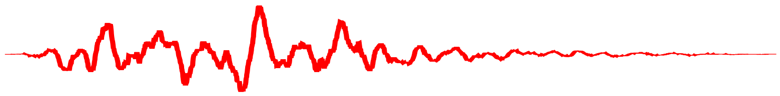
BOUMERDES EARTHQUAKE

May 21, 2003

Japanese Reconnaissance Team



Japan Association of Earthquake Engineering (JAEE)
Japan Society of Civil Engineering (JSCE)
Architectural Institute of Japan (AIJ)
Japan Geotechnical Engineering Society (JGES)

OCTOBER 2004

I sincerely express my highest gratitude to the following people for their kind supports and assistance to the Japanese Team's survey activities in Algeria, particularly to Dr. Belazougui of the National Earthquake Engineering Centre of Algeria (CGS).

I firmly believe that the Japanese experts and the Algeria counterparts could create a close and tight relationship and partnership through the cooperative survey and the eager discussions on the recent disastrous earthquake in Algeria, and hope that this collaboration between the two countries will be strongly advanced in order to mitigate earthquake disasters in the world.

Professor Masanori HAMADA,
Leader of Japanese Reconnaissance Team

ACKNOWLEDGEMENT

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Chapter 1

Introduction

On May 21, 2003 at 19:44:19 local time the Boumerdes earthquake struck the Zemmouri region in northern Algeria. Zemmouri is approximately 70 km east of the capital, Algiers. The moment magnitude of this event is 6.8. The location of epicenter is 36.90N 3.71E determined by U.S.G.S. The focal depth of the earthquake was about 10 km. This earthquake, which is the biggest to hit Algeria since 1980, killed 2278 people and injured more than 11,000 people. The large number of collapsed houses and public buildings was the direct cause of the loss of the human lives

Japan Association of Earthquake Engineering (JAEE), Japan Society of Civil Engineering (JSCE), Architectural Institute of Japan (AIJ) and Japan Geotechnical Society (JGS) have cooperatively organized a reconnaissance team that was sent to investigate the damage inflicted by the Boumerdes Earthquake

The team is composed of 12 experts from Japanese universities, research institutes and construction companies. The experts' background is wide covering fields from geology, geotechnical engineering, earthquake resistant design, civil and infrastructure engineering and risk management. Details of the 12 experts can be found in the next page.

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The first Japanese investigation team visited Algeria in early July 2003 and conducted a preliminary survey and made a preparation for the main Japanese investigation team (Second Japanese Investigation Team).

The main team spent six days from July 14 to 19 for its investigation into the damaged site and for the visit to the concerned research institutes and organizations. Details of the activities by the main team are shown Table 1.1.

Table 1.1: Investigation Activities in Algeria by the Main Japanese Investigation Team

	Date	Schedule (Group I)	Schedule (Group II)
1	July 14 (Mon.)	- Visit to the Japanese Embassy - Verification of arrangement for field inspection with Nikki	- Visit to the Japanese Embassy - Verification of arrangement for field inspection with Nikki
2	July 15 (Tue.) AM	- Visit to CTC and CGS - Briefing on Damage and Discussion on Field Survey	- Visit to CTC and CGS - Briefing on Damage and Discussion on Field Survey
	PM	- Visit to CRAAG - Visit to University of Algiers (USTHB) - Survey on Damage in Alger	- Visit to CTC Office at City Office - Survey on Structural Damage in Dar El Beida and Rouiba
3	July 16 (Wed.) AM	- Survey on Damaged Silos and Damaged Bridge in Corso - Visit to CTC Boumerdes Office and Damage Survey in Boumerdes	- Survey on Damaged Silos and Damaged Bridge in Corso - Visit to CTC Boumerdes Office and Damage Survey in Boumerdes
	PM	- Survey on Structural Damage in Zemmouri and Damaged Bridge crossing over Oued Isser River due to Liquefaction located between Zemmouri and Djenet - Survey on Liquefaction around Zemmouri, Boumerdes and Corso. - Survey on Geo-related Damage along coastline, Ground Deformation, Slope Failure,…..	- Survey on Structural Damage in Zemmouri and Damaged Bridge crossing over Oued Isser River due to Liquefaction located between Zemmouri and Djenet - Survey on Surface Rupture on the Ground between Zemmouri and Bordj Menaiel. - Survey on Structural Damage in Bordj Menaiel and Boumerdes.
4	July 17 (Thur.) AM	- Survey on Damage in Djenet and Dellys - Survey on Liquefaction around Zemmouri, Boumerdes and Corso. - Survey on Alluvial soil Damage along Oued Isser River.	- Detailed survey on Structural Damage in Boumerdes using Microtremor Measurement System.
	PM	- Damage survey in Tizi Ouzou. - Visit to Rock-Fill Dam at Keddara and to ground motion observation stations. -	- Detailed survey on Structural Damage in Ain El Beida using Microtremor Measurement System.
5	July 18 (Fri.) AM	- Survey on Damage to Port and Harbor Facilities from Alger to Cap Matifou	- Damage survey on Buildings and Houses, and Industrial Facilities in Reghaia and Ain Taya.
	PM	- Forum for quick report survey results and exchange of experiences at CTC/CGS office. - Thank-you Dinner	- Forum for quick report survey results and exchange of experiences at CTC/CGS office. Thank-you Dinner
6	July 19 (Sat.) AM	- Visit to Japanese Embassy and quick report of survey results. - Site Visit in the City, especially, Structures from the Turkish Era, which have been retrofitted.	- Visit to Japanese Embassy and quick report of survey results. - Site Visit in the City, especially, Structures from the Turkish Era, which have been retrofitted.

Summary of the Report
This report is divided into seven chapters as follow:

Chapter 1: Introduction

Chapter 2: Geology, History and Characteristics of the Earthquake

Chapter 3: Liquefaction and Geo-Related Failure

Chapter 4: Damage to Structures

Chapter 5: Damage In Boumerdes

Chapter 6: Disaster Response

Chapter 7: Conclusions and Suggestions
.

Chapter 2

Geology, History and Characteristics of the Earthquake

2.1 Geography and History of Algeria

Boumerdes is 50 km east of the Algerian capital of Algiers, in the Mediterranean zone of North Africa (Fig. 2.1). Boumerdes *Wilaya* (regional administrative entities similar to Prefecture or provinces) is relatively a young prefecture. It became a prefecture in 1984. Located in north of Algeria, on the Mediterranean coast, one finds there magnificent beaches, scenery, and delicious fig trees. In 2003, the population was estimated at 647,389 habitants for an area of 1591 km2. The majority of the population is young due to the existence of several Universities. Boumerdes one of the 48 Prefectures is divided into 7 *Dairas* (wards) and 38 *Communes* (cities). These are:

Dairas:
Boumerdes, Thenia, Dellys, Boudouaou, Bordj-Menail, Isser, and Naciria.

Communes:
Afir, Ain Taya, Ammal, Baghlia, Ben Choud, Beni Amrane, Bordj El Bahri, Bordj Menaiel, Boudouaou, Boudouaou El Bahri, Boumerdes, Bouzegza Keddara, Chabeut El Ameur, Corso, Dellys, Djinet, El Kharrouba, Hammedi, Haraoua Isser, Khemis El Khechna, Larbatache, Leghata Marsa Naciria, Ouled Aissa, Ouled Hedadj, Ouled Moussa, Reghaia, Rouiba, Si Mustapha, Sidi Daoud, Souk El Had, Taourga, Thenia, Tidjelabine, Timezrit, Zemmouri.

Figure 2.1: Location of Algeria

Algeria the second largest African country after Sudan is located in the Mediterranean zone between Morocco and Tunisia. It lies in a zone of narrow valley separated by two parallel ranges of the Atlas Mountains, characterized mostly by the high plateau, desert, and discontinuous coastal plain. More than ninety percent of the Algerian people of 32,818,500 (July 2003 est.) live along this zone of 12 percent of the country's land area (total area is 2,381,740 km^2).

The principal domestic objectives of the Algerian government, after independence in 1962, were to achieve economic development through industrialization and to raise the standard of living. Algeria is fortunate to have substantial petroleum resources to aid in this process. The country faced a myriad of problems in attempting to modernize a traditional society and to raise the living standard in the face of rapid population growth. High rates of unemployment (more than 30%, 2002 est.) and underemployment; a lack of well-trained higher and middle-level cadres; a lagging agricultural sector; and difficulties in providing health, education, and other services are still major problems. These maybe caused by the civil conflict and terrorist attacks that had caused a lot of harm to Algeria for more than a decade.

Up to now housing has been one area of substantial government investment; new apartment complexes may be seen throughout the nation. Boumerdes due to its proximity to the capital has had its rapid growth in the years since the 80's. The government instituted a special development for Boumerdes which included urban dwellings, suburban dwellings, universities, schools, ……. The performance of these buildings in the May 21, 2003 earthquake is discussed later in this report..

2.2 Geologic and Tectonic Setting

The northernmost portion of Algeria has historically experienced a moderate amount of shallow (less than 70 km deep) seismic activity. In light of modern plate tectonics, this activity is thought to be associated with plate motions and interactions at plate boundaries.

Nearly all of the African continent lies on the African plate. To the north, the Eurasian plate is thought to be colliding with, and being thrust over, the African plate, with some plate consumption-taking place (see Fig. 2.2). The types of features normally associated with a subducting plate boundary are not observed because of the continental lithosphere with respect to plate subduction. Rather than the formation of an arc-trench complex, a wide belt of folded mountains is produced because the continental material is too light to sink into the earth's mantle. This collision belt makes up the Atlas Mountains of North Africa (Morocco, Tunisia and Algeria), a broad zone of crustal shortening up to 400 km wide which has extensively folded and thrust faulted. The geologic structures within the Atlas Mountains trend generally east-west to east-northeast, parallel to the plate boundary and normal to the direction of plate convergence.

The plate boundary west of Spain changes from one of overthrusting to one characterized by right lateral strike-slip faulting (predominantly horizontal motion with the opposite side moving to the right) as determined from earthquake focal mechanisms (Mc Kenzie).

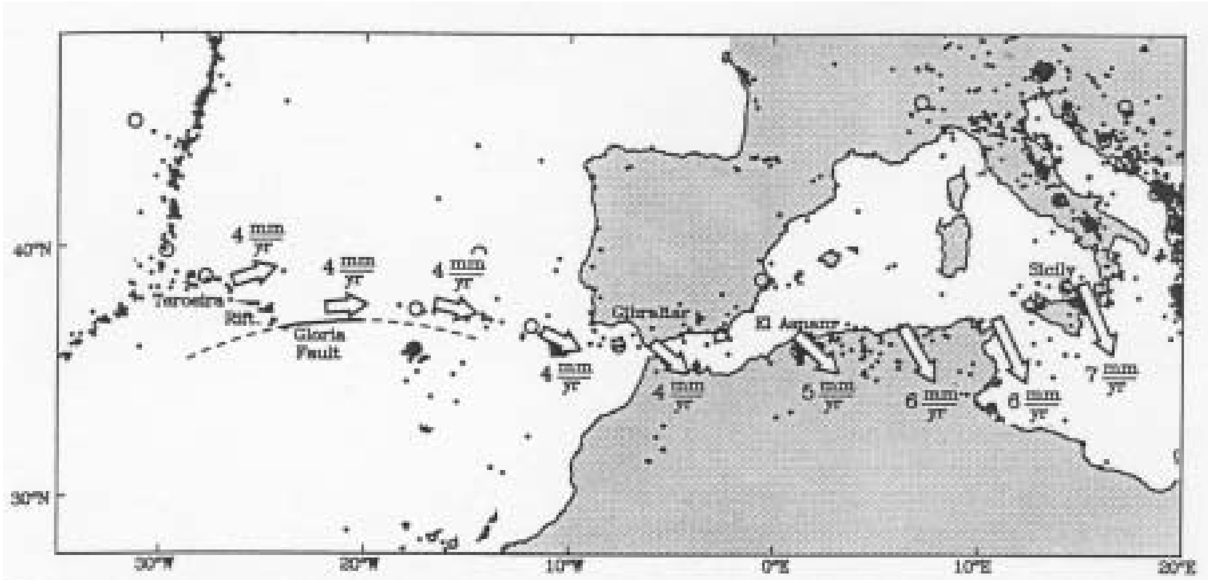

Figure 2.2: movement of the boundary region between the Eurasian and the African plates

Although there is much uncertainty and controversy regarding the exact configuration and character of this complex plate boundary, it is generally believed that the boundary begins as a transform fault at the Mid-Atlantic Ridge, extends eastwards as subduction zone through the Mediterranean Sea, then connects to the Arabian plate boundary. The slow descent of the African Mediterranean Sea, then connects to the Arabian plate boundary. The slow descent of the African plate under the Eurasian plate [about 3 cm per year as compared to the fast subduction rate of 10 cm per year of the Cocos plate under the North American plate] constitutes one of the major subduction zones of the earth. Because of the slow rate of the African slab's subduction, its lithosphere is absorbed into the mantle before it can reach a considerable depth; thus, the associated earthquakes are not generally deep. It appears that the rate of subduction is impeded by the rigidity and buoyancy of both the African and the European plates.

The wide and diffuse band of seismic activity that extends into both continents and the Atlas and Alpine mountain belts are clearly the result of compressional forces that originate from the difficulty of consumption of continental lithosphere in a continental collision.

Contrary to what is stated above, Ritsema claims that in North Africa most earthquakes are transcurrent east-west, oriented with right lateral motion

2.3 Past Earthquakes

Algiers and the surrounding region has experienced moderate to large earthquakes at least a dozen times (including major aftershocks) during the past 300 years. Table 2.1 is a list of earthquakes in Algeria between 1365 and 1994. Of particular interest are the 1934 El-Abadia and the 1954 El-Asnam (Orleanville) events. These two earthquakes were caused by activity of the same fault system as the October 1980 event. The September 9, 1954 Orleanville earthquake had a Richter magnitude of 6.7, killed about 1500 people, and destroyed 20,000 homes. Most of the buildings destroyed by October 10, 1980 earthquake were built after the 1954 earthquakes. Furthermore, the city of El Asnam (formerly Orleansville) was severely damaged by a magnitude 7.1 on October 10, 1980. At that time, the earthquake killed at least 5000 people. The site of El Asnam is situated approximately 250 km to the west of the recent earthquake.

Table 2.1 : Majors quakes of Algeria between 1365 and now

Localité	Date	Io	M	Victims	Observations
Alger	03.01.1365	Strong	Strong	Many	Destructor: Alger completely destroyed and a part of Alger flooded
Alger	03.02.1716	X		Numerous	
Oran	09.10.1790	X		About 3000	Destructor
Mascara	03.1819	X		Numerous	
Blida	02.03.1825	X		About 7000	
fZamora El Guenzet	09.02.1850	VIII			
Mascara	22.11.1851	VII-VIII			
Jijel Bejaia	22.08.1856	IX-VIII			
Mouzaia	02.01.1867	X-XI		About 100	
Biskra	16.11.1968	IX			
N'Gaous	19.01.1885	VIII			
Mansoura	08.01.1887	VII			
Kala	29.11.1887	IX-X		20	
Mouzaia	06.01.1888	VIII			
Gouraya	15.01.1891	X	7.5	38	Destructor
Blida	11.03.1908	VII-VIII			
Constantine	04.08.1908	VIII	5.1		
Masqueray	24.01.1910	X	6.4		
Sour. el Ghouzléne (Aumale)	24.06.1910	X (VIII)	6.4/ 6.6	30	Important damage
Oued Marsa	06.08.1912	VI	5.3		
A. el Hassan (Cavaignac	25.08.1922	IX-X	5.1	2	Destructor
Batna	16.03.1924	IX	5.6	several	
Near Algiers	05.11.1924	VIII	5.0		
Near Boghar	10.01.1925	VIII			
Oued Rhiou	24.08.1928	VIII	5.4	4 dead	
Djebel Dira	15.08.1931	VIII	4.9		
El Abadia (Carnot)	07.09.1934	IX (VII)	5.0	None	Damage
Near Chetaibi	19.09.1935		5.1		
Near Guelma	10.02.1937	VIII	5.4		
Near Mansoura	16.04.1943	IX	4.0		

M=Magnitude ; **Io**= maximum intensity; FM= Focal Mecanism ; Mercalli Scale

Table 2.1 : Majors quakes of Algeria between 1365 and now (continued)

Localité	Date	Io	M	Victims	Observations
Hodna Mountain	12.02.1946	VIII-IX	5.6	246	
Oued Hama	06.08.1947	VIII-IX	5.3	Many	
Asla	13.03.1948	VIII	4.9		
Near Kerrata	17.02.1949	VIII	4.9		
Near Aflou	20.04.1950	VI-VII	5.1		
Near Ain Bessam	05.07.1953	VIII			
Hotdna Mountains	29.08.1953	VIII-IX		1	
Chlef (Orléansville-ElAsnam)	09.09.1954	X-XI	6.7	1243	Destructor
Zamora, El Guenzet	24.05.1959	VII-VIII	5.5		
Bou Medfa	07.11.1959	VIII	5.5		
Béjaia	12.02.1960	VIII- IX	5.6	264	1000 houses destroyed
M'sila	21.02.1960	VIII	5.6	47	Damage
Annaba (at sea)	02.12.1961		5.5		
Near Setif	04.09.1963		5.7	1	
M'sila	01.01.1965	VIII	5.5	5	1300 houses destroyed
Ames	05.02.1971		5.9		
Mansourah	24.11.1973	VII	5.1	4	Damage.
Setif	11.07.1975	VIII	5.0	1	18 injured
Chlef	10.10.1980	IX	7.3	2633	Destructor
Constantine	27.10.1985	VIII	5.9	0010	Little damage
El Affroun	31.10.1988	VII	5.4	none	Many damages
Dj. Chenoua	29.10.1989	VIII	6.0	22	Many damages
Mascara	18.08.1994	VII	5.6		Important damages

M=Magnitude ; **Io**= maximum intensity; FM= Focal Mecanism ; Mercalli Scale

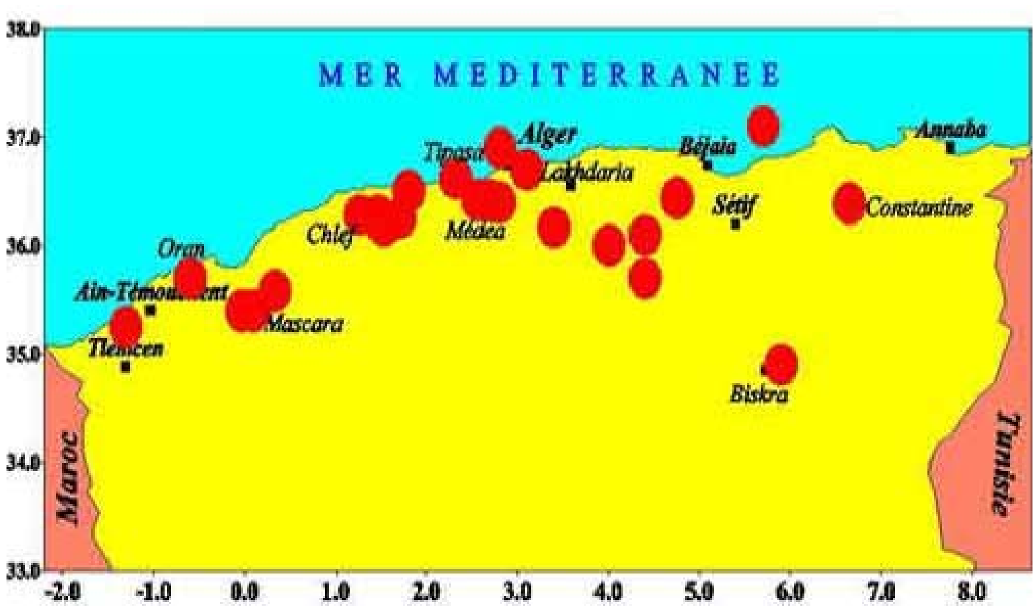

Figure 2.3: Majors quakes of Algeria between 1365 and 2000

Earthquakes in North Algeria are in majority related to thrust-faulting which illustrate the movements in compression along the limit of the plates Africa-Europe (Meghraoui, 1988). From the historical seismic activity, the most severe earthquake which affected the area of Algiers dates from February 3, 1716 and reached an intensity of X (Rossi).

Figure 2.3 shows the majors quakes of Algeria between 1365 and 2000. Furthermore, Figure 2.4 shows the majors quakes, which occurred in the 20th century.

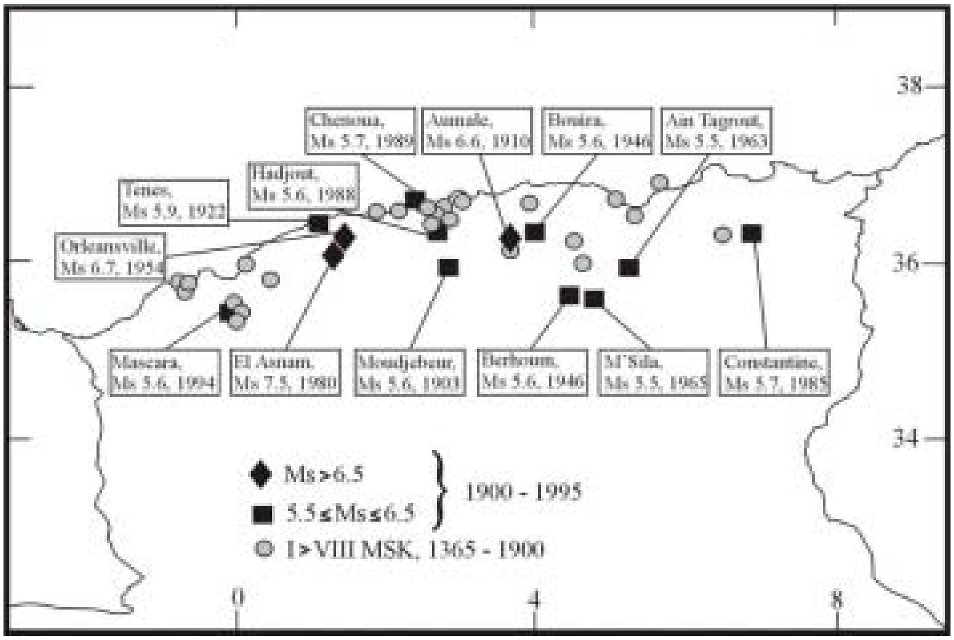

Figure 2.4: Majors quakes of Algeria in the 20th century .

As for the historical seismic activity of the region of immediate surrounding of Boumerdes, reported by the various publications published so far, shows that the earthquakes which affected this area are moderated or slightly strong. However, Boumerdes city did not know any important events similar to that of the 21 May 2003 with a magnitude of: Ml = 6.2, MW = 6.8.

2.4 Boumerdes Earthquake

On May 21, 2003 at 19:44:19 local time the Boumerdes earthquake struck the Zemmouri region in northern Algeria. Zemmouri is approximately 70 km east of the capital, Algiers. The moment magnitude of this event is 6.8. The location of epicenter is 36.90N 3.71E determined by U.S.G.S. The focal depth of the earthquake was about 10 km. Figure 2.5 shows the location of affected area by the earthquake. This earthquake was the biggest earthquake to hit Algeria since 1980.

However, the Thenia fault is a major active structure in the fault zone, the earthquake was generated by an unknown offshore reverse fault. It is oriented N 35 and extents about 40km from Dellys to Corso. This fault was named Zemmouri fault after the earthquake. The Thenia and Zemmouri faults are shown in Figure 2.6. This fault caused the uplift of the coastal region.

Figure 2.5: Location of affected area by the earthquake

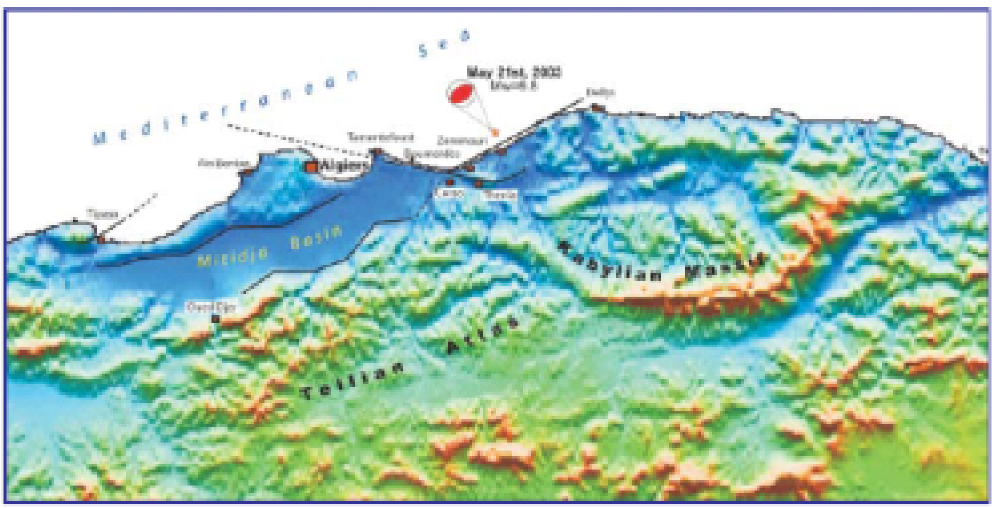

Figure 2.6: Zemmouri and Thenia fault

On June 1, the Government of Algeria reported that the earthquake killed 2,278, wounded 11,450, and left approximately 200,000 people homeless. The worst-affected cities include Bourmedes, Zemmouri, Thenia, Belouizdad, Rouiba, and Reghaia. The earthquake disrupted health services, water supply lines, electricity, and telecommunications in the region.

2.4.1 Characteristics of the 21st May Earthquake

The earthquake occurred in the boundary region between the Eurasian plate and the African plate. Along this section of the plate boundary, the African plate is moving northwestward against the Eurasian plate with a velocity of about 4-6 mm/year as shown in figure 2.2. The relative plate motions create a compressional tectonic environment, in which earthquakes occur by thrust-faulting and strike-slip faulting. Analysis of seismic waves generated by this earthquake shows that it occurred as the result of thrust-faulting.

This earthquake is among the major quakes of the Western Mediterranean. It was felt very largely to the coasts of the Northern Mediterranean (Nice area and Genoa). The observation of a wave tsunami in the Balearic Islands (Spain), but also on the French coast seems to confirm that the localization of this earthquake is at the sea, as this wave is due to the movement even along the fault which may have caused the destruction of the underwater cables.

Mr. Meghraoui provided a preliminary image of the localization of the damage in the area of Algiers. Figure 2.7 shows the principal active thrust faults, their extension at sea and the zone of the major damage following the Boumerdes earthquake.

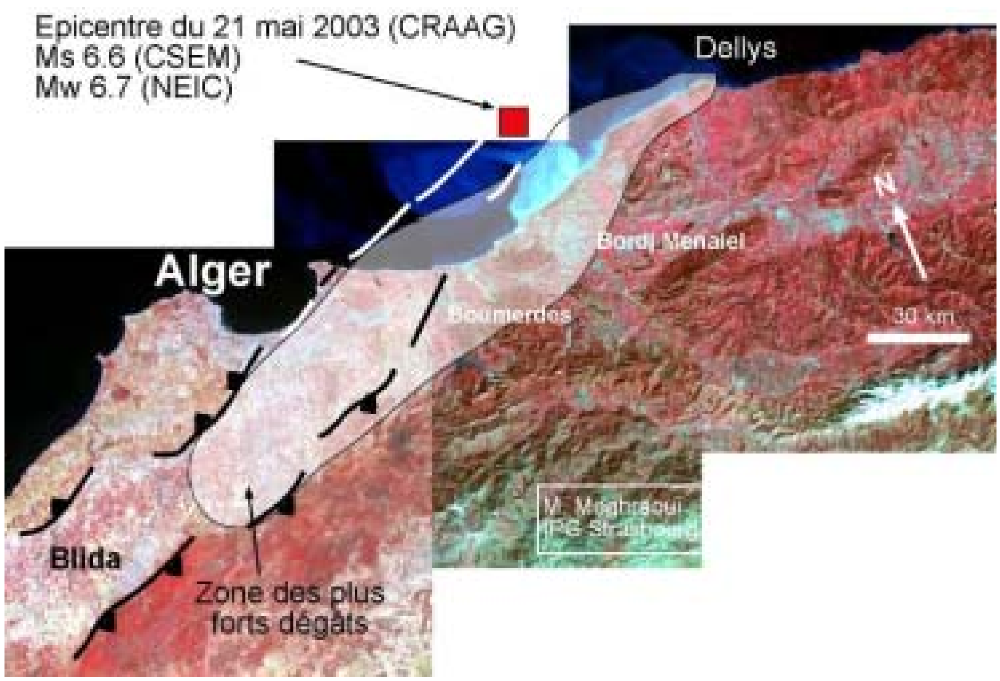

Figure 2.7: The principal thrust fault and the affected region.

2.4.2 Fault Mechanism

The earthquake occurred in the boundary region between the Eurasian plate and the African plate (Figure. 2.2), which is in a compression state. Therefore, the earthquake which occurs in this area is mostly caused by a reversed fault or strike slip fault.

The focal mechanism of the main shock, the total moment-rate function and the distribution of co-seismic slip are shown in Figure 2.8. Two asperities are recognized by this figure. Figure 2.9 shows the snapshots of fault dislocation. From this figure, it is clear that the rupture process on the fault plain is asymmetric bilateral rupture propagation. The rupture mainly propagated 30 km to the southwest and 20 km northeast and extended to the ground surface. The maximum dislocation is about 2.3 m and located near the ground surface.

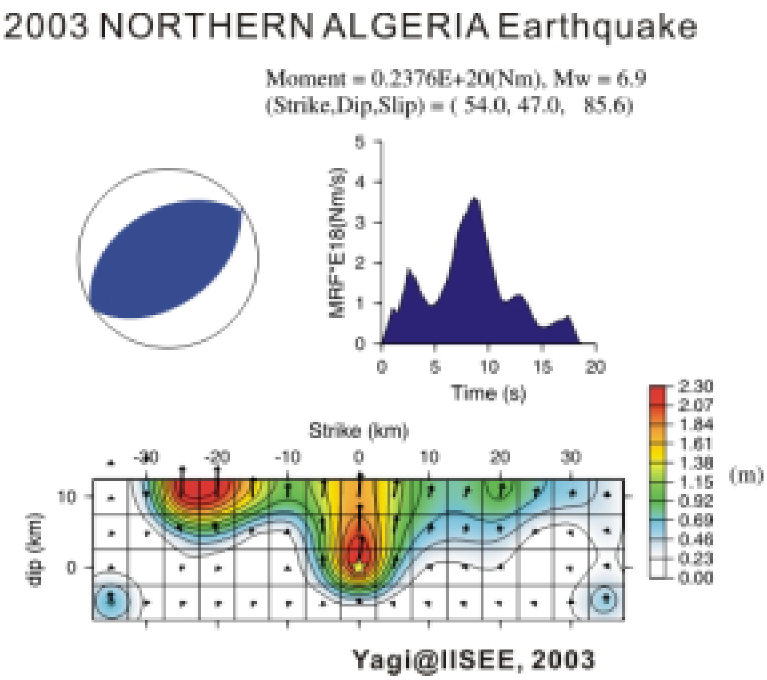

Figure 2.8: Focal mechanism, Total moment-rate function and Slip distribution by Yagi.

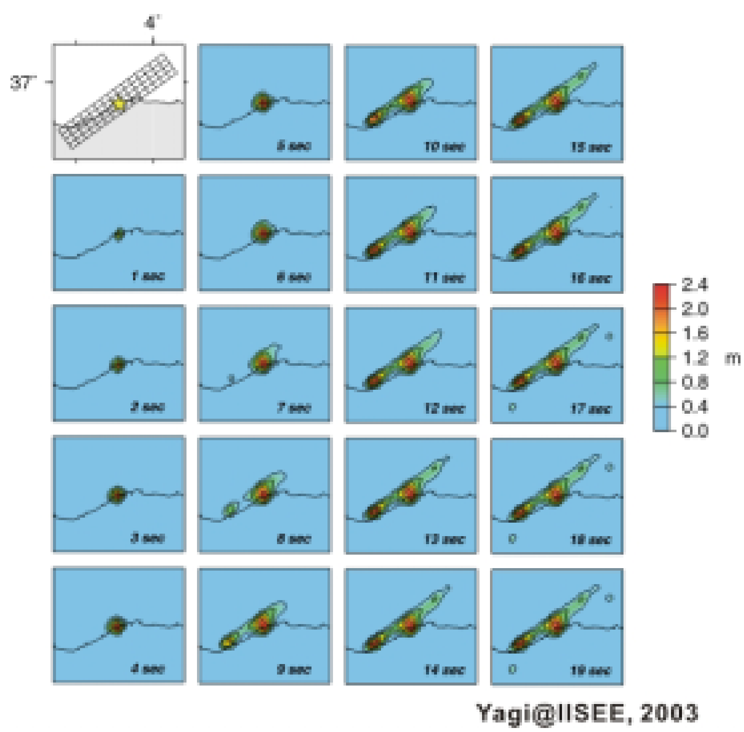

Figure 2.9: Snapshots of fault slip by Yagi.

2.4.3 Distribution of Seismic Intensity

The detailed distribution of the seismic intensity near the fault is not yet cleared. Here, the distribution of the JMA (Japan Meteorological Agency) Seismic Intensity calculated using the records described in the following chapter is shown in Figure 2.10. Unfortunately since the record of the main shock was not obtained, the JMA Seismic Intensity in Boumerdes where suffered from the most serious damage.

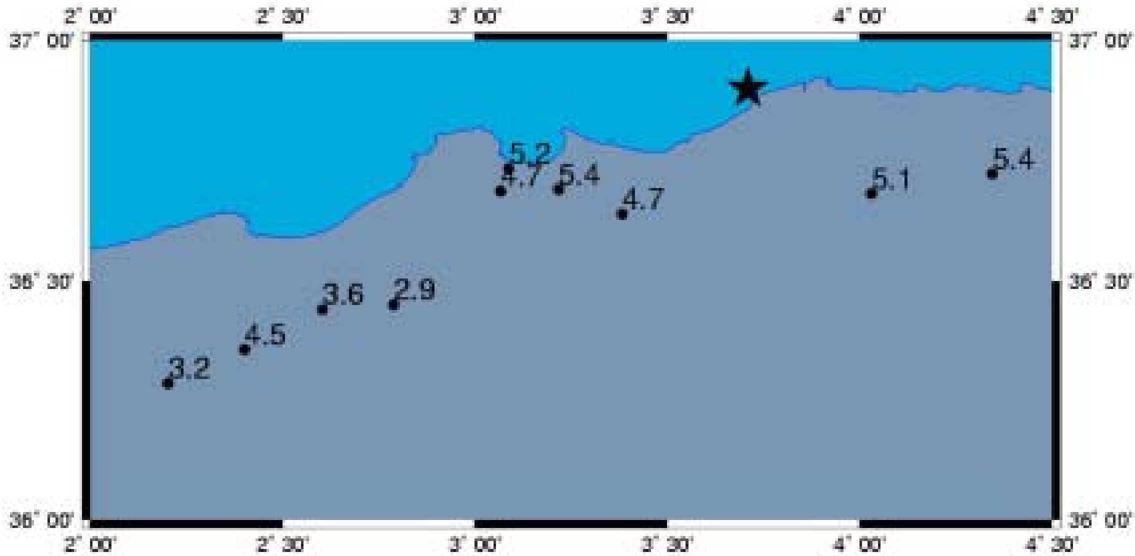

Figure 2.10: Distribution of JMA Seismic Intensity

2.4.4 Ground Motion Records including Response Spectrum Analysis

Many stations of the national accelerograph network monitored by CGS recorded the main shock. The list of recorded ground motions during main shock is shown in Table 2.2. In addition, the epicenter distance and PGA are shown in this Table. Figure 2.11 shows the location of the stations. The ground condition where each station is located is not clear.

The closest station to the epicenter is Keddara No.1. There is also Keddara No.2 station which is close to Keddara No.1 and the distance of these two stations is about 150 m. Peak ground accelerograms recorded at Keddara No.2 are as follows:

E-W: 0.58 g N-S: 0.35 g U-D: 0.22 g

The maximum PGA of the main shock is 0.58g, which recorded at Keddara No.2 station, but the accelerogram of this record is not distributed by C.G.S. Thus, the characteristics of this record are unknown.

Accelerograms and response spectra of the ground motion records listed in Table 2.2 are shown in Figure 2.12 to 2.21.

Table 2.2: List of recorded strong ground motions and those PGA

Station Name	D(km)	E-W (g)	N-S (g)	U-D (g)
KEDDARA No.1	19.7	0.34	0.25	0.26
DAR EL BEIDA	27.0	0.52	0.46	0.16
HUSSEIN DEY	36.8	0.27	0.23	0.09
KOUBA	40.0	0.31	0.16	0.25
TIZI OUZOU	46.7	0.20	0.19	0.09
BLIDA	73.9	0.05	0.04	0.03
AZAZGA	75.0	0.12	0.09	0.05
EL AFROUN	90.2	0.16	0.09	0.03
HAMMAM RIGHA	110.1	0.10	0.07	0.06
MELIANA	129.5	0.03	0.026	0.02

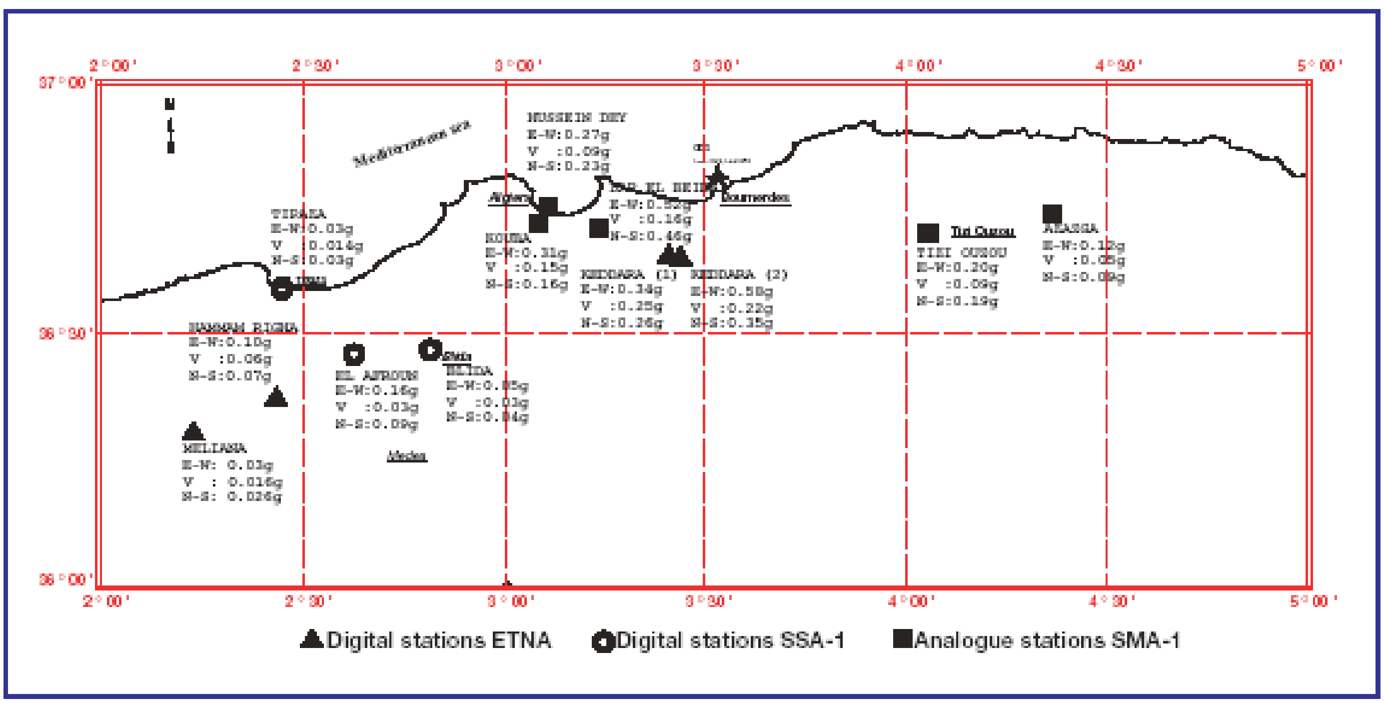

Figure 2.11: Locations of stations and the recorded PGA by C.G.S.

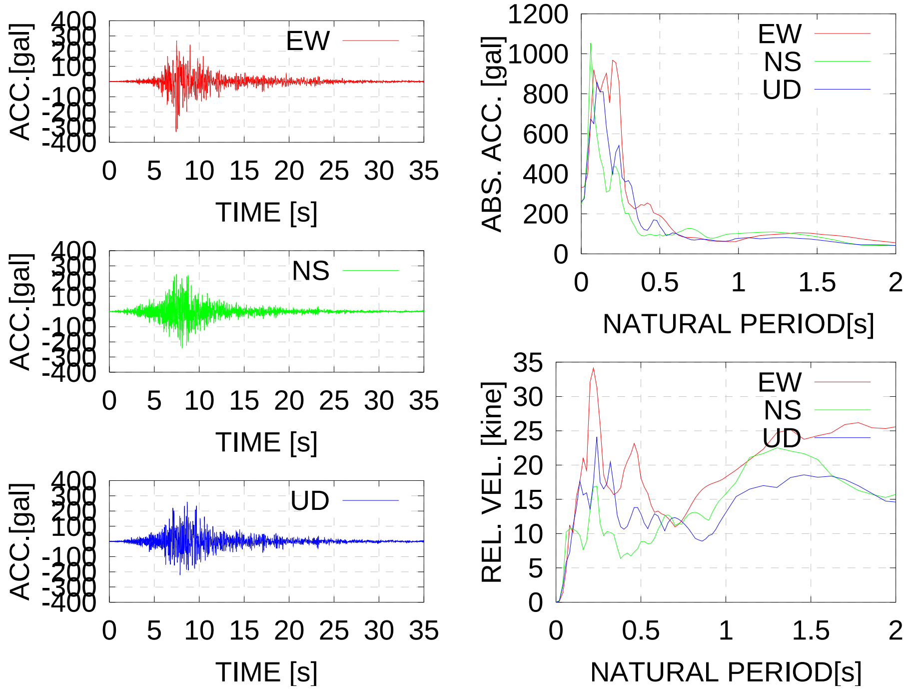

Figure 2.12: Ground motions record at Keddara No.1 and the corresponding response spectra

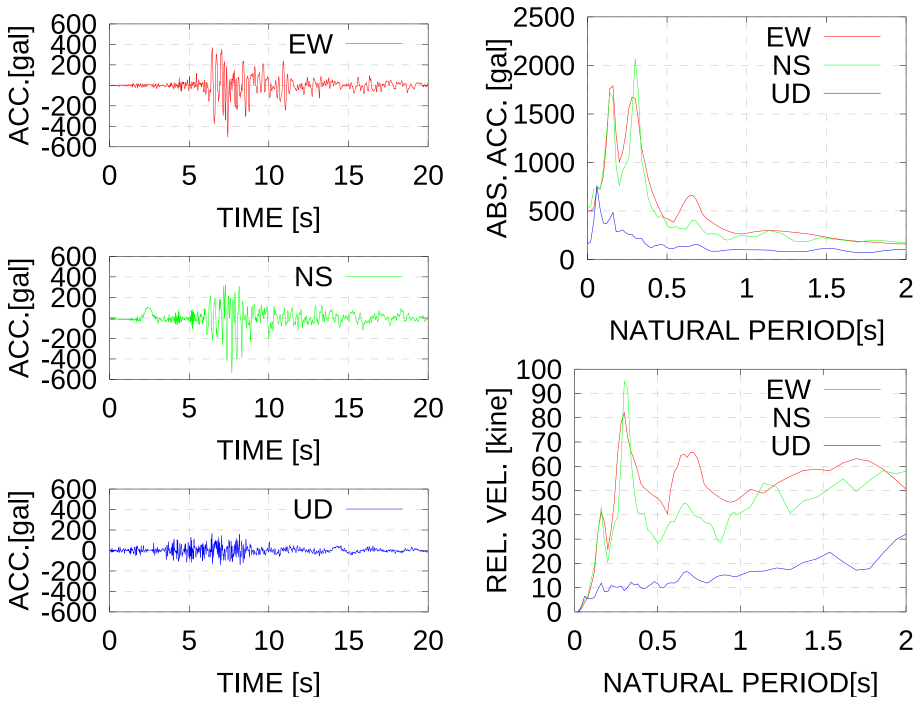

Figure 2.13: Ground motions record at DAR EL BEIDA and the corresponding response spectra

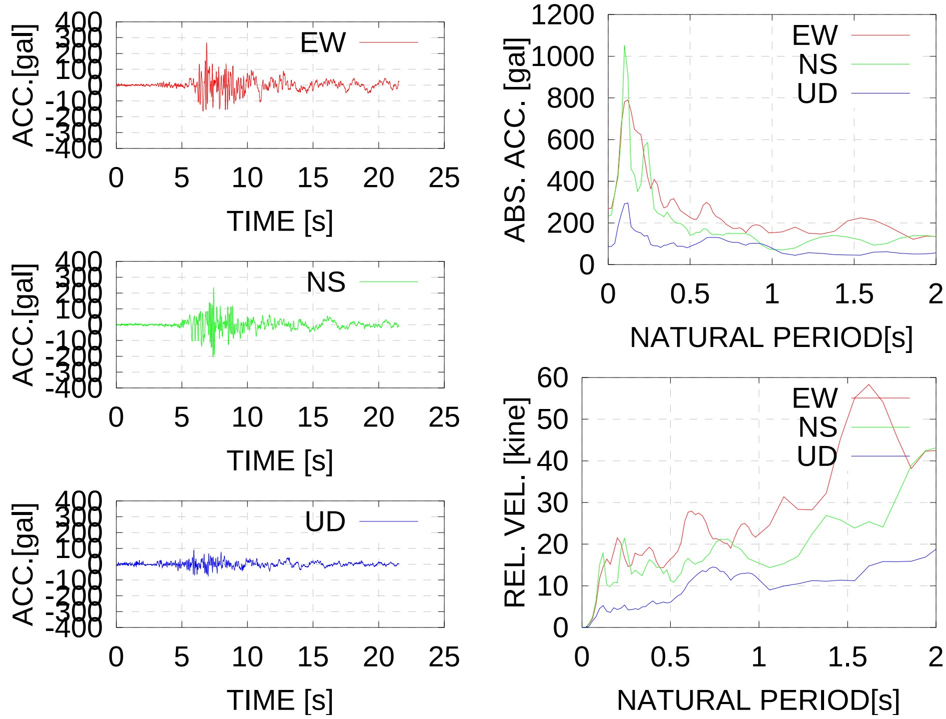

Figure 2.14: Ground motions record at HUSSEIN DEY and the corresponding response spectra

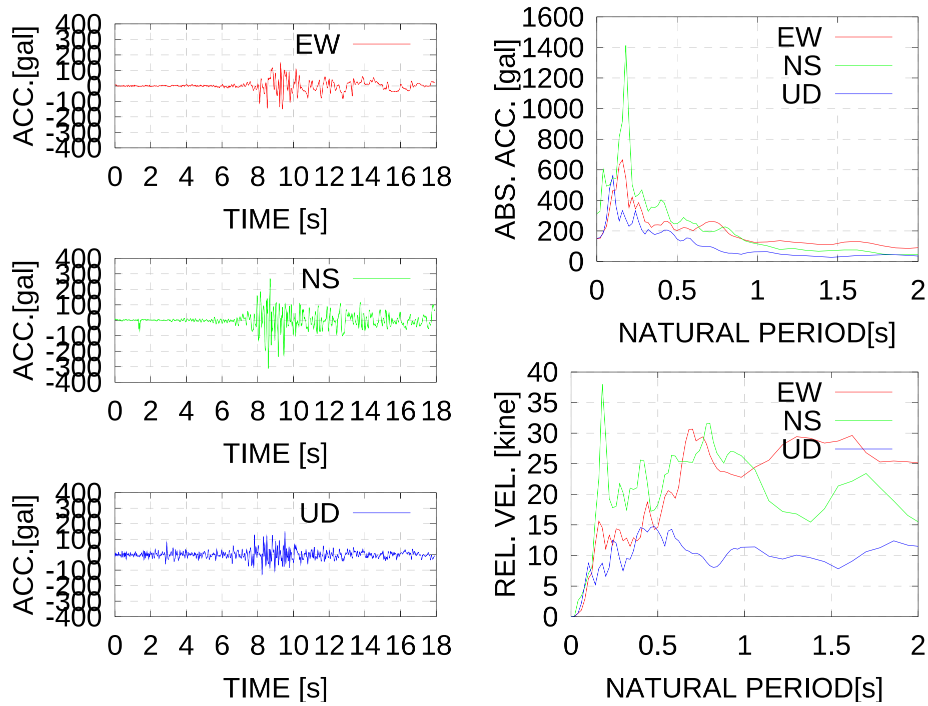

Figure 2.15: Ground motions record at KOUBA and the corresponding response spectra

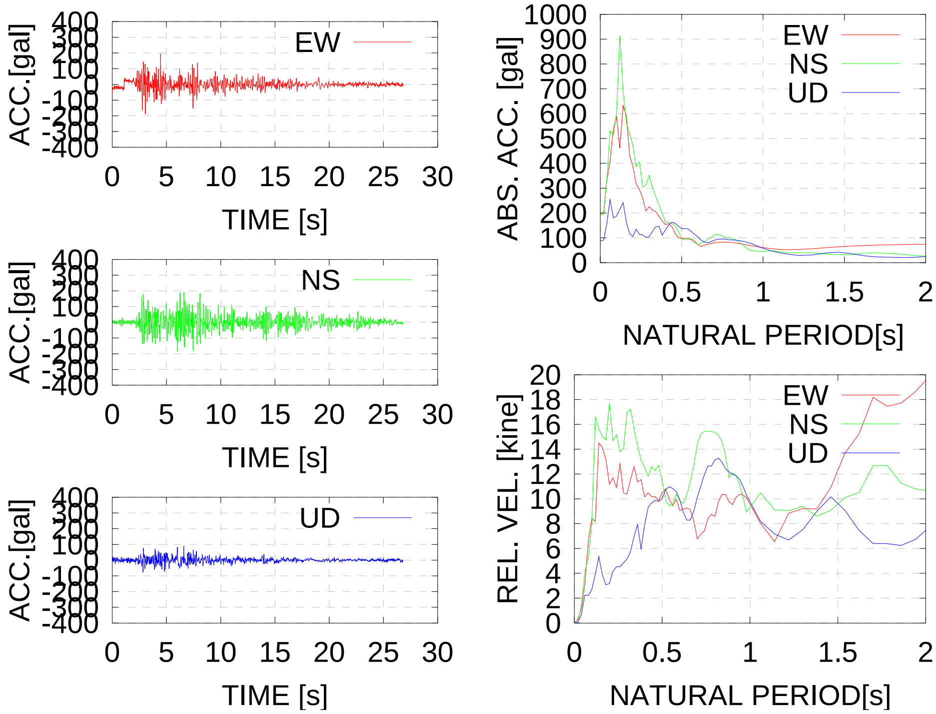

Figure 2.16: Ground motions record at TIZI OUZOU and the corresponding response spectra

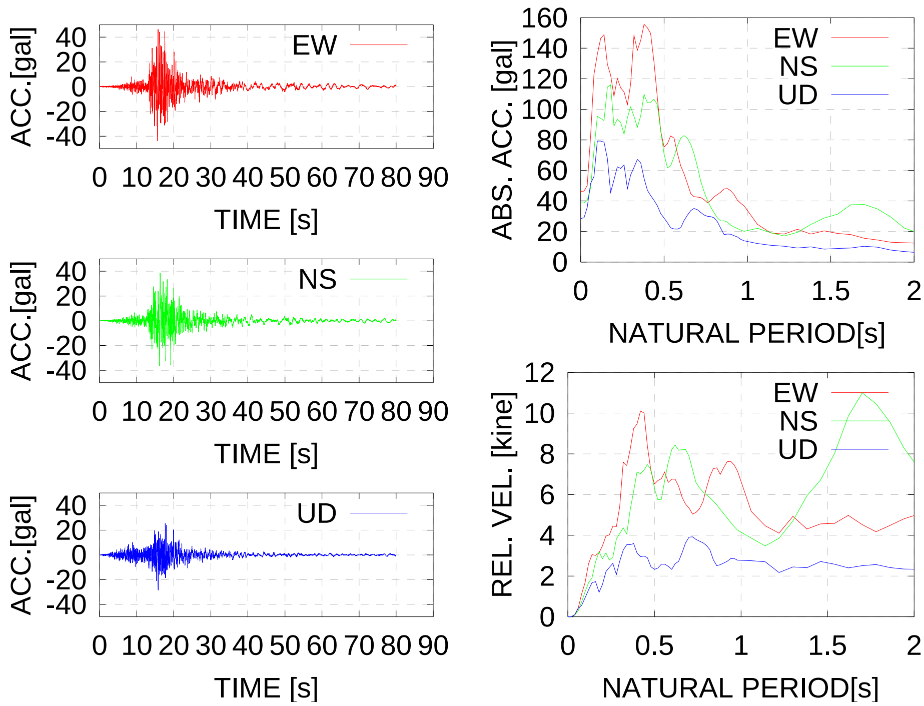

Figure 2.17: Ground motions record at BLIDA and the corresponding response spectra

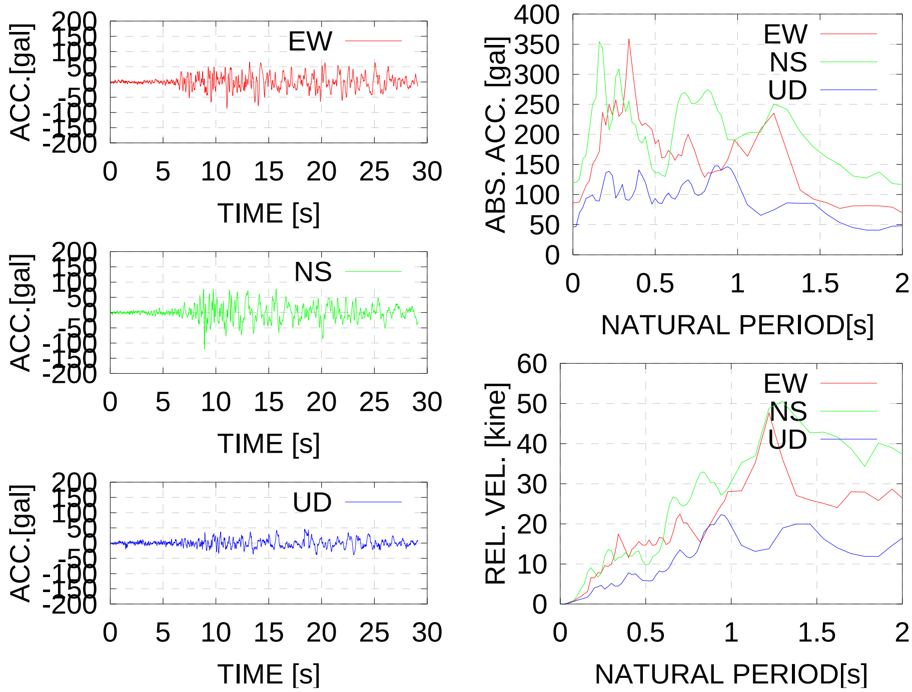

Figure 2.18: Ground motions record at AZAZGA and the corresponding response spectra

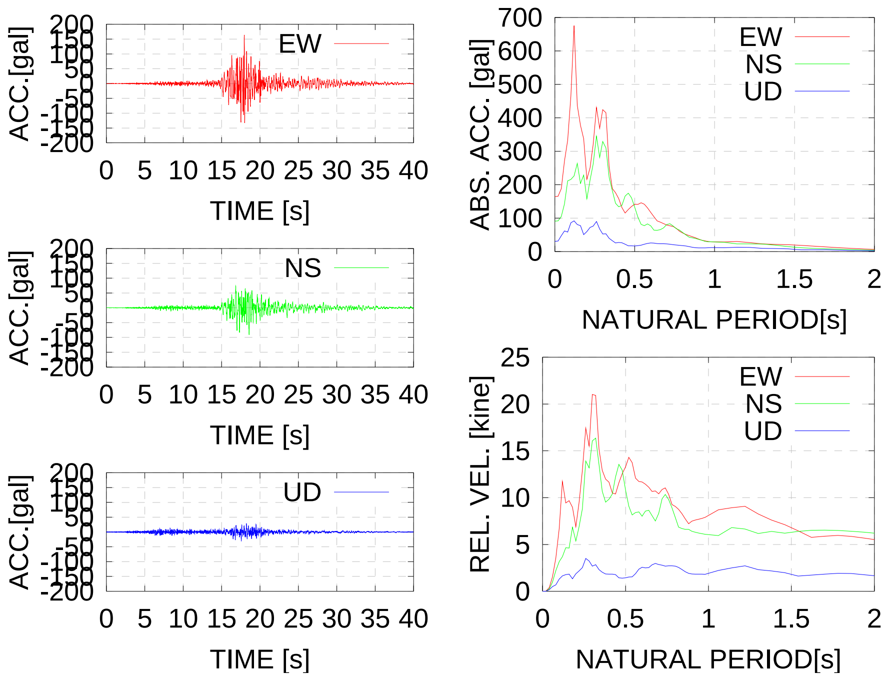

Figure 2.19: Ground motions recorded at EL AFROUN and the corresponding response spectra

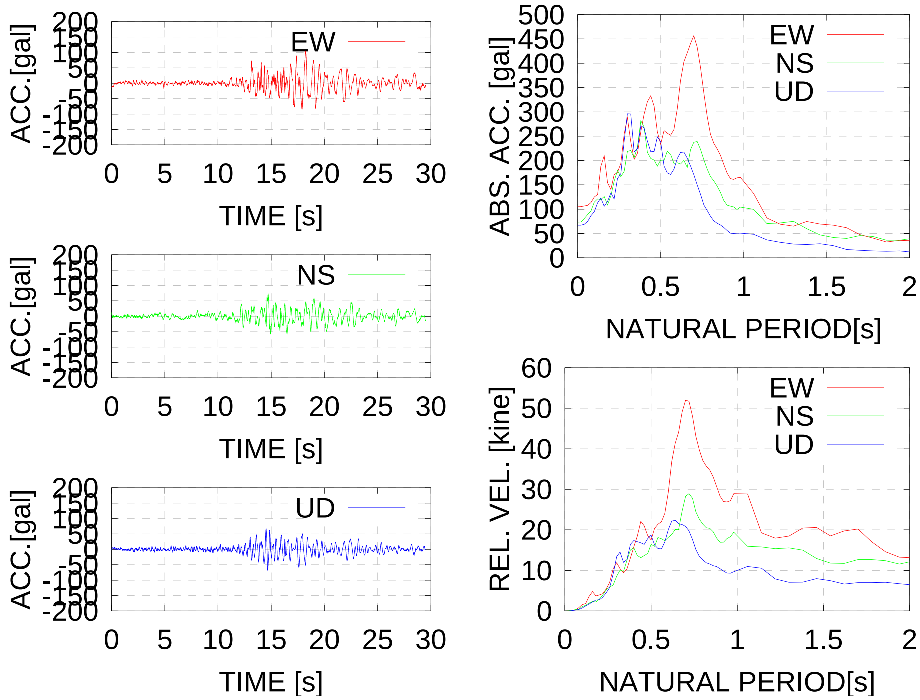

Figure 2.20: Ground motions record at HAMMAN RIGHA and the corresponding response spectra

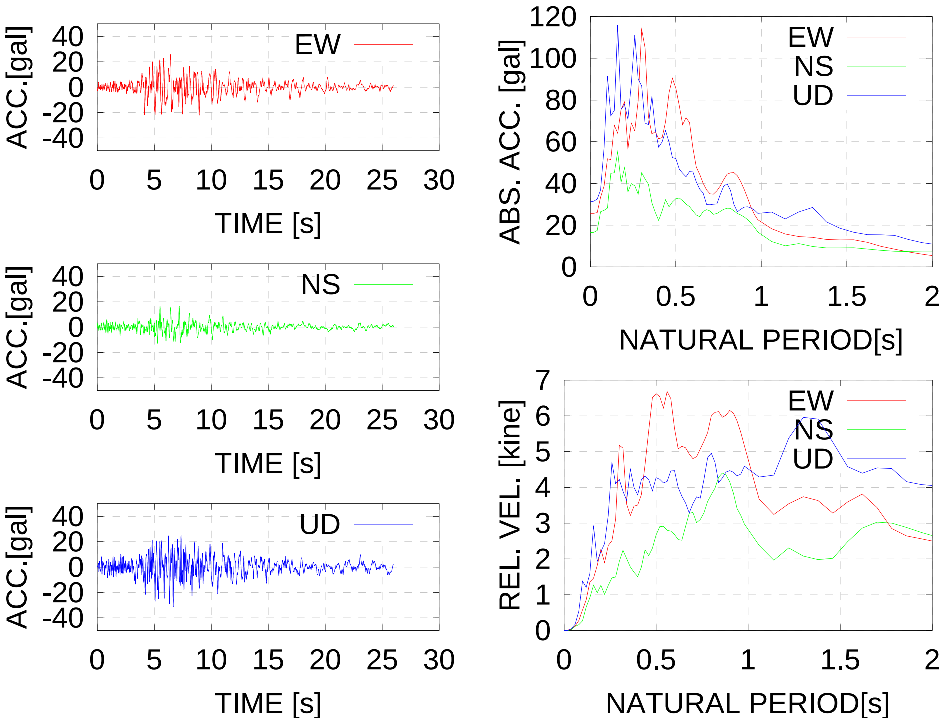

Figure 2.21: Ground motions record at MELIANA and the corresponding response spectra

2.5 Damage Statistics

In addition to the number of people killed, wounded and/or left homeless, the earthquake interrupted medical services, water supply lines, electricity, and telecommunications in the region. The following cities are declared disaster zones by the central government decree of May 24, 2003

Boumerdes Prefecture: Cities of Boumerdes, Corso, Tidjalabine, Zemmouri, Bordj-Menaeil, Djinet, Legata, Boudouaou, Ouled-Hadadj, boudouaou-El-Bahri, Dellys, Benchhoud, Sidi-Daoud, Baghlia, Thenia, Béni-Amrane, Isser, Si-Mustapha, Timezrit, Ouled Moussa, Hammadi, Khemis-El-Khechna et Naceria.

Alger Prefecture : Cities of Rouiba, Réghaia, Heuraoua, Ain-Taya, Bordj el Bahri, Bordj-El-Kiffan ; et parts of Dar-El-Beida, Mohamadia, Bab-Ezzouar, El-Marsa, Baraki, Eucalyptus, Sidi Moussa, Birtouta, Hussein-Dey, Belouizded, Magharia, Kouba, Gué de Constantine, Saoula, Birkhadem, Draria, El-Harrah, Bourouba, Badjarah et Oued Smar.

Tizi-Ouzou Prefecture : Cities of Sidi Naamane, Tigzirt et Tadmait.

Soon after the quake, the Ministry of Housing and Construction directed several organization and research centres to investigate the engineering aspects of the earthquake and to assess the damage caused by the earthquake. Accordingly, 728 engineers from the Ministry of Construction (CTC, CGS, CNERIB, DLEP and OPGI) were mobilized. In addition to that 626 other engineers and architects from other sectors joined for assessing the damaged area. A total of 243 brigades (a brigade is about 10 engineers with a leader and a deputy leader) were deployed throughout the 53 cities as declared disaster zones.

The assessment was carried out by investigating every structure using an evaluation form for the quick inspection, named as phase A. The first task of this field investigation was to classify all buildings into one of the categories shown in Table 2.3.

Table 2.3: Categories of building damage

Category	Damage state
Green	Very little damage. Can be reoccupied immediately.
Orange	Needs further study before it can be either occupied or condemned.
Red	Condemned and should be demolished.

In phase B a thorough investigation of the Orange tags is carried out to determine whether the structure is to be repaired and occupied or to be demolished.

Based on the investigation, the number of damaged buildings and the corresponding classification as of the 23 June 2003 are shown in Table 2.4 and 2.5, respectively. A total of 181658 buildings were investigated.

A total of 6181 public structures were investigated. Details and the corresponding classifications of these investigated public structures are shown in Table 2.6 and 2.7, respectively. Public structures include schools, official buildings, hospitals, sports and cultural buildings, commercial buildings, industrial and warehouse buildings and others.

Table 2.4: Numbers of Damaged Buildings

Prefecture	Number of damaged buildings
Alger	94328
Boumerdes	66869
Blida	4093
Tizi Ouzou	9238
Tipaza	1694
Bouira	4457
Bejaia	837
Medea	142

Table 2.5: Buildings investigated and the corresponding classification (tags)

Classification	Green	Orange	Red	Collapsed
Alger	41811	44783	7734	338
Boumerdes	37310	21582	6239	1420

Table 2.6: Damaged Public Structures

Prefecture	Number of damaged public structures
Alger	2943
Boumerdes	1875
Blida	147
Tizi Ouzou	1031
Tipaza	32
Bouira	126
Bejaia	15
Medea	12

Table 2.7: The corresponding classifications of investigated public structures

Classification	Green	Orange	Red
Alger	1084	686	105
Boumerdes	1706	946	291

As for human losses and injuries, the distribution of the casualties with respect to the declared disaster zones (prefectures) and other prefectures is shown in Table 2.8 and Figure 2.22.

It is clear that the most affected prefectures are Boumerdes and Alger.

Table 2.8: Numbers of death and injured persons (as of June 21, 2003)

Prefecture	**Deceased persons**	**Injured persons**
Boumerdes	1382	3442
Alger	883	6787
Tizi -ouzou	07	261
Bouira	02	127
Béjaia	02	03
Blida	02	709
Médéa	00	121
TOTAL	**2278**	**11450**

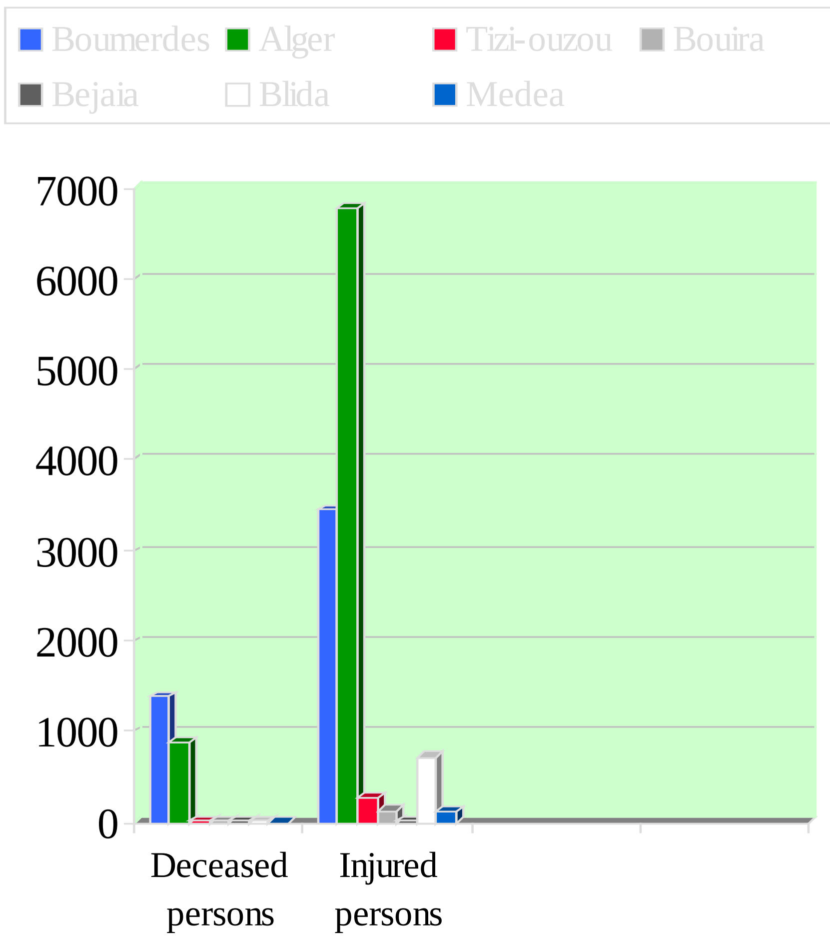

Figure 2.22: The distribution of the casualties with respect to the Prefectures

Furthermore, Figure 2.23 and Figure 2.24 show the distribution of the casualties with respect to the gender and age of deceased people, respectively. It can be noticed that female victims percentage is higher than that of male. Moreover, since Boumerdes is a young Prefecture and town developed in the early 80's where several Universities and Institutes were built, the number of young casualties is extremely high. At the same time this may reflect the Algerian demography.

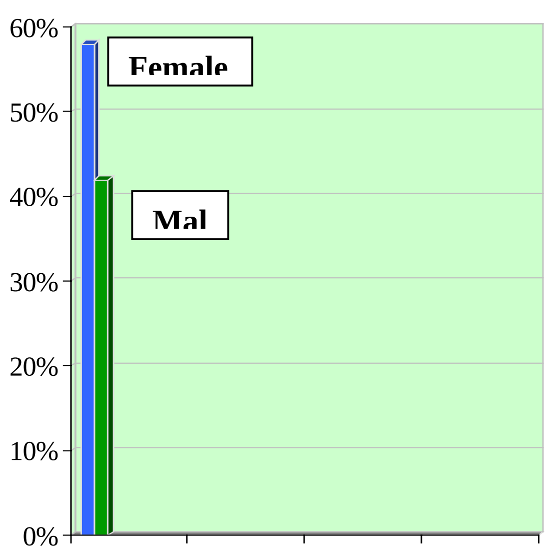

Figure 2.23: the distribution of the casualties with respect to the gender.

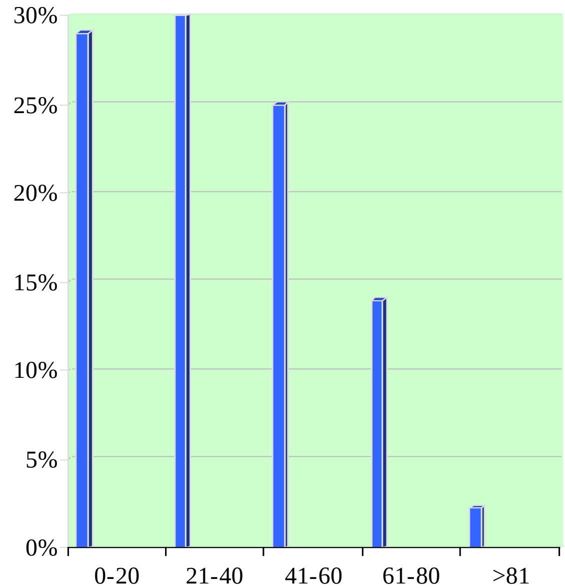

Figure 2.24: the distribution of the casualties with respect to the age.

2.6 Conclusion

On May 21, 2003 at 19:44:19 local time the Boumerdes earthquake struck the Zemmouri region in northern Algeria. Zemmouri is approximately 70 km east of the capital, Algiers. The moment magnitude of this event is 6.8. The location of epicenter is 36.90N 3.71E determined by U.S.G.S. The focal depth of the earthquake was about 10 km. The earthquake occurred in the boundary region between the Eurasian plate and the African plate, which is in a compression state. Earthquakes that occur in this area are mostly caused by a reversed fault or strike slip fault. And this tremor is among the major quakes of the Western Mediterranean.

On June 1, the Government of Algeria reported that the earthquake killed 2,278, wounded 11,450, and left approximately 200,000 people homeless. The worst affected cities include Bourmedes, Zemmouri, Thenia, Belouizdad, Rouiba, and Reghaia. The earthquake disrupted health services, water supply lines, electricity, and telecommunications in the region.

The sheer intensity of the earthquake demanded significant amounts of money, in addition to significant manpower that was beyond the Algerian capacity alone and was in need of assistance for rebuilding the affected region.

2.7 References

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- CGS, National Earthquake Engineering Centre, http://www.cgs-dz.org/

Chapter 3

Liquefaction and Geo-Related Failure

3.1 Overview

Serious damage induced by soil liquefaction occurred in the basin of the Isser and Sebaou Rivers. They are located at about 40km eastward from Alger; the capital of Algeria. Figure 3.1 shows a topographical map of the stricken area and the epicenter of this earthquake as reported by USGS. The locations of liquefied sites found by the investigation team of the National Research Center of Earthquake Engineering in Algeria (CGS) are also shown in Figure 3.1. Based on the relationship between the limit distance of occurrence of liquefaction and the magnitude of Japan Meteorological Agency M_{JMA} as given in Eq.(1) (Kuribayashi and Tatsuoka), the limit distance was estimated and found to equal approximately 40 km.

$$\mathrm{Log}_{10}R = 0.77M_{JMA} - 3.6 \qquad \text{Eq.(1)}$$

Substituting the surface wave magnitude M_s (6.8; specified by USGS) for the JMA magnitude, it is found that all of the liquefaction sites shown in Figure 3.1 are located within the limit distance from the epicenter. The results of investigation conducted by our team at three sites are described in this chapter.

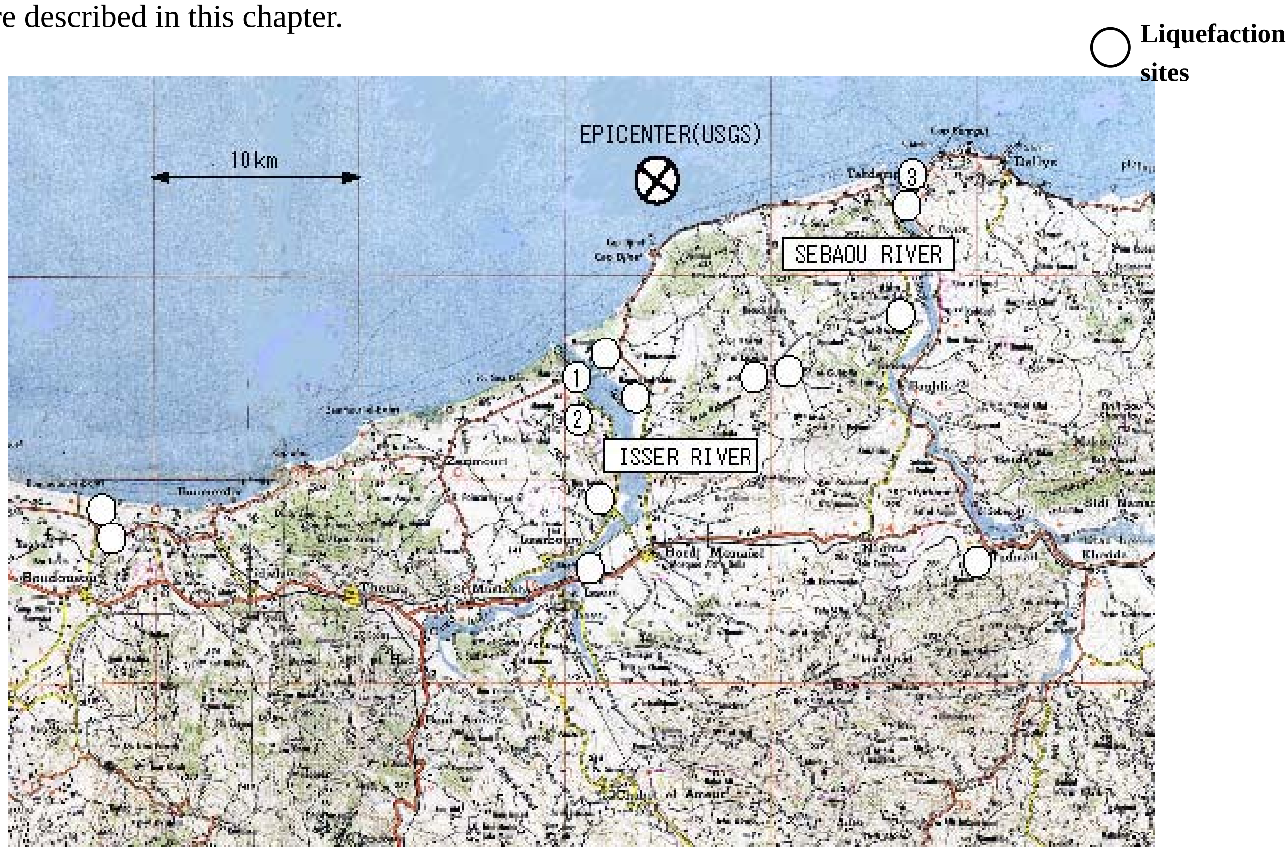

Figure 3.1: Locations of liquefaction sites observed in this earthquake.

3.2 Basin of the Isser River

3.2.1 Bridge of National Road No.24 crossing over the Isser River

Figure 3.2 shows a geological map in the basin of the Isser River. The damage due to liquefaction occurred at the flood plain whose width was about 5 km along the river.

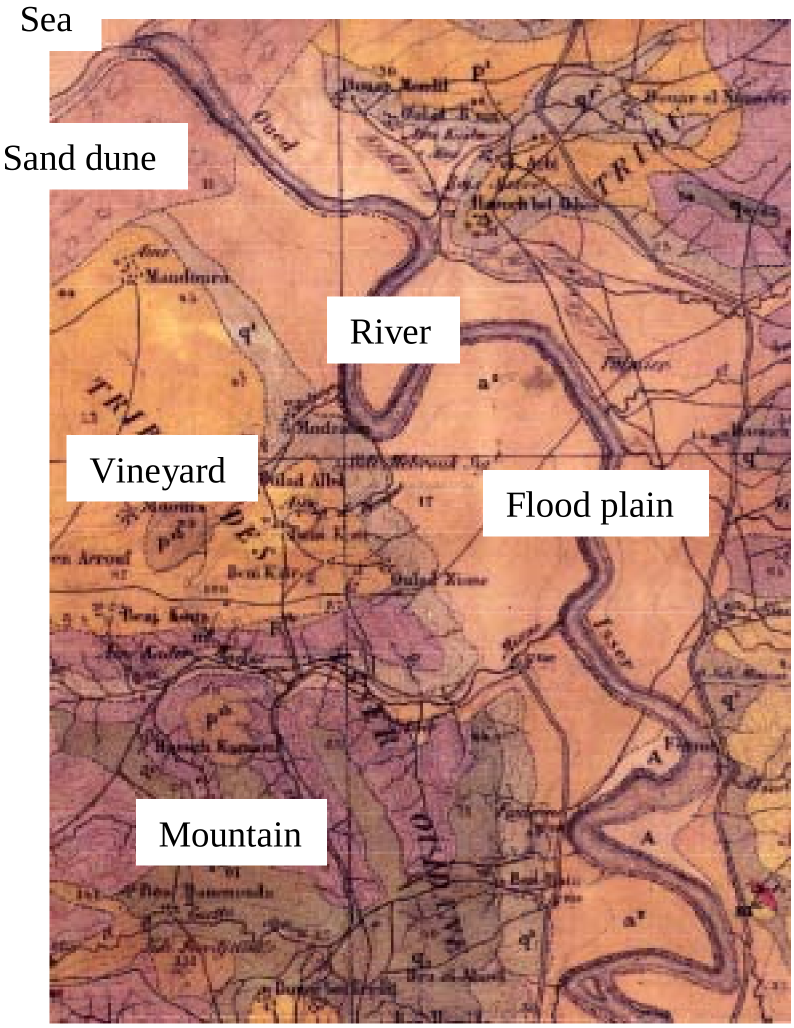

Figure 3.2: Geological map of the basin of the Isser Bridge.

The lateral flow induced by the liquefaction occurred at the bridge of the National Road No.24 crossing over the Isser River at the Point 1 shown in Figure 3.1. The bridge is 454 m in length and consists of thirteen concrete girder spans supported on twelve concrete piers as shown in Figure 3.3.

Figure 3.3: Overview of the bridge crossing over the Isser River.

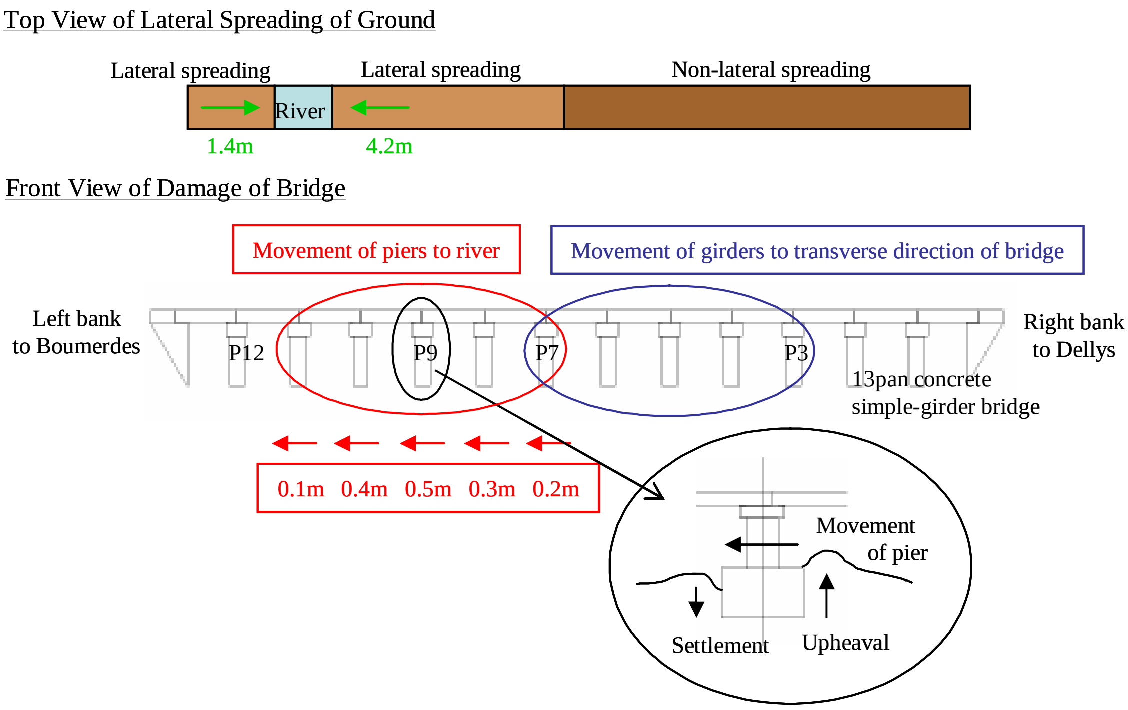

Figure 3.4: Overview of the bridge crossing over the Isser River and the corresponding damage.

Figure 3.4 illustrates the overview of the damage to the bridge and the surrounding ground. Girders between piers P3 and P7 moved in the transverse direction of the bridge. The maximum displacement was about 20 cm as shown in Figure 3.5. The finger-typed expansion joints were also broken by shearing and/or pounding of the girders as shown in Figure 3.6. It is considered that the movement of the girders was reduced by an effect of restrainers installed at the top of the piers and the bottom of the girders. As a result, many restrainers made of concrete blocks were damaged by colliding between each other as shown in Figure 3.7.

Figure 3.5: Movement of the girder to the transverse direction of the bridge.

Figure 3.6: Damage to the finger-typed joints between the girders (Photo Provided by CGS)

Figure 3.7: Damage to the restrainers.

The gap between the girders' joint and the center of the bridge seat in the axial direction of the bridge at the pier P9 as shown in Figure 3.6. The relative displacement was about 50 cm. The displacements at the other piers were drawn as the movement of the pier as shown in Figure 3.4.

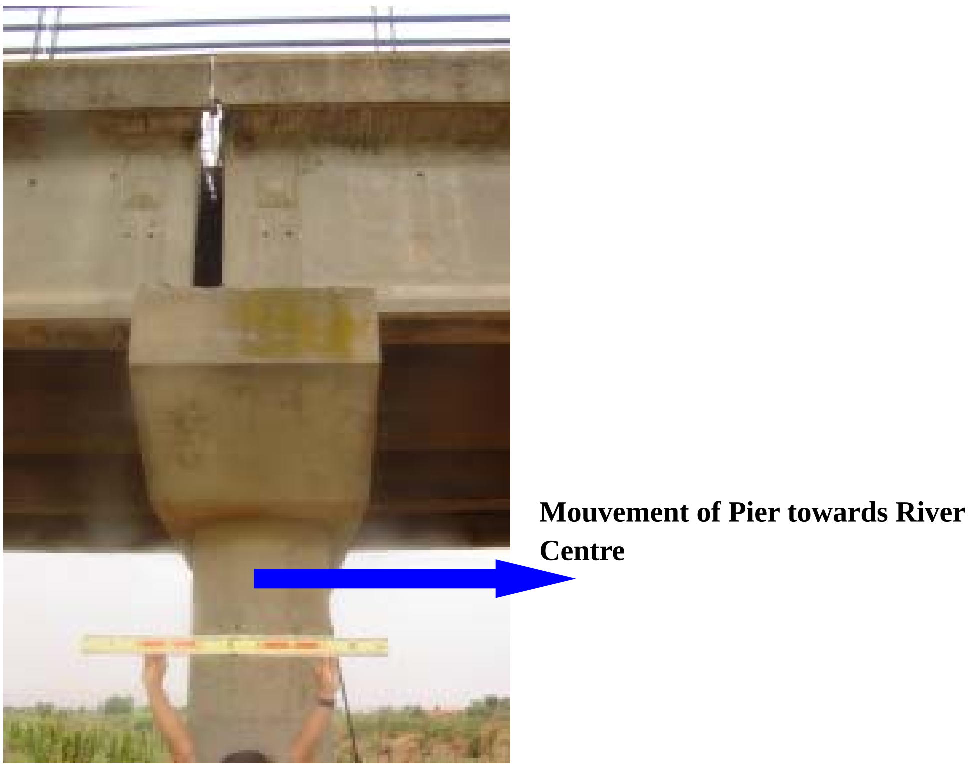

Figure 3.8: Relative displacement between the girder and the pier.

These gaps mentioned above seem to be primarily due to river-ward movement of liquefied soils. Figure 3.9 shows many fissures around the pier P9 at the left side of the bank. The ground moved toward the river. Figure 3.10 shows the difference in level of the ground behind the fissures. It seems that the movement of the ground induced the settlement. The lateral displacement of the ground at the right side of the bank was about 4.2 m, which was measured as the amount of crack width parallel to the river.

Figure 3.9: Fissures and lateral spreading of the ground.

Figure 3.10: Difference in the level of the ground behind the fissures.

Figure 3.11 shows the gap between the ground and the footing. Since the movement of the ground toward the river was larger than that of the footing, the settlement of the ground and the gap occurred on the side faced to the river of the footing and the upheaval of about 10 cm occurred at the opposite side, as shown in Figure 3.4.

Figure 3.11: Relative displacements between the footing of the pier and the ground.

Since the concrete stoppers restrained the movement of girders in the axial direction of the bridge, only the footings between piers P7 and P11 were moved to the center of river by the liquefied ground flow, and the relative displacement occurred between the pier and the girder. As an extreme liquefaction did not occur at the ground between piers P3 and P7, the movement of girders in the transverse direction and the damage of the expansion joints were caused by the effects of the strong ground motion rather than damaged due to the liquefaction.

Figure 3.12 shows the ejected sand around the fissure near the pier P9. Since the earthquake occurred two months ago, the sand volcanoes and the ejected sand induced by the soil liquefaction were not clearly visible. It seems that the liquefied sand could not spout out easily, because the surface soil was a non-saturated silt or clay,.

Figure 3.12: Boiled sand around the fissure.

Figure 3.13 shows the ground failure around pier P12. The surface ground around the pier collapsed and moved toward the river. However, the gap between the girders' joint and the center of the bridge which seat in the axial direction of the bridge as shown in Figure 3.8 did not occur at pier P12.

Figure 3.13: Ground failure at pier P12.

Figure 3.14 shows the fissures at the left bank. The lateral displacement of the ground on the left bank was 1.4 m. It was smaller than that of the right bank as shown in Figure 3.4. The displacement of the lateral spreading and the force caused triggered to the pier seem to be small since the area of liquefiable soil layer was limited to the left bank.

Figure 3.14: Fissures and lateral spreading of ground on the right bank.

3.2.2 Large Ground Fissure in Legatta Town

A large ground fissure whose length was over 100 m appeared in Legatta town is shown in Figure 3.15. It is located at is Point 2 in the southern part of Point 1 as shown in Figure 3.1. The maximum depth of the fissure was about 1.4 m, the width of the opening was about 0.5 m and relative vertical displacement was about 0.6 m. Although there were no sand volcano and ejected sand in this area when we carried out our investigation, it can be seen that there are ejected sands near the fissure as shown in Figure 3.15. The photo was taken just after the earthquake by the CGS. Since there was a stream parallel to the fissure, it is considered that liquefaction-induced lateral spreading of the ground toward the stream caused the fissure.

Figure 3.15: Large ground fissure at Point 2 (Photo Provided by CGS).

Figure 3.16: Deformation of the road on the extension of the fissure (Photo Provided by CGS).

Figure 3.17: Damage of house on the extension of the fissure.

Figures 3.16 and 3.17 show the damage to pavement and house on the extension of the fissure. A private house on the extension of the fissure suffered severe damage induced by liquefaction. An inhabitant who lived at the house said that a large amount of liquefied sand ejected from the ground into the room. Figure 3.18 shows the mark of the liquefied sand and water spouted out at about 80 cm in height.

Figure 3.18: Height of spouted sand and water.

3.3 Basin of the Sebaou River

Figure 3.19 shows a well in a vineyard and the ejected sands from the well due to soil liquefaction at the right bank of the Sebaou River. It is located at Point 3 as shown in Figure 3.1. The well was made of concrete rings of diameter 0.7 m and of depth of 12 m approximately. According to witnesses, the sand and water spouted out from this well to several ten meters of height just after the earthquake and consequently the well dried up. The sands spouted out of the well were distributed like a concentric circle of diameter over 10 m. The maximum thickness of the sand deposit was over 1 m.

Figure 3.19: Ejected sand around the well in a vineyard.

3.4 Grain Size Distribution of Liquefied Soil

Figure 3.17 shows the grain size distribution curves of the soil samples taken from the liquefied ground at three sites. The ranges of high possibility of liquefaction and possibility of liquefaction, which are recommended by the Technical Standard on Port Facilities and Its Explanation (1989) is also shown in this figure. It can be seen that most of the samples are in the range of "High possibility of liquefaction".

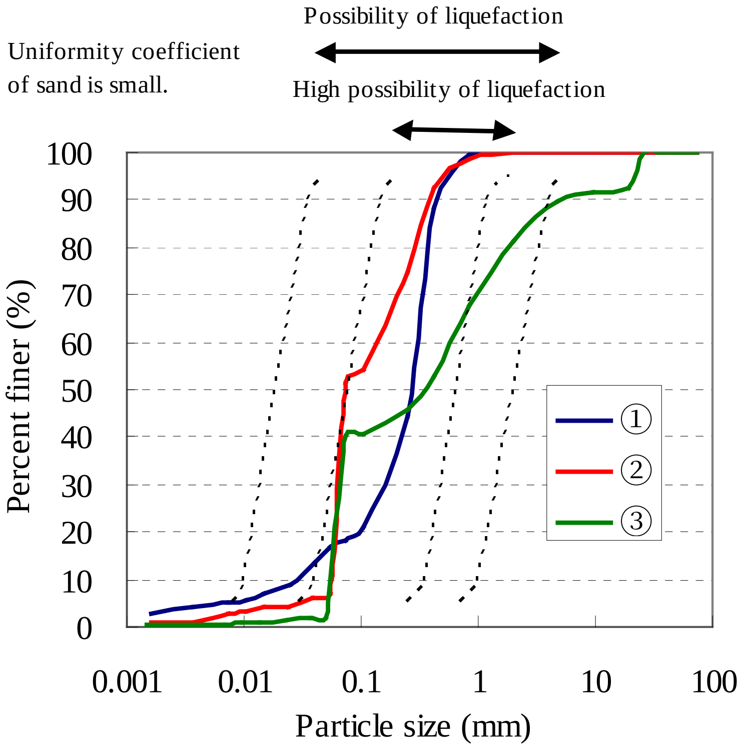

Figure 3.20: Grain Size Distribution of the Liquefied Soil.

3.5 Conclusions

The ground failures such as the liquefaction were not so severe as compared with the damage induced by the strong ground motion. Therefore, there was a little damage to structures induced by the ground failures. The major cause is considered that the soft ground exists in limited sites of the basin.

3.6 References

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Chapter 4

Damage to Structures

4.1 Introduction

A large extent of building damage was observed in the area near the epicenter including Zemmouri, Boumerdes and the suburbs of the capital, as shown in Figure 2.7 of Chapter 2. As emphasized in previous chapters, more than 2200 people were killed and 10,000 people were injured mainly because of the collapse of buildings. This devastating earthquake caused an estimated 5 billion U.S. dollars to the Algerian economy. In this chapter damage to structures is discussed.

4.2 Seismic Design Code

4.2.1 Current seismic design code

The Algerian government adapted French practice of seismic design after the 1954 earthquake disaster. This design practice did not consider properly the specific feature of strong earthquakes in Algeria. In 1978, a new guideline adapting the up-to-date knowledge of seismic design was proposed by the CGS (National Earthquake Engineering Center) with the assistance of Stanford University, U.S.A. This guideline was adopted in design practice after the occurrence of El-Asnam 1980 earthquake disaster. In 1999, the guideline was officially regulated as a law, RPA99, and was enacted in 2000.

In the current seismic design code, RPA99, the design base shear is calculated by the following equation:

$$V = ADQW / R$$

where;
A is a seismic zoning factor taking into consideration both the importance of a building and the seismic activity in the construction area, which ranges between 0.1 and 0.35. D is a dynamic amplification factor taking 2.5 as its maximum value. Q is a penalty factor to consider the quality of construction and the irregularity of building configuration, which takes 1.35 as its maximum value. W is the total weight of a building and R is a behavior factor changing its value between 2 and 5; depending on the building system.

For example, in case of a reinforced concrete frame with masonry walls constructed in Alger city, the design base shear factor (V/W) will be around 0.1 (A=0.15, D=2.5, Q=1.0 and R=3.5), which is almost 1/3 of the seismic design force for a reinforced concrete frame in Japan.

The design code also stipulates the detail of element design. For example, the width of a short column must be less than the value of 1/4 of the column height to avoid short column failure. Also, the stirrup must be arranged with less than 10 cm interval at both ends of a column, and less than the interval of the minimum between the half of column width and the length of 10 times of rebar size.

A number of Algerian engineers pointed out that the buildings constructed before 1980 developed relatively heavy damage when compared to buildings constructed after 1980. This fact suggests the correlation between the building damage and the change of design code. Further study should be carried out to clarify the cause of damage and find out the items of the design code to be improved.

Figure 4.1 shows the seismic zoning map which was used to determine the seismic zoning factor, A, in the design code. The map has four different zones; Zone 0, I, II and III, depending on the seismic activity in each region. The highest value of A is assigned to Zone III, which is located in the region of epicenters of the 1954 and 1980 earthquakes.

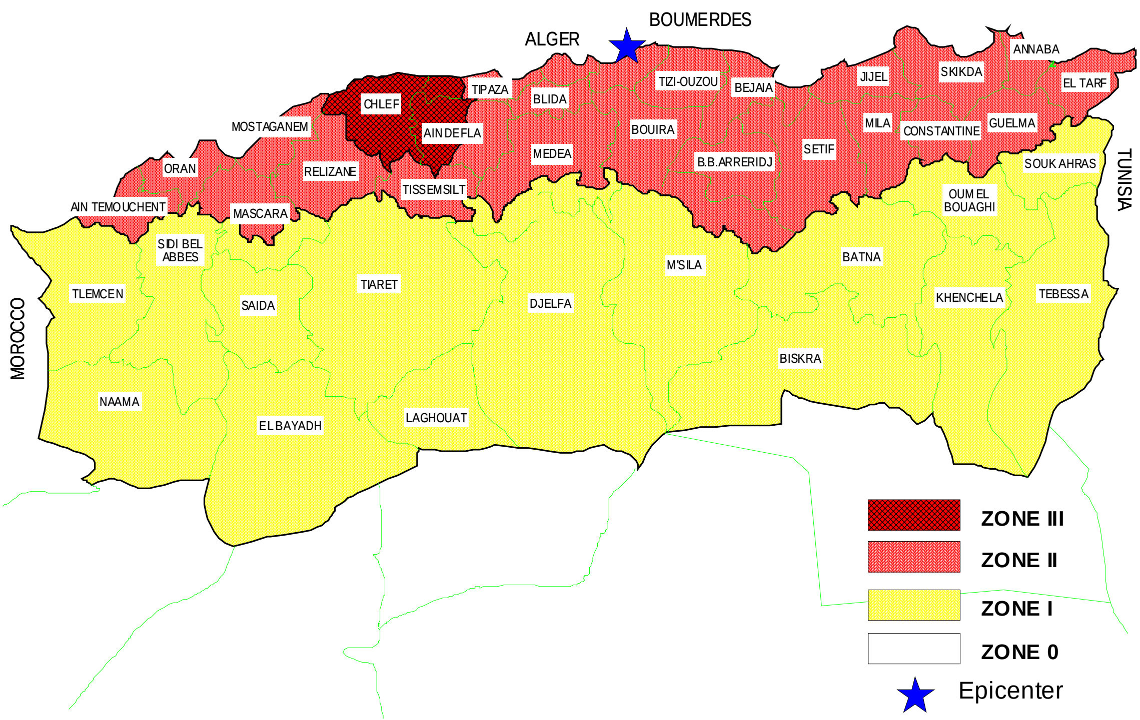

Figure 4.1: Seismic Zoning Map

4.2.2 Revision of seismic design code

Reflecting the severe earthquake damage, the CGS prepared the draft of partial revision of seismic design code. The followings are the major points of revision:

- The classification of seismic zoning is changed to be five levels; Zone 0, I, IIa, IIb and III.
  The seismic zoning map is revised to include the recently affected area in Zone III.
  The maximum value of the seismic zoning factor, A, is increased to 0.40 from 0.35.

- The new requirement is added to adopt reinforced concrete shear walls for certain buildings in Zone IIa, IIb and III.

- Some statements are added to regulate:
  Open space at the ground floor level to avoid the soft story problem,
  Strength of the cast-in-place concrete,
  The size of structural elements, especially, columns,
  Others.

4.3 Damage to RC Structures (in Boumerdes City)

The typical construction in Boumerdes City consists of RC moment resisting structures with unreinforced masonry infill walls. A significant number of the mid-rise RC buildings suffered dramatic failure as a result of the May 21, 2003 Boumerdes Earthquake. According to the governmental report, the earthquake caused devastation. In Boumerdes City only, 7,400 concrete buildings were destroyed and 7,000 buildings were heavily damaged. Table 4.1 shows the damage levels of approximately 96,974 buildings surveyed by the CGS in Algeria. The damage level was divided into five categories from slight damage (level 1) to partial or total collapse (level 5). As it can be seen from Table 4.1 most of the damage occurred to the residential buildings.

Table 4.1 Structural damage level in Algeria and Boumerdes cities

CONSTRUCTION USE	Green		Orange		Red	Total
	Level 1	Level 2	Level 3	Level 4	Level 5	
Residential buildings	181,30	32,352	19,343	11,727	10,183	91,735
Administrative buildings	213	300	184	76	52	825
Schools	420	814	467	286	103	2,090
Hospitals	94	114	44	23	10	285
Sportive and cultural buildings	106	97	90	87	32	412
Commercial buildings	189	193	140	82	137	741
Industrial facilities and hangars	85	153	98	73	66	475
Other (water tanks, etc…)	54	112	110	74	411	411
Total	19,291	34,135	20,476	12,428	10,644	96,974
Percentage (%)	**19.90**	**35.20**	**21.11**	**12.82**	**10.97**	**100**
	55.10		**33.93**		**10.97**	**100**

Source: European-Mediterranean Seismological Center Newsletter, No. 20, September 2003. (http://www.emsc-csem.org/NewsLetter/NewsLetter_20.pdf)

4.3.1 Overiew of the Damage

The features of building damage are different depending on the structural systems adopted for the buildings. Herein in this section is a brief review of the damage caused to typical building in Algeria:

- **RC frame with infill brick wall (Figures 4.2-4.19)**

This structural system is very popular in Algeria for both low-rise and high-rise buildings. It consists of reinforced concrete frames (beams and columns) and plane brick walls inside the frames.

The common feature of building damage to this structural type was the collapse of brick walls and flexural failure at the both ends of the column elements. Quite a few buildings completely crumpled showing the so-called "pancake shape" collapse.

Apparently, the damage resulted from the slender reinforced concrete frame with insufficient lateral resistance against earthquake force. It is speculated that the heavy roof laying sand for thermal insulation might increase the inertia force during earthquake and aggravate the damage. In most cases, the damage to the columns was found in the cold joint area at the top of the columns and in the connection area with the beams. Also, the evidences of bad construction practice, such as severe rust of reinforcement steel bars inside concrete, low quality of concrete material, lack of stirrup in connection area, were observed.

In Zemmouri area, a number of private houses suffered story collapse at the level of ground floor that had open space probably used for garages or shops.

- **RC building with sanitary space (Figures 4.20-4.21)**

This structural system is widely adopted for medium story apartment buildings in Algeria. It has a sanitary space in the underground level, and the upper structure with residential space is supported by short columns less then 50 cm tall from the ground level. It constitutes a soft story at the level of short columns; therefore, the earthquake damage generally concentrate to this level with severe shear failure at the short columns.

- **RC shear wall structure (Figure 4.22)**

The adoption of reinforced concrete shear wall system is not common for the buildings in Algeria. However, it is apparent that the shear wall is a quite effective element to provide large lateral resistance against earthquake force. Several apartment buildings near Alger constructed by pre-cast reinforced concrete walls demonstrated the effectiveness of shear wall system by showing good performance without any structural damage.

- **Damage to non-structural elements (Figures 4.23-4.24)**

In a new apartment complex in Zenmouri area, a large number of pre-cast concrete panels which attached to the main structures were broken or fell down on the ground because of the break of small steel joints. Apparently the strength of joints was not enough to resist a large inertia force induced by the earthquake. Even the main structure did not suffer severe damage, failure and collapse of these heavy non-structural elements might cause serious human losses.

Figure 4.2: Collapse of brick walls at the ground floor

Figure 4.3: Collapse of brick walls at the ground floor

Figure 4.4: Building collapse in Zemmouri

Figure 4.5: Pancake shape collapse

Figure 4.6: Severe damage of a building

Figure 4.7: Failure at the column top

Figure 4.8: Story collapse of a building

Figure 4.9: Failure of walls and columns at the ground story

Figure 4.10: Failure of a joint between column and beam elements

Figure 4.11: Break of reinforcement bars inside a column

Figure 4.12: Soft first story collapse of a private house

Figure 4.13: Soft first story collapse of a private house

Figure 4.14: Building damage in a new residential area

Figure 4.15: Damage of new buildings

Figure 4.16: Collapsed buildings and survived buildings

Figure 4.17: damage inside a building

Figure 4.18: Damage around the cold joint of a column

Figure 4.19: Damage around the cold joint of a column

Figure 4.20: Damage of the building with sanitary space

Figure 4.21: Damage of a short column

Figure 4.22: Buildings with RC shear walls (no damage)

Figure 4.23: Damage of pre-cast concrete panels

Figure 4.24: Pre-cast concrete panels dropped on the ground

4.3.2 Assessment of the Building Damages

As can be seen from the brief review shown in the section above, a great number of buildings and industrial structures collapsed or suffered severe damages that required their total demolition. For our detailed study, several damaged buildings and public structures were investigated. These structures are:

i) A building block of the 11 December of Boumerdes
ii) A building block of the 102 apartments of Corso
iii) A school building of the 1200 apartments of Boumerdes
iv) A building block of the 24 apartments of Dar El Baida, Alger

i) A building block of the 11 December of Boumerdes

The structure is 11 years old and its main characteristics and observed damages are:

- (R+3) RC dwelling (Figure 4.25 and 4.26)
- Earthquake resistant: Stable RC Frame in both directions
- RC Slabs
- Façade is masonry (hollow brick)
- 3.70 m for the ground floor (commercial) and 3 m for the other levels
- Columns 30x40, beams 30x40 or 30x30
- Damage level is ORANGE 3
- Damage concentrated in the ground floor only
- Most the facades collapsed
- Hinges were formed in most top of the columns
- Beam-column damage
- Collapse of the stairs of the ground floor
- Due to the landing of the stairs some short column failures were observed
- Quality of concrete mediocre
- No victims

Figure 4.25: View of the building blocks

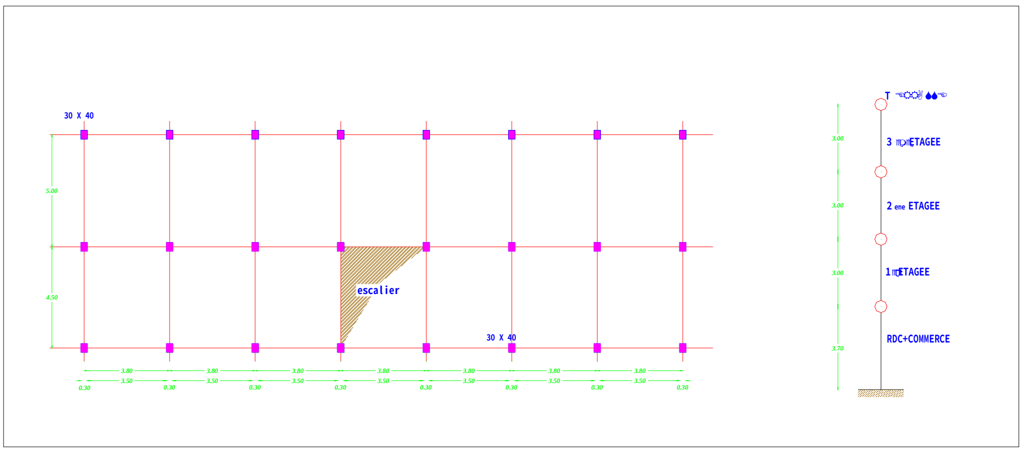

Figure 4.26: Architectural plans of the building

The observed damages on the ground floor are shown in the following Figures.

Figure 4.27: Collapse of the facades

Figure 4.28: Collapse of the stairs

Figure 4.29: Short column failure

Figure 4.30: Top end column failure

Detail of the damage caused by the stairs' landing is shown in the figures below.

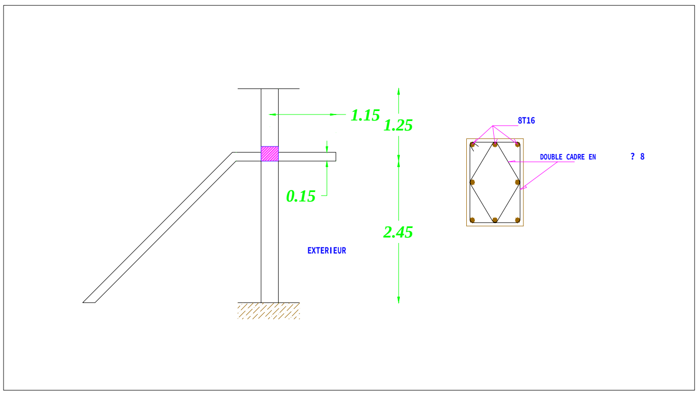

Figure 4.31: Configuration of the stairs landing

ii) Building block of the 102 Apartments in Corso city The structure is 20 yrs old and its main characteristics and observed damages are:

- (R+3) RC dwelling with sanitary (crawl space)
- Earthquake resistant,
- 1 block consists of 12 apartments
- RC Frame in both directions
- RC slabs
- Façade is masonry (hollow brick)
- About 3.0 m for all the floorsDamage level is ORANGE 4
- Damage concentrated in the ground floor only
- Most the facades collapsed
- Hinges were formed in most top and bottom of the columns
- Beam-column damage
- Collapse of some stairs of the ground floor
- Some collapse of the sanitary craw space was observed at the ground level
- Quality of concrete mediocre
- No victims

Figure 4.31: View of the building blocks

The observed damages on the ground floor are shown in the following Figures.

Figure 4.32: Failure at the column's top level

Figure 4.33: Failure at the sanitary level

Furthermore, bad quality of concrete such as segregation and/or the lack of enough bars are clearly shown in the Figures below.

Figure 4.34: Bad quality of concrete inside the apartments

Figure 4.35: Lack of reinforcement bars causing failure at the column's top level

iii) Ibn Khaldoun School in 1200 apartments in Boumerdes city This structure is 15 yrs old and its main characteristics and observed damages are:

- (R+1) RC structure
- Earthquake resistant: RC Frame in both directions
- RC slabs
- Façade is masonry
- About 3.40 m for both floors
- Damage level is ORANGE 4
- no victims

Figure 4.36: View of the school building

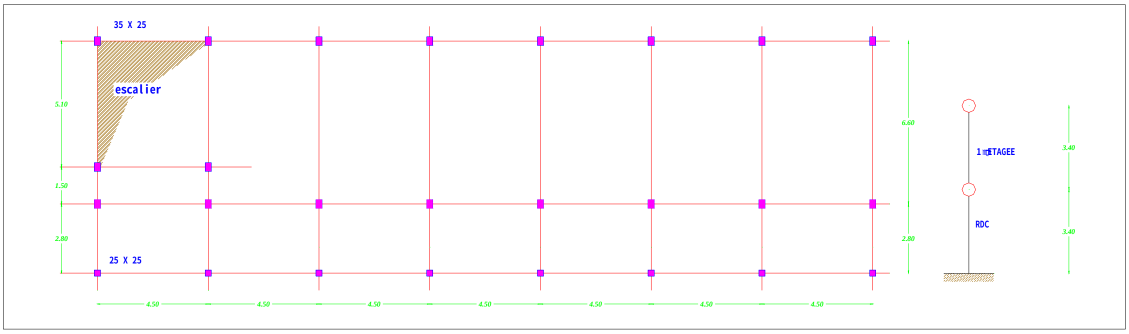

Figure 4.37: The architectural plans of the school building

Furthermore, the observed damages on the ground floor are shown in the Figures below:

Figure 4.38: Short columns failures

Figure 4.39: Failure of stair's landing

Furthermore, details of short columns the stairs' failures are shown in the Figures below.

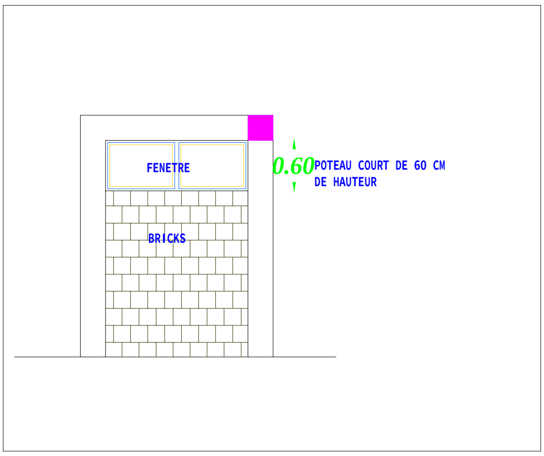

Figure 4.40: Detail of the short column failure

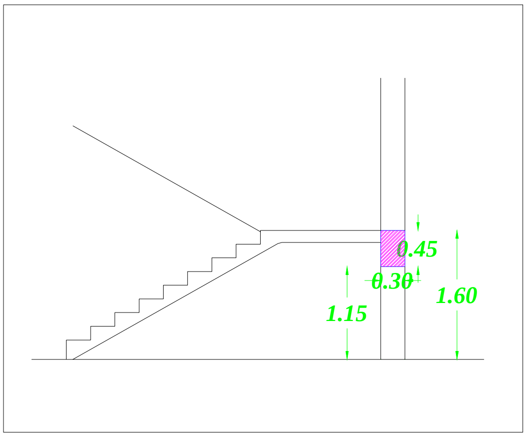

Figure 4.41: Detail of the stairs' failure

iv) 24 apartments of Dar El Beida

The main characteristics of the structure and the observed damages are:

- (R+3) dwelling RC Structure
- The structure is not earthquake-resistant following the code of 1960
- Stable RC Frame in both directions
- Façade is masonry (hollow brick)
- 3.25 m for the ground floor and 3.06 for the other levels
- The structure underwent structural and non-structural damage
- The structure did not go any settlement or excessive differential settlement
- Only the ground floor went structural damages (shown in the Figures below)
- Concrete presents a good compression strength > 270 kg/cm2
- Damage level is ORANGE 3

Figure 4.42: View of the building block

Figure 4.43: Weak reinforcement in both directions

Figure 4.44: Column severely damaged due to stiff frame of the door

Figure 4.45: Pulling of the cover and weak reinforcement at the bottom of the column

Figure 4.46: Pulling of the cover and damage at the top of the column

From the sclerometric tests, which were led on a small sample (10 tests) of columns and beams at the ground floor, one can conclude that the used concrete presents a good compression resistance (> 270 kg/cm2). However, since the structure is not earthquake-resistant following the code (1960), .it underwent structural and non-structural damages as shown in the Figure 4.43 to 4.46.

v) Summary

Looking at the extend of the damage; one might question the reasons for such extensive destruction. Was it due to 1) severity of the ground motion? 2) Soil conditions which may have amplified the intensity of the ground shaking? 3) Shortcomings in building design and/or construction method? 4) Or a combination of several factors?

It is difficult to precisely determine the triggering cause of such catastrophe without full investigation (on site and numerical analysis), however, the field survey showed that the damage to RC building structures could be attributed to:

1. Soft story effects
2. Short column effects
3. Use of weak and slender columns poorly reinforced (generally unconfined)
4. Poor detailing of structural joints
5. Inadequate transverse reinforcing steel detailing (tie spacing and 90 degree hook)
6. Poor material quality and unsound construction practice.
7. Lateral force was not considered in design
8. Inappropriate anchoring of beam and slab reinforcement.
9. Use of irregular building configurations with discontinuities in mass, stiffness, strength and ductility.
10. Use of weak materials for facades.
11. Use of stiff spandrel masonry walls resulted in short captive columns that increased the shear demand beyond the shear capacity supplied.

4.3.3 Damage versus soil conditions

A quick inspection of three buildings in Boumerdes city was carried out to investigate the fundamental periods of sample structures in the damaged area.

- **Field survey**

Three RC buildings were investigated in detail in order to study damage causes and measure their fundamental period (Figure 4.47). The location of each structure is marked on a post-event satellite image (Figure 4.48). A detailed analysis of the soil response characteristics at sixteen different sites in Boumerdes city, including those where the surveyed structures are located, is presented in Chapter 4. The fundamental period was obtained with microtremor measurements. Since damage increases the fundamental period by 1.5 times at most (Abe et al., 1979), microtremor measurements may be used to identify damage by recognizing changes in the fundamental period. Table 4.2 shows the number of stories, building height, fundamental period in longitudinal and transverse directions, and damage level based on the CGS survey. The fundamental period for each building was obtained from five 40.96 sec microtremor measurements. The corresponding five spectra were averaged to obtain the fundamental period as shown in Figure 4.49. The procedure was carried out in both longitudinal and transverse directions. It should be noted that heavy demolition equipments that were in operation near to the observation area might have affected the measurements. It should also be reported that the first observed structure was a four-story buildings with “soft story” type of damage. From Table 4.2 it is clear that the fundamental period for that structure increased due to the high seismic damage. The microtremor measurements can be used to identify damage by recognizing changes in the fundamental period.

(a) Structure 1 (4-story RC structure with soft floor type of damage)

(b) Structure 2 (Boumerdes University)

(c) Structure 3 (5-story RC building

Figure 4.47: Investigated structures

Figure 4.48: Location of the investigated buildings

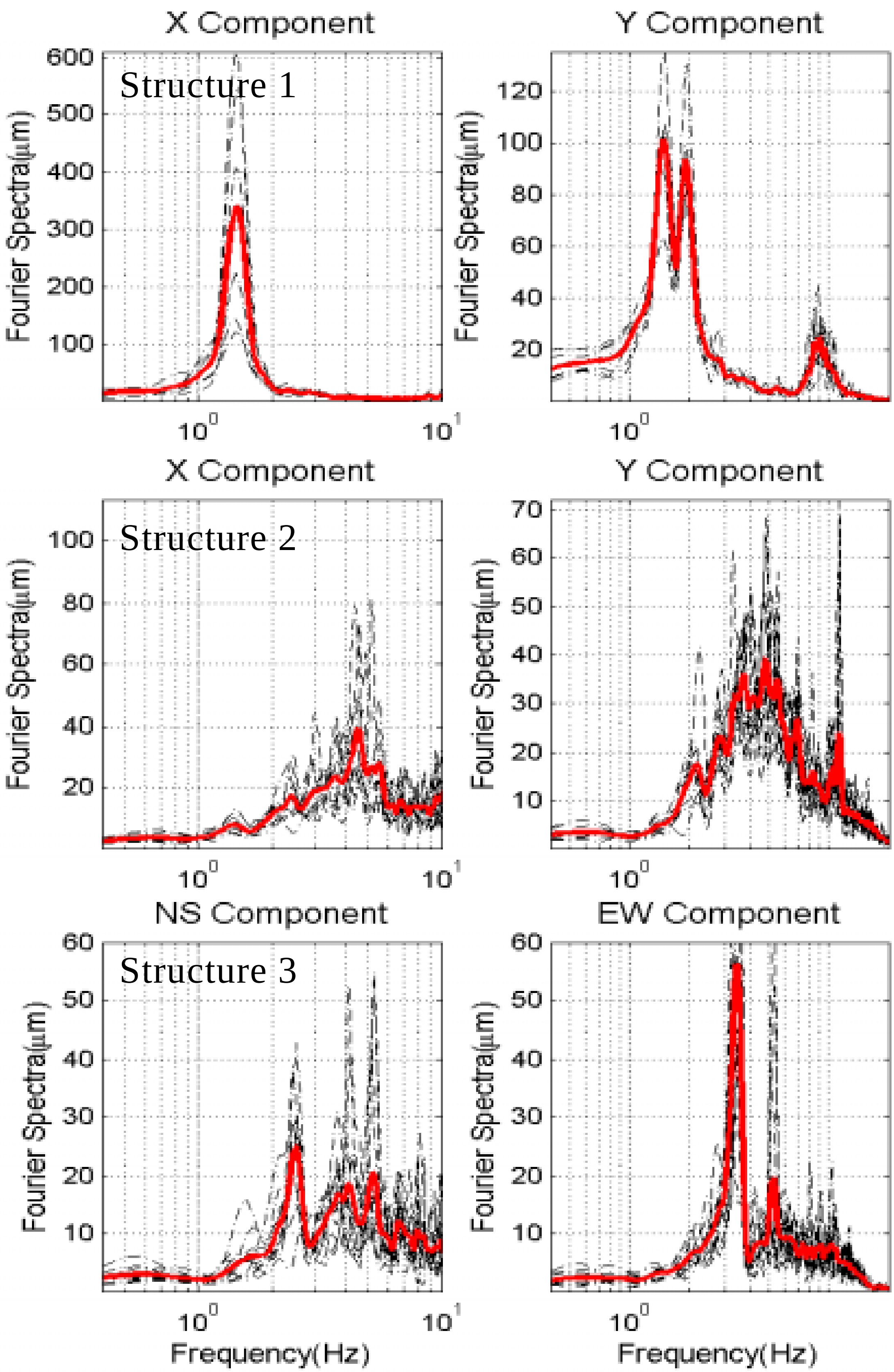

Figure 4.49: Fourier spectra of the three investigated structures

Table 4.2: Investigated RC buildings in Boumerdes City

No.	Building name	Location	No. of stories	Height	Fundamental Period (s)		Damage Level
					Longitudinal	Transversal	
1	Residential building	G14	4	15.00	0.68	0.70	5
2	Boumerdes University	G11	4	25.00	0.22	0.22	3
3	Residential building	G12	5	15.00	0.29	0.40	3

Damage level 5 is Red colour, the structure is condemned and should be demolished
Damage level 3 is Orange colour, there is very little damage and the structure can be reoccupied immediately.

4.4 Other Structural Damage

4.4.1 Significant damage to silos (Outside Boumerdes city)

The structure inspected is located in Corso City, it was built in 1978 consists of (Figure 4.50):

- 45 reinforced concrete Silos for storing wheat, of cylindrical shafts composed of 5 blocks
- Each block has 9 circular cells of diameter of 8.4 m, about 18 cm of thickness and height of 66 m
- Dimension of each block is 25.96 x 29.28 m
- Each block lays on 72 piles of 24 m
- Poor soil is of clay
- The structure is earthquake-resistant
- Constructed using sliding formwork
- The design concrete strength was supposed to vary between 210 and 290 kg/cm2. But hardly reached 200 kg/cm2


Figure 4.50: General view for the RC grain silos in Corso City

Figure 4.50: General view for the RC grain silos in Corso City

Although no total collapse was observed as a result of the ground shaking of Boumerdes, many of the RC cylindrical shafts developed circumferential flexural cracks at heights between 3 to 12 meters above the ground level as shown in Figure 4.51. The damage could be due to bad quality of concrete, insufficient bars, bad quality control on site during construction, soil conditions and maybe dynamic effect due to content of wheat not so well considered in the dynamic analysis.

As part of the study during our visit to Corso, a dynamic behavior of the reinforced concrete silos was investigated using microtremor observations. The soil conditions at the silos area were also evaluated.

- **Measurements**

Measurements were performed at four positions: 1P, 2P, 3P, and 4P, as shown in Figure 4.52. Microtremors at the ground surface were simultaneously recorded at a distance of 10cm and 30m from the structure. The sampling frequency was 100 Hz and the length of each record, 40.96 sec. Five measurements were taken at each observation point.

Figure 4.51: Damage to RC silos showing cracks at different heights

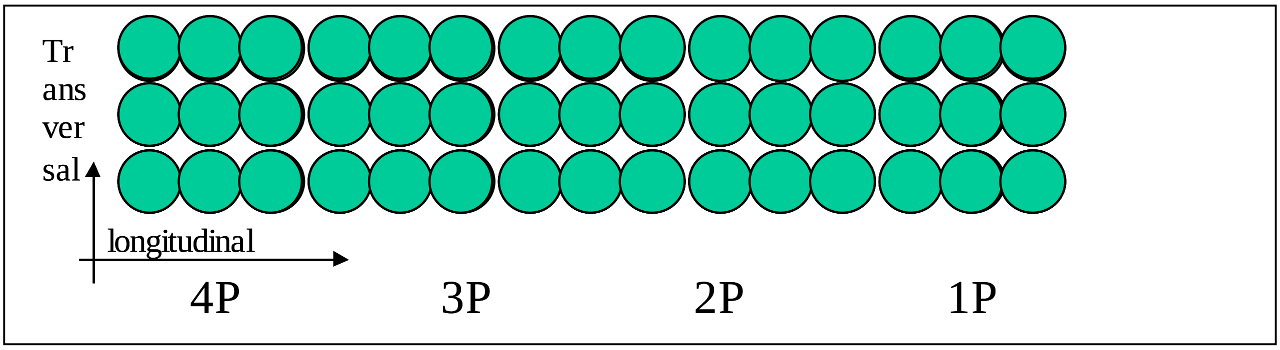

Figure 5.52: Location of measurement points

- **Results and discussion**

The Quasi-Transfer Spectra (QTS) for the sensors located 30 m from the silos are shown in Figure 4.53. Those spectra can be used for evaluating the soil condition. From the H/V spectral ratio, it can be followed that soil deposit has an amplification factor approximately equal to 2. The soil deposit fundamental frequencies are listed in Table 4.3. Considerable peaks are observed in the high frequency range. These may be due to the effect of the silos as well as the different soil characteristics at these points.

Table 4.3: Soil dynamic characteristics at the observed silos area (30 m from the silos)

Site Name	Longitudinal direction		Transverse direction	
	Frequency (Hz)	Maximum H/V	Frequency (Hz)	Maximum H/V
1P	1.30	2.20	1.30	3.00
2P	0.60~2.00	2.00	0.60~2.50	3.00
3P	0.80	2.00	1.00~1.30	3.00
4P	1.30	2.00	1.30	2.00

The H/V spectral ratios at the four observed points based on the sensors placed 10 cm from the silos are shown in Figure 4.54. The fundamental period of the silos can be evaluated by comparing the H/V spectral ratios of the two sensors at each observation point (see Figure 4.53 and 4.54). The reduction in the amplification factor corresponding to the fundamental frequency at the observation point nearest to the silo compared to the corresponding amplification factor at the other sensor is owed to the soil structure interaction. That base had been used as the indicator to estimate the silos fundamental frequency at each observed location. The so-obtained frequencies are shown in Table 4.4. The fundamental frequency for each observed group varies between 1.6 to 1.9 Hz in the longitudinal direction and between 1.5 to 1.8 Hz in the transverse direction. It should be noted that different damage level was observed for each silo as shown in Figure 4.55. This may have been the cause of the variation in the fundamental frequencies. Comparing the observed damage levels and the estimated fundamental frequency shows again the validity of using microtremor to investigate structural damage level.

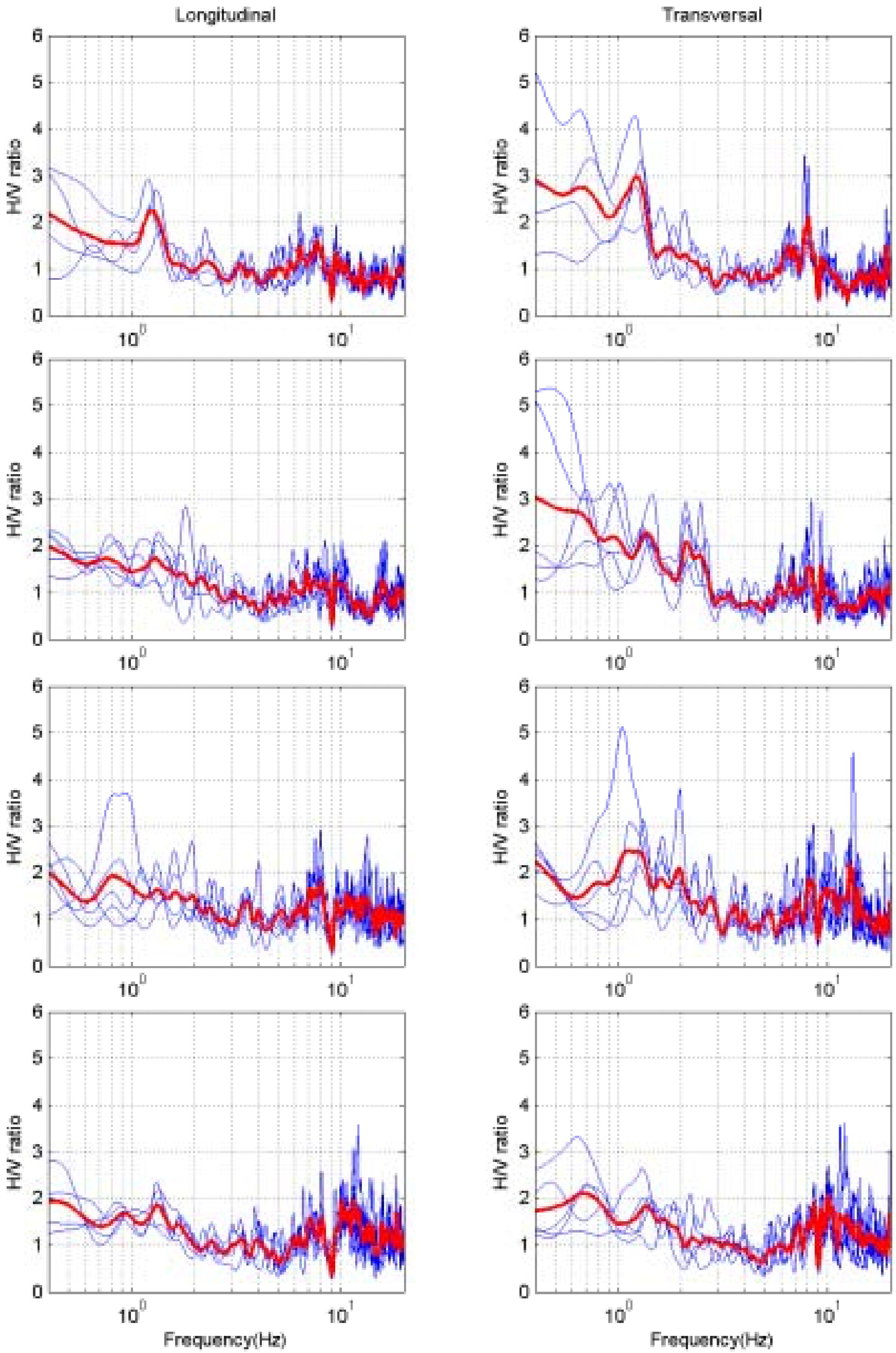

Figure 4.53: H/V spectral ratios for the observations points located at a distance of 30 m from the silos

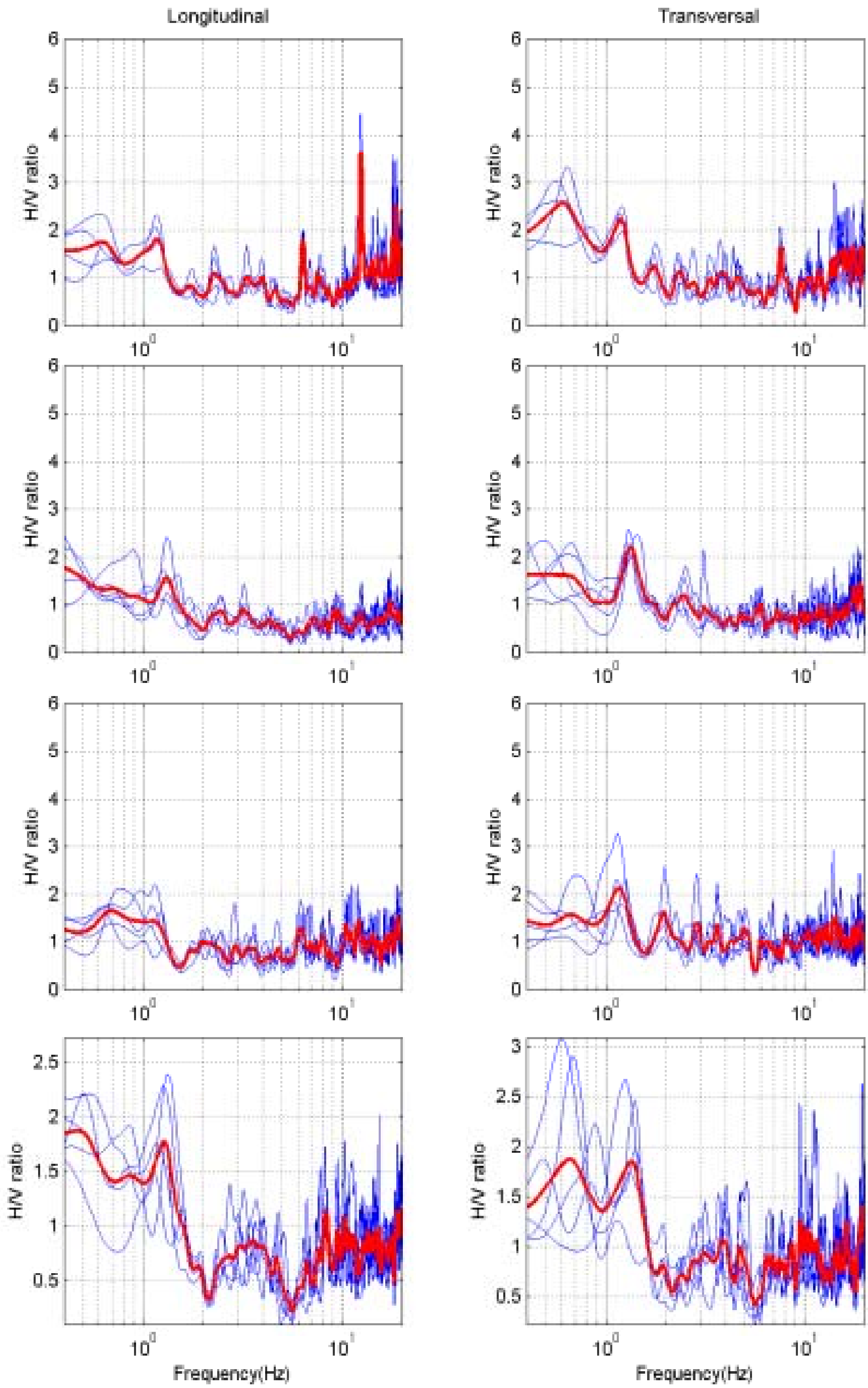

Figure 4.54: H/V spectral ratios for the observations points located a distance of 10 cm from silos

Table 4.4: Estimated fundamental frequency of silos at the different observed points

Site Name	**Fundamental frequency (Hz)**	
	Longitudinal direction	**Transverse direction**
1P	1.70	1.60
2P	1.90	1.80
3P	1.80	1.70
4P	1.60	1.50

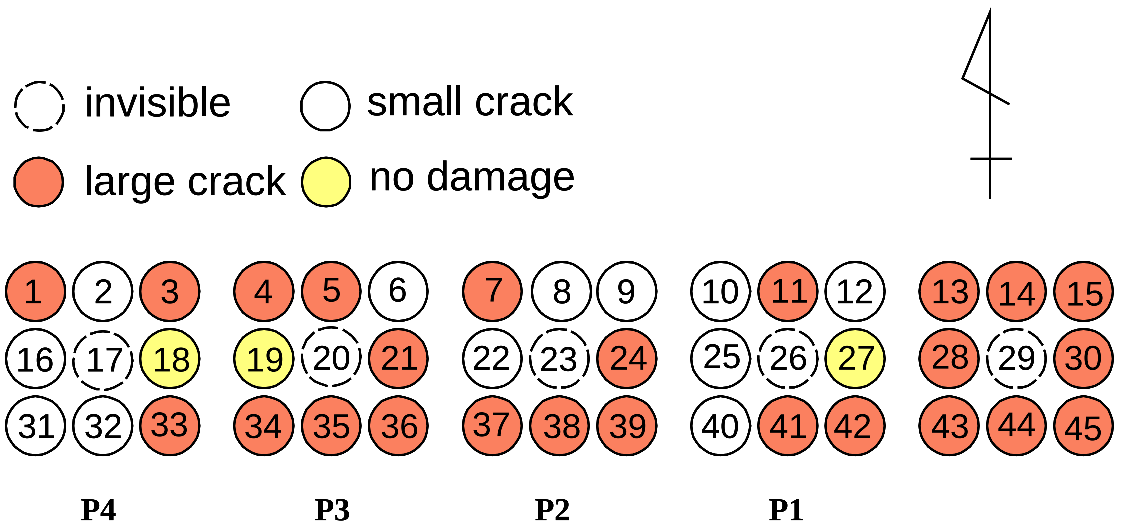

Figure 4.55: Observed crack levels for each silo

4.4.2 Damage to Bridges

Damage to bridges is reported in the Appendix. The report deals with the inspection of bridges on the National Roads (RN); RN25 and RN5, as well as bridges on the Prefectural Roads (CW); CW146. A total of 25 bridges were inspected. Details of these inspections can be found in the Appendix.

4.5 Conclusion

Algeria has experienced many destructive earthquakes. The latest devastating one is of the May 21, 2003 of magnitude 6.8 struck Alger-Boumerdes region causing at least 2,278 people to be killed, 11,450 injured, 200,000 homeless, and more than 15,000 buildings damaged or destroyed. Damage estimated at 5 billion U.S. dollars. At the moment it is early to speculate on the factor or factors that have caused such an extensive damage. However, from the inspection of the damaged buildings during our 6-day stay in the affected region, some of the main defects in the design and construction method of the buildings were discussed in this chapter and which can be summarized as follow:

1. Soft story effects
2. Short column effects
3. Use of weak and slender columns poorly reinforced (generally unconfined)
4. Poor detailing of structural joints
5. Inadequate transverse reinforcing steel detailing (tie spacing and 90 degree hook)
6. Poor material quality and unsound construction practice.
7. Lateral force was not considered in design
8. Inappropriate anchoring of beam and slab reinforcement.
9. Use of irregular building configurations with discontinuities in mass, stiffness, strength and ductility.
10. Use of weak materials for facades.
11. Use of stiff spandrel masonry walls resulted in short captive columns that increased the shear demand beyond the shear capacity supplied.

4.6 References

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- CGS, National Earthquake Engineering Centre, http://www.cgs-dz.org/

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Chapter 5

Damage In Boumerdes

5.1 Introduction

Important lessons from a devastating earthquake can be learned only if we can rationally describe the cause of damage in terms of important characteristics of strong ground motion. However, seismometer distribution is in general too sparse to discuss damage distribution, which can differ in every few blocks reflecting local site effect. Boumerdes where several Universities and Institutes are located is facing the Mediterranean in a latitude 36°44' 46" North and a longitude of 3°27 '29" East, located at 36 km west of Alger, the capital of Algeria. Around this area, rivers are eroding deep in an about 40 m altitude terrace that consists of sedimentary uncemented silty sand, on which a group of RC middle high rise residents and university buildings were built. The damages to RC buildings were mainly observed at top and bottom ends of columns and beam-column joints on the ground floor. Many buildings collapsed and leaned under the massive pressure of floors above, whose situation resembles Corso (2 km southwest), and Zemmouri (15 km east of Boumerdes). The city area of Boumerdes is concentrated in a small area stretching 2 km from north to south and 3 km from east to west. And since the distribution of damages differs from area to area, three different surveys were conducted in Boumerdes for investigating the local site effect on the distribution of structural damage. This investigation include a survey of cracks at the mortar supports of lampposts, which were seen everywhere in the city, microtremor measurement and data from satellite imageries.

5.2 Relation between Structural Damage and Site Condition

5.2.1 Damage to Lampposts

As damages can differ in every few blocks, it is important to find an indication that shows the distribution of intense ground shaking. To do so, we considered investigating structures that are spotted everywhere in the area and have common features. Because this area used to be under the influence of France as its suzerain state, they did not use utility poles nor electric wires but they equipped every street with lampposts. Therefore, we decided to use cracks of mortar supports of the lampposts as an indicator to study the regional distribution of ground shaking. The lampposts can be divided into three groups according their heights (Table 5.1). That is, 4 m or 6 m high lampposts which were dominant, and over 10 m high, which were used along the main streets' sides that run from the suburbs to the city center.

Table 5.1: The numbers of resonance frequency of bent lampposts

4m pole	6 m pole	10 m pole
5.6 Hz	3.5 Hz	2.2 Hz

Furthermore, an opening near the bottom end of a lamppost for puling cables out was noticed. With this opening, there is a torsional vibration superimposed on the recorded accelerations that are excluded from the resonance frequencies listed in Table 5.1.

Both locations of lampposts and altitudes of the investigated routes are measured by using a GPS receiver. Due to changes in the meteorological conditions and visibility of the sky, the number of satellites that the GPS receiver captured varied from place to place causing some recognizable errors that are included notably in the data for altitude. However, as indicated in Figure 5.1, the data show that a river cut into the terrace on a gentle slant towards north (the Mediterranean).

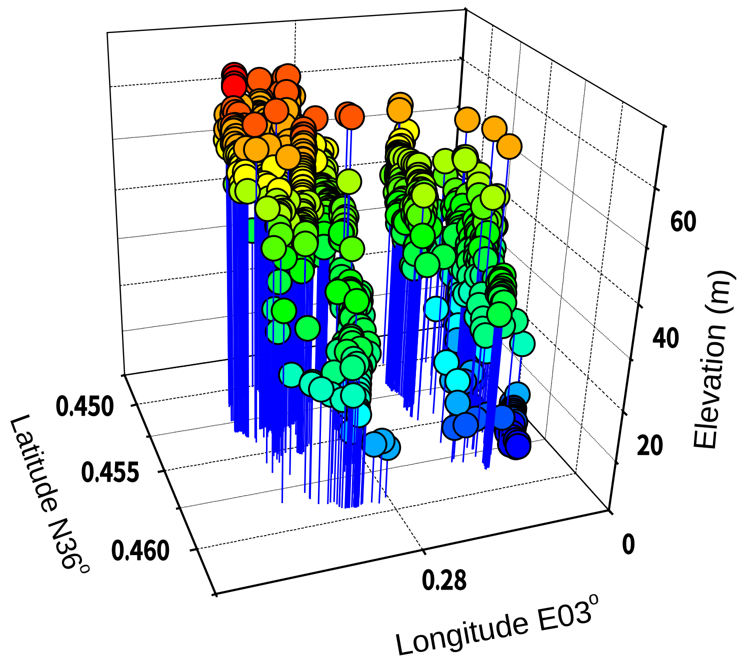


Figure 5.1: The distribution of altitude of the city areas in Boumerdes by GPS receiver: overlooked from north

Figure 5.2 shows the distribution of crack openings. Areas of widely opened cracks seem to be distributed along the rims where the hill slopes dropped suddenly alongside the valleys. Among those areas, A, D and E areas had many RC middle high rise buildings (apartments) seriously damaged. Additionally, the dominant direction of the seismic motions presumed from the cracks was northwest to southeast. This localization of damage may be explained by high site amplification near the rims and/or soft-soil condition as will be explained in the following sections.

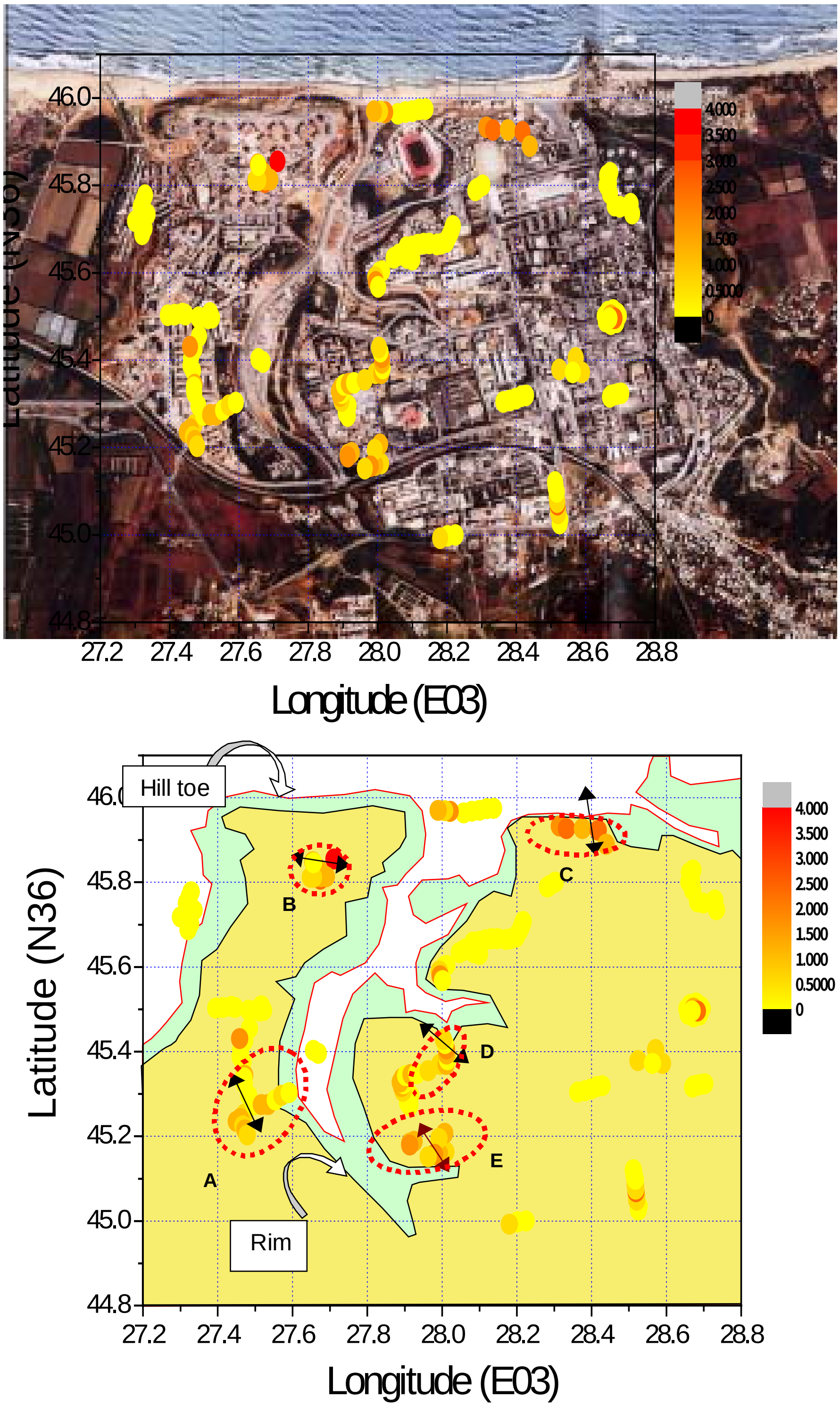


Figure 5.2: Cracks of supporting mortar parts of lampposts in Boumerdes city

5.2.2 Microtremor measurement

Microtremors were measured in Boumerdes city to investigate the relation between damage extent to structures and local site effects. In this study Nakamura's technique was adopted since it allows a quick evaluation of site seismic response. The main advantage of this technique is that it does not require any information about geotechnical or geological properties of the soil deposit at the investigated site. The technique allows to estimate the site response (the fundamental period and amplification factor) by means of the spectral ratio between horizontal (H) and vertical (V) components of microtremors registered at a single point[1), 2)]. This technique has been widely accepted to investigate site conditions[3)-8)].

Microtremor measurements were conducted at sixteen different sites in Boumerdes city (G01-G16). The measurement points are shown on a post-event satellite image (Figure 5.3**)**. The sensor was set on the asphalt or the soil to simultaneously record two horizontal components (NS and EW directions) and a vertical component. At each point, four to five 40.96sec microtremor measurements were taken with a sampling frequency of 100Hz.

i. <u>Analysis</u>

The portions of the record with strong, local impulsive sources, such as traffic, were eliminated. The remaining portions were divided into windows of 2048 samples each and their spectra were calculated after correcting the baseline. The spectrum of one component was estimated by averaging three Fourier spectra. Then, the Quasi-Transfer Spectrum (QTS) was calculated from the spectral ratio of horizontal to vertical components according to Nakamura[2)]. The group of spectral ratios was used to determine the soil deposit dynamic characteristics, namely the predominant frequency (F) and amplification factor (A). Only the frequency range between 0.4 to 20Hz is discussed here because it corresponds to the instrument measuring frequency range.

ii. <u>Results</u>

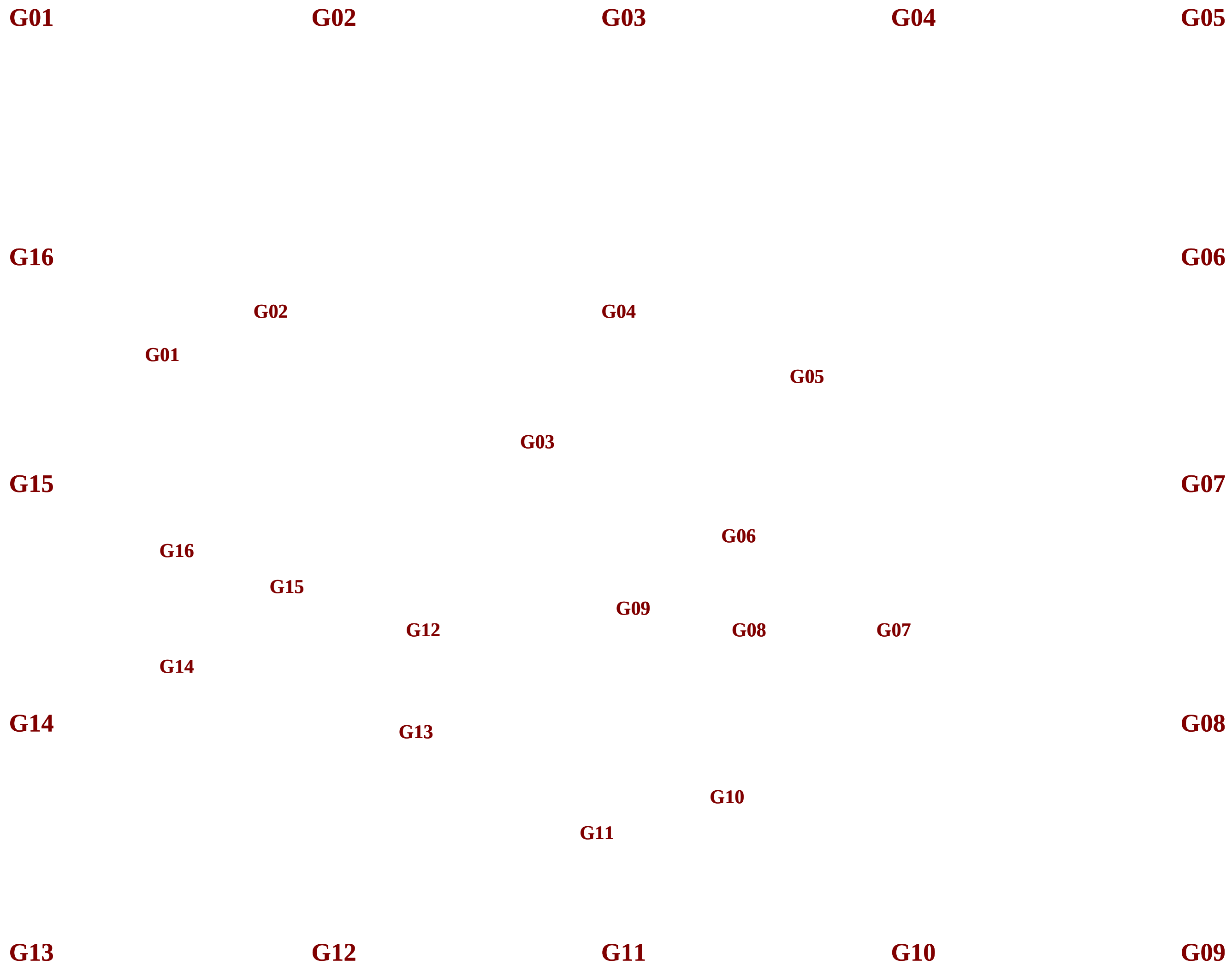
Figure 5.4 and Figure 5.5 show the horizontal to vertical spectral ratios at the longitudinal (NS) and transversal (EW) directions. In both figures, the thin blue curves correspond to a single measurement whereas the red thick curves represent the average of all measurements. The figures show the large variation in both predominant frequency (F) and amplification factor (A). Table 5.2 lists the fundamental frequency and amplification factors of the sixteen measured points.

Figure 5.6 shows the measurements at sites G02, G03, G04, G08, G13, and G15, which present a rather high amplification factor thus indicating a poor soil condition. The influence of the surface topography was also noted at some observation points like G02, G04, and G15. The changes in the frequency and amplitude of H/V spectrum ratios at those points may be explained by the presence of ridge crests.

Figure 5.7 shows spectral ratios at G05, G06, G07, G09, G10, and G16, sites with good soil condition. At these locations, the H/V spectrum ratio is almost flat and the maximum amplification factor is approximately two.

Figure 5.8 show the distribution of soil conditions based on the microtremor observations. The figure shows how hazard levels may vary inside wide municipal territories. In order to verify the ability of microtremor measurements to characterize site effects, the site parameters obtained from microtremor measurements were compared with the earthquake damage levels observed in the field survey. Generally, the locations with poor soil conditions exhibited the severest structural damage. Thus, it can be concluded that the local site amplification factors obtained through microtremor measurements may be used to determine the expected seismic hazard levels.

Figure 5.3: Location of microtremor measurements


G01
G02
G03
G04
G05
G16
G06
G02
G04
G01
G05
G03
G15
G07
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G15
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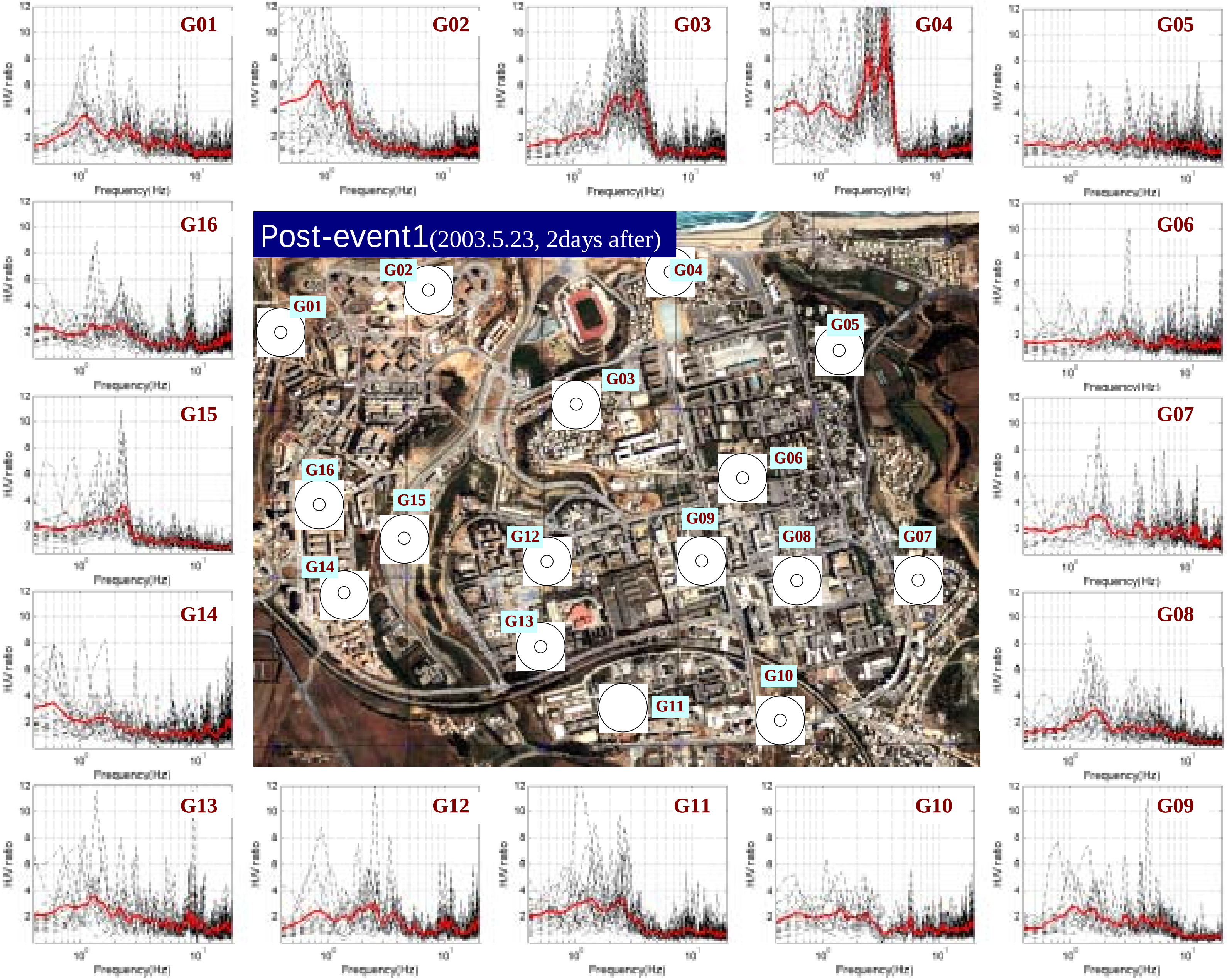


Figure 5.5: H/V spectral ratio (EW components) of the microtremor measurements at Boumerdes City

Table 5.2: Dynamic characteristics of the soil deposit at measured locations

Site Name	NS component		EW component		Soil type
	Frequency (Hz)	Maximum H/V	Frequency (Hz)	Maximum H/V	
G01	**1.00**	**3.40**	**1.10**	**3.80**	**Medium**
G02	**1.06**	**4.50**	**0.85**	**6.20**	**Bad**
G03	**3.50**	**5.00**	**1.8~4.00**	**5.8**	**Bad**
G04	**1.00~4.00**	**11.00**	**1.60~3.80**	**11.8**	**Bad**
G05	**5.00**	**2.80**	**flat**	**2.80**	**Good**
G06	**flat**	**2.80**	**flat**	**2.20**	**Good**
G07	**flat**	**2.00**	**1.50~2.00**	**3.00**	**Good**
G08	**1.00~2.00**	**4.00**	**0.90~2.00**	**3.00**	**Bad**
G09	**2.00**	**2.20**	**1.00~5.00**	**2.20**	**Good**
G10	**1.10~2.3**	**3.00**	**flat**	**2.70**	**Good**
G11	**1.10~2.50**	**3.75**	**1.00~3.00**	**3.75**	**Medium**
G12	**flat**	**2.80**	**0.80~1.50**	**3.00**	**Medium**
G13	**1.00~3.50**	**3.50**	**0.50~2.50**	**3.80**	**Bad**
G14	**0.40**	**3.00**	**Flat**	**3.70**	**Medium**
G15	**1.00~2.5**	**5.00**	**1.00~2.50**	**3.80**	**Bad**
G16	**flat**	**2.20**	**flat**	**2.50**	**Good**

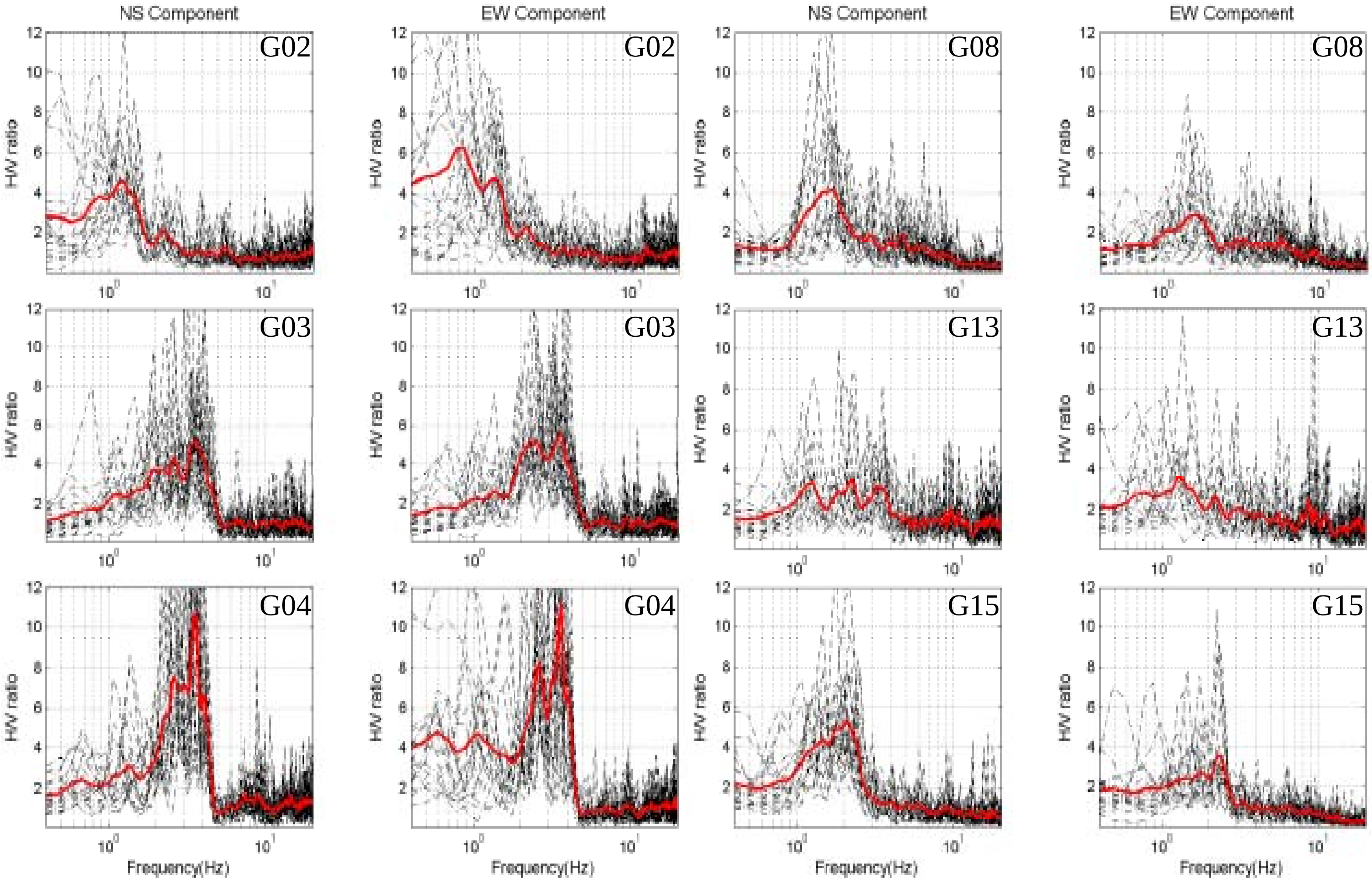


Figure 5.6: H/V spectral ratios at the sites with poor soil conditions

5.2.3 Visual damage detection of buildings from satellite images

Recent advancements in remote sensing and its application technologies made it possible to use remotely sensed imagery data for assessing vulnerability of urban areas and for capturing damage distribution due to disasters. Capability of optical/SAR satellite imagery has been demonstrated for damage detection in large-scale natural disasters. Using the pre- and post-event images of the 1995 Hyogoken-Nanbu (Kobe) earthquake observed by Landsat/TM, JERS/SAR, and ERS/SAR satellites, the areas with heavy building damage, fire and liquefaction were identified (Matsuoka & Yamazaki 1999, 2000). Similar approaches comparing the pre- and post-disaster satellite images were carried out for the 1999 Kocaeli, Turkey earthquake (Estrada et al. 2000) and the 1990 Luzon, Philippine earthquake (Yamazaki & Matsuoka 1999). The satellite images together with GPS were also employed in a damage survey (Eguchi et al. 2000) after the Kocaeli earthquake. However, the spatial resolution of these satellite images is 20 m to 30 m. Hence it was difficult to identify the damages of individual buildings and bridges from these images although wide spread damage areas were possible to detect using change detection techniques.

It is worth mentioning that recently commercial high-resolution satellites with the maximum spatial resolution of 0.6 m to 1.0 m have been launched successfully (IKONOS on September 25, 1999 and QuickBird on October 18, 2001) and they are sending clear images of urban areas to the ground. Hence, these images can be used to detect damages of individual buildings and infrastructures after earthquakes and other disasters. Using the images obtained by QuickBird after the 21 May, 2003 Algeria earthquake, this section presents a preliminary result of building damage detection for the city of Boumerdes.

i. <u>QuickBird images taken before and after the 2003 Algeria earthquake</u>

Only two days after the earthquake (May 23, 2003), QuickBird satellite observed Boumerdes area and sent a clear image of the city to the ground. Another clear image was also taken 28 days after the event (June 18, 2003). The area was also observed previously, about one year before (April 22, 2002). These set of images are considered to be the first clear high-resolution satellite images taken both before and after an earthquake disaster. Table 5.3 summarizes the acquisition parameters of the three QuickBird images.

Table 5.3: Acquisition parameters of QuickBird images for Boumerdes, Algeria.

	Pre-event	**Post-event 1**	**Post-event-2**
Date (from 21 May, 2003 Earthquake)	**2002/04/22 394 days before**	**2003/05/23 2 days after**	**2003/06/18 28 days after**
Time	**10:38:03**	**10:36:03**	**10:25:18**
Sun azimuth (°)	**144.199**	**133.243**	**121.119**
Sun elevation (°)	**61.4057**	**68.3441**	**68.0023**
Satellite azimuth (°)	**352.244**	**276.214**	**177.692**
Satellite elevation (°)	**78.73**	**64.1615**	**81.6418**
In track view angle (°)	**10.2273**	**-1.49957**	**-7.48382**
Cross track view angle (°)	**-3.11488**	**-23.9894**	**1.48885**
Off nadir view angle (°)	**11.2451**	**24.3754**	**7.8038**
Mean collected GSD (Multi/Pan) (m)	**2.539/0.635**	**2.855/0.714**	**2.477/0.620**

In order to observe target areas on the ground in a short time interval, QuickBird can change the view angle of its sensors. Thus these three images have different off nadir view angles: 11.2, 24.3, and 7.8 degree. Hence it is by no means easy to superpose these images exactly and to perform automated change detection. The difference in shadows of buildings on the different days gives additional difficulty. Thus the present authors performed visual damage interpretation (Ogawa & Yamazaki 2000).

First, pan-sharpened images were produced by combining panchromatic images (0.6 m resolution) and multi-spectral images (2.4 m resolution) using ENVI software as shown in Figure 5.9. By this image enhancement, buildings, cars and even debris can clearly be seen. Figure 5.10 shows a typical area where totally collapsed buildings are observed in the post-event images. Cleaning-up of debris can also be seen in the image one month after the event.

ii. <u>Visual damage interpretation and GIS mapping</u>

Using these images, visual inspection of building damage was conducted based on the classification in the European Macroseismic Scale (EMS), shown in Figure 5.3. First, using the post-event pan-sharpened image of May 23, 2003 only, totally collapsed buildings (Grade 5), partially collapsed buildings (Grade 4), and buildings surrounded by debris (Grade 3) were identified. Since the QuickBird images were taken from the almost vertical direction, the damages to walls and columns were difficult to judge. Debris around damaged buildings was one of the most important key to estimate the damage level for the high-resolution satellite images. However, in some cases, shadows of buildings hide debris because debris often spreads around buildings where cast shadows exist.

Figure 5.9: Pan-sharpened natural color QuickBird image of Boumerdes city acquired on May 23, 2003.

(a) April 22, 2002 (b) May 23, 2003 (c) June 18, 2003

Figure 5.10: A part of Boumerdes city observed by QuickBird satellite. Debris of collapsed buildings is clearly observed in the May 23, 2003 image. Some debris has already been removed in the June 18, 2003 image.

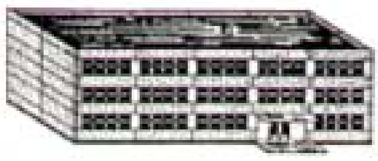
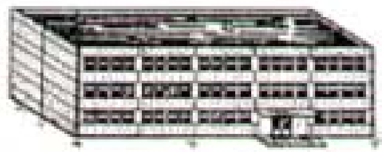
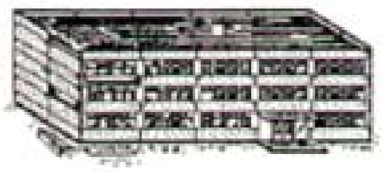
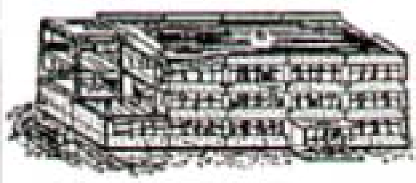
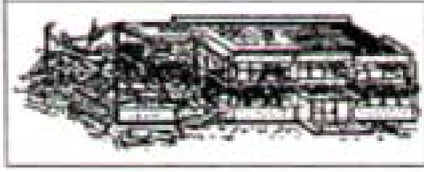
Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Figure 5.11: Classification of damage to reinforced concrete buildings of (http://www.gfz-potsdam.de/pb5/ pb53/ projekt/ ems/eng/core/emsa_cor.htm)

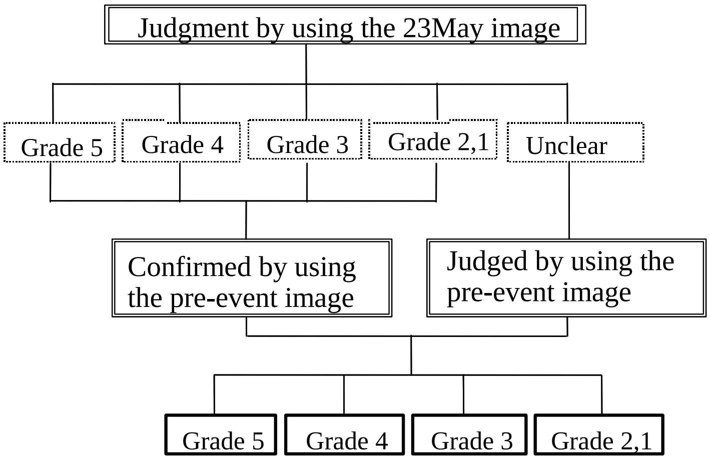


Figure 5.12: Flow of the damage classification used in this study

Some buildings were difficult to judge their damage levels due to the limitations of spatial resolution, view angle, and shadows. For these buildings, the pre-event image was employed as a reference to judge the damage status. Figure 5.12 shows the flowchart of the damage detection employed in this study.

Figure 5.13 shows QuickBird image on May 23, 2003 and photographs take from the ground for the buildings in the south campus of Boumerdes University. Buildings A, B, and C in the image are judged as Grade 5 and all the other buildings as Grade 1 or 2 based on visual interpretation. The ground photographs verify the accuracy of the judgment for buildings A, B, C since their damages are apparent even from the vertical direction. Although building D was judged as no to moderate damage (Grade 1 or 2), the ground photograph indicates that it suffered from some damage (may be Grade 2 or 3), especially inside the building. The field observation revealed that the debris seen in the photo was gathered between the buildings in the stage of clearing works.

Figure 5.14 shows another example for a high damage area. Building E is judged as Grade 4, building F as Grade 1 or 2, building G as Grade 4, and building H as Grade 3 based on visual interpretation. Compared with the ground photographs, it is observed that story collapses, like buildings E and G, are not so easy to judge with confidence from the vertical image because the settlements are mostly to the vertical direction. A similar observation was obtained in case of vertical aerial photographs as demonstrated before (Ogawa & Yamazaki 2000). The short-column collapse of building F was almost impossible to detect from the vertical image because the settlement is only about 10-20cm and the spread of debris is not so much. Compared with the ground photograph, building H seems to be judged correctly, but its interpretation was not so easy because its debris mostly spread in the shadow and the adjacent building collapsed completely.

Figure 5.13: QuickBird image on May 23, 2003 and photographs take from the ground for the buildings in the south campus of Boumerdes University. Buildings A, B, and C are judged as Grade 5 and all the other buildings as Grade 1 or 2 based on visual interpretation.

Figure 5.14: QuickBird image on May 23, 2003 and photographs take from the ground for a high damage area. Building E is judged as Grade 4, building F as Grade 1 or 2, building G as Grade 4, and building H as Grade 3 based on visual interpretation

By this visual interpretation, a total 3,446 buildings are classified based on their damage grades as shown in Figure 5.15. The numbers of identified damaged buildings are 71 buildings for Grade 5, 54 for Grade 4, and 261 for Grade 3. Figure 5.16 shows the break down of buildings classified as Grades 3, 4 and 5. For Grade 5, 47 buildings could be classified as Grade 5 using only the post-event (May 23, 2003) image while it was difficult for 6 buildings to judge their damage grades using only the post-event image, and the pre-event image changed the interpretation result using only the post-event image for 18 buildings. For Grade 4, 29 buildings were judged as Grade 4 using only the post-event image while it was difficult for 20 buildings to judge their damage grades using only the post-event image, and the pre- event image changed the interpretation result using the post-event image for 5 buildings. For Grade 3, 70 buildings were judged as Grade 3 using only the post-event image while it was difficult for 175 buildings to judge their damage grades using only the post-event image, and the pre-event image changed the interpretation result using the post-event image for 16 buildings. In this way, the pre-event image was found to be more important for the lower damage grades in the visual damage interpretation.

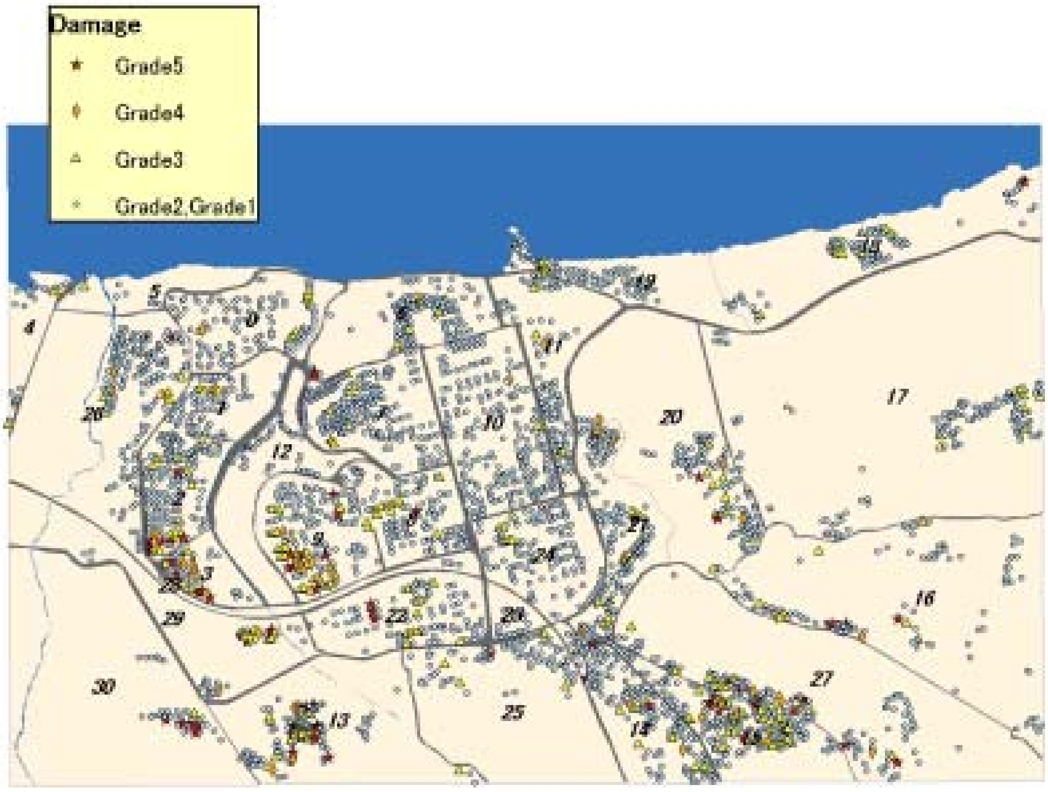


Figure 5.15: Damage grade of 3,446 buildings obtained by visual interpretation of the May 23, 2003 QuickBird image.

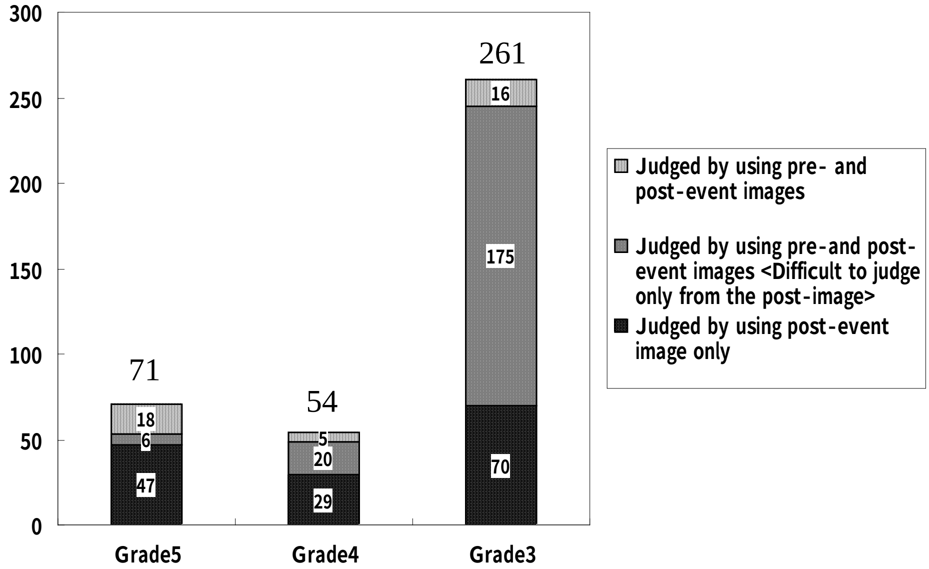


Figure 5.16: Number of buildings classified as Grades 3, 4, and 5.

The damage ratio of buildings in each city block (surrounded by major roads, total 31 blocks) are calculated and shown in Figure 5.17. The blocks with high damage ratios are seen to be located along two rivers. This damage concentration may be explained by soft-soil condition and high site amplification in these areas as already explained in the previous section.

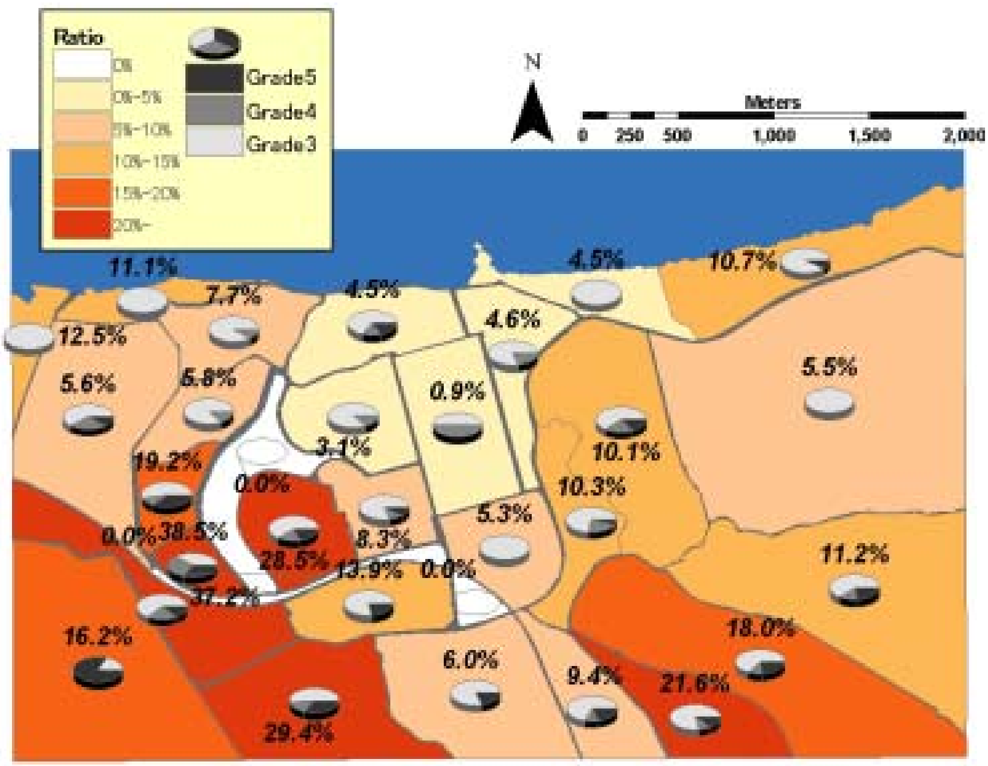


Figure 5.17: Building damage ratio (A total of Grades 3, 4, 5 in each block divided by the number of buildings in each block)

Figure 5.18: Deployment of disaster victims' tents on the two post-event days (May 23 and June 18, 2003) at an open space and photographs of tents in the field survey.

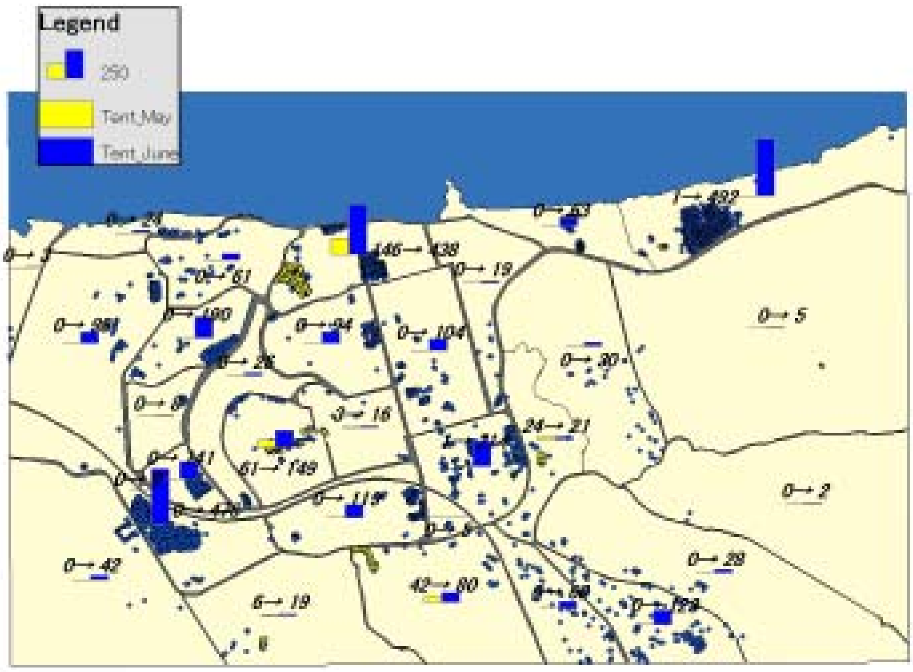


Figure 5.19: Distribution of disaster victims' tents on the two post-event days (May 23 and June 18, 2003) counted from the QuickBird images.

Tents for disaster victims' could be observed in the post-event images as shown in Figure 5.18. The locations of tents in the two post-event images were identified as shown in Figure 5.19. A total of 284 tents were observed in the May 23, 2003 image and the number increased to 3,150 in the June 18, 2003 image.

These observations on building damage and disaster victims' tents indicate that high-resolution satellite images can provide quite useful information to post-event disaster management.

iii. Summary

Using QuickBird satellite images of Boumerdes city before and after the 21 May, 2003 Algeria earthquake, visual interpretation of building damage was conducted. Using the post-event pan-sharpened image of May 23, 2003 only, totally collapsed buildings (Grade 5), partially collapsed buildings (Grade 4), and buildings surrounded by debris (Grade 3) were identified. Some buildings were difficult to judge their damage level, and for these buildings, the pre-event image was employed as a reference to judge the damage status. A total 3,459 buildings were classified their damage grades by the visual interpretation. The locations of tents in the two post-event images were also identified. These observations indicate that high-resolution satellite images can provide quite useful information to emergency management after natural disasters.

5.3 Conclusions

Boumerdes was one of the cities that was most seriously hit by this earthquake. The city area spreads over a terrace facing the Mediterranean, stretching 2 km from north to south in latitude 36 44 46 N and 3 km from east to west at a longitude of 3 27 29 east. As the distribution of damages differed from area to area, three different surveys were conducted in Boumerdes for investigating the local site effect on the distribution of structural damage. This investigating included survey of cracks at mortar supports of lampposts, which were spotted everywhere in the city, microtremor measurement and data from satellite imageries.

Through the satellite imagery analysis, city blocks with high damage ratios were seen to be located on the about 40 m altitude terrace along rivers eroding deep in the terrace. Both the lamppost-support crack survey and the microtremor measurement also indicated high site amplifications near the rims and/or the presence of soft soil deposits in these city blocks.

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Acknowledgement

QuickBird images of Boumerdes, Algeria used in this study were made available through Earthquake Engineering Research Institute, Oakland California, USA.

Chapter 6

Disaster Response

6.1 Introduction

The affected region is a densely populated area and when the earthquake occurred most of the people were at their homes. Many dwellings were damaged or collapsed. Consequently, human losses were relatively high compared to previous earthquakes with such a relative low magnitude.

Since several buildings collapsed, the disaster response program activities, such as search and rescue, injured people care, life recovery and housing reconstruction, were further complicated. This chapter describes these activities based on the damaged area situation report.

6.2 Hospitals and health care

Some members of the investigation team visited a number of health care facilities to assess the damage and to discover the most common vulnerable factors that lead to the malfunction of the health care facilities.

Before our visit, the Algerian engineers had already visited the affected health care facilities and assessed their damage. The assessment was conducted in accordance with the level of structural damage used by the Algerian concerned authorities.

At least 242 hospitals of varying importance were affected in the province of Boumerdes; more than 30 of them suffered very severe damage or total collapse. Figure 6.1 shows the distribution of their damage according to the scale used.

More than 73% of the health care facilities suffered damage to their furniture and non-structural elements; the remaining 27% approximately, suffered slight to severe damage to their structures.

The main materials that were used for the construction of health care facility structures were RC, masonry and bricks.

The age of the facilities were also variable, some facilities that were built in the era of the French colonization were still in use. This issue made many facilities very vulnerable and weak to resist against any earthquake of such intensity and maybe even weaker.

During our visit, we carried out interviews with the staff of two hospitals to assess the damage and learn about the problems that hampered the treatment of patients. These hospitals were: the “CHU Algiers Central Hospital” and the “Thenia Hospital”. Obviously we had hoped to visit more facilities, but the time was limited since the damage was widespread and the number of camps was very large as well as the collapsed buildings; some of those buildings were completely new. Therefore, it was obvious that hospitals would not be in better condition than those collapsed buildings.

The interview was carried out with medical staff, since they are the only ones who have direct contact with the injuries and they know the most. Unfortunately, we could not meet with any of the administrative staff since the first visit was late afternoon and the second visit was on Thursday, which is considered to be the weekend in Algeria.

The interview discusses three main issues: Organizational vulnerabilities and their affect on human life, lifeline damage and their impact on human life and finally structural/non-structural damage and their impact on human life.

This section is composed of two main parts: the first section reveals the results of the interview and the damage that was observed in the hospitals and the second presents the conclusion as well as the lessons that can be learned from this earthquake and further propose some measures that should be taken to avoid the reoccurrence of such a state of confusion during the event of natural disasters.

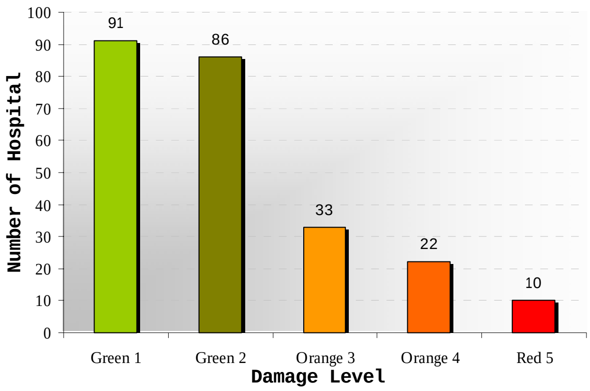

Figure 6.1: Distribution of structural damage

6.2.1 CHU Central Hospital, Algiers

This hospital is located in the capital Algiers, and it is considered to be the biggest in the whole country according to some sources. It has a capacity of 2,500 beds. It is an old hospital, built by the French during their colonization of Algeria so it is older than 60 years old. The facility is composed of many buildings; each building is allocated for one or more services. The hospital suffered only slight damage; and therefore it did not stop functioning after the earthquake.

The facility was overcome by a huge number of casualties, thus in some cases the staff had to transfer some injuries since they were incapable of treating them.

Some onsite medical staff helped in dispatching the injuries according to the possibility in the hospitals to which they belong. One of those teams stated that they had no plan of rescue; therefore the destination was decided by doctors.

The interview was conducted by asking direct questions to the personnel or by giving them forms to fill in. A total of five personnel were interviewed:

1/ Two residents,
2/ Two IDE, and
3/ One assistant

i. Organizational aspects:

Among the five interviewed people, only one person who started working one year before the occurrence of the event stated that he had attended a training course; however he affirmed that it was not enough to prepare medical staff for such a disaster. The rest of the interviewed staff had not attended any kind of activities that could help them to act correctly during an emergency during natural disasters. They declared that the situation would have been made better if they had had any kind of training.

The number of staff was also a dilemma; part of the personnel was also affected by the earthquake. Others could not go to the facility because the roads were closed. Moreover, some of those interviewed said that the number of personnel was insufficient even before the earthquake.

The result of the inadequate organization resulted in inferior management of the patients, also it resulted in increased stress levels and/or difficult work conditions for the staff, is resulting in a poor quality of treatment.

ii. Lifeline damage:

The electricity and telecommunications were cut for more than 12 hours. The staff stated that the commercial electric power was replaced by alternative sources. However telecommunication was cut in many buildings until the day of our visit, almost two months after the occurrence of the event; there were no alternative sources that could be used. Some personnel stated that they were trying to use their own mobile phones. The water supply and gas were cut in some areas, and alternative sources were used. Other staff, stated that some equipment including medical equipment had fallen down, which caused their damage or their un-operability. The radiology service stopped functioning due to the damage to its equipment. Figure 6.2 shows an example of the equipment that fell because of weak attachment to its support; two months after the earthquake and the equipment was not fixed and therefore it was unused.

Figure 6.2**:** Damage to electric equipment, CHU Hospital

This damage caused delay in treating patients, difficulty in transferring injured people to other hospitals. Additionally, the damage decreased the quality and increased the working stress environment as some of the personnel stated.

iii. Structural/non-structural damage:

The facility suffered slight structural damage. Some cracks in the walls were noticed during the visit, see Figure 6.3. Some of the interviewed staff stated that they had spotted some structural damage, which had an impact on their tasks by making the areas inaccessible.

Non-structural equipment had fallen down, broke and made some areas inaccessible which made moving the patients difficult.

Figure 6.3: Cracks in the structure, CHU Hospital

6.2.2 Thenia Hospital

The hospital is located about 60 km east of the capital, Algiers. The facility has a capacity of 213 beds. It is composed of 2 parts; the French built the original part in 1870 during their colonization of the country. The second part was added in recent years. The older part suffered very severe damage due to ageing of the building and the masonry that was used as the structural material, see Figures 4-6.

The interview was carried out in two ways, talking to staff and distributing questionnaires. In total four people were interviewed:
1/ Two doctors, and
2/ Two administrative staff.

Figure 4: Damage to the emergency wing

Figure 5: Collapsed roof of another wing

Figure 6: Cracks in the walls of the emergency wing

i. **<u>Organizational aspects</u>:**

All the questioned personnel stated that they had never received any kind of preparedness such as lectures or training to help them in dealing with such a huge disaster. All of them stated that the situation would have been made better had they undergone some training or preparation. The number of personnel was not sufficient even before the earthquake.

Furthermore, after the quake, many members of the staff could not work due to their injury or because of road closures that hampered them from going to the facility.

The problems of organization stressed the personnel and made them uncomfortable during their work. The same problems resulted in difficulties in treating patients and decreased the quality of the treatment.

ii. **Lifeline damage:**

The situation of the hospital was mediocre; at least until the day of our visit, many facilities were still unavailable. Electrical power was cut for approximately 12 hours. During the first hours, candles were used until emergency power began to operate. The gas and water supplies were cut off for more than 2 days. However alternative sources were used such as water tanks shown in Figure 6.7. Telecommunications were also cut, and there was no alternative source for replacement. Telecommunications were still not restored at the day of our visit, two months after the event.

The lifeline damage made the treatment difficult or even impossible. Personnel stated that they could not work in the hospital under such difficult conditions. Damage to lifelines in particular affected human life saving. It delayed their treatment, delayed the moving of the patients and hindered the transfer of casualties to other hospitals, since equipment were strewn everywhere.

iii. **Structural/non-structural damage:**

The building had suffered severe damage. The staff we interviewed stated that they noticed a lot of damage to its structural and non-structural elements; also they confirmed that the damage had an affect on their work tasks. The structural elements totally collapsed in the majority of the facility. Non-structural elements had fallen, were broken and made the area inaccessible from all wings. The damage obliged the government to bring prefabricated buildings that were used instead of the actual facility, as it is shown in **Figure 6.8**. Patients were receiving treatment in the prefabricated buildings. The prefabs were equipped with electricity and air conditioners to make life easier for the medical staff as well as the patients.

The structural damage had a clear impact on the patients since they had difficulty being treated, and many patients had to be transferred to other hospitals because their treatment was impossible.

Figure 6.7: Reservoir of water used as alternative source, Thenia Hospital

Figure 6.8: Prefabricated buildings used instead of the actual building, Thenia Hospital

6.2.3 Discussion and Recommendations

The level of preparedness of Algeria's health care facilities for natural disasters, particularly earthquakes can be clearly understood. Thousands of buildings collapsed, no alternative sources were provided or available in hospitals.

It should be noted that Figure 6.1, which presents the hospital damage distribution, while being practical in viewing clearly the damage to structural elements, is not so useful for the case of health care facilities. Structural elements represent 10-15% of the whole cost of a hospital and the other part represents the cost of the non-structural elements including medical equipment. Health care facilities, with all their types (fixed or mobile) are the only locations where a patient can receive complete treatment. Therefore their importance cannot be judged by their structural elements without taking consideration of the other important elements. Algeria, as well as many other countries, imports medical equipment that has a direct affect on the national economy of the country. Therefore such a type of equipment should be seriously protected.

The colour-coded classifications of Green 1- Red 5 are not so practical for the case of hospitals. Therefore a better classification is necessary, one that is more relevant to life saving.

Both hospitals suffered damage to their elements. It should be noted however that although the CHU hospital is over 70 km away from the epicenter, it suffered considerable damage. This was not visibly evident to us at the time of our visit; nevertheless this was reported clearly by staff members through our interviews. Replacement services were not available straight away; it was even necessary to wait for some time before "emergency" services were set up. This needs immediate attention. Also requiring immediate attention is the lack of training and organization among the hospitals' personnel.

The use of tanks that were brought after sometime cannot be considered as an alternative source of water. An alternative source should be present always in hospitals to be used immediately after the lack of any lifeline. Water, Electric power, gas, telecommunications are very important for the functioning of a health care facility; without these lifelines hospitals cannot function.

On the other hand, structures of 130 years old cannot function properly and should have been rebuilt a long time ago. In case these structures are considered national treasures they should be protected by retrofitting, paying particular attention to methods to make them perform well during natural hazards. Moreover, if a hospital experiences any damage to one of its lifeline, the damage should be fixed immediately after the disaster so that it can be used during the rescue operations.

Hospitals must be prepared according to particular methods. In the following we propose some ideas that might inspire the Algerian concerned authorities, as well as those who are living in countries that are facing the same natural disasters.

- Building structures that perform well during earthquakes and hence can resist disasters.

- Organizing the inside and the outside of the facilities to avoid any equipment from falling and harming displacement inside and outside the facility. Equipment should be well attached to their support with flexible couplings.

- Providing the health care facilities with the necessary number of personnel.

- Providing the medical staff as well as the rest of the staff with special emergency response lectures and training to help them to behave correctly during a disaster.

- Providing the hospitals with the necessary medical products that are needed in the case of an emergency.

- Providing the hospitals with alternative sources that can be used *immediately* after the lack of the principal lifeline such as electric generators for the case of a blackout.

6.3 Emergency response

6.3.1 Situation report

The Algeria Earthquake caused more than 2,200 human losses and approximately 100,000 heavily damaged residential units. After the earthquake many people were buried under the rubble. Both, public and private sectors conducted the search and rescue operations. However, it was difficult to perform these activities efficiently due to the great confusion in the damaged areas.

The Emergency Response Plan consists of a series of modules as shown in Table 6.1 and Figure 6.9. Additionally, Figure 6.10 shows the center of module 'Expertise' in Boumerdes local government. According to the person in charge of this plan in Boumerdes, who was interviewed by the Team, the most difficult module to implement was the 'Rescue' module. The reason for this is that the organization spent several hours constructing a framework due to the lack of reliable damage information and professional human resource for search and rescue at the initial stage of the response.

This problem is a common issue in large-scale disasters around the world. Surely it is important to systematically organize the emergency response team as soon as possible. However, it is difficult to manage a team in the confused situation at the beginning of the disaster response. In the case of the Algeria Earthquake, the search and rescue operations undertaken by the government were not too much delayed compared to other cases. As a matter of fact, critical difficult tasks as the coordination of international rescue teams and human resource allocation in local governments around the damaged areas were dealt within a few days.

Another module, which was as difficult to implement as the 'Rescue' module, was the 'Medical care, Evacuation, and Hygiene' module. According to the interviewed, particularly complicated was the evacuation plan – for instance providing the tents, grasping the tent needs, and getting the space for setting the tent sites. The lack of tents and confusion in the material distribution within an organization and among organizations led to delays in the support to victims. This issue, however, was not more serious than in the case of the Hanshin-Awaji Earthquake.

From the global viewpoint of disaster management, the response of the agencies (national government, local governments, and municipalities) worked out well in this case. It can be concluded that the emergency response plan and the framework of the emergency response were practical and useful.

Table 6.1: Emergency response plan modules

1 Rescue	*8 Provision of temporary housings*
2 Maintenance of Public Security	*9 Help of provision of food and issue in kind*
3 Medical care, Evacuation, Hygiene	*10 Transport*
4 Expertise, Counsel	*11 Water Service*
5 Various Material, Equipment	*12 Energy*
6 Connection, Telecommunication	*13 Public Works*
7 Information	*14 Evaluation, Assessment*

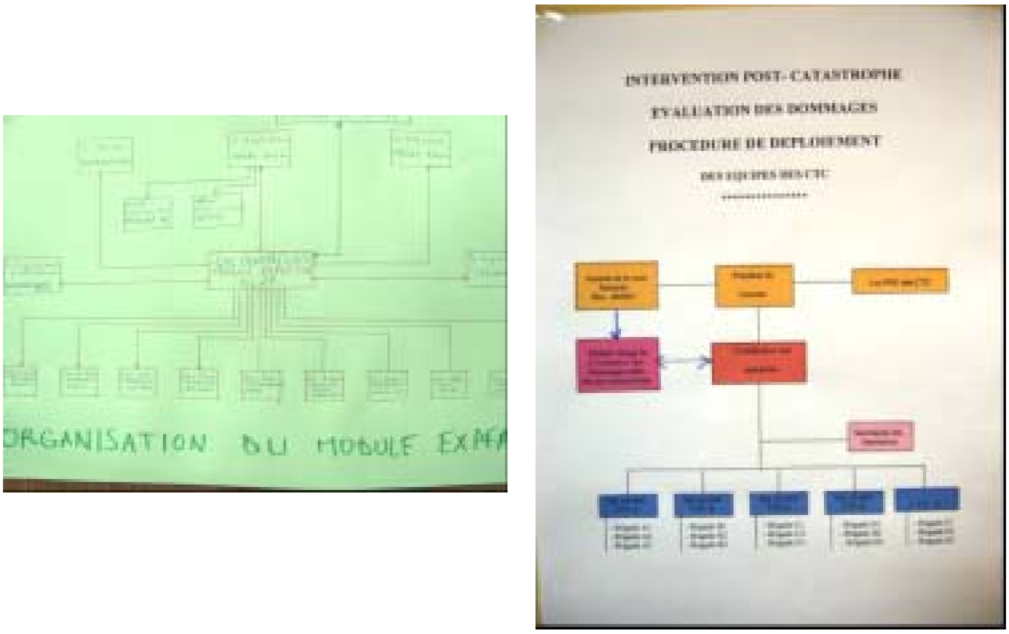

Figure 6.9: The document about module ‘Expertise’ and ‘Evaluation’

Figure 6.10: The center of module ‘Expertise’ in Boumerdes local government

6.3.2 Decrees for emergency response in Algeria

Reportedly, emergency response activities of the local government and municipalities worked out well in the aftermath of the Algeria Earthquake with exception of the confusion at the time of the initial response. The main reason for this are two decrees (No.85-231 and 232), related to the government emergency response plan, which were enacted in 1985. Thus, the legal framework for the disaster response was defined.

This chapter shows some articles of these decrees and points out characteristics of the emergency response in Algeria.

Decree 85-231

<Chapter 1 General Provisions>

This chapter establishes meanings and roles of the emergency response plan developed by the local government and municipalities. According to these contents, the local government and municipalities in the damaged area would have standard disaster response plans and would surely share an understanding of the disaster response activities of each other.

Article 3, 4, 5 in Chapter 1 of Decree 85-231

Article 3

Each public sector must work out its own plan for emergency response.

Article 4

When some sectors share a common risk, they should work out a unique plan integrating their basic plans completely or partially, according to the characteristic of the risk.

Article 5

In consideration of regional characteristics, natural risk, and magnitude of the disaster risk, the emergency response plan must stipulate all of the necessary actions for the emergency response.

<Chapter 2 Development and coordination of the emergency response plan>

This chapter establishes the responsible officer for the emergency response plan and the relationship among sectors concerned and roles of each public sector. According to these contents, the framework of the emergency response in Algeria is a hierarchical system in which local governments and municipalities manage the recovery and reconstruction of damaged areas according to a plan under the leadership of the national government.

Article 17, 23 in Chapter 2 of Decree 85-231

Article 17

The emergency response plan developed by municipalities must be passed in the assembly and must be put before the governor.

Article 23

Emergency response plans must be coordinated wholly or partly in the framework of national programs.

<Chapter 3 Bases of operation and implementation of the emergency response plan>

This chapter establishes the organization control for the disaster management and main tasks to be taken care at the disaster response time. It clarifies that the responsibility lies not only on the organization but also on the commanders of activities and thereby becomes practical for the disaster response activities.

Article 25, 29 in Chapter 3 of Decree 85-231

Article 25

Emergency response plans of the local governments and municipalities must establish the persons who have the commandership for the implementation of missions. Commands of warning signal and procedures for communication are described in the plan.

Article 29

A base of the emergency response operation of the local governments and municipalities should be the only organ responsible for the implementation of the plan. This organization must be responsible of the following.

-To grasp the disaster magnitude	*-To oversee the information flow*
-To determine a needed command on the plan	*-To oversee the security of human lives and property*
-To assemble means to implement the plan	*-To take care of temporary housings for victims*
-To organize the rescue operations	*-To requisition all additional public burdens if necessary*
-To ask reinforcements if required	*-To produce the assessment of operations*

<Chapter 4 Emergency Response Modules>

This chapter defines 'Modules' as components of the activities for the implementation of the emergency response plan. This concept is similar to the 'Incident Command System' in the United States. It shows that local governments and municipalities have the same modules for disaster response everywhere in Algeria and thereby the public sectors including the national government can work together on the disaster response in case of a wide-area disaster.

Article 33, 34 in Chapter 4 of Decree 85-231

Article 33

The emergency response plan of local governments and municipalities consists of modules of intervention.

Article 34

In the case of local governments, these modules are as follows.

1 Rescue	*8 Provision of temporary housings*
2 Maintenance of Public Security	*9 Help of provision of food and issue in kind*
3 Medical care, Evacuation, Hygiene	*10 Transport*
4 Expertise, Counsel	*11 Water Service*
5 Various Material, Equipment	*12 Energy*
6 Connection, Telecommunication	*13 Public Works*
7 Information	*14 Evaluation, Assessment*

Decree 85-232

This decree establishes the role of the agency concerned with the emergency response and the administrative measures about the program.

Article 1 of Decree 85-232

Article 1

Under the regulations and laws, authorities and agencies concerned with the emergency response must minimize the disaster which has the possibility of threatening the safety of humans, property, and environment, and must efficiently take legal and technical measures in order to minimize the damage caused by the disaster.

6.4 Life in affected areas (disaster victims' camp) and housing recovery plan

6.4.1 Life in affected areas (disaster victims' camp)

Since many buildings collapsed and were damaged by the earthquake in the affected area, the government needed to provide spaces and tents for homeless people.

According to the IFRC report of June 23, 2003 approximately 30,291 tents were installed during the emergency phase under the responsibility and direction of the Algerian Government and up to 27,371 families have been sheltered there at the locations shown in Table 6.2. The tents were located in parks, sports grounds, and damaged buildings empty lots.

Table 6.2. Tents provided by the government and international donors

Location	Number of sites	Number of tents	Number of persons
Alger	95	11,985	65,461
Boumerdes	125	17,796	108,493
Tizi-Ouzou	45	1,352	7,852
Blida	6	158	445

Source: Algeria Earthquake Appeal No. 14/03 Operations Update No.3 (IFRC)

According to a person in charge of a tent site, who was interviewed during the survey, some sites with large number of tents are managed by a director from the government, the Civil Protection, the Red Crescent, etc. The director is responsible for the tent site. The Civil Protection watches over the site and maintains the order. Additionally, some organizations, such as the Red Crescent and the medical team, support and assist the disaster victims' lives. The authorities often hold meetings with a representative of the inhabitants to discuss about the site management and strategies to improve their lives.

At the site, there are also some large tents that serve as clinics for sick or injured persons as well as for mental patients. After a disaster it is necessary to treat the symptoms of the Post Traumatic Stress Disorder (PTSD). Therefore, it is very important to consider such facilities at this stage of the evacuation process.

Common facilities such as water supply outlets and public lavatories are located at the disaster victims' camps. Electric equipment is also installed. In general, a living environment at a subsistence level is provided. Additionally, the government provides public support services, such as food distribution.

The organization described in the previous paragraphs has allowed large tent sites to have a management system similar to a community. In this way, the government and rescue agencies have ensured safety and a convenient subsistence level to the disaster victims as shown in Figures 6.11 to Figure 6.14.

Figure 6.11: Water supply facilities and lavatories

Figure 6.12: Red Crescent tent

Figure 6.13: Tent camp

Figure 6.14: Mobile library for children

6.4.2 Recovery and reconstruction activities

In the recovery process, the activity following the evacuation stage is the ‘reconstruction’ especially in terms of house reconstruction. In this sense, the government’s plan has three parts: construction of new dwellings, support the reparation of slightly and moderately damaged houses, and provision of temporary dwellings. According to this plan, all tents should be dismantled by the end of 2003.

Ten thousand temporary dwellings will be provided to the people whose houses were largely damaged and cannot be reconstructed within a short time. Domestic construction companies will take care of the building works. The government is not considering importing temporary houses as in the case of the 1999 Turkey and Taiwan Earthquakes, according to the report.

The agencies have signed contacts with structure research and construction companies for the reparation of the damaged dwellings. Works for the reinforcement and reconstruction of these buildings had already started a month after the earthquake.

Twenty thousand new houses will be constructed by the end of 2003.

6.5 Response of the International Community

The dilemma of thousands of earthquake victims initiated a wave of solidarity among the local population and the international community. The response from the local population and industry, and international community were overwhelming. Before even that the Algerian government issues the request for emergency assistance, rescuers equipped with sniffer dogs and thermal imaging kits, as well as with medical teams flow in from all over the world to help search and rescue operations. Countries that sent immediately rescue teams are: ***Australia*** (34-member team), ***China*** (30-member team with rescue dogs), ***France*** (10 peace officers with 10 rescue dogs; and 25 field hospital workers), ***Germany*** (a rescue team with 4 dogs), ***Ireland*** (17-member team), ***Italy*** (9-member team with rescue dogs), ***Japan*** (a rescue team of 61 personnel and a medical team of 22 members), ***Luxembourg*** (6-member team with 4 rescue dogs), ***Poland*** (a 27-member team with 6 rescue dogs), ***Portugal*** (31-member team with rescue dogs), ***South Africa*** (24-member team with 4 rescue dogs), ***South Korea*** (a rescue team of 21), ***Spain*** (a rescue team), Sweden (75 rescuers), ***Russia*** (70-member team).

Figure 6.15 depicting the activities of the Spanish and French Red Cross Societies and Japan Disaster Relief (JDR) Rescue Team in Boumerdes.

The Spanish Red Cross (ERU), begins construction of a basic health care centre. *Photo: Rana Sidani*

Japan Disaster Relief (JDR) searching for victims

The French Red Cross ERU team member assists in construction of a water distribution system *Photo: Chris Black*

Japan Disaster Relief (JDR) Searching for victims in the rubble

Figure 6.15: Rescue activities of the International Community

At that time, the International Federation of the Red Cross and Red Crescent Societies deployed international medical teams to assist the Algerian Red Cross, team of expert to evaluate the damage and assess the needs of the affected population. The Federation also released $154,00 from its disaster fund and issued an appeal to the international community to help the people of Algeria.

The response from the National Red Cross sisters and Red Cross National Societies was rapid. Two Emergency Response Units (ERU) were dispatched by the French Red Cross. Also the Spanish Red Cross sent a Basic Health Care Unit, which could assist up to 500 people a day. Other National Red Cross included the American, the Swiss Red Cross, the German Red Cross, the Saudi Red Crescent, the Iranian and Turkish Red Crescents, the Belgian and British Red Cross Societies

Although the Algerian Government immediately established an Emergency Control Unit, under the Head of Government and line Ministries including the Defense Forces, the sheer intensity of the earthquake demanded significant amounts of money, in addition to significant manpower that was beyond the Algerian capacity alone and was in need of further assistance. Hence the Government of Algeria requested emergency assistance from the international community. Again, as a result, extraordinary solidarity quickly came into play and a huge assistance came from the international community (governments, ONGs, UN, UNICEF, CONGAF, and others.....), including the financial support, donations in kind, food, and the offer of active help. In deed, the International response resulted in a surplus of goods in kind for the immediate response. Table 6.3 and 6.4 show the financial pledges as well as pledges in kind and services, respectively, received by the Algeria government (from the International Federation of the Red Cross as of 7/12/2003).

The humanitarian assistance further continued and was provided by the International Community assisting therefore the Algerian government, responding to the urgent needs of the affected population. These needs were to provide;

- **Shelter:** in the form of tents and plastic sheeting for shade. Table 6.2 shown above illustrates the numbers of families and the locations of the temporary shelters provided by the government and international donors

- **Relief:** Food and water, emergency relief items like blankets, kitchen sets, hygienic sets and jerry cans

- **Water and sanitation:** Hygiene and sanitation.

- **Health:** The health system has remained effective thanks to the Spanish Basic Care Unit.

- **Psychological Support:** Psychological assistance was needed to those who lost close relatives, homes and belongings and were facing the idea of uncertain future.

- **Rehabilitation:** Significant rehabilitation work were required to repair infrastructure damage, re-establish the water supply system, and provide permanent housing for those made homeless.

- **Disaster Preparedness and Response:** The response by the International Community was effective, however the Algerian government and national societies need to continue to improve disaster preparedness.

Table 6.3: Pledges received by the Algeria government

DONOR	TYPE	QTY	UNIT	VALUES CHF	DATE	COMMENT
AMERICAN – PRIVATE DONORS				7,734	03.06.03	
AMERADA HESS LTD		25,000	USD	32,188	22.05.03	
AUSTRALIAN – PRIVATE DONOR		85	USD	109	18.06.03	
BELGIUM – GOVT		2,782	EUR	4,309	26.05.03	CUSTOM FEES & LOGISTICS
BP (CAF)		400,000	USD	540,400	29.07.03	
BRITISH – GOVT/DFID		93,137	GBP	207,136	30.06.03	DREF REIMBURSMENT
BRITISH – RC		490,000	DZD	8,196	02.07.03	DIRECTLY TO DELEGATION
BRITISH – PRIVATE DONORS				33,733	30.05.03	
BRITISH – RC		16,232	GBP	35,865	09.10.03	
ABACUS TSY		79,340	USD	107,188	14.07.03	
CANADIAN – GOVT/RC		198,000	CAD	185,526	22.05.03	
CANADIAN – RC		90,495	CAD	91,445	12.09.03	
CHINESE – RC		50,000	USD	64,375	13.06.03	BILATERAL
CROATIAN – RC		15,000	EUR	22,665	27.05.03	
DANISH –GOVT		6,702	USD	8,629	16.06.03	PROGRAMME SUPPORT
FINNISH – RC		50,000	EUR	73,175	30.05.03	
HELLENIC – RC		10,000	EUR	15,110	26.05.03	PURCHASE OF 3000 BLANKETS
ICELANDIC - RC		1,000,000	ISK	17,898	22.05.03	DREF REIMBURSMENT
IRISH – GOVT		500,000	EUR	771,500	26.05.03	
JAPANESE – RC		49,900	USD	67,839	21.05.03	
KOREA, REPUBLIC –RC				30,000	28.05.03	
KUWAIT – RC		200,000	USD	272,000	28.05.03	
LIBYAN – RC				10,000	24.05.03	
LIECHTENSTEIN – PRIVATE DONORS				100	01.07.03	
MEDICOR FOUNDATION		100,000	GBP	220,350	---	
MONACO – RC		15,000	EUR	22,838	03.06.03	
MONACO – RC		29,719	EUR	45,856	04.07.03	
NORWEGIAN – GOVT/RC		1,133,333	NOK	219,300	03.06.03	
OPEC		500,000	USD	679,750	23.05.03	
PRIVATE DONORS				25,906	03.07.03	
SWEDISH – GOVT		1,000,000	SEK	168,000	23.05.03	PSYCHOLOGICAL & OTHER SOCIAL SUPPORT
WHO/VERF				2,000	26.05.03	
SWISS – PRIVATE DONORS				100	18.06.03	
SWISS – PRIVATE DONOR		500,000	USD	679,750	23.05.03	
WESTERN UNION FOUNDATION		50,000	USD	67,975	28.05.03	
SUB/TOTAL RECEIVED IN CASH				**4,738,945**	**CHF**	

Source: International Federation of the Red Cross as of 7/12/2003

Table 6.4: Pledges in kind and services received by the Algeria government

DONOR	TYPE	QTY	UNIT	VALUES CHF	DATE	COMMENT
AMERICAN – RC/BULGARIAN - RC				28,000	28.05.03	4000 HYGIENIC PARCELS
BELGIUM - RC		42,794	EUR	66,288	28.05.03	100 TENTS, 1020 BLANKETS, 10`0000 WAT PURIF. TAB., 5 HEALTH KITS
BRITISH – RC				209,045	28.05.03	599 TENTS, 6030 BLANKETS, 2010 PLASTIC SHEET, 603 KITCHEN SETS, 1960 JERRY CANS
BRITISH – PRIVATE DONOR				15,500	28.05.03	900 BLANKETS, 500 PLASTIC SHEETS
CANADA	DELEGATES			6,242	29.07.03	
DANISH –GOVT		103,113	USD	132,758	16.06.03	2400 TARPAULINS, 5040 KITCHEN SETS
FRENCH - RC		255,000	EUR	385,305	26.05.03	LOGISTICS & WATSAN ERU FOR 1 MONTH
FRENCH - RC				346,000	28.05.03	1480 TENTS, 10`000 BLANKETS
GERMAN - RC				17,000	28.05.03	1000 BLANKETS, 480 KITCHEN SETS
IRANIAN - RC				70,000	28.05.03	200 TENTS, 4000 BLANKETS, 400 KITCHEN SETS
SLOVENIAN – RC				1,390	28.05.03	278 BLANKETS
SPANISH – RC		167,585	EUR	259,757	27.05.03	BASIC HEALTH CARE ERU FOR 1 MONTH
SPANISH – RC				10,102	28.05.03	586 HYGIENIC PARCELS, 600` WATER PURIFICATION TABLETS
SWISS – RC				142,600	28.05.03	215 TENTS, 1000 PLASTIC SHEETS, 2000 KITCHEN SETS, 10 GENERATORS
SYRIAN – RC				45,000	28.05.03	200 TENTS, 1000 BLANKETS
TURKISH – RC				40,000	28.05.03	200 TENTS
UAE - RC				35,000	28.05.03	150 TENTS, 1500 BLANKETS
YUGOSLAVIAN – RC				20,000	21.05.03	3000 BLANKETS, 200 KITCHEN SETS
HUNGARIAN –RC		20,675	USD	27,931	09.07.03	BILATERAL, MEDICAL RELIEF
SUB/TOTAL RECEIVED IN CASH				**1,857,918**	**CHF**	

Source: International Federation of the Red Cross as of 7/12/2003

6.6 Conclusions

Due to time constraints it was only possible to interview a limited number of staff in only two hospitals however it is hoped that even this small scale interview will provide a valuable alternative view of hospitals in areas of the world where earthquake preparedness is not yet as advanced and highly valued as in others.

One must emphasise that hospitals must be prepared according to particular methods. Herein we propose some ideas that might inspire the Algerian concerned authorities, as well as those who are living in countries that are facing the same natural disasters.

- Building structures that perform well during earthquakes and hence can resist disasters.

- Organizing the inside and the outside of the facilities to avoid any equipment from falling and harming displacement inside and outside the facility. Equipment should be well attached to their support with flexible couplings.

- Providing the health care facilities with the necessary number of personnel.

- Providing the medical staff as well as the rest of the staff with special emergency response lectures and training to help them to behave correctly during a disaster.

- Providing the hospitals with the necessary medical products that are needed in the case of an emergency.

- Providing the hospitals with alternative sources that can be used *immediately* after the lack of the principal lifeline such as electric generators for the case of a blackout.

In the case of the Algeria Earthquake, the search and rescue operations undertaken by the government were not too much delayed compared to other cases. As a matter of fact, critical difficult tasks as the coordination of international rescue teams and human resource allocation in local governments around the damaged areas were dealt within a few days.

From the global viewpoint of disaster management, the response of the agencies (national government, local governments, and municipalities) worked out well in this case. It can be concluded that the emergency response plan and the framework of the emergency response were practical and useful.

As far as the Emergency Response Plan is concerned, the ‘Rescue’ and ‘Medical care, Evacuation, and Hygiene’ modules were difficult to implement. According to the interviewed, particularly complicated was the evacuation plan – for instance providing the tents, grasping the tent needs, and getting the space for setting the tent sites. The lack of tents and confusion in the material distribution within an organization and among organizations led to delays in the support to victims.

Finally, one ought to acknowledge the response from the local population and industry, and international community (Red Cross Societies, foreign government and ONGs…), which was overwhelming and rapid.

6.7 References

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Chapter 7

Conclusions and Suggestions

7.1 General

As residents of northern Algerian cities settled down on the evening of May 21, 2003, their ceilings and walls began to shake and crumble. The magnitude 6.8 earthquake struck at 17:44 local time, wreaking extensive damage throughout five Provinces.

Centered in the Boumerdes region some 50km east of the capital city of Algiers, the worst affected urban areas include the cities of Boumerdes, Zemmouri, Thenia, Belouizdad, Rouiba and Reghaia, together with eastern areas of the capital. According to the latest reports, deaths total 2,278, with a further 11,450 injuries. Structural damage within urban areas was severe, with an estimated 200,000 people displaced from their homes, provisionally re-housed in temporary tent camps and an estimated $5 billion of damage. The May 21st earthquake is the largest to strike Algeria since 1980, when a magnitude 7.2 struck El-Asnam city, about 250 km west of the capital.

Major natural disasters will strike Algeria again during the next several years. Lives will be lost, property damage will occur, and the economy will suffer. Algeria's central and local governments should properly prepare themselves to mitigate those losses. A National Disaster Mitigation Act ought to be endorsed; requiring cities, prefectures, and special districts to have their own Local Hazard Mitigation Plan

7.2 Conclusions

7.2.1 Geology, History and Characteristics of the Earthquake

On May 21, 2003 at 19:44:19 local time the Boumerdes earthquake struck the Zemmouri region in northern Algeria. Zemmouri is approximately 70 km east of the capital, Algiers. The moment magnitude of this event is 6.8. The location of epicenter is 36.90N 3.71E determined by U.S.G.S. The focal depth of the earthquake was about 10 km. The earthquake occurred in the boundary region between the Eurasian plate and the African plate, which is in a compression state. Earthquakes that occur in this area are mostly caused by a reversed fault or strike slip fault. And this tremor is among the major quakes of the Western Mediterranean.

Beside the human losses and structural damages, the earthquake disrupted health services, water supply lines, electricity, and telecommunications in the region. The sheer intensity of the earthquake demanded significant amounts of money, in addition to significant manpower that was beyond the Algerian capacity alone and was in need of assistance for rebuilding the affected region.

7.2.2 Liquefaction and Geo-Related Failure

The ground failures such as the liquefaction were not so severe as compared with the damage induced by the strong ground motion. Therefore, there was a little damage to structures induced by the ground failures. The major cause is considered that the soft ground exists in limited sites of the basin.

7.2.3 Damage to Structures

Algeria has experienced many destructive earthquakes. The latest devastating one is of the May 21, 2003 of magnitude 6.8 struck Alger-Boumerdes region. Damage estimated at 5 billion U.S. dollars. At the moment it is early to speculate on the factor or factors that have caused such an extensive damage. However, from the inspection of the damaged buildings during our 6-day stay in the affected region, some of the main defects in the design and construction method of the buildings were discussed and which can be summarized as follow:

1. Soft story effects
2. Short column effects
3. Use of weak and slender columns poorly reinforced (generally unconfined)
4. Poor detailing of structural joints
5. Inadequate transverse reinforcing steel detailing (tie spacing and 90 degree hook)
6. Poor material quality and unsound construction practice.
7. Lateral force was not considered in design
8. Inappropriate anchoring of beam and slab reinforcement.
9. Use of irregular building configurations with discontinuities in mass, stiffness, strength and ductility.
10. Use of weak materials for facades.
11. Use of stiff spandrel masonry walls resulted in short captive columns that increased the shear demand beyond the shear capacity supplied.

7.2.4 Damage in Boumerdes

Boumerdes was one of the cities that was most seriously hit by this earthquake. The city area spreads over a terrace facing the Mediterranean, stretching 2 km from north to south in latitude 36 44 46 N and 3 km from east to west at a longitude of 3 27 29 east. As the distribution of damages differed from area to area, three different surveys were conducted in Boumerdes for investigating the local site effect on the distribution of structural damage. This investigating included survey of cracks at mortar supports of lampposts, which were spotted everywhere in the city, microtremor measurement and data from satellite imageries.

Through the satellite imagery analysis, city blocks with high damage ratios were seen to be located on the about 40 m altitude terrace along rivers eroding deep in the terrace. Both the lamppost-support crack survey and the microtremor measurement also indicated high site amplifications near the rims and/or the presence of soft soil deposits in these city blocks.

7.2.5 Disaster Response

Hospitals must be prepared according to particular methods. Herein we propose some ideas that might inspire the Algerian concerned authorities.

- Building structures that perform well during earthquakes and hence can resist disasters.

- Organizing the inside and the outside of the facilities to avoid any equipment from falling and harming displacement inside and outside the facility. Equipment should be well attached to their support with flexible couplings.

- Providing the health care facilities with the necessary number of personnel.
- Providing the medical staff as well as the rest of the staff with special emergency response lectures and training to help them to behave correctly during a disaster.
- Providing the hospitals with the necessary medical products that are needed in the case of an emergency.
- Providing the hospitals with alternative sources that can be used *immediately* after the lack of the principal lifeline such as electric generators for the case of a blackout.

In the case of the Algeria Earthquake, the search and rescue operations undertaken by the government were not too much delayed compared to other cases. As a matter of fact, critical difficult tasks as the coordination of international rescue teams and human resource allocation in local governments around the damaged areas were dealt within a few days.

From the global viewpoint of disaster management, the response of the agencies (national government, local governments, and municipalities) worked out well in this case. It can be concluded that the emergency response plan and the framework of the emergency response were practical and useful.

As far as the Emergency Response Plan is concerned, the 'Rescue' and 'Medical care, Evacuation, and Hygiene' modules were difficult to implement. According to the interviewed, particularly complicated was the evacuation plan – for instance providing the tents, grasping the tent needs, and getting the space for setting the tent sites. The lack of tents and confusion in the material distribution within an organization and among organizations led to delays in the support to victims.

Finally, one ought to acknowledge the response from the local population and industry, and international community (Red Cross Societies, foreign government and ONGs…), which was overwhelming and rapid.

7.3 SUGGESTIONS

Earthquakes will strike Algeria again during the next several years. Although Boumerdes is not a large city in Algeria such as Alger, Oran, Costantine, Annaba, Setif, ...the Boumerdes Earthquake dramatically illustrates the damage that can be expected from earthquakes to small to relatively large urban areas. Most of what happened could have been predicted, and much of the damage was preventable. Hopefully, the disaster will spur building officials, engineers, and owners to continue—and to increase where needed—their efforts to improve the earthquake resistance of their properties.

There are relatively few new lessons to be learned from this earthquake from an engineering viewpoint. This event that lasted few seconds caused 2,278 deaths and an economic loss of 5 billion US dollars which is a huge amount comparing it to the Algerian GDP. To my surprise, much of the infrastructure and building stock of the modern city, which many considered to be prepared to withstand a strong earthquake, was destroyed. In fact my suggestions that I may reveal from my own experience and from lessons learned from this disaster can be summarized as follow:

1/ Emergency preparedness and response capabilities will always be required and I must motivate the Algerian Community to act - to replace or strengthen deficient structures and systems, and improve Algeria's planning and preparedness.

2/ Organization and training of volunteer post-disaster damage assessment and building safety engineers; and organization of several seminars and workshops for government officials, the public, and professional architectural and structural engineering communities.

3/ Encouraging development of innovative techniques for improved response such as automated, rapid post-event damage assessment and decision-making using high-resolution satellite imagery and geographic information system-based tools.

4/ Seismologists can, and do, evaluate past and present seismic activity to determine the likelihood of future damaging earthquakes in a region. This evaluation is what determines the earthquake hazard zonation for a region. Seismologists, engineers, researchers and scientists are not expected to withhold information. Their duty is to make the information public. After the Boumerdes Earthquake, the region that was rated zone 2 became 3. Shall the Algerian Society wait, each time, for a major devastation ground shaking to make new modifications and update the Algerian Seismic Design Regulations in order to provide adequate public safety?

5/ The determination of the earthquake hazard or the appropriate earthquake zonation does nothing to reduce the damage from future earthquakes unless that information is acted upon by the public and by public officials. Practical information on steps that can be taken to mitigate the known hazards is a critical part of the information the scientific community should provide. The Algerian Seismic Design Regulations should enclose information from the seismological and structural engineering communities to reduce the risk of damage from future earthquakes.

6/ Deficiencies in the construction methods must be eliminated. Such deficiencies probably would not have led to the collapse of several buildings. These construction practices must be e addressed by the Algerian Seismic Design Regulations. If this issue is not considered soon, I expect that more of this type of damage will inevitably occur from the next large earthquakes.

7/ The Algerian Seismic Design Regulations is a set of regulations developed in the early 80's by Algerian engineers with the help of foreign experts. Adoption and enforcement of this Seismic Regulations by the Algerian government are done to provide for public safety and to reduce the costs of natural disasters to society. However, now there is a need for the Algeria Engineering Community to establish its own Seismic Design Code based on the current regulations and by making appropriate modifications based on fundamental research (experimental) as done in developing countries. The Algerian government should therefore encourage Research Centres and Universities to carry out experimental work and further encourage cooperative work between those institutions for the benefit of the Algerian Society. International cooperation with leading countries in the field of Earthquake Engineering such as Japan and USA is imperative.

8/ Although Seismic Design Regulations and Codes are modernized, their adoption would concern newly build structures. Therefore what would happen to structures built before the modernization of the earthquake-resistent seismic design codes? The Algerian authorities, would therefore, consider with the assistance of different organizations, industries, societies, and insurance companies, a policy for upgrading and retrofitting older structures which represents the history and the pride of Algeria.

9/ Establishment of several working groups (committees), combining several university professors, civil and structural engineers and researchers to work on specific topics such as updating a seismic hazard map, hazard assessment and mitigation and to foster cooperative projects among government agencies, academic institutions. Such working groups would ultimately lead to improving the Seismic Design Regulations.

10/ Improvement of the curriculum of Civil Engineering education is essential. Integration of several subjects on Earthquake Engineering in the five-year cycle is necessary.

11/ Finally, in several countries where natural disaster often occur, since companies with financial assets are exposed to catastrophes, catastrophe modeling technology has become a vital tool for quantifying, managing, and transferring risk in the insurance industry. Hence, developing catastrophe-modeling solutions to insurers and corporations, with a focus on event-specific probabilistic modeling to quantify risk, is necessary nowadays.

It should be mentioned herein that the above suggestions are Dr. Ramdane Kheir-Eddine opinion based on his experience in Algeria and has nothing to do with the Japanese Reconnaissance Team. Dr. Ramdane is a member of the Japanese Reconnaissance Team and he is currently an assistant Professor at the University of Science and Technology of Oran –Mohamed Boudiaf. He obtained his Civil Engineering degree from the same University in 1987. After lecturing one year at the same University and working on a construction site, he went to United Kingdom to continue his studies. He received his PhD from the University of Westminster in London. Then he came to Japan to further continue his research work. He has lived 8 years in Japan.

APPENDIX

Inspection of 25 bridges on RN24, RN5 and CW146

(Translated from: Inspection de 25 Ponts sur RN24, RN5 et CW146 Après Le Séisme du 21/05/2003)

Bridge No 1

"RN24 Bridge of Boudouaou River"

1- Description :

The structure is composed of two bridges; each one is designed for each way (direction). The first (direction Boumerdes→Algiers) is a very old structure. Two lateral truss steel beams and roadway between both of them constitute the structure of the bridge. The elements were assembled by rivet.

The second bridge, newer, was constructed to split the traffic into two parts. The bridge has only one span. It is a mixture of RC and steel: it has steel beams, which are non-standard sections. RC was used for its roadway. There are four transversal beams, steel truss, in the extremities of the bridge.

2- Diagnosis:

a- Truss bridge:

The motion of the roadway did not affect the structure. The majority of the elements of the most important beams are corroded. Deformation or rupture of the vertical elements (upright) of the beams will be measured as the bridge experiences shocks from the vehicles. The inferior feet of the beams are covered by a stockpile brought by the water of the river.

b- The mixed-bridge:

The roadway and the abutments are in good state. No degradation was noticed. There is one transversal crack in the soil near the abutment. The crack is the only effect due to the earthquake.

3- Recommendations

a- In both bridges no transversal displacement was noticed. The evidence is that the masonry under the transversal beams is still adequate. However the crack in the soil shows that the seismic motion was predominant in the longitudinal direction.

b- The truss structure needs maintenance (cleaning, painting…) as well as the uprights of the principal beams. The mixed structure does not need any repair.

c- The two bridges do not need any particular action.

Bridge No 2

“RN24 Bridge of the railways in Corso”

1- Description:

The bridge is situated near Corso train station; it permits the road RN24 to get over the railways. The bridge is composed of non-dependents 7 pre-fabricated and pre-stressed girders. The roadway was constructed in site. There are no transversal beams that connect the main girders. The abutments are RC walls covered by soil. There are 5 piles and each pile supported by 3 circular feet. Horizontally the structure has the shape of “S”. Each span contains 8 girders and only the span over the railway contains 15 girders. The bridge does not contain any anti-seismic elements.

2- Diagnosis:

The bridge suffers from the following:

- Shearing of the walls of the transversal beams (supported by the piles),
- Cracks in the joint of the roadway on the abutment side of Algiers.
- Bursting of the supports (RC elements supporting the girders) in the last two spans.
- Some beams fell from their initial supports.
- The 2nd, 3rd and the 4th spans moved in the direction Corso→Algiers.
- The extremity of one beam supported by the 2nd pile burst (direction Algiers→Corso); one of the inferior cables of the pre-stress became uncovered.

3- Recommendations:

a- The height of the supports is sufficient therefore there was a direct contact between the main girders and the horizontal beams (built on the piles), the problem is clear under the spans that have steep longitudinal slope.

b- As result of the earthquake some girders moved and destroyed some of the supports. The burst concrete could be clearly seen.

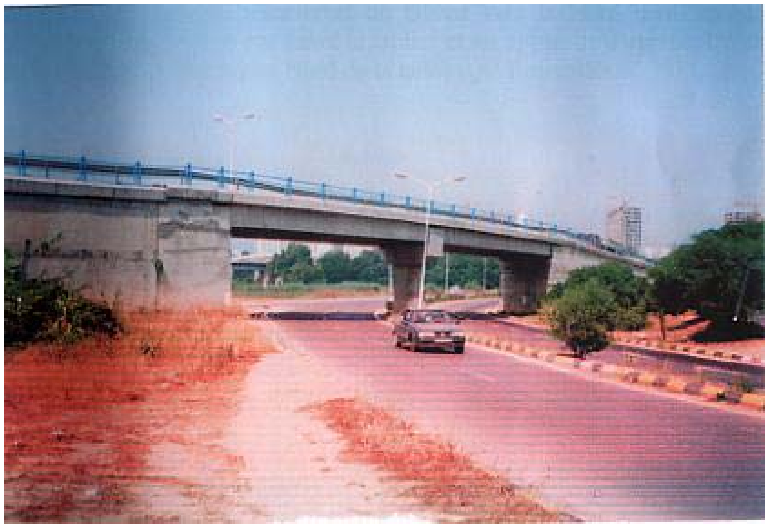
c- The bridge should be inspected to decide on the reparation that should be carried out:

- Restoration of the roadway (horizontal movement)
- Reparation and even retrofitting of the damaged girders
- Re-design and re-building of the supports
- Modification of the girders' supports
- Design and positioning of the anti-seismic elements.
- Reparation of the roadway joints.

d- No decision will be taken before the reparation.

Bridge No 3

"RN24 Bridge over the expressway"



1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. It contains 2 non-dependent spans, each span composed of seven girders. There are no transversal beams to connect the main girders. The abutments are very strong with back walls. The type of the pile is wall-hammer. The structure contains anti-seismic elements: one pair on each abutment and 2 pairs on each pile.

2- Diagnosis:

No anterior degradation is observed as a result of the earthquake. The structure experienced a transversal movement of the roadway towards the North; however the anti-seismic elements saved the bridge and the support elements. One of the anti-seismic element fractured: it is located in the north of the abutment in Boumerdes side.

3- Recommendations:

a- The fractured anti-seismic element has to be re-built: demolition of the concrete with preservation of the reinforcement (steel bars), re-building the new element using a high strength concrete quality (450Kg CPA).

b- No particular action will be taken for the structure.

Bridge No 4
"RN24 Bridge over Corso River"

1- Description:

It is an RC bridge, composed of two spans and each span composes six girders. There are transversal beams that connect the main girders in their extremities and their midpoint. The pile is a frame supported by 3 circular piers. The abutments are Pile-Abutment re-constructed on the masonry abutment of the old bridge (that was destroyed and replaced by the new bridge). Wire mesh walls are used to protect the foundation and the embankment in Corso side.

2- Diagnosis:

The bridge did not suffer action from the earthquake. The girders moved slightly from the supports, but no damage to the anti-shocks elements was observed. This setback is a result from non-correct placement during the construction of the bridge. The bridge is still intact, the girders still supported correctly by the abutments.

3- Recommendations:

a- The impenetrability should be re-done.

b- No particular action will be taken for the structure.

Bridge No 5

"Expressway over Corso River"

1- Description:

It is a bridge composed of two independents spans. Each span composed of 11 pre-fabricated and pre-stressed girders. Transversal beams are added to join the main girders. The abutments are huge with back walls. The pile is a frame structure supported by 4 circular piers.

2- Diagnosis:

The earthquake did not affect the bridge. Some bursts were noticed in some concrete blocks near the abutments; however the roadway did not displaced. The anti-seismic elements did not let the roadway move. No other degradation was noticed in the bridge.


3- Recommendations:

a- It is recommended to obliterate the concrete blocks to be able to check thoroughly the anti-seismic elements.

b- No particular action will be taken for the structure.

Bridge No 6

Connection RN24-Express way "Bridge of the railway"

1- Description:

The bridge is composed of one span that composes seven pre-stressed and prefabricated girders. The abutments are strong with back walls. The transversal beams supported by the piles contain anti-seismic elements.

2- Diagnosis:

Inclined cracks in some girders were observed. As result of the earthquake the roadway went down and made contact with the West element causing a great damage to the East element. The cracks in the beam can be explained by the result of the vertical reaction. This damage is probable since the height of the anti-seismic should be at least twice the supports.

3- Recommendations:

a- The structure must be inspected and visited to make decision on the kind of reparation that must be carried out.

b- No decision will be taken for the bridge.

Bridge No 7

Bridge over railway (station of Boumerdes) connecting downtown and the RN24

1- Description:

The bridge is very close to the station (by the station). It is composed of 5 spans of RC pre-fabricated beams. The girders were turned to be dependent during the construction. The piles are frame structures supported by 4 circular piers and the abutments are buried.

2- Diagnosis:

No Diagnosis is signalled. It is interesting to note the way the bridge is functioning: iso-static under dead loads and hyper-static under live loads.


3- Recommendations:

The bridge resisted very well to the earthquake and therefore no action will be taken.

Bridge No 8

RN24 Bridge of the railway with the crossroad with the CW16

1- Description:

It is a Slab Bridge, composed of 3 RC dependent spans. The roadway is fixed in the 2 extremities to the pile-abutments, and it is simply placed on the supports. Non-soft neoprene is used between the slab and the piles.

2- Diagnosis:

The bridge did not suffer any damage due to the earthquake.

3- Recommendations:

No Recommendations.

Bridge No 9

CW16 Bridge over the railways (Tidjelabine)

1- Description:

The bridge permits the CW16 to continue over the railway in Tijelabine. The structure is horizontally slanted, and it is composed of 3 spans. The roadway is composed of 4 girders connected transversally by beams. It (roadway) is fixed in its supports that are 4 piers, rectangular shape placed under the 4 girders. The girders are strengthened near their median supports.

2- Diagnosis:

The concrete of the slab was burst near the intermediate support side of Boumerdes, as well as the last two piers. Also The junction beam-column of the abutment, side Boumerdes, was burst. Un-stabilization and damage of the masonries that support the embankment was observed. These were the damages resulted from the earthquake.

3- Recommendations:

a- Bursting of the concrete on the top of the columns shows that the elements were subjected to compression and bending + compression action.

b- The bridge must be assessed.

c- No decision will be taken before the conclusion of the assessment.

Bridge No 10

Bridge RN5-CW16 (Tidjelabine)

1- Description:

The bridge permits the CW16 to cross over the RN5. It is a Beam Bridge, pre-fabricated and pre-stressed composed of two non-dependent spans (15 beams/span). The two abutments are empty supported by embanked walls; the piles are RC walls.

2- Diagnosis:

The earthquake caused damage to the non-reinforced concrete that used as a fill around the supports (for protection of the bridge). The anti-seismic elements resisted well the earthquake.

3- Recommendations:

a- All the concrete that was used for filling around the supports must be removed. The ones of the pile should be done as soon as possible to not damage the cars using lane 3.

b- The embankment should be protected by using weak concrete; if not possible there is a risk that the embankment will sink and it can cause the destruction of the roadway.

c- No decision will be taken until testing the concrete (that was used for filling) of the pile.

Bridge No 11

Railway Bridge, RN5, direction Algiers-Bouira.

1- Description:

The bridge is composed of 3 continuous spans. The roadway is composed of 6 girders, connected by a slab and horizontal beams. The girders are simply supported by the abutments and fixed at the extremities of the piles using RC variables sections. The supports of the abutments are con pre-fabricated RC support.

2- Diagnosis:

The earthquake burst the support situated on the abutment side of Algiers. Some snatches were noticed on the other abutment that has less danger.

The girders, in contact with the supports, suffered burst of the concrete (snatch and burst until destitution of steel bars).

Degradation of the head of the lateral column side Boumerdes, and in pile side Algiers.

The coating of the roadway near the joints was raised and pulled out.

3- Recommendations:

a- The bridge should be assessed in order to fix the mode of repair of the support on abutment and the head of the column.

b- Steel holds should be placed beside the destroyed RC supports. The retrofitting of the roadway (near the joints) must be repaired using special material “enrobé a chaud”.

Bridge No 12

Railway Bridge, RN5, direction Bouira-Algiers

1- Description:

The bridge represents a pre-fabricated and pre-stressed bridge, composed of 3 continuous spans (6 girders per span). The abutments are buried in an embankment. The embankment is stabilized by concrete reinforced by steel trusses.

The piles are frames of 5 circular piers.

The bridge contains anti-seismic elements placed on the horizontal beams that connect the piles.

2- Diagnosis:

The anti-seismic elements resisted well, therefore no Diagnosis will be indicated for the structure.

3- Recommendations:

No recommendation.

Bridge No 13

Bridge over a river (between Tidjilabine and Thenia), RN5, direction Algiers-Bouira

1- Description:

The bridge represents a beam bridge and it is composed of 1 span. There are eight beams connected by horizontal beams. There is a longitudinal joint that cuts the bridges into two parts. The abutments are of masonry type.

2- Diagnosis:

The structure did not suffer any damage as result of the earthquake. Unsound construction methods caused the degradation at start for the two beams.

3- Recommendations:

a- The joint will be repaired in the next retrofitting operation.

b- No specific measures will be taken.

Bridge No 14

Bridge over a river (between Tidjilabine and Thenia), RN5, direction Bouira-Algiers

1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. It is composed of 3 non-dependent spans (6 beams per span). The abutments are buried and the piles are frames composed of 3 circular piers. Walls made from stone-filled cubes protect the embankments around the abutments. The bridge possess anti-seismic elements.

2- Diagnosis:

The bridge is in a very good condition. The anti-seismic elements have resisted well the earthquake.

3- Recommendations:

No recommendation.

Bridge No 15

Upside road RN5 Thenia Bridge exit toward Algiers

1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. It is composed of 3 non-dependents spans (5 beams per span). The abutments are very strong. The piles are wall-hammer type.

Some elements were built between the extremities of the girders to protect the support.

2- Diagnosis:

The earthquake caused the dislocation of the supports used as protection, but slightly moved the roadway. The geometry of the bridge helped the bridge to resist against the transversal effort coming from the roadway.

3- Recommendations:

a- The structure resisted well and does not show any degradation.

b- Only rubbles (placed on the horizontal beam, upside the piles) need to be removed as soon as possible.

Bridge No 16

Upside road RN5 Thenia

1- Description:

The bridge is a pre-fabricated and pre-stressed beam bridge. It is composed of 4 non-dependents spans (5 beams per span). The abutments are buried in an embankment protected by concrete reinforced by steel truss. The piles are frames composed of 3 circular piers. The structure contains anti-seismic elements.

2- Diagnosis:

The structure did not suffer any damage as result of the earthquake. However deterioration of the structure was observed after the earthquake: problem of watertight of the roadway. Some bursts in the two extreme beams side of the span of Algiers-Bouira direction were seen.

3- Recommendations:

a- An expert opinion is necessary to determine the way of retrofitting of the damaged beams, and define the necessary work for repairing the structure.

b- No special measure will be taken until the final expert’s conclusion. However the residue of the rubble must be eliminated.

Bridge No 17

Bridge entrance of the hospital Thenia

1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. The bridge is composed of 3 spans (14 beams per span). It is divided into two structures placed side by side (juxtaposed) separated by an open joint. The abutments are buried in an embankment protected by concrete reinforced by steel truss. The piles are frames with 2x4 circular piers. The structure possesses anti-seismic elements. Rubbles were built to fill-in the space between the beams and supports.

2- Diagnosis:

The structure resisted well the earthquake. Only the concrete protecting the embankment cracked (abutment side Algiers). The concrete of the end of the beam burst and caused the steel to be bareness.


3- Recommendations:

a- The degradation affected the concrete protecting the embankment without any consequences.

b- The foot of the fragmented beam must be repaired.

c- No special measurement will be taken except the cleaning the rubble residues over the piles.

Bridge No 18

Link Thenia-Carriere Si Moustapha

1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. It is composed of 3 non-dependents spans (5 spans per span). The abutments are buried in the embankments. The embankments are protected by concreted reinforced by steel truss. The piles are frames of 3 circular piers. The structure possesses anti-seismic elements.

2- Diagnosis:

The structure did not suffer damage related to the earthquake. However there was a problem related to the watertight that can be seen in feet of some beams. A beam in the last span (direction Bouira-Algiers) was much damaged.

3- **Recommendations:**

a- The structure resisted well the earthquake.

b- An expert opinion must determine the type of the retrofitting of the damaged beam and the required maintenance.

c- No special measurement will be taken, excepting the rubble that fills the spaces between the beams.

Bridge No 19
Bridge over the railway

1- Description:

The structure allows the RN5 to pass over the railway Thenia-Tizi Ouzou. The structure is a pre-fabricated and pre-stressed beam bridge. It is composed of 3 non-dependent spans (14 beams per span). The abutments are buried in the embankments that are protected by concrete reinforced by trusses. The piles are frames on 2x4 piers (the structure is divided into 2 parts related by longitudinal joint). The structure possesses anti-seismic elements.

2- Diagnosis:

No degradation was noticed, the bridge resisted well the earthquake. Only fragments of rubbles is still remaining.

3- Recommendations:

No recommendation.

Bridge No 20

RN5, Bridge toward Thenia (direction Rouiba-Algiers)

2- Description:

The structure is an opened RC frame. The abutments have long walls with aisle. The slab (of the roadway) is fixed in the abutments without change of the geometrical section.

3- Diagnosis:

No Diagnosis.

4- **Recommendations:**

The bridge resisted well and this shows that the “half buried” structure resist well the earthquake.

Bridge No 21

Exchanger RN5/RN12

Bridge of the RN12 over RN5 (direction Bouiba-Algiers)

1- **Description:**

The structure is a pre-fabricated and pre-stressed bridge, composed of 3 non-dependent spans (6 beams per span). The abutments are buried in an embankment protected by concrete reinforced by truss. The piles are composed of a frame with 4 circular piers. The structure possesses anti-seismic elements.

2- **Diagnosis:**

The structure resisted well the earthquake. However it suffered a nuisance of watertight in the slab of the roadway.

3- Recommendations:

a- The slab for the watertight must be reconstructed.

b- No special measures will be taken except cleaning the rubbles (problem of safety for the users).

Bridge No 22

RN24, exit of Boumerdes

Bridge over a river

1- Description:

The structure is a pre-fabricated and pre-stressed beam bridge. It consists of two non-dependent spans (21 beams per span). The abutments are very strong. The pile is a frame with 5 circular piers. The structure possesses anti-seismic elements.

2- Diagnosis:

The slab (roadway) did not move in the transversal direction. One crack was seen on the sidewalk over the pile (direction Boumerdes-Dellys). The crack is due to the continuity of sidewalk (the roadway is divided by a joint).

3- Recommendations:

a- The sidewalk needs to be repaired.

b- No measure will be taken for the structure.

Bridge 23

RN24, Bridge over Isser River

1- Description:

The structure is a viaduct composed of 13 independents girders with 4 beams per span. The girders are precast (pre-fabricated) and pre-stressed. The roadway is provided with end (extremity) spacers that were flowed (constructed) on site between the pre-stressed and the girders. Two pair of contiguous elements makes up the anti-seismic components. The piles are frames based on rectangular feet.

2- Diagnosis:

The bridge suffered transversal displacement towards the downstream water (toward the sea) after the destruction of the anti-seismic components. The beams moved from their initial supports and became resting on the horizontal beam in the piles P3, P4, P5, P6 and P7 (direction Dellys→Boumerdes).

3- Recommendations:

a- The structure must e inspected to define the method of repairing the roadway and the supports and the anti-seismic elements.

b- Nothing will be done before the conclusion of the assessment.

Bridge No 24

RN24, bridge over the river Larbaa

1- Description:

The structure is a cantilever type composed of 1 span. In 1999 the structure was reinforced using carbon fibre. The slab is composed of 3 beams related by others (horizontally). The beams are fixed to the pile. The pile is a frame composed of 3 columns and each column supports a beam. The spans at the two extremities do not have supports at their ends. At the start and at the end of the bridge there is embankment that is protected by stone-fill cubes.

2 Diagnosis:

No degradation was been noticed. The reinforcement using the carbon fibre has well resisted.

2- Recommendations:

a- The handrail of the road must be repaired.

b- The structure resisted well the earthquake.

Bridge 25

RN24, Bridge over Sebaou River

1. Description:

The structure is a viaduct type constructed with girders precast and pre-stressed. The two border spans were re-built in 1996. One span is composed of 7 beams in each and the other one is composed of 4 beams. The majority of the horizontal beams do not possess anti-seismic component, except those which were placed on the horizontal beams. The piles are frames supported on cylinder shaped feet.

2. Diagnosis:

Most of the girders moved toward the downstream water, except the first girders in Boumerdes side did not move. The girders left their supports and rested on the horizontal beam. The last span in Dellys side, which did not show any movement, suffered a light damage. The anti-seismic components in the median spans were completely crushed.




3. Recommendations:

a- The bridge needs to be inspected in order to decide on the method of reparation.

b- Nothing will be done before the conclusion of the assessment.

Conclusion and synthesis

To wrap up this inspection of the 25 bridges it can be concluded:

a. No bridge stopped completely from operation.

b. The bridges that possess anti-seismic steel elements did not suffer any damage.

c. The anti-seismic studs (concrete) for the damaged beam bridges were revealed to be inefficiently reinforced (bridge over River Isser), inefficiently in number (bridge over River Sebaou).

d. Structures that have 1 or 2 spans (in particular the slab bridges) resisted well because they were well blocked by the lateral elements on the horizontals beams over the abutments.

e. The hyper-static (more than 2 spans) structures suffered only the vertical component of the seismic acceleration (the supports suffered instantaneous vertical differential motion).

f. Nine out of the 25 inspected bridges ought to be assessed. Six out of the 9 were evaluated because of the disorder that they suffered from the earthquake.