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Evaluation of Buildings Quality and Soil Condition in Boumerdes City Using Damage Data Following the 2003 Algeria Earthquake

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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

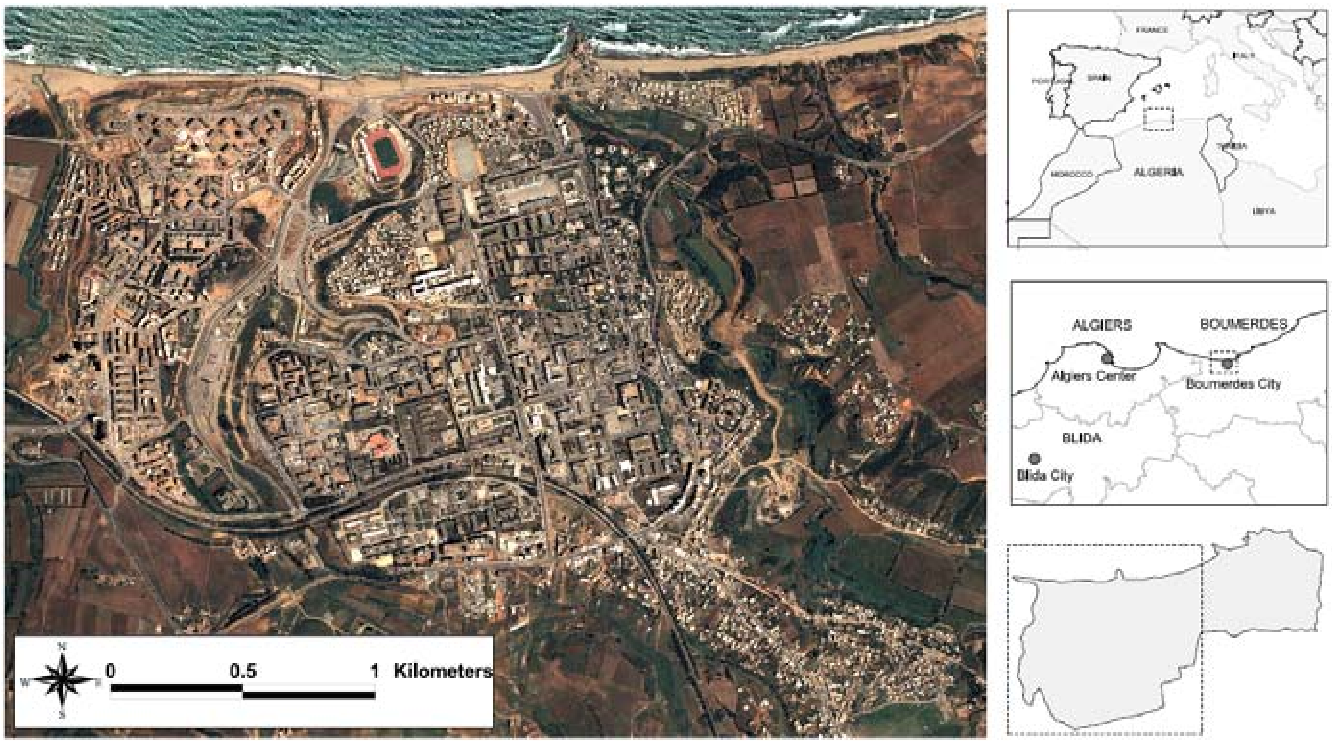

Figure 1. Location and administrative boundary of Boumerdes City.

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.

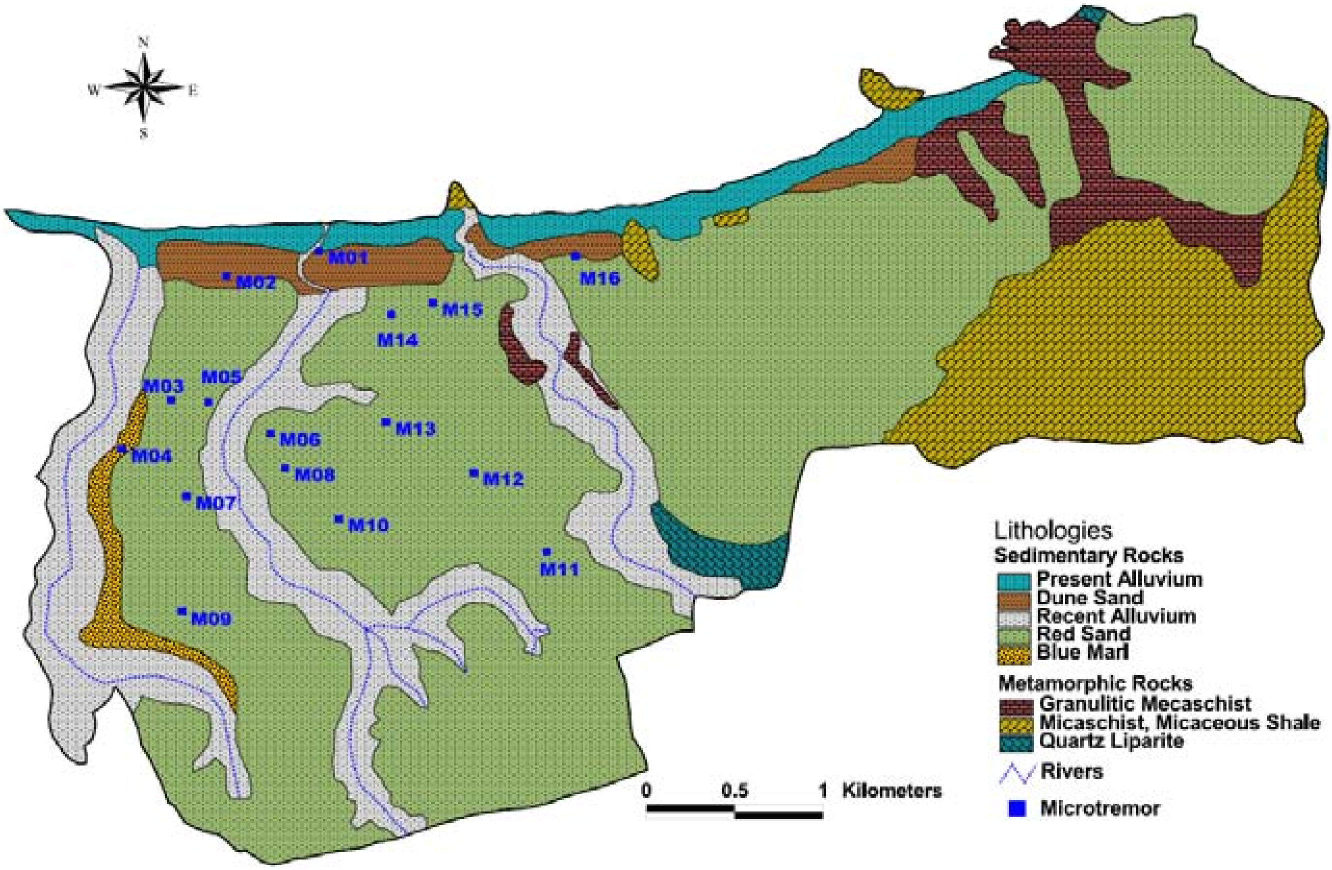

Figure 2. Lithology in the area of Boumerdes City and microtremor measurement locations.

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.

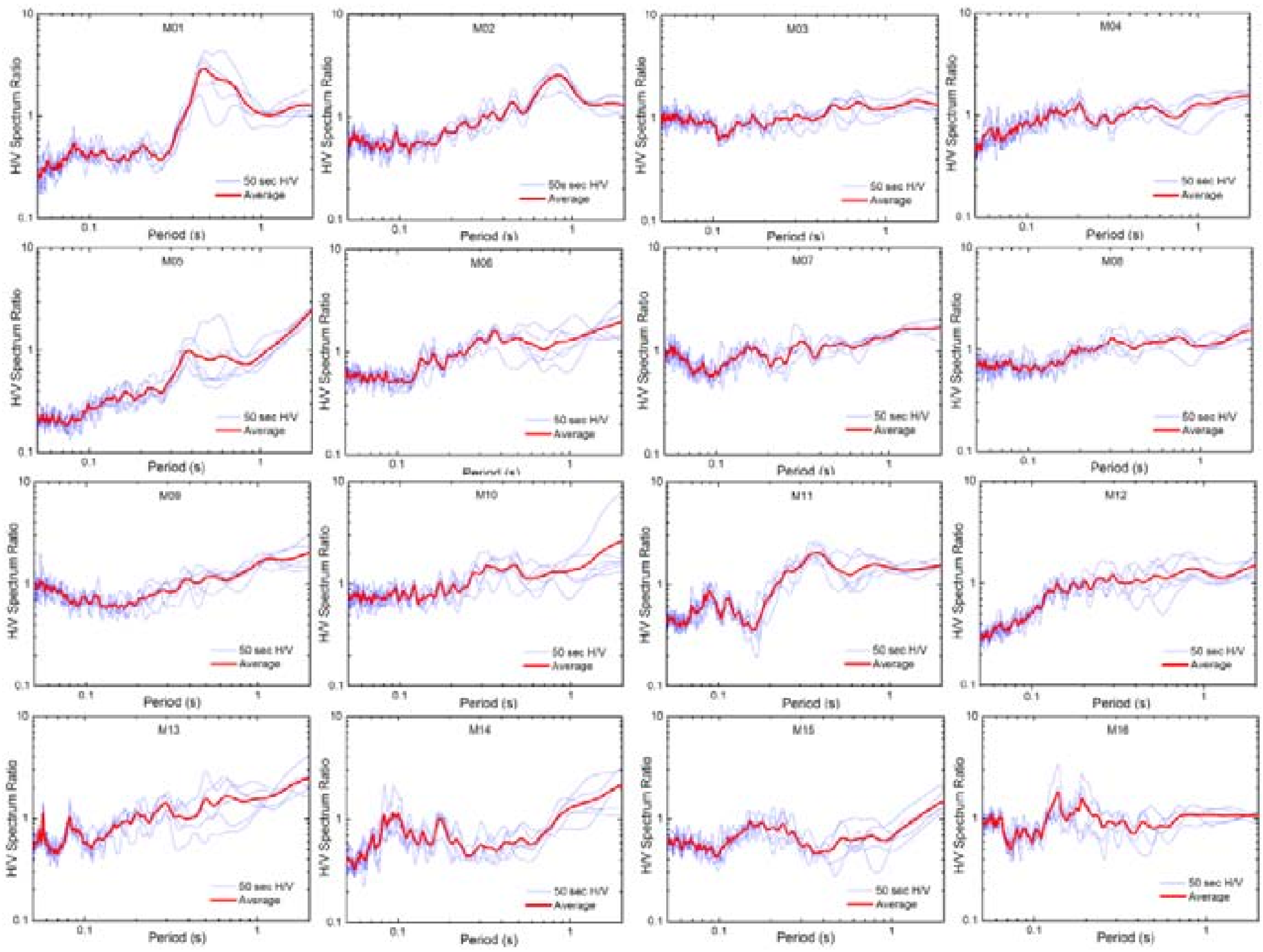

Figure 3. Microtremor observation for several locations of damaged area in Boumerdes City.

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.

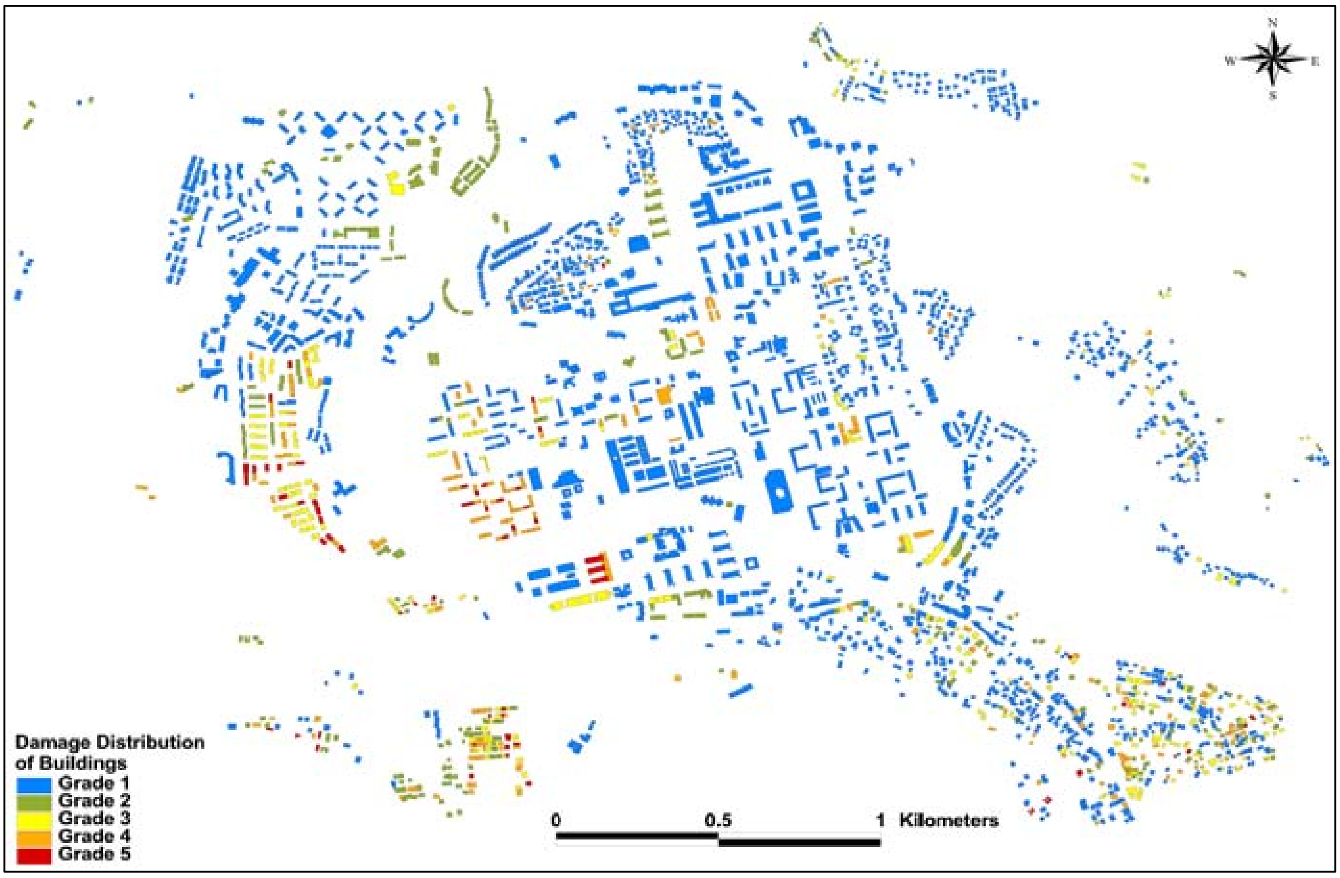

Figure 4. Damage distribution of Buildings in the City of Boumerdes following the 2003 Algeria earthquake.

	***Good:*** RC public building for residential use and activities in the first floor. Built in 2003 in the year of earthquake. A very slight non-structural damage was observed in the earthquake. Classified as damage Grade 1.
	***Acceptable:*** RC public for residential use and activities in the first floor. Built 1998 and showed a good behavior during the earthquake with recorded damage between 1 and 2.
	***Medium*:** RC public building for residence use, built in 1996. Characterized by a soft first-storey. A remarkable number of them suffered from damage Grade 3, 4 and 5.
	***Poor:*** RC private building for residential use. Newly built without any seismic code characterized by low concrete strength, undersized sections, etc.
	***Very Poor:*** RC private building for residential use. Built without seismic code characterized by poor concrete strength and infill breaks, undersized element sections, insufficient longitudinal reinforcement.

Figure 5. Example of quality condition classification of buildings in Boumerdes city.

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-

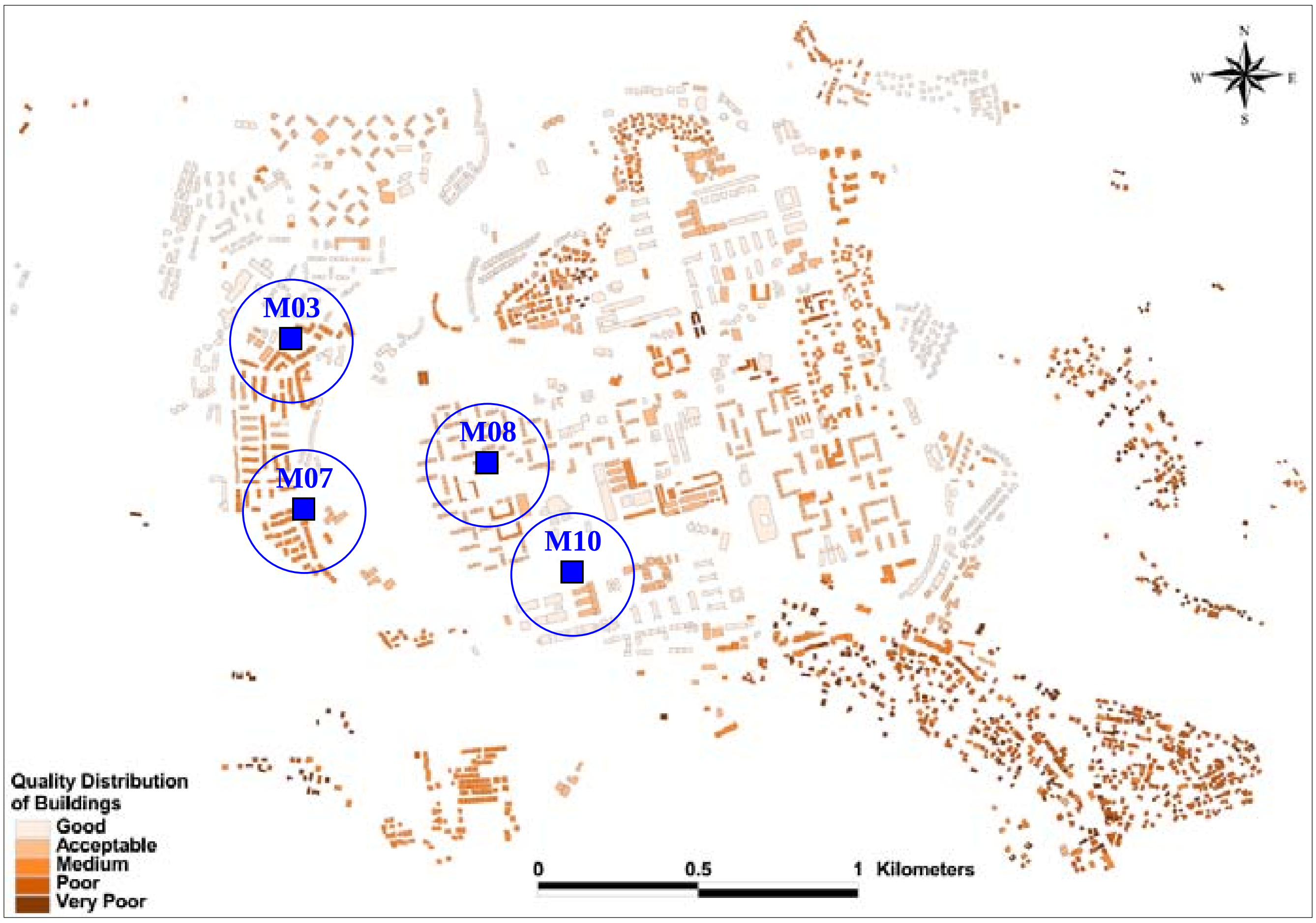

Figure 6. Distribution of buildings with respect to the quality classification in Boumerdes City. Open circles correspond to the selected buildings located within 200 m from microtremor observation points.

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 theses 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.

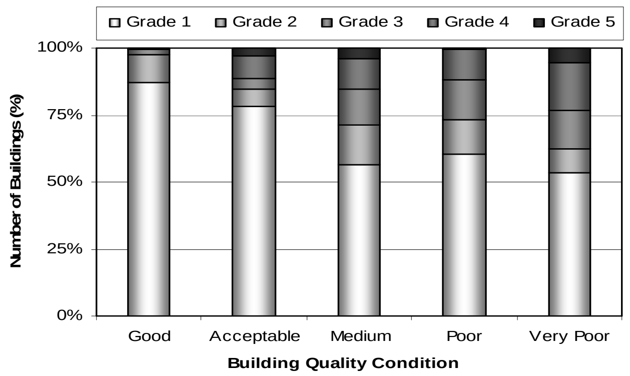

Figure 7. Relationship between Condition of Building Quality and observed Damage Grade.

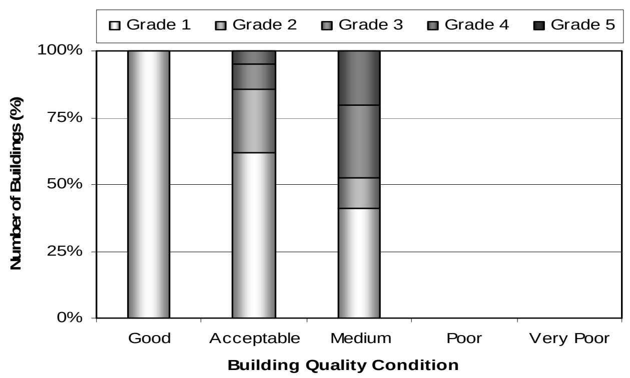

Figure 8. Damage Rank to Quality Class of selected buildings for M03.

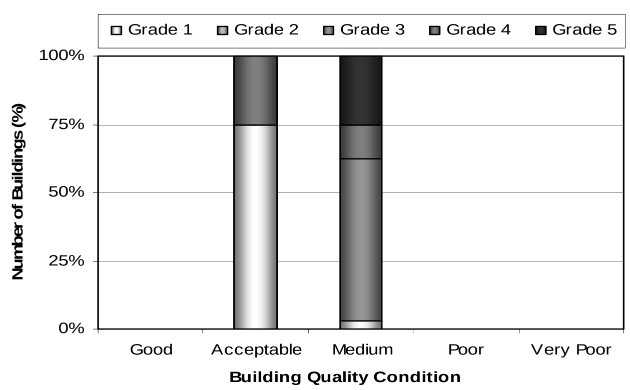

Figure 9. Damage Rank to Quality Class of selected buildings for M07.

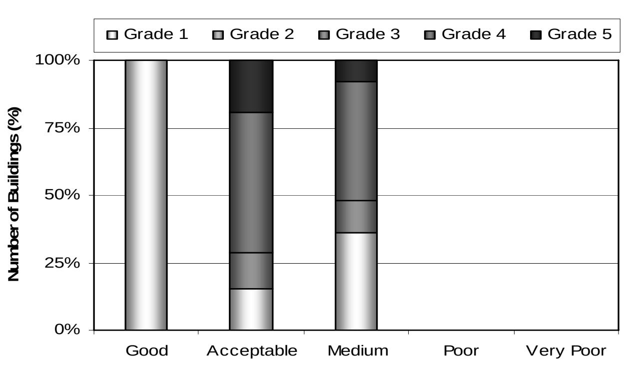

Figure 10. Damage Rank to Quality Class of selected buildings for M08.

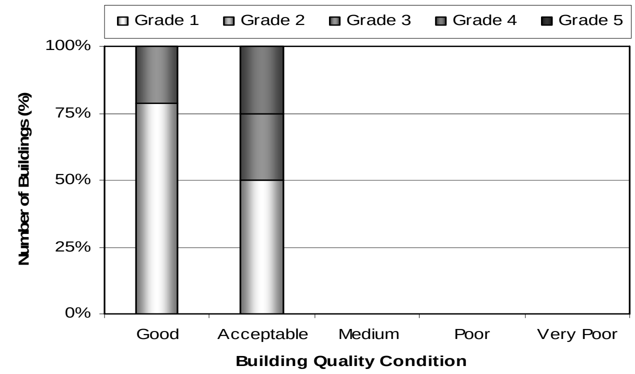

Figure 11. Damage Rank to Quality Class of selected buildings for M10.

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.

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.

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