VALIDATING THE JUANG METHOD IN ORDER TO ASSESS LIQUEFACTION POTENTIAL OF SOILS IN THE NORTHERN MOROCCAN REGION OF TANGIER
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ABSTRACT

Liquefaction is a phenomenon which is related to sudden dramatic reduction of the bearing capacity of a soil under the effect resulting from intense and fast seismic or any other dynamic loading. Liquefaction occurs generally in saturated soil. This phenomenon is of considerable importance because of the destructive impact that can provoke on civil engineering infrastructures, economy and human life. Classical works studying the problem of soil liquefaction include many empirical approaches such as the deformation approach, the stress approach and the energy approach, were the liquefaction resistance is usually assessed using methods and procedures developed based on field tests. The standard penetration test and the cone penetration test are two tests that are widely used to analyse the potential of soil liquefaction. These tests are deemed reliable and permit to estimate the soil liquefaction potential. The correlation formulas depend however on the site where they were established. To adapt them to another site such as soils existing in the northern Moroccan city of Tangier requires a further investigation study. The semi-empirical Juang approach was found to be more suited to predict the liquefaction potential of soils found in the region of Tangier. In this work predictions of Juang method are compared to those obtained with a rigorous two-dimensional physical modelling where DeepSoil software was used to develop the numerical model.

Keywords: Liquefaction, soil, seism, empirical approach, physical modelling.

1. INTRODUCTION

Soil liquefaction is a phenomenon that happens when the bearing capacity of the soil vanishes under the action of a dynamic solicitation resulting form a seism or from any other dynamic and intensive vibration. It occurs only in saturated soils.

Liquefaction is of great interest because of the destructive damage that could be generated on the infrastructure, economy and human casualties. Among the works that have dealt with liquefaction problem of soils, one can cite Dobry [1] who has introduced the strain approach, Seed and Harder [2] who have introduced the stress approach and Park et al. [3] who have introduced the energetic approach. Correlation between the static resistance measured by means of the cone penetration test and the shear capacity ratio which determines the soil resistance to liquefaction were introduced by Robertson and Wride [4]. The rational approaches that are based on continuum mechanics equations for modelling the liquefaction phenomenon were also developed by some authors like Pastor and Zienkiewicz [5].

Liquefaction resistance is usually evaluated by using procedures that need in situ tests. The Standard Penetration Test (SPT) and the Cone Penetration Test CPT are the mean known standard tests that are used in the field of evaluating liquefaction potential of soils. These tests are known to be reliable and enable estimating the liquefaction potential by means of established correlation formulas. These correlations depend on the site where they were derived. Their adaptation to another site is questionable. In this work, we study how these correlations can be validated to predict liquefaction in the particular case of soils that are encountered in the northern region of Morocco near from Tangier city.

In a previous work [6] we have compared the different approaches that are used to predict liquefaction potential for this special case of Tangier soils. We have demonstrated that Juang method is well suited to predict liquefaction event occurrence. This method was found to be more secure and less sensitive with regards to the stochastic variations affecting soil parameters.

The objective of this work is to investigate to what extent the semi-empirical Juang method can predict the liquefaction potential for Tangier soils by comparing its predictions with the results of a full physical based two dimensional modelling of the problem. The continuum mechanics based modelling of the liquefaction phenomenon enables through using the physical equations of the problem considering parameters such as damping, seism duration and spectra in order to simulate more realistically their influence on liquefaction. This provides a way to discuss validity of the semi-empirical method of Juang to be used in predicting liquefaction of Tangier soils. The open source software package DeepSoil was used to develop the
numerical model based on the complete physical representation of liquefaction problem. The case study
that was examined is the site where the tourist complex Tangier City Centre was built. This site shows a
high liquefaction risk due the particular composition of its foundation soil.

2. EVALUATING LIQUEFACTION POTENTIAL BY MEANS OF JUANG METHOD

The mean factors controlling liquefaction of cohesionless saturated soils are the duration and the intensity
of the earthquake motion, soil density and the confining effective pressure. In order to characterise soil
response under the action of cyclic seismic acceleration, a lot of methodologies were developed [2].
Actually studies in this field are based on three mean approaches:
- cyclic stress approach;
- cyclic strain approach;
- energetic approach.

Method that are based on cyclic stresses and strains were developed from laboratory tests. Due to the fact
that the cyclic response of a soil is controlled by factors such as the nature of soil, the existing pre-strains,
the loading history and the altering effects that could not be reproduced exactly during laboratory tests, use
is made frequently of empirical relationships that were developed upon using in situ collected parameters.
These are obtained from the well known standard tests such as the CPT which characterises the dynamic
resistance of a soil and the SPT test which is quick and cost effective and gives the static resistance of a
soil to penetration action. As the rod can be subjected to bucking problem for depths exceeding 30 m, the
domain of validity of these tests is limited to depths less than that limit. Moreover, these tests do not apply
for soils containing grains having diameters greater than 20 mm. The SPT test enables extracting the other
soil characteristics whereas the CPT does not provide them.

In order to represent soil motion resulting from an earthquake by using only one parameter an effective
procedure was developed by Seed and Harder [2]. The liquefaction potential is evaluated by comparing a
normalized index which is relates the cyclic soil resistance capacity \( R_{CS} \) to the ratio of the cyclic stress
demand \( R_{CS} \) being applied to the soil. This enables evaluating the security factor \( F_S \) as

\[
F_S = \frac{R_{CR}}{R_{CS}}
\]

The ratio \( R_{CS} \) is defined as

\[
R_{CS} = \frac{\tau_{ave}}{\sigma_v'} = 0.65 \frac{a_{max}}{g} \frac{\sigma_v}{\sigma_v'} r_d
\]

where \( \tau_{ave} \) is the average shear stress resulting form the earthquake at the given depth, \( a_{max} \) is the
maximum acceleration at the soil surface, \( g \) the acceleration of gravity, \( \sigma_v \) the total vertical stress at the
considered depth, \( \sigma_v' \) the effective vertical stress at the considered depth and \( r_d \) the reduction stress
factor. Factor \( r_d \) is given as function of the depth \( z \). Seed and Harder [2] had given an explicit formula
which enables evaluating the mean value of this factor as function of \( z \) which is expressed in m.

The earthquake magnitude influences the seism duration and may increase significantly the number of
stress cycles. The amplitude effect of an earthquake is not included in equation (1). In order to take this
effect into account, a scaling factor denoted MSF (Magnitude Scaling Factor) has been introduced. The
reference amplitude for a stress based approach was fixed at degree 7.5 according to Richter scale.
Various formulas were presented in the literature to give the MSF coefficient. When this factor is calculated
as function of the seism magnitude \( M \) which is retained in the analysis of liquefaction risk, the
normalisation of the \( R_{CS} \) ratio is performed according to the following equation

\[
R_{CSMT7.5} = \frac{R_{CS}}{MSF} = \frac{\tau_{ave}}{\sigma_v' \text{MSF}} \frac{\tau_{MT7.5}}{\sigma_v'}
\]

Evaluation of the cyclic resistance ratio \( R_{CS} \) depends on the performed test. Various methods were
proposed to estimate the capacity coefficient \( R_{CS} \). In case of Juang method, \( R_{CR} \) is evaluated by using the
following formula

\[
R_{CR} = \left[ -0.016 \left( \frac{\sigma_v}{100} \right)^3 + 0.178 \left( \frac{\sigma_v}{100} \right)^2 - 0.063 \left( \frac{\sigma_v}{100} \right) + 0.903 \right] \exp \left[ -2.957 + 1.264 \left( \frac{q_{crit,CS}}{100} \right)^{1.25} \right] \quad (4)
\]

with
where $I_c$ is the index of soil behaviour which is computed according to the method described in Mitchell and Tseng [4].

3. NUMERICAL SIMULATIONS UNDER DEEPSOIL

The soil is modelled as a column that is formed by a given number of layers. Parameters for each layer are identified from laboratory and in situ tests. When the boundary conditions are specified and the water level table is entered, the seismic acceleration which reproduces a typical seismic motion is imposed at the soil substratum.

The type of analysis is selected along with the constitutive of the considered soil. Analysis of the liquefaction potential for a given depth is directly performed on the obtained results by examining the ratio of inter-pore pressure over the effective soil stress. If this ratio is close to the unity then the liquefaction risk is high. Practically it is admitted that when the last ratio exceeds 0.9 liquefaction is very likely to happen. If this ratio is less that 0.9 than liquefaction risk can be discarded.

Soil behaviour was assumed to be described by a hyperbolic dependent pressure curve which enables considering the reduction of soil shear modulus under the following form

$$R = P_1 + P_2 \left(1 - \frac{G}{G_0}\right)^{P_3} \quad \text{(6)}$$

where $P_1, P_2$ and $P_3$ are phenomenological parameters to be identified for a given soil.

The inter-pore pressure is assumed to be given by Matasovic law [7] which predicts the inter-pore pressure $u_N$ to be given as

$$u_N = \frac{2pN_cF(\gamma_{ct} - \gamma_{tup})}{1 + 2N_cF(\gamma_{ct} - \gamma_{tup})} \quad \text{(7)}$$

where $N_c$ is the number of cycles, $\gamma_{tup}$ the shear limit strain and $\gamma_{t}$ the last known shear undergone before sign changing.

Coefficient $\gamma_{tup}$ is comprised between 0.01% and 0.02% for most of sands. Parameters $p, s$ and $F$ enable adjusting the model to experimental results. Triaxial cyclic non drained tests are necessary for that.

4. RESULTS

In order to compare predictions provided by the Juang semi-empirical approach with simulation results obtained from physical modelling under Deepsoil, the site where the complex Tangier City Center was built is chosen. CPT test results as well as laboratory tests were performed.

![Figure 1. Variation of Juang security factor as function of depth](image-url)
Juang factor of security as to liquefaction occurrence is calculated according to the method mentioned above. Figure 1 gives this factor as function of the depth. One can notice the existence of points for which the security factor is less than unity, this indicates that the soil is likely to liquefy under the action of a seism having the magnitude 7.5 in Richter scale.

Figure 2 presents curves giving the inter-pore pressure ratio as function of time for various depths. For depths varying from 4.7m to 10 m, one observes an increase of the inter-pore pressure in the time interval 3s to 8s. The inter-pore pressure reaches the maximum 0.4 before starting to decrease. For depths situated between 11.50m and 14.50 m, one observes the same phenomenon in the interval 3s to 6s where the pressure reaches 0.33.

These results show that the apparition of liquefaction begins after 12s for the most depth layers, 8s for the intermediate layers and after only 6s for the higher layers. This shows that liquefaction occurs at first in the higher layers before expanding into the more profound layers.

<table>
<thead>
<tr>
<th>Depth</th>
<th>DeepSoil</th>
<th>Juang</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>4s - 12s</td>
<td>Not liquefiable</td>
</tr>
<tr>
<td>2 m – 3.50 m</td>
<td>4s - 12s</td>
<td>Liquefiable</td>
</tr>
<tr>
<td>4.70 m</td>
<td>3s - 8s</td>
<td>Liquefiable</td>
</tr>
<tr>
<td>6 m – 11.50 m</td>
<td>3s - 8s</td>
<td>Non liquefiable</td>
</tr>
<tr>
<td>13.50 m – 14.50 m</td>
<td>3s - 6s</td>
<td>Liquefiable</td>
</tr>
</tbody>
</table>

Figure 2. Variations of the inter-pore pressure as function of time for the different soils depths

5. CONCLUSION

Comparison of liquefaction predictions as obtained by the semi-empirical Juang method and the more accurate physical modelling was performed. The physical modelling was performed by means of DeepSoil software and has shown that a good concordance exists between the two approaches.

This has shown the ability of Juang method to predict liquefaction potential in the particular case of Tangier soils. This constitutes an important step towards validating this empirical method as a tool that can be used to analysis liquefaction risk of soils in this particular region.

6. REFERENCES


