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ASSESSEMENT OF LIQUEFACTIONIN BOUMERDES (ALGERIA) USING RELIABILITY ANALYSIS

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ABSTRACT: A destructive earthquake of magnitude Mw=6.8 hit the region of Boumerdes and Algiers (Algeria) on May 21, 2003. Evidence of soil liquefaction was observed ina site located in the vicinity of Boumerdes. The results of traditional analysis of soil liquefaction potential using simplified procedures are usually presented in terms of safetyfactor. However, these methods do not take into account inherent variability which is expressed in terms of liquefaction probability related to safety factors. An answer to this problem can be found by reliability analysis. In this study, a practical reliability based method is used for assessing the soil liquefaction potential. As an application, the Boumerdes region belongs to the Tell Atlas thrust of Algeria is investigated for liquefaction potential. The investigated are based on in situ tests in which the results of SPT are analyzed.It was found that even with a safety factor of 1.34, the soil still has a liquefaction probability about 30.85% for the given design earthquake.

Keywords: Soil Liquefaction, Reliability analysis; SPT

1. INTRODUCTION

Liquefaction is a process of transforming any substance into a liquid. Fine-grained soilsare transformed from a solid state to a liquefied state as a consequence of increased pore pressure and reduced effective stress[1,2]. In situ tests and simplified procedures are frequently used to evaluate the liquefaction of soils. The most widely used simplified procedure for evaluating soil liquefaction was originally proposed by Seed and Idriss (1971) [3]. This procedure is based on blow counts from the standard penetration test (SPT). The results of traditional analysis of soil liquefaction potential using the simplified procedures are usually presented in a factor of safety, defined as the ratio of the cyclic resistance ration over the cyclic stress ratio. However, this method does not take into account inherent variability. Hence it desirable to have a methodology that gives the liquefaction probability related to a safety factor.

Various models for estimating the probability of liquefaction have been proposed [4]. Some of these models are data driven, meaning that they are established based on statistical analyses of the databases of casehistories. To calculate the probability using these empirical models, only the best estimates,i.e. the mean values, of the input variable are required, the uncertainty in the model, namedmodel uncertainty, and the uncertainty in the input variables, namedparameters uncertainties, are excluded from the analysis.

Thus, the calculated probabilities might be subject to error if the effect of model and or parameter uncertainty is significant. **A** more fundamental approach to this problem would be to adopt a reliability analysis that considers both model and parameters uncertainties [5]. The reliability method requires a detailed investigation of the member strength and the applied loading data, from witch statistical indices, such as the mean value and the coefficient of variation, can be derived. Using the first order and second moment method, the relationships between the failure probability, the reliability index and the safety factor can be deduced.

In this study, the practical reliability method proposed by Hwang and Young [6] is used. This method is based on the Seed liquefaction analysis method. Using data obtained after the major earthquakes of Boumerdes, Algeria (magnitude Mw=6.8) in 2003, both safety factor and the liquefaction probability in some site are computed.

2. DESCRIPTION OF THE APPRAOCH DEVELOPED BY HWANG AND YOUNG [6]

The reliability model uses the concept of action and reaction which are expressed by the terms R for resistance and S for action. In the classical approach used to estimate the liquefaction potential both CSR (cyclic stress ratio) and CRR (cyclic resistance ratio) are used. The CSR is set for S and CRR is set for R. Hence the performance function which gives the status of the equilibrium is Z=R-S. Hereafter the term failure will used when liquefaction occurs and safe when we do not have liquefaction. Obviously, we have three states: (a) if $Z<0$ then the failure will occur and alternatively (b) if $Z>0$ then the performance function is „safe", i.e, there is no liquefaction. The particular case when (c) Z=0 it set the boundary between liquefaction and no liquefaction. Both CRR and CSR have inherent uncertainties thus R and S could not be considered as deterministic but as random variables, hence the liquefaction performance function will also be a random variable.

A simplified calculation method involving statistics is being used in this paper by Hwang and Yang [6] for basic independent random variable, i.e, R and S in this case. Although not totally independent a conservative approach will forces us to consider them as independent. According to the Central limit theorem, the performance function Z is also a normal distribution random variable, if both R and S are iid (independent and identically distributed) random variables. The liquefaction probability **Pf** equals the probability of Z<0. Hence, it can be expressed as:

$$\mathbf{Pf} = \int_{-\infty}^{0} f_Z(Z)dz = F_Z(0) \quad (1)$$

Where, $f_Z(z)$ is the probability density function (PDF) of Z and $F_Z(z)$ is cumulative probability function (CPF) of Z. Although Z has been assumed to follow a normal distribution, the developed method could be readily extended to other forms of PDF. Assuming that Z follows a normal distribution, **Pf** could be regarded as the dashed area under the probability density function curve (Fig 1). The mean and standard deviation parameters related to R and S are shown by μ_R and $\mu_S$and σ_R,σ_S, respectively.Therefore, the mean μ_Z, the standard deviation σ_Z and the variance coefficient δ_Z are expressed as:

$$\mu_Z = \mu_R - \mu_S \quad (2)$$

$$\boldsymbol{\sigma_Z} = \sqrt{\boldsymbol{\sigma_R^2} + \boldsymbol{\sigma_S^2}} \quad (3)$$

$$\boldsymbol{\delta_Z} = \frac{\mu_Z}{\sigma_Z} = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}} \quad (4)$$

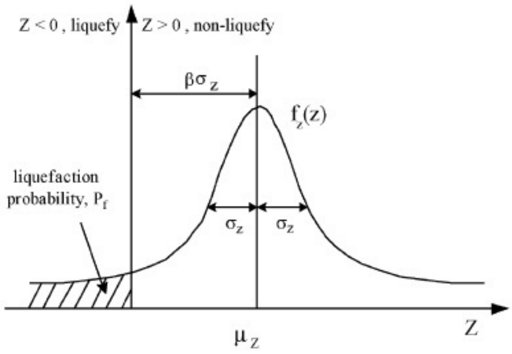

Fig.1 Probability density distribution for the liquefaction performance function [6]

Usingthese equations, the probability that Z exceeds 0 or any other value could be simplycalculated using the statistics for the basicvariables R and S. Thereliability index βcan be written as:

$$\boldsymbol{\beta} = \frac{\mu_Z}{\sigma_Z} \quad (5)$$

As Z follows a normal distribution, then:

$$\mathbf{Pf} = \int_{-\infty}^{0} \frac{1}{\sigma_Z\sqrt{2\pi}} \mathbf{e}^{-\frac{1}{2}\left(\frac{z-\mu_Z}{\sigma_Z}\right)^2} \mathbf{dz} \quad (6)$$

With new variable $\mathbf{t} = \frac{z-\mu_Z}{\sigma_Z}$

$$\mathbf{Pf} = \int_{-\infty}^{-\frac{\mu_Z}{\sigma_Z}} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dz = \Phi\left(-\frac{\mu_Z}{\sigma_Z}\right) \quad (7)$$

$$\mathbf{Pf} = \Phi(-\beta) = 1 - \Phi(\beta) \quad (8)$$

Where$\boldsymbol{\Phi}(*)$ is the standardized normal distribution function.The application of this method to estimate the probability that liquefaction will occur imposes to have the statistics of R and S. Keep in mind that these variables are simply CRR and CSR, thus it is necessary to have the statistics of both CRR and CSR. These later could be determined using the inherent variability associated with the excitation and data collected in a particular site.Hwang and Young [6] develop a methodology to estimates the above mentioned statistics. This methodology can be used following the steps described in Fig. 2. Careful examination of this flowchart shows that the assumption of independency remains acceptable since CRR does not influence CSR.This flowchart has been implemented to find the probability of liquefaction using data obtained after the major earthquakes of Boumerdes, 21 mai 2003 and SPT data collected in the epicentral area.Here the model provides us with the liquefaction probability, using which it may be concluded that which soil sample would be more susceptible to liquefaction than others. Hence here the soil sample giving higher probability of liquefaction is being considered to be “failure” and the ones with lower probability are considered to be “safe”(Fig 2)

3. CASE STUDY

A destructive earthquake of magnitude of MW=6.8 hit the region of Boumerdes and Algiers (Algeria) on May 21, 2003. This is among the strongest seismic events of the Mediterranean and causes widespread damage in the epicentral region, with more than 2200 causalities and 10,000 injured 10000, about 20000 housing units affected and left about 160000 homeless [1].

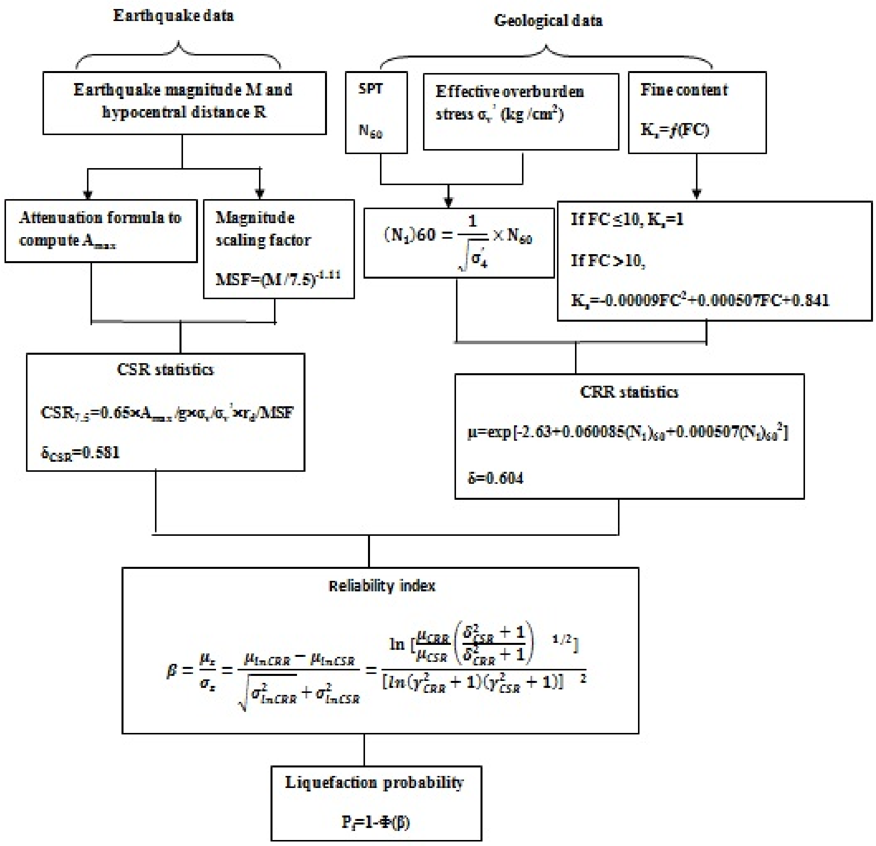

Fig. 2 Flow chart of the proposed reliability method for liquefaction analysis [6]

The main shock was felt about 250 Km far from the epicenter and triggered sea waves of 1- 3 m in amplitude in Balearic Islands (Spain). Based on field observations and press report intensity IX (MSK scale) is attributed to the epicentral area. The main shock triggered ground deformation, particularly liquefaction. After the main shock, extensive liquefaction in the epicentral area, particularlyin the Oued Sebaw and OuedIsser Rivers as well as along the Boumerdes- Dellys beach (Fig 5).A view of liquefaction and evidence of sand boil in the zone after earthquake are shown in Fig 3 and Fig 4.

Fig. 3 Example of liquefaction phenomenon in Boumerdes area (Algeria, 2003)

Fig. 4 Example of liquefaction phenomenon in Boumerdes area (Algeria, 2003)

As an application of the method, the region of Boumerdes is investigated for liquefaction potential. SPT was conducted in many boreholes located in the area. A summary of the information available and the related calculations are presented in the table (1).

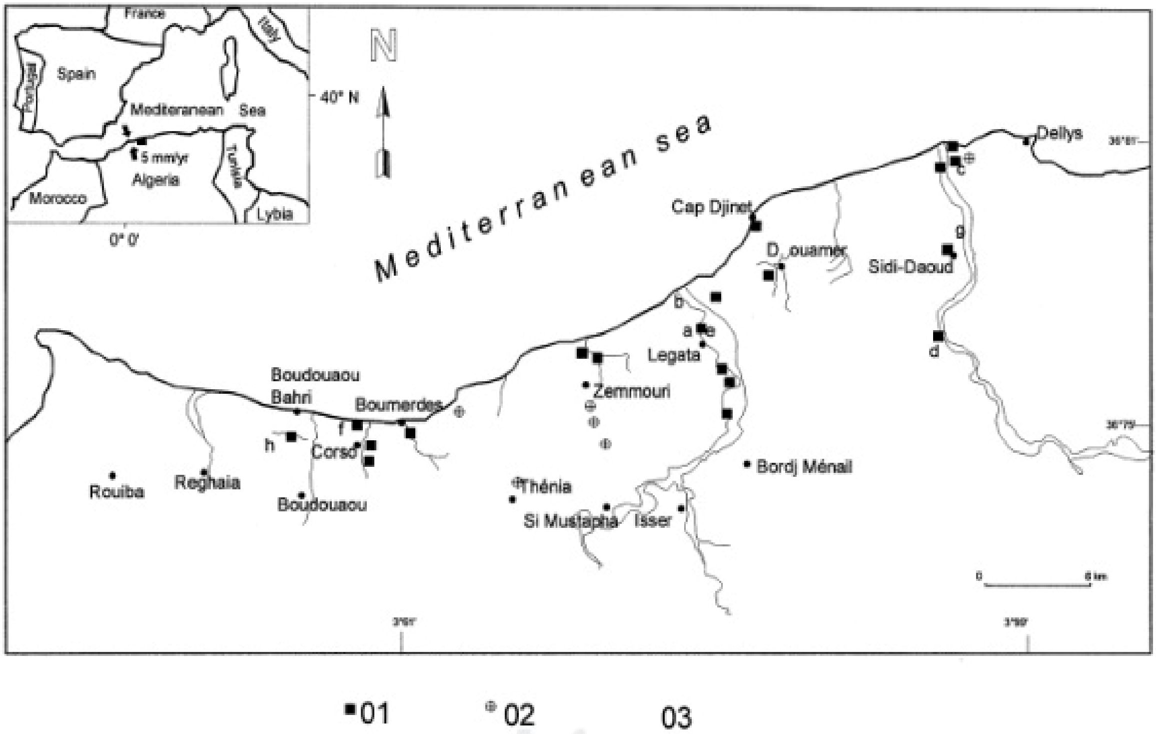

Fig.5 Distribution of liquefaction during the main shock of May 21, 2003 earthquake (01= liquefaction, 02= Landslides, 03= Waterways).

Table 1 Summary of the information and calculations of liquefaction potential in the region

Depth (m)	SPT. N	FS	Pf
9	18	0.93	46.02
10.5	24	0.68	17.62
12	12	1.34	30.85
13.5	10	1.55	21.186
15	13	1.4	27.43
16.5	12	1.4	29.46
18	21	0.92	45.23
19.5	20	1.02	18.41

The different parameters of soil and the results of liquefaction for the area of Boumerdes are shown in the Fig7 and Fig 8.As shown in the results five depths are safe against liquefaction where the factor of safety is greater than on

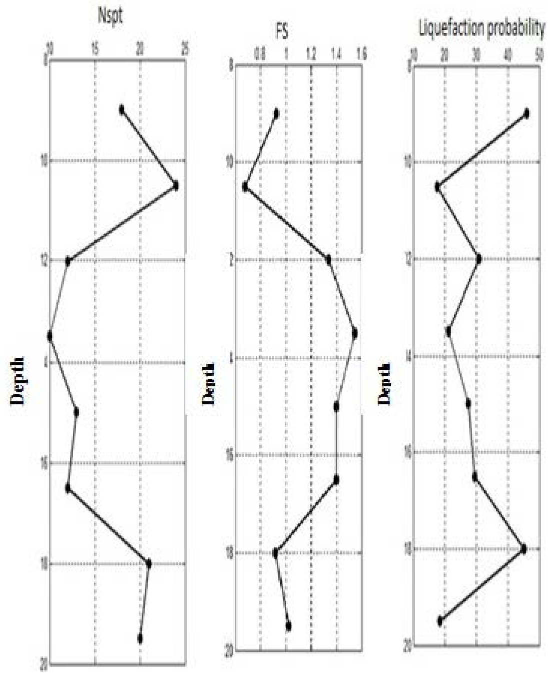

Fig.6 Soil parameters for the area

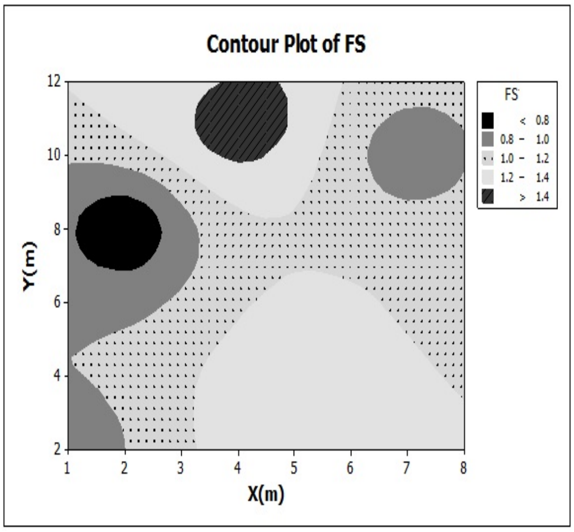

Fig.7. Contour of the FS in the area

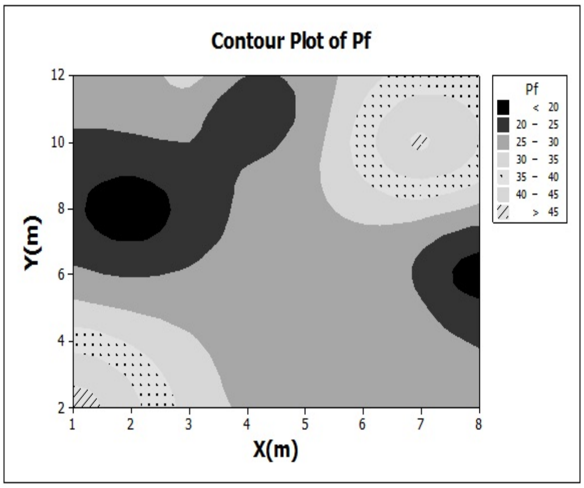

Fig.8. Contour of the Pf in the area

Careful examination of these results show that even with of safety factor greater than 1, some site have a probability of liquefaction of about 30%.

4. CONCLUSION

In this study, a practical reliability based method proposed by Hwang and Young is used. This method is used to find out the liquefaction probability of SPT case data of the major earthquakes of Boumerdes, Algeria (magnitude Mw=6.8) in 2003.The deterministic safety factor and probability of liquefaction are calculated. As shown in the results five depths are safe against liquefaction where the factor of safety is greater than one. At the same time, the probability of liquefaction for this safe depth varies from 17.60 – 46 %.In the example, it was found that even with a safety factor of 1.34, the soil still has a liquefaction probability about 30.85% for the given design earthquake.

Through this study we conclude that a deterministic approach is not always reliable since the reliability approach leads to a liquefaction probability that could reach 35%

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