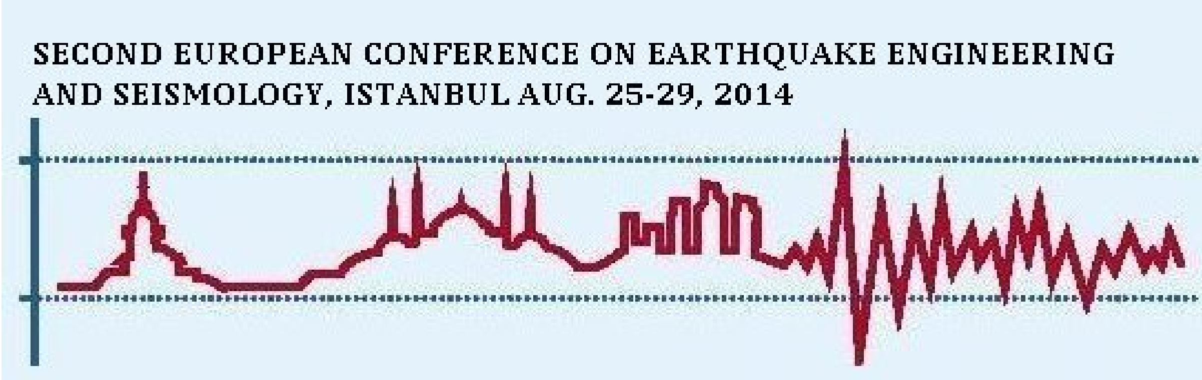

SITE EFFECTS AND DAMAGE ANALYSE IN BOUMERDÈS AND ZEMMOURI URBAN AREAS FOLLOWING THE BOUMERDÈS EARTHQUAKE OF MAY 21, 2003

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I. ABSTRACT

The Boumerdes (Algeria) earthquake of May 21, 2003 caused extensive damage in Boumerdes and Zemmouri (Algeria) areas, mainly concentrated in the Southwest of each of these municipalities. In the rest of the surrounding villages, damages are very sparse and much less important. These observations, led us naturally to ask if the damages in these two municipalities have a link with the site effects. The aim of this work, therefore, is to investigate if a relationship exists between the observed damages on structures and geological and geotechnical conditions of soil deposits. To achieve this goal, the microzoning maps of the two urban sites are established on the basis of geological, geotechnical, hydrogeological investigations, etc., and damage maps are produced on the basis of post- seismic surveys and the use of satellite images. These maps (microzoning and damage) are then superposed. This superposition shows that there is no relationship between site effects and damages. The damages observed on the constructions are due to poor building design, poor quality of materials, etc.

INTRODUCTION

Seismic activity affects more than 70% of the North of the Algeria where are concentrated at least 90% of socio-economic and policy of the country facilities. Boumerdès and surrounding areas suffered earthquakes of moderate to strong magnitude in recent years. The last earthquake of May 21, 2003 (Mw = 6.8) has caused huge losses of human life (2276 dead) and material and economic damages estimated at 5 billion US$. This earthquake, which has the highest magnitude in Algeria since 1980 (El - Asnam, Mw = 7.3 earthquake), also caused geological effects such as liquefaction, ground subsidence, landslides and surface fault ruptures.

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In the cities of Boumerdes and Zemmouri, the damages are mainly concentrated in South-West of each of them. Following these observations, the study which follows was initiated to highlight the link, if it exists, between damages and site effects.

Many studies focused on the correlation between the damages caused by an earthquake and site effects. Some of these studies have found a good correlation between site effects and damages (e.g. Gold *et al.*., 1998;) Panou *et al*., 2005; TEVES Costa *et al.*., 2007. Cara *et al.*., 2008), others have concluded that this relationship was not clear or non-existent (e.g. Fallahi, 2003; Gonzales *et al*., 2004; Chandra *et al*., 2008A; Jennifer *et al*., 2010). The experience gained from the recent large earthquakes, including Mexico (1985), Loma Prieta (1989) and Kobe (1995) (Marie-José Nollet et al., 2007), tragically demonstrated the tremendous impact of the site effects (such as the presence of alluvial deposits, topography and mechanical properties of soils).

STUDIED AREA LOCATION

The studied area is Zemmouri and Boumerdès urban areas (Fig. 1), located 50 Km East of Algiers. It covers a total surface of approximately 75 Km2. It is formed by orographic sets (Fig. 2) coastal landforms or the coastal, plateau on which are built the largest parts of the two cities and intermediate reliefs with hilly character whose average altitude are ranging between 100m and 200m

Figure 1: Studied areas location in Algiers region.

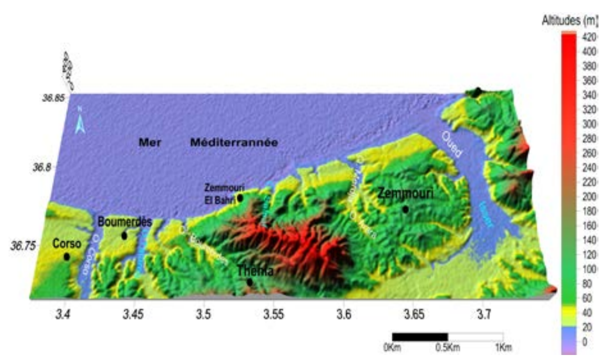


Figure 2 : Major morphological sets in the region of study based on the digital elevation model (DEM)

REGIONAL SEISMIC HAZARD CONTEXT

Algiers-Boumerdes region is characterized by seismic activity due to the presence of potential active faults, passing near Boumerdes (Fig. 3), such as the Sahel fault, Thénia fault, fault of South Mitidja, and those assumed in the sea identified recently and are the cause of the earthquake of

May 21, 2003 ((Philip and Meghraoui1983; Meghraoui, 1988; Meghraoui et al. 2004; Déverchère et al., 2005).

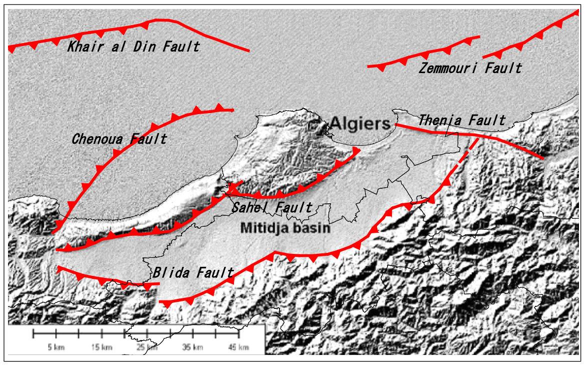


Figure 3: Active faults in the Algiers-Boumerdes region (JICA, 2006)

Geotechnical and hydrogeological map of the Boumerdes area (Fig. 4) shows that the city is largely built on quaternary clay sands (villafranchien) of 10 to 30 meters thick, resting on blue marl Plaisancian outcropping in places.

Subsoil of Zemmouri city (Fig. 5) is covered in its major part by a complex villafranchien sandy clay. The thickness of this formation increases from west (6 m) to the east where it reaches 18 meters.

In the south direction of the Zemmouri city, thickness of this complex gradually increased from 12m to 40m.

This sandy clay complex that covers the entire plateau of Zemmouri is characterized by compactness and high average density increases in depth, plasticity, compressibility and low swelling.

Figure 4 : Geotechnical and hydrogeological map Boumerdes site

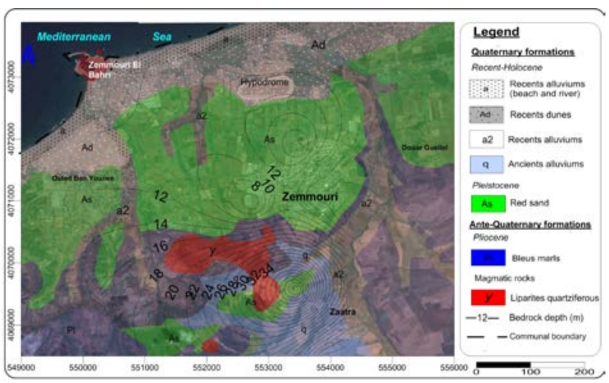
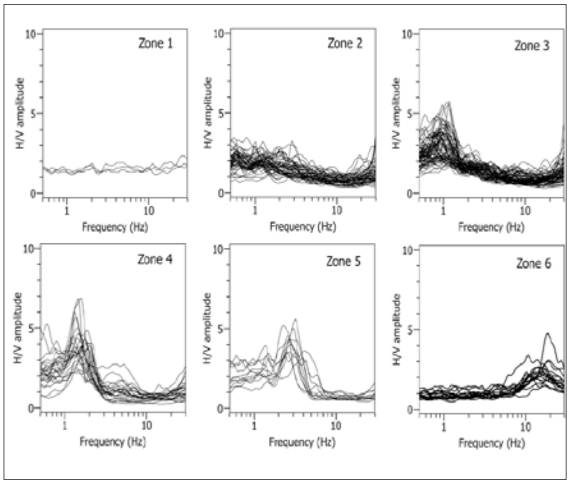


Figure 5: geotechnical and hydrogeological map of Zemmouri site

ACQUISITION AND ANALYSIS OF AMBIENT VIBRATIONS DATA IN BOUMERDES CITY

A total of 260 records were used in this study for which we calculated the H/V ratio (Fig. 6) defining 6 zones: zone 1 flat curves, zone 2 curves showing no clear peak, zone 3 frequency ranges: 0.5 - 1.2 Hz, zone 4: 1.3 - 2 Hz, zone 5: 2.1 - 4.5 Hz and zone 6: 11-20 Hz (Fig. 7).



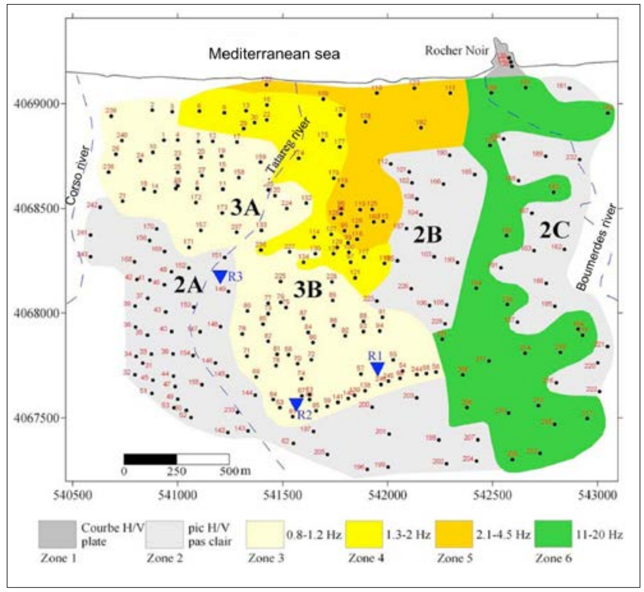


Figure 6: H/V curves of Boumerdes urban area (Hellel, 2010)

Figure 7: Frequency soil distribution Map in Boumerdes city. (Hellel, 2010)

ACQUISITION AND ANALYSIS OF AMBIENT VIBRATIONS DATA IN ZEMMOURI CITY

142 ambient vibrations signals were recorded for which the H/V curves have been calculated and spatialy distributed in Zemmouri city according to the frequency values. 4 zones are thus highlighted (Fig. 8): frequency peak not clear (zone 1), 1-3 Hz (zone 2), 3-6 Hz (zone 3) and frequency greater than 6 Hz (zone 4).

The frequencies of soil obtained in Zemmouri urban area are not, in the majority of cases, corresponding to the frequencies of the buildings (estimated from formula based on the number of storeys), this can confirm the absence of resonance between the ground and structures.

SEISMIC MICROZONING

Seismic microzoning studies of geotechnical hazards were carried out in Boumerdes and Zemmouri urban areas. Three microzones have been defined:

Area I- areas of high potential of liquefaction (I_l) that contain Sands subject to compaction loose ('$I_{l,\ t'}$)**;**

Area II- areas of moderate potential liquefaction and contain Sandy alluvium subject to settlement- ('$II_{the\ t'}$);

Area III- areas of low-potential of landslide, liquefaction and surface fault rupture that contain sometimes Sandy alluvium subject to settlement ('III $_{t'}$).

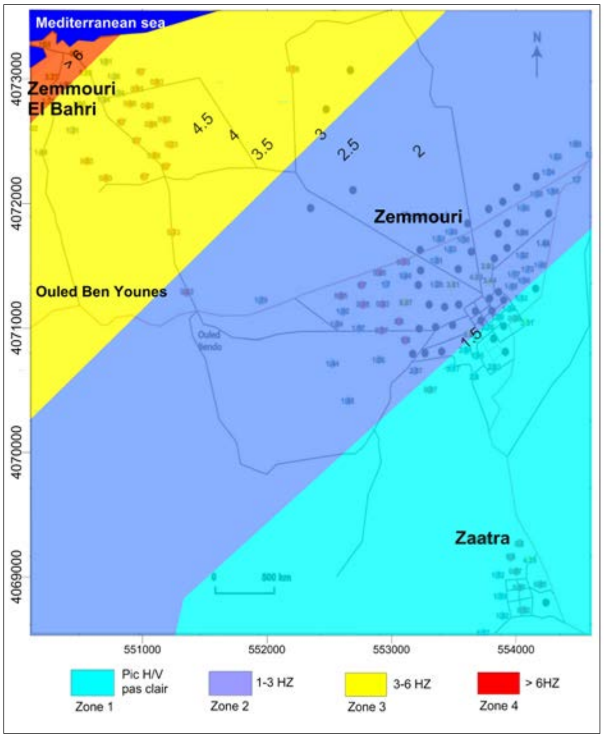


Figure 8 : Frequency distribution map of the soil in Zemmouri city

Due to a low potential of liquefaction for most part of the city, urban area of Boumerdes is generally classified as area III (fig. 9). The beds of Corso river, Boumerdes river and Tatareg river and their banks are classified zone I and II according to the high to moderate potential of liquefaction.

Adjacent areas of the current beds of these rivers located on Holocene alluvium are classified zone II according to the moderate potential of liquefaction and high potential of compaction. Due to high potential of liquefaction, he coastal area of the city is also classified as zone I

The major part of Zemmouri city is classified as zone III according of the low potential of liquefaction. Riverbeds and adjacent areas are classified as zone II for the moderate potential of liquefaction and high potential of settlement.

For the goal of the superposition of site effects map and building damages map in order to estimate the resonance phenomena in Boumerdes city, we have taken as example the buildings located in two districts, “1200 logements” and “800 logements” **(**fig. 9**)**. The buildings at “1200 logements” are RC frames system having 5 stories and built in the 1970s. While the buildings of “800 logements” were built in 1986 with RC shear walls system and have between 5 and 10 stories.

The buildings located in the "1200 logements" district suffered significant damage. 121 buildings have been destroyed (level 5) and 36 have been severely affected (level 4). This district is located in zone 3B (fig. 7) where H/V curves show a weak soil amplification (0.8 to 1.2 Hz) far from the buildings frequencies having values around 3.5 Hz, this shows that he did not had resonance phenomena. Geotechnical site effects are excluded in this area because the "1200 logements" district is located in zone III (Fig. 9) where geotechnical seismic hazards (potential liquefaction, landslide and settlement) are low. The most important factor causing damage is the poor quality of concrete and the week RC frame system of these buildings.
In the "800 logements" district, located in zone 3A (fig. 7), a soil amplification has been identified. This city is located in zone III (low seismic hazards) near the zone I (high seismic hazards) (fig. 9). The buildings of this district (52 units) have suffered light damage, sometimes negligible. This is due certainly to shear wall system of these buildings having natural frequencies values outside the soil fundamental frequency range.

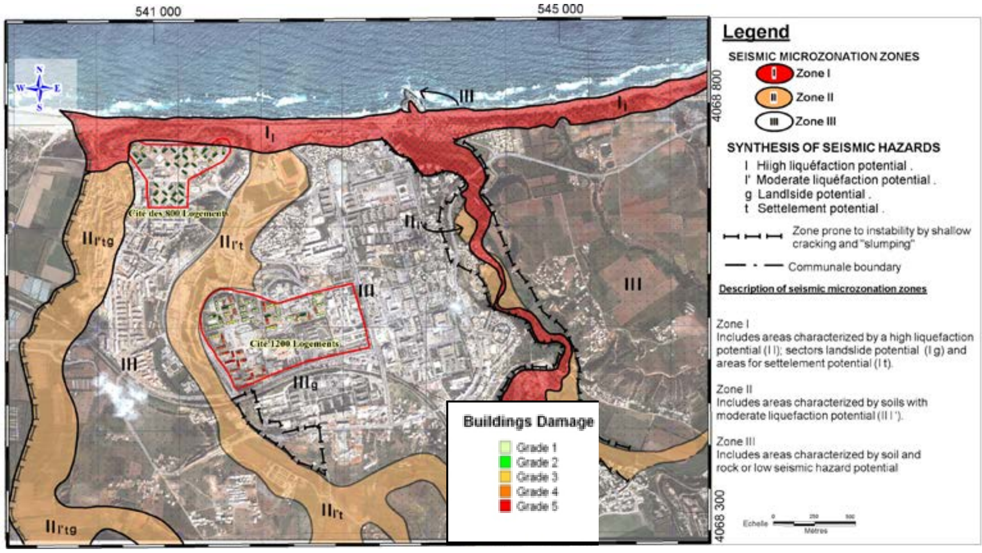


Figure 9: Superimposition of microzoning map and damage map in "1200 logements" and "800 logemnts" districts

To develop the damage map of Zemmouri urban area, Yamazaki (Yamazaki et al., 2004) used the remote sensing technique by satellite Quick Bird (a pre-event of May 13, 2003 image, and two images post-event on may 23 and June 13, 2003 have been used).

A total of 1.399 buildings in the central part of Zemmouri city have been classified according to their damage ratio (fig. 10).

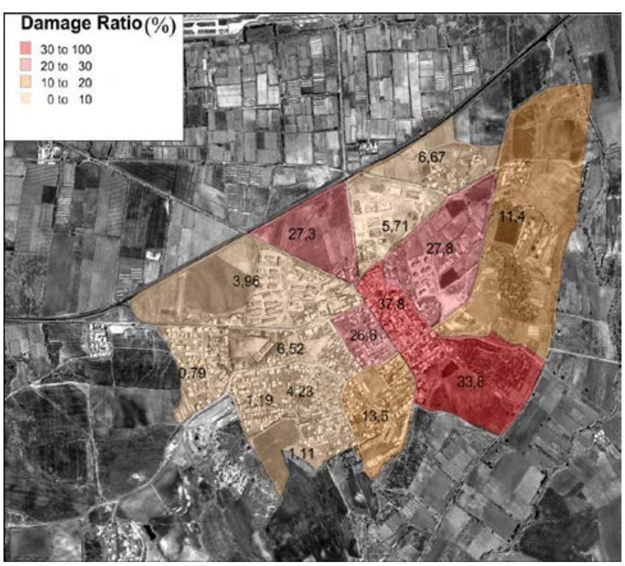


Figure 10: Damage ratio of the 1,399 buildings in Zemmouri city (Yamazaki et al., 2004).

In the Zemmouri case also, the two maps of damage and seismic microzoning have been superimposed in order to highlight eventual resonance phenomena between the buildings behavior ant the soil behavior (fig. 11).

In Zemmouri city, building damage ratios were 0 to 30%, except in the southeast of the city where the damage ratios was greater than 30% (fig. 10).
In this figure 10, we can see that more than 90% of the damaged buildings are located in Zone III with low site effects (liquefaction, landslide and settlement). In this zone III the soil frequencies are around 1 to 3 Hz.

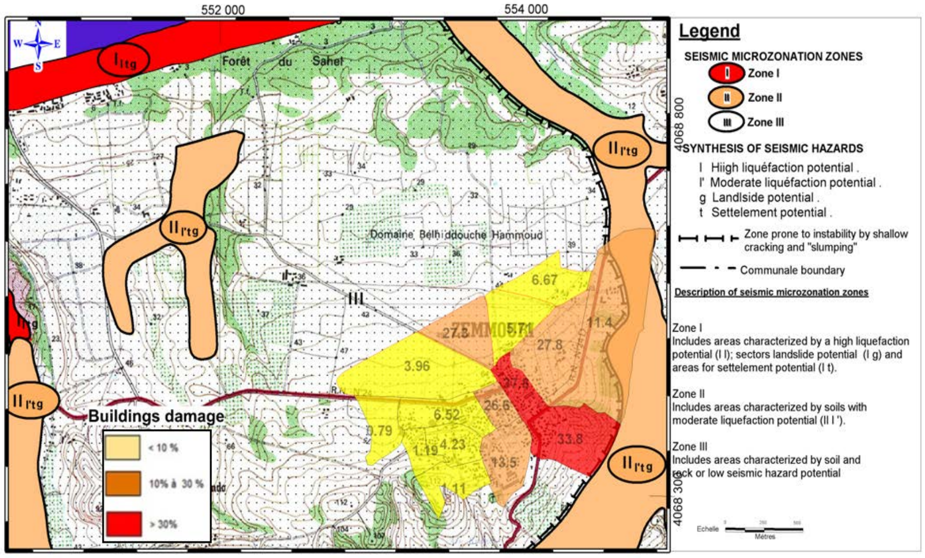


Figure 11: Superimposition of Microzoning map and building damage map of in Zemmouri city

CONCLUSION

The superimposition of geotechnical site effects (liquefaction, landslide and settlement) map, soil amplification map and damage buildings map in Boumerdes and Zemmouri urban areas, shows that is no link between the damages and site effects. All the buildings concerned by this study are located in areas with low geotechnical hazards (low liquefaction, landslide and settlement) and the buildings frequencies are outside of soil frequencies range, eliminating thus the resonance effect.

Observed damages are related to several factors, other than the site effects factors. These factors that are causing damages are those such as the intrinsic earthquake characteristics, the near position to the epicenter of these two cities (Boumerdes and Zemmouri), the poor quality of building materials, the non-compliance with earthquake-resistant standards, the significant aftershocks reaching a magnitude Mw = 5.8, the effect of the buildings orientation relative to the fault orientation, the presence of many flexible first floors, etc. Although site effects were observed here and there, they were not causing damage to buildings

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