Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Mapping liquefaction potential based on SPT and SWV data

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ABSTRACT: A set of liquefaction potential maps of Tai-yuan City in China under probabilistic design earthquakes were compiled mainly based on SPT and shear wave velocity data. A method for compiling the maps was proposed in this paper. These maps incorporate factors obtained through the following studies: geographic, geologic and geotechnical investigations, seismic risk analysis and design ground motion microzoning using probabilistic method, liquefaction analyses for over 2000 boring records. The liquefaction zone was divided into 21-23 subzones. An average liquefaction index showing liquefaction susceptibility and maximum liquefaction depth limits were given in each subzone.

1 INTRODUCTION

In order to increase the ability of seismic disaster prevention for the important cities or zones gradually, and to mitigate the earthquake damage extremely, the seismic resistance and disaster prevention planning should be compiled for these places lying in the seismic zones. Seismic microzoning is their basic research, and liquefaction potential map is an important part of seismic microzoning.

An urban seismic resistance and disaster prevention planning was set in Tai-yuan City, the capital of Shan-xi Province, China. The planning zone incuding Tai-yuan City is situated in an alluvial plain in the Shan-xi Basin, with total area of 225 Km^2. To compile the liquefaction potential maps was a part of the project.

Therefore, the information about over 2000 borings with the depths of 15-20m in this zone was collected. Standard penetration test (SPT) data and conventional geotechnical test data were obtained from most of borings. Numbers of supplementary borings with the depths of 30-100m for the seismic microzoning were explored. The SPT and shear wave velocity (SWV) measurement, conventional geotechnical tests and resonant column tests for dynamic moduli and damping of soil were performed for these borings. The Boring Distribution Map, Geography Map, Geology Map, Water Table Distribution Map, Engineering Geology Profile Figures (14 sheets of Figures from east to West and 5 sheets of Figures from south to north) and the Liquefiable Soil Distribution Map etc. were collected or compiled. The seismic risk analysis and design ground motion microzoning were performed by using probabilistic method. Liquefaction potential was evaluated by using empirical method mainly based on SPT blow N_{SPT} or SWV V_s-value data. The empirical method was set from the information of liquefied and not-liquefied sites after six earthquakes in China and checked with the information of liquefied and not-liquefied sites after Hai-cheng earthquake in 1975 and Tangshan earthquake in 1976 in China (The Seismic Codes of China 1978 and 1985).

For the liquefaction borings evaluated, the liquefaction susceptibility index and maximum liquefaction depth limits were calculated for each boring.

Combining the results of liquefaction potential evaluation for borings with the distribution of site conditions and factors relevant to liquefaction potential, the liquefaction zone boundaries can be found and the liquefaction potential maps can be compiled. This research achievement has been approved by the state administration department in China.

2 LIQUEFIABLE SOIL DISTRIBUTION MAP

The liquefiable zones with saturated sands and silts in strata are first compiled and the liquefaction zones can be found among it to save a lot of work in the not-liquefiable zones. The map can be compiled according to the following

empirical principles:

1. The soil deposited in the geologic age of the Quaternary Epileistocene (Q_3) or before may be evaluated as nonliquefaction soil;

2. With the seismic intensity in China VII, VIII and IX (they correspond to about the Modified Mercalli intensity 7,8 and 9, respectively.), if the clay fraction (finer than 0.005mm) content percentage P_c(%) in silts are not less than 10, 13 and 16, respectively, then the soil may be evaluated as non-liquefaction soil;

3. If one of the inequalities (1), (2) and (3) is true, the influence of liquefaction will not be considered

$$d_u > d_o + d_b - 2 \quad (1)$$

$$d_w > d_o + d_b - 3 \quad (2)$$

$$\frac{d_u}{d_o + d_b - 2} + \frac{d_w}{d_o + d_b - 3} > 1.5 \quad (3)$$

where d_b is the depth of foundation buried, d_u is the accumulated thickness of overburden nonliquefaction strata, d_w is the depth of water table, and d_o is the characteristic depth of liquefaction soil which is taken from Table 1:

Table 1. Characteristic depth of liquefaction soil

Type of saturated soils	Intensity in China VII	VIII	IX
Silts	6	7	8
Sands	7	8	9

These principles were set from the investigations for a lot of exploration and tests and the information about liquefied and not-liquefied sites after some major earthquakes in China. It also referred to the relevant international research achievement (The Seismic Codes of China 1978, 1985). The principles were applied to all liquefaction potential evaluation.

3 LIQUEFACTION POTENTIAL EVALUATION

Liquefaction analyses for the boring records are performed by layers according to the following methods:

1. All of borings are preliminarily evaluated according to the principles mentioned above and the liquefiable borings will be evaluated further.

2. The following method is used to evaluate the liquefiable borings in calculation:

For saturated liquefiable soil, the critical SPT blow value N_{CR} is calculated from the formula (4):

$$N_{CR} = N_o[0.9 + 0.1(d_s - d_w)]\sqrt{3/P_c} \quad (4)$$

where d_s is the depth of the penetration point, P_c is the percentage of the clay fraction (finer than 0.005mm) content in silts, if P_c(%) < 3, take $P_c = 3$, and N_o is the basic value of SPT blow for evaluating liquefaction potential, it is taken from Table 2:

Table 2. Basic value of SPT blow for evaluating liquefaction potential.

Depth of the penetration point	Intensity in China VII	VIII	IX
$0m < d_s \leq 15m$	6	10	16
$15m < d_s \leq 20m$	9	14	19

For the SPT blow value measured in the same location N_{SPT}, if $N_{SPT} < N_{CR}$, it will be evaluated as liquefaction, otherwise, nonliquefaction.

3. Liquefaction potential is evaluated by using SWV V_s-values.

A correlation formula between SWV V_s-value and SPT blow N_{SPT} was obtained according to a large number of data measured in Tai-yuan Planning Zone by author (Wang 1990). For that zone only having SWV, V_s measured in field can be converted into an equivalent SPT blow N_E through formula (5):

$$N_E = (V_s/53.91)^{10/6} \quad (5)$$

then N_E is substituted for N_{SPT} which should be measured in the same location. After N_{CR} is calculated from formula (4), if $N_E < N_{CR}$, it will be evaluated as liquefaction; otherwise, nonliquefaction.

The reliability of the method was investigated by comparing 8 kinds of methods based on SWV V_s-value with SPT blow method using formula (4) in the same 44 locations in Tai-yuan Planning Zone (Wang 1990). The results evaluated by using formula

(5) were all closest to that evaluated by using formula (4) with the seismic intensity in China VII, VIII and IX.

4 CLASSIFICATION OF THE DEGREE OF LIQUEFACTION SUSCEPTIBILITY

For the liquefaction borings evaluated, the liquefaction indices P showing the degree of liquefaction susceptibility are calculated from formula (6):

$$P = \sum_{i=1}^{n} (1 - \frac{N_i}{N_{cri}}) d_i w_i \qquad (6)$$

where n is the total number of the liquefaction points evaluated according to SPT blow method, N_i, N_{cri} are the SPT blow value and the critical SPT blow value at the ith point, respectively, if $N_i > N_{cri}$, let $N_i = N_{cri}$, d_i is the soil stratum thickness represented by the ith point, and W_i is a weighting function showing the influence of the ith point position $W_i = (25 - d_{si})/2$, d_{si} is the ith point depth, if $d_{si} < 5$m, take $d_{si} = 5$.

The degree of liquefaction susceptibility is classified into three grades according to P values. As $P \leq 5$, $15 > P > 5$ and $P \geq 15$, they are defined as low, middle, and high susceptibility, respectively. The case with an unequal settlement up to 20 cm may occur for the middle susceptibility, and more than 20 cm for the high susceptibility.

The calculating liquefaction potential analyses for the borings lying in the liquefiable zone in Tai-yuan Planning Zone were performed according to the methods mentioned above by using a computer program.

5 SEISMIC GROUND MOTION STRENGTH

The seismic ground motion strength as for evaluating liquefaction potential by SPT blow method is taken as seismic intensity. If the maximum acceleration on ground surface $a_{max}(g)$ is given, it may be converted into equivalent intensity from Table 3 (Hu 1988).

According to the results studied (Yuan 1990), corresponding to 10% of probability of exceedance in 50 years, the maximum acceleration on ground surface in Tai-yuan Planning Zone is $0.18g \leq a_{max} \leq 0.35g$. The equivalent seismic intensity is VIII as referred to Table 3, and if corresponding to 2.5% of probability of exceedance in 50 years, then the maximum acceleration on ground surface is increased to

Table 3. Relationship between seismic intensity and maximum acceleration on ground surface.

Intensity in China	Maximum acceleration on ground surface $a_{max}(g)$	
	Range of value	Average value
VII	0.090-0.177	0.125
VIII	0.178-0.353	0.250
VX	0.354-0.707	0.500

$0.25g \leq a_{max} \leq 0.45g$, the equivalent intensities are IX in the where is a narrow belt along the Fen River and VIII in the other place of the zone.

6 LIQUEFACTION POTENTIAL MAPS

The work in calculative evaluation of liquefaction potential and determination of liquefaction susceptibility and maximum liquefaction depth limits is for the borings, which will give the data for mapping liquefaction extent and depth of the zone.

Mapping liquefaction potential is based on the technique to combine useful information as much as possible about site conditions and factors relevant to liquefaction potential in the depth of less than 20m, including soil stratum conditions, water table depths, clay fraction (finer than 0.005mm) content percentage in silts, relative density of sand, accumulated thickness of overburden nonliquefaction strata, percoration of groundwater, seismic intensity etc. If the conditions of site and factors relevant to liquefaction potential around a boring are similar to the boring, the extent of liquefaction potential of the boring can be spread up to the place where the conditions changed obviously with the boring. After doing the things for all borings, the boundaries between liquefaction and nonliquefaction sites can be found. The liquefaction zones with the same susceptibility grade are pieced together into some continuous zones. The large piece of liquefaction zone with the same susceptibility grade may be further divided into several subzones according to liquefaction index and liquefaction depth. An average liquefaction index and maximum liquefaction depth limits are given in each subzone, which is convenient for the engineers to use both at present and /or in future.

The liquefaction potential maps of Tai-yuan Planning Zone are shown in Fig.1. and Fig.2. Corresponding to 2.5% ofprobability of exceedance in 50 years, the detail

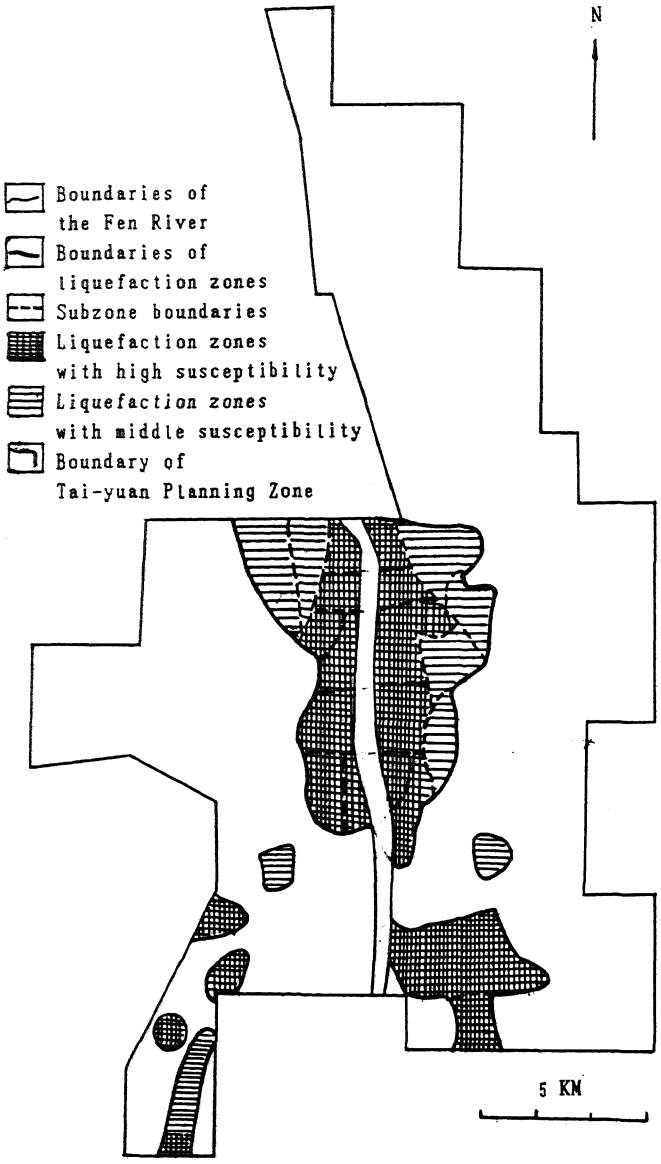

Fig.1 Liquefaction potential map of Tai-yuan Planning Zone for the seismic ground motion corresponding to2.5% of probability of exceedance in 50 years

Figure similar to Fig.2 is omitted as space is limited.

7 CONCLUSIONS

A set of liquefaction potential maps under the seismic ground motion with two levels of probability of exceedance in 50 years in the Tai-yuan Planning Zone, China were compiled mainly according to SPT and SWV data, and a method for compiling the maps was proposed. Liquefaction susceptibility is classified into three grades as low, middle, and high. The whole liquefaction zone was composed of 21-23 subzones. An average liquefaction index and maximum liquefaction depth limits were given in each subzone.

Corresponding to 10% of probability of exceedance in 50 years, the total area of liquefaction zone, was 42 Km^2 (18.6% of the planning area), in which 65% of the liquefaction area has a high liquefaction susceptibility, 24% a middle susceptibility and 11% a low susceptibility.

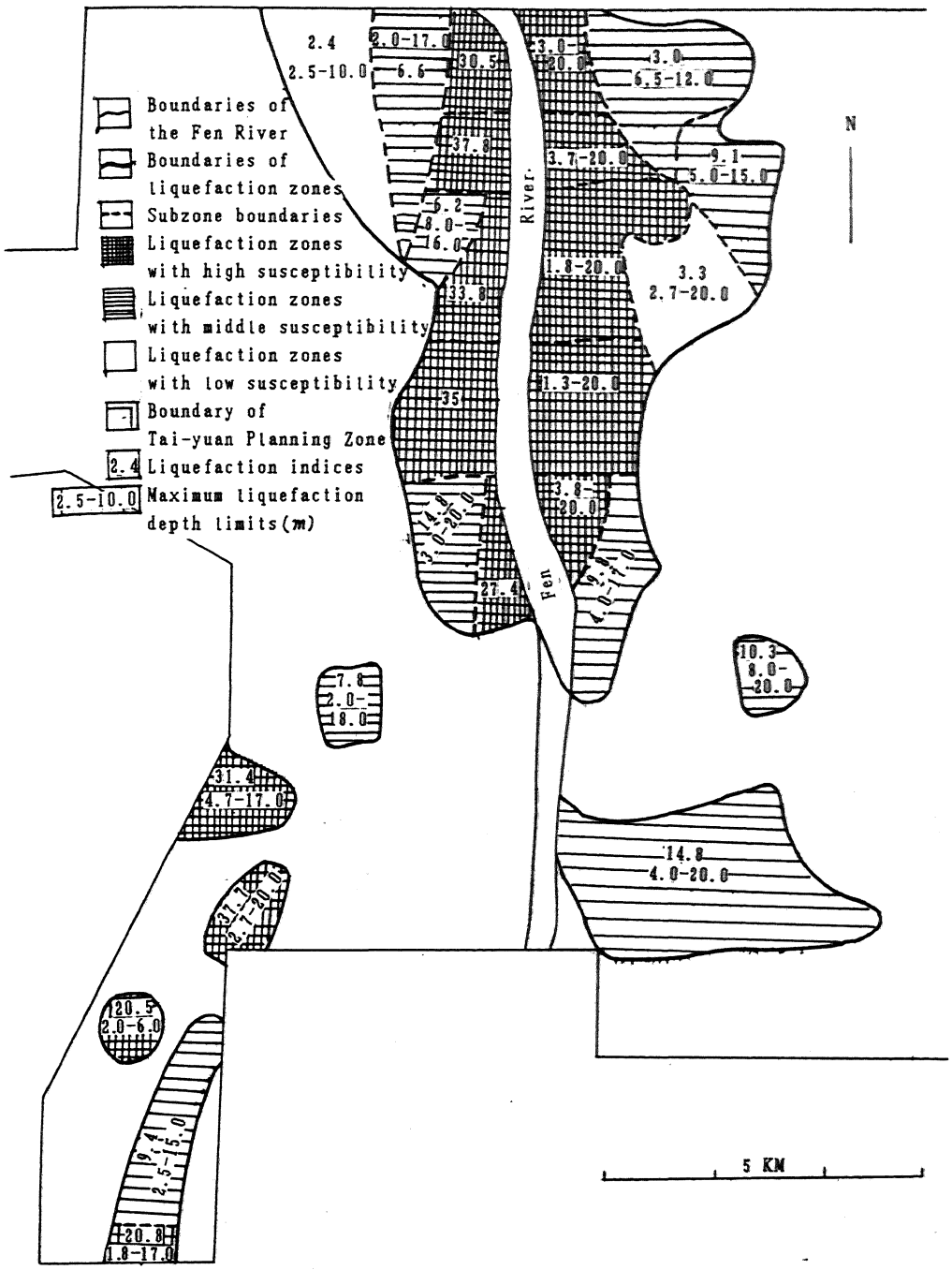

Fig. 2 Liquefaction potential zoning of Tai-yuan Planning Zone for the seismic ground motion corres ponding to 10% of probability of exceedance in 50 years

Corresponding to 2.5% of probability of exceedance in 50 years, the total area of liquefaction zone became 44.5Km^2 (19.7% of the planning area), and two more liquefaction subzones were added, the area of high liquefaction susceptibility was changed to 75% of liquefaction area, the area of middle susceptibility to 25%, and of low susceptibility, none. The liquefaction potential maps are useful

to the planning of seismic disaster prevention and engineering construction as well as to the design and site selection of engineering.

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