LIKELIHOOD OF LIQUEFACTION

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SYNPOSIS

Traditionally, a deterministic approach is utilized in liquefaction study. Recently a stochastic approach was proposed to study the liquefaction problem by assuming a probable shear stress envelope distribution function and simulating the liquefaction phenomena by fatigue behavior in material. Also, a discriminant analysis technique was applied to evaluate the liquefaction potential by using the available data for relative densities and corrected accelerations. Both studies utilize the probabilistic approach to determine the "yes" or "no" to liquefy, leaving the unsolved question of how probable this condition will occur.

This paper will study the liquefaction potential based on the findings of the apparent scatter in correlating the soil properties and the liquefaction. A probabilistic assessment will be applied to each contributing parameter.

INTRODUCTION

Earthquakes are reminders to us as to how incompletely we know our planet. Recent earthquakes of February 4, 1976 in Guatemala, which killed nearly 23,000 people (1)[III], proved that more attention in earthquake resistant design is necessary and urgent in establishing building design practice.

The investigation regarding the structural behavior during simulated earthquake shaking has been active in recent years. The findings in the response of upper structure to earthquake loading will improve our knowledge in earthquake-resisting design. The soil, which serves as the foundation of the upper structure, also posts an important role in evaluating the overall stability of the structure-soil system. This paper will deal primarily with the soil problem during the earthquake shaking, specifically the liquefaction likelihood. The likelihood of liquefaction in general, consists of two parts: the probability of earthquake occurrences and the conditional likelihood of liquefaction given that an earthquake occurs. The former factor has been discussed in previous paper (2), the later will be the main concern in the paper.

LIQUEFACTION

The terminology "liquefaction" has been introduced to geotechnic science most recently. The phenomena is induced primarily due to fluctuating loading conditions. The liquefaction is generally divided into two categories due to different soil behaviors.

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A saturated soil increases the pore pressure, when it is subjected to earthquake loading. The "generalized liquefaction" is referred to as the condition which the loose sand can behave as fluid when the increase in pore pressure reaches the same value as the confining stress (3-8). However, the denser sand and cohesive soil usually cannot reach this generalized liquefaction condition. These soils will show a slower increase in pore pressure, reach an unacceptable strain level for the upper structures before the pore pressure reaches the confining pressure. This large displacement condition is referred to as "cyclic mobility" as opposed to the previous liquid condition. In this paper, the generalized liquefaction condition with zero shearing resistance will be considered.

Recent major earthquakes in Niigata, Japan (June 16, 1964) and in Alaska, USA (May 27, 1964), stimulate the study of liquefaction among researchers. Soil liquefaction during earthquakes has been discussed extensively in a number of recent papers. A comprehensive list of references has been compiled in a recent state-of-the-art publication (9). As a result, an analytical method of evaluating liquefaction potential has been established (10). In addition, a simplified procedure has also been developed recently based on the past experience in liquefaction studies (11). Nevertheless, this analytical method uses a deterministic approach to either state whether or not the soil will liquefy, or evaluate the factor of safety and/or strain level during earthquake loading.

Recently, a stochastic approach was proposed to studying the liquefaction problem by assuming a probable shear stress envelope distribution function and simulating the liquefaction phenomena by fatigue behavior in material (12). Also, a discriminant analysis technique was applied to evaluate the liquefaction potential by using the available data for relative densities and corrected accelerations (13). Both studies utilize the probabilistic approach to determine the "yes" or "no" to liquefy, leaving the unsolved question of how probable this condition will occur.

This paper will study the liquefaction potential based on the findings of the apparent scatter in correlating the soil properties and the liquefaction. A probabilistic assessment will be applied to each contributing parameter.

LIKELIHOOD OF LIQUEFACTION

Let E_k be the event that the soil will liquefy due to parameter k and P_k is defined as $P(E_k)$ where P ( ) is the probability of having the event described between parentheses. If $E_{\ell/i}$ defines the event that the soil will liquefy, due to earthquake of intensity i, then

$$E_{\ell/i} = E_1 \cap E_2 \cap E_3 \cap E_4 \ldots\ldots\ldots \cap E_n \ldots\ldots\ldots\ldots \quad (1)$$

where $\cap$ denotes the intersection of events. For simplicity, it is assumed that E_k's, k = 1 to n, are independent events. Thus,

$$P_{\ell/i} = P(E_{\ell/i}) = P(E_1 \cap E_2 \cap E_3 \ldots \cap E_n)$$

$$= P(E_1)\, P(E_2)\, P(E_3) \ldots P(E_n)$$

$$\text{or} \quad P_{\ell/i} = P_1 \cdot P_2 \cdot P_3 \ldots P_n \ldots\ldots\ldots\ldots \quad (2)$$

The likelihood of liquefaction is then

$$P_\ell = \int P_{\ell/i}\, f_I\,(i)\, di \qquad \ldots \qquad (3)$$

where f_I (i) is the probability density function of earthquake occurrence with intensity i.

The critical soil and environmental parameters mostly influencing liquefaction were found to be 1) relative density of the soil, 2) uniformity coefficient of the soil, 3) intensity of ground motion, and 4) the water table depth. Each parameter will be discussed in detail in order to establish the associated probability mass function which appears in equation 2.

1) Relative Density, D_R

In the aftermath of Mino-Owari, Tohnankai and Fukui earthquakes in Japan, it was concluded that soil with relative density greater than 75 percent have little or no chance of liquefaction during an earthquake(14). A probability mass function, composed of three linear segments was, therefore, conservatively assumed as: between 0 to 20 percent relative density, a constant value of unity was assumed, with a constant value of 0.1 when relative density is 75 percent or greater, assuming linear variation between 20 percent and 75 percent relative densities. The mass function is plotted in Figure 1.

2) Uniformity Coefficient (D_{60}/D_{10})

Poorly graded soil are more susceptible to liquefaction than well-graded soils. It was observed that soils with uniformity coefficient less than 10 are more susceptible to liquefaction (12,13). An envelope of the sieve analysis of soils most liquefiable has also been presented by some investigators (10,16). These curves show that soils with uniformity coefficient less than 25 percent are most liquefiable. A linear probability mass function was, therefore, assumed with value of unity at U=1 and zero at U=25 as shown in Figure 2.

3) Intensity of Ground Motion (I)

The earthquake with higher intensity will inevitably have higher possibility of liquefaction. For design practice, the peak acceleration level is utilized. Incorporating the vertical component into seismic analysis, it is assumed that the peak acceleration of vertical components equals to 2/3 of the horizontal peak acceleration. When the horizontal peak acceleration reaches 1.5 of gravity, the vertical acceleration will reach the gravity which will cause the generalized liquefaction condition. Therefore, the probability mass function is assumed to vary quadratically with unity at acceleration level of 1.5g and zero at acceleration level of 0.00g as shwon in Figure 3.

4) The Water Table Depth

When the soil is not saturated, it is impossible to have the generalized liquefaction condition. Therefore, the probability mass function is assumed to be a step function as shown in Figure 4.

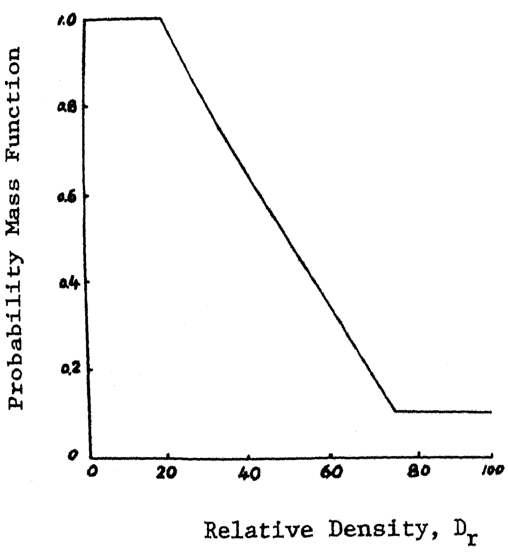

Figure 1

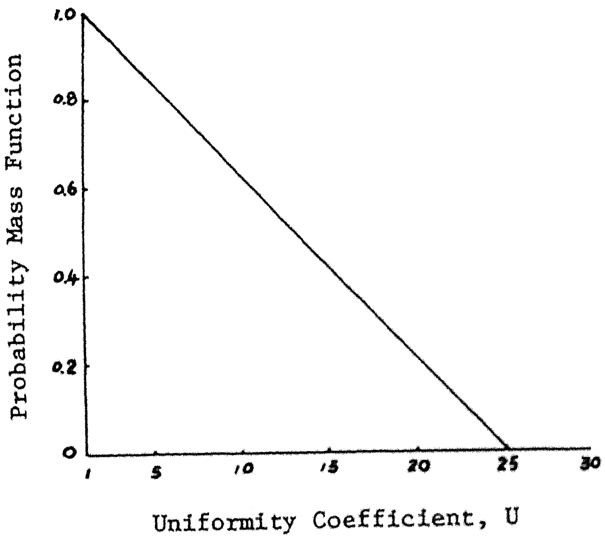

Figure 2

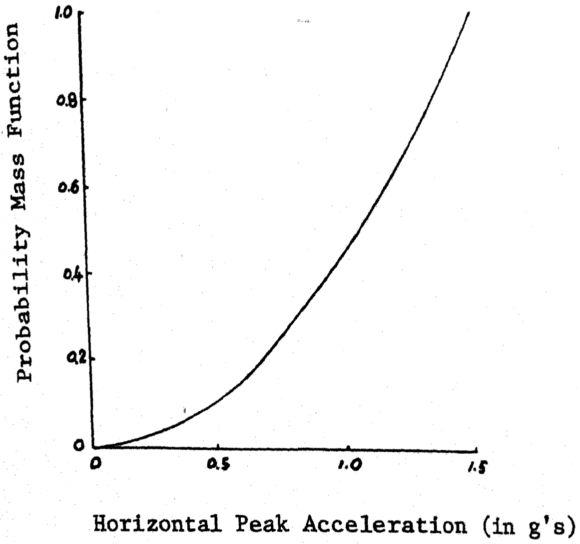

Figure 3

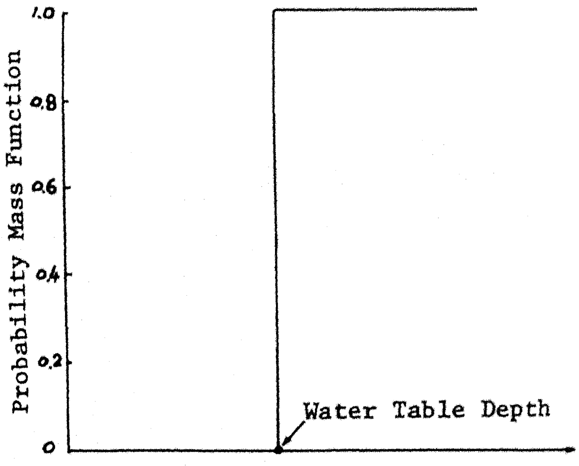

Figure 4

CONCLUSION

It is obvious that an earthquake loading is not deterministic function in nature. A stochastic approach serves better in studying the soil behaviors during an earthquake loading. Through stochastic approach, this paper discusses the likelihood of liquefaction which has found to be the most critical threat the soil can impose to the upper structure supported by them during an earthquake.

The likelihood of liquefaction due to earthquake consists of two parts: the probability of earthquake occurrences and the conditional likelihood of liquefaction given that an earthquake has occurred. The conditional likelihood has been evaluated in the paper by combining the contributions from the critical soil and environmental parameters: 1) relative density of the soil, 2) uniformity coefficient of the soil 3) intensity of ground motion and 4) the water table depth.

The proposed method, objective in nature, can be extended if more relevant knowledge concerning the contributing parameter is available. For example, the earthquake duration can come into the picture if its correlation with intensity of the shaking can be evaluated in relating the liquefaction. Also, more data collected in the future can be incorporated into the analysis through the Bayesian theory. The proposed method will throw a light on evaluating the likelihood of liquefaction, based on the available information from the field observation.

REFERENCES

1. U.S. News and World Report, April 19, 1976.

2. Fischer, J. A. and Chou, I. H., "Procedures and Confidence Limits for Earthquake Hazard Studies", 5th European Conference on Earthquake Engineering, Paper 155, Turkey, 1975, pp. 1-14.

3. Lee, K.L. and H. B. Seed, "Cyclic Stress Conditions Causing Liquefaction of Sand". Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 93, No. SM 1, Jan. 1967, pp. 47-70.

4. Seed, H. B. and K. L. Lee, "Liquefaction of Saturated Sands During Cyclic Loading", Journal, Soil Mechanics and Foundation Division, ASCE, Vol 92, No. SM 6, Nov. 1966, pp. 105-134.

5. Castro, Gonzalo, "Liquefaction and Cyclic Mobility of Saturated Sands," Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 101, No. GT6, June 1975, pp. 551-569.

6. Schaefer, J. Dixon, and J. W. Burke, "Liquefaction Case History", Journal of the Soil Mechanics and Foundation Division, ASCE Vol. 99, No. SM 11, November 1973; pp. 921-937.

7. "The San Fernando, California Earthquake of February 9, 1971", U.S. Department of the Interior, U.S. Department of Commerce, U.S. Geological Survey and the National Oceanic and Atmospheric Admin., Geological Survey Professional Paper 733, 1971.

8. Duke, C.M., and D. J. Leeds, "Response of Soils, Foundations and Earth Structures to the Chilean Earthquake of 1960", Bulletin, Seismological Society of America, Vol. 53, No. 2, February 1963, pp. 309-357.

9. "Soil Behavior Under Earthquake Loading Conditions", Shannon & Wilson, Inc. and Agbabian-Jacobsen Ass., NTIS Publication No. TID-25953, January, 1972.

10. Seed, H. B. and Idriss, J. M., "Analysis of Soil Liquefaction - Niigata Earthquake," J. Soil Mechanics and Foundation Div., ASCE, Vol. 93, No. SM3, May 1967, pp. 83-108.

11. Seed, H. B. and Idriss, J. M., "Simplified Procedure for Evaluating Soil Liquefaction Potential," J. of Soil Mechanics and Foundation Div., ASCE Vol. 97, No. SM9, September 1971, pp. 1249-1273.

12. Donovan, N. C., "A Stochastic Approach to the Seismic Liquefaction Problem", Proc. of the 1st International Conference of Applications of Statistics and Probability to Soil and Structural Engineering, Hong Kong, 1971, pp. 514-535.

13. Christian, J. T. and Swiger, W. F., "Statistics of Liquefaction and SPT Results," Jour. of the Geotechnical Div., ASCE, Vol. 101, No. GT11, November, 1975, pp. 1135-1150.

14. Kishida, H., "Characteristics of Liquefied Sands During Mino-Owari, Tohnankai and Fukui Earthquakes", Soils and Foundation (Japan), Vol. 9, No. 1, 1966, pp. 75-92.

15. Ohsaki, Y., "Effects of Sand Compaction on Liquefaction During the Tokaiichi-Oki Earthquake", Soils and Foundation (Japan), Vol. 10, 1967, pp. 112-128.

16. Lee, K. L. and Fitton, J. A., "Factors Affecting the Cyclic Loading Strength of Soil", STP 450, Symposium on Vibration Effects of Earthquakes on Soils and Foundations, ASTM, 1968, pp. 71-95.