Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

2-2-6

LIQUEFACTION POTENTIAL MAP IN TOKYO LOWLAND

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SUMMARY

To estimate liquefaction susceptibility in Tokyo lowland, the lots and zoning maps are presented. These maps incorporate factors obtained through the following studies; inquiry of liquefaction during the 1923 Kanto earthquake, calculation of liquefaction potential indices for over 11,000 boring records, investigation of geography and geology. The results of these studies show that the liquefiable area is about one fourth of Tokyo lowland.

INTRODUCTION

Information useful for liquefaction potential mapping of wide area may be divided into the three categories; information about actually liquefied and not-liquefied sites during past earthquakes, information about geography and geology, information about liquefaction potential indices for boring records. The liquefaction potential map in Tokyo lowland was compiled from not only the indices of liquefaction potential analysis but also the information about liquefaction generated during the Kanto earthquake and the characteristics of geography and geology. In this study, the mapping procedures had been developed by using Computer Aided System for Assessing Liquefaction Potential (Refs. 1,2). The degree of liquefaction susceptibility is classified into three ranks as high, low and very low. The lots map gives a general liquefaction potential condition, and therefore knowledge of the liquefaction potential is useful for disaster preparedness preliminary planning. The zoning map is useful for the design and location of structures.

INFORMATION USEFUL FOR LIQUEFACTION POTENTIAL MAPPING

Inquiry of Liquefaction during the 1923 Kanto Earthquake There are several documents concerning liquefaction phenomena such as spouting sand and mud water in Tokyo lowland during a few historic earthquakes. But these collected documents could not cover all over the area under consideration. Therefore, interviews with over 300 persons who experienced the hazard in Tokyo lowland were carried out. Liquefied and not-liquefied sites were clarified as shown in Fig. 1. It can be seen that liquefied sites distribute along rivers and in reclaimed land of Tokyo Bay.

Liquefaction Analysis for Boring Records Undrained cyclic triaxial tests on undisturbed specimens were performed about 200 cases in Tokyo lowland. The liquefaction strength of sandy deposits containing fines are larger than the estimated strength using the simplified analysis proposed by Iwasaki and Tatsuoka(Ref. 3). Therefore, the modified formula are proposed. The liquefaction resistance in-situ R are given in the following equations,

$D_{50} < 0.074\text{mm}\,(F_c > 50\%)$

$$R = 0.0882\sqrt{\frac{N+0.5}{\sigma_v'+0.7}} + 0.0025F_c + 0.055 - 0.055\log_{10}\sigma_v' \qquad (1)$$

$0.074\text{mm} \leqq D_{50} \leqq 0.5\text{mm}$

$$R = 0.0882\sqrt{\frac{N+0.5}{\sigma_v'+0.7}} + 0.20\log_{10}\frac{0.20}{D_{50}} + 0.055\log_{10}(F_c+1) - 0.055\log_{10}\sigma_v' \qquad (2)$$

$D_{50} > 0.5\text{mm}$

$$R = 0.0882\sqrt{\frac{N+0.5}{\sigma_v'+0.7}} - 0.08 + 0.055\log_{10}(F_c+1) - 0.055\log_{10}\sigma_v' \qquad (3)$$

where N, σ_v' (kgf/cm^2), D_{50} (mm) and Fc(%) are SPT N-values, effective overburden pressure, mean diameter and fines content ratio, respectively. The dynamic load factor L is given in the following equation,

$$L = (\alpha_{s,max}/\ g\ )\ (\ \sigma_v\ /\ \sigma_v'\ )\ r_d \qquad (4)$$

where $\alpha_{s,max}$, g, σ_v, σ_v' and r_d are the estimated maximum acceleration on ground surface, the acceleration of gravity, the total overburden pressure, the effective overburden pressure and the reduction factor for dynamic shear stress, respectively. The reduction factor is determined from the average of shear stress on the ground at 78 sites calculated by program SHAKE.

$$r_d = 1 - 0.025\,Z \quad (\ Z\ ;\ \text{depth in meter}\ ) \qquad (5)$$

Liquefaction resistance factor FL is defined at the ratio of R to L. To estimate the degree of severity in liquefaction-induced ground failures, Liquefaction Potential Index PL was defined by Iwasaki and Tatsuoka (Ref. 3) as

$$PL = \int_0^{20} F \cdot w(z)\,dz \qquad (6)$$

where $F = 1 - FL$ or $F=0$ according as $FL \leq 1.0$ or $FL > 1.0$ and $w(Z) = 10 - 0.5Z$, respectively. The accumulated percentage of PL-values included in heavily liquefied and not-liquefied sites except the lands reclaimed after the Kanto earthquake are shown in Fig. 2. PL-value is considerably different between liquefied and not-liquefied sites. The degrees of liquefaction susceptibility concerning PL-value are classified three ranks as $PL \geqq 15$, $15 > PL \geqq 5$ and $PL < 5$ called high, low and very low, respectively. Liquefaction in shallow sandy deposit is generally prone to induce sever ground failures. We proposes the criteria of liquefaction susceptibility with FL-value of sandy surface layers as shown in Table 1, where l and h are the thickness and the depth of the liquefiable sandy layers within six meters from the ground surface, respectively. It has been disclosed from the comparison between the analytical information and actually liquefied sites during the Kanto earthquake that the combination of PL-value and FL-value of sandy surface layers gives more reasonable estimation. The combination table is determined as shown in Table 2.

LIQUEFACTION POTENTIAL MAPPING

Liquefaction Potential Lots Map This map is based on the technique to combine useful information as much as possible. To fix the lots previously, the estimation is able to be made at each lot independently. The lots system is determined according to the Standard Regional Grid and Mesh Code System of Geographical Survey Institute. The size of each lot is about 460 x 570 meters and Tokyo lowland under consideration is divided into 1,679 lots. Block diagram for the compilation of information is shown in Fig. 3. The procedure consists of two major categories. One is the analytical information concern with the results of the liquefaction analysis. The other is qualitative information illustrated on maps. Each category is assumed to have not only the rank of susceptibility but also the rank of reliability. The susceptibility rank on basis of analytical information is determined by the compilation with the statistical mode of PL-values and FL-values of sandy surface layers. The reliability depends on the number and distribution of boring sites included in the lot. For example, the number of boring records are more than 15 and the distribution is uniform, and the reliability is determined as high. Conversely, a small number of boring records or localized distribution gives low reliability. To display the lot on CRT connected to a micro computer, susceptibility and reliability ranks were decided interactively. As the information about maps, six kinds of map were adopted. Ranks of susceptibility and reliability are shown in Table 3. These maps were selected from the statistical interrelationships among the analytical information, Liquefaction Distribution Map, geographical and geological maps. Computer Aided System and Geographic Information System were used for this procedure. For example, some legends such as Marsh and Reclaimed land of Land Condition Map were closely related to liquefied sites and were determined as high rank. Upland and Bars were clearly related to not-liquefied sites and were determined as very low. However, other legends were not related and the degree of low susceptibility was supposed to them. If many legends mingle in the lot, the susceptibility was selected as the highest liquefiable rank of the legends. The reliability was determined by the area of the selected legend in the lot, but the weight of reliability were taken account for six maps. Then, these results were incorporated by generally called "2 out of 3" concept of systems engineering. Though a predicted rank on each map is individually fuzzy, the accuracy of prediction may be improved by this concept. The incorporation of information about maps is made by using the flow chart as shown in Fig. 4. Analytical information and information about maps are combined into final susceptibility rank using combination table as shown in Table 4. On this table, analytical information is more trustworthy a little bit than information about maps. The lots map is shown in Fig 5.

Liquefaction Potential Zoning Map The zoning map is based on indices calculated by the liquefaction analysis. The zone boundaries of liquefaction susceptibility are determined by the PL regional map and FL regional map. The zone boundaries of the sites which lack boring were compensated with Land Condition Map, Liquefaction Distribution Map and Liquefaction Potential Lots Map. To overlap two sheets of the regional map, the final liquefaction susceptibility ranks and zone boundaries are determined in accordance with the Table 2. The zoning map is shown in Fig 6.

CONCLUSION

The liquefaction potential maps are presented for future earthquakes as large as the 1923 Kanto earthquake. For the level of shaking intensity within Tokyo lowland, 24 percentage of area has a high liquefaction susceptibility, 63 percentage a low liquefaction susceptibility, and 13 percentage a very low liquefaction susceptibility.

ACKNOWLEDGMENTS

This study was carried out as part of the project of seismic disaster prevention in Tokyo. The authors wish to acknowledge Department of General Affairs of 14 Wards in Tokyo lowland and 309 persons who complied with the interview.

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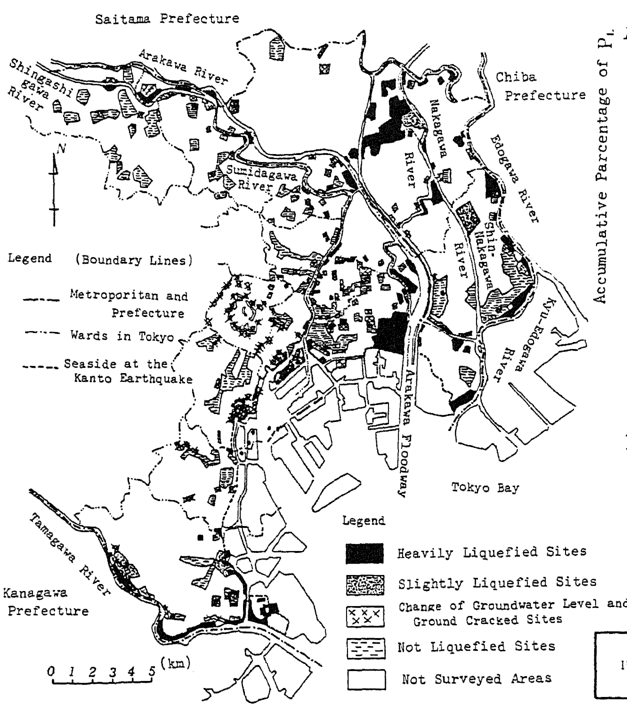

Fig. 1 Liquefaction Distribution Map in Tokyo Lowland during the 1923 Kanto Earthquake

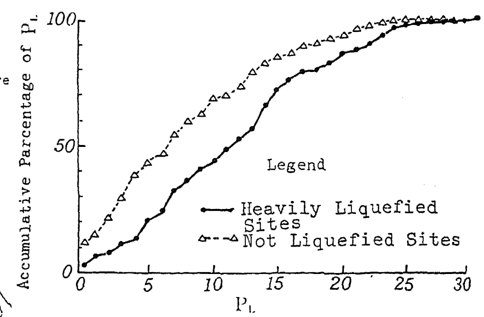

Fig. 2 Relation between Accumulative Percentage of PL and PL for Liquefied and Not Liquefied Sites

Table 1

Criterion of Liquefaction Susceptibility with FL-value of Surface Layers

Liquefiable Layer Depth h

Thickness l (Meter) \ Meter	$h \leq 3$ $F_L < 0.8$	$h \leq 3$ $0.8 \leq F_L < 1.0$	$3 < h \leq 6$ $F_L < 0.8$	$3 < h \leq 6$ $0.8 \leq F_L < 1.0$	$h \geq 6$ $F_L < 1.0$
$3 \leq l$	A	A	A	B	C
$2 \leq l < 3$	A	B	B	C	D
$1 \leq l < 2$	B	C	C	C	D
$0 \leq l < 1$	C	C	C	D	D

A;Very High, B;High, C;Low, D;Very Low

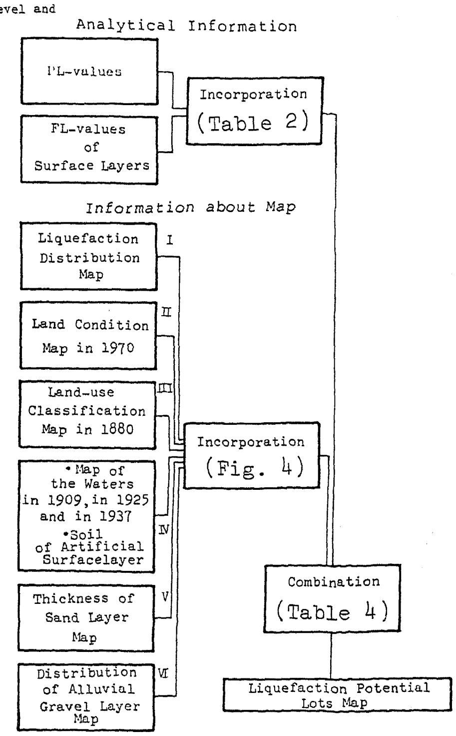

Fig. 3 Block Diagram of Lots Mapping

Table 2
Estimating Liquefaction Method with PL-rank and FL-value of Surface Layers

Liquefiable Rank Obtained from Table 1

P_L-rank	A	B	C	D
$P_L \geqq 15$	○	○	△	△
$5 \leqq P_L < 15$	○	△	△	×
$0 \leqq P_L < 5$	△	△	×	×

Legend; Liquefaction Susceptibility

○ High, △ Low, × Very Low

Table 4
To combine Analytical Information and Information about Map into Final Susceptibility Rank

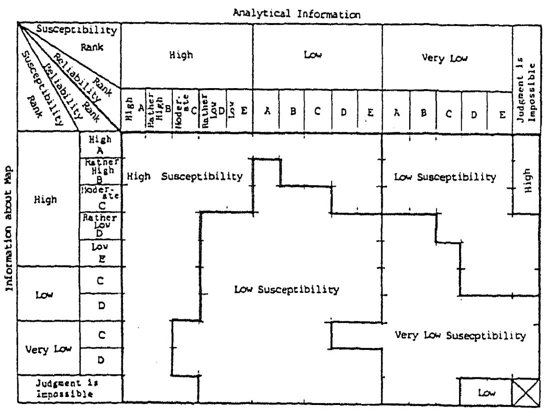

Table 3 Liquefaction Susceptibility and Reliability based on Information about Maps

see Fig. 3	Liquefaction Susceptibility High: Reliability	Rank	Liquefaction Susceptibility Low: Reliability	Rank	Liqufaction Susceptibility Very Low: Reliability	Rank
Map I	Heavily and Slightly Liquefied Sites Large Area Rather Large Moderate Rather Small Small	 High A Rather High B Moderate C Rather Low D Low E	—		Not Liquefied Sites Large Others	 High A Moderate C
Map II	Present River Bed, Waterfront and Sea Old River Bed Marsh Reclaimed Land Artificial Low Fill on the Past Waters Large Rather Large Moderate	 High A Rather High B Moderate C	Flood Plain · Delta · Coastal Plain River Valley Plain · Shallow Valley Gentle Slope Alluvial Fan Natural Levee · Collurial Slope Enclosed Depression Artificial High Fill on the Past Waters Artificial High and Low Fills Large Rather Large Moderate	 High A Rather High B Moderate C	Diluvial Upland Bars Large Area Rather Large	 High A Rather High B
Map III	Marsh Large Area Others	 Moderate C Rather Low D	—		—	
Map IV	Artificial Sand Fill on the Past Waters Over 2 Sites in the Lot Over 2 Sites the Waters only Syowa era	 Moderate C Rather Low D	Artificial Sandy Soils Fill on the Past Waters Over 1 Site	 Moderate C	—	
Map V	Thickness of Sand Layer Over 10 meters Large Area Rather Largh Moderate	 High A Rather High B Moderate C	—		—	
Map VI	—		—		Gravel Layer existing less than 5 meters Large Area Rather Large Others	 High A Rather High B Moderate C

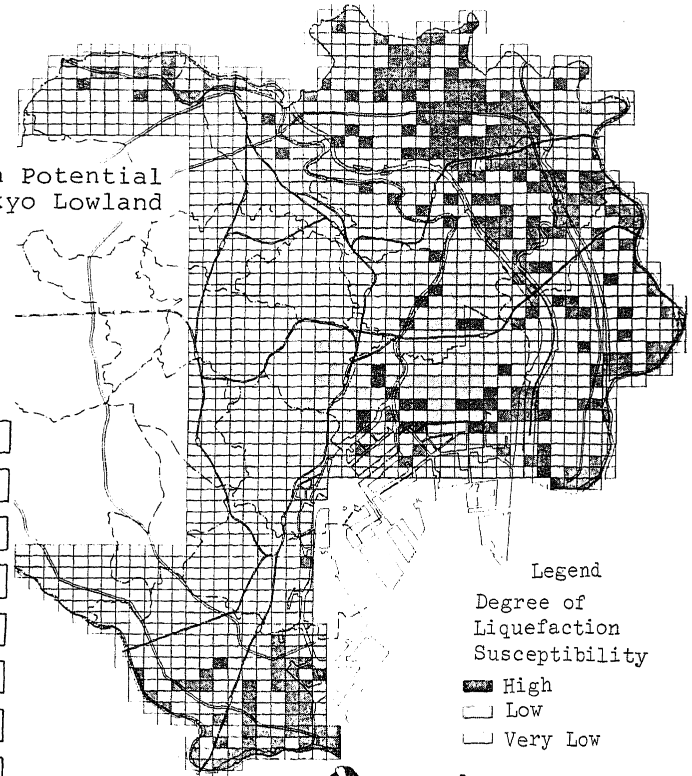

Fig. 5 Liquefaction Potential
Lots Map in Tokyo Lowland

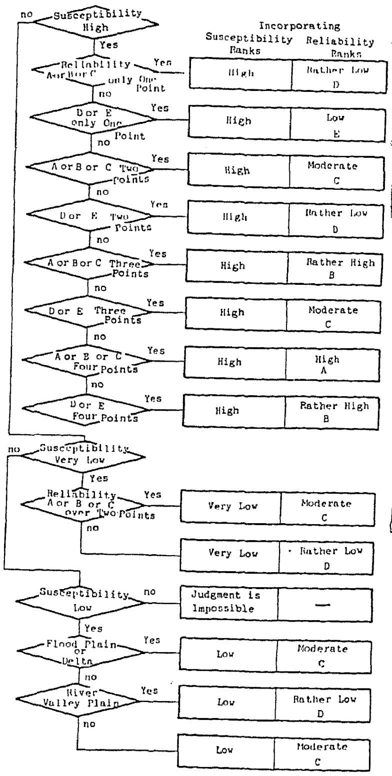

Fig. 4 Flow Chart for
Incorporating Information
about Maps

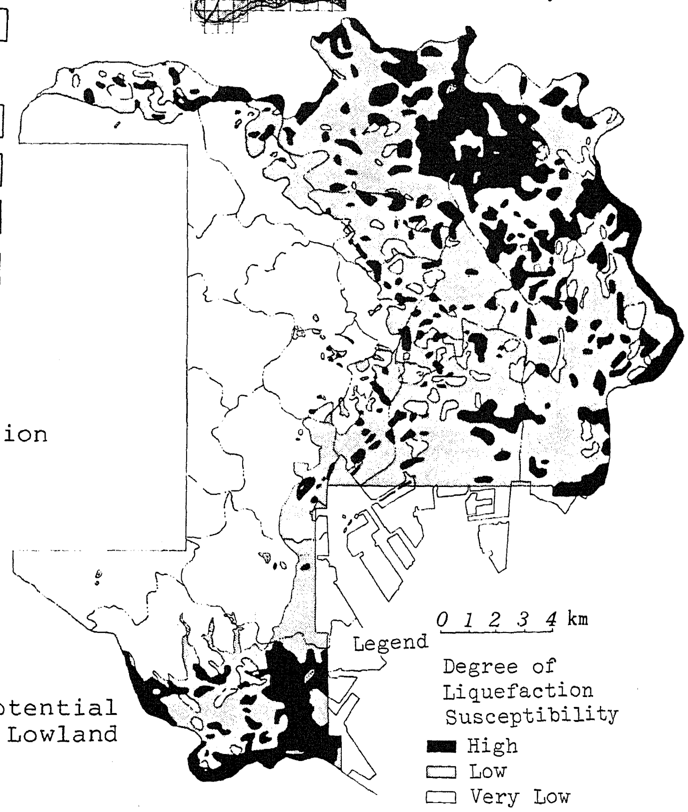

Fig. 6 Liquefaction Potential
Zoning Map in Tokyo Lowland