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Evidence for fault-related directionality and localized site effects from strong motion recordings of the 2003 Boumerdes (Algeria) earthquake: Consequences on damage distribution and the Algerian seismic code

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Abstract

The Algiers–Boumerdes region has been struck by a destructive magnitude 6.8 (M_w) earthquake on May 21, 2003. The study presented in this paper is based on main shock strong motions from 13 stations of the Algerian accelerograph network. A maximum 0.58*g* peak ground acceleration (PGA) has been recorded at 20 km from the epicenter, only about 150 m away from a PGA of 0.34*g*, with both a central frequency around 5 Hz, explained by a strong very localized site effect, confirmed by receiver function technique results showing peaks at 5 Hz with amplitudes changing by a factor of 2. Soil amplifications are also evidenced at stations located in the quaternary Mitidja basin, explaining the higher PGA values recorded at these stations than at stations located on firm soil at similar distances from the epicenter. A fault-related directionality effect observed on the strong motion records and confirmed by the study of the seismic movement anisotropy, in agreement with the N65 fault plan direction, explains the SW–NE orientation of the main damage zone. In the near field, strong motions present a high-frequency content starting at 3 Hz with a central frequency around 8 Hz, while in the far field their central frequency is around 3 Hz, explaining the high level of damage in the 3- to 4-story buildings in the epicentral zone. The design spectra overestimate the recorded mean response spectra, and its high corner frequency is less than the recorded one, leading to a re-examination of the seismic design code that should definitively integrate site-related coefficient, to account for the up to now neglected site amplification, as well as a re-modeling of the actual design spectra. Finally, both the proposed Algerian attenuation law and the worldwide laws usually used in Algeria underestimate the recorded accelerations of the 6.8 (M_w) Boumerdes earthquake, clearly showing that it is not possible to extrapolate the proposed Algerian law to major earthquakes.

Keywords: Directionality; Site effect; Strong motion; Attenuation law; PGA; Damage; Seismic code; Earthquake; Boumerdes; Algeria

1. Introduction

Algeria is located on the northern edge of the African plate, which is converging with the European plate since the Mesozoic, with a shortening rate of about 4–8 mm/yr [1–3] (Fig. 1). Northern Algeria is a highly seismic area, as evidenced by the historical (1365–1992) seismicity [4–6] (Fig. 2). During the last two decades, northern Algeria experienced several destructive moderate-to-strong earthquakes. Since 1980, El Asnam earthquake (M_s 7.3), which claimed over 2700 lives and destroyed about 60,000 housings, many moderate, but destructive, earthquakes occurred, such as the Constantine October 27, 1985 (M_s 5.7), Chenoua October 29, 1989 (M_s 6.0), Mascara August 18, 1994 (M_s 5.6), Algiers September 4, 1996 (M_s 5.6), Ain Temouchent December 22, 1999 (M_s 5.6), and Beni Ourtilane November 10, 2000 (M_s 5.5) earthquakes.

On May 21, 2003, the Algiers–Boumerdes region was struck by a magnitude 6.8 (M_w) earthquake, which caused considerable damages and claimed over 2300 lives. The

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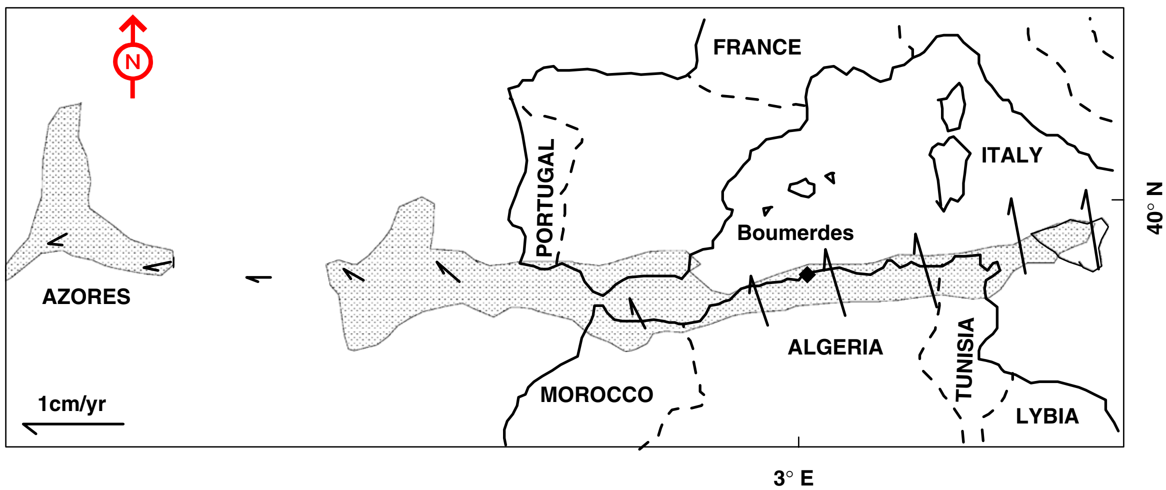

Fig. 1. Map describing the convergence between the African and Eurasian plates (re-drawn from [1]). The dotted zone represents the seismicity area. The arrows indicate the shortening orientation, their length being proportional to the shortening rate. The city of Boumerdes, close to the epicenter of the May 21, 2003 earthquake, is represented by a filled diamond.

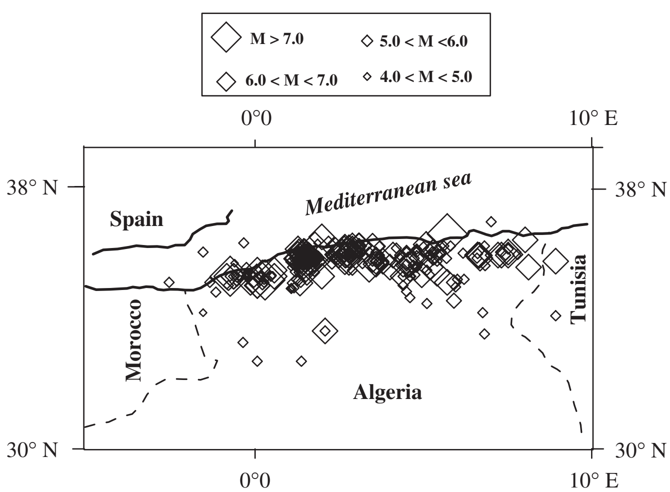

Fig. 2. Seismicity map of Algeria for the period 1365–1992, after the catalogues of CRAAG [5] and Benouar [6] (Magnitudes M_s).

earthquake was located offshore, next to the coastline (see main shock parameters in Table 1), with a reverse fault focal mechanism striking NE–SW (USGS). It triggered liquefaction in the epicentral zone and tsunamis of about 1.5 m along the coast of Spain. The main shock was followed by numerous aftershocks, some of them with magnitude over 5.0 that were recorded at the stations of the national accelerograph network monitored by CGS.

This paper deals with the analysis of main shock strong motion records, from 13 accelerographs located between about 20 and 150 km from the epicenter. A maximum 0.58g peak ground acceleration (PGA) has been recorded 20 km from the epicenter. The earthquake was felt inside a 250 km radius zone at the limits of which accelerations of about 0.02g were recorded. The seismic movement is investigated through various analyses, including maximum acceleration distribution, site effects, frequency contents, and fault-related directional effects, leading to the explanation of the shape of the most damaged zone, the level of destruction in the 3- to 4-story buildings in the epicentral zone, and to the observation of the inadequacy of the Algerian regulatory design spectra. Finally, a comparison is made between the Algerian law proposed by Laouami [7] and the worldwide laws actually used in Algeria with the recorded accelerations of the Boumerdes earthquake.

2. The Algerian accelerograph network

The lack of strong ground motion data was significantly experienced when elaborating the first Algerian aseismic building code in 1976. It was therefore decided to implement a countrywide accelerometer network. The installation of 335 3-component accelerographs started in 1980, 218 of which are already installed in the free field, and 30 in structures (buildings, dams, etc.) (Fig. 3). The network was acquired in three stages: (i) following the 1980 El Asnam earthquake, 90 analog SMA-1 accelerographs were installed mainly in the free field, (ii) in 1990, 80 SMA-1 analog and 40 SSA-1 digital accelerographs were acquired in order to densify the existing network, with more emphasis on structures (buildings, dams), and (iii) 125 Etna digital accelerographs, acquired in 2002–2003, are currently being installed.

3. Boumerdes earthquake accelerations and data processing

The Boumerdes earthquake was felt as far as 250 km from the epicenter, where accelerations of about 0.02g have been recorded. Among the CGS stations that recorded the