２００３年アルジェリア北部の地震
報告２：ALGER - BOUMERDES, ALGERIA EARTHQUAKE OF MAY 21, 2003

Kheir-Eddine Ramdane, JSPS Research Fellow
Building Research Institute, 1 Tachihara, Tsukuba, Ibaraki 305-0802
eddine_r@yahoo.fr or eddine_r@kenken.go.jp

PART I : INTRODUCTION, EARTHQUAKE CHARACTERISTICS AND DAMAGE

Introduction

On May 21, 2003, a 6.8 magnitude earthquake with a depth of 10 km struck northern Algeria in the Zemmouri region, 70 km east of the capital, Algiers, figure 1. This earthquake As of August 3, significant aftershocks continued in heavily populated areas, including magnitudes greater than 5.0. The initial 6.8 magnitude earthquake was the biggest earthquake to hit Algeria since 1980.

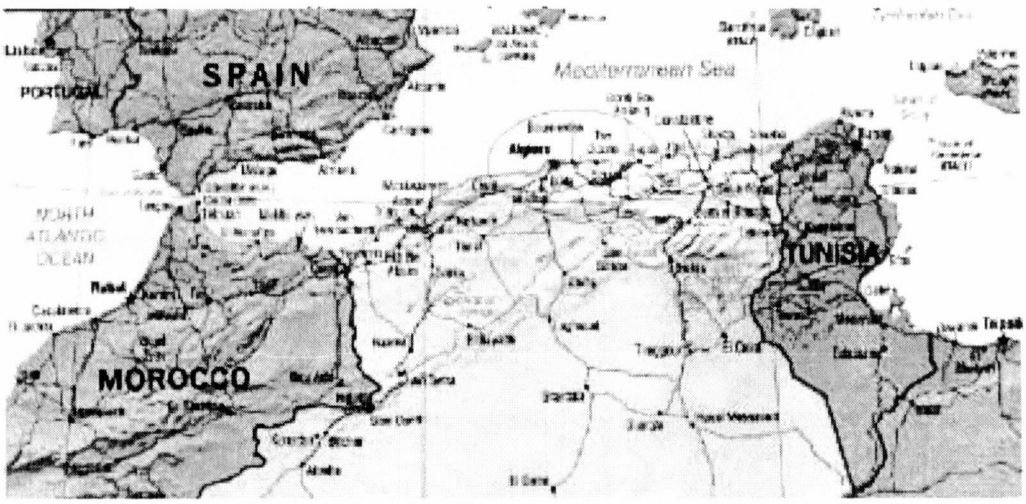


Figure **1**: Location of affected area by the earthquake

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 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 5-6 mm/year as shown in figure 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.

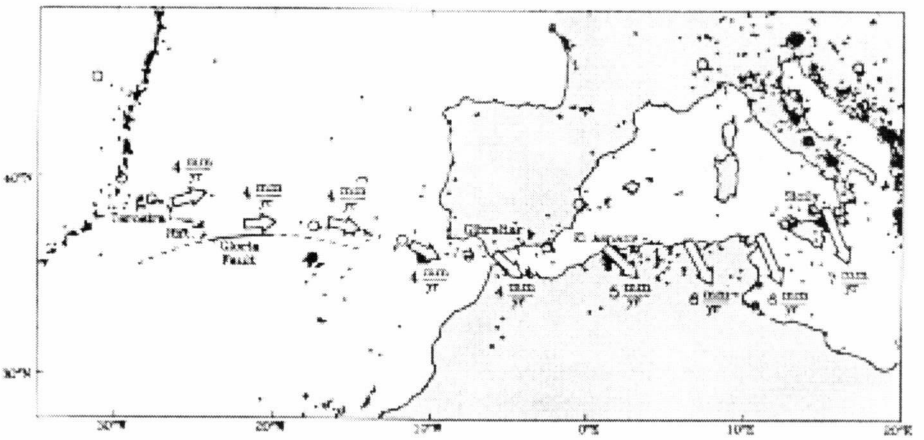
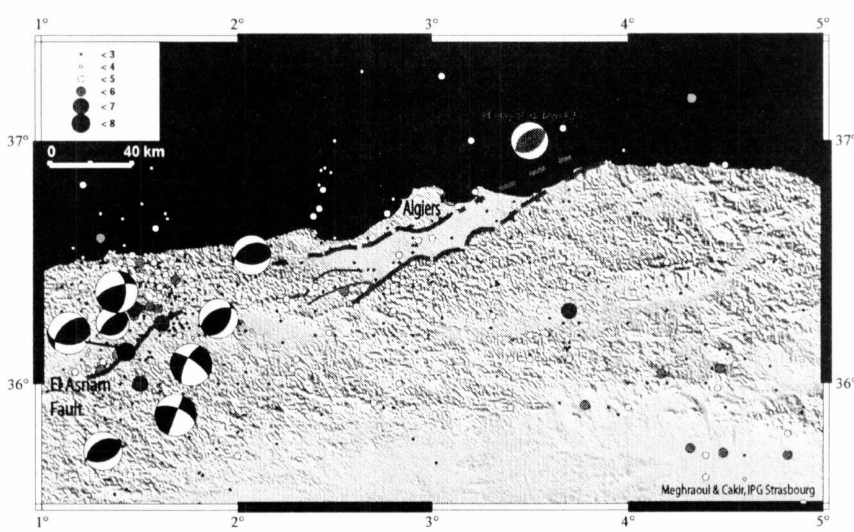


Figure 2: movement of the boundary region between the Eurasian and the African plates

Algeria has experienced many destructive earthquakes. On October 10, 1980, the city of El Asnam (formerly Orleansville) was severely damaged by a magnitude 7.1 earthquake that killed at least 5000 people. The site of El Asnam is situated approximately 250 km to the west of the recent earthquake. The same city, i.e. Orleansville, had been heavily damaged on September 9, 1954, by a magnitude 6.7 earthquake that killed over 1000 people. On October 29, 1989, a magnitude 5.9 earthquake struck about 110 km to the west of the recent earthquake and killed at least 30 people.

Characteristics of the 21st May Earthquake

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.



LE SEISME D'ALGER DU 21 MAI 2003 (Ms=6.6, Mw=6.7)

Figure 3: The trust fault system of the May 21, Earthquake

Figure 3 above shows the earthquake of the 21st May, 2003 and its relation to the thrust fault system the Algiers' area. The focal solution and the magnitude of the earthquake are those of the NEIC (Harvard). As for the epicenter localization it is that of the CRAAG.

Mr. Meghraoui provided a preliminary image of the localization of the damage in the area of Algiers. Figure 4 shows the principal active thrust faults, their extension at sea and the zone of the major damage following the seism of May 21, 2003 (Ms 6.6, CSEM).

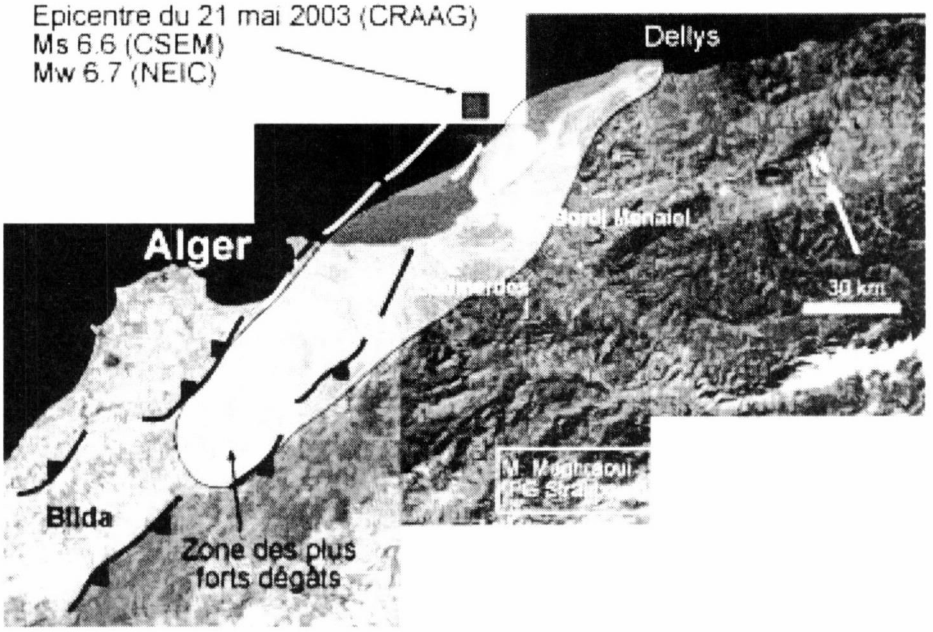


Figure 4: The principal thrust fault and the affected region (*)

History of the Seismic Activity in Boumerdes Area and Algeria

The historical seismic activity of the Boumerdes region and its immediate surroundings reported by the various publications published so far, shows that the earthquakes which affected this area are moderated or slightly strong.

The principal significant historical seismic activities which occurred with the immediate surroundings of the area of Boumerdes are as follows:

Date	HH: MM : SS	Latitude Longitude	Mg	Intensity
23.11.1922	12:34:39	36.70°N 03.40°E	--	V
01.03.1953	04 :32:41	36.80°N 03.40°E	4.1	V
22.07.1965	11:47:04	36.70°N 03.70°E	4.6	VI
23.05.1982	13:17:00	36.69°N 03.70°E	4.6-5.2	VI-VII
16.09.1987	22:00:00	36.69°N 03.50°E	4.6	VI

In addition, 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. However this area will not be saved in the future by earthquakes of this kind.

Following the main shock of the May 21, CRAAG, through its seismological network, has recorded so far a thousand of aftershocks of magnitudes varying from 0,9 to 5,8. This activity in the Boumerdes area is part of a normal process after such an important shock. Figure 5 shows the daily seismic activity (aftershocks).

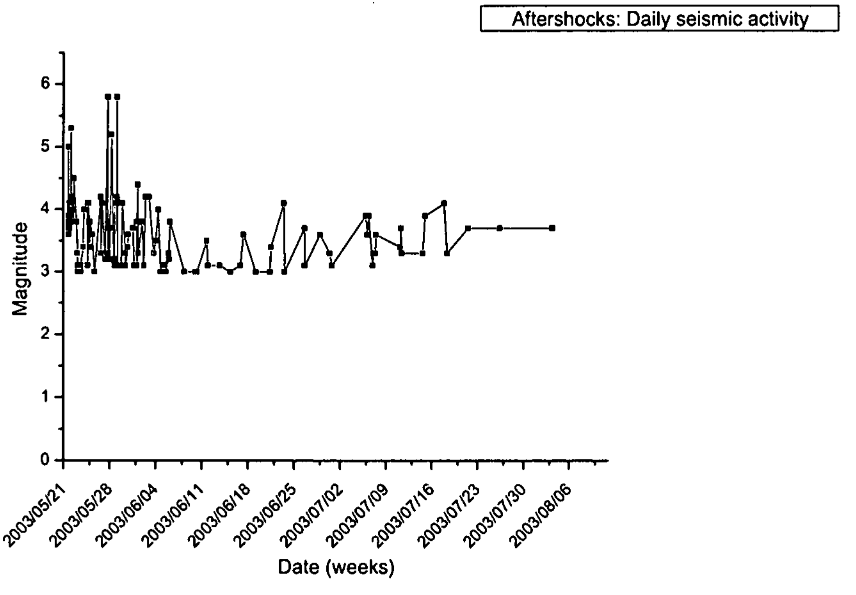


Figure 5: The recorded aftershocks in the Boumerdes area

North Algeria has experienced several moderate to slightly strong earthquakes during the last century. The most violent recorded is that from October 10, 1980 in El Asnam which reached a magnitude of 7.1.

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, according to Rothè, 1949). Other moderate to slightly strong earthquakes occurred in this area in 1365 (VIII-IX), 1735 (VIII), 1756 (VIII), 1802 (VIII), 1847 (VII), 1891 (IX) ; 1910 (X, M 6.4) ; 1922 (VIII) ; 1924 (VIII), 1954 (X, M 6.7)/; 1942 (VII, M 5.2), 1979 (M 5.5), and 1989 (M 6.0) (Rothè, 1949; Benouar, 1994; Harbi et al., 2003).

Figure 6 and table 1 show the majors quakes of Algeria between 1365 and 2000. Furthermore, figure 7 shows the majors quakes which occurred in the 20th century

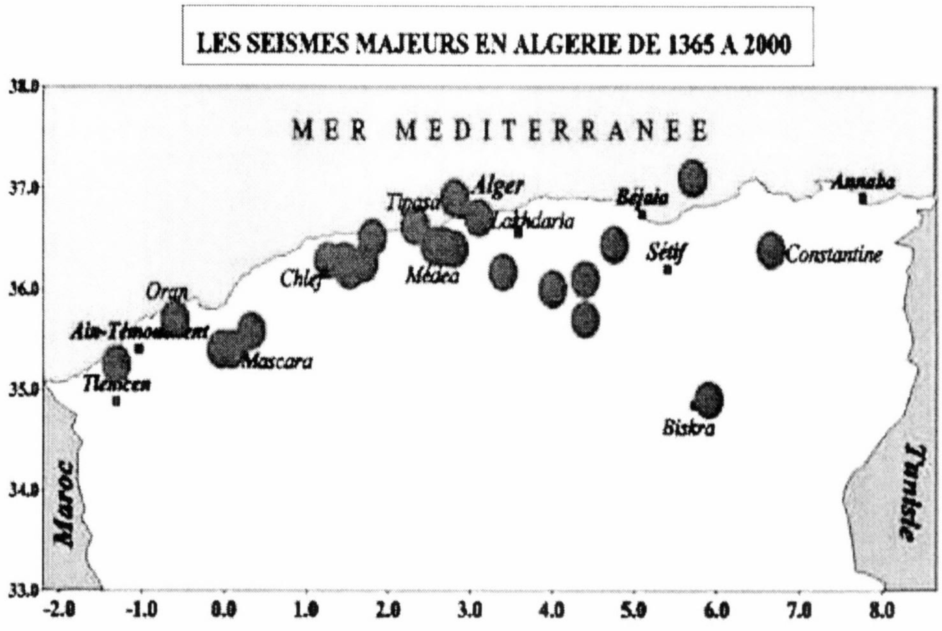


Figure 6: Majors quakes of Algeria between 1365 and 2000

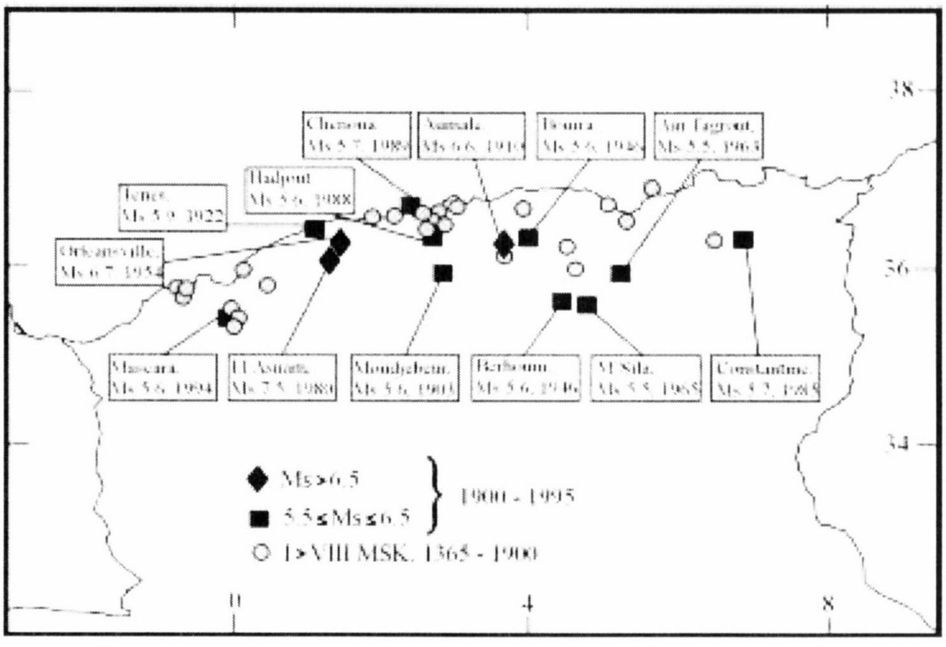


Figure 7: Majors quakes of Algeria in the 20th century (Bennouar, 1994).

Table 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
Gouraya	15.01.1891	X	7.5	**0038**	**Destructor**
El Kalaâ	29.11.1887	IX-X (VIII)	6.5-7.5	0020	**Destructor**
Sour. el Ghouzléne (Aumale)	24.06.1910	X (VIII)	6.4/ 6.6	0030	**Important damage**
A. el Hassan (Cavaignac)	25.08.1922	IX-X	5.1	2	**Destructor**
El At -El Ab (Carnot)	07.09.1934	IX (VII)	5.0	none	**Damage**
Béjaia	12.02.1960	VIII- IX	5.6	264	**1000 houses destroyed**
Chlef (Orléansville-ElAsnam)	09.09.1954	X-XI	6.7	1243	**Destructor**
M'sila	21.02.1960	VIII	5.6	47	**Damage**
M'sila	01.01.1965	VIII	5.5	5	**1300 houses detroyed**
Mansourah	24.11.1973	VII	5.1	4	**Damage.**
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	0022	**Many damages**
Mascara	18.08.1994	VII	5.6		**Important damages**

M=Magnitude ; Io= maximal intensity; FM= Focal Mecanism ; Mercalli Scale

Investigation of the Alger-Boumerdes Disaster Area

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 Alger – Boumerdes 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 following categories:

Green: Level 1 and 2, very little damage. Can be reoccupied immediately

Orange: Level 3 and 4. 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 of damaged structures, the official data presented to the government as of the 23 June 2003 are as follow:

- **Damaged Buildings**
  - Alger: 94 328 (74 561 collective and 19 767 individual)
  - Boumerdes : 66 869 (20 361 collective and 46 508 individual)
  - Blida : 4093
  - Tizi Ouzou : 9238
  - Tipaza : 1694
  - Bouira : 4457
  - Bejaia : 837
  - Medea : 142

A total of 181 658 housing were investigated.

- **Buildings investigated and the corresponding classification (tags)**

Classification	Green 1	Green 2	Orange 3	Orange 4 (repairable)	Orange 4 (not repairable)	Red	Collapsed
Alger	11 890	29 921	25 906	17 556	1321	7734	338
Boumerdes	15 311	21 999	14 286	6568	728	6239	1420
Total	**27 201**	**51 920**	**40 192**	**24 124**	**2049**	**13 973**	**1758**

➢ **Damaged Public Structures**

A total of 6181 public structures were investigated. Details are as follow:

- Alger : 2943
- Boumerdes : 1875
- Blida : 147
- Tizi Ouzou : 1031
- Tipaza : 32
- Bouira : 126
- Bejaia : 15
- Medea : 12

The corresponding classifications of these investigated public structures are as follows:

classification	Green 1	Green 2	Orange 3	Orange 4 (repairable)	Orange 4 (not repairable)	Red	Collapsed
Alger	400	684	455	231	---	105	---
Boumerdes	766	940	540	406	---	291	---
Total	**1318**	**2347**	**1257**	**797**	**25**	**436**	**01**

These investigated public structures are divided into the following types:

School & Univ. Bldg.	Official Bldg. (Administrative)	Hospitals	Sports and Cultural Bldg.	Commercial Bldg.	Industrial & warehouse Bldg.	Others
2788	860	296	368	626	443	543

➢ **Human losses and injuries**

As of June 21, 2003 the number of deceased and injured people reached 2278 and 11 450 persons, respectively. The distribution of the casualties with respect to the declared disaster zones (prefectures) and other prefectures is shown in the table below:

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**

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

PART II : IMPLICATION OF BUILDING DAMAGE

Introduction

As can be seen from the investigation 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:

- A building block of the 11 December of Boumerdes
- A building block of the 102 apartments of Corso
- A building block of the 24 apartments of Dar El Baida, Alger
- A school building of the 1200 apartments of Boumerdes
- Silos of Corso.

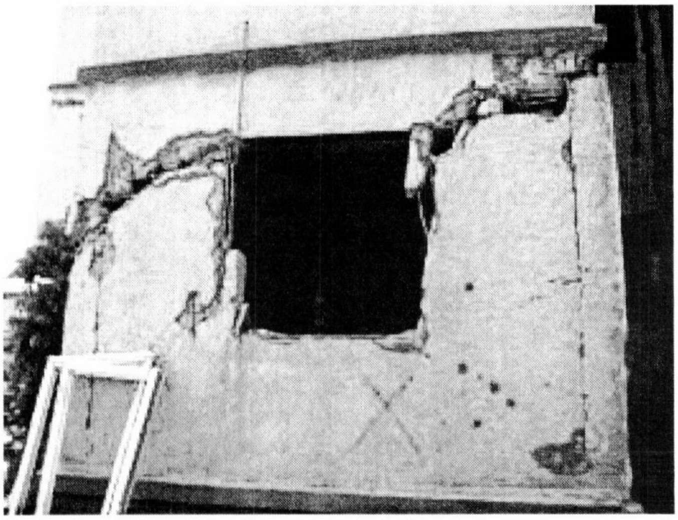
Looking at the extend of the damage; one might question the reasons for such extensive destruction. Was it due to 1) severity of the ground motion? 2) Soil conditions which may have amplified the intensity of the quake? 3) Shortcomings in building design and/or construction method? 4) or a combination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

At the moment it is early to speculate on the factor or factors until full investigation is completed, therefore, it is difficult to precisely determine the triggering cause of such catastrophe. However, from the inspection of the damaged buildings, some of the main defects in the design and construction method of the buildings are discussed hereafter. These can be:

- Use of irregular building configurations with discontinuities in mass, stiffness, strength and ductility.
- Use of thermal expansion construction joints about 20 - 30 m without proper separation between adjacent parts of the building.
- Weak beam-column joints due to poor detailing.
- Use of a crawl space (*vide sanitaire*) about 1 m above ground level causing the columns to behave as short columns and hence suffering shear failure due to increased shear demand beyond the supplied shear capacity.
- Use of weak and slender columns poorly reinforced (generally unconfined).
- Use of stiff spandrel masonry walls resulted in short captive columns that increased the shear demand beyond the shear capacity supplied.
- Use of weak materials for facades.
- Poor structural concrete and strength were found as low as 15 Mpa.
- Poor inspection and construction methods.

Example from the investigated structures

➢ Shear failure of column and beam-column joint failure (102 apartment, Corso), figure 8



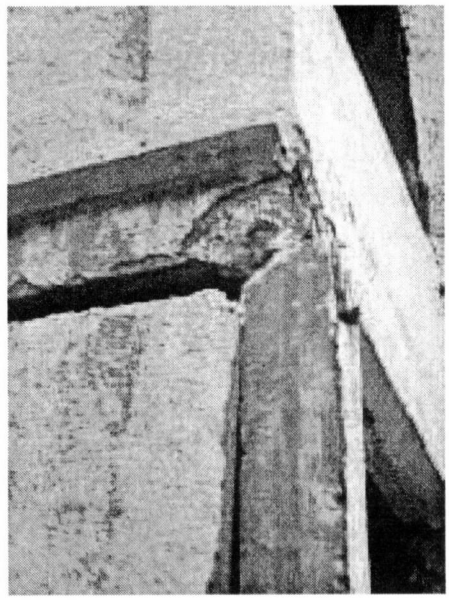
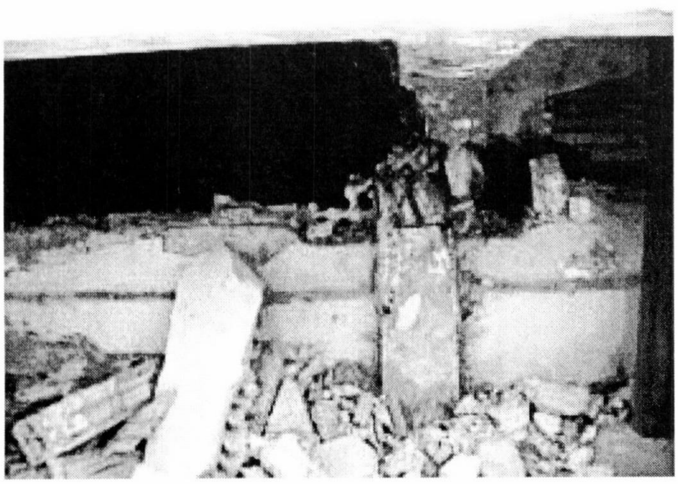


Figure 8: Shear failure of column and beam-column joint failure

➢ Use of a crawl space and short column failure, figure 9



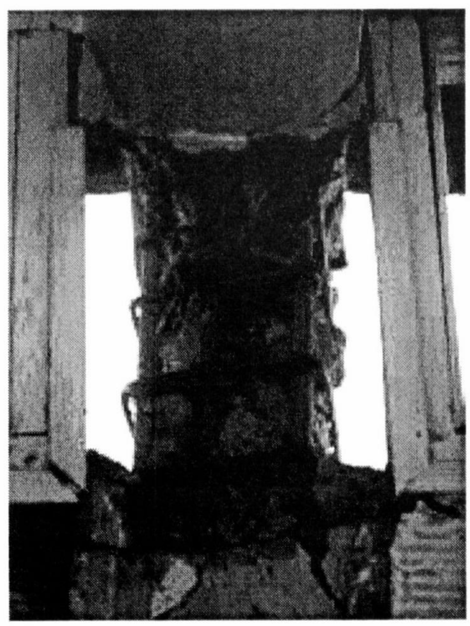


Figure 9 : Use of a crawl space and short column failure

➢ Poor reinforcement and poor inspection, figure 10

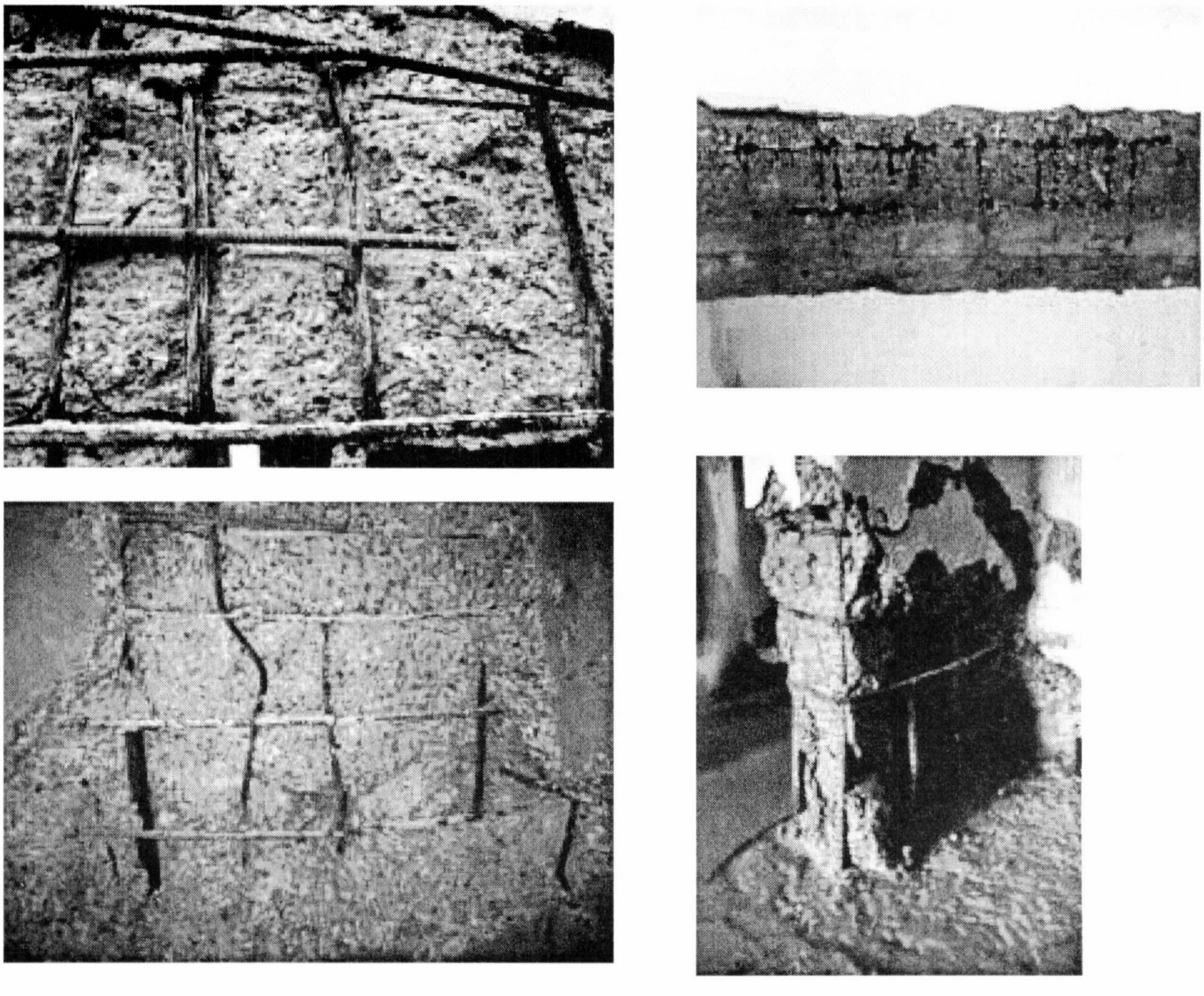


Figure 10: Poor reinforcement and poor inspection

Case Study : Retrofitting the 24 apartment of Dar El Beida, Alger

Herein a quick inspection for retrofitting is described due to some damage caused by the recent quake. Prior to this major seismic event, this structure was classified in Zone II by the Algerian paraseismic design code (RPA 99), however after the event of May 21, 2003, Prefectures of Algiers and of Boumerdes have been classified temporarily in Zone III by a ministerial communication (this zoning will be studied in detail later on). These 24 residences set out on 02 buildings separated by an expansion joint.

Description of the structure

The structure investigated is (R+3) dwelling made of reinforced concrete. The resistance to seismic force is assured by an auto – stable frame made of reinforced concrete according to the longitudinal and transverse directions. The structure includes a type of slab with beams semi prefabricated + hollow body of 21cm of thickness (16+5) with a coating in tiling. The masonry is executed with hollow brick dig (double partition for exterior walls and simple partition for the separation walls).

Height of the ground floor	3.25 *m*
Height of the other levels	3.06 *m*

From this investigation, we observed the following :

(i) The structure in question is not earthquake-resistant following the code (1960).

(ii) The structure underwent structural and non-structural damages:

One line of structural columns underwent bursting of concrete at the plastic hinges (at the base and top), without rupture of the reinforcement. The bursting is accompanied by a light buckling of longitudinal reinforcement.

(iii) This structure is founded on isolated foundation.

(iv) This structure did not undergo settlement or excessive differential settlement.

(v) Only the ground floor which underwent structural damages.

Test on concrete

Some sclerometric tests have been led on a small sample of columns and beams, especially at the level of the ground floor.

(i) visual Aspect of the concrete

The columns and the beams present rough surfaces (the structure of the concrete is non homogeneous) and present some segregation in some parts due to the bad concreting (formwork surface).

(ii) Results of the tests sclérométriques

A test of 10 strokes has been done on average on every column and beam. The nominal resistance of the concrete is calculated according to the following formula:

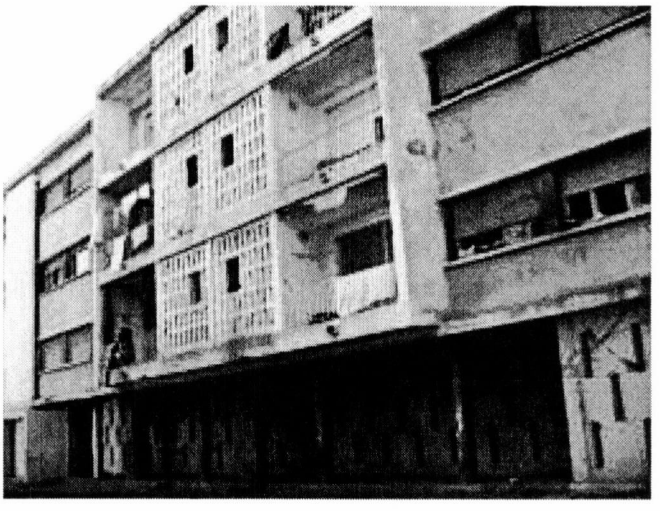
$$R_{rest} = \left[-184 + 13 \cdot (R + \alpha R)\right] \cdot \Delta R$$

For $\alpha = 0°$, and since the age of structure is more than 30 years, $\Delta R = 0.65$

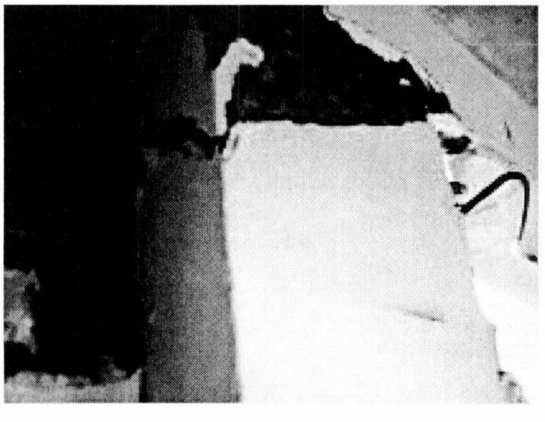
The sclerometric results are summarized in the following table:

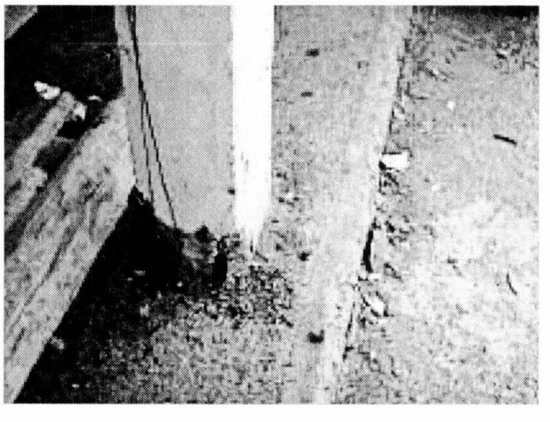
Columns	Mean value (kg/cm2)
1	270
2	290
3	300
4	270
5	280
6	290
7	300
8	270
9	270

From the obtained results, we can conclude that the used concrete presents a good compression resistance (> 270 kg/cm2).



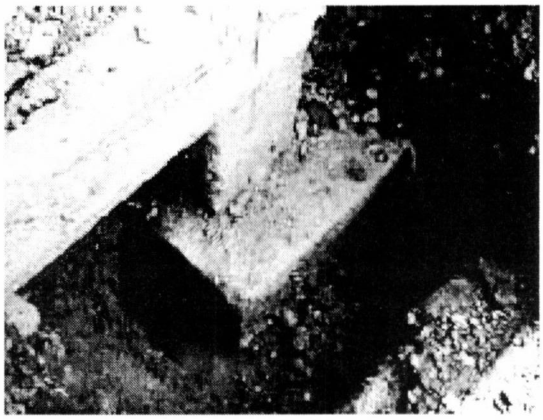
General vue of the building block





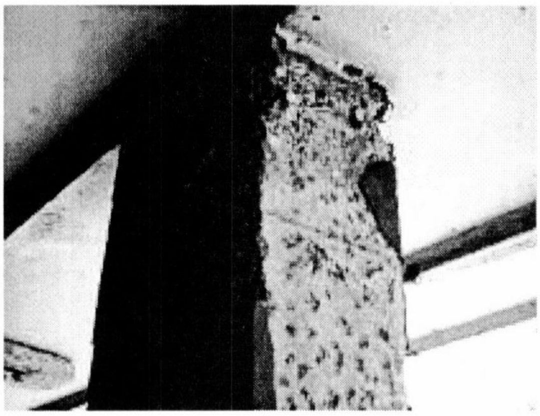
Damaged hinge at the top

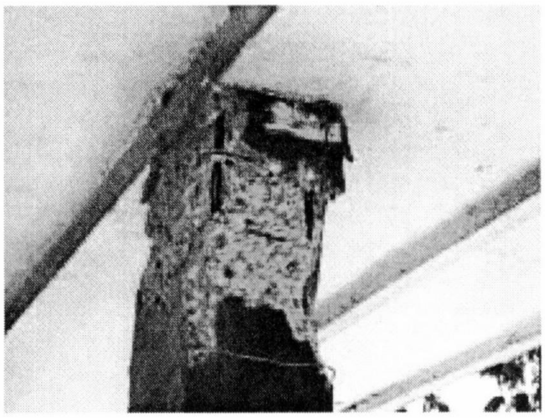
Damaged hinge at the base



Damaged hinge at the base

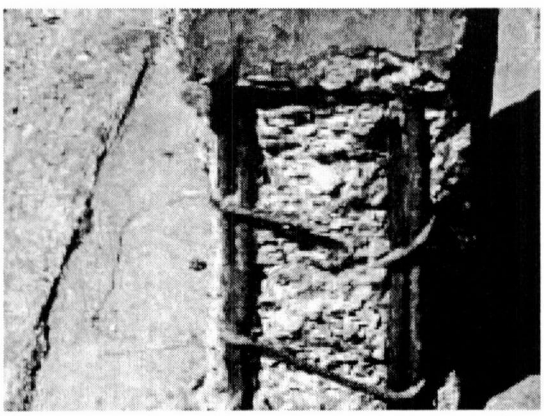
foundation 65 x 85

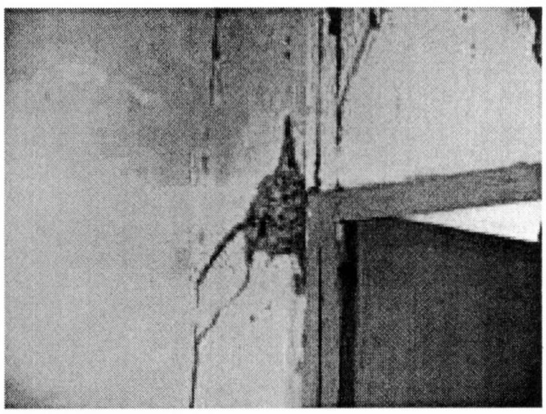




pulling off of the cover concrete

weak reinforcement in both directions





transversal reinforcement failing in shear due to initial corrosion

Column severely damaged due stiff still frame of the door.

Figure 11 : Photos showing damaged columns.

Analysis for retrofitting

The existing structure has been checked with respect to the design codes **CBA 93** and **RPA 99** supposing that the structure is in both zones II and III.

From this study, it is imperative to proceed with the retrofitting of the building by jacking the columns of the ground floor. It is to be noted that:

- If the structure is to resist a future earthquake, it is very important to proceed to the column jacking by symmetry, because strengthening one direction only can cause an important torsion at the time of strong shaking ground. This type of strengthening is oriented for both vertical and horizontal loads.

- If the structure is just to be repaired because of the damage caused by the earthquake, then only the damaged columns have to be jacked. This type of strengthening is oriented for vertical load solely.

The strengthened structure (jacking) is studied supposing that the structure is implanted in III zone, and the solution of strengthening is verified by mean of the software SAP2000 version 7.4. A 3-D finite element is used. Besides, the soil considered for the structure is a strengthened Earth.

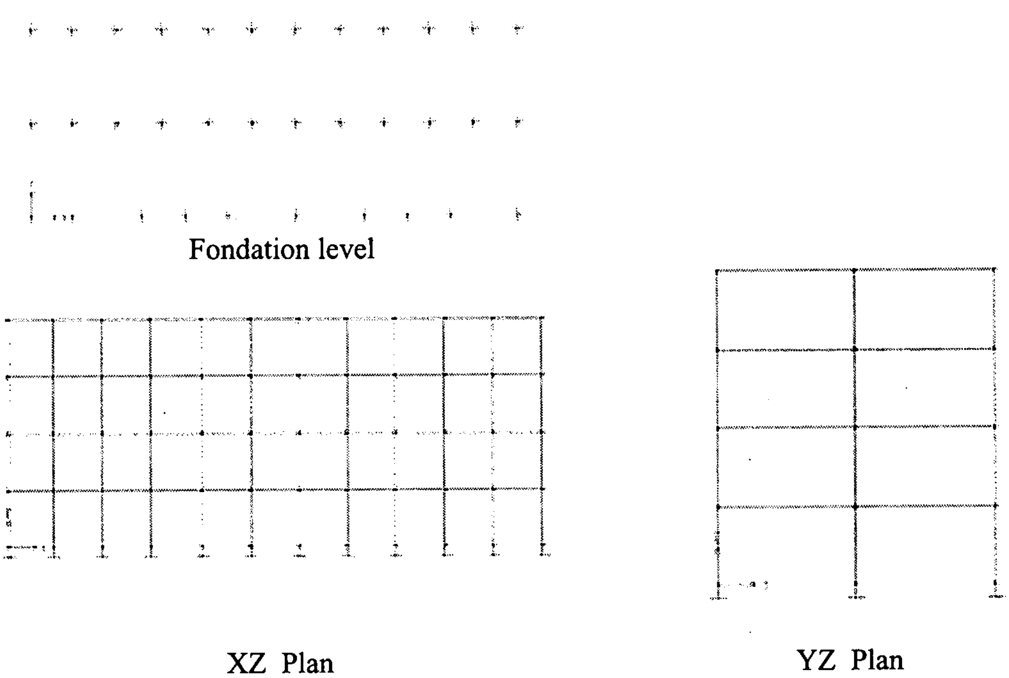


Figure 12 : structural model

Dimensions for the jacking
(i) columns

Ground floor : instead of 30x20 $\rightarrow$ jacking of = 50x 40
Ground floor : instead of 50x30 $\rightarrow$ jacking of = 70x 50

(ii) beams

beam (parallel toY-axis) 30 x 50
beam (parallel to X-axis) 30 x 30

(iii) slabs

slab of hollow body of 16 + 5 cm.

Analysis of the strengthened structure
It is important to note that this structure is analyzed while considering a reduced modulus of elasticity of 1/3, in order to take account of the rigidity deterioration caused by the earthquake.

For the data file, the S product (" Acceleration scale ", in the SAP2000 code) is defined as follows (RPA 99):

$$\frac{S_a}{g}=\begin{cases} 1.25A\left(1+\frac{T}{T_1}\left(2.5\eta\frac{Q}{R}-1\right)\right) & 0\le T\le T_1 \\ 2.5\eta(1.25A)\left(\frac{Q}{R}\right) & T_1\le T\le T_2 \\ 2.5\eta(1.25A)\left(\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{2/3} & T_2\le T\le 3.0s \\ 2.5\eta(1.25A)\left(\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{2/3}\left(\frac{3}{T}\right)^{5/3} & T\succ 3.0s \end{cases}$$

In this case:

$A=0.25$,	Coefficient of acceleration due to the zone
$\eta=0.9354$,	Factor for damping correction
$R=3.5$,	Coefficient for structural behaviour
$Q=1.2$,	Factor of quality

In absence of reliable data on the site, it can be considered that the category of site is S_3, where $T_1=0.15s$ et $T_1=0.5s$.

The meshing adopted that respects the conditions of convergence and precisions is given as follows:

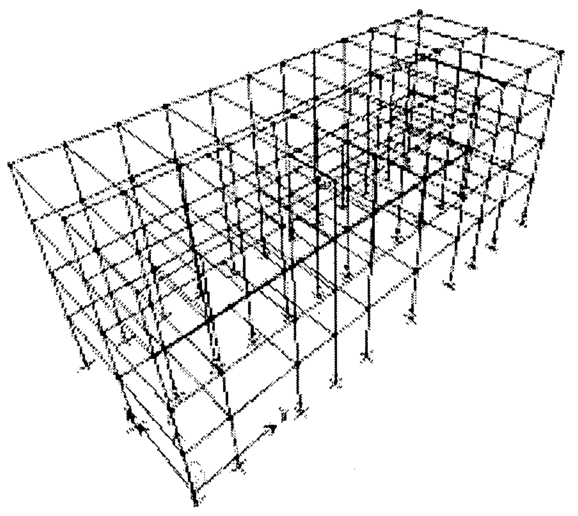
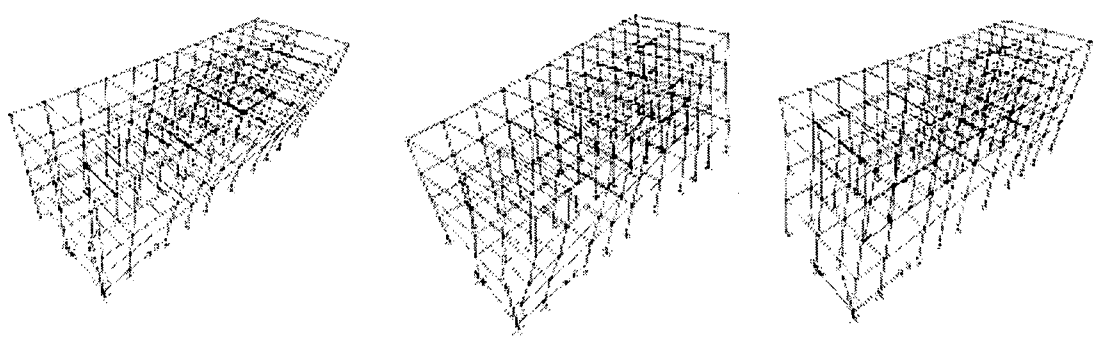


Figure 13 : the considered 3-D Structure for analysis

The three first free vibration modal shapes for this structure are as follows:



Mode 1 **Mode 2** **Mode 3**

Figure 14 : Modes of vibration

The forces - as well as the generalized deformations – of all structural elements of the structure are now known for the dynamic analysis (spectral response); these are given for all considered combinations. The shape of the structure brought us to keep the first 12 modes of vibrations for the structure.

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M O D A L   P A R T I C I P A T I N G   M A S S   R A T I O S

MODE      PERIOD     INDIVIDUAL MODE (PERCENT)       CUMULATIVE SUM (PERCENT)
                       UX        UY        UZ          UX        UY        UZ
   1    0.411310     0.0007   83.3464   0.0000      0.0007   83.3464   0.0000
   2    0.376332     0.3807    0.3584   0.0000      0.3814   83.7048   0.0000
   3    0.319995    85.9555    0.0002   0.0000     86.3369   83.7049   0.0000
   4    0.231771     0.0019    0.0862   0.0000     86.3388   83.7911   0.0000
   5    0.213973     0.0711    0.0024   0.0000     86.4099   83.7935   0.0000
   6    0.164720     0.0015    0.0002   0.0000     86.4114   83.7936   0.0000
   7    0.147202     0.0726    0.0000   0.0000     86.4840   83.7936   0.0000
   8    0.130064     0.0000   10.4900   0.0000     86.4840   94.2837   0.0000
   9    0.129243     0.0000    0.0004   0.0000     86.4840   94.2841   0.0000
  10    0.124823     0.0037    0.0512   0.0000     86.4877   94.3353   0.0000
  11    0.112773     0.0015    0.3352   0.0000     86.4892   94.6705   0.0000
  12    0.107761     8.9395    0.0001   0.0000     95.4287   94.6705   0.0000
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Finally, the reinforcement is established by the use of software based on the **CBA93** design code, then checked by the **RPA 99** design code for zone III. Evidently an optimal solution for the reinforcement was opted for privileging the security of the building on the one hand and the conditions for comfortable realization on the other hand.

The results of the reinforcement calculation for the columns are shown below:

Longitudinal reinforcement

	Initial section (cm^2)	**Minimale section with respect to RPA99** cm^2	**Added steel section**
Ground level Col. 30x50	6.78	8.1	12 T14
Ground level Col. 20x30	6.78	8.1	12 T14

Transversal reinforcement
4 T8 ; 10 cm spacing in the plastic hinge and 15 cm outside the hinge.

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 herein. Further work and detailed investigation should be published in the near future.

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Acknowledgements

Dr. Ramdane Kheir-Eddine expresses his appreciation to the Japan Society for the Promotion of Science (JSPS) for the two-year sponsorship at the Building Research Institute, Tsukuba, Japan. Special thankfulness is also extended to the CGS, GRAAG and CTC and in particular to the research engineers: Nour Ali, Mehani Youcef, Naili Mounir, Bourzam Abdelkrim and Haddid for their kind assistance and cooperation.