Ground motion analysis of the 2003 Zemmouri, Algeria, earthquake

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Abstract

A On 21 May 2003, a major earthquake with magnitude 6.8 Mw (6.9 Ms) struck the environs of Algiers, the capital of Algeria, causing important damages in different provinces in the center-north of the country. The contribution of this event in the seismic hazard assessment in the central part of Algeria was examined. The result in terms of PGA shows seismic hazard values 40% higher on average than previously reported, especially in the south-west part of the Mitidja basin. This work is related to the results obtained in the processing of the accelerogram records of this earthquake. From the accelerograms, several interesting parameters in seismic engineering studies have been obtained such as PGA, PGV and PGD, duration, arms, and Arias and Housner intensities. Hodograms, pseudo acceleration spectra and H/V spectral ratios from earthquake data have been computed as well. The strong ground motion is in agreement with the rupture propagation, i.e., an asymmetric bilateral rupture. A strong directivity is obtained from the processing of the records, also inferred, for example, from the isoseismal map. Besides, a clear site effect appears in certain stations, due to their location on Quaternary alluvial deposits. In other records, surface waves generated at the edges of the sedimentary basin can be seen. Finally, bstract

Keywords: strong ground motion, 2003 Zemmouri earthquake

Introduction

On 21 May 2003, an earthquake with magnitude Mw 6.8 (Ms 6.9) struck the environs of Algiers, the capital of Algeria, causing extensive damages in different provinces in the north-center of the country. This earthquake took place where we have no evidence of previous significant earthquakes, either instrumental or historical. It was been felt with macroseismic intensity IX-X in two small cities near the epicenter, Boumerdes and Zemmouri, and an intensity of VII-VIII in several districts of Algiers, where many modern building collapsed and many others were seriously damaged. It has been one of the most destructive events in northern Algeria since the 10 October 1980, El Asnam earthquake (Ms 7.3) (Hamdache *et al*., 2004).
The northern Algeria area, as a part of the Ibero-Maghrebian region, have experienced different moderate to low seismic events as a result of the compressional movement between the African and Eurasian plates. The tectonics of this region has been the subject of numerous studies, including Meghraoui (1988), Yielding *et al*. (1989), and Aoudia and Meghraoui (1995). The main structures are briefly and clearly summarized in Peláez *et al*. (2003, 2005). The studied earthquake occurred at the eastern part of Algiers city, in the region of Boumerdes, which is located on the coast, in the central part of Algeria. Much of the coastal area is characterized as broad alluvial plains punctuated by metamorphic rocks from the Atlas thrust belt to the south. The gently sloping alluvial plains have been uplifted by past earthquakes. The marine terraces along the coastline have been uplifted at an estimated rate of about 0.25 mm/yr (Wang *et al*., 2004). This region is the eastern edge of the Quaternary Mitidja basin (figure 1), which has been formed during north-south Miocene extension (Philip, 1983).

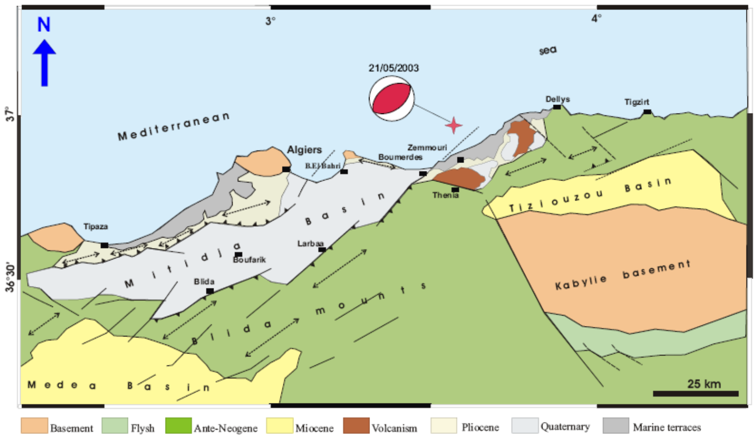

Figure 1. Tectonic map of the Mitidja basin (Ayadi *et al*., 2003)

This extension has been followed by a north-south to NW-SE compression. The compressional movement continued during the Quaternary (Meghraoui, 1988; Boudiaf *et al*., 1998) and is still active, as shown by recent recorded seismicity (Mokrane *et al*., 1994) and re-cent deformation. This deformation is represented by active folding oriented northeast-southwest (Meghraoui, 1988). The east-west to ENE-WSW trending Mitidja basin is bordered, as shown in figure 1, by the Mediterranean sea and Blida mountains to the north and south, respectively. Long term regional seismicity reveals several large earthquake in the Algiers region, including the 1365 earthquake (Io = IX), and the 28 January 1716 event, which was felt with intensity X, destroying Algiers and causing more than 20000 deaths (Mokrane *et al*., 1994). The region of Zemmouri and Boumerdes has been affected by recent small earthquakes with magnitude up to ML 5.3. The most important seismic event near Algiers during the twentieth century was on 16 September 1987 (mb 5.2). This earthquake did not cause significant damage. Others minor events occurred in the region including some felt events.

In this study, we present the results obtained in the processing of the accelograms recorded on 21 May 2003 earthquake, which occurred on the north-east edge of the Mitidja basin, on the Zemmouri coast.

Ground motion records

The 21 May 2003 earthquake was characterized by an offshore reverse faulting resulting from the compressional movement described above. The focal mechanism corresponded to an inverse fault with ENE-WSW direction dipping towards the S (figure 2). The modelled rupture (Yagi, 2003) corresponded with a plane of 75 km in length and 20 km in width. The duration of the rupture modelisation was about 18 s, producing a maximum displacement throughout the surface of the fault of about 2.3 m (figure 2).

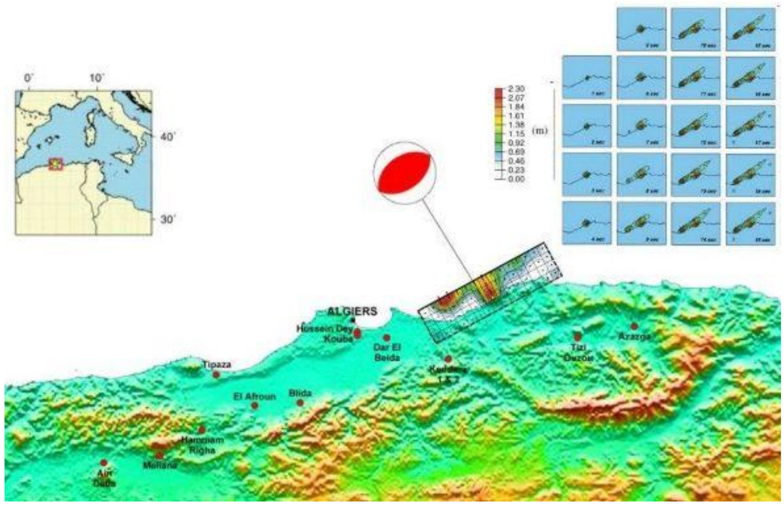

Figure 2. Map showing the modelled rupture (Yagi, 2003), the focal mechanism and the accelerograph stations that properly recorded this event

The rupture pattern is characterized by an asymmetric bilateral propagation of the rupture, propagating from the epicenter about 30 km towards the WSW. Two asperities are clearly distinguished. It is shown that the rupture propagation condition influences the obtained records at accelograph stations. At this point, the Algerian network of accelerographs, monitored by the CGS (Centre National de Recherche Appliquée en Génie Parasismique), consisted of a total of 87 stations; 29 digital stations (Etna and SSA-1), and the rest analogical ones (SMA-1, with photographic records). From all of them, only 13 records have been usable, corresponding to the stations shown in the figure 2. Unfortunately, the quality of these 13 records is not optimal, presenting and/or displaying some of them problems that determine their use and the results, like wrong operation of the instrument at diverse moments, spikes, and records without coda or pre-event.
As shown in the figure 2, most of the accelerograph stations are located to the SW of the fault area, with a very poor azimuthal coverage. Stations are located in different soil type as defined by CEN (2003): 3 stations are on soil type A (BLI, HAM and MEL), 8 on soil type B (TIZ, KED1, KED2, AZA, HUS, KOU, TIP and AIN), and the two others on soil type C (DAR and AFR). The distance of the stations to the rupture plane varies between 9.8 km (KED1 and KED2) and 136.0 km (AIN). The geological site conditions are related to the Quaternary Mitidja basin; almost of them can be characterized by a stuffed sedimentary river basin of alluvial quaternary deposits. Especially the two stations located at Dar El Beida (station DAR) and El Afroun (AFR) are exactly within the own river basin. It is important to point out that stations KED1 and KED2 are located at the same site and distant only 150 m. The first station is in the embankment of a dam, down, just on the basement, whereas the second one is something remote of the dam. Other two stations, HUS and KOU, are only 1.5 km distant.

Processed records

The previously quoted 13 accelerogram records have been considered as optimal. The records obtained at the different stations, shown in the figure 3, have been processed with great attention to derive reliable results for seismic engineering purposes. The records are used to derive in a first step the corrected acceleration, velocity and displacement time histories. The obtained results show some particularities.

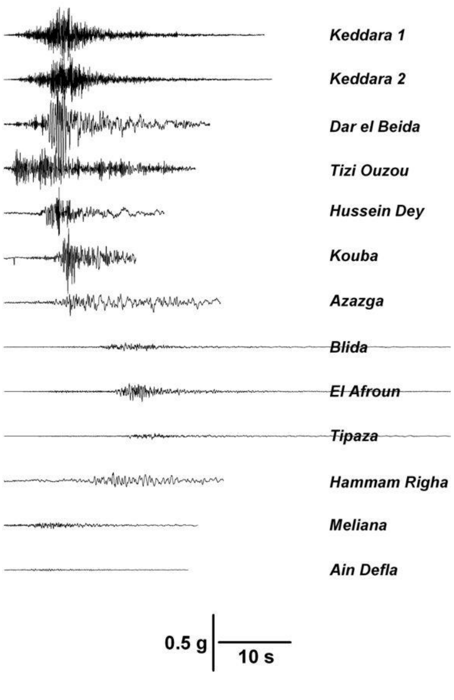

Figure 3. Corrected acceleration records. NS component

The predominance, in average, of the obtained results in the EW components, is opposed to the NS ones. In the opposite, the computed displacement shows a great predominance of the NS component. Considering the a_{rms} and maximum pseudo-acceleration spectra values derived for each component, in average, any predominance of any component on other is observed. The maximum obtained PGA value is equal to 0.59g, occurring at the KED2 station, on the EW component, which is associated to a frequency of 12.5 Hz. At the DAR station, a PGA value equal to 0.51g is obtained on the EW component, associated in this case with a frequency equal to 3.6 Hz. The same component at the DAR station provides a maximum computed PGV value equal to 40.3 cm/s, and a maximum computed PGD value equal to 17.3 cm. For each NS and EW component, the Arias and Housner intensities have been derived. For example, the obtained results at DAR station are the following. For the Arias intensity, 3.8 m/s for the horizontal intensity, and 4.2 m/s for the total intensity have been obtained. For the Housner intensity, 101 and 124 cm for components NS and EW, respectively, have been obtained. For the maximum pseudo-acceleration spectra, with a 5% damping, 2.06g and 1.94g, for NS and EW components, respectively, have been computed. The maximum displacement in the horizontal hodogram is equal to 18.6 cm. The particularity of the DAR station is the fact that it is located in the Mitidja basin (figure 2), at only 16.2 km of the rupture, on a soil type C and, just in the direction of the rupture propagation, showing a clear directivity effect. All these parameters have been clearly influenced the record in this station.

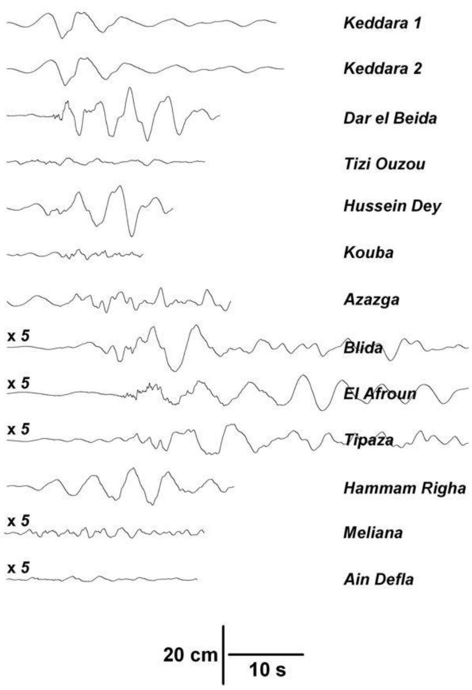

Figure 4. Computed displacements. NS component

The results displayed in figures 3 and 4 show a clear amplification at the HAM station, which is not explain by the site soil type (figure 2). At the stations BLI, AFR and TIP a clear ground wave pattern appear on the acceleration plots (figure 3), which is more clearly observed on the plot displaying velocity and displacement (figure 4). This result could be explained by the fact that stations are located on the border of the Quaternary Mitidja basin (figure 2) and some edge effect is observed.
The records at the two stations located around the Keddara dam (KED1 and KED2) show some similarities. The distance between these two stations is about 150 m, and computed displacements are practically the same. Nevertheless, in other two stations 1.5 km distant (HUS and KOU), any similarities appear neither on the acceleration records nor on displacement or velocity.
The 21 May 2003 earthquake is the most destructive event since the 1980 El Asnam earthquake. This event caused extensive damage on building. It is one of the most and best

documented event from the macroseismic point of view (figure 5). Preliminary macroseismic investigations and macroseismic map have been published by Ayadi *et al*. (2003).
This map is considered at this moment the most appropriate, and it agrees very well with our computed data. It is possible to relate obtained instrumental results to the macroseismic intensity assigned to the site. Thus, station DAR is located within the isoseismal of degree VIII, stations HUS and KOU within the one of degree VII, and stations KED1, KED2 and BLI within the one of degree VI. The Dar El Beida site (DAR) is, comparatively to the other sites, where the higher macroseismic intensity and the biggest computed values for all parameters, except for the PGA value, are obtained.
The Housner intensity is probably the most appropriate value related to the damage level that we have computed at each station site. The obtained results are the following: 113 cm at the DAR site, 62 cm at HUS, 46 cm at KOU, and 33.4 and 31.9 cm at KED1 and KED2, respectively. The extensive damage on recent buildings, suggest us to compare the pseudo acceleration spectra derived from the recorded accelerograms at each station with the design spectra proposed by the CEN (2003) code and the uniform hazard spectra (UHS) obtained in previous works (Peláez *et al*., 2006) using a probabilistic approach.

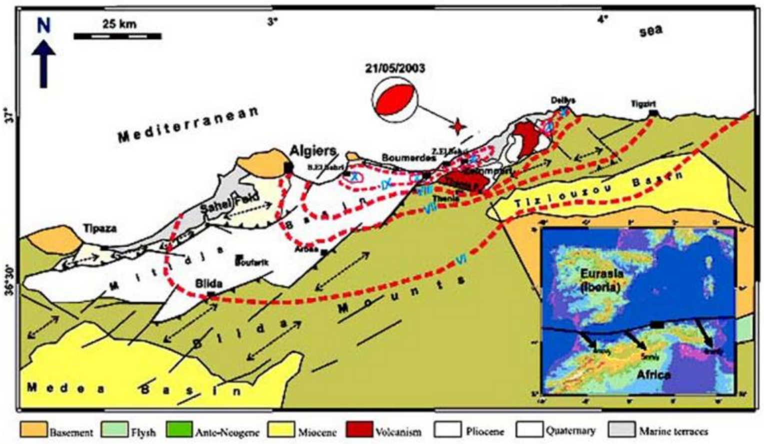

Figure 5. Isoseismal map for the 21 May 2003 earthquake (Ms 6.8) (Ayadi *et al*., 2003)

The pseudo acceleration spectra derived from records agree with the two others graphs in most stations, nevertheless, in other ones the computed pseudo acceleration spectra is clearly greater than the design spectra proposed by the CEN (2003) code and the UHS proposed in the paper by Peláez *et al*. (2006). The obtained results at the DAR station are shown in figure 6.

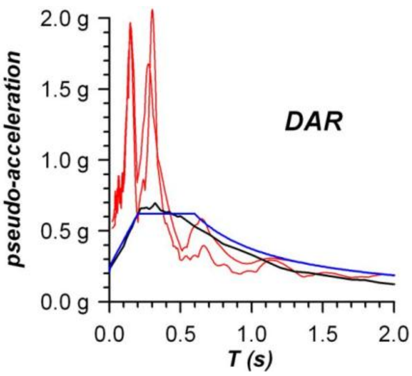

Figure 6. Pseudo acceleration spectra (in red) for the NS and EW components, UHS (in black) specifically computed for the site, and EC-8 horizontal elastic response spectra (in blue), all damped at 5%, for the DAR station

This case has been pointed out by other authors (*v.g.* Bommer *et al.,* 2002) in other earthquakes. It proposes the fact to promote or not a change in the building code in the site or re-

gion, by considering or not this computed pseudo-acceleration spectra. In our case (figure 6), they appear values of about 2.0g in the range 0.0-0.4 s, a period range very interesting in any building code.
Finally, the duration of the records obtained from the horizontal components in the stations less than 25 km away of the rupture plane is of about 10.2 s.

Site effects, attenuation and directivity

Here we examine some aspects related to the site effects, ground motion attenuation and directivity in the occurrence of the main event.
The site effect has been examinated in detail at each station using the well known approach of spectral H/V ratio (horizontal-to-vertical ratio) from pseudo acceleration spectra and from Fourier spectra. Clear site effects can be observed at DAR (figure 7) and AFR stations, for frequencies of the order of 3.5 and 2.0-3.5 Hz, respectively. In the other stations, typical consolidated site ratios are obtained.

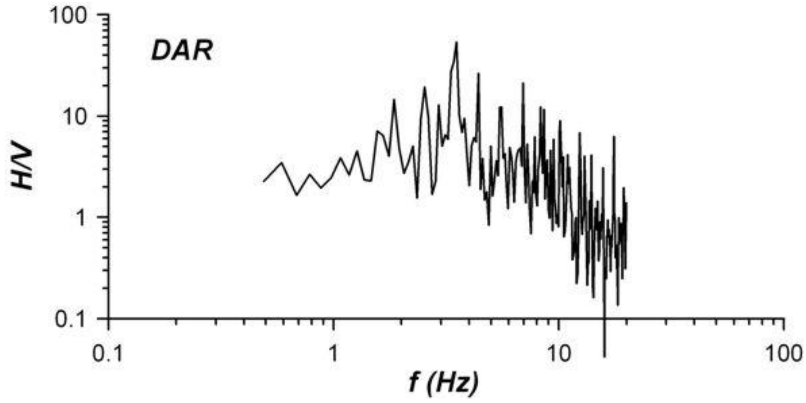

Figure 7. Computed H/V spectral ratio at the DAR station

The ground attenuation for different parameters has been carried out using the Joyner-Boore distance, that is, the distance to the rupture. Taking into account the insufficient records, the clear amplification in some stations, the observed directivity, especially in the nearest stations, and the poor azimuthal coverage, data don't allow us to model in a suitable way the ground motion attenuation. For example, figure 8 shows the PGA values, computed for the two horizontal components, versus the Joyner-Boore distance.

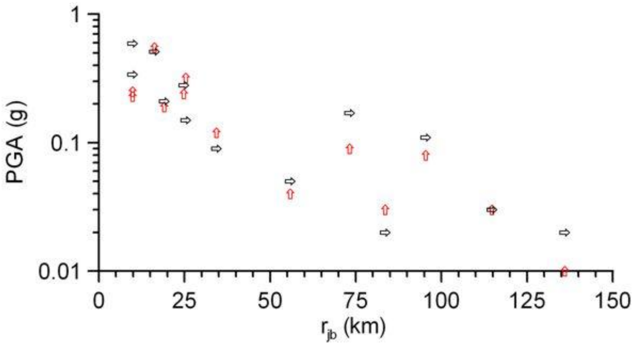

Figure 8. PGA vs. r_{jb}. EW component: ⇨. NS component: ⇧

The behavior showed in figure 8 is observed independently of the used parameter. A clear amplification in the AFR and HAM stations, located 73 and 95 km distant to the fault plane, respectively. This is explained by the soil type conditions and topographic effects. In the nearest stations, below 30 km, there is not a clear behavior, very influenced by the directivity.
The last step in the record processing has been devoted to derive the hodogram. To do so, we have composed the first 15 s of computed NS and EW displacements from the arrival of

the more energetic phase. Obtained results are shown in figure 9, where we have added surface fault projection.

On the one hand, the obtained results in DAR, KOU, HUS and TIP approximately show a polarization of the displacement in the direction of the rupture propagation, that is, NE-SW. Coseismic deformations measured in this zone (Yelles Chauche *et al*., 2004) show net displacements in this same direction. The results obtained in KED1, KED2, TIZ and AZA show a polarization of the displacement in direction practically perpendicular to the previous one. They agree with the focal mechanism and the propagation of a less energetic NW-SE rupture (focal mechanism). Also they agree with the coseismic deformations measured in this area (Yelles Chauche *et al*., 2004). Finally, in stations BLI, AFR and HAM, although it is not so clear, it can be seen a displacement also in the NW-SE direction due to surface waves (Semmane *et al*., 2005).

A similar pattern was observed in the 1994 Northridge, California, earthquake (Wald *et al*., 1996). The earthquake keeps a great parallelism with the one from Algiers in magnitude, focal mechanism and focal parameters. In this case, a strong directivity due to the directivity in the propagation of the rupture was also observed.

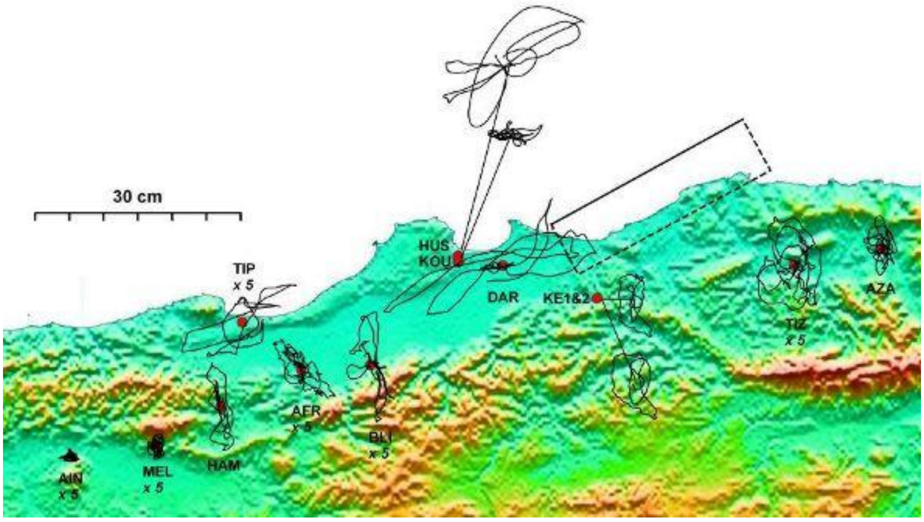

Figure 9. Computed hodograms and surface fault projection

Conclusions

The aim of this study has been the process of the recorded accelograms during the 21 May, 2003 earthquake. The process takes into account the specificity of the different records and the insufficient data to derive suitable attenuation of the ground motion. Nevertheless, with these data, some important results have been obtained related to the station soil type and to the directivity. The results obtained at some stations like KED1 and KED2, or at HUS and KOU, have been examined in detail to derive possible similarities. The horizontal hodograms obtained at each station agree with the fault rupture model derived by using coseismic deformation data. This result has been also obtained for the Northridge earthquake. Great attention has been made to the relation between estimated ground motion parameters and macroseismic intensity, finding a clear similarity between Housner intensity and damage. The extensive damage generated by this earthquake suggest us to compare the pseudo spectral acceleration derived from the records, the design spectra suggested by EC-8 and the uniform hazard spectra estimated through probabilistic methods. The obtained result is similar to the one obtained for the 2001 El Salvador earthquake.

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