EVALUATION OF LIQUEFACTION POTENTIAL OF SANDY DEPOSITS BY A STATISTICAL METHOD

by

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SYNOPSIS

A method of evaluating the liquefaction potential of sandy deposits is proposed. The expression for prediction of liquefaction occurrence is derived by a statistical treatment of basic data for known cases of liquefaction and no liquefaction in past experiences. The examination of this expression shows that it can discriminate the cases of liquefaction from those of no liquefaction not only in the basic data but in the other data.

INTRODUCTION

The evaluation of liquefaction potential of soil deposits at construction sites in seismically active region is very important. Many researches in this branch yielded the four types of methods: the method of using past experiences, the method by standard blasting, the method by ground response analyses and laboratory test procedures, and the method by design acceleration level at ground surface and laboratory test procedures. The method presented in this paper is derived by a statistical treatment of only basic data of earthquake and soil conditions. In this study, liquefaction potential, defined as a function of some basic factors, expresses a measure of susceptibility to liquefaction and makes it possible to predict easily liquefaction occurrence at any sites for given soil conditions and assumed earthquake data.

LIQUEFACTION POTENTIAL

Liquefaction potential depends on variable factors, such as relative density of soil, earthquake magnitude, epicentral distance, etc. Hence, [1] liquefaction potential L is a function of such factors x_i (i =1,2,-- k). For simplicity, the function L is assumed to be a linear function of normalized factors y_i (i =1,2,-- k) instead of x_i , i.e.,

$$L = l_1 y_1 + l_2 y_2 + \cdots + l_k y_k \quad , \qquad (1)$$

where l_i (i =1,2,-- k) are coefficients to be properly determined.

A policy of determining l_i is that the function L should be a good indication of susceptibility to liquefaction based on past experiences. The function L consists of $L^{(1)}$ and $L^{(2)}$; $L^{(1)}$ is for the group of liquefaction and $L^{(2)}$ is for the group of no liquefaction. For good discrimination of two groups from each other, it may be necessitated that i) the averages of $L^{(1)}$ and $L^{(2)}$ are separated from each other as far as possible and ii) the variance of L in each group is as small as possible. This conditions are satisfied if a function:

$$G = \frac{(\bar{L}^{(1)} - \bar{L}^{(2)})^2}{\sum_{p=1}^{2}\sum_{j=1}^{n_p} (L_j^{(p)} - \bar{L}^{(p)})^2} \qquad (2)$$

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takes its maximum, where

$\bar{L}^{(p)}$: mean value of $L^{(p)}$ (p =1,2),

$L_j^{(p)}$: value of L for j -th case belonging to group p (p =1,2),

n_p : number of cases belonging to group p (p =1,2).

After some manipulation, eq. (2) can be transformed into

$$G = \frac{\sum_{m=1}^{k}\sum_{n=1}^{k} l_m l_n d_m d_n}{\sum_{m=1}^{k}\sum_{n=1}^{k} l_m l_n S_{mn}} = \frac{A}{B} , \tag{3}$$

where

$$d_n = \bar{y}_n^{(1)} - \bar{y}_n^{(2)} \quad (n = 1, 2, \text{----} k) , \tag{4}$$

$$S_{mn} = \sum_{p=1}^{2}\sum_{j=1}^{n} (y_{mj}^{(p)} - \bar{y}_m^{(p)})(y_{nj}^{(p)} - \bar{y}_n^{(p)}) , \tag{5}$$

and A and B denote the numerator and the denominator of the middle term of eq. (3), respectively.

To determine the coefficients l_i which make the function G maximum, the partial derivatives of G with respect to l_i are put zero, then

$$\frac{\partial B}{\partial l_i} = \frac{1}{G}\cdot\frac{\partial A}{\partial l_i} \qquad (i = 1, 2, \text{-----} k) \tag{6}$$

From eq. (6), we can get a simultanuous equation:

$$\left.\begin{array}{l} S_{11} l_1 + S_{12} l_2 + \text{------} + S_{1k} l_k = d_1 \\ S_{21} l_1 + S_{22} l_2 + \text{-------} + S_{2k} l_k = d_2 \\ \vdots \\ S_{k1} l_1 + S_{k2} l_2 + \text{-------} + S_{kk} l_k = d_k \end{array}\right\} \tag{7}$$

for the determination of the coefficients l_i .

RESULTS OF COMPUTATION

a) Liquefaction potential with four factors

In the first trial of computation, the basic factors x_i (i =1,2,3,4) are taken as:

x_1 : position of water table below ground surface (m),

x_2 : **depth under study** (m)**,**

x_3 : penetration value at **depth under study,**

x_4 : maximum acceleration level at ground surface (g).

The normalized factors y_i (i =1,2,3,4) are taken to have their j -th component given by the relation:

$$y_{ij} = \frac{x_{ij} - \bar{x}_i}{s_i} \tag{8}$$

where y_{ij} : j -th value of y_i ,

x_{ij} : j -th value of x_i ,

$\bar{x}_i$: mean value of x_i and

s_i : standard deviation of x_i

To solve eq. (7), the basic data in Table 1, summarized by Seed and Idriss,[2] are used, and the result gives the expression:

$$L = y_1 + 4.05 y_2 - 31.93 y_3 + 22.14 y_4 \tag{9}$$

The values of L for 35 cases in Table 1 are calculated by eq. (9), as shown in Fig. 1(a). For the discrimination of the two groups, the critical value L_0 should be specified. A method is employed here which gives an equal ratio of successful discrimination to each group, i.e.,

$$\int_{-\infty}^{L_0} f_2(L)\,dL = \int_{L_0}^{\infty} f_1(L)\,dL$$

where f_1 and f_2 are probability density functions for the group of liquefaction and no liquefaction, respectively. The application of this method to Fig. 1(a) gives the critical value L_0 =-2.36 and the ratio of successful discrimination P_r =80.5%.

b) Liquefaction potential with six factors

If we assume the basic factors x_i (i =1,2,--6) as follows:

x_1 : magnitude of earthquake,
x_2 : epicentral distance (km),
x_3 : position of water table below ground surface (m),
x_4 : depth under study (m),
x_5 : penetration value at depth under study,
x_6 : duration of ground motion (sec),

then the expression:

$$L = y_1 - 1.15y_2 - 0.14y_3 - 1.30y_4 - 4.39y_5 + 5.37y_6 \qquad (10)$$

is obtained. The values of L for the cases in Table 1 are plotted in Fig. 1(b), which gives P_r =83.4% for L_0 =-2.46.

APPLICATIONS

a) The applicability of eqs. (9) and (10) to other cases

The discrimination charts are drawn by applying eqs. (9) and (10) to the other cases in Table 2, summarized by Whitman.[3] From Fig. 2(a) and (b) for eqs. (9) and (10) respectively, it is seen that the ratios of successful discrimination are 6/9 and 8/9 for corresponding specified critical value in preceding section.

b) The evaluation of critical penetration value

The liquefaction potential evaluation charts, as shown in Fig. 3, are proposed by Seed et al.[2] The used parameters correspond to eq. (9) with four basic factors. Two solid lines in Fig. 3 are calculated by eq. (9). The L_0 line shows the critical condition and the 99% line is the line of no liquefaction with probability of 99%. The shaded zones given by Seed et al. are a little wider than the zones between the L_0 and 99% lines.

CONCLUSIONS

A statistical analysis of known data for earthquakes during which liquefaction had occurred was carried out to establish a predictive method for the occurrence of liquefaction of sandy deposits. Liquefaction potential was derived herein as a function of some factors related to liquefying process. The examination of eqs. (9) and (10) proves that they are well discriminable between the groups of liquefaction and no liquefaction.

It is considered that a shortcoming of statistical method is in its independency of the mechanism of liquefying process. However, the method using only basic and objective factors is, first of all, simple and practical, and also makes it possible to avoid theoretical assumptions and experimental errors which may exist in the study of the mechanism.

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2) Seed, H. B. and Idriss, I. M.: Simplified Procedure for Evaluating Soil Liquefaction Potential, Proc. of ASCE., Vol. 97, No. SM9, pp. 1249-1273, 1971.

3) Whitman, R. V.: Resistance of Soil to Liquefaction and Settlement, Soils and Foundations, Vol. XI, No. 4, pp. 59-68, 1971.

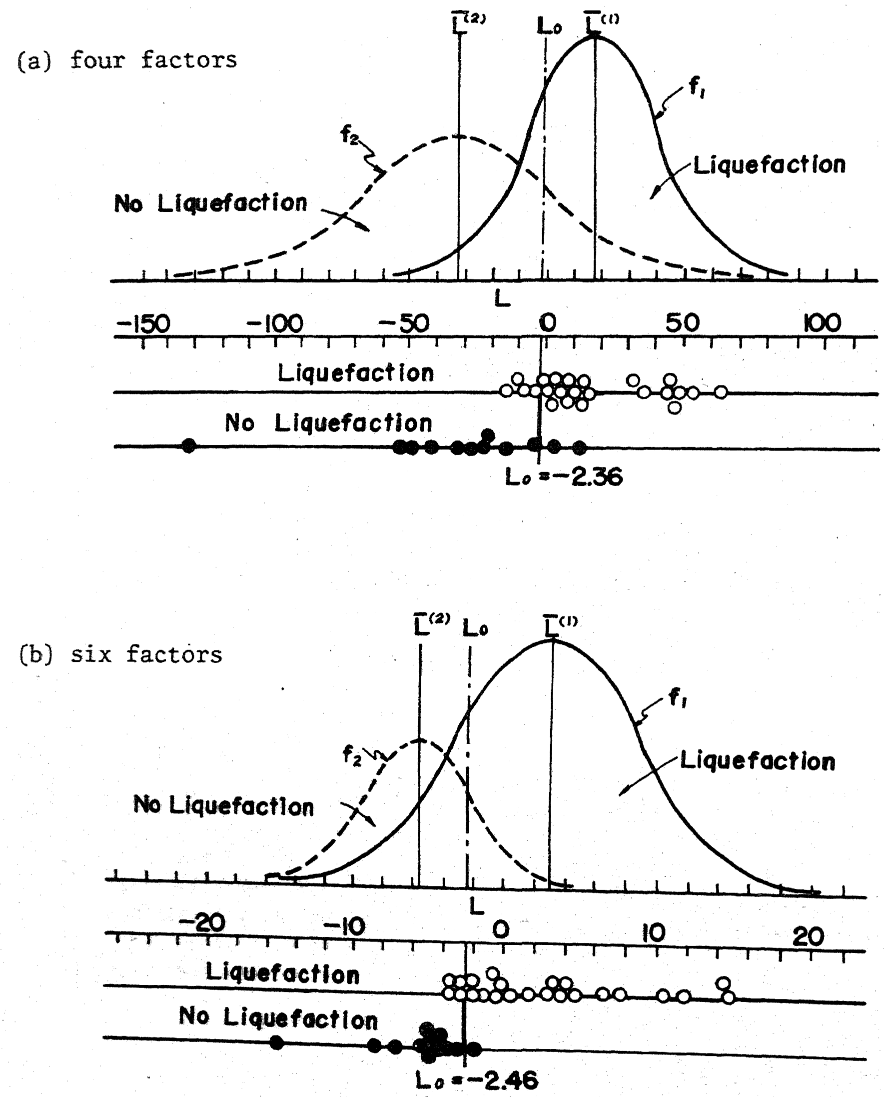

Fig. 1 Discrimination charts for 35 cases listed in Table 1.

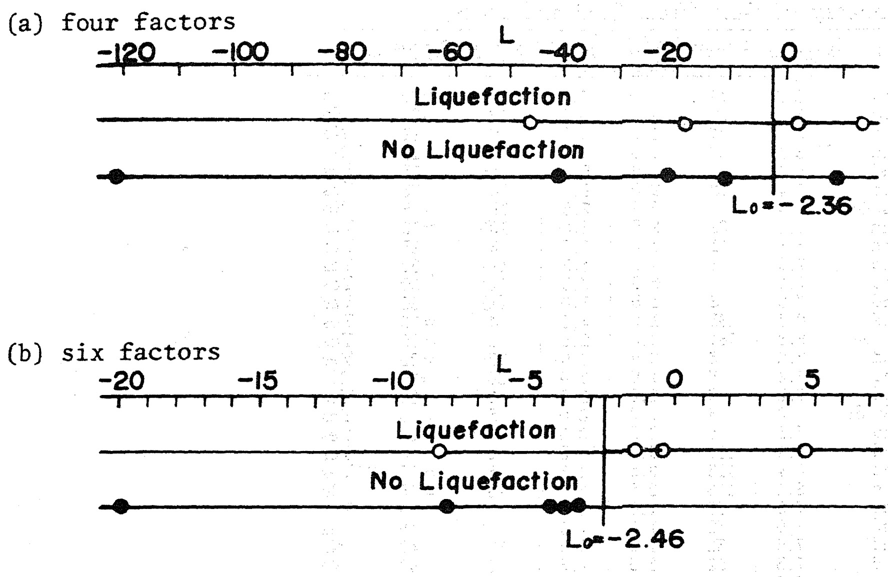

Fig. 2 Discrimination charts for 9 cases listed in Table 2.

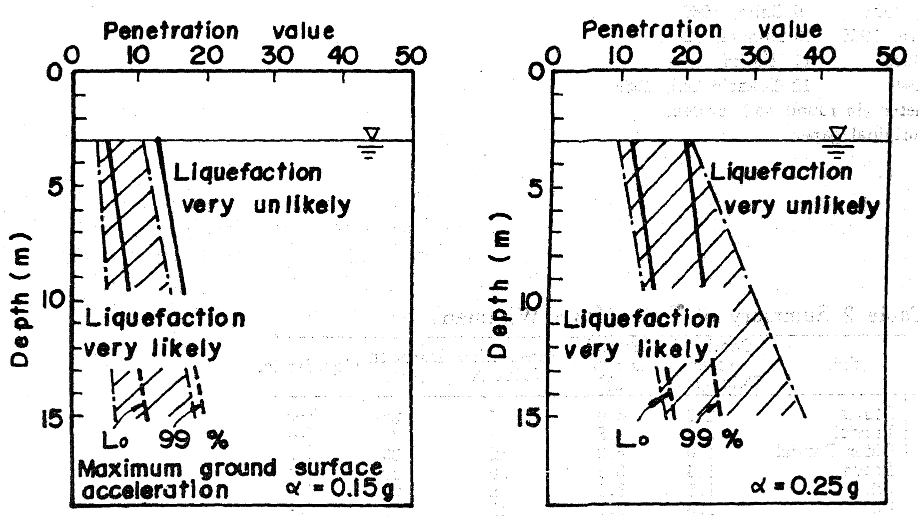

Fig. 3 Liquefaction potential evaluation charts (Seed and Idriss) and L_0 and 99% lines.

Table 1 Summary of Data (from Seed and Idriss)

a	Location	Soil	Magnitude	Distance (km)[b]	Depth of Water Table(m)[b]	Critical Depth (m)[b]	Penetration Value N	Duration (sec)	Liquefaction
1	Niigata	Sand	6.6	39	1.0	6.0	6	≈20	No
1	Niigata	Sand	6.6	39	1.0	6.0	12	≈20	No
2	Niigata	Sand	6.1	47	1.0	6.0	6	≈12	No
2	Niigata	Sand	6.1	47	1.0	6.0	12	≈12	No
3	Ogaki	Sand	8.4	32	1.0	5.0[c]	4[c]	≈75	Yes
3	Ginan West	Sand	8.4	32	2.0	9.0	10	≈75	Yes
3	Unuma	Sa. & Gr.	8.4	32	2.0	7.5	19	≈75	No
3	Ogase Pond	Sand	8.4	32	2.5	4.0[c]	10[c]	≈75	Yes
4	Sheffield Dam	Sand	6.3	11	4.5	7.5	(3)	15	Yes
5	Brawley	Sand	7.0	8	4.5	4.5	(9)	30	Yes
5	All-Am. Canal	Sand	7.0	8	6.0	7.5	(4)	30	Yes
5	Solfatara Canal	Sand	7.0	8	1.5	6.0	(1)	30	Yes
6	Komei	Sand	8.3	161	1.5	4.0	4	≈70	Yes
6	Meiko St.	Si. & Sa.	8.3	161	0.5	2.5	1	≈70	Yes
7	Takaya	Sand	7.2	6	3.5	4.0[c]	12[c]	≈30	Yes
7	Takaya	Sand	7.2	6	1.0	7.0	28	≈30	No
7	Shonenji Temple.	Sand	7.2	6	1.0	3.0	3	≈30	Yes
7	Agr. Union	Sa. & Si.	7.2	6	1.0	6.0	5	≈30	Yes
8	Lake Merced	Sand	5.5	6	2.5	3.0	7	18	Yes
9	Puerto Montt	Sand	8.4	113	3.5	4.5	6	≈75	Yes
9	Puerto Montt	Sand	8.4	113	3.5	4.5	8	≈75	Yes
9	Puerto Montt	Sand	8.4	113	3.5	6.0	18	≈75	No
10	Niigata	Sand	7.5	52	1.0	6.0	6	40	Yes
10	Niigata	Sand	7.5	52	1.0	7.5	8[c]	40	Yes
10	Niigata	Sand	7.5	52	1.0	6.0	12	40	No
10	Niigata	Sand	7.5	52	3.5	7.5	6	40	No
11	Snow River	Sand	8.3	97	0.0	6.0	5	180	Yes
11	Snow River	Sand	8.3	97	2.5	6.0	5	180	Yes
11	Quartz Creek	Sandy Gr.	8.3	113	0.0	7.5	35	180	No
11	Scott Glacier	Sand	8.3	89	0.0	6.0	10	180	Yes
11	Valdez	Sand	8.3	56	1.5	6.0	13	180	Yes
12	Hachinohe	Sand	7.8	172	1.0	3.5	14	45	No
12	Hachinohe	Sand	7.8	172	1.0	3.5	6	45	Yes
12	Hachinohe	Sand	7.8	172	1.5	3.0	15	45	No
12	Hakodate	Sand	7.8	283	1.0	4.5	6	45	Yes

a. 1 Niigata, 1802 — 7 Fukui, 1948
2 Niigata, 1887 — 8 San Francisco, 1957
3 Mino-Owari, 1891 — 9 Chile, 1960
4 Santa Barbara, 1925 — 10 Niigata, 1964
5 El Centro, 1940 — 11 Alaska, 1964
6 Tonankai, 1944 — 12 Tokachi-Oki, 1968

b. Changed to meter (in round no.) system

c. Revised from original papers

Table 2 Summary of Data (from Whitman)

a	Lacation	Soil	Depth of Water Table(m)[b]	Critical Depth (m)[b]	Penetration Value N	Duration (sec)	Liquefaction
1	Niigata Zone C	Fluvial	1.0	6.0	7	20	Yes
1	Niigata withfill	Fluvial	3.5	8.5	7	20	No
1	Niigata Zone B	Older Fluvial	1.0	6.0	12	20	No
2	Hachinohe	Beach	1.5	3.5	18	20	No
2	Hachinohe	Fill	1.5	3.5	6	20	Yes
2	Hakodate	Fill	1.0	5.5	13	20	Yes
3	Conception	Fluvial	3.5	7.0	10	20	No
3	Huachipato	Beach	3.5	8.0	35	20	No
4	River Bridges	Fluvial	0.0	4.5	16	120	Yes

a. 1 Niigata, Japan, 1964 — 3 Southern Chile, 1960
2 Tokachi-Oki, Japan, 1968 — 4 Prince William Sound, Alaska, 1964

b. Changed to meter(in round no.) system.