of instrumentally monitored earthquakes can be utilized. These catalogues are available for almost all areas of the world and contain information on locations, magnitudes, focal mechanisms, etc. for recent large earthquakes. Historical data on various kinds of damage may also be available in many areas, and this can be used to gain an overall picture of the areal distribution of shaking intensity during historical earthquakes. Information on past earthquakes can also be used to make a rough delineation of seismic source zones and to generate estimates of the magnitude and frequency of future earthquakes. Using existing ground motion attenuation correlations, preliminary maps for ground motions can be compiled.

Existing geologic and geomorphological maps are usually very important sources of information for the assessment of the potential for ground failure. Although they vary considerably in detail and applicability from area to area, such maps usually provide useful information on geologic characteristics of Quaternary sediments. Reports of site investigations carried out for major construction projects in the region can also provide useful information on geologic and soil conditions. By correlating regional geology or geomorphology with different levels of hazards, maps for slope instability and liquefaction hazard can be prepared. The quality of the zonation map is likely to vary strikingly depending on the quality of the data base; mapping at this level of zonation is likely to be in the range 1:1,000,000 to 1:50,000.

**Grade-2: Detailed Zonation**

The quality of the Grade-1 zonation map may be improved considerably, at moderate cost, by making use of additional sources of data. For example aerial photographs can help to better define fault structures and geologic conditions. In some cases, older photographs may be more helpful in understanding the structure of local geologic units if they pre-date urban development. Additional field studies may be performed to map out geologic units pertinent to local ground motion amplification, slope instability potential and liquefaction susceptibility. Geotechnical engineering reports from governmental or local or prefectural agencies and private companies may provide additional field and laboratory test data. Local residents may provide detailed historical information on slope instability and liquefaction occurrence during past earthquakes. Microtremor measurements can also be utilized to obtain more detailed information on subsurface stratigraphy or amplification characteristics of ground motions. This approach can usually be achieved at reasonable cost and permits a substantial upgrading of the zonation maps to scales of about 1:100,000 to 1:10,000.

**Grade -3: Rigorous Zonation**

Where a very high and very detailed level of zonation is required, for example, in scales in range 1:25,000 to 1:5,000, additional site investigation data will be needed, specific to the site in question. The findings from such investigations may be incorporated into computer-aided analyses of seismic ground response, slope instability behavior, or liquefaction potential. This level of zonation, requiring detailed site-specific information, is generally expensive, but for sites where the hazard potential is considered very high, or existing or proposed development is regarded as critical or of high value, this level of investment may be warranted.

In this paper, zoning methods for slope instability and liquefaction are introduced briefly.

## 3 ZONING FOR SLOPE INSTABILITY

Slope instability basically depends on two factors: an external driving force and the resistance of the material to movement. The external driving force includes gravitational and seismic forces while the material resistance is governed by geological and geotechnical conditions. At present, few methods have been developed for properly evaluating these factors which are suitable for zoning studies. This is because standard approaches to slope stability require detailed information, but over a wide area existing geological and topographical data are generally insufficient in quality and in-situ investigations are too difficult to conduct to enable these approaches to be used. In conducting the zoning for slope instability, therefore, these limitations have to be borne in mind.

## (1) GRADE-1 METHODS

The lowest-cost but most cursory level of zonation is based on earthquake magnitude or seismic intensity. This level of zonation screens potential areas of slope instability using magnitude or intensity criteria based on past earthquakes. Since the rate of slope failures reduces with distance from the seismic source, the exact outer boundary of slope instabilities is generally not well defined. In zoning studies, the slope failure rate is defined by the areal ratio and used as a parameter in defining the outer boundary.

Published magnitude-distance criteria and relevant data were studied for the manual. Then the magnitude-distance criteria and historic information was summarized as a function of the maximum distance from a fault or an epicenter and as a function of the slope failure rate. It was clear that the maximum distance of slope failure sites from an epicenter or a fault in dry-weather countries (Iran and Armenia) is smaller than that in wet-weather countries (Japan and the Philippines). And, it is known that the maximum distance of slope failure sites from a fault is smaller than that from an epicenter.

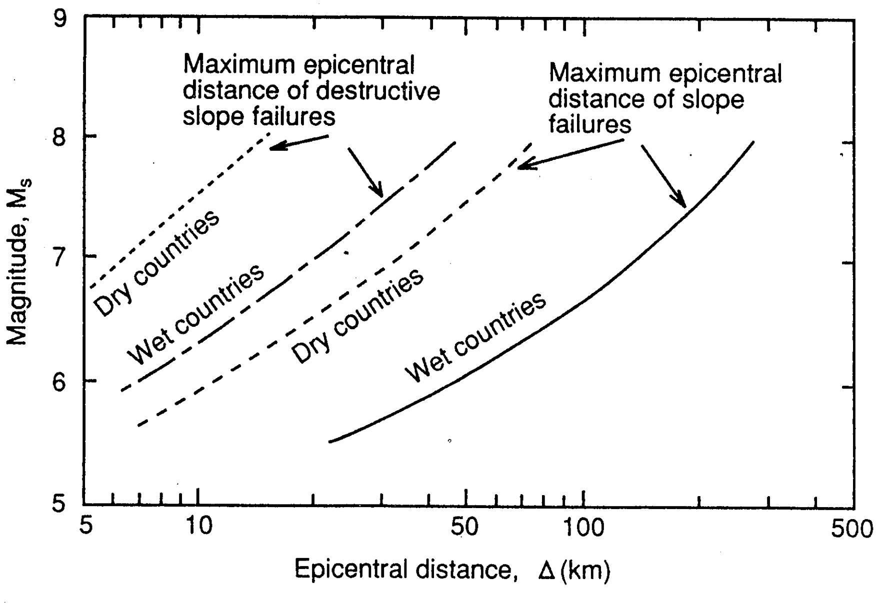


Fig.1 General relationships between magnitude and the epicentral distance of slope failures

Based on these observation, the curves as shown in Fig.1 is recommended for use in the Grade-1 zoning giving maximum epicentral distance for slope failure as a function of magnitude. The maximum fault distance could be estimated by reducing the epicentral distance appropriately.

## (2) GRADE-2 METHODS

Because of the lack of information on material parameters, zoning maps based on a Grade-1 approach do not provide definitive information for site specific evaluations. Such assessments require zoning based on at least Grade-2 and incorporate additional topographical and geological information in the area concerned. This may require additional field investigations. To minimize the effort and expense of further investigations however, existing topographical and geological reports should be used wherever possible. Three approaches are discussed here under Grade-2, illustrating the range of factors which are considered significant in predicting general susceptibility to slope failure. They are (1) method proposed by Kanagawa Prefectural Government (1986), (2) method proposed by Mora and Vahson (1991), and (3) method proposed by Japan Road Association (1988).

The first method proposed under Grade-2 was developed and used for zoning on slope failure susceptibility in Kanagawa Prefecture, Japan (Kanagawa Prefectural Government, 1986) based on slope failures during three large recent earthquakes in Japan: the 1974 Izuhanto-oki earthquake; the 1978 Izuohshima-kinkai earthquake; and the 1984 Naganoken-seibu earthquake.

In this approach, slope failure susceptibility zones were plotted on a 500 m by 500 m mesh area on maps at 1/50,000 or 1/25,000 scale. Seven factors including seismicity, topography, geology, and subsurface soil conditions were identified as the main factors governing slopes instability in each area.

### (3) GRADE-3 METHODS

By combining geotechnical surveys with the methods described under Grade-1 and Grade-2, a detailed level of zonation with higher accuracy can be achieved for each hazard zone. Grade-3 zonation requires additional information suitable for performing detailed slope stability analysis. These analyses are usually performed on a site specific basis, and given a sufficiently detailed site investigation, reliable zonation maps may be compiled. Site investigation data from public and private sources should be used where possible. The methodologies pertaining to Grade-3 are to be regarded as being still under study by many workers, and there is no one method that is applicable to all situations. In the mannual, two methods are introduced: the method proposed by Wilson et al.(1979) and that by Siyahi and Ansal (1993). Examples of zonation mapping by the first method is displayed in Fig.2.

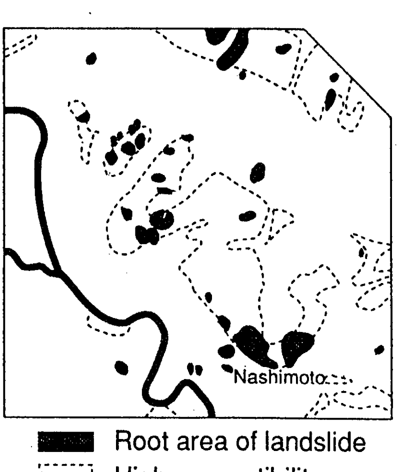


Fig.2 Map of Nashimoto area showing actual and predicted slop failures caused by 1978 Izu-Oshima Kinkai earthquake (Tanaka, 1982)

## 4 ZONING FOR SOIL LIQUEFACTION

Soil liquefaction has been a major cause of damage to soil structures, lifeline facilities and building foundations in past earthquakes and clearly poses a significant threat to the integrity of structures and facilities during future earthquakes. Zonation for liquefaction, therefore, has been an important goal for recent work. Liquefaction potential depends on two factors; the nature of shaking (intensity and duration) and material susceptibility to liquefaction. Various methods have been proposed for predicting liquefaction potential and in this chapter, these methods are classified within the Grade-1, 2 and 3 approaches adopted throughout this manual.

## (1) GRADE-1 METHODS

### (a) Assessment of the maximum extent of a liquefaction susceptible area

#### i) Magnitude-Maximum distance criteria

If earthquake activity in an area is known from historic seismic data, the maximum extent of the liquefaction susceptible area can be estimated directly from the magnitude of the predicted earthquake. Several investigators have analyzed the distribution of liquefaction during past earthquakes and have compared the distance from the epicenter to the farthest liquefied site, *R*, with the earthquake magnitude, *M*.

All the upper bound relationships studied by the investigators are plotted in Fig.3, using surface wave magnitudes, $M_s$, defined by Gutenberg (1945) and based on the relationships published by Utsu (1982). The bound proposed by Wakamatsu's work, is the most conservative among the bounds. This is because the definition of liquefaction used by Wakamatsu includes even minor signs of liquefaction effects.

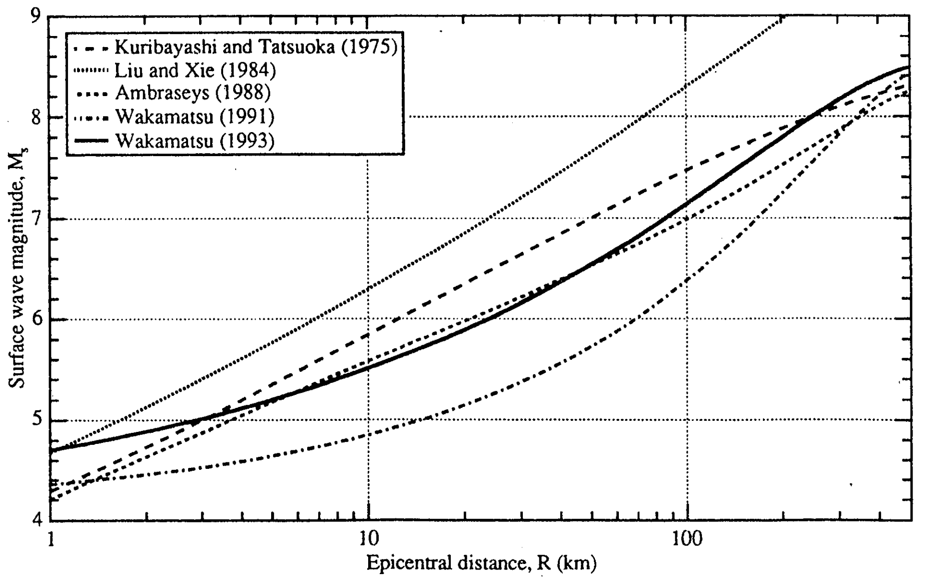


Fig.3 Epicentral distance to farthest liquefied sites,*R*, in km for surface wave magnitude $M_s$

#### ii) Intensity Criteria

The maximum extent of liquefaction susceptible area may also be estimated roughly based on seismic intensity. It has been shown that liquefaction was generally induced in areas underlain by liquefiable Holocene sediments by seismic shaking with an intensity in excess of V on the Japan Meteorological Agency (J.M.A.) scale, or VIII on the Modified

Mercalli (M.M.) scale.

**(b) Estimation of liquefaction susceptibility based on existing data**

**i) Geological and Geomorphological Criteria**

Liquefaction is known to occur repeatedly at the same site. Thus, maps showing the localities of past liquefaction may be considered as potential areas of liquefaction in future earthquakes.

**ii) Liquefaction Severity Index (*LSI*)**

To quantify the severity of liquefaction effects the concept of "liquefaction severity index" was introduced by Youd and Perkins (1987). This approach may be used as well to develop overall survey on liquefaction potential.

## (2) GRADE-2 METHODS

Grade-2 approaches to zonation for liquefaction differ from Grade-1 in the incorporation of available but generally unpublished data from public and private sources. Because of the lack of a unique relationship between geological and/or geomorphological criteria and geotechnical properties, susceptibility maps based on these Grade-1 criteria generally do not provide definitive information for site specific evaluations. Other data which may be available include:

i) interpretation of aerial photographs defining detailed geomorphological and geological units;
ii) field studies classifying units susceptible to liquefaction;
iii) analysis of aerial photographs taken shortly after major flood events delineating zones of flooding and sediment accumulation;
iv) interviews with local residents providing historical information on liquefaction occurrences during past earthquakes.

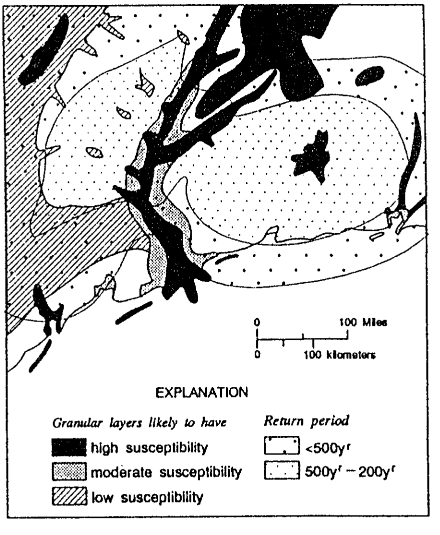


Fig.4 Map of liquefaction-induced ground failure potential for hypothetical area (Youd and Perkens, 1978)

Although this distinction between Grade-1 and 2 may appear minor, the amount of effort required for the collection of data to the detail required for Grade-2 may be sometimes many times greater than for Grade-1.

Geological and geomorphological criteria for identifying areas of high liquefaction potential are proposed by Youd et al. (1978) and Wakamatsu (1992).

Figure 4 shows an example of a zoning map for liquefaction-induced ground failure potential prepared by Youd and Perkins (1978).

### (3) GRADE-3 METHODS

By combining site-specific geotechnical surveys with the approaches described under Grade-1 or Grade-2, high accuracy and detailed zonation can be achieved for liquefaction potential for each geological and geomorphological unit. Grade-3 zoning requires additional detailed site specific information, commonly requiring new site investigations and testing. As with Grade-2, valuable data will often be found from governmental agencies and private companies.

For liquefaction assessment, however, Grade-3 methods generally require new specialized subsurface investigations and field and laboratory testing, at a significantly greater cost than required for Grade-2. Grade-3 approaches to the assessment of liquefaction potential consist of the following steps:

i) estimation of the liquefaction resistance of soils in a deposit;

ii) estimation of the maximum or equivalent cyclic shear stress likely to be induced in the soil deposit during an earthquake;

iii) estimation of the liquefaction potential of the deposit, based on (1) and (2).

Liquefaction resistance can be estimated using either in-situ testing or laboratory tests on undisturbed samples. In practice, in-situ testing procedures are more widely used, since these are not subject to the difficulties experienced in obtaining truly undisturbed samples that retain their in-situ liquefaction resistance. Of the in-situ tests available, the standard penetration test (SPT) and cone penetration test (CPT) are the most commonly used for liquefaction assessment.

#### (a) Evaluation of in-situ liquefaction susceptibility based on Standard Penetration Test

Techniques using data from the SPT and CPT have been developed by various workers. As an example, the Japan Road Association's method is described briefly below.

The method outlined in the Japanese Bridge Code (Japan Road Association, 1991) is based on a procedure developed by Iwasaki et al. (1978) termed "simple geotechnical analysis". The method is similar to the Seed and Idriss approach in that a soil liquefaction capacity factor, R, is calculated along with a dynamic load, $L$, induced in a soil element by the seismic motion. The ratio $R/L$ is defined as the liquefaction resistance factor, $F_L$. The soil liquefaction capacity is calculated from the sum of three factors which take into account the overburden pressure, the grain size and fines content.

#### (b) Evaluation of the effects of liquefaction

For engineering purposes, it is not merely the occurrence of liquefaction itself that is important but its consequences for damage to the ground or adjacent structures. Two approaches are introduced here for identifying the effects of liquefaction, based on data from site specific geotechnical investigations.

**i) Damage in the presence of an unliquefiable surface layer or crust**

To decide whether liquefaction will or will not exert damage on the ground surface, the thickness of the liquefiable layer can be compared with the thickness of the surface crust using criteria such as the one proposed by Ishihara (1985). If the thickness of the surface layer, $H_1$, is larger than that of the underlying liquefied layer, resulting damage on the ground surface may be insignificant.

**ii) Liquefaction potential index**

Iwasaki et al. (1982) quantified the severity of possible liquefaction at any site by introducing a factor called the liquefaction potential index, $P_L$, defined as follows:

$$P_L = \int_0^{20} F(z)w(z)dz \tag{1}$$

where $z$ is the depth below the ground surface, measured in meters; $F(z)$ is a function of the liquefaction resistance factor, $F_L$, where $F(z)=1-F_L$ but, if $F_L>1.0$, $F(z)=0$; and $w(z)=10-0.5z$. Equation 1 gives values of $P_L$ ranging from 0 to 100. By calculating this index for 63 liquefied and 22 nonliquefied sites in Japan, Iwasaki et al. concluded that sites with $P_L$ values greater than about 15 suffer severe liquefaction effects whereas effects are minor at sites with a value of $P_L$ less than about 5.

As an example, the Institute of Civil Engineering of the Tokyo Metropolitan Government developed a liquefaction map for the Tokyo Lowlands as shown in Fig.5. The

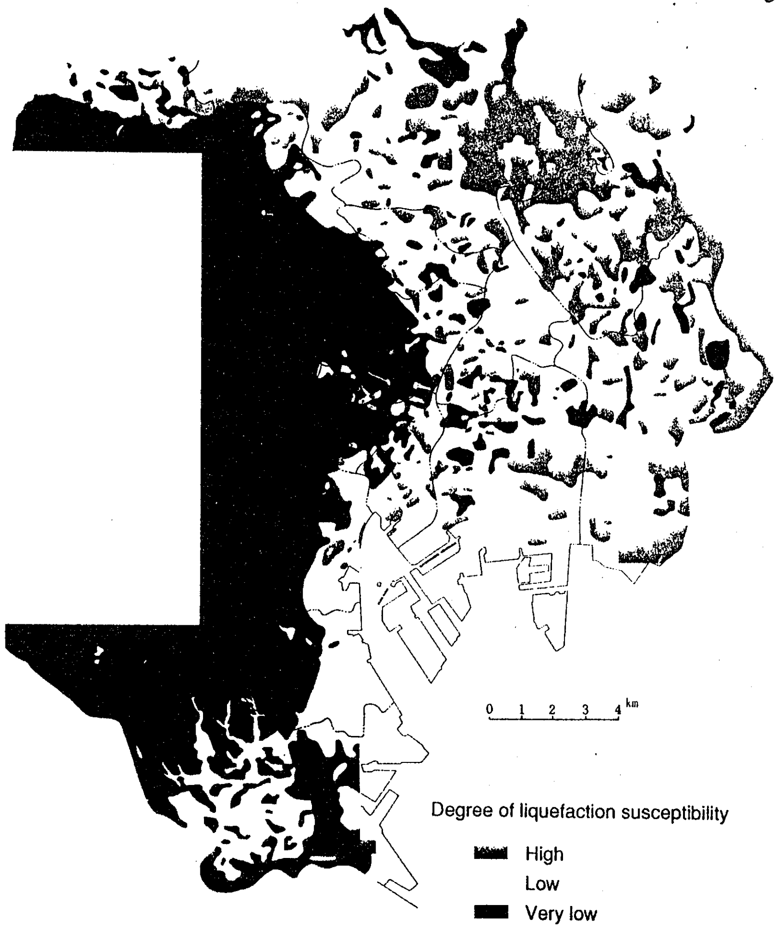


Fig.5 Liquefaction potential zonation map for the Tokyo Lowland (Kusano et al., 1987)

map incorporated the results of liquefaction analyses, historical occcurrence of liquefaction, geographic and geological studies into liquefaction zones.

## 5 CONCLUDING REMARKS

The manual is a synthetization of the present state-of-the-art on evaluating and mapping out the geotechnical hazards caused by earthquakes, but it is arranged in ways that are applicable for zonation works. Investigations are under progress in efforts to upgrade the accuracy of the methodologies. It is thus hoped that the manual is reviced in future reflecting outcome of most recent development in respective areas.

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