Site-Response Characteristics and Building Damage Distribution in the 2003 Boumerdes, Algeria Earthquake

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Following the destructive Mw=6.8 earthquake which shook the northern part of Algeria on the 21st of May 2003, the observation of recorded accelerations of the mainshock showed a remarkable difference in maximum values among neighbouring stations. However, for some stations, no such difference was observed in the velocity or acceleration for aftershocks. In addition, the distribution of damage observed from the survey mission in the city most strongly affected, namely Boumerdes, showed that in some zones the constructions were completely destroyed, while in others zones they did not suffer any damage or the damage was slight. It is well known that local site conditions can generate significant amplifications and spatial variations of earthquake ground motion, therefore have a great influence on the damage distribution.

Through this dissertation, we have organized and established database from numerous earthquake records obtained following the Boumerdes earthquake of 2003. This database constitutes a value in the information presented and in its application for technical issues, also an important addition to the literature for Algeria as case of study.

Site-response characteristics at seismic stations were investigated using a seismic-motion dataset of the 2003 Boumerdes earthquake, including data from microtremor measurements conducted for this study at seismic stations. The H/V spectral ratios were calculated for strong and weak motion events with aim of estimating the possibility of nonlinear site effects during the earthquakes. Comparison of calculated H/V spectral ratios with site-transfer functions obtained from existing soil profiles enables us to examine the applicability of the H/V method regarding the expected predominant periods and the amplification of soil layers under each station. The results of H/V from microtremor measurements were compared to that from ground motions.

Aiming estimation of local site conditions on observed damage distribution in the City of Boumerdes, the performance of buildings that shaken by the earthquake was examined based on the
damage they incurred. The buildings were classified so that their differences in seismic capacity were properly carried out. The result from performance and damage analysis was then used as reference to compare with data from microtremor observations, as conducted during this study at several free-field locations, and Digital Elevation Model (DEM) data extracted from ASTER satellite image to estimate local site effects on observed damage distribution.

The last part of this dissertation is the implications on using remote sensing imagery for damage assessment. We have examined the accuracy in detecting the damage grades from QuickBird images, considering the nature of urban environment and typology of buildings.
I would like to express my sincere gratitude to my academic supervisor, Professor Fumio Yamazaki, for his advice, constructive criticisms and continual guidance throughout the period of my study.

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CHAPTER 1

Introduction

1.1 Overview

Historically, the northern part of Algeria has suffered from numerous seismic events (Benouar 1996). Examples of recent disastrous events include the September 9, 1954 Orleansville earthquake (Ms 6.7), which caused over 1,200 deaths and damaged over 20,000 buildings and the 10 October, 1980 El-Asnam earthquake (Ms 7.2), which caused over 2,640 deaths and damaged about 20,000 buildings. The most recent such event was the May 21 2003 Boumerdes earthquake (Mw 6.8), 18:44:31 (GMT) (Ayadi et al. 2003, EERI 2003); the Algerian Ministers’ Council (12 December, 2003) reported 2,278 deaths, 11,450 injured, and an estimated 250,000 homeless, i.e., about 40,000 families (DLEP 2004). Due to damage to buildings, 17,000 structures had to be demolished and 116,000 were repaired. The resulting direct economic loss was estimated to be US $5 billion (Ousalem and Bechtoula 2005).

Regarding the availability of strong-motion records for Algeria, the 2003 Boumerdes earthquake is the first event in Algeria for which a large number of strong motions were successfully recorded at several seismic stations by the National Accelerometer Network operated by Algerian National Research Center of Earthquake Engineering (CGS). This is because the countrywide accelerometer network was established only after the Algerian government established CGS following the 1980 El-Asnam earthquake (Laouami et al. 2006). These records from the earthquake of 2003 were obtained from a wide variety of geologic environments. A site response study of this dataset would be a valuable addition to the literature.

The observation of recorded accelerations of the mainshock of the 2003 Boumerdes earthquake showed a remarkable difference in maximum values among neighbouring stations. However, for some stations, no such difference was observed in the velocity or acceleration for aftershocks. In addition, particular attention was paid to the city most strongly affected, namely Boumerdes, which is located at a hypocentral distance of 21 km. The distribution of damage observed from the survey mission showed that in some zones the
constructions were completely destroyed, while in others zones they did not suffer any damage or the damage was slight. It is well known that local topographical and geological conditions can generate significant amplifications and spatial variations of earthquake ground motion, therefore have a dominant influence on the damage distribution.

1.2 Objectives of Study

This dissertation addresses some of the key issues relation to site-response and strong motion distribution to improve the understanding about the recorded peak ground motion and the observed damage distribution. However, at first stage is it important to create and organize a necessary database from a wide range of seismic ground motions in aim to examine the implication of these challenges. In addition, GIS database of building characteristics and damage distribution is quite important to examine the performance of buildings in aim to estimate the local site conditions on observed damage distribution. Figure 1.1 visualizes the schemes of the work and the principal outcome results that will be presented in this dissertation. The objectives are summarized as follows:

Creation and organization of earthquake strong motion database:

The first objective of this dissertation is to organize and establish dataset related to seismic ground motions. Indeed, for the framework of this study we have done much effort to create and organize database from numerous earthquake records, from the National Accelerometer Network operated by CGS, following the earthquake of 2003. Several technical problems, which occurred during the recording, have been discussed and addressed. The established database constitutes a value in the information presented and in its application for technical issues, also an important addition to the literature for Algeria as case of study. GIS database of building characteristics and damage distribution has been also created and discussed in the second part of this study.

Evaluation of site-response under seismographs using seismic motion dataset and microtremors:

With the aim of estimating local site-response characteristics, Nakamura (1989) proposed the well known H/V spectral ratio technique, which uses the ratio of the horizontal (H) and vertical (V) Fourier spectra of microtremors recorded at a site, since soil profiles and PS logging data are not always available. Few years latter, this method has been used for
earthquake records (Field and Jacob 1993, Huang and Teng 1999). Through this technique, two period parameters are generally evaluated: the fundamental period and the predominant periods. The fundamental period (or natural period) corresponds to the first mode of vibration of the soil system, and has been used by several authors as a microzoning parameter (Bour et al. 1998, Chavez-Garcia and Cuenca 1998, Gamal 2008). The predominant period, on the other hand, which is defined as the period in which the maximum soil amplification occurs, is used more as a significant parameter in the assessment of building damage (Fallahi et al. 2003, Gosar 2007). Several authors have shown the dependent relationship between building damage, and the correspondence between the natural period of buildings and the predominant period of the soil layers (Oliveira et al. 2006). In addition, observations in different parts of the world have already provided an evidence of the significance of nonlinear site effects on
ground-motion records (Shearer and Orcutt 1987, Beresnev et al. 1998,). Several researchers reported the nonlinear site effects, which is characterized by the increase of the damping ratio and the reduction of the shear wave velocity, using the spectral ratio technique (Wen 1994, Dimitriu et al. 2000, Wen et al. 2006).

In the framework of this dissertation, site-response characteristics at seismic stations were investigated using a seismic-motion dataset of the 2003 Boumerdes earthquake, including data from microtremor measurements conducted for this study at seismic stations. The spectral ratios were calculated for strong and weak motion events with aim of estimating the possibility of nonlinear site effects during the earthquakes. Comparison of calculated H/V spectral ratios with site-transfer functions obtained from existing soil profiles enables us to examine the applicability of the H/V method regarding the expected predominant periods and the amplification of soil layers under each station. The results of H/V from microtremor measurements were compared to that from ground motions. Figure 1.2 shows the flowchart for the study of site-response under selected seismic stations.

**Estimation of local site conditions on building damage distribution**

Apart that building damage is highly related to the condition of buildings, local site conditions can also play a dominant role in damage distribution as well. Aiming to estimate local site conditions on observed damage distribution, the performance of buildings that shaken by the 2003 Algeria earthquake in the City of Boumerdes is examined based on the damage they incurred. The buildings are classified so that their differences in seismic capacity can be properly carried out. The possibility that there is a significant difference in the distribution of seismic intensity in the city is discussed with reference to the results of an examination of local site conditions using data from free-field microtremor observations, conducted at 16 locations in the city, and Digital Elevation Model (DEM) data extracted from ASTER satellite image for this city. Figure 1.3 presents the flowchart for the study of buildings performance and the effect of local site conditions on damage distribution.

**Perspective on application of remote sensing in building damage assessment**

After an earthquake or other disasters it is quite important for emergency management and recovery works to identify immediately building damage sustained in urban environment. On the other hand, in several cases the building damage data obtained from mission of field survey does not include GPS location of each surveyed building, especially for large area.
Accordingly, this last part of present dissertation is the implications on using remote sensing imagery for damage assessment. According to the existed works, the visual extraction of damage Grades using high resolution satellite images is mainly based on geometry changes and debris. QuickBird, a high-resolution satellite, captured a clear image of Boumerdes city on 23 May 2003, two days after the mainshock. The city was also observed by QuickBird on 22 April 2002, 394 before the mainshock. In this study, we have examined the accuracy of using QuickBird images, for detecting damage Grades considering the nature of urban environment and typology of buildings. The visual damage interpretation is carried out building by building based on the European Macroseismic Scale (EMS-98), comparing the pre-event and post-event images and registered on GIS. The result of the damage inspection is compared with field survey data. Figure 1.4 shows the flowchart for the perspective study of QuickBird satellite images in building damage assessment.

1.3 Organization of this thesis

This present chapter highlights the objectives and background information for this study. Corresponding overviews of related literature will be found at the beginning of each chapter.

Chapter 2 deals with organization and analysis seismic-motions dataset by the National Accelerometer Network operated CGS. Several technical issues, which constitute a value in the information presented, are discussed. The analyzed seismic motions were recorded from a total of 13 seismic stations from a wide variety of geologic environments. The EMS, MMI, and JMA seismic intensities and other strong motion parameters, e.g., PGA, and PGV are calculated using these data sets.

Chapter 3 presents the site-response under seismic stations using seismic motion dataset and microtremor. As process of study, seismic motions are classified into weak and strong events to estimate non-linearity effect by using horizontal-to-vertical spectral ratios. This chapter presents the certificate of applicability of the H/V methodology and explains the observed strong motion distribution.

Chapter 4 deals with the purpose of building performance and damage analysis in aim to estimate the effect of local site conditions on damage distribution, selecting Boumerdes city as area of study. In addition of GIS buildings database, data from microtremor measurement in free-field and Digital Elevation Model extracted from ASTER image are used.
Chapter 5 deals with the use of high-resolution satellite imagery as new perspective for quick building damage assessment after disastrous event. QuickBird images captured before and after the 2003 Algeria earthquake are used to evaluate visually the damage grade. This Chapter is supplemental to Chapter 4 since the results from QuickBird images are compared with damage data from field survey that are used previously in Chapter 4.

Finally, Chapter 6 presents conclusions of the study along with possible directions for further study.

**Figure 1.2.** The flowchart for Chapter 3: Study of site-response under selected seismic stations.
Figure 1.3. The flowchart for Chapter 4: Study of buildings performance and the effect of local site conditions on damage distribution.
Figure 1.4. Flowchart for Chapter 5: Perspective study of QuickBird satellite images in building damage assessment.
CHAPTER 2

Strong Motion Records of the 2003 Boumerdes Earthquake

2.1 Introduction

The mainshock of the 2003 Boumerdes earthquake, which hit the northern part of Algeria causing extensive damage and human casualties, was felt inside a 250 km radius from the epicenter (Laouami et al. 2006). The location of the epicenter, as provided by the Algerian Research Center of Astronomy Astrophysics and Geophysics (CRAAG), was 36.91° N and 3.58° E. However, Bounif et al. (2004) determined that the epicenter of the mainshock was at 36.83 N and 3.65 E (Figure 2.1), at a depth of 8–10 km. The rectangle in Figure 2.1 shows the focal plane projected to the surface as proposed by Delouis et al. (2004). The source model runs for an eastern distance of 55 km (3.4°–4.0°E). According to Meghraoui et al. (2004), the model fault (reverse-faulting mechanism) has a strike of N 54° E and dip of 50° to the southeast, and it extends 1–15 km below the ground surface.

In this chapter an observation and analysis of ground motion records was conducted using a seismic-motion dataset of the 2003 Boumerdes earthquake that have been organized and established within the framework of this dissertation and would be a valuable addition to the literature. These motion records were obtained from a wide variety of geologic environments through several seismic stations by the National Accelerometer Network operated by Algerian National Research Centre of Earthquake Engineering (CGS).

2.2 Mainshock of the 2003 Boumerdes earthquake

Regarding the availability of strong-motion records for Algeria, the 2003 Boumerdes earthquake is the first event in Algeria for which a large number of strong motions were successfully recorded at several seismic stations by the national accelerometer network operated by CGS. This is because the countrywide accelerometer network was established only after the Algerian government established CGS following the 1980 El-Asnam earthquake (Laouami et al. 2006).
Figure 2.1 shows the locations of 11 free-field seismic observation stations deployed by CGS, from which the main shock was recorded at a hypocentral distance of 31–165 km. However, due to some instrument problems (out of order) during the event, the main shock

Figure 2.1. Geological background (Ayadi et al. 2003) of the epicentral area and the mainshock’s epicenter (star) of the 2003 Boumerdes, Algeria earthquake. The rectangle represents the estimated fault plane (reverse-faulting mechanism) (Delouis et al. 2004). The graduated circles correspond to 167 aftershocks during May 25-30, 2003. The triangles represent the CGS accelerograph network stations located in the central part of northern Algeria.

Figure 2.2. The estimated starting time of the main shock and seismic wave propagation in the 2003 Boumerdes, Algeria earthquake (EW components).

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Figure 2.1 shows the locations of 11 free-field seismic observation stations deployed by CGS, from which the main shock was recorded at a hypocentral distance of 31–165 km. However, due to some instrument problems (out of order) during the event, the main shock
and many aftershocks could not be recorded at some locations where the damage was most extensive. In addition, at some stations, the primary wave of the mainshock was missed, especially for the stations located far from the hypocenter. Figure 2.2 shows the estimated relative starting time of the earthquake for each station. The starting time of the earthquake at each station is not available because the accelerographs were not equipped with GPS.

2.2.1 Strong-motion records

Instruments deployed by CGS record seismic ground motion by means of electronic transducers that produce an output voltage proportional to acceleration. Using the recorded acceleration time history, the velocity and displacement time histories were computed by integration in the frequency domain through a rectangular filter with a low cut-off frequency of 0.05 Hz. Figure 2.3 shows particle traces of the displacements computed from the main shock records on a horizontal plane at 11 seismic observation stations. These orbits show that the maximum displacements were recorded at Dar El-Beida ST (18.3 cm) and Hussein-Dey ST (11.4 cm). The displacement orbits at two nearby stations, Keddara ST1 and Keddara ST2, show similar shapes but appear to have a rotation angle about the vertical axis. Because the distance between two stations is very small, approximately 100 m, the observed rotation angle may be inferred as being caused by orientation errors during instrument installation. It was reported that some seismometers have been reported as being deployed with unexpected orientation errors. Seismographs used may involve unexpected errors in their orientations from the preassigned directions which sometimes difficult to see visually (Yamazaki et al. 1992). However, it is quite important to correct the error orientation of recorded motion since might causes the miss precisely for different studies based on use of recorded ground motions. For the case of Keddara stations, the orientation error is considered to be a rotation angle about the vertical axis of the instrument.

Since we do not know which of these two stations has the correct orientation, to estimate the orientation errors, let us consider that the orientation of instrument at Keddara ST1 as a reference and correcting the angle orientation error for Keddara ST2 as presented by Figure 2.4. The ground motion at Keddara ST1 and ST2 was recorded under a vector process:

$$\mathbf{K}_1(t) = \begin{bmatrix} \mathbf{NS}_1(t) & \mathbf{EW}_1(t) & \mathbf{UD}_1(t) \end{bmatrix}^T$$ and $$\mathbf{K}_2(t) = \begin{bmatrix} \mathbf{NS}_2(t) & \mathbf{EW}_2(t) & \mathbf{UD}_2(t) \end{bmatrix}^T$$
respectively with: $NS_1(t)$, $EW_1(t)$ and $UD_1(t)$ indicating the ground motion components to the reference correct orientation directions at Keddara ST1; $NS'_2(t)$, $EW'_2(t)$ and $UD'_2(t)$ indicating the ground motion components to the orientation error directions at Keddara ST2.

Figure 2.3. Orbit plots of displacement computed from the recorded mainshock for 11 seismic stations. The open circle corresponds to the direction of the maximum resultant value.

Figure 2.4. Process of instrument rotation angle about the vertical axis at Keddara stations.
The orientation error is considered to be a rotation angle $\alpha$ about the vertical axis of the instrument. A direction measurement of preassigned correct orientation may be denoted by:

$$
T_{2222} = \begin{bmatrix}
T_{UD} & T_{EW} & T_{NS} & T_{KD}
\end{bmatrix}
$$

which can be obtained using the relationship between the error and preassigned orientation components through the transform matrix function of the orientation angle $\alpha$ as following:

$$
\begin{bmatrix}
  \cos(\alpha) & \sin(\alpha) & 0 \\
  -\sin(\alpha) & \cos(\alpha) & 0 \\
  0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
  NS_2(t) \\
  EW_2(t) \\
  UD_2(t)
\end{bmatrix}
\begin{bmatrix}
NS_2'(t) \\
EW_2'(t) \\
UD_2'(t)
\end{bmatrix}
$$

This equation may takes the following general form:

$$
KD_2(t) = T(\alpha)KD_2'(t)
$$

with $T(\alpha)$ is the transform matrix between the both vectors $KD_2(t)$ and $KD_2'(t)$ as:
The instrument orientation error was estimated using the recorded ground motions and then the records was corrected by coordinate transform. Analytically, an estimated rotation angle at Keddara ST2 is calculated to be 20.7 degrees about the vertical axis. The orientation error of the instrument at Keddara ST2 can be corrected by rotating back the error angle. Figure 2.5(a) shows a comparison of displacements between Keddara ST1 and ST2 before and after the correction. Displacement time histories for Keddara ST1 and ST2 become very similar after the correction, while they were clearly different before the correction. The corresponding coherence functions are shown in Figure 2.5(b). Coherence increased after the correction. The similarity after correction can be also seen from the orbit plots shown in Figure 2.6. Thus, when two stations are located close to each other, we can calculate their orientation errors; however, it is difficult to do so for stand-alone stations. Hence, in this study, the resultant $A_{res}$ of the two horizontal components (Ansary et al. 1995) was used to eliminate or avoid the possibility of orientation error.

$$A_{res}(t) = \sqrt{A_{NS}(t)^2 + A_{EW}(t)^2}$$  \hspace{1cm} (2.4)

Table 1 shows the recorded peak ground acceleration (PGA) with the computed peak ground velocity (PGV) and peak ground displacement (PGD) corresponding to the maximum values resulting from two horizontal components (NS and EW). Figure 2.7 shows the attenuation of strong motion in terms of PGA and PGV. The regression curves for attenuation law are also shown (Molas and Yamazaki, 1995).

The largest PGA values were recorded at Keddara ST2 (580.5 cm/s$^2$) and Dar El-Beida station (540.0 cm/s$^2$). The PGAs for some of the stations differed greatly from those of neighboring stations, but the PGVs and PGDs for other stations showed no such difference. Although a considerable difference was seen in the PGAs for Keddara ST1 (330.0 cm/s$^2$) and the nearby Keddara ST2, the PGV (18.5 and 19.8 cm/s, respectively) and PGD values (6.4 and 6.6 cm, respectively) were very close. Acceleration is well known to be sensitive to high-frequency content, but the velocity and displacement are much less so. Hence, the big difference in PGA and small differences in PGV and PGD might be due to the high-frequency content of seismic motion.
Table 1. Peak ground acceleration, velocity, and displacement corresponding the resultant of the horizontal components for the mainshock of the 2003 Boumerdes earthquake, and the instrumental JMA intensity and estimated MMI. The EMS-98 intensity was estimated following the macroseismic survey conducted by CRAAG.

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Hypocentral Distance (km)</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
<th>PGD (cm)</th>
<th>JMA</th>
<th>MMI</th>
<th>EMS-98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boumerdes</td>
<td>36.75 N 03.47 E</td>
<td>21</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>X</td>
</tr>
<tr>
<td>Keddara ST1</td>
<td>36.65 N 03.41 E</td>
<td>31</td>
<td>333.0</td>
<td>18.5</td>
<td>6.4</td>
<td>4.7</td>
<td>VII</td>
<td>VII</td>
</tr>
<tr>
<td>Keddara ST2</td>
<td>36.65 N 03.41 E</td>
<td>31</td>
<td>580.5</td>
<td>19.8</td>
<td>6.6</td>
<td>4.8</td>
<td>VII</td>
<td>VII</td>
</tr>
<tr>
<td>Tizi Ouzou</td>
<td>36.70 N 04.07 E</td>
<td>41</td>
<td>231.7</td>
<td>13.9</td>
<td>4.6</td>
<td>4.4</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>Dar El-Beida</td>
<td>36.71 N 03.20 E</td>
<td>43</td>
<td>540.0</td>
<td>41.9</td>
<td>18.3</td>
<td>5.6</td>
<td>VIII</td>
<td>VIII</td>
</tr>
<tr>
<td>Hussein Dey</td>
<td>36.74 N 03.09 E</td>
<td>52</td>
<td>272.0</td>
<td>20.1</td>
<td>11.4</td>
<td>4.8</td>
<td>VII</td>
<td>VI-VII</td>
</tr>
<tr>
<td>Kouba</td>
<td>36.71 N 03.09 E</td>
<td>53</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>VI</td>
</tr>
<tr>
<td>Azazga</td>
<td>36.74 N 04.37 E</td>
<td>66</td>
<td>120.5</td>
<td>14.8</td>
<td>4.0</td>
<td>4.6</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>Blida</td>
<td>36.47 N 02.82 E</td>
<td>53</td>
<td>120.5</td>
<td>14.8</td>
<td>4.0</td>
<td>4.6</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>El Affroun</td>
<td>36.47 N 02.63 E</td>
<td>100</td>
<td>164.4</td>
<td>5.6</td>
<td>0.4</td>
<td>4.2</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Hammam Righa</td>
<td>36.35 N 02.39 E</td>
<td>125</td>
<td>114.8</td>
<td>14.0</td>
<td>5.4</td>
<td>4.6</td>
<td>VI</td>
<td>IV</td>
</tr>
<tr>
<td>Miliana</td>
<td>36.30 N 02.23 E</td>
<td>140</td>
<td>34.2</td>
<td>2.4</td>
<td>1.5</td>
<td>3.3</td>
<td>IV</td>
<td>IV</td>
</tr>
<tr>
<td>Ain Defla</td>
<td>36.26 N 01.95 E</td>
<td>165</td>
<td>36.1</td>
<td>1.8</td>
<td>0.9</td>
<td>3.1</td>
<td>IV</td>
<td>IV</td>
</tr>
</tbody>
</table>

Figure 2.7. Attenuation law of seismic motion in terms of PGA and PGV. BM in red colour shows the estimated PGA and PGV at Boumerdes station.
2.2.2 Seismic intensity

The Modified Mercalli Intensity (MMI) scale (Wood and Neumann 1931), European Macroseismic Scale (EMS-98) (Grünthal 2001), and Japan Meteorological Agency (JMA) scale (Karim and Yamazaki 2002), developed in the USA, Europe, and Japan, respectively, are among the most widely used to estimate the ground motion severity. The MMI and EMS-98 generally estimate the ground shaking intensity during an earthquake using scales based on the effects felt at the time of the earthquake and on later observations of damage to the built environment. Twelve grades denoted by the Roman numerals I–XII are defined. Each degree in these scales describes the effects of ground motion on nature or the built environment in terms of damage, ranging from I, denoting a weak earthquake motion, to XII, denoting almost total destruction. Recently, the estimation of MMI intensity has been related to the ground motion records (Wald et al. 1999a and 1999b), where the scale of MMI intensity can be estimated according to the value ranges of peak ground motions recorded at a seismic station.

In contrast, JMA scale is based on strong-motion records. Although the JMA intensity scale is initially based on the intensity felt with eight shaking levels, it was later revised to allow the use of seismic intensity computed from strong-motion records. The computation of JMA intensity (also denoted as $I_{JMA}$) involves combining the three components of recorded motion; the numerical seismic intensity value is determined from the acceleration value $a_0$ that persists for a sufficient duration (Shabestari and Yamazaki 2001).

Figure 2.8. Comparison of JMA and EMS-98 seismic intensities using (a) PGA and (b) PGV for the mainshock records.
\[ I_{\text{JMA}} = 2.01 \log a_o + 0.94 \] (2.5)

In this study, JMA and MMI intensity scales were applied to mainshock records obtained during the 2003 Boumerdes earthquake. The computed JMA intensities ranged from 3.1 to 5.6, as shown in Table 1. The maximum value was obtained at Dar El-Beida station, about 43 km from the hypocenter. For the two stations, Keddara ST1 and Keddara ST2, the JMA intensity values were similar at 4.7 and 4.8, respectively. The estimated MMI intensities for the mainshock records at their corresponding seismic stations are also shown by Table 1.

In addition, the EMS-98 intensity scale was applied to the 2003 Boumerdes earthquake (Harbi et al. 2007) following the macroseismic survey conducted by CRAAG. The EMS-98 intensity was estimated for 600 sites. The maximum attributed intensities IX and X were assigned to 11 sites, where many constructions suffered heavy to very heavy damage or collapse. An intensity of VIII was assigned to 22 sites where damage to buildings and loss of life were recorded. As shown in Table 1, we associated each strong-motion record obtained from the free-field recording sites with the EMS-98 value assigned to where the strong motion was recorded and felt by people.

As shown in Table 1, almost all of the estimated MMI intensity grades matched quite well with the EMS-98 intensities. Figure 2.8 shows a comparison of JMA and EMS-98 intensities with the peak ground motions of the mainshock. The correlation of PGA to EMS-98 is clearly not as good as the correlation of the latter to JMA.

2.3 Conclusions

In the framework of this study, an observation and analysis of ground motion records was conducted using a seismic-motion dataset of the 2003 Boumerdes earthquake that have been organized and established within this chapter. The motion records were obtained from a wide variety of geologic environments through several seismic stations by the National Accelerometer Network operated by Algerian National Research Centre of Earthquake Engineering (CGS), and which constitute a valuable addition to the literature for Algeria as case of study.

The observation of recorded accelerations shows a remarkable difference in maximum values among neighbouring stations. However, for some stations, no such difference was observed in velocity or acceleration from the aftershocks. As well known from the
experienced past earthquakes in different parts of the world local site conditions could generate significant amplifications and spatial variations of earthquake ground motion. Accordingly, the site response characteristics under accelerograph stations will be investigated in the next chapter, using these seismic-motion dataset, to explain the recorded high peak ground acceleration (PGA) value.

Apart from the afore-mentioned analyses, it is clearly understood that the number of free field seismic stations which recorded the mainshock, especially in the severely affected areas, is not sufficient for estimating a detailed strong motion distribution and for analyzing the building damage distribution. In addition, we could notice that several technical problems have been occurred during recording the mainshock and aftershocks (many events have been missed to be recorded).

Orientation errors of the accelerographs were found from the recorded motions. The orbit figures formed by two horizontal components between both stations at Keddara had similar shapes but different directivities. This might causes the miss precisely for different studies based on use of recorded ground motions. To avoid the possibility of orientation error, the resultant of the two horizontal components of ground motion records from dataset will be used in this study.
CHAPTER 3

Evaluation of Site-Response Characteristics under Seismic Stations

3.1 Introduction

In this study, we use a seismic-motion dataset of the 2003 Boumerdes earthquake, recorded from Algerian Accelerograph Network and provided by Algerian National Research Center of Earthquake Engineering (CGS), together with microtremor records measured at the accelerograph stations to investigate site-response characteristics by the H/V spectral ratio technique. We calculated the spectral ratios for strong and weak motion events to estimate the possibility of nonlinear site effects during earthquakes. Comparison of the calculated H/V spectral ratios with site-transfer functions obtained from existing soil profiles allowed us to examine the applicability of the H/V method regarding the expected predominant periods and amplification of soil layers under each station.

3.2 Selected seismic stations

To examine the local site effects of recorded strong motions of the 2003 Boumerdes, Algeria earthquake, six near-field seismic stations were selected: Hussein-Dey, Kouba, Dar El-Beida, Boumerdes, Keddara ST1, and Keddara ST2. All of these stations are located approximately along the fault trace (Figure 2.1). The average distance between adjacent stations is about 20.4 km. According to the geological background (Ayadi et al. 2003) shown in Figure 2.1, the area where these stations are located is comprises mainly of Quaternary and Neogene formations. Quaternary formations, which are generally soft deposits, consist of mostly sand, gravel, and sandy clay covering Plaisancian (lower Pliocene) blue marl and Cristallophyllian rocks; they extend to 30 m beneath the ground surface.

Figure 3.1 shows the damage map of the mainshock in terms of the EMS-98 intensity scale at selected area of study estimated following the macroseismic survey conducted by CRAAG (Harbi et al. 2007).
At Hussein-Dey and Kouba cities, old masonry residential buildings built before 1960, an example of which is shown in Figure 3.2(a), were the most affected by the mainshock. The recorded mainshock at Hussein-Dey ST had PGA = 272.0 cm/s² and PGV = 20.1 cm/s (Table 1), which corresponds to $I_{JMA} = 4.8$ and EMS-98 = VI–VII. These intensities were at the lower limit at which structural damage starts to occur to vulnerable buildings. For Dar El-Beida city, the mainshock caused heavy damage with $I_{JMA} = 5.6$ and EMS-98 = VIII. Damaged buildings tended to be made of reinforced concrete as well as old masonry. In Boumerdes city, the mainshock was particularly destructive with EMS-98 = X. Many constructions, mostly mid-rise reinforced concrete buildings (4 and 5 stories) built after 1970 (Figure 3.2(b)), were destroyed, and many people were killed as a result of the destruction of buildings. For Keddara ST1 and ST2, located 13 km away from Boumerdes city, the JMA
The mainshock of the May 21, 2003 event was followed by many aftershocks, some of them with magnitudes over 5.0. A total of 167 aftershocks were recorded from May 25 to 30, 2003, as shown in Figure 2.1. From the six selected seismic recording stations, 239 seismic events (mainshock and aftershocks) were recorded: 89 from Boumerdes, 47 from Keddara ST2, 34 from Keddara ST1, 28 from Kouba, 27 from Dar El-Beida, and 14 from Hussein-Dey. Figure 3.3 shows the levels of all recorded PGA and PGV for the six stations. Strong aftershocks were mostly observed at Boumerdes, Dar El-Beida, and Keddara. The largest aftershock record was obtained at Boumerdes (M = 5.8, on May 27, 2003 at 17:11:40 GTM at 36.78°N and 3.60°E), with PGA = 441.5 cm/s² and PGV = 23.59 cm/s. Figure 3.4 shows the recorded acceleration and the computed velocity time histories for this event at

![Figure 3.3. Number of recorded ground motions and range of PGV and PGA values at six seismic stations.](image)
Boumerdes city. Table 2 shows details of 14 selected seismic records (with a sufficient record length) from each of the six stations: one record from the mainshock and 13 records from aftershocks. However, only aftershock records for Boumerdes and Kouba were selected because the mainshock could not be recorded.

Figure 3.4. Recorded acceleration and computed velocity time histories of the largest aftershock obtained in the city of Boumerdes on May 27, 2003 - 17:11:40 GTM (M = 5.8 at 36.78° N, 3.60°).
### Table 2. Resultant peak horizontal acceleration and velocity for 14 seismic records for the 2003 Boumerdes earthquake

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<th>PGV (cm/s)</th>
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(*) records considered for computing the average of H/V for weak seismic motions in Figure 3.8.

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(*) records considered for computing the average of H/V for weak seismic motions in Figure 3.8.
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3.3 H/V Spectral Ratios

Aiming to estimate local site-response characteristics, Nakamura (1989) proposed the well-known H/V spectral ratio technique, which uses the ratio of horizontal and vertical Fourier spectra of microtremors recorded at a site. Several researchers have attempted to apply the technique to earthquake records (Yamazaki and Ansary 1997). In general, the H/V spectral ratio is used to estimate the predominant period (peak period of the H/V ratio), which is used as a significant parameter in building damage assessment (Fallahi et al. 2003, Gosar 2007) and in estimating soil amplification characteristics (Rodriguez and Midorikawa 2003). In recent years, studies have demonstrated that nonlinear behavior (shear-modulus degradation) can be evaluated using H/V spectral ratios. When nonlinearity occurs in a soil layer under a seismic station, the predominant period is lengthened accordingly (Wen 1994, Wen et al. 2006). The nonlinear effect is evidenced through an increase in the predominant period of soil deposits with an increasing level of excitation (Beresnev et al. 1998, Huang 2002).

We calculated the H/V Fourier spectral ratio for all seismic records used in this study as the spectral ratio between the two horizontal components (EW and NS) and vertical (UD) component, defined by
\[ R(f) = \frac{\sqrt{F_{NS}(f) \cdot F_{EW}(f)}}{F_{UD}(f)} \]  

(3.1)

where \( F_{NS}(f) \), \( F_{EW}(f) \), and \( F_{UD}(f) \) are the smoothed Fourier-amplitude spectra for the two horizontal and vertical components of a seismic-motion record, respectively. These Fourier spectra were smoothed by a Parzen window of 0.4 Hz bandwidth. Figure 3.5 shows examples of the H/V spectral ratios for six stations using three seismic records (see Table 2) with different excitation levels (PGV levels). The H/V spectral ratio for an earthquake ground motion appeared to be influenced by the site characteristics, which correlates well with the fact that the H/V spectral ratio is sensitive to ground-motion intensity (Dimitriu et al. 2000).

In general, each station had similar shapes for the H/V spectral ratios, with no clear difference in amplitude for differing PGV levels of seismic motion. The shapes of the ratios showed the presence of noise, including fluctuation around the expected predominant period, which is defined as the period at which the maximum soil amplification occurs (Fellahi et al. 2003). These peaks were observed at the Boumerdes, Dar El-Beida, Kouba, and Hussein-Dey stations. In contrast to these stations, the two neighboring stations Keddara ST1 and ST2, which were only separated by about 100 m, exhibited H/V ratios with an almost flat form and no particular difference in the shape between them except for the presence of a small peak around 0.10–0.15 s in Keddara ST1; this peak was unclear according to the criteria defined by SESAM project (SESAME 2004) for reliable and clear peaks.

For selected stations, the evidence of soil nonlinearity from the H/V spectral ratios for different PGV levels is not clear; the small shifts in peaks shown in Figure 3.5 are almost negligible. From literature, when the H/V-ratio technique is used, the predominant period should correspond to the highest peak amplitude of a H/V curve (Oliveira et al. 2006). Hence, for each event, we estimated the predominant period from the computed H/V spectral ratio. Figure 3.6 shows the extracted predominant periods from the H/V spectral ratio for 14 seismic motions with respect to PGV. The results from all of the stations do not present convincing evidence of an increase in the predominant period with the motion intensity. Only two stations, Boumerdes and Dar El-Beida, showed even slight increases, which seems insignificant (Figure 3.6).
Figure 3.5. Comparison of the H/V spectral ratios among strong and weak seismic motions at six seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, (d) Kouba, (e) Keddara ST1, and (f) Keddara ST2.
Figure 3.6. Predominant periods of the H/V spectral ratios with respect to PGV (Table 2) at five seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, (d) Kouba, and (e) Keddara ST1.
Figure 3.7. Soil classifications and S-wave velocity profiles for four seismic stations in Algiers and Boumerdes provinces. (a) and (b): The measured S-wave velocity (thick line) was measured by a downhole survey. (c) and (d): The estimated S-wave velocity (thin line) used existing engineering classification models for different geological units in these areas.
3.4 Comparison between the H/V Spectral Ratio and Transfer Function

Out of the six seismic stations, detailed soil profiles are only available for four (Figure 3.7): Hussein-Dey (up to −58 m), Kouba (up to −40 m), Dar El-Beida (up to −60 m), and Boumerdes (up to −25 m). Shear-wave (S-wave) velocity profiles are only available for two stations, Hussein-Dey and Kouba, and were obtained from in situ downhole measurements. For Dar El-Beida and Boumerdes, generalized S-wave velocity profiles were estimated using the standard S-wave velocity with respect to geological layers; these were proposed for Algiers province by the Japan International Cooperation Agency (JICA) in cooperation with CGS (JICA and CGS 2006).

The transfer function, defined as the ratio of the surface motion with respect to the rock

![Figure 3.8](image_url)

**Figure 3.8.** Average of the six selected H/V spectral ratios for weak seismic motions (thick black line) versus the transfer function (thin black line) at four seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, and (d) Kouba. The dashed line shows the plus-minus one standard deviation range of the averaged H/V ratio.
outcrop motion, was calculated for four stations using the computer program SHAKE91 (Idriss and Sun 1992). The behavior of soil sites was considered linear assuming that the shear wave velocity and damping did not change. Damping ratios of 2% for different soil layers and 1% for bedrock (outcrop) were used to compute the transfer function. Figure 3.8 compares the average H/V spectral ratio (Field and Jacob 1995) with the transfer function for the Boumerdes, Dar El-Beida, Hussein-Dey, and Kouba stations. Since PGV levels may be relevant for soil nonlinearity, the average for the H/V spectral ratios, which may reduce uncertainty (Aki and Richards 1980), was computed using six weak motion records, i.e., using similar levels of excitation without nonlinearity. The selected records for averaging are denoted in Table 2 by asterisks.

In general, the H/V spectral ratio was reliable in characterizing the site response of soil deposits under a seismic station. The shapes of the averaged H/V ratio matched well with that of the transfer function for each site. Almost all of the predominant periods, corresponding to the maximum peak of the transfer function for a subsoil model, matched the closest peaks from the H/V ratios at the respective sites. However, the fluctuation around these peak periods from the averaged H/V ratios was rather significant for Hussein-Dey and Kouba (Figure 3.8).

3.5 Site amplification effects

Several authors have shown that building damage is dependant on the proximity between the natural period of a building and the predominant period of the site (Oliveira et al. 2006). Since the period range of an ordinary site is less than 1 s, the expected predominant periods (highest peak of the H/V spectral ratio) for the ground surface at the seismic stations were about 0.1–0.25 s (Figure 3.5 and 3.8).

For the Hussein-Dey and Kouba stations, which are 3 km apart, the shapes of the H/V spectral ratio did not show any significant amplification. The response spectra of the recorded mainshock at Hussein-Dey for a damping ratio of 5% (Figure 3.9) showed a maximum response acceleration at a period of about 0.1 s.

According to the H/V spectral ratios, the ground motion at Dar El-Beida station seems to have been strongly affected by the local soil conditions, with remarkable amplification around 0.22 s. The response spectra for Dar El-Beida, shown in Figure 11, had two large peaks at 0.15 and 0.3 s. Quaternary deposits are known to cover almost the entire area of this
city (Figure 2.1), and this soil condition may be responsible for the amplification around 0.15–0.3 s.

At Boumerdes station, the H/V spectral ratios did not show any significant amplification, and the estimated predominant period of the site was around 0.15 s. As mentioned earlier, the mainshock was not recorded at this station; however, many strong aftershocks were recorded. This city is located just above the source plane; thus, the ground motion was very intense, and the observed damage was very extensive (Figure 3.2(b)).
For the two neighboring stations Keddara ST1 and ST2, which were located at the southwest edge of the strong shaking zone, the shapes of the H/V spectral ratios for seismic motions showed a similar flat form corresponding to the existence of hard surface layers, with an insignificant difference occurring at the short period around 0.11 s at Keddara ST1.

Figure 3.10 shows a comparison for the PGA and PGV of the mainshock and aftershocks between Keddara ST1 and ST2. Most of the events clearly had similar values for the two stations, although the response spectra of the mainshock for Keddara ST1 was relatively flat compared to that for Keddara ST2, which showed a higher amplitude at 0.08 s (Figure 3.9). High-frequency content in seismic ground motion is well known to contribute significantly to the maximum values (Kramer 1996, Rathje et al. 2004). This observation suggests the need for detailed geotechnical data to investigate the reason for this difference in more detail.

Figure 3.11. Example of microtremor measurements at the two Keddara stations. (a) Location of earth dam at 700 m away from Keddara ST2. (b) Microtremor measurement at ST2. (c) Seismograph of ST2.
3.6 Nonlinear site effects.

The observation of significant nonlinearity effect depends on the existence of resonance, which is related to the properties of soil deposits. Dimitriu et al. (1999) used the HV spectral ratio technique to observe a considerable drop in the effective resonance frequency of a soil site with simple geology at the town of Lefkas in western Greece and linked it to nonlinear behavior (shear-modulus degradation) of the top sandy-silt layer. Furthermore, they found a significant correlation between the resonance frequency and PGA and PGV.

For the selected stations in this study, we did not register evidence of significant nonlinear site effects. Except for Dar El-Beida station, the H/V spectral ratios were not dominated by a clear period; moreover, the two close stations, Keddara ST1 and ST2, showed flat H/V curves (Figure 3.5). The shift of the dominant period from the H/V ratio was almost negligible (Figure 8); thus, we can say that the nonlinear soil effects were not so significant. In general, this characterizes the case for the presence of firm or hard soil conditions (Wen et al. 2006). With nonlinear effects, strong motions are generally less amplified than weak motions in the H/V spectral ratio (Dimitriu et al. 2000), which was not clearly seen for this study (Figure 3.5) throughout the range of the period.

3.7 Microtremor measurements at seismic stations

Free-field microtremor measurement has been conducted at each location of selected six seismic stations to compare with the estimated site-response characteristics from the seismic motion. Figure 3.11 shows example of microtremor measurement at Keddara STs. The duration of a microtremor observation was set as 5 min, and the record was divided into six segments of 50 s duration to calculate an average H/V spectral ratio as defined by Equation 3.1 and by following the same procedure as used for seismic-motion data. Figure 3.12 shows the averaged H/V Fourier spectrum ratio of the microtremors at each location of six seismic stations.

The shape of the ratio for microtremor does not match well with that of seismic motion or the transfer function seismic-station subsoil for each site. Except for Dar El-Beida ST, observing a microtremor peak was difficult. For the two nearby stations Keddara ST1 and ST2, the shape of the H/V ratio is almost flat, with a small peak around 0.11 s at Keddara ST1.
3.8 Conclusions

This chapter analyzed the site response of accelerograph stations and the recorded strong-motion distribution during and following the 2003 Boumerdes, Algeria earthquake. The H/V spectral ratios between strong and weak motion events were compared with the aim of estimating the nonlinear site response during the earthquake. The averaged H/V spectral ratio was calculated and compared with the transfer function; it was computed using a soil layer model for each station to examine the applicability of the H/V technique regarding the

Figure 3.11. Averaged H/V Fourier spectrum ratio of microtremors computed from 6 segments of 50 s recorded at each location of six seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, (d) Kouba, (e) Keddara ST1, and (f) Keddara ST2.
predominant period and soil amplification of each station. However, by using microtremor measurements the shape of the H/V ratio did not match well with that of seismic motion or the transfer function seismic-station subsoil for each site.

For the selected six stations, no significant nonlinear site effect was observed. Almost no remarkable difference in the H/V ratio was seen between the weak and strong events. The H/V ratio showed a rather flat form for some stations; hence, the predominant period was not very easy to determine in some cases. This observation suggests the presence of firm to hard soil layers under the stations, except for one station—Dar El-Beida—that showed a remarkable amplification at the predominant period, which seems to agree well with the known geological nature of the site and justifies the recorded high PGA.

This study validates the use of the H/V ratio technique to evaluate site response characteristics. However, geotechnical and geophysical investigations are needed to understand site amplification in greater detail.
CHAPTER 4

Building Performance and Local Site Conditions on Damage Distribution in the City of Boumerdes

4.1 Introduction

Following the earthquake 2003, particular attention was paid to the city most strongly affected, namely Boumerdes, which is located at a hypocentral distance of 21 km (Figure 4.1). The distribution of damage observed from the survey mission, which was conducted by the Algerian Ministry of Housing, showed that in some zones the constructions were completely destroyed, while in others zones they did not suffer any damage, or the damage was slight.

Apart that building damage is highly related to the seismic performance of buildings, local site conditions (local soil effects, local topographical and surface geological conditions) can also play a dominant role in damage distribution as well.

Aiming the estimation of local site conditions on observed damage distribution, the performance of buildings that shaken by the earthquake is examined based on the damage they incurred. The buildings are classified so that their differences in seismic capacity, or in other words, the difference in the damage ratio in the areas concerned, can be properly taken into account. For the typical forms of Algerian construction, applicable in the case of Boumerdes, the principal parameters or factors considered to have an important impact on the damage distribution, are structural material, construction category (building or house), and height (low-rise, mid-rise, and high-rise). Accordingly, a comparison is carried out among various building classifications to evaluate their seismic capacity.

The result from performance and damage analysis is then used as reference to compare with data from microtremor observations, as conducted during this study at several free-field location, and Digital Elevation Model (DEM) data extracted from ASTER satellite image to estimate local site effects and examine the possibility that there is a significant difference in the distribution of seismic intensity in the city.
4.2 Location and lithology of Boumerdes City

Boumerdes city is the capital of Boumerdes province, located in the north of Algeria about 50km east of Algiers on the Mediterranean Sea. Its previous name, during French occupation of Algeria (before 1962), is "Rocher Noir", translated from French as Black Rock. The city became the capital of the province having the same name according to the administrative division in 1984. In 1998 the population was estimated to be 33,646 inhabitants. Figure 4.1 shows the location and administrative boundary of Boumerdes city. The urban area is concentrated only in the western part of the administration boundary of the city. The eastern part of the city is mainly used as agriculture land. A high resolution satellite (QuickBird) image captured on 23/05/2003 (two days after the earthquake) shows the urbanized area of Boumerdes city (Figure 4.1).

In terms of geological conditions, the area of Boumerdes province mainly consists of cristallophyllian rocks overlain by quaternary sandy clay formations. In the city of Boumerdes, the geological layers are made up by granulitic micaschists formations at the basis which show up on surface in some locations mainly in the eastern part of the city. These formations are overlain by pre-consolidated marl of lower Pliocene, then by red sands, recent clays, beach sands and dune quaternary. Figure 4.2 shows the lithology in the area of
Boumerdes city (Menerville 1895 Number 22). In addition, the area of Boumerdes city is crossed by three rivers namely: the Boumerdes river valley, the Tatareg river valley and the Corso river valley, whose flow direction towards the sea is directed mainly South-North. This leads to a rugged topography site, and has left its mark on the urbanization of the city (Figure 4.1). Figure 4.3 represents a 15-m Digital Elevation Model (DEM) of the Boumerdes city generated from ASTER satellite image.

**Figure 4.2.** Lithology in the area of Boumerdes City (Menerville 1895 Number 22).

**Figure 4.3.** A 15-m Digital Elevation Model (DEM) of the study site “Boumerdes City” generated from ASTER satellite image.
Due to the major earthquake on May 21, 2003, 1382 people killed and 3442 injured in the city. As mentioned earlier in the chapter 2, at Boumerdes city the mainshock has been missed to be recorded due to the technical problem. According to the attenuation low of strong motion that has been created in this study, as shown by Figure 2.7, the mainshock in this city is estimated to be with a value of PGA and PGV around 740cm/s² and 45cm/s respectively. The largest event that has been recorded in Boumerdes was the aftershock of May 27, 2003 at 17:11:40 GTM (M = 5.8 at 36.78° N, 3.60° E) with PGA = 441.5 cm/s² and PGV = 23.59 cm/s (see Figure 3.4).

4.3 Classification of buildings

4.3.1 Urban evolution and structural types

In Algeria, masonry construction was used during the first half of the 20th century. After the 1960s, construction with a reinforced-concrete (RC) frame and un-reinforced hollow brick infill-walls became more typical (Benouar and Meslem 2007). According to the database created from the data collected for this study, in Boumerdes the total number of existing buildings before the earthquake is estimated to be 2,794 (Figure 4.3). Ninety-two percent (92%) of this total were RC structures built between 1969 and 2003, consisting of columns and beams, with un-reinforced hollow bricks used as external and internal walls and with RC shear walls. The existing masonry buildings were built before 1962, and comprised but a small fraction (4%) of the total. There were very few buildings of steel or wood (2%
and 1%, respectively), most of which were for industrial use. Figure 4.4 shows the distribution by material type of the 2,794 buildings in Boumerdes before the earthquake, by GIS. In this study, only RC structures will be considered, since the number of buildings constructed of other materials is almost negligible.

### 4.3.2 RC buildings and RC houses

Before the May 21, 2003 Boumerdes earthquake, the existing seismic design codes were required to be applied only to public buildings, and not to private houses. In fact, most private houses were built without following the seismic code or quality control measures during construction, and are generally evaluated as non-engineered constructions. The presence of soft stories, undersized sections, insufficient longitudinal reinforcement, and weak concrete strength, have always been considered responsible for the damage to the majority of private houses during the earthquake. In response to this, beginning in September
2004, all private houses were for the first time required to incorporate seismic design in order to obtain building insurance.

In Boumerdes, 43% (1,097) of the RC structures were RC buildings owned by the public for residential use, industrial or commercial activities, offices, education, etc. The number of
stories for this type of RC construction ranged from 1 to 10. In this study, RC buildings are divided into three classes of height: low-rise (buildings with 1 to 3 stories) which comprised 30% of the total (332 buildings), mid-rise (buildings with 4 to 6 stories) which comprised 61% (663 buildings), and high-rise (buildings with 7+ stories), which comprised the remaining 9%.

The remaining 57% (1,476) of the RC structures in Boumerdes were privately owned RC houses for residential use, some of which housed commercial activity (shops) on the first floor (ground floor). The number of stories for existing houses ranged from 1 to 3 stories. Figure 4.5 shows an example of an existing RC building and an RC house in Boumerdes.

4.3.3 Seismic Design Codes

During the French colonial period in Algeria, there was no official seismic design code for the construction of buildings. Serving as guidelines and recommendations for the design of buildings, AS55 was introduced in 1955, and PS62 to PS69 were introduced from 1962 to 1969. After the independence of Algeria in 1962, the government established an organization for Construction Technology Control (CTC) for the inspection of public construction in 1971. Soon after the disastrous earthquake of El Asnam on October 10, 1980, the National Research Center for Earthquake Engineering (CGS) was established, and the first official Algerian seismic design code appeared as RPA81 in 1981. This was revised in 1983 as RPA83, and underwent a second revision in 1988 in the form of RPA88. In 1999 the Algerian seismic code was revised yet again as RPA99, which was the latest version before the 2003 Boumerdes earthquake (CGS 1983, 1988, 1999).

Table 3 presents a summary of applied seismic design loads for existing buildings in Boumerdes for seismic design codes RPA81 (revised in 1983), RPA88, and RPA99. In all three versions there were three seismic zones: Zone I (low seismicity), Zone II (moderate seismicity), and Zone III (high seismicity), as well as Zone 0 (no seismicity) in the desert. Boumerdes was classified as a zone of moderate seismicity (II), with 0.15g as the peak ground acceleration (PGA) for design. In terms of the requirements for reinforced concrete structures in Zone II, a specified minimum column size of 25 cm was the same in all versions of RPA prior to the earthquake. RPA83 specified that the main reinforcing bars must constitute a minimum of 1% of the total cross sectional area of columns. This was changed to
0.8% in RPA88 and RPA99. In all RPA versions before the earthquake, 15 cm was specified as the minimum interval of hoop reinforcing at the top and bottom of columns for Zone II.

After the 2003 earthquake, RPA99 was revised to become the new seismic design version RPA99’03 (CGS 2003), in which Boumerdes was reclassified as a zone of high seismicity (III) with higher design accelerations.

Table 3. Summary of design loads for RC buildings as recommended by Algerian seismic codes for different time periods, according to the seismic zoning of Boumerdes.

<table>
<thead>
<tr>
<th>Years</th>
<th>Code</th>
<th>Static Seismic Load: V</th>
<th>Zone</th>
<th>Acceleration Coefficient: A</th>
<th>Dynamic Amplification Factor: D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983 - 1988</td>
<td>RPA83</td>
<td>V = ADBQW</td>
<td>II</td>
<td>Group1: 0.25</td>
<td>2 in case: 0&lt;T&lt;0.3 (Firm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group2: 0.15</td>
<td>0&lt;T&lt;0.5 (Soft)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group3: 0.10</td>
<td></td>
</tr>
<tr>
<td>1988 - 1999</td>
<td>RPA88</td>
<td>V = ADBQW</td>
<td>II</td>
<td>Group1: 0.25</td>
<td>2 in case: 0&lt;T&lt;0.3 (Firm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group2: 0.15</td>
<td>0&lt;T&lt;0.5 (Soft)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group3: 0.10</td>
<td>Formula is revised</td>
</tr>
<tr>
<td>1999 - 2003</td>
<td>RPA99</td>
<td>V = (ADQ/R)xW</td>
<td>II</td>
<td>Group1A: 0.25</td>
<td>2.5 in case: 0&lt;T&lt;0.3 (S1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group1B: 0.20</td>
<td>0&lt;T&lt;0.4 (S2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group2: 0.15</td>
<td>0&lt;T&lt;0.5 (S3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group3: 0.1</td>
<td>0&lt;T&lt;0.7 (S4)</td>
</tr>
<tr>
<td>2003 - up to date</td>
<td>RPA99’03</td>
<td>V = (ADQ/R)xW</td>
<td>III</td>
<td>Group1A: 0.40</td>
<td>2.5 in case: 0&lt;T&lt;0.3 (S1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group1B: 0.30</td>
<td>0&lt;T&lt;0.4 (S2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group2: 0.25</td>
<td>0&lt;T&lt;0.5 (S3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group3: 0.18</td>
<td>0&lt;T&lt;0.7 (S4)</td>
</tr>
</tbody>
</table>

where
- V: Total Static Seismic Load
- A: Zone Acceleration Coefficient
- D: Mean Dynamic Amplification Factor
- Q: Quality Factor
- R: Behavior Factor
- B: Structural Component Factor
- T: Natural Period in sec.

Classification of Construction:
- Group 1A: Vital Importance
- Group 1B: High Importance
- Group 2: Moderate Importance
- Group 3: Low Importance

Classification of Soil:
- S1: Rocky
- S2: Firm
- S3: Soft
- S4: Very Soft
Table 4. Damage grading for reinforced concrete and masonry buildings according to the European Macroseismic Scale (Grünthal 2001). This damage grading corresponds exactly to that adopted by CGS during field of survey following the 2003 earthquake correspond

<table>
<thead>
<tr>
<th>Damage Pattern</th>
<th>Description of damage level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforce Concrete</td>
<td>Masonry</td>
</tr>
<tr>
<td>Grade 1</td>
<td>None or negligible-to-slight damage to non-structural elements, and no damage to structural elements</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Moderate to slight damage to non-structural elements, and slight damage to structural elements</td>
</tr>
<tr>
<td>Grade 3</td>
<td>Heavy to slight damage to non-structural elements, and moderate damage to structural elements</td>
</tr>
<tr>
<td>Grade 4</td>
<td>Very heavy to slight damage to non-structural elements, and heavy damage to structural elements</td>
</tr>
<tr>
<td>Grade 5</td>
<td>Very heavy structural damage, with part of building collapsed, or total collapse</td>
</tr>
</tbody>
</table>

Table 3 also shows a comparison between earlier versions of the seismic codes and the more recent seismic code RPA99’03. Peak ground acceleration for the design of apartment buildings (Group 2) was increased from 0.15g to 0.25g in RPA99’03. In addition, in this new version, application of the seismic design code became obligatory for private house owners.

4.4 Performance of buildings in an earthquake

Basically, the comparisons among the previous seismic codes do not show the important difference regarding the seismic capacity for RC structures located in Zone II. Accordingly, we assume that the parameter regarding which version of the RPA (seismic code) is used, does not have much of an effect upon the distribution of damage observed in existing RC buildings in Boumerdes after the earthquake. Based on this, along with the background provided in the previous chapter regarding Algerian building characteristics, our examination of the distribution of observed damage will take into account the following points: (a) For the RC structures, the categories of both buildings and houses will be considered as a parameter that can influence damage distribution, since houses are presumed to have less seismic capacity than buildings; and (b) The height classes for RC buildings will be also considered in the examination of damage distribution. As mentioned before, all the existing RC houses
Figure 4.7. Ratio of damage grade for different types of RC structures that existed in Boumerdes during the 2003 Algeria earthquake.

Figure 4.8. Ratio of damage grade in relation to year of construction for different types of RC structures at the time of the earthquake.

were low-rise structures. Figure 4.6 shows the final classification of RC structures according to their categories and height classes.
In the week after the 2003 Boumerdes earthquake, a damage assessment mission was conducted by the Ministry of Housing, covering all affected areas in the provinces of Boumerdes and Algiers (Belazougui 2008). This mission, which lasted until June 30, 2003, employed five Grades of damage classification, ranging from none/slight damage (Grade 1) to very-heavy/collapsed (Grade 5), each of them corresponds almost exactly to that of European Macroseismic Scale EMS-98 (Grünthal 2001) as shown by Table 4. Figure 4.7 shows the ratio of damage for different types of RC structures. The damage in Grades 4 and 5 (collapsed, very heavily damaged, or building rendered unusable), represents 10.21% (112 units) of the total number of existing RC buildings, most of which are buildings of mid-story height (4 to 5 stories) (107 units). Only a few (5 units) RC buildings of low story height (1–3 stories) suffered damage at the level of Grade 4, while no heavy damage was observed for RC buildings of high story height. For RC houses, the damage in Grades 4 and 5 represents 10.23% (151 units) of the total number of this type.

Furthermore, the relationship between the ratio of damage and the year of construction, which is related to the version of the seismic code that was applicable at that time, reveals important variations. This can be seen in Figure 4.8, which shows the extent of damage in terms of both year of construction and type of structure. For the type of structure which suffered the most extensive damage, RC buildings of mid-story height, there is almost no correlation between the damage ratio and the year of construction. This observation is similar to that for RC houses, which are generally evaluated as being non-engineered, and whose construction did not conform to a seismic design code.

Figure 4.9 represents a GIS map of damage distribution for RC constructions in Boumerdes following the earthquake. From the observation of damage distribution, it can be seen that in the south-western part of the city the damage was extensive, affecting the entire zone, in which most buildings were RC construction of mid-story height, as seen in Figure 4.6. Figure 4.10(a) shows an example of damaged buildings from this location. Several buildings which were built in two periods before 1983, and in 1996, and which were mostly for residential use, collapsed or suffered severe damage. The fact that in this zone there were very few low-rise type buildings, and almost no high-rise types, explains why the damage ratio is more important in the case of mid-rise buildings, as can be seen in Figures 4.7 and 4.8.

On the other hand, in the south-eastern part of the urbanized area, where almost all the existing constructions were single, non-engineered, 1-3 story private houses (Figure 4.6),
damage was incurred by only some houses, and not in the entire zone. Analysis of the houses in this zone that were damaged showed that poor design in terms of seismic resistance, and poor quality of construction and structural material were mainly responsible for the damage.
incurred. These poor characteristics are explained by the very low strength concrete that was used (an average of 14-17 MPA, as opposed to the 25 MPA required by current standards), and the inadequate restart of concrete pouring in columns. Figure 4.9(b) shows an example of a RC house from this part of the city, which was in a poor condition but sustained no severe damage due to the earthquake.

Apart from these zones, in the northern part of the city, damage to the same type of construction either did not occur, or a small number of buildings and houses suffered slight damage.

For RC structures with unreinforced infill masonry or with RC shear walls, the Algerian seismic code RPA gives two empirical relations for determining the building period $T$. The two methods are an approximation that implies that the natural period increase as the height of the structure increase.

\[ T = C_T \cdot \frac{h_n^{3/4}}{D} \]

with:

- $h_n$ is the actual height (in meters) of the building above the base to the nth height in meters;
- $D$ is the horizontal dimension (in meters) of building for the considered direction;
- $C_T = 0.05$ for RC structures with unreinforced masonry infill or RC shear walls;

The final estimation of fundamental period for this type of buildings is defined as the smallest value computed from the two empirical relations. Table 5 shows the comparison of fundamental period between the results of computation from the above empirical relations and results from ambient vibration conducted for several buildings in the city.

Figure 4.11 presents the fundamental period of shaken RC structures in the city of Boumerdes computed from empirical method presented by RPA. The damage was concentrated in the area where almost all the existed buildings have period ranging from 0.25 to 0.40 sec. Figure 4.12 shows the details for the estimated range of fundamental period for building suffered from damage Grade 4 and Grade 5.
**Table 5.** Comparison of fundamental period between the results from empirical relations proposed by RPA and results from ambient vibration conducted for several building.

<table>
<thead>
<tr>
<th>Number of storeys</th>
<th>Area of building (m²)</th>
<th>Measured Period (sec)</th>
<th>Estimated Period from RPA (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NS</td>
<td>EW</td>
</tr>
<tr>
<td>4</td>
<td>970</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>5</td>
<td>242</td>
<td>0.37 (*)</td>
<td>0.30 (*)</td>
</tr>
<tr>
<td>5</td>
<td>194</td>
<td>0.25 (*)</td>
<td>0.25 (*)</td>
</tr>
<tr>
<td>10</td>
<td>324</td>
<td>0.48 (*)</td>
<td>0.53 (*)</td>
</tr>
</tbody>
</table>

(*): Measurements conducted by Dunand et al (2004).

**Figure 4.11.** Distribution of fundamental period for RC structures computed using empirical relations proposed by Algerian Seismic Code (RPA).
Figure 4.12. Estimated range of fundamental period for building suffered from damage Grade 4 and Grade 5.

Figure 4.13. Damage ratios of very heavily damaged and collapsed (Grades 4 and 5) for RC constructions. (a) RC Houses, (b) Low-rise RC Buildings, (c) Mid-rise RC Buildings, (d) High-rise RC Buildings.
4.5 Damage ratio distribution

In order to better ascertain the discrepancies in damage distribution for the same type of construction in the entire city, the damage ratio was calculated on the level of district blocks. For each structure type, the computation of damage ratio was carried out by taking the total number of buildings surveyed as the denominator, and the sum of the damage at Grades 4 and 5 as the numerator. Figure 4.13 shows the density function of building type per block and the damage ratio distribution for various types of structures. This result clearly shows where the damage was most extensive for the same type of structure. These discrepancies in the grade of damage incurred lead to the hypothesis that the seismic intensity was not uniformly distributed throughout the city, since it is well known from past earthquakes that local site conditions can play a dominant role in determining the distribution of damage, as well as the distribution of strong motion.

A comparison was carried out among various building classifications in order to evaluate their relative seismic capacity. Figure 4.14 presents a comparison of damage ratios among different classes of structures. Unfortunately, due to the small number of damaged buildings (Grades 4 and 5) in each block, we are unable to express this comparison as a compatible
relationship. In the figure it can still be seen, however, that mid-rise RC buildings and RC houses demonstrated a low seismic capacity during this event.

4.6 Local site conditions on damage distribution

4.6.1 Free field measurements of Microtremor

To correlate the distribution of observed damage with the performance of buildings in the actual soil conditions, 16 free-field microtremor measurements at several locations in Boumerdes have been conducted, as shown in Figures 4.9 and 4.15. We calculated the H/V Fourier spectral ratio from microtremor records as the spectral ratio between the two horizontal components (EW and NS), and the vertical (UD) component as defined by Equation 3.1 in the earlier chapter. The Fourier spectra of recorded measurements were smoothed by a Parzen window of 0.4 Hz bandwidth. The duration of a single microtremor observation was set at 5 min, and the record was divided into six segments lasting 50 s each, to calculate an average H/V spectral ratio.

Figure 4.16 shows the averaged H/V Fourier spectrum ratio of the microtremors at each location. In general, the measured H/V from several locations exhibit certain differences which could reflect variations in local site conditions. The shape of the H/V ratio is almost flat at most sites, with the appearance of medium to small peaks in some of them, which correspond to the high period which occurred around 0.9 s (M02) and 0.4 s (M11). Following the criteria defined by the SESAME project for reliable measurements (SESAME 2004), these peaks are considered unclear, since none of them fulfill the criterion for a clear peak, which is based on the relation of peak amplitude to the level of the H/V curve (the Amplitude of peak period $A$: $A > 2$, and the reliability of its period value increases with the sharpness of the H/V peak).

As shown in Figure 4.16(a), all the H/V ratios measured for the sites that sustained heavy damage were characterized by unclear peaks in a flat shape. In this area, which is the southwestern part of city, the existing soil condition report, dated 1970 (Scandinavian Engineering Corporation 1970), states that the geological layers are composed of granulitic micaschist formations (hard soil) as the basis, which in some locations can be seen on the surface. These formations are overlain by pre-consolidated marl from the lower Pliocene (hard to stiff soil). It is known that for hard soil, the observation of microtremors may not be sufficient to
estimate soil response characteristics. On the other hand, there has been some discussion of the fact that the H/V peak amplitude underestimates the actual site amplification (Bard 1999, SESAME 2004).

At the sites that sustained no damage or slight damage, which correspond to the northern and south-eastern parts of the city, the measured H/V ratios show more variations in shape, as can be seen in Figure 4.16(b). In the northern part of the city, the pre-consolidated marl of the lower Pliocene is expected to be overlain by red sands, recent clays, beach sands, and dune Quaternary (soft deposits), which might explain the unclear peak observed at location M02 (period = 0.9 s). In this location, only a few 10-story RC buildings suffered damage at the level of Grades 2 and 3. The natural period measured for 6 buildings in this category showed values ranging between 0.4 s and 0.5 s (Dunand 2004). For the observed unclear peak at location M11 (period = 0.4 s) in the south-eastern part of the city, only a few RC houses that were in very poor condition suffered damage.

Figure 4.15. Microtremor measurement at site of heavily damaged building in the city of Boumerdes.
(a) H/V spectrum characteristics at several sites of heavily damaged in Boumerdes city

(b) H/V spectrum characteristics at several sites of none or slightly damaged in Boumerdes city

(c) H/V spectrum characteristics along the Tatareg river valley in the city

**Figure 4.16.** Averaged H/V Fourier spectrum ratio of microtremors computed from 6 segments of 50 s recorded at each location.
4.6.2 Measurements in buildings

We selected the case of two 3-story RC buildings, B1 and B2, that have same structural configuration but are located on two different campuses of the University of Boumerdes, within around 1 km of each other (Figures 4.9 and 4.17). B1, located on the south campus, was designed in 1970, and completely collapsed during the earthquake. B2, located on the north campus, was designed in 1998, and did not suffer any damage during the earthquake. As mentioned in the earlier section, before the earthquake of 2003, the seismic capacity mandated by different versions of the seismic code in different time periods did not differ significantly.

![Figure 4.17](image)

**Figure 4.17.** Example of two 3-story RC buildings with the same structural configuration located in two different zones in Boumerdes, within aprox. 1 km of each other (see Figure 8). B1 is located on the south campus of Boumerdes University, while B2 is located on the north campus.

![Figure 4.18](image)

**Figure 4.18.** Analysis of possible amplification effect for 3-story RC buildings. (a) Measured H/V on ground surface where B1 collapsed. (b) Measured H/V on ground surface close to B2. (c) H/H Fourier spectral ratio between building B2 and ground surface M14.
Accordingly, microtremor testing was conducted for two points simultaneously: one on the roof-top of building B2, and the second point on the ground surface M14, close to the location of B2. In addition, at the location where building B1 collapsed, microtremor testing was conducted for ground surface M10, as shown in Figure 4.17. A comparison of the H/V microtremor measured at the damaged site, M10 (Figure 4.18(a)), with that measured at the non-damaged site, M14 (Figure 4.18(b)), shows no clear difference regarding the effect of amplification. As shown in Figure 4.18(c), the computed H/H Fourier spectral ratio between building B2 and ground surface M14 shows a clear predominant period around 0.2 s, which is the fundamental period of a building.

At this stage, it seems difficult to interpret the observed microtremor in order to estimate the soil conditions in the city. Hence, more detailed investigation should be conducted regarding soil profiles, including PS logging, to better explain the relationship between the seismic capacity of buildings and the actual damage distribution with regard to building performance.

Figure 4.19. Ground elevation and building damage distribution in Boumerdes City.
On the other hand, the influence of topography on the seismic motion is well known. Surface topography can considerably affects the amplitude and frequency contents of ground vibrations. Figure 4.19 shows the ground elevation from DEM, extracted using ASTER satellite image, and building damage distribution in the city.

The zones with high damage were located along the Tatareg river valley. This damage concentration may be explained by the topographical feature in this location.

At many destructive earthquakes it has been often reported that buildings located on hill tops or close to steep slopes suffer more intensive damage than those located at the base. Topography of the basin may significantly affect the amplitudes of the motion at the hill-site relative to the centre of the basin (Oliveira et al. 2006).

The above description maybe explains the observed concentration of damage along Tatareg river valley (see Figure 4.19 and 4.2) where the measured microtremors as shown by Figure 4.16(c) for locations M01 and M05 they present high site amplification.

4.7 Conclusions

To assess the distribution of damage observed in Boumerdes following the 2003 Algeria earthquake, a detailed analysis of building characteristics was conducted, and the buildings existing at the time were classified in order to evaluate their performance. An examination of the relationship between the buildings’ seismic capacity and the actual damage distribution, showed some variation among same types of buildings at different locations, which might have been the result of a non-uniform distribution of seismic intensity. Using damage ratios that were calculated for the city on a district block level, a comparison was carried out among various building classifications to evaluate their seismic capacity. It was observed that the mid-rise RC buildings were more vulnerable during the earthquake, as well as RC houses which were generally evaluated as non-engineered structures.

To correlate the observed damage distribution with the actual local site conditions, free-field microtremor observation was conducted at several locations in the city. From the measured H/V of microtremors, no clear difference in amplitude between the damaged and non-damaged locations could be observed. Most of the measured H/V ratios at different locations exhibited a flat shape, with the presence of unclear peaks in some cases of non-damaged areas.
According to the geology of the area investigated, hard soil is expected in the shallow layer beneath the surface. In addition to that, hard soil appears at the ground surface in some areas. It is known that for hard soil, the observation of microtremors might not be sufficient to estimate soil response characteristics.

On the other hand, by using Digital Elevation Model DEM it has been found that in the area where damage was most concentrated and which is along river valley the topographical feature may have very important effects upon the variation of the earthquake ground motion. In addition, the measured microtremor along this river shows a high amplification effects.

Detailed geotechnical information is needed in order to better analyze the soil response characteristics. And more details about topographical features is also quite important to be considered in further studies that aim to better explain the observed distribution of damage.
CHAPTER 5

The 2003 Boumerdes Earthquake and High-Resolution Satellite Imagery for Building Damage Detection

5.1 Introduction

Recent advancements in remote sensing and its application technologies made it possible to use remotely sensed imagery for capturing damage distribution of urban areas due to natural disasters (Yamazaki 2001). Especially it is important for emergency management and recovery works to capture damage distribution immediately after an earthquake or other disasters. The information about damages should be obtained at an early stage.

Following natural disaster events, damage sustained in urban environments has been identified through visual inspection of optical images by several researchers (Chiroiu et al. 2002, Huyck et al. 2002, Mitomi et al. 2002, Yusuf et al. 2002, Saito and Spence 2004). The QuickBird imagery was used for detecting damaged areas following the Bam (Iran) earthquakes in 2003, and Java (Indonesia) earthquake 2006. However, due to the lack of detailed GIS ground truth data the accuracy of damage detection for this category of image was not analyzed deeply. Besides of truth damage grades data from field survey, the examination of accuracy of identified or judged damage Grade might also depends on the nature of existing buildings and also the urban planning and environment of the zone.

In the present chapter, we introduce the results of visual damage Grades interpretation from high resolution satellite images for the 2003 Boumerdes, Algeria earthquake. The visual damage interpretation based on the European Macroseismic Scale EMS-98 was carried out building by building, comparing the pre-event and post-event images. The extraction of damage Grades is mainly based on geometry changes and debris. The result of the damage inspection was compared with field survey data, and the accuracy and usefulness of the high-resolution satellite images in damage detection was demonstrated by considering typology of buildings and urban environment.
5.2 Remote sensing imagery for assessing damage distribution of urban area

Since remote sensing data observed by various platforms have both advantage and disadvantage in immediacy and resolution, it is necessary to consider the characteristics of each platform and sensor and the quality of data when they are used. In order to examine the applicability of remote sensing technologies to emergency management after earthquakes,
Hasegawa et al. (2000) performed visual damage detection using aerial images from high-definition television cameras, and Ogawa and Yamazaki (2000) performed visual detection using aerial photographs. These kinds of images can identify individual buildings but they cannot cover a large area with one acquisition time. On the other hand, satellite images have an advantage to observe a large area at one time. Capability of optical satellite imagery has been examined for damage detection in large-scale natural disasters (Matsuoka and Yamazaki 2000, Matsuoka et al. 2001, Mitomi et al. 2002).

QuickBird, a high-resolution commercial satellite with the maximum spatial resolution of 0.6 m, has been launched successfully on October 18, 2001 and it acquires optical images of urban areas, in which individual buildings can be identified. Yamazaki et al. (2005) performed damage assessment using pre- and post-earthquake QuickBird images for Bam, Iran. It has been found that more detailed ground truth data is needed to better evaluate the difference of damage ratios and examine the accuracy.

5.3 QuickBird imagery in response to 2003 Algeria earthquake

5.3.1 QuickBird imagery for Boumerdes city: pre- and post-earthquake

QuickBird satellite observed the area of Boumerdes City in the province of Boumerdes as shown by Figure 5.1. These pan-sharpened images were produced by combining panchromatic images of 0.6 m resolution and multi-spectral images of 2.4 m resolution as shown by Figure 5.2. The images were taken about one year before (April 22, 2002) and two days after (May 23, 2003) the event, with different off nadir view angles: 11.2 and 24.3 degrees respectively. These images are considered to be the first sets of clear images acquired by civilian high resolution satellite. From such image, buildings, cars and debris can clearly be seen. Figure 4.16 from previous chapter shows a typical area in Boumerdes city where collapsed buildings are clearly observed in the image of two days after the event. Debris of collapsed buildings can be seen.

5.3.2 Visual building damage grades detection

Using both pre- and post-earthquake satellite images, a visual detection of building damage grades was conducted based on the classification in the European Macroseismic
Scale (Grünthal 2001), as shown in Table 4, in order to compare with real damage data from field survey as mentioned in the earlier section.

In this general, for visual detection from vertical image the damage can be detected by observing the absence of the decrease of shadows, geometric irregularities of contours, the heterogeneity of the roofs. Accordingly, totally collapsed buildings (Grade 5), partially collapsed buildings (Grade 4), and buildings surrounded by debris (Grade 3) could be identified using only post-event image. In addition, it is clearly understandable that Grade1, Grade 2, and a slighter part of Grade 3 can not be detected from QuickBird images. This is because non-structural damage (see Table 4) can not be identified from vertical images. However, severer damage than a slighter part of Grade 3 can be detected, and it is easier for

![Figure 5.3](image1.png)

**Figure 5.3.** Comparison of GIS damage distribution map of existing buildings in Boumerdes during the 2003 Algeria earthquake. (a) Map made from mission of field survey. (b) Map made from visual detection using QuickBird images of pre- and post-event.

![Figure 5.4](image2.png)

**Figure 5.4.** Building damage ratios of very heavily damaged and collapsed (Grades 4 and 5). (a) Result by field survey. (b) Result by visual detection from QuickBird images.
Grade 4 and Grade 5. Accordingly, the judgment damage Grades of buildings were classified into four parts that is Grade 1-2, Grade3, Grade4, and Grade5.

By this visual interpretation through QuickBird images, a total 2,794 buildings (existed RC buildings, masonry buildings... etc, including houses) were classified based on their damage grades. The numbers of different identified damage grades were 2526, 169, 35, and 64 for Grade 1-2, Grade 3, Grade 4, and Grade 5, respectively. This result from satellite images was compared with ground truth data from which a field survey classified 2258 buildings between Grade 1 and 2, 230 buildings as Grade 3, 243 buildings as Grade 4, and 63 buildings as Grade 5.
In this study, we have created two maps of GIS damage Grades distribution of buildings in Boumerdes city from the two types of data: (a) data from the result of field survey (see previous chapter), (b) data from the result of visual detection using QuickBird images. Figure 5.3 shows comparison of the two GIS damage mappings.

Basically, it is clearly seen that in zones level mapping the result of visual detection from QuickBird images is very close to that from ground truth data from field survey. In buildings level mapping, the very heavy damages seem to be well localized from satellites images through visual detection. Figures 5.4 and 5.5 show comparison of damaged building ratios of very heavily damaged and collapsed (Grades 4 and 5) between the field survey and the visual detection from the satellite images. The damage ratios based on the visual damage detection

**Figure 5.7.** Accuracy of distinguished building damage Grades, from high resolution imagery, in relation to building height classes.

In this study, we have created two maps of GIS damage Grades distribution of buildings in Boumerdes city from the two types of data: (a) data from the result of field survey (see previous chapter), (b) data from the result of visual detection using QuickBird images. Figure 5.3 shows comparison of the two GIS damage mappings.

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would be underestimated compared with those based on the field survey. According to Figure 5.6 the buildings suffering from damage Grade 3 and also some buildings with damage Grade 4 were incorrectly judged from visual detection.

5.4 Examination of Accuracy by considering urban environment and typology of buildings

We have examined the accuracy of using QuickBird images, for detecting damage Grades considering the nature of urban environment and building height classes. Figure 5.7 shows the comparison of damage Grades detection in relation to building height classes between low-rise buildings with mid- and high-rise buildings.

In general, in case of total collapse, the damage is easily detectable. However, for low-rise construction located in densely urban environment, sometimes there are difficulties for detecting damage even by using pre- and post-event images. Figure 5.8(a) shows an example of view, from post-earthquake, of densely built-up area. This image corresponds to the southeastern part of the city, where almost all the existing constructions were single, non-engineered, 1-3 story private houses, and damage was incurred by only some houses as mentioned in the previous chapter and also shown by Figure 4.9.

Figure 5.8(b) shows an example of view, from post-earthquake, corresponding southwestern part of the city where there are many modern mid-rise buildings. In this zone the
damage was extensively concentrated which explains why the damage ratio is more important in the case of mid-rise buildings.

In addition, Figure 5.9 shows clearly that some of mid-rise buildings suffering from damage Grades 3 and 4 were incorrectly judged from visual detection through QuickBird images. This can be understood if we take a look to the Figure 5.10 showing 4-storied buildings suffering from soft storey damage (Grade 4) and incorrectly judged as Grade 1-2 in visual detection. This type of damage is difficult to be detected from vertical image, including the case of buildings suffering sever damage from inside. This observation explains why the percentage of incorrectly judged damage for buildings with Grades 3 and 4 is remarkable.

**Figure 5.9.** Example of damage detection accuracy to different damage Grades. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Damage Grades distribution from field survey, (d) Damage Grades distribution from QuickBird images.

**Figure 5.10.** Example of 4-story building (shown by red circle in Figures 5.8-a and -b) suffered from soft story damage corresponding to Grade 4, was incorrectly judged as Grade 1-2 through visual detection from QuickBird images.
Table 6. Classification of observed damage patterns from field survey Grades 3, 4 and 5 and relationship to the visual detection accuracy.

<table>
<thead>
<tr>
<th>Damage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 3-1</td>
<td>Slight damage in column/beam and walls, building surrounded by few debris.</td>
</tr>
<tr>
<td>Grade 3-1(bis)</td>
<td>Slight damage in column/beam and walls, debris hidden by shadow through image.</td>
</tr>
<tr>
<td>Grade 3-2</td>
<td>Slight damage in column/beam and walls, building is not surrounded by debris.</td>
</tr>
<tr>
<td>Grade 4-3</td>
<td>Heavy damage in column/beam and walls, building surrounded by debris.</td>
</tr>
<tr>
<td>Grade 4-3(bis)</td>
<td>Heavy damage in column/beam and walls, debris hidden by shadow through image.</td>
</tr>
<tr>
<td>Grade 4-4</td>
<td>Heavy damage in column/beam and walls, building is not surrounded by debris; Presence of soft story and slight displacement; building slightly tilted; collapse of short column.</td>
</tr>
<tr>
<td>Grade 5-5</td>
<td>Totally collapsed building, massive debris surrounded.</td>
</tr>
<tr>
<td>Grade 5-6</td>
<td>Section of the building collapsed; building heavily tilted.</td>
</tr>
<tr>
<td>Grade 5-7</td>
<td>First storey collapse.</td>
</tr>
</tbody>
</table>

Figure 5.11. Damage detection accuracy for collapsed buildings with small rotation, debris surrounded the buildings is hidden by shadow. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Photograph of damaged building.
Figure 5.12. Damage detection accuracy for building slightly tilted, with no debris surrounded. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Photograph of damaged building.

Figure 5.13. Damage detection accuracy for building heavily tilted. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Photograph of damaged building.
Figures 5.11, 5.12, 5.13, and 5.14 show some examples of comparison for several cases of damage patterns using pre- and post-event. Table 6 shows a summary of results regarding the relationship between the observed buildings damage patterns from field survey to the visual detection accuracy for Grades 3, 4, and 5. Figure 5.15 shows the classification of damage patterns and comparison with results from visual detection for Grades 3, 4, and 5. Figures 5.12, 5.13, 5.14It is well seen that for low-rise buildings as well as for mid- and high-rise ones the debris plays a predominant role in the accuracy of visual detection and also the nature of observed damage patterns.

5.5 Conclusions

Using the satellite images acquired by QuickBird for Boumerdes city following the 21 May, 2003 Algeria earthquake, we have examined the capability of such high-resolution optical imagery in visual detection of building damage grades, based on ground truth regarding the urban nature, typology of a total 2,794 buildings and the real damage they incurred. The results were presented as GIS damage mappings in buildings level created from field survey and from QuickBird images.
In general, the comparison showed that totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris can be identified using only post-event pan-sharpened image. However, due to the nature of damage incurred, some heavily damaged buildings were judged incorrectly even with employing the pre-event image as a reference to judge the damage status.

The accuracy of identified or judged damage Grade might also depend on the building typologies and also the urban planning and environment of the zone. It is has also found that

**Figure 5.15.** Accuracy of distinguished building damage Grades, from high resolution imagery, in relation to nature of damage patterns from field survey.

In general, the comparison showed that totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris can be identified using only post-event pan-sharpened image. However, due to the nature of damage incurred, some heavily damaged buildings were judged incorrectly even with employing the pre-event image as a reference to judge the damage status.

The accuracy of identified or judged damage Grade might also depend on the building typologies and also the urban planning and environment of the zone. It is has also found that
there are difficulties for detecting damage for low-rise construction specially those located in dense urban environment.
CHAPTER 6

General Conclusions

On May 21, 2003, 18:44:31 (GMT), a destructive earthquake (Mw = 6.8) hit the northern part of Algeria, causing extensive damage and human casualties. The mainshock was felt inside a 250 km radius from the epicenter. Observation of recorded accelerations shows a remarkable difference in maximum values among neighbouring stations. However, for some stations, no such difference was observed in velocity or acceleration from the mainshock and aftershocks. In addition, the distribution of damage observed from the survey mission in the city most strongly affected, namely Boumerdes, showed that in some zones the constructions were completely destroyed, while others zones suffered no damage, or suffered just slightly. As well known from the experienced past earthquakes in different parts of the world local site conditions could generate significant amplifications and spatial variations of earthquake ground motion, therefore have great influence on the damage distribution. Through this dissertation we have examined the implication of these challenges using seismic-motion dataset of the earthquake 2003, microtremor data, and GIS database of building characteristics and damage distribution created during this study.

As first part of this work (Chapter 2), we have done much effort to create and organize database from numerous earthquake records, from the National Accelerometer Network operated by CGS, following the earthquake of 2003. Several technical problems, which occurred during the recording, were discussed and addressed. Indeed, we have registered some technical problems that have occurred at several stations while recording the earthquake motions. We have also pointed out the problem of orientation errors for used seismographs. Hence, it is quite important to consider this observation for future investigation, since might causes the miss precisely for different studies based on use of recorded ground motions.

The established database constitutes an important addition to the literature for Algeria as case of study. GIS database of building characteristics and damage distribution was also created and discussed in the second third of this study.
As second part of this work (Chapters 3), site response characteristics at seismic stations were investigated based on the horizontal-to-vertical (H/V) spectral ratios calculated from a seismic-motion dataset of the 2003 Boumerdes earthquake, data from microtremor conducted at selected seismic stations and the transfer functions evaluated from soil profile data. Although high peak ground acceleration (PGA) values were recorded at some sites, nonlinear effect was not so clear at these stations. The H/V spectral ratios calculated from weak and strong motion events do not show a clear difference in the predominant period and amplitudes, and the shapes of the H/V ratios are flat for some stations. This observation characterizes the presence of firm to hard layers under the stations, except for one station with Quaternary deposits causing remarkable amplification at the predominant period and a high PGA value recorded.

In the third part of this work (Chapter 4) and in aim to examine the local site conditions on damage distribution, we investigated the performance of buildings to be compared with damage distribution in the city of Boumerdes. The buildings were classified according to the regional culture and the forms of construction that are typical in Algeria. After considering the distribution of observed damage, the results showed that the damage was extensive in the south-western part of the city, but that there was either no damage, or slight damage, to equivalent types of construction in the rest of the city. A comparison of seismic capacity was carried out using damage ratios for various classifications of buildings. An evaluation based on a district block level for the city showed that mid-rise RC buildings, including RC houses, were more vulnerable during the event. Additionally, free-field microtremor observation conducted during this study to determine local soil effects, showed almost a flat shape, with no clearly predominant period of measured H/V ratios for damaged locations. However by using Digital Elevation Model DEM it has been found that in the area where damage was most concentrated along river valley the topographical feature may have very important effects on the variation of the earthquake ground motion. In addition, the measured microtremor along this river shows the possibility of high amplification effects.

It has been found from this third part, including the second part, of this work that detailed geotechnical and geophysical information is needed in order to better analyze the soil response characteristics and damage distribution. More detailed topographical features are also needed be considered in further studies.
For the final part of this work (Chapter 5), we examined the accuracy of usefulness of the high-resolution satellite imagery namely QuickBird in damage Grades detection urban environments. Using the event of the 2003 Algeria earthquake as case of study, the visual damage interpretation based on the European Macroseismic Scale (EMS-98) was carried out building by building, comparing the pre-event and post-event images for Boumerdes city. The result of the damage inspection was compared with field survey data. It was clearly seen that for totally or partially collapsed buildings the damage Grade can be easily detected from vertical images of QuickBird, but sometimes the identification of the damage Grades can be difficult for the case of buildings that just suffered a low damage. Furthermore, the accuracy of identified or judged damage Grade might also depend on the building typologies (size and height classes) and also the urban planning and environment of the zone. It has also found that there are difficulties for detecting damage for low-rise construction specially those located in dense urban environment. For mid-rise buildings the detection of damage Grade might also be difficult in case of soft story damage.
Bibliography


APPENDICES
Site response characteristics at seismic stations were investigated using horizontal-to-vertical (H/V) spectral ratios calculated from a seismic-motion dataset of the 2003 Boumerdes earthquake, and transfer functions were evaluated from soil profile data. Although high peak ground acceleration (PGA) values were recorded at some sites, the nonlinear effect was at these stations was not clear. The H/V spectral ratios calculated from weak and strong motion events did not show a clear difference in the predominant period and amplitudes, and the shapes of the H/V ratios were flat for some stations. These observations are characteristic of the presence of firm to hard layers under the stations; however, one station was located on Quaternary deposits showed a remarkable amplification at the predominant period and a high PGA value.

INTRODUCTION

On May 21, 2003, at 18:44:31 (GMT), a destructive earthquake (Mw = 6.8) struck the northern part of Algeria, causing extensive damage and human casualties (Ayadi et al. 2003, EERI 2003). The main shock was felt within a 250 km radius from the epicenter (Laouami et al. 2006). The location of the epicenter, as provided by the Algerian Research Center of Astronomy Astrophysics and Geophysics (CRAAG), was 36.91°N and 3.58°E. However, Bounif et al. (2004) determined that the epicenter of the main shock was at 36.83°N and 3.65°E (Figure 1), at a depth of 8–10 km. The rectangle in Figure 1 shows the focal plane...
projected to the surface as proposed by Delouis et al. (2004). The source model runs for an eastern distance of 55 km (3.4°–4.0°E). According to Meghraoui et al. (2004), the model fault (reverse-faulting mechanism) has a strike of N 54°E and dip of 50° to the southeast, and it extends 1–15 km below the ground surface.

Observations of recorded accelerations show a remarkable difference in maximum values among neighboring stations. However, for some stations, no such difference was observed in the velocity or acceleration for aftershocks. Local topographical and geological conditions can generate significant amplifications and spatial variations in earthquake ground motions. In recent years, the horizontal-to-vertical (H/V) spectral ratio method (Nakamura 1989) has become increasingly popular in studies of site effects and determination of the predominant period of a site using earthquake records (Field and Jacob 1993, Huang and Teng 1999). In addition, observations from different parts of the world have already provided evidence of the significance of nonlinear site effects on ground-motion records (Shearer and Orcutt 1987, Beresnev et al. 1998). Several researchers have reported nonlinear site effects, which are characterized by an increase in the damping ratio and reduction in the shear wave velocity, using the spectral ratio technique (Wen 1994, Dimitriu et al. 2000, Wen et al. 2006).

In this study, we used a seismic-motion dataset of the 2003 Boumerdes earthquake, which was recorded from the Algerian Accelerograph Network and provided by the Algerian National Research Center of Earthquake Engineering (CGS), to investigate site-response characteristics through the H/V spectral ratio technique. We calculated the spectral ratios for strong and weak motion events to estimate the possibility of nonlinear site effects during earthquakes. Comparison of the calculated H/V spectral ratios with site-transfer functions obtained from existing soil profiles allowed us to examine the applicability of the H/V method regarding the expected predominant periods and amplification of soil layers under each station.

**MAIN SHOCK OF THE 2003 BOUMERDES EARTHQUAKE**

Historically, the northern part of Algeria has suffered from numerous seismic events (Benouar 1996). Examples of recent disastrous events include the September 9, 1954 Orleansville earthquake (Ms 6.7), which caused over 1,200 deaths and damaged over 20,000 buildings and the 10 October, 1980 El-Asnam earthquake (Ms 7.2), which caused over 2,640 deaths and damaged about 20,000 buildings. The most recent such event was the May 21,
2003 Boumerdes earthquake (Mw 6.8); the Algerian Ministers’ Council (12 December, 2003) reported 2,278 deaths, 11,450 injured, and an estimated 250,000 homeless, i.e., about 40,000 families (DLEP 2004). Due to damage to buildings, 17,000 structures had to be demolished and 116,000 were repaired. The resulting direct economic loss was estimated to be US $5 billion (Ousalem and Bechtoula 2005).

The 2003 Boumerdes earthquake is the first event in Algeria for which a large number of strong motions were successfully recorded at several seismic stations by the national accelerometer network operated by CGS. This is because the countrywide accelerometer network was established only after the Algerian government established CGS following the 1980 El-Asnam earthquake (Laouami et al. 2006). Figure 1 shows the locations of 11 free-field seismic observation stations deployed by CGS, from which the main shock was recorded at a hypocentral distance of 31–165 km. However, due to some instrument problems during the event, the main shock and many aftershocks could not be recorded at some locations where the damage was most extensive.

STRONG-MOTION RECORDS

The instruments deployed by CGS record seismic ground motion using electronic transducers that produce an output voltage proportional to acceleration. Using the recorded acceleration time history, the velocity and displacement time histories are computed by integration in the frequency domain through a rectangular filter with a low cut-off frequency of 0.05 Hz. Figure 2 shows particle traces of the displacements computed from the main shock records on a horizontal plane at 11 seismic observation stations. These orbits show that the maximum displacements were recorded at Dar El-Beida ST (18.3 cm) and Hussein-Dey ST (11.4 cm). The displacement orbits at two nearby stations, Keddara ST1 and Keddara ST2, show similar shapes but appear to have a rotation angle about the vertical axis. Because the distance between two stations is very small (approximately 100 m), the observed rotation angle may be inferred as being caused by orientation errors during instrument installation. Some seismometers have been reported as being deployed with unexpected orientation errors (Yamazaki et al. 1992).

We do not know which of these two stations has the correct orientation. If we consider the orientation of the instrument at Keddara ST1 as a reference, the rotation angle at Keddara ST2 is estimated as 20.7° about the vertical axis, on the basis of the method proposed by
Yamazaki et al. (1992). The orientation error of the instrument at Keddara ST2 can be corrected by rotating back the error angle. Figure 3(a) shows a comparison of displacements between Keddara ST1 and ST2 before and after the correction. Displacement time histories for Keddara ST1 and ST2 became very similar after the correction, while they were clearly different before the correction. The corresponding coherence functions are shown in Figure 3(b). Coherence increased after the correction.

Thus, when two stations are located close to each other, we can calculate their orientation errors; however, it is difficult to do so for stand-alone stations. Hence, in this study, the resultant $A_{res}$ of the two horizontal components (Ansary et al. 1995) was used to eliminate or avoid the possibility of orientation error.

$$A_{res}(t) = \sqrt{A_{NS}(t)^2 + A_{EW}(t)^2}$$ (1)

Table 1 shows the recorded peak ground acceleration (PGA) with the computed peak ground velocity (PGV) and peak ground displacement (PGD) corresponding to the maximum values resulting from two horizontal components (NS and EW). The largest PGA values were recorded at Keddara ST2 (580.5 cm/s²) and Dar El-Beida station (540.0 cm/s²). The PGAs for some of the stations differed greatly from those of neighboring stations, but the PGVs and PGDs for other stations showed no such difference. Although a considerable difference was seen in the PGAs for Keddara ST1 (330.0 cm/s²) and the nearby Keddara ST2, the PGV (18.5 and 19.8 cm/s, respectively) and PGD values (6.4 and 6.6 cm, respectively) were very close. Acceleration is well known to be sensitive to high-frequency content, but the velocity and displacement are much less so. Hence, the big difference in PGA and small differences in PGV and PGD are due to the high-frequency content of seismic motion.

SEISMIC INTENSITY

The Modified Mercalli Intensity (MMI) scale (Wood and Neumann 1931), European Macroseismic Scale (EMS-98) (Grünthal 2001), and Japan Meteorological Agency (JMA) scale (Karim and Yamazaki 2002), developed in the USA, Europe, and Japan, respectively, are among the most widely used to estimate the ground motion severity. The MMI and EMS-98 generally estimate the ground shaking intensity during an earthquake using scales based on the effects felt at the time of the earthquake and on later observations of damage to the built environment. Twelve grades denoted by the Roman numerals I–XII are defined. Each degree in these scales describes the effects of ground motion on nature or the built
environment in terms of damage, ranging from I, denoting a weak earthquake motion, to XII, denoting almost total destruction. Recently, the estimation of MMI intensity has been related, to the ground motion records (Wald et al. 1999a and 1999b), where the scale of MMI intensity can be estimated according to the value ranges of peak ground motions recorded at a seismic station.

In contrast, JMA scale is based on strong-motion records. Although the JMA intensity scale is initially based on the intensity felt with eight shaking levels, it was later revised to allow the use of seismic intensity computed from strong-motion records. The computation of JMA intensity (also denoted as $I_{JMA}$) involves combining the three components of recorded motion; the numerical seismic intensity value is determined from the acceleration value $a_0$ that persists for a sufficient duration (Shabestari and Yamazaki 2001).

$$I_{JMA} = 2.01 \log(a_0) + 0.94$$ (2)

In this study, JMA and MMI intensity scales were applied to mainshock records obtained during the 2003 Boumerdes earthquake. The computed JMA intensities ranged from 3.1 to 5.6, as shown in Table 1. The maximum value was obtained at Dar El-Beida station, about 43 km from the hypocenter. For the two stations, Keddara ST1 and Keddara ST2, the JMA intensity values were similar at 4.7 and 4.8, respectively. The estimated MMI intensities for the mainshock records at their corresponding seismic stations are also shown by Table 1.

In addition, the EMS-98 intensity scale was applied to the 2003 Boumerdes earthquake (Harbi et al. 2007) following the macroseismic survey conducted by CRAAG. The EMS-98 intensity was estimated for 600 sites. The maximum attributed intensities IX and X were assigned to 11 sites, where many constructions suffered heavy to very heavy damage or collapse. An intensity of VIII was assigned to 22 sites where damage to buildings and loss of life were recorded. As shown in Table 1, we associated each strong-motion record obtained from the free-field recording sites with the EMS-98 value assigned to where the strong motion was recorded and felt by people.

As shown in Table 1, almost all of the estimated MMI intensity grades matched quite well with the EMS-98 intensities. Figure 4 shows a comparison of JMA and EMS-98 intensities with the peak ground motions of the mainshock. The correlation of PGA to EMS-98 is clearly not as good as the correlation of the latter to JMA.
GROUND RESPONSE ANALYSIS

SELECTED SEISMIC STATIONS

To examine the local site effects of recorded strong motions of the 2003 Boumerdes, Algeria earthquake, six near-field seismic stations were selected: Hussein-Dey, Kouba, Dar El-Beida, Boumerdes, Keddara ST1, and Keddara ST2. All of these stations are located approximately along the fault trace (Figure 1). The average distance between adjacent stations is about 20.4 km. According to the geological background (Ayadi et al. 2003) shown in Figure 1, the area where these stations are located is comprises mainly of Quaternary and Neogene formations. Quaternary formations, which are generally soft deposits, consist of mostly sand, gravel, and sandy clay covering Plaisancian (lower Pliocene) blue marl and Cristallophyllian rocks; they extend to 30 m beneath the ground surface.

At Hussein-Dey and Kouba cities, old masonry residential buildings built before 1960, an example of which is shown in Figure 5(a), were the most affected by the mainshock. The recorded mainshock at Hussein-Dey ST had PGA = 272.0 cm/s² and PGV = 20.1 cm/s (Table 1), which corresponds to \( I_{JMA} = 4.8 \) and EMS-98 = VI–VII. These intensities were at the lower limit at which structural damage starts to occur to vulnerable buildings. For Dar El-Beida city, the mainshock caused heavy damage with \( I_{JMA} = 5.6 \) and EMS-98 = VIII. Damaged buildings tended to be made of reinforced concrete as well as old masonry. In Boumerdes city, the mainshock was particularly destructive with EMS-98 = X. Many constructions, mostly mid-rise reinforced concrete buildings (4 and 5 stories) built after 1970 (Figure 5(b)), were destroyed, and many people were killed as a result of the destruction of buildings. For Keddara ST1 and ST2, located 13 km away from Boumerdes city, the JMA intensities of the mainshock were 4.7 and 4.8, respectively, with an estimated EMS-98 = VII. Note that the two neighboring stations are located in a mountain basin; an earth dam was located only 700 m away from the two stations.

The mainshock of the May 21, 2003 event was followed by many aftershocks, some of them with magnitudes over 5.0. A total of 167 aftershocks were recorded from May 25 to 30, 2003, as shown in Figure 1. From the six selected seismic recording stations, 239 seismic events (mainshock and aftershocks) were recorded: 89 from Boumerdes, 47 from Keddara ST2, 34 from Keddara ST1, 28 from Kouba, 27 from Dar El-Beida, and 14 from Hussein-Dey. Figure 6 shows the levels of all recorded PGA and PGV for the six stations. Strong
Aftershocks were mostly observed at Boumerdes, Dar El-Beida, and Keddara. The largest aftershock record was obtained at Boumerdes (M = 5.8, on May 27, 2003 at 17:11:40 GTM at 36.78°N and 3.60°E), with PGA = 441.5 cm/s² and PGV = 19.8 cm/s. Table 2 shows details of 14 selected seismic records (with a sufficient record length) from each of the six stations: one record from the mainshock and 13 records from aftershocks. However, only aftershock records for Boumerdes and Kouba were selected because the mainshock could not be recorded.

**H/V SPECTRAL RATIOS**

Aiming to estimate local site-response characteristics, Nakamura (1989) proposed the well-known H/V spectral ratio technique, which uses the ratio of horizontal and vertical Fourier spectra of microtremors recorded at a site. Several researchers have attempted to apply the technique to earthquake records (Yamazaki and Ansary 1997). In general, the H/V spectral ratio is used to estimate the predominant period (peak period of the H/V ratio), which is used as a significant parameter in building damage assessment (Fallahi et al. 2003, Gosar 2007) and in estimating soil amplification characteristics (Rodriguez and Midorikawa 2003). In recent years, studies have demonstrated that nonlinear behavior (shear-modulus degradation) can be evaluated using H/V spectral ratios. When nonlinearity occurs in a soil layer under a seismic station, the predominant period is lengthened accordingly (Wen 1994, Wen et al. 2006). The nonlinear effect is evidenced through an increase in the predominant period of soil deposits with an increasing level of excitation (Beresnev et al. 1998, Huang 2002).

We calculated the H/V Fourier spectral ratio for all seismic records used in this study as the spectral ratio between the two horizontal components (EW and NS) and vertical (UD) component, defined by

\[
R(f) = \frac{\sqrt{F_{NS}(f) \cdot F_{EW}(f)}}{F_{UD}(f)}
\]

(3)

where \(F_{NS}(f)\), \(F_{EW}(f)\), and \(F_{UD}(f)\) are the smoothed Fourier-amplitude spectra for the two horizontal and vertical components of a seismic-motion record, respectively. These Fourier spectra were smoothed by a Parzen window of 0.4 Hz bandwidth. Figure 7 shows examples of the H/V spectral ratios for six stations using three seismic records (see Table 2) with different excitation levels (PGV levels). The H/V spectral ratio for an earthquake ground
motion appeared to be influenced by the site characteristics, which correlates well with the fact that the H/V spectral ratio is sensitive to ground-motion intensity (Dimitriu et al. 2000).

In general, each station had similar shapes for the H/V spectral ratios, with no clear difference in amplitude for differing PGV levels of seismic motion. The shapes of the ratios showed the presence of noise, including fluctuation around the expected predominant period, which is defined as the period at which the maximum soil amplification occurs (Fellahi et al. 2003). These peaks were observed at the Boumerdes, Dar El-Beida, Kouba, and Hussein-Dey stations. In contrast to these stations, the two neighboring stations Keddara ST1 and ST2, which were only separated by about 100 m, exhibited H/V ratios with an almost flat form and no particular difference in the shape between them except for the presence of a small peak around 0.10–0.15 s in Keddara ST1; this peak was unclear according to the criteria defined by SESAM project (SESAME 2004) for reliable and clear peaks.

For selected stations, the evidence of soil nonlinearity from the H/V spectral ratios for different PGV levels is not clear; the small shifts in peaks shown in Figure 7 are almost negligible. From literature, when the H/V-ratio technique is used, the predominant period should correspond to the highest peak amplitude of a H/V curve (Oliveira et al. 2006). Hence, for each event, we estimated the predominant period from the computed H/V spectral ratio. Figure 8 shows the extracted predominant periods from the H/V spectral ratio for 14 seismic motions with respect to PGV. The results from all of the stations do not present convincing evidence of an increase in the predominant period with the motion intensity. Only two stations, Boumerdes and Dar El-Beida, showed even slight increases, which seems insignificant (Figure 8).
COMPARISON BETWEEN THE H/V SPECTRAL RATIO AND TRANSFER FUNCTION

Out of the six seismic stations, detailed soil profiles are only available for four (Figure 9): Hussein-Dey (up to –58 m), Kouba (up to –40 m), Dar El-Beida (up to –60 m), and Boumerdes (up to –25 m). Shear-wave (S-wave) velocity profiles are only available for two stations, Hussein-Dey and Kouba, and were obtained from in situ downhole measurements. For Dar El-Beida and Boumerdes, generalized S-wave velocity profiles were estimated using the standard S-wave velocity with respect to geological layers; these were proposed for Algiers province by the Japan International Cooperation Agency (JICA) in cooperation with CGS (JICA and CGS 2006).

The transfer function, defined as the ratio of the surface motion with respect to the rock outcrop motion, was calculated for four stations using the computer program SHAKE91 (Idriss and Sun 1992). The behavior of soil sites was considered linear assuming that the shear wave velocity and damping did not change. Damping ratios of 2% for different soil layers and 1% for bedrock (outcrop) were used to compute the transfer function. Figure 10 compares the average H/V spectral ratio (Field and Jacob 1995) with the transfer function for the Boumerdes, Dar El-Beida, Hussein-Dey, and Kouba stations. Since PGV levels may be relevant for soil nonlinearity, the average for the H/V spectral ratios, which may reduce uncertainty (Aki and Richards 1980), was computed using six weak motion records, i.e., using similar levels of excitation without nonlinearity. The selected records for averaging are denoted in Table 2 by asterisks.

In general, the H/V spectral ratio was reliable in characterizing the site response of soil deposits under a seismic station. The shapes of the averaged H/V ratio matched well with that of the transfer function for each site. Almost all of the predominant periods, corresponding to the maximum peak of the transfer function for a subsoil model, matched the closest peaks from the H/V ratios at the respective sites. However, the fluctuation around these peak periods from the averaged H/V ratios was rather significant for Hussein-Dey and Kouba (Figure 10).
DISCUSSION

SITE AMPLIFICATION EFFECTS

Several authors have shown that building damage is dependant on the proximity between the natural period of a building and the predominant period of the site (Oliveira et al. 2006). Since the period range of an ordinary site is less than 1 s, the expected predominant periods (highest peak of the H/V spectral ratio) for the ground surface at the seismic stations were about 0.1–0.25 s (Figure 7 and 10).

For the Hussein-Dey and Kouba stations, which are 3 km apart, the shapes of the H/V spectral ratio did not show any significant amplification. The response spectra of the recorded mainshock at Hussein-Dey for a damping ratio of 5% (Figure 11) showed a maximum response acceleration at a period of about 0.1 s.

According to the H/V spectral ratios, the ground motion at Dar El-Beida station seems to have been strongly affected by the local soil conditions, with remarkable amplification around 0.22 s. The response spectra for Dar El-Beida, shown in Figure 11, had two large peaks at 0.15 and 0.3 s. Quaternary deposits are known to cover almost the entire area of this city (Figure 1), and this soil condition may be responsible for the amplification around 0.15–0.3 s.

At Boumerdes station, the H/V spectral ratios did not show any significant amplification, and the estimated predominant period of the site was around 0.15 s. As mentioned earlier, the mainshock was not recorded at this station; however, many strong aftershocks were recorded. This city is located just above the source plane; thus, the ground motion was very intense, and the observed damage was very extensive (Figure 5(b)).

For the two neighboring stations Keddara ST1 and ST2, which were located at the southwest edge of the strong shaking zone, the shapes of the H/V spectral ratios for seismic motions showed a similar flat form corresponding to the existence of hard surface layers, with an insignificant difference occurring at the short period around 0.11 s at Keddara ST1. Figure 12 shows a comparison for the PGA and PGV of the mainshock and aftershocks between Keddara ST1 and ST2. Most of the events clearly had similar values for the two stations, although the response spectra of the mainshock for Keddara ST1 was relatively flat compared to that for Keddara ST2, which showed a higher amplitude at 0.08 s (Figure 11). High-frequency content in seismic ground motion is well known to contribute significantly to
the maximum values (Kramer 1996, Rathje et al. 2004). This observation suggests the need for detailed geotechnical data to investigate the reason for this difference in more detail.

NONLINEAR SITE EFFECTS

The observation of significant nonlinearity effect depends on the existence of resonance, which is related to the properties of soil deposits. Dimitriu et al. (1999) used the HV spectral ratio technique to observe a considerable drop in the effective resonance frequency of a soil site with simple geology at the town of Lefkas in western Greece and linked it to nonlinear behavior (shear-modulus degradation) of the top sandy-silt layer. Furthermore, they found a significant correlation between the resonance frequency and PGA and PGV.

For the selected stations in this study, we did not register evidence of significant nonlinear site effects. Except for Dar El-Beida station, the H/V spectral ratios were not dominated by a clear period; moreover, the two close stations, Keddara ST1 and ST2, showed flat H/V curves (Figure 7). The shift of the dominant period from the H/V ratio was almost negligible (Figure 8); thus, we can say that the nonlinear soil effects were not so significant. In general, this characterizes the case for the presence of firm or hard soil conditions (Wen et al. 2006). With nonlinear effects, strong motions are generally less amplified than weak motions in the H/V spectral ratio (Dimitriu et al. 2000), which was not clearly seen for this study (Figure 7) throughout the range of the period.

CONCLUSION

This study analyzed the site response of accelerograph stations and the recorded strong-motion distribution during and following the 2003 Boumerdes, Algeria earthquake. The H/V spectral ratios between strong and weak motion events were compared with the aim of estimating the nonlinear site response during the earthquake. The averaged H/V spectral ratio was calculated and compared with the transfer function; it was computed using a soil layer model for each station to examine the applicability of the H/V technique regarding the predominant period and soil amplification of each station.

For the selected six stations, no significant nonlinear site effect was observed. Almost no remarkable difference in the H/V ratio was seen between the weak and strong events. The H/V ratio showed a rather flat form for some stations; hence, the predominant period was not very easy to determine in some cases. This observation suggests the presence of firm to hard
soil layers under the stations, except for one station—Dar El-Beida—that showed a remarkable amplification at the predominant period, which seems to agree well with the known geological nature of the site and justifies the recorded high PGA.

This study validates the use of the H/V ratio technique to evaluate site response characteristics. However, geotechnical and geophysical investigations are needed to understand site amplification in greater detail.

ACKNOWLEDGMENTS

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REFERENCES


Table 1. Peak ground acceleration, velocity, and displacement corresponding to the resultant of the horizontal components for the mainshock of the 2003 Boumerdes earthquake, and the instrumental JMA intensity and estimated MMI. The EMS-98 intensity was estimated following the macroseismic survey conducted by CRAAG.

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Hypocentral Distance (km)</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
<th>PGD (cm)</th>
<th>JMA</th>
<th>MMI</th>
<th>EMS-98</th>
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<td>Boumerdes</td>
<td>36.75 N 03.47 E</td>
<td>21</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>X</td>
</tr>
<tr>
<td>Keddara ST1</td>
<td>36.65 N 03.41 E</td>
<td>31</td>
<td>333.0</td>
<td>18.5</td>
<td>6.4</td>
<td>4.7</td>
<td>VII</td>
<td>VII</td>
</tr>
<tr>
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<td>36.65 N 03.41 E</td>
<td>31</td>
<td>580.5</td>
<td>19.8</td>
<td>6.6</td>
<td>4.8</td>
<td>VII</td>
<td>VII</td>
</tr>
<tr>
<td>Tizi Ouzou</td>
<td>36.70 N 04.07 E</td>
<td>41</td>
<td>231.7</td>
<td>13.9</td>
<td>4.6</td>
<td>4.4</td>
<td>VI</td>
<td>VI</td>
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<tr>
<td>Dar El-Beida</td>
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<td>43</td>
<td>540.0</td>
<td>41.9</td>
<td>18.3</td>
<td>5.6</td>
<td>VIII</td>
<td>VIII</td>
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<td>Hussein Dey</td>
<td>36.74 N 03.09 E</td>
<td>52</td>
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<td>20.1</td>
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<td>4.8</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<td>Azazga</td>
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<td>4.0</td>
<td>4.6</td>
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<td>VI</td>
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<tr>
<td>Blida</td>
<td>36.47 N 02.82 E</td>
<td>85</td>
<td>52.3</td>
<td>3.6</td>
<td>1.2</td>
<td>3.6</td>
<td>V</td>
<td>V</td>
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<tr>
<td>El Affroun</td>
<td>36.47 N 02.63 E</td>
<td>100</td>
<td>164.4</td>
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<td>0.4</td>
<td>4.2</td>
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<td>V</td>
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<tr>
<td>Hammam Righa</td>
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<td>14.0</td>
<td>5.4</td>
<td>4.6</td>
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<tr>
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<td>140</td>
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<td>2.4</td>
<td>1.5</td>
<td>3.3</td>
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<td>IV</td>
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<tr>
<td>Ain Defla</td>
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<td>36.1</td>
<td>1.8</td>
<td>0.9</td>
<td>3.1</td>
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<td>IV</td>
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Table 2. Resultant peak horizontal acceleration and velocity for 14 seismic records for the 2003 Boumerdes earthquake

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
<th>Date</th>
<th>Time (GMT)</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
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<td>441.5</td>
<td>23.59</td>
<td>21/05/2003</td>
<td>18:44:31</td>
<td>539.97</td>
<td>41.89</td>
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<tr>
<td>28/05/2003</td>
<td>06:36:59 (*)</td>
<td>4.64</td>
<td>0.06</td>
<td>27/05/2003</td>
<td>18:06:13 (*)</td>
<td>2.21</td>
<td>0.04</td>
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<tr>
<td>28/05/2003</td>
<td>14:41:18 (*)</td>
<td>5.97</td>
<td>0.07</td>
<td>28/05/2003</td>
<td>06:58:44</td>
<td>396.02</td>
<td>8.67</td>
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<td>28/05/2003</td>
<td>11:26:27 (*)</td>
<td>7.71</td>
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<td>2.44</td>
<td>0.03</td>
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<td>14:41:18</td>
<td>3.12</td>
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<td>29/05/2003</td>
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<td>310.9</td>
<td>12.23</td>
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<td>19:05:31 (*)</td>
<td>9.16</td>
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<td>1.16</td>
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<td>02:15:07</td>
<td>251.97</td>
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<td>03/08/2003</td>
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<td>0.8</td>
<td>05/06/2003</td>
<td>21:54:44</td>
<td>26.71</td>
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<td>11/08/2003</td>
<td>20:03:53</td>
<td>126</td>
<td>2.44</td>
<td>16/10/2003</td>
<td>06:38:16</td>
<td>99.56</td>
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(*): records considered for computing the average of H/V for weak seismic motions in Figure 10.

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Figure 1. Geological background (Ayadi et al. 2003) of the epicentral area and the mainshock’s epicenter (star) of the 2003 Boumerdes, Algeria earthquake. The rectangle represents the estimated fault plane (reverse-faulting mechanism) (Delouis et al. 2004). The graduated circles correspond to 167 aftershocks during May 25–30, 2003. The triangles represent the CGS accelerograph network stations located in the central part of northern Algeria.
Figure 2. Orbit plots of displacement computed from the recorded mainshock for 11 seismic stations. The open circles correspond to the direction of the maximum resultant value.
Figure 3. Comparison of (a) displacements and (b) coherence functions between Keddara ST1 and Keddara ST2 before and after the orientation-error correction.
Figure 4. Comparison of JMA and EMS-98 seismic intensities using (a) PGA and (b) PGV for the mainshock records.
Figure 5. Typical damaged buildings in the area of study. (a) Exterior wall collapse of a 6-storied old masonry building (EMS-98 = VI) located in a dense urban area, not far from Hussein-Dey ST. (b) Collapse of the first and second floors of a 5-storied RC building (EMS-98 = X) 600 m away from the Boumerdes ST.
Figure 6. Number of recorded ground motions and range of PGV and PGA values at six seismic stations.
Figure 7. Comparison of the H/V spectral ratios among strong and weak seismic motions at six seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, (d) Kouba, (e) Keddara ST1, and (f) Keddara ST2.
Figure 8. Predominant periods of the H/V spectral ratios with respect to PGV (Table 2) at five seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, (d) Kouba, and (e) Keddara ST1.
Figure 9. Soil classifications and S-wave velocity profiles for four seismic stations in Algiers and Boumerdes provinces. (a) and (b): The measured S-wave velocity (thick line) was measured by a downhole survey. (c) and (d): The estimated S-wave velocity (thin line) used existing engineering classification models for different geological units in these areas (JICA and CGS 2006).
Figure 10. Average of the six selected H/V spectral ratios for weak seismic motions (thick black line) versus the transfer function (thin black line) at four seismic stations: (a) Boumerdes, (b) Dar El-Beida, (c) Hussein-Dey, and (d) Kouba. The dashed line shows the plus-minus one standard deviation range of the averaged H/V ratio.
Figure 11. Resultant acceleration response spectra (5% damping) for the horizontal components of the mainshock at Dar El-Beida ST, Hussein-Dey ST, Keddara ST1, and ST2.
Figure 12. Comparison of PGAs and PGVs between Keddara ST1 and Keddara ST2 for the mainshock and aftershocks.
Evaluation of Buildings Quality and Soil Condition in Boumerdes City Using Damage Data Following the 2003 Algeria Earthquake

A. Meslem, F. Yamazaki & Y. Maruyama
Department of Urban Environment Systems, Chiba University, Chiba, Japan

ABSTRACT: Considering the typicality of Algerian buildings, a number of major factors which influence the earthquake resistance have been identified using the collected data on the characteristics of construction and the damage status due to the 2003 Algeria earthquake. These factors allow to evaluate the condition or quality of existing buildings into five classes. Since the local site condition has an influence on the seismic ground motion and thus on the damage status, the damage of buildings and their construction quality have been examined to evaluate the local soil effects. The results obtained from this investigation are compared with the microtremor records observed at several locations in Boumerdes City to reveal the local site effects.

1 INTRODUCTION

The May 21, 2003, at 18:44:31 (GMT), a destructive Mw=6.8 earthquake hit the northern part of Algeria, causing huge structural and non-structural damages and human casualties (DLEP 2004). The ground motions of the mainshock were recorded by accelerographs, deployed by the Algerian National Research Center of Earthquake Engineering (Laouami et al. 2006).

Concerning the damage of buildings caused by the earthquake, a practical attention is paid to the most affected city, Boumerdes, located in the hypocentral distance of 18 km. In the city, the obtained damage distribution by the mission of survey, conducted by Ministry of Housing, shows that some buildings were completely destroyed, but others with the same type and in the same district suffered just slightly. After analyzing the damage distribution, it is clearly concluded that in some cases, damaged buildings were in poor conditions of seismic resistance before the earthquake; the presence of soft stories, undersized sections, insufficient longitudinal reinforcement, weak concrete strength, etc. (Bechtoula & Ousalem 2005, Ousalem & Bechtoula 2005).

It is well known that the earthquake resistance of buildings is highly related to the year of construction and the type of used material (masonry, reinforced-concrete, etc.). In fact, in Algeria, public buildings were built with quality control following the seismic code. However, the private buildings were built without any control and seismic code before the 2003 Boumerdes earthquake. Moreover, some public buildings for residential use were built with no sufficient seismic resistance or were in poor conditions since the maintenance of residential buildings is not always enough. In order to explain the damage distribution of buildings in the city of Boumerdes following the 21 May 2003 Boumerdes earthquake, it is necessary to evaluate the distribution of buildings quality before the earthquake, for a better understanding the relationship between the damage and the quality of buildings.

In this study, a detailed analysis on the characteristics of existing buildings is conducted to identify the major factors which influence the earthquake resistance. The earthquake resistance of buildings is evaluated by five classes for the Boumerdes city. The damage data is analyzed to show the relationship between the damage ratio and estimated quality of buildings. Based on the obtained results and microtremor observations conducted by the present authors, the local site effects on seismic motion are examined for Boumerdes city.

2 LOCATION AND LITHOLOGY OF BOUMERDES CITY

Boumerdes city is the capital of Boumerdes province, established after the independence of Algeria in 1962. The population was estimated to be 33,646 in 1998. Figure 1 shows the location and administrative boundary of Boumerdes city. The urban area is concentrated only in the western part of the administration boundary of the city. The eastern part of the city is mainly used as agriculture land. A high resolution satellite (QuickBird) image captured on
23/05/2003 (two days after the earthquake) shows the urbanized area of Boumerdes city (Fig. 1).

In terms of geological conditions, the area of Boumerdes province mainly consists of cristallophyllian rocks overlain by quaternary sandy clay formations. In the city of Boumerdes, the geological layers are made up by granulitic micaschists formations at the basis which show up on surface in some locations mainly in the eastern part of the city. These formations are overlain by pre-consolidated marl of lower Pliocene, then by red sands, recent clays, beach sands and dune quaternary. Figure 2 shows the lithology of different layers in Boumerdes city (Scandinavian Engineering Corporation, 1970). For our study, microtremor measurements were conducted at several locations in the city of Boumerdes as shown in Figure 2. Figure 3 shows the averaged H/V Fourier spectrum ratio of microtremor computed from 6 segments of 50 s record at each station. The shape of the H/V ratio is almost flat at the most of the locations with apparition of medium to small peak for some of them, corresponding to the period ranging from 0.4 to 0.9 s. This might indicates the existence of soft soil layers but with small thickness.

3 EVALUATION OF BUILDING QUALITY

It is well known that the building damage is highly related to the condition of buildings and site response characteristics. In this chapter, a procedure is adopted to evaluate the quality of buildings before the event, and then it is compared with the observed damage distribution. The collected data on the characteristic of each building was analyzed and a certain number of factors, which are related to Algerian buildings based on the regional culture of the country, were identified. The damage data collected by the Ministry of Housing, Algeria, were also used for analyzing the different causes of damage observed after the earthquake. At this stage, the factor related to the construction quality was estimated and used for the final decision on the building quality distribution in Boumerdes city.

To create the damage distribution and quality distribution of buildings, a GIS database is needed for a better investigation on the spatial relationship. The selected information from the data assessment conducted by the Ministry of Housing concerns the material type of building, year of construction, use category (private, residential public, non-residential public), number of stories, and data related to the damage caused by the earthquake. Since this data does not include the coordinate information for the surveyed buildings, the QuickBird images captured before and after the event provided helpful information through visual inspection. From this high resolution images with spatial resolution of 0.6m, the coordinate of an individual building can be extracted.

The city was digitalized for all the existed buildings and divided into different zones. An additional field survey was conducted recently in the study area, through which a total of 2,794 buildings have been identified. A GIS database was created by combining the collected building data with their coordinates, extracted from the QuickBird images.
3.1 Characteristics of buildings in Boumerdes City

In Algeria, masonry buildings had been constructed as non-engineered buildings until 1962. After the independence, reinforced-concrete (RC) frame buildings with un-reinforced hollow brick infill-walls became more typical. According to our database created in this study from the collected data, most of the buildings (85%) in Boumerdes city are with RC frame, consisting of columns and beams with un-reinforced hollow bricks used for external and internal walls. The number of stories for this type of buildings is ranging from 1 to 10, built in between 1969 and 2003. Reinforced-concrete shear walls are the second typical (7%) type after RC frame, with number of stories ranging from 1 to 10, built since 1970. The existing masonry buildings were built before 1962 and they are not remaining so many (4%) with number of stories ranging from 1 to 2. Steel and wooden buildings are very few (2% for Steel and 1% for Wooden buildings) and most of them are industrial facilities. 51% (1,424) of total buildings (2,794) are owned by public and 49% (1,370) are private.

3.2 Building damage distribution in Boumerdes city following the 2003 Algeria earthquake

In the week after the disastrous event of the 2003 Boumerdes earthquake, a mission for damage assessment had been conducted by the Ministry of Housing, covering all the affected areas in the provinces of Boumerdes and Algiers (Belazougui et al. 2003). This mission lasted until 30 June 2003, using five levels of damage classification ranging from negligible/slight damage to very-heavy/collapse. In Boumerdes city, from the identified 2,794 buildings, 65 buildings were totally or partially collapsed (Grade 5), 250 buildings suffered from very-heavy damage (Grade 4), 261 buildings were classified as Grade 3, 313 buildings as Grade 2, and 1,905 buildings as Grade 1. The damaged buildings with Grades 5 and 4 had been completely removed and new constructions have started in the area. Figure 4 shows the GIS map of building damage created in this study.
3.3 Definition of the major factors for the quality estimation of typical Algerian buildings

To evaluate the quality of buildings, we first introduced the major factors which might have highly affected the seismic resistance of typical Algerian buildings. These factors are based on the real conditions of buildings before the earthquake and observed damages for all the existed material type of buildings:

3.3.1 Period of Construction

The construction year of buildings leads to know which version of seismic code was used for design. Since the independence of Algeria in 1962, the official implementation of the first Algerian seismic code RPA81 was following the 10 October 1980 El-Asnam, Algeria earthquake. All the buildings constructed before 1981 were not based on a seismic code except for public buildings, which were constructed using the existed guidelines or recommendations, namely PS62 and PS69 corresponding to 1962 and 1969, respectively. However, the RPA81 was relatively low in comparison with necessary seismic capacity. Hence, the new seismic code RPA83 was set up. The second revision of Algerian seismic code was in 1988 as a form of RPA88. In 1999, the Algerian seismic code was revised again as RPA99 and this was the latest version before the 2003 Boumerdes earthquake (CGS 1999 & 2003).

Among the 2,794 identified buildings in Boumerdes city, the number of buildings following Algerian seismic design codes rises 33 % (928) of the total; almost all of them were public buildings. Public constructions built before 1983 and the majority of private constructions built before 2003 were considered as ones without seismic design. To estimate the quality of buildings, the period of construction is classified into four periods: before 1983, from 1983 to 1988, from 1988 to 1999, and from 1999 to 2003.

3.3.2 Building Use Category

In Algeria, the application of seismic code was required only for public buildings, but not for private buildings. Most of private buildings had been built without following the seismic code and quality control during construction until the 21 May 2003 Boumerdes earthquake. The new seismic code RPA99’03 became an obligation to private building owners.
Based on these backgrounds, three classes are defined to classify the quality of buildings: private, public for residential use, and public for general use. In Boumerdes city, 32% (887) of public buildings are for residential use, some of them with the presence of commercial activity (shops) on the first floor, public buildings for general use (industrial activity, office, education, etc.) comprise 19% (537). Private buildings are generally for residential use.

3.3.3 Quality of construction
The quality of structural materials and workmanship may highly affect the requested seismic resistance of buildings. The low concrete strength, undersized sections, and insufficient longitudinal reinforcement are considered as the causes of damage. For the quality classification of buildings in Boumerdes city, the observed damage category of buildings have been taken into account as a factor to judge the quality of construction, based on expert opinion.

The building quality was defined in the similar manner as the damage grade.

3.4 Definition of building quality classes
Five classes were used to determine the building quality as follows: Class 1 (good quality), Class 2 (acceptable), Class 3 (Medium), Class 4 (poor), and Class 5 (very poor). Each class is defined by com-
bining the different factors presented in the previous section. Figure 5 shows examples of quality classification of buildings. The distribution of building quality in the city of Boumerdes is shown in Figure 6. The results from this analysis show that 22% (627) are classified as good quality, 19% (539) acceptable quality, 30% (827) medium, 20% (571) poor, and 8% (230) very poor quality. The buildings associated with poor and very poor qualities are mostly private buildings. The constructions with good and acceptable qualities are mostly for public buildings.

3.5 Discussion

According to Figure 7, which shows the percentage of building damage grade with respect to the building quality, it is generally observed that severer damages were associated with poor quality condition. However, there are some buildings classified as acceptable or medium quality but suffered from severe damages (Grades 4 and 5) due to the earthquake. On the other hand, even though classified as poor or very poor quality, some buildings did not suffer extensive damages. If we assume the similarity of soil condition and seismic motion for the whole area, the damage grade should be a function of building quality, i.e. damage Grade 1 mainly corresponds to quality Class 1 (good quality) and damage Grade 5 corresponds to quality Class 5 (very poor quality). Because of dissimilarity of soil condition in different locations, the relationship between the building quality and damage grade includes some variation.

To compare the results of microtremor observation with the damage grade and building quality, a certain number of buildings which located within 200m from the microtremor measurement points were selected as in Figure 7. The selected locations M03, M07, M08, and M10 correspond to the most severely affected areas in the city where a large number of buildings were totally collapsed. As shown in Figures 8, 9, 10 and 11, the most of existed buildings are classified between good (Class 1) and medium (Class 2), according to the result of our investigation. The damage grade is between 1 (none or slight damage) to 5 (very heavy to total collapse). In fact, the observed H/V ratios at these locations (Fig. 3) show the peak period around 0.7s, which suggests the existence of soft soil. However, since the amplitude at these peaks is quite small, the soft soil layers seem to be thin.
To assess the observed damage distribution in Boumerdes city following the 2003 Algeria earthquake, a detailed analysis of buildings characteristics was conducted and the existed buildings were classified by a quality condition. The examination on the relationship between the building damage and building quality showed some variation at several locations, which is considered due to soil condition.

To investigate site effects, microtremor observation was conducted at several locations in the city. The measured H/V ratios showed flat shape at most of the locations with small amplitude, having small peaks corresponding to period ranging from 0.4 to 0.9 s. In the area with heavy damage, the peak is around 0.7 to 0.9 s.

According to the geology of the study area, the hard soil is expected in the shallow layer from the surface. In addition to that, the hard soil appears on ground surface in some areas. It is known that the observation of microtremor might not be sufficient to estimate soil response characteristics for hard soil. Detailed geotechnical information is needed to better analysis of the soil response characteristics and explain the damage distribution.

4 CONCLUSION

To assess the observed damage distribution in Boumerdes city following the 2003 Algeria earthquake, a detailed analysis of buildings characteristics was conducted and the existed buildings were classified by a quality condition. The examination on the relationship between the building damage and building quality showed some variation at several locations, which is considered due to soil condition.

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REFERENCES


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STRONG MOTION DISTRIBUTION AND MICROTREMOR OBSERVATION FOLLOWING THE 21 MAY 2003 BOUMERDES, ALGERIA EARTHQUAKE

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ABSTRACT:
Detailed analysis was conducted for the recorded mainshock across the country during the 21 May 2003 Boumerdes, Algeria earthquake. A remarkable difference has been recorded between neighbour stations. Since local site conditions have a significant effect on the ground motions, and hence on the damage distribution caused by the earthquake, microtremor survey was conducted at several sites of seismic observation stations. In this study, a particular attention is paid to 4 seismic network stations located in the most affected area between Algiers and Boumerdes provinces. Using the microtremor records and the strong motion records from five stations, the effect of soil condition on seismic motion is investigated and the damage distribution caused by this event is explained. The results from this study show that in some stations, the recorded high PGA values were influenced by high-frequency contents. However, in other stations, soil amplification is considered to be responsible for high PGV values. Hence, in order to conduct a further engineering and seismological study, it is highly recommended to conduct an investigation to identify the local soil profile at the seismic stations.

KEYWORDS: the 2003 Boumerdes earthquake, ground motion, microtremor, damage distribution

1. INTRODUCTION

On May 21, 2003, a destructive Mw=6.8 earthquake hit the northern part of Algeria, causing a huge structural and non-structural damages and human casualties. The last report by the Algerian ministers’ council (December 12, 2003) deplores that 2,278 deaths and 11,450 injured were claimed by the earthquake. The number of homeless was counted as 250,000, corresponding to 40,000 families. As for the building damage, 17,000 units were demolished and 116,000 were repaired. The resulted direct economic loss was estimated to be 5 billion US dollars (Ousalem and Bechtoula, 2005).

The earthquake was felt inside a 250 km radius zone from the epicenter (Laouami et al., 2006) and provoked the occurrence of liquefaction in the epicentral area. An uplift of coastal line was marked with the average of 0.55m (Harbi et al., 2007; Bouhadad et al., 2004; Meghraoui et al., 2004). In the European side of Mediterranean Sea, tsunamis of about 1.5m high were recorded along the coast of Spain (Alasset et al., 2006). Soon after the event, several international organizations located the 21 May 2003 Boumerdes earthquake. The location given by the Algerian Research Center of Astronomy Astrophysics and Geophysics (CRAAG) was 36.91N, 3.58E. However, the mainshock was relocated at 36.83N, 3.65E with the focal depth of 10 km (Bounif et al., 2004).

The acceleration records of the mainshock were recorded by a number of accelerographs, deployed by the Algerian National Research Center of Earthquake Engineering (CGS). However, several technical problems have occurred during recording the mainshock. The number of free field seismic stations which recorded the mainshock, especially in the severely affected areas, is not sufficient for estimating a detailed strong motion
distribution and for analyzing the building damage distribution. Figure 1 shows the location of the mainshock with the seismic observation stations deployed by CGS from which the mainshock was recorded. The mainshock of the 21 May 2003 event was followed by several aftershocks (Bounif et al., 2004), and some of them were measured as magnitude over 5.0.

Figure 1 Location of the location (star) of the 2003 Boumerdes earthquake and the CGS accelerograph network that recorded the mainshock. Ah\textsubscript{r} and Vh\textsubscript{r} are the maximum resultants of the horizontal acceleration and velocity, respectively. D is the hypocentral distance.

Figure 2 The estimated starting time of the mainshock and seismic wave propagation in the 2003 Boumerdes, Algeria earthquake (NS components).

2. STRONG MOTION RECORDS FROM THE 2003 BOUMERDES EARTHQUAKE

The provinces of Algiers and Boumerdes were classified as most struck by this event and huge damages and human losses were registered (Bechtoula and Ousalem, 2005). Before the 2003 Boumerdes earthquake, the two provinces were classified as the zone with medium seismic intensity, according to the Algerian seismic code RPA99 (RPA, 1999). But after the event, the both provinces were reclassified as the zone with high seismic intensity in the new seismic code RPA99’03 (RPA, 2003).
For Algiers province with 766 km\(^2\), only two free field records were obtained at Dar El-Beida and Hussein-Dey stations, with hypocentral distances of 43 km and 52 km, respectively. In case of Boumerdes province with 1451 km\(^2\), the only available free field records from the mainshock were those obtained at two Keddara stations, located 31 km away from the hypocenter. The only existing seismic station in Boumerdes city, which is closest to the hypocenter, about 21 km, could not record the mainshock. In fact, many technical problems occurred at several stations while recording the earthquake motions. At some stations, the primary wave of the mainshock was missed, especially for the stations located far from the hypocenter. Figure 2 shows the estimated relative starting time of the earthquake for each station. The starting time of the earthquake at each station is not available because the accelerographs were not equipped with GPS.

<table>
<thead>
<tr>
<th>Station</th>
<th>Hypocentral Distance (km)</th>
<th>Max Acceleration (cm/s(^2))</th>
<th>Max Velocity (cm/s)</th>
<th>Max Displacement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NS</td>
<td>EW</td>
<td>Resultant</td>
</tr>
<tr>
<td>Keddara St1</td>
<td>31</td>
<td>260.1</td>
<td>333.0</td>
<td>333.0</td>
</tr>
<tr>
<td>Keddara St2</td>
<td>31</td>
<td>345.0</td>
<td>586.4</td>
<td>586.4</td>
</tr>
<tr>
<td>Tizi Ouzou</td>
<td>41</td>
<td>192.0</td>
<td>231.7</td>
<td>231.7</td>
</tr>
<tr>
<td>Dar El Beida</td>
<td>43</td>
<td>501.1</td>
<td>540.0</td>
<td>540.0</td>
</tr>
<tr>
<td>Hussein Dey</td>
<td>52</td>
<td>231.6</td>
<td>272.0</td>
<td>272.0</td>
</tr>
<tr>
<td>Azazga</td>
<td>66</td>
<td>86.1</td>
<td>120.5</td>
<td>120.5</td>
</tr>
<tr>
<td>Bilia</td>
<td>85</td>
<td>38.6</td>
<td>52.2</td>
<td>52.2</td>
</tr>
<tr>
<td>El Affroun</td>
<td>100</td>
<td>90.9</td>
<td>164.0</td>
<td>164.0</td>
</tr>
<tr>
<td>Hammam Righa</td>
<td>125</td>
<td>73.5</td>
<td>114.8</td>
<td>114.8</td>
</tr>
<tr>
<td>Miliana</td>
<td>140</td>
<td>25.7</td>
<td>34.2</td>
<td>34.2</td>
</tr>
<tr>
<td>Ain Defla</td>
<td>165</td>
<td>24.3</td>
<td>36.0</td>
<td>36.0</td>
</tr>
</tbody>
</table>

Figure 3 Attenuation law of seismic motion in terms of PGA and PGV

### 3. ANALYSIS OF RECORDED SEISMIC MOTIONS

A total of 11 free field records from the mainshock were selected for this study. These records were obtained at the seismic stations in a hypocentral distance of 31 km to 165 km (Figure 1, Table 1). According to the implemented documents by CGS, seismic ground motion is recorded in terms of electronic transducers that produce an output voltage proportional to acceleration.

The peak horizontal acceleration (PHA) at each station is seen to be not so proportional to the hypocentral distance. A high PHA value was recorded in a station while in its neighboring stations, the recorded values of...
PHAs were not so large, especially for the EW component. However, the dominant direction of the seismic motion is not necessarily consistent with the direction of instruments (EW and NS), and hence, the resultant of the two horizontal components was calculated (Ansary et al., 1995). Table 1 shows the maximum resultant values of the recorded seismic motions. It is well known that the peak acceleration is highly affected by high frequency contents of a seismic motion (Kramer, 1996). The integration of an acceleration record has a similar effect as smoothing or filtering in the frequency domain. This leads to the observation that the velocity time history is less sensitive to the higher-frequency contents of seismic motion.

<table>
<thead>
<tr>
<th>Station</th>
<th>Acceleration in EW (cm/s²)</th>
<th>Displacement in EW (cm)</th>
<th>Acceleration in NS (cm/s²)</th>
<th>Displacement in NS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keddara St1</td>
<td>Max = 64.4 cm/s²</td>
<td>Max = 6.4 cm</td>
<td>Max = 164.4 cm/s²</td>
<td>Max = 36.0 cm</td>
</tr>
<tr>
<td>Keddara St2</td>
<td>Max = 42.2 cm/s²</td>
<td>Max = 6.6 cm</td>
<td>Max = 114.8 cm/s²</td>
<td>Max = 34.2 cm</td>
</tr>
</tbody>
</table>

Figure 4 Particle traces of the acceleration records at different seismic stations. Open circle corresponds to the direction of the maximum resultant value.

(a) Mainshock: 21/05/2003 18:44:31 (M=6.8)  
(b) Aftershock: 27/05/2003 17:11:29 (M=5.8)

Figure 5 Orbit plots of displacement at Keddara St-1 and St-2. Open circle corresponds to the direction of the maximum resultant value.

For the recorded accelerograms of the mainshock, the velocity and displacement time histories were computed through the integration in the frequency domain using a rectangular filter with low cut-off frequency of 0.05 Hz. Table 1 also presents the peak horizontal velocities and displacements in the two horizontal components and their resultants. Figure 3 shows the attenuation of strong motion in terms of PGA and PGV. The regression curves for attenuation law are also shown (Molas and Yamazaki, 1995).

Figure 4 shows the particle traces of the acceleration records on a horizontal plan at the 11 seismic observation stations. As we can see, none of those stations has shown any predominant direction for acceleration. For the case of the two stations in Keddara, located 31 km from the hypocenter, the displacement orbits at the two stations show the similar shape, but they look to have a rotation angle about the vertical axis. Figure 5 (a) and (b)
show the orbit plots of displacement at Keddara St-1 and St-2 for the mainshock and the selected aftershock. The measured difference in angle between the both stations is 20.7 degrees and 20.9 degrees for mainshock and aftershock respectively. Since the distance between the two stations is very small, only 100 m or so, the observed rotation angle may be caused by the orientation error of instrument installation (Yamazaki et al., 1992). The maximum resultant acceleration at Keddara St-1 is 333.0 cm/s$^2$ but that at Keddara St-2 is 580.4 cm/s$^2$ (Table 1). However, no such difference is seen for the resultant velocity (18.5 cm/s and 19.7 cm/s) and the resultant displacement (6.4 cm and 6.6 cm) for the stations 1 and 2.

Figure 6 Microtremor measurements at the seismic stations. The selected seismic stations are located in Algiers and Boumerdes provinces, which are most severely affected by the 21 May 2003 Boumerdes earthquake.

Figure 7 Acceleration response spectra of recorded mainshock at Keddara, Dar El-Beida and Hussein-Dey.

4. COMPARISON OF THE H/V RATIOS OF STRONG MOTION AND MICROTREMOR

In order to evaluate site response characteristics, microtremor measurement was conducted at 4 seismic stations located in Algiers and Boumerdes provinces (Figure 6). Figure 7 shows the acceleration response spectra of recorded mainshock in this area from the stations of Keddara, Dar El-Beida and Hussein-Dey. The average distance between the adjacent stations is about 20 km. The amplitude at Dar El-Beida is quite different from those of the others.

The duration of microtremor observation was set to as 5 minutes, and in order to conduct Fourier analysis, the record was divided into six parts of 50 s duration. The Fourier spectrum was smoothed by Parzen window of 0.4 Hz bandwidth. The horizontal-to-vertical (H/V) Fourier spectral ratio was calculated between one of horizontal (EW and NS) component and the vertical component, as well as the average spectral ratio defined as follows:
where $R_{\text{ave}}$ is the average H/V spectrum ratio, $F_{\text{NS}}(T)$, $F_{\text{EW}}(T)$, and $F_{\text{UD}}(T)$ are the smoothed Fourier spectra for the two horizontal (NS and EW) and vertical components, respectively.

4.1. Keddara

In case of Keddara, in addition to the two seismic stations, microtremor measurement was conducted at two more points to explain the difference in seismic motion. Thus microtremor was measured at the 4 points with about 50 m distance in Keddara. Figure 8 shows the microtremor measurement points in Keddara and the H/V Fourier spectral ratios at these points. For Keddara St-1 (PT2), the H/V ratio is seen to be almost flat with a small peak in the period less than 0.1 s, while in Keddara St-2 (PT4), the H/V ratio looks almost flat without peaks. PT1 and PT2 (Keddara St-1) show the similar H/V behavior with a low peak at a short period. This peak may be due to the presence of soft soil with small thickness. PT3 and PT4 have resemble H/V ratios without a peak. For all the four points, it is clear that the area has a hard soil condition, note that Keddara earth dam is located approximately 400 m from PT4 (Keddara St-2).
According to Yamazaki and Ansary (1997), the amplitude and the shape of H/V spectrum ratio of seismic motion also indicate the site characteristics. A comparison between the H/V spectrum ratios of microtremor and seismic motion is presented in Figure 9 for Keddara stations 1 and 2. At Keddara St-1 the peak period of the H/V spectral ratio gets longer in the order of mainshock, aftershock, and then microtremor, with the similar shape. For Keddara St-2, the H/V ratios are very flat without clear peaks. The selected aftershock corresponds to the event of 27 May 2003 17:11:29 (GMT) with magnitude of 5.8, located at 36.88N, 03.55E. The maximum resultant acceleration and velocity are (123.8 cm/s² and 4.4 cm/s) for Keddara St-1 and (150.3 cm/s² and 4.2 cm/s) for Keddara St-2.

4.2 Dar El-Beida
Dar El-Beida is one of the cities in the province of Algiers affected by the 2003 Boumerdes earthquake. The mainshock recorded by the seismic station in the city, with about 43 km hypocentral distance, has a maximum resultant value of 540.0 cm/s² (Table 1). In the city, 2,369 houses were classified as 3 to 4 damage level in European Microseismic Scale (EMS-98) and 66 houses as level 5 damage, which corresponds to very heavy damage or collapse (Azzouz et al., 2005).

According to the H/V ratio of microtremor at this seismic station, the predominant period about 0.25 s with amplification around 3 is observed (Figure 10.a). The soil condition is considered to be softer than other sites, e.g. Kaddara. But this site is not classified as a soft site although the largest strong motion values among neighboring stations were recorded. This observation may be explained by soil amplification, as well as the shortest distance to the source. Comparison of H/V ratios between microtremor and seismic motion for Dar El-Beida City is also shown in the figure. The used aftershock corresponds to the event of 29 May 2003 02:15:07 (GMT) with magnitude of 5.8, located at 36.82N, 03.42E. The maximum resultant acceleration and velocity are 252.0 cm/s² and 7.3 cm/s, respectively. The predominant peak is also seen for the mainshock and the aftershock. The peak period gets longer in the order of the mainshock, aftershock and microtremor.

4.3 Hussein-Dey
Figure 10.(b) shows the H/V ratios of microtremor and seismic motion for Hussein-Dey city. The H/V ratio of microtremor does not show any predominant peak, and thus this site is considered to be on hard soil. The H/V ratios for microtremor and seismic motion show quite different shapes, which is sometimes the case of hard soil. The selected aftershock was recorded on 16/10/2003 06:38:16 (GMT) with resultant PGA=6.8 cm/s² and resultant PGV=0.2 cm/s. The magnitude of this aftershock is 3.6 located at 36.45N 3.63E. The affected buildings by the mainshock in this city are mostly old masonry residential buildings built before 1960’s.

5. CONCLUSION
The strong motion records obtained in the 2003 Boumerdes, Algeria earthquake were investigated. The accelerograms show the clear phases of P-wave and S-wave propagations. The attenuation of seismic motion is
seen from the source to the recording sites in terms of PGA and PGV. The orbit plots of the recorded motion exhibit the possibility of orientation error between the two closely located stations near Keddara dam. Since the density of the seismic network is not so high and the geotechnical survey data for the area is sparse, microtremor observation was carried out at several seismic stations. The H/V Fourier spectral ratio was calculated and compared for microtremor and seismic records. In Keddara site, microtremor was measured at 4 points and the H/V ratios show the existence of soil layers in two points while not for two other points. The H/V ratios of some seismic stations, e.g. Dar El Beida, show the predominant peak corresponding to site amplification while no clear peak is observed at some seismic stations, e.g. Hussein-Dey, located on hard soil. A further research will be conducted on the relationship between the building damage and site characteristics.

REFERENCES


