Liquefaction hazard mapping at the town of Boumerdès, Northern Algeria

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Abstract. The town of Boumerdès, located in Northern Algeria, has been badly affected during the Zemmouri 2003 earthquake (Mw=6.8), where extensive liquefaction has been reported. The aim of this paper is to assess and map the liquefaction potential for the Boumerdes city. Data from 154 boreholes, 56 SPT (standard penetrations tests test) and inventory of 35 level water points have been collected and analyzed in the framework of GIS. The liquefaction potential index (LPI) has been assessed by considering two seismic hazard scenarios corresponding respectively to $a_{\text{max}}= 0.45g$, provided by the seismic hazard study of the area and $a_{\text{max}}= 0.30g$ recorded during the 2003 earthquake. LPI values have been correlated to compile the liquefaction hazard maps indicating the quantitative characteristics of the liquefiable layers and the probability area of induced disruption. The results indicated that the main part of the city fall with a low liquefaction potential area except for a narrow corridor along the Corso waterway, where the liquefaction potential is moderate to high.

Keywords: Liquefaction, assessment, hazard maps, GIS, Algeria.

1- Introduction

Liquefaction is a secondary effect of strong ground shaking that has frequently been observed during damaging earthquakes. Affecting mostly saturated sand deposits, the phenomenon has been a major cause of structural damage and loss of human life, as has been the case in several earthquakes worldwide, such as Valdez- Alaska (1964), Niigata -Japan- (1964), Nihonkai-Chubu (1983), Luzon-Philippines (1990), Kobe -Japan (1995), Loma Prieta- San Francisco (1989), Luzon - Philippines (1999) and Kocaeli- Turkey (1999). During the 2003 Zemmouri earthquake (Mw=6.8) liquefaction induced ground deformation has been extensively observed in the most susceptible areas around the Boumerdes city, mainly along riversides and along the beach land (Bouhadad et al. 2004; Machane et al. 2004). We aim in this work to assess the liquefaction potential in the city of Boumerdes and elaboration of liquefaction hazards maps by using GIS technology. Boumerdes city, the capital of the Boumerdes province, is located in north central Algeria about 50 km east of Algiers and along the Mediterranean Sea (Figure 1).

2- Methodology

The adopted methodology in this study requires four steps: (i) collection and analysis of seismic, geological, hydrogeological, geotechnical and geophysical data including field observations (ii) evaluation of the liquefaction potential index (LPI) of the soil layers using data from geotechnical profiles of borings and SPT and by considering two seismic hazard scenarios corresponding respectively to $a_{\text{max}}= 0.45g$, provided by the seismic hazard study of the area and $a_{\text{max}}= 0.30g$ recorded during the2003 earthquake, (iii) Preparation of the liquefaction hazard maps for the city of Boumerdès by correlation between results of the LPI values in the GIS.
3- Seismic hazard

The Boumerdes region belongs to the central part of the Tellean Atlas chain of northern Algeria characterized by a NW-SE convergence between the African and Eurasian tectonic plates. A seismic hazard study performed in this area (Swan and CGS, 1998) provided a values of peak rock acceleration (PRA) $a_{\text{max}}=0.45\, \text{g}$ for a return period of 475 years (Figure 2) in the Boumerdes city.

4- Geological, Hydrogeological and geotechnical data: Spatial data base

In order to assess liquefaction hazard, the available geological, geotechnical and hydrogeological data, carried out by local companies in the framework of construction projects studies, have been compiled,
analyzed and processed. It consists of 154 boreholes, 56 SPT test, 6 Down-Hole and 35 water points levels and laboratory test. The locations of boreholes, SPT, Down-Hole and water points are shown in Figure 3. The data analysis required a coding in a data base (Boumerdes_Data_Base and Geo_Map) under SIG framework that allow easy handling, processing, management, exploitation, treatments and interpreting the large amount of data.

4.1 Geological conditions

The studied area is, geologically, characterized by the metamorphic basement overlain by a Mio-Pliocene and Quaternary deposits clays and sand (Figure 4). The metamorphic basement that outcrops in the eastern part is mostly constituted by micashistes and quartzites (Ficheur, 1895). Mio-Pliocene deposits are discordant on the basement and represented by Miocene clay and marl and Plaisancien blue marls. Quaternary deposits are represented by the following units: (i) Pleistocene red sand (as) principally formed by clayey sand deposit, ii) recent Holocene alluviums (a₂) mainly along waterways, constituted by sand, gravels, clays with a thickness of more the 50 meters in Corso plain and (iii) recent sandy dune (ad) and sandy beach (a) along the coastaline.
4.2 Hydrogeological conditions

Analysis of piezometric data from 35 water points (19 wells, 2 drillings, 14 piezometers) shows that the static level of the groundwater table ranges between 6 and 20 m in the quaternary red sands and between 0.5 m to 6 m near the water ways (Figure 5).

Figure 5. Map of the static level (SL) of the water table in the Boumerdès city.

4.3 Geotechnical conditions

The statistical analysis of the geotechnical data shows a great variability of the geotechnical characteristics related to the lithological variation of the formations (Bourenane 2010). In table 1, the average of the geotechnical characteristics of the lithological units is shown.

Tableau 1: The average of the geotechnical characteristics related to the lithological units of the Boumerdès.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lithology</th>
<th>W (%)</th>
<th>Sr (%)</th>
<th>γd (t/m³)</th>
<th>Fe (%)</th>
<th>D50 (mm)</th>
<th>Ip (%)</th>
<th>W1 (%)</th>
<th>Nspt</th>
<th>Vs (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ad</td>
<td></td>
<td>20.313</td>
<td>96.446</td>
<td>1.347</td>
<td>6.89</td>
<td>0.032</td>
<td></td>
<td>35</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>a2</td>
<td></td>
<td>25.739</td>
<td>87.905</td>
<td>1.526</td>
<td>33.863</td>
<td>0.010</td>
<td>23.125</td>
<td>45.241</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>as</td>
<td></td>
<td>15.394</td>
<td>67.900</td>
<td>1.663</td>
<td>37.650</td>
<td>0.369</td>
<td>13.450</td>
<td>34.914</td>
<td>28.92</td>
<td>550</td>
</tr>
<tr>
<td>Pl</td>
<td></td>
<td>21.284</td>
<td>95.878</td>
<td>1.694</td>
<td>70.474</td>
<td>0.002</td>
<td>22.383</td>
<td>42.465</td>
<td>12.604</td>
<td>360</td>
</tr>
</tbody>
</table>

5 Liquefaction susceptibility evaluation

Liquefaction susceptibility is a first step in the liquefaction hazard assessment of a given area. Soil liquefaction susceptibility depends on geological, hydrogeological and geotechnical site conditions according to the guidelines published by the French Association for Earthquake Engineering AFPS (1995) and the guidelines published by Youd and Perkins (1978), Youd (1998) and Seed et al. (2003).
### 5.1- Geological and hydrogeological susceptibility

The soil liquefaction susceptibility depends on the age of the deposits and the depth of the static groundwater table, it depends also on the medium or type of sediments (AFPS 1995; Youd and Perkins 1978, Seed et al. (2003). Usually, liquefaction concerns the Holocene deposits where the depth of water table is less than 10 m. By using these criteria, in the studied area, the city of Boumerdes appears as built on the loose dunes sands, actual alluvial, Holocene recent alluvial and Pleistocene sandy clays (Figure 4). These deposits are classified as liquefiable when are saturated according to Youd and Perkins (1978). Furthermore, water points data indicates that the depth of the ground water varies from 0.5 to 20 m (Figure 5).

### 5.2. Geoetchnical susceptibility

Seed et al. (2003) suggested that a soil layer is likely to liquefy when its LL is less than 37% and the PI is less than 12%. The distribution of the soil layers based on their LL and PI is shown in Fig. 6. With solid squares are plotted the areas prone to liquefaction soils and with open squares the nonliquefiable ones. Concluding, figure 6 shows that the non-liquefiable soil coincides with the Plaisancien marls unit and the clays contained in the Pleistocene red sands unit, characterized by high plasticity. The majority of the non-liquefiable soils have values up to 60% LL and 40% PI. Liquefiable soils correspond to the sand dunes, Holocene recent alluvial and Pleistocene sands.

**Figure 6:** Evaluation of the liquefaction susceptibility based on the criteria proposed by Seed et al. (2003).

### 6- Evaluating liquefaction potential

In order to evaluate liquefaction occurrence in a given deposit the widely used methodology is that one proposed by Iwasaki et al. (1982). The objective is, therefore, the assessment of liquefaction hazard and the compilation of a map showing spatially the probability of liquefaction-induced surface disruption in the studied area. It consists in calculating the values of liquefaction potential index (LPI) of the soil columns of a given site at a depth of 20 m, and for boreholes were computed using the equation of (Iwasaki et al. 1982):

\[
LPI = \int_0^{20} F(z)w(z)dz
\]

Where \( z \) is the depth below the ground surface in meters and is calculated as \( w(z) = 10 - 0.5z \); \( F(z) \) is a function of the safety factor against liquefaction, \( F_s \), where \( F(z) = 1 - F_s \) when \( F_s < 1 \) and \( F(z) = 0 \) when \( F_s > 1.0 \). \( F_s \), as the ratio of cyclic resistance ratio (CRR) to the cyclic stress ratio (CSR) developed by Seed et al. (1971).

The liquefaction assessments in the Boumerdes city has been performed by using data from geotechnical profiles of 154 borings with 56 SPT tests and 35 water points and two seismic scenarios, namely the Mw of 6.8 recorded during the 2003 earthquake and Mw of 7.0, taken from the seismic
hazard study. The results from liquefaction potential index (LPI) show the horizontal fluctuations of LPI index according to the values of accelerations. It varies between 0 to 19, for accelerations $a_{\text{max}} = 0.45g$ and between 1 to 17 for $a_{\text{max}} = 0.30g$. The results suggest that the moderate and high liquefaction surface have been observed in the sand layer characterized by moderate and high susceptibility to liquefaction, particularly along the Corso waterway at the west of the Boumerdes city. These results show also a good agreement with the observations performed during the 2003 Zemmouri earthquake in this area (Bouhadad et al. 2004; Machane et al, 2004; Bouhadad et al. 2009).

7 Liquefaction potential mapping

Liquefaction potential mapping of the study area is obtained by linear interpolation of the liquefaction potential index LPI obtained for the above mentioned two scenarios. For that, two liquefaction hazard maps were obtained (Figures 7a et 7b). The maps show that liquefaction is low in the center and the east of the city includes/understands the zones located on clay soils or on bedrock, or zones located on dense sand with a deep water table (generally a depth higher than 12 meters). The liquefaction potential is moderated high in the West of the city which generally includes/understands the zones whose basement is formed by sands deposits fairly dense and relatively loose of the alluvial plain characterized by a shallow water table (ranging between 0 and 10 meters).

8 Conclusion

A study of liquefaction hazard of the subsoil layers in the city of Boumerdes, badly affected during the Zemmouri 2003 $\text{Mw}=6.8$ earthquake has been performed and the results are shown hereafter. The obtained maps indicate the quantitative characteristics of the liquefiable layers and the area where there was a probability of surface evidence of liquefaction. The study concluded that the urban area of Boumerdes city exhibits a low potential to liquefaction, except for the Corso waterway valley, to the west of the city, where the liquefaction potential is moderated to high.

REFERENCES


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