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LIQUEFACTION HAZARD ASSESSMENT AND GIS-BASED ZONING OF SOUTH-EAST REGION OF IRAN

Behrouz GATMIRI [1], Alireza MIRLATIFI[2], Alireza ALEMZADEH[3]

ABSTRACT

In this paper the methodology of liquefaction hazard assessment in two south-eastern provinces in Iran in GIS system has been described. The area of studied zone is about 78000 Km2, equal to 4.8 % of Iran. In this study, available data from different sources are collected and analyzed. Site visit and field investigations are performed in the region. Some hundred investigation boreholes up to 10 to 15 meters have been drilled. From each bore hole as a data point, soil and rock description and classification, Atterburg limits, water content, water table, pocket penetrometer resistance, standard penetration test (S.P.T), and some other necessary data have been collected. After analyzing the collected information and using the suitable methodology, the liquefaction zoning maps in GIS system are produced. In this paper applicability of different methods for evaluation of the liquefaction potential are discussed and the selected liquefaction hazard assessment methodology and the detail of map preparation are described. Finally the limitations and field of applications of liquefaction hazard map in this scale are described.

Keywords: zoning, hazard assessment, liquefaction, GIS.

INTRODUCTION

With the growth of population and urban concentration, the necessity of physical planning of settlement pattern and urban development is highly felt. Land use optimisation plays an important role in settlement of population in future. Moreover, protection and optimized consumption of natural resources, prevention of land deterioration, security against natural hazards (flood & earthquake), prevention of construction on valuable mineral resources zones, construction compatibility with geotechnical and geological site conditions are major aspects in planning and urban management. One of the major natural hazards is liquefaction during an earthquake.

It is widely recognized that the basic mechanism of liquefaction in a deposit of loose saturated sand during earthquakes is the progressive build up of excess pore water pressure due to cyclic shear stresses induced by the upward propagation of shear waves from the underlying rock formation and it can cause enormous destructions in urban areas.

In this paper the methodology of liquefaction hazard assessment and GIS based zoning of south-east region of Iran has been discussed.

[1] Professor, University of Tehran, Iran and Ecole National des Ponts et Chaussées, Paris, Email: gatmiri@enpc.fr
[2] PhD Student of Geotechnical Eng. University of Tehran and Daryakhakpay Consulting Engineers, Iran, Email: almircivil@yahoo.com
[3] Daryakhakpay Consulting Engineers, Email: alemzadeh@daryakhak.com

METHODS OF LIQUEFACTION HAZARD AND POTENTIAL ASSESSMENT IN THIS STUDY

Liquefaction hazard assessment

Whereas the purpose of this study is general site selection and primary regional urban planning in the scale of 1:250000, the liquefaction potential assessment has been carried out. The other induced aspects such as post liquefaction behavior, displacement evaluation after liquefaction and their effects on the structures, urban facilities, lifelines and etc have been out of scope of this study. The results of such study can help also the decision makers to determine the main areas for further investigations.

Liquefaction potential assessment

Three following main categories of criteria for liquefaction potential assessment are used according to their accuracy: 1) The historical, 2) The geological and geomorphological, and 3) The site-specific susceptibility criteria.

Geological and geomorphological criteria

The sediments which are susceptible to liquefaction are formed in a special geological condition. Type of sediments, hydrological conditions and the age of the sediment have direct effect on liquefaction potential (Youd and Perkins 1978). The Table 1 shows the geological susceptibility during the strong seismic shaking.

Table1. Estimated susceptibility of sedimentary deposits to liquefaction during strong seismic shaking based on geologic age and depositional environment-Youd and Perkins (1978), reproduced from R. B. Seed (1991)

Type of deposit	General distribution of cohesionless sediments in deposits	Likelihood that cohesionless sediments, when saturated, would be susceptible to liquefaction (by age of deposit)			
		<500 years	Holocene	Pleistocene	Pre-Pleistocene
Continental deposits					
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Marine terrace/plain	Widespread	Unknown	Low	Very low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Tephra	Widespread	High	High	Unknown	Unknown
Colluvium	Variable	High	Moderate	Low	Very low
Glacial till	Variable	Low	Low	Very low	Very low
Lacustrine and playa	Variable	high	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Floodplain	Locally variable	High	Moderate	Low	Very low
River channel	Locally variable	Very high	High	Low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low
Residual soils	Rare	Low	Low	Very low	Very low
Tuff	Rare	low	Low	Very low	Very low
Coastal zone					
Beach-large waves	Widespread	Moderate	Low	Very low	Very low

Beach-small waves	Widespread	High	Moderate	low	Very low
Delta	Widespread	Very high	High	low	Very low
Estuarine	Locally variable	High	Moderate	low	Very low
Foreshore	Locally variable	High	Moderate	low	Very low
Lagoon	Locally variable	High	Moderate	low	Very low
Artificial					
Compacted fill	Variable	Low	Unknown	Unknown	Unknown
Un compacted fill	variable	Very low	Unknown	Unknown	Unknown

Site-specific susceptibility Criteria

As the excess pore water pressure and dissipating rate is the principal cause of liquefaction, physical soil characteristics such as grain size distribution and grain shapes play the important roles in liquefaction potential. Indeed, it is known that clean sands with less fine content (SM) are very susceptible to liquefaction. However, some reserves about liquefaction potential of silty soils and gravels and even clays should be taken into account.

The effect of the fine percent on liquefaction susceptibility is significant. It is shown that non-plastic silts are very susceptible to liquefaction (Ishihara 1993). On the other hand, clays are not generally susceptible to liquefaction. However, if the three following conditions are satisfied simultaneously for fine grain soils, the liquefaction is probable.

- Clay fine content becomes less than 15% (according to Chinese method the grain size of clay is less than 0.005 millimeters.)
- Liquid limit becomes less than 35%.
- Natural water content becomes equal or more than 90%.

Figure 1 shows these criteria for fine grain soils.

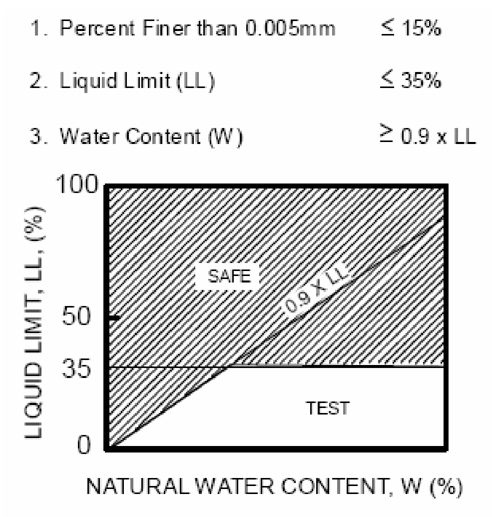

Figure1. The modified Chinese method for fine grain soils (Seed & Idriss 1982, Wang 1979)

Martin & Andrew 2000 have suggested the criteria given in Table 2 which is a revision of Chinese method. In this method grain size for clays is less than 0.002 millimeters.

Table2. Liquefaction potential of clays and silty sands (Martin & Andrew 2000)

Fine content (%) \ Liquid limit	LL≥ 32	LL<32
F.C. < 10%	More investigation is needed	Susceptible to LIQ.
F.C. ≥ 10%	Improbable	More investigation is needed

The assessment of liquefaction potential by the site-specific susceptibility evaluation generally consists of the following steps:

1) Evaluation of the cyclic resistance ratio of soils
2) Estimation of the cyclic shear stress ratio induced in the soil during an earthquake
3) Assessment of the liquefaction potential by comparing 1 and 2.

LIQUEFACTION HAZARD ASSESSMENT AND GIS ZONING IN THIS STUDY

Liquefaction hazard assessment maps in the south-eastern region of Iran are prepared by using a procedure consisted of the following steps:

1- The preparation of the basic geotechnical map

A basic geotechnical map has been prepared on which all topographical, geological and geomorpholigical data are reported. The available information, the interpreted data from the satellite images, the visual-manual site investigation data and the soil characteristics obtained from the borehole are also reported on this basic geotechnical map. This map plays an important role in progress of study. All information from the different parts of study are reported on this basic map and on the other hand, this basic map is used as a principal data source and the bottom map for each part. Liquefaction potential assessment has been performed by using the available information on this map, and it has added some relevant information on this basic geotechnical map at the end of evaluation. Figure 2 illustrates the basic geotechnical map in the region.

2- Classification of the deposit and rocky zones

Classification of the deposit and rocky zones has been carried out by using the basic geotechnical map in the scale of 1:250000 as:

- Gravelly deposits
- Silty and sandy deposits
- Fine grain size deposits
- Rocky zones

The liquefaction index for rocky zones has been considered "Nothing".

3- Underground water iso-depth map

The knowledge of depth of water table is necessary in liquefaction mechanism, underground water iso-depth maps help to omit many zones in which the water table level does not affect the analysis. Therefore, three zones are defined by considering the depth of water table as:

High level of water table (0-5 meters)
Medium level of water table (5-10 meters)
Low level of water table (more than 10 meters)

The liquefaction index for low level of water table has been considered "Nothing".

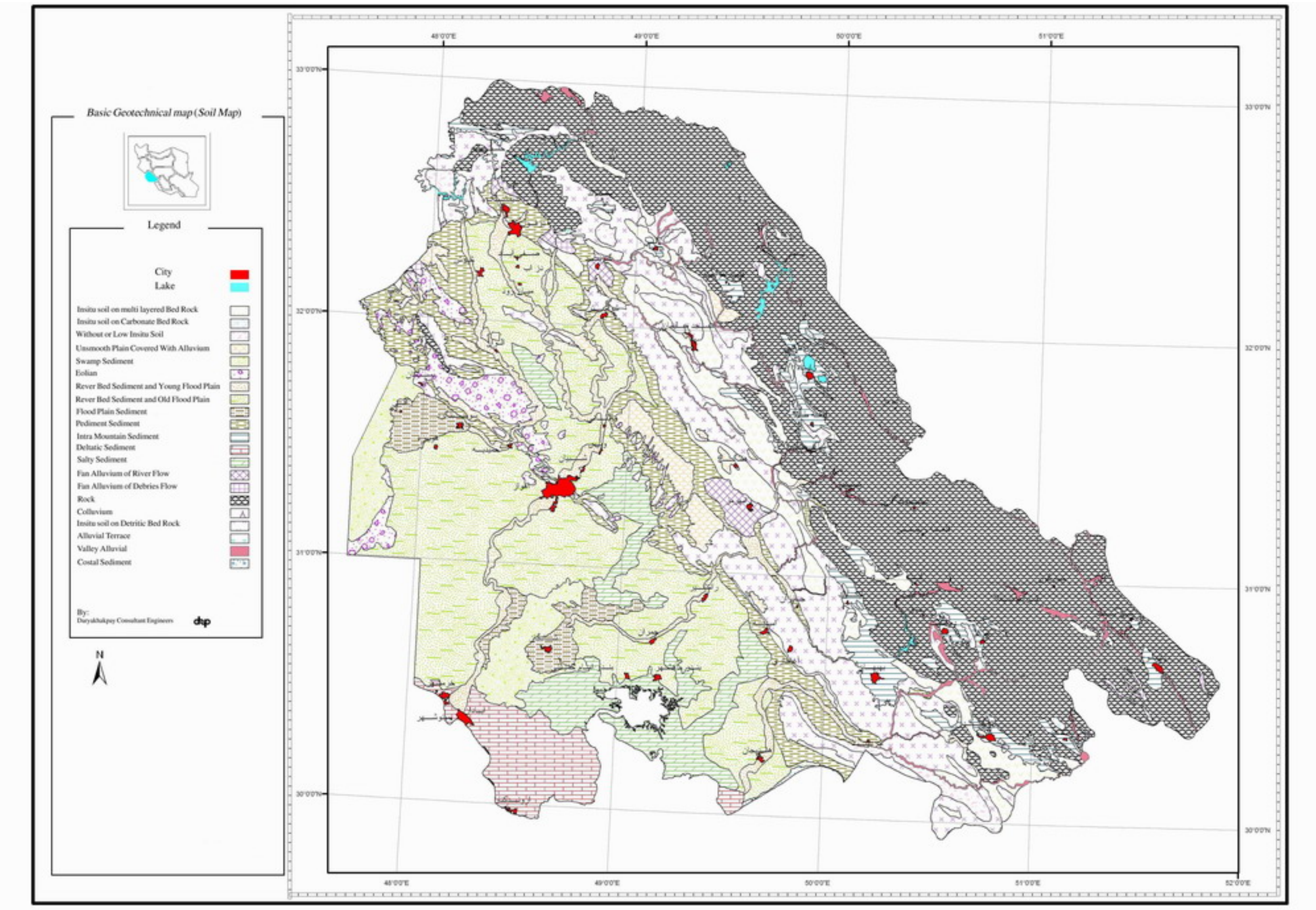

Figure2. Basic Geotechnical Map

4- Earthquake hazard acceleration map with return period of 500 years

One of the basic factors in evaluation of liquefaction potential is nature of shaking such as intensity and duration of earthquake. For this propose the seismic hazard maps which have been produced by probabilistic approach in another part of this study in Urban Planning and Architecture Research Center of Iran are used. The map is for Design Base Level (D.B.L.) for return period of 500 years. Figure 3 depicted the earthquake hazard acceleration map of this zone with the return period of 500 years.

5- Geotechnical investigation

In this area more than Three hundreds geotechnical boreholes up to 10 meters drilled and in-situ tests such as SPT and CPT and laboratory tests including grain size distribution, Atterburg limits, moisture content, and cyclic triaxial tests have been performed on the samples obtained from the bore holes. More than two thousands bore holes information is collected from the several geotechnical projects performed during the past 25 years. It is tried to have at least some consistent boreholes in each uniform deposit zone.

6- Liquefaction potential analyses

According to the geotechnical investigation including SPT and CPT, grain size distribution, and Atterburg limits plus the estimated susceptibility of sedimentary deposits to liquefaction during strong seismic shaking based on geologic age and depositional environment, liquefaction potential of each zone has been determined. In this case, to determine the liquefaction potential, Seed method (1984, 85) with modification factors has been used. The correlation between cyclic resistance ratio (CRR) and SPT numbers in this method illustrates in figure 4 for a given magnitude which is usually 7.5. For the other magnitude, a Magnitude Scaling Factor (MSF) has been considered based on Seed and Idriss proposition. The average cyclic shear stress ratio (CSR) is calculated by Equation (3).

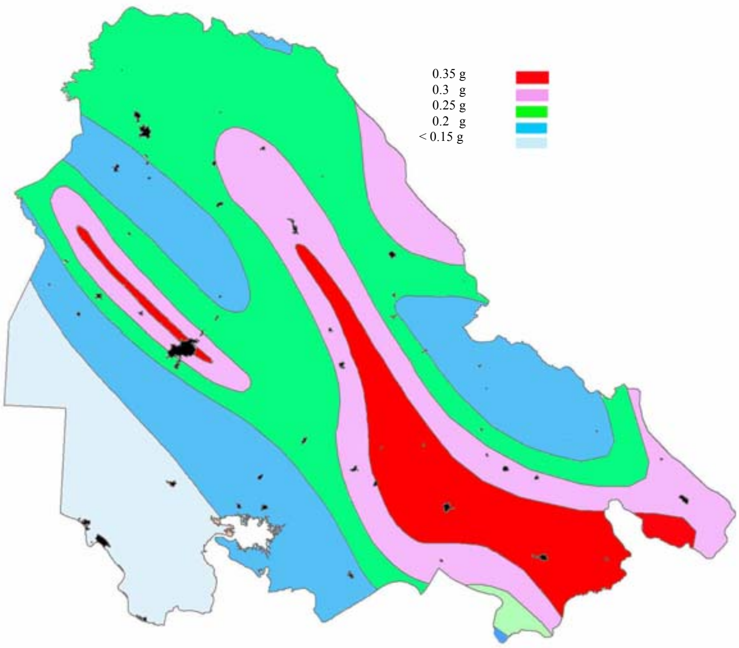

Figure3. The Earthquake hazard acceleration map with return period of 500 years (Seismic hazard map in Iran by: Urban Planning and Architecture Research Center of Iran 1997)

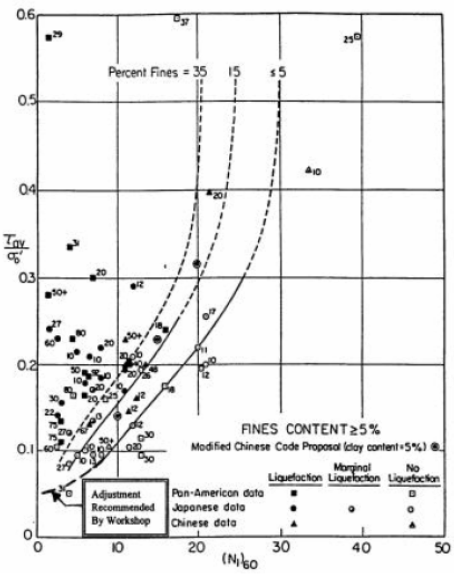

Figure4. The correlation between Cyclic Resistance Ratio and SPT numbers (N_{60}), (Modified Seed et. al., 1978)

$$CSR = 0.65 \cdot \left(\frac{\sigma_{VO} a_{\max}}{\sigma'_{VO} \cdot g} \right) r_d \qquad (3)$$

Where a_{max} is maximum horizontal acceleration (from iso acceleration maps), σ_{v0} is total vertical stress, σ'_{v0} is effective vertical stress, and r_d is a stiffness reduction factor and depends on depth (Eq. (4)). (Figure 6)

$$r_d = 1 - .0015z \qquad (4)$$

Where z is the depth in meters below the ground surface; finally, the factor of safety against liquefaction, F_L, estimated as:

$$F_L = (CRR_{7.5} / CSR)\ MSF \qquad (5)$$

7- GIS-based zoning

Finally, by using the above described procedure, the liquefaction factors for different zones are obtained in a Geographical Information System and the liquefaction hazard maps have been prepared for the studied regions. The liquefaction hazard assessment classified to four levels: "High", "Medium", "Low", and "Nothing" in this study as Figure 7. Indeed, The rocky zones, the zones without water table, the zones with water table depth more than 10 meters and the areas with FL greater than 1.25 are classified as "Nothing"; the areas with FL between 1.0 and 1.25 are classified as "Low"; the areas with FL between 0.9 and 1.0 are classified as "Medium"; and the areas with FL lower than .9 are classified as "High".

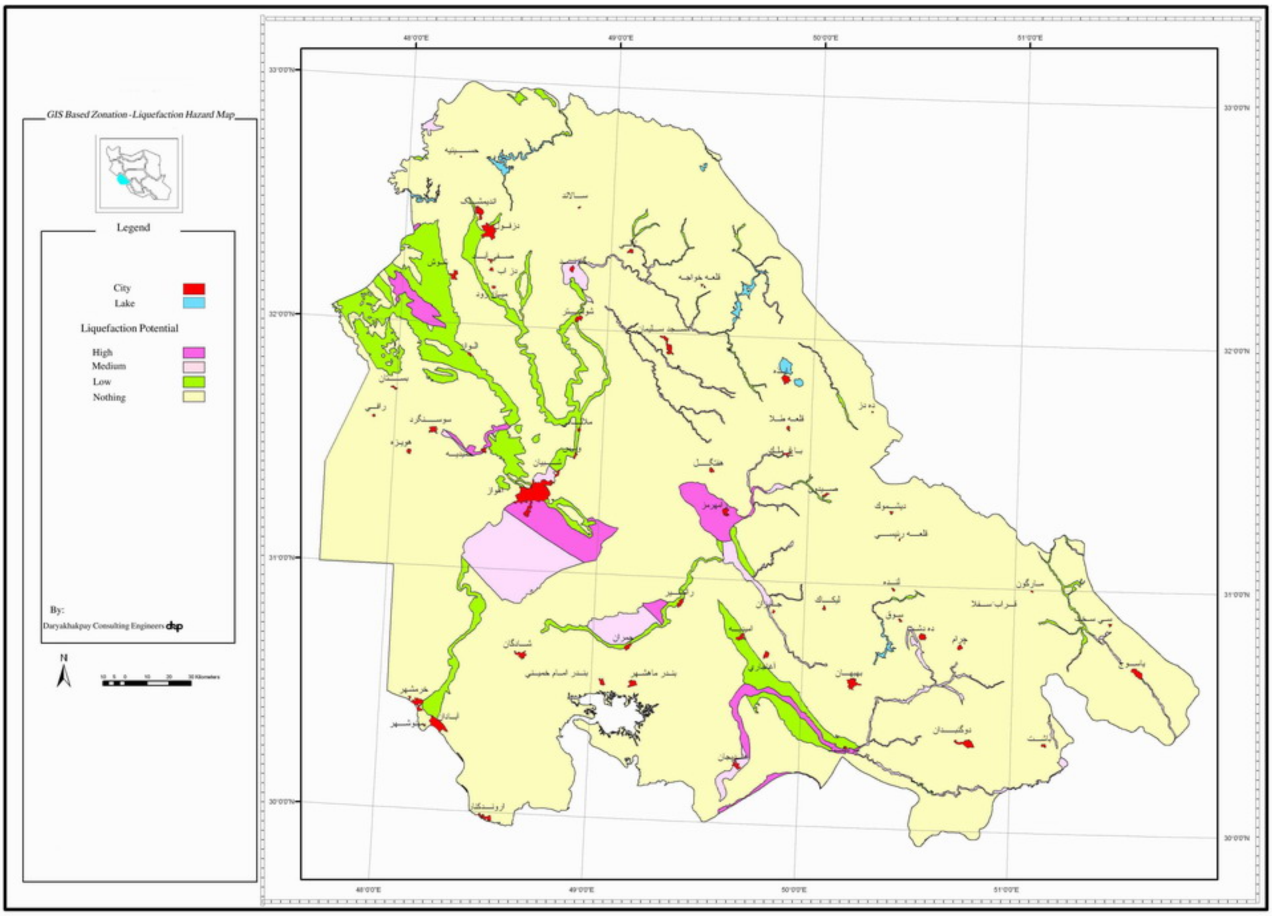

Figure7. The liquefaction hazard map in south-east region of Iran

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