

PROBABILISTIC EVALUATION OF LIQUEFACTION POTENTIAL

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Typically, a deterministic method is used to determine the potential for liquefaction. In a deterministic method the uncertainty of many factors that may contribute to the occurrence of liquefaction aren't incorporated. As a result, liquefaction potential is evaluated only by the factor of safety. In this paper, probabilistic concepts are used in determination of liquefaction potential. In order to determine the conditional probability of liquefaction, the Taylor's Series reliability method and Monte Carlo simulation method are used. The "simplified procedure", as embodied in the "NCEER report" will be used as the basis for the probabilistic procedure. The methods which are described in this paper are applied to an actual site after Manjil-Rudbar earthquake of June 21, 1990.

INTRODUCTION

Evaluation of liquefaction potential of soils is an important aspect in geotechnical investigations in earthquake-liable region. The most common deterministic procedure around the world for evaluating liquefaction resistance is "simplified procedure" developed originally by Seed and Idriss (1971) using blow counts from the Standard Penetration Test correlated with a parameter called the cyclic stress ratio which represents the cyclic loading on the soil. Since 1971, this procedure has been modified and updated.

In deterministic methods, the values of parameters that may contribute to the occurrence of liquefaction are considered constant. But there is uncertainty in many parameters, so deterministic methods aren't reliable methods. The probabilistic methods differ in incorporating the uncertainty of parameters compared with deterministic methods. Some probabilistic methods include Haldar and Tang (1979) and the Taylor's Series reliability method, Wolf (1994); USACE (1997, 1998); Duncan (2000).

In this paper probabilistic concepts are used in determination of liquefaction potential. In order to determine the conditional probability of liquefaction, the Taylor's Series reliability method and Monte Carlo simulation method are used.

SIMPLIFIED PROCEDURES FOR DETERMINISTIC LIQUEFACTION EVALUATION

The most common deterministic method to evaluate liquefaction potential of a site, is the "simplified procedure" originally developed by Seed and Idriss (1971). The method has been modified and improved since it was developed. A review of the current state-of-practice in liquefaction evaluation using the simplified procedure is given in the "1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance", Youd et al. (2001), referred as "NCEER Report" in this paper. The current version of the simplified procedure calculates the factor of safety FS against liquefaction of a level ground in terms of the cyclic stress ratio CSR (the demand), and the cyclic resistance ratio CRR (the capacity) according to:

$$FS = \frac{CRR_{7.5}}{CSR} MSF.K_{\sigma} \quad (1)$$

Where $CRR_{7.5}$ =Cyclic resistance ratio for magnitude 7.5 earthquakes, CSR =cyclic stress ratio, MSF = magnitude scaling factor, and K_{σ} = correction for non-linear effects of confining stress. The complete equations are given in NCEER Report.

PROBABILITY OF LIQUEFACTION

The Taylor's Series reliability method

In the Taylor's Series reliability method, Wolff (1994); USACE (1997, 1998); Duncan (2000), conditional probability of liquefaction P_L is determined, assuming a log-normal distribution of the factor of safety. This requires the calculation of a reliability log-normal reliability index β_{LN} and using the formula:

$$p_L = 1 - \Phi(\beta_{LN}) \quad (2)$$

Where $\Phi(\)$ = the standard normal cumulative distribution function. To calculate β_{LN} , the moments of the function of the safety factor must be calculated from the moments of the parameters.

Monte Carlo simulation method

Generation of random numbers with predefined probability distribution functions is one of the most important applications of Monte Carlo simulation method. In Monte Carlo simulation, values of the random variables are generated consistent with their probability distribution, and the function of the safety factor is calculated for each generated set of variables. The process is repeated numerous times, typically thousands, and the expected value, standard deviation, and probability distribution of the function of the safety factor

are taken to match that of the calculated values. Monte Carlo method permits one to estimate the shape of distribution of the function of the safety factor, permitting more accurate estimation of probability of liquefaction.

LIQUEFACTION POTENTIAL ANALYSIS IN ASTANEH AFTER MANJIL-RUDBAR EARTHQUAKE OF JUNE 21, 1990

The Manjil, Iran earthquake, $M_s=7.7$, Berberian et al. (1992), occurred on June 21, 1990. Official estimates indicate that more than 35,000 people lost their lives. During the earthquake, the liquefaction of soils played a significant role in the destruction of many houses and commercial and public buildings. There was dramatic evidence of this widespread liquefaction-induced damage as far away as 80 km from the fault.

Astaneh-Ashrafieh region is located to the east of the major city of Rasht. Liquefaction on the east of Rasht occurred almost entirely in the levee deposits along the banks of the Sefid and Heshmat rivers.

To evaluate the in situ properties of the liquefied soils in the town of Astaneh-Ashrafieh, standard penetration tests (SPT) were conducted in 16 boreholes. It is noted that these field borings were made in the summer of 1991 almost a year after the earthquake. In all cases, the SPT tests were performed using a standard 2-inch split spoon sampler without a liner. The borehole AS-3 located in the area that liquefaction was observed after Manjil earthquake. But in the borehole AS-14 liquefaction was not observed, Yegian et al. (1995).

Figure 1 shows SPT, N_s -values in boreholes AS-3 and AS-14 from Astaneh-Ashrafieh. The sands from this region are characterized as gray poorly graded fine sands with less than 10 % silts. The density of soil is about $19.5 \text{ (KN/m}^3\text{)}$. At the time of the earthquake the ground water level was about 2 meters below the ground surface.

According to the peak ground acceleration obtained from this earthquake, Naderzadeh (1991), the peak ground acceleration in Astaneh-Ashrafieh was $0.18g$.

To evaluate the conditional probability of liquefaction, the average values and estimated coefficient of variation (COV) of the uncertainty involved parameters have been considered according to table 1.

The standard penetration test (SPT) results show that the distribution function of N_{spt} is lognormal. In this paper the distribution function is assumed normal for the other uncertainty involved parameters.

Figure 1 shows the liquefaction safety factor in different depths of boreholes AS-3 and AS-14. The safety factor has been determined according to the deterministic method, Youd et al. (2001).

Figure 2 shows the conditional probability of liquefaction in the different depths of boreholes AS-3 and AS-14. The conditional probability of liquefaction has been determined according to the probabilistic methods, Monte Carlo simulation method and the Taylor's Series Reliability Method, Wolff (1994); USACE (1997, 1998); Duncan (2000). Monte Carlo simulation was carried with 5000 iterations.

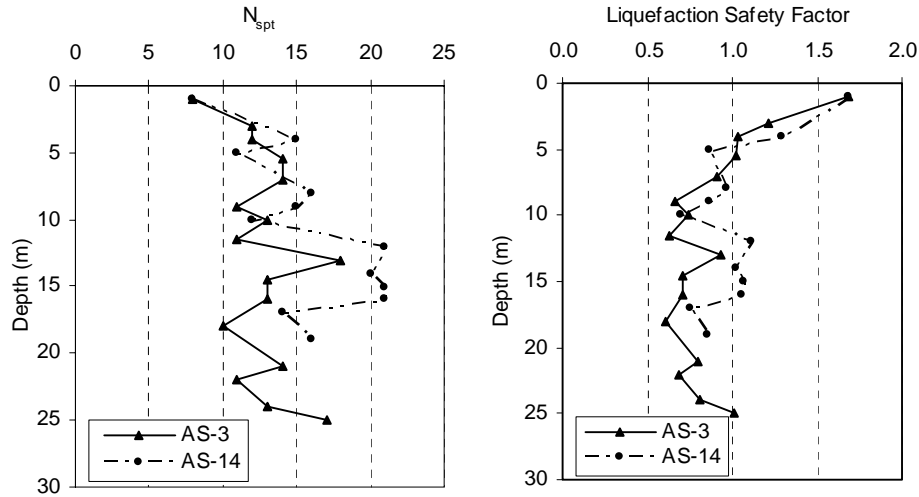


Figure 1. N_{SPT} values, Yegian et al. (1995), and Safety Factor in Boreholes AS-3, AS-14.

Table 1. The average and estimated coefficient of variation (COV).

Parameter	Average value	Estimated COV (%)	Reference
Magnitude scaling factor, MSF	NCEER Report	$COV(MSF-1)=22$	from three-sigma rule
Stress-reduction coefficient, r_d	NCEER Report	$COV(1-r_d)=22$	from three-sigma rule
moist unit weights, γ_m	Actual data	$COV(\gamma_m)=9$ (SP-SW)	Based on in-place density data from several USBR dams
SPT blow count, N_{spt}	Actual data	In this paper $COV=30$	$COV=15-40\%$ (from Harr (1984), Kulhawy (1992))
Overburden correction factor, C_N	NCEER Report	$COV(1-C_N)=23.1$	Based on data from Castro (1995)
Energy correction factor, C_E	0.95	9	Based on data for Safety hammer in NCEER Report
Borehole diameter correction factor, C_B	1.07	1	Based on data for NCEER Report
Rod length correction factor, C_R	0.82	24	Based on data from Skempton (1986)
Sample correction factor, C_S	1.2	3	Based on data for NCEER Report

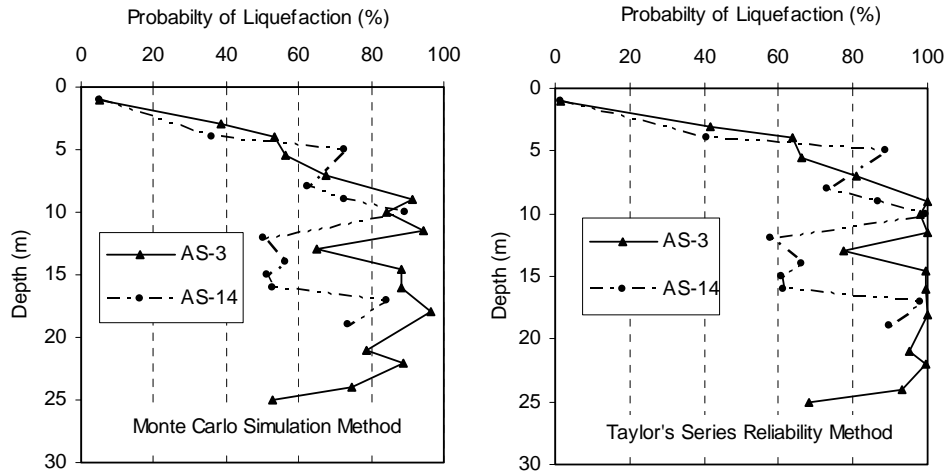


Figure 2. Probability of Liquefaction in Boreholes AS-3, AS-14.

Figure 3 shows the relation between safety factor and probability of liquefaction. According to figure 3, if safety factor is 1.5 and if coefficient of variation of parameters is as indicated in this paper, then the predicted probability of liquefaction is 0.17 in Monte Carlo simulation method and 0.18 in the Taylor's Series reliability method. Also the value of safety factor required to have the probability of liquefaction be less than 0.1 is about 1.6. According to the figure 3 the Taylor's Series reliability method is more conservative than Monte Carlo simulation method.

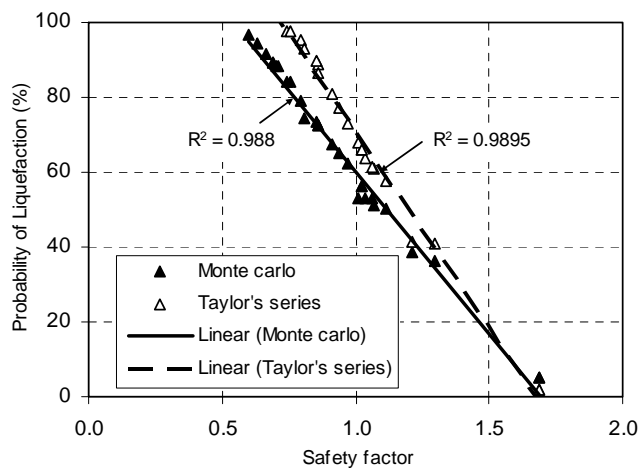


Figure3. Probability of Liquefaction versus Safety Factor.

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