BOUMERDES ALGERIA EARTHQUAKE OF MAY 21, 2003: DAMAGE ANALYSIS AND BEHAVIOR OF BEAM-COLUMN REINFORCED CONCRETE STRUCTURES

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ABSTRACT:

The important earthquake of May 21, 2003, with 6.8 Magnitude that struck mainly the province of Boumerdes and the eastern part of Algiers province has resulted in very high toll of human losses (more than 2300 dead and 10000 injured people) and in very important damage to built environment (more than 100.000 dwellings or constructions collapsed or more or less seriously damaged).

The great majority of the built environment of the region is constituted by reinforced concrete beam-column structures which are the most widely used building system in Algeria.

In this paper, the main features of this major seismic event triggered by a previously unknown off shore fault will be briefly presented. Then, the building damage will be analyzed in terms of nature and degrees of damage to different categories of beam-column structures and the main weaknesses and insufficiencies of such structures and the main causes of damage will be underlined.

Finally the main lessons learned from this very important event, in terms of beam-column building system behavior, will be presented and some recommendations will be given in order to improve Algerian building practice and Algerian seismic code requirements related to such a system.

KEYWORDS: Reinforced concrete, moment resisting frames, earthquake damage analysis, seismic code

1. INTRODUCTION

The 21st of May 2003 at 18h44 G.M.T an earthquake of magnitude 6,8 shook the central region of Algeria where several wilayas (provinces) were hit: Algiers, Boumerdes, Tizi-Ouzou, Bouira and Blida, (Fig. 1).
This earthquake has been felt extensively in the surrounding wilayas (Medéa, Tipaza, Bejaïa, Médéa, etc.), and until the Balearic Islands in the North at 300 km from the epicenter. The main shock has been followed, in the following days, by more than 200 after-shocks, the two strongest reaching a magnitude of 5.8. The stations of the Accelerographs network of CGS installed in the region recorded the main shock and the main after-shocks.
The cities where have been recorded the important building damage and life losses are Boumerdes city, Dellys, Zemmouri, Corso, Bordj Menaiel, Rouiba, Reghaïa, Boudouaou, Bordj El Bahri.
About 7 400 buildings have been destroyed and about 7 000 others have been heavily damaged in the wilaya of Boumerdes. Nearly 8500 apartments were lost and more of 20 000 others were heavily damaged in the wilaya of Algiers.
We deplore otherwise (last official report) 2 278 deaths, more than 10 000 injured and about 180 000 homeless.

2. CHARACTERIZATION OF THE EARTHQUAKE

2.1 The Seismic Event

As reported previously, it is therefore on May 21, 2003 at 18H44 G.M.T that a Magnitude 6.8 earthquake shook the central region of Algeria, mainly the two wilayas (provinces) of Algiers and Boumerdes (Fig. 2.1).

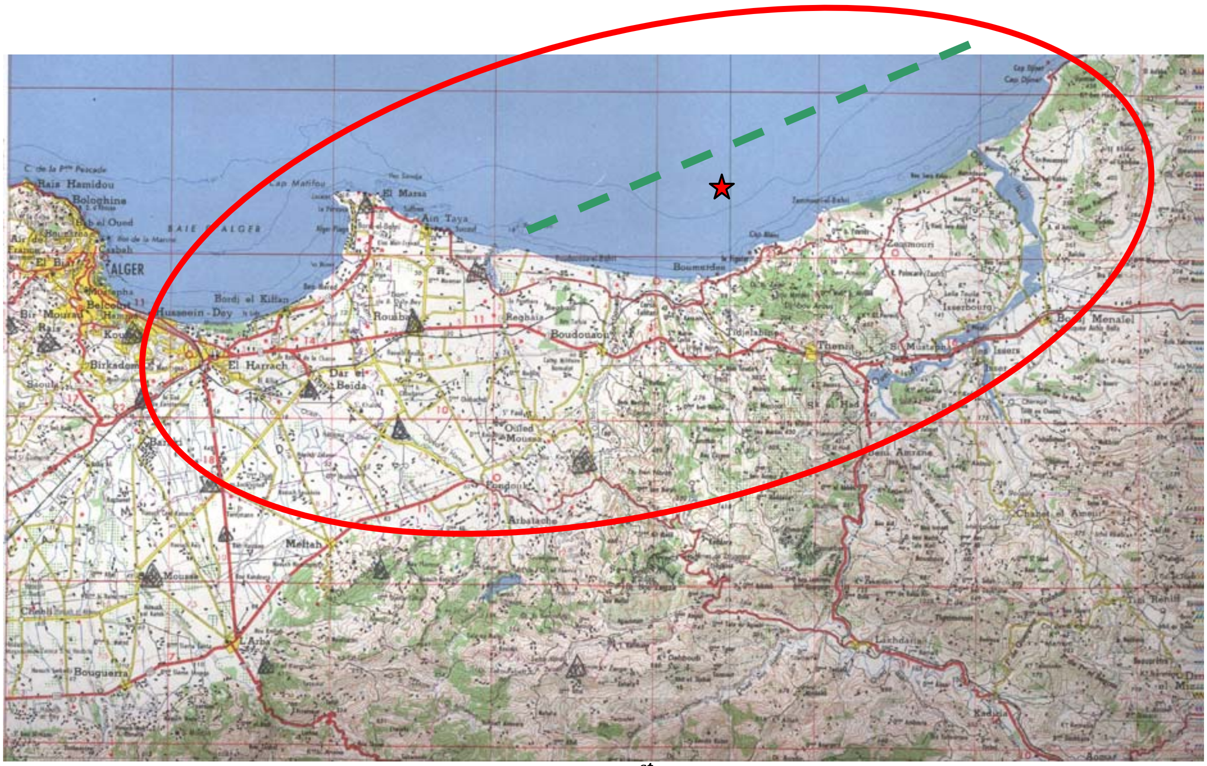

Figure 2.1: Region Hit by the May 21st, 2003 Boumerdes Earthquake

Different Institutes worldwide gave the magnitude and the epicenter coordinates as shown in Table 2.1.

Table 2.1: Earthquake characteristics

Institute	Magnitude	Latitude	Longitude	Depth
IISEE (Japan)	6.9	36.89N	03.78E	10 km
USGS	6.8	36.90N	03.71E	10 km
CSEM	6.8	37.02N	03.77E	20 km
CGS*	7.0	36.81N	03.53E	-
CRAAG	6.8	36.91N	03.58E	-

* Results obtained from accelerograms data

In the hours that followed the main shock, several after-shocks have been recorded. These after-shocks continued the days after without overtaking a magnitude of 5.8.

2.2 Seismic Records

Concerning strong motion, several records have been obtained by the national accelerographs network of C.G.S. The stations in nearest free field that recorded the main shock are located at about 20 Km from the epicenter. The maximal accelerations recorded by six (06) stations are given in Table 2.2.
The distance between the two stations at Keddara is about 100 m. This difference between the values of the maximal accelerations of the two stations is may be due to site effects.

As well as for other after-shocks, the one of the 27/05/2003 (M = 5.8, CRAAG) has been recorded, with the following values: E-W: 0.29 g, Vert.: 0.4 g, N-S: 0.13 g

Table 2.2: Recorded accelerations of the main shock

Station	Component (g)			Distance between the station and the epicenter (Km)
	E-W	Vert.	N-S	
Keddara 1	0.34	0.26	0.24	20
Keddara 2	0.58	0.35	0.22	20
Hussein - Dey	0.27	0.09	0.23	36
Dar El Beida	0.52	0.16	0.46	29
Blida	0.046	0.028	0.038	72
El Affroun	0.16	0.03	0.09	86

3. DAMAGE ASSESSMENT AND ANALYSIS

To rehouse the maximum number of the homeless as soon as possible in adequate conditions of security, and to ensure a normal education in next September, a mission for damage assessment has been required expressly by the Ministry of Housing, mobilizing more than 700 experts from scientific and technical Organizations as CGS, C.T.C, OPGI, local technical administrations, Engineering offices, etc…
In the week after the earthquake, these experts were already in the field forming several teams of about 2 or 3 experts controlled by two (02) Head Quarters: one at Algiers city and the other at Boumerdes city.

3.1 Damage Assessment Form

To assess damage and to classify immediately buildings that require repair and/or strengthening, and those that are irretrievable, a damage assessment form containing about sixty informations has been used.
This form that has already been used for Chlef earthquake in 1980, Tipaza in 1989, Mascara in 1994 Ain Benian in 1996, Ain Témouchent in 1999, and Beni-Ourtilane in 2000 acts as guide for the structural engineers who are in charge of damage assessment.
Each form has been filled to consign the damage report of each assessed building. The use of this form contributed to make the procedure of assessment of the damages systematic and to make homogeneous the appreciations of the engineers.
This form includes general information (as building identification, building occupancy, number of levels, etc.), soil problems, an assessment of the structural and non structural elements damage, commentaries on the damage causes, global building damage level and the recommendations of emergency measures if necessary. For damage level assessment of the construction elements and global building damage level, a classification of 5 levels (and 3 colors) has been used.

GREEN (levels 1 and 2): for the constructions having undergone no damage or slight and can be reoccupied immediately

ORANGE (levels 3 and 4): for the constructions having undergone some damage and requiring a second extensive expertise that will permit to decide if (and how) these constructions can or can't be repaired and strengthened according to the damage importance and the cost of repair and strengthening.

RED (level 5): for the constructions partially or totally collapsed and definitely lost.

3.2 Damage Distribution

This section presents the general damage results that constitute a balance as well as statistics of damage levels. Table 3.1 shows the distribution of the assessed 97044 constructions in the area hit by the May 21st, 2003 Zemmouri earthquake. The damage assessment was done till 30-06-2003 according to the five damage levels regrouped in three colors (green: levels 1 and 2; orange: levels 3 and 4; and red: level 5). We note that the major assessed constructions among the total (97044) are residential buildings (91735, 94.53%).
Among the 97044 assessed buildings we note that:

- 53496 have been classified into the levels 1 and 2 (green color), that is to say among the buildings not having undergone practically any damage or having undergone light damages requiring simple repair. The percentage of this class represents 55.12%

- 32904 are classified into the intermediate levels 3 and 4 (orange color), that means these buildings are requiring a more deepened expertise for future repair and strengthening. The percentage of this class represents 33.91%.

- 10644 have been classified to the level 5 (red color), that means these constructions were partially or totally collapsed and are requiring a demolition and an ulterior reconstruction according to the seismic code. This class represents 10.97%.

Table 3.1: Building damages distribution in total area (Wilayas of Algiers and Boumerdes)

CONSTRUCTION USE	GREEN		ORANGE		RED	TOT
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	
Residential buildings	18130	32352	19343	11727	10183	91735
Administrative buildings	213	300	184	76	52	825
Schools	490	814	467	286	103	2160
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	61	411
TOTAL	19361	34135	20476	12428	10644	97044
%	19.95	35.17	21.10	12.81	10.97	100
	55.12		33.91		10.97	100

4. DAMAGE CAUSES AND FEATURES

4.1. Kinds of Damage Encountered in reinforced concrete beam-column buildings

Damage that different buildings have suffered in the two regions of Algiers and Boumerdes can be summarized as follow:

- Collapse of buildings for diverse reasons
- Shear of short columns
- Hinging of reinforced concrete columns due to diverse reasons (under dimensioning, global torsional effect and lateral displacement due to soft storeys)
- Horizontal or diagonal cracks in masonry infill
- Shear failure of reinforced concrete columns joints with two cases :
  * Shearing of the joint core (« strong masonry… »)
  * Shearing of the upper part of the column after crushing of the masonry infill corner («weak masonry.»)
- Shearing and dislocation of numerous masonry infill due to important inter-storey drifts
- Cracking of many external covers (that are often thick)
- Many vertical and horizontal cracks at the junction of structure and infill due to lateral and vertical displacements

4.2. Causes of Damage

In addition to the severity of the earthquake magnitude and the important urbanization of the concerned regions, the great amplitude of damage suffered by the reinforced concrete beam-column buildings is mainly due to insufficiencies in design and construction of the buildings. The main causes of damage are given here after.

4.2.1 Poor conceptual design (Building Configuration and Structural Layout) for seismic resistant buildings.

The most notable defects are the following:

- Presence of soft storeys, generally at the ground zero (first storey) used as car parking or stores , with lack of infill and/or height greater than for upper storeys (Photo 4.1)
- Short columns in « vides sanitaires » (crawl spaces under the first story) and between upper windows of classrooms (Photos 4.2)
- Use of irregular building configurations with severe discontinuities in mass, stiffness, strength, and ductility resulting in torsional effects and stress concentration
- Use of very heavy roofs
- Use of "strong girders / weak columns" and masonry-structure interaction (Photo 4.3)
- Use of important and heavy cantilevers
- Insufficient dimension of the seismic joint (between two blocks of the same building, or between two buildings)
- Use of many heavy ornamental elements at building facades, as well as unnecessary parapets on the roofs



Photo 4.1: Soft (First) storey **Photo 4.2 (a) and 4.2 (b): Short columns**

Photo 4.2 (c): Short columns

Photo 4.3: Masonry-structure interaction

4.2.2 Lack of structural design or under-dimensioning (non seismic resistant design)

This is the case of all the buildings aged before 1981 or the great majority of individual or private houses built after 1980 (more than 60% of the new built environment)

4.2.3 Poor quality of execution and poor quality of structural material

In this framework we can note the very low strength of concrete (average of 14-17 MPA instead of 25 MPA required by the standards for current buildings) and the very inadequate recastings of concrete in columns (Photo 4.4).

Photo 4.5: Non adequate detailing

Photo 4.4: Poor concrete quality and execution

4.2.4 Inadequate proportioning and detailing of structural elements (Photo 4.5)

4.2.5 Poor inspection and control of construction process

4.2.6 Inadequate building maintenance

5. REGULATORY COUNTERMEASURES TO LESSEN LOSSES AND TO STRENGTHEN SEISMIC RESISTANCE OF REINFORCED CONCRETE BEAM-COLUMN BUILDINGS

Among several countermeasures initiated by the concerned Authorities after the 2003 destructive Zemmouri earthquake, we can at first mention the enactment of the **"Law 04-05 of 14 Aug., 2004, modifying and supplementing the law 90-29 of 1 Dec., 1990, related to land management and urban planning" .**

The modifications introduced by this document deal with a better definition of the hazards and the hazards prone areas where building is forbidden or limited, but, above all, stipulate two (2) **very important requirements**, that are:

* Immediate demolishing of all new construction without legal permit; if the municipality does not undertake the pulling down within 8 days after the certified report made by the habilitated inspector, the provincial governor (Wali) has to substitute the Mayor and proceed with the demolition with the Wilaya engines in the following 30 days.

* Compulsory Introduction, in addition to architectural lay-out signed by an architect, of designed structural plans signed by a certified civil engineer, in the technical file presented with the demand of building permit. With this last requirement it is expected that, at least, the earthquake resistant building requirements will be applied for design phase, especially for self-built "small houses"(that are actually 2 to 5 storey buildings).

Besides that, and more specifically, important improvements have been provided to seismic code "RPA 99" (which has become "RPA 99 version 2003") with new requirements or modified requirements, among which, we can mention:

- Severe limitation of the height of reinforced concrete moment resisting frames buildings (2 storeys maximum in the highest seismic zone III to 5 storeys maximum in the lowest seismic zone I).
- Severe restrictions and specific requirements in case of weak or soft storeys. In particular, when parking or stores are previously planned to be in one particular storey, the moment resisting frames are forbidden and, at least, dual systems (frames and shear walls) are to be used.
- Dimensions of outlying or ring columns must not be less than for central columns (Figure 5.1).
- Strict and severe requirements for restarting in concrete casting for columns: only one at the base and an other at the top, with a great care (Figure 5.2).
- The minimum strength for concrete at 28 days age is 20 MPa, not only at the design stage, but also at the execution stage.

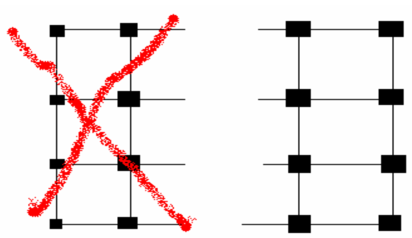

Figure 5.1: Increasing the dimensions of the outlying columns

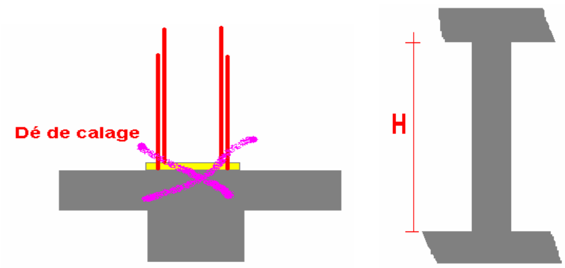

Figure 5.2: Restricted requirements for concrete recasting

6.-CONCLUSION

The May 21st , 2003 earthquake that hit the regions of Algiers and Boumerdes is then characterized by the high human and material losses. This is due, in addition to the high level of magnitude (Mw=6.8) and the urban concentration in the epicenter region, to the deficiency of many constructions in design and quality of materials and execution.

In this framework, we can particularly note the special (and new) range of damage due the soft storeys (first storey of RC framed buildings of 2 to 6 storeys dedicated to garages and services) and the very bad quality of concrete (very low resistance compared to the level required by the Building Code).

Four (4) main recommendations seemed to be evident after this dramatic event:

- Classify the Algiers and Boumerdes wilayas in higher seismic zone of the seismic building code (that has been done in new version of seismic code “RPA 99/2003”)
- New and precise regulatory requirements to ovoid the soft story phenomena in first story of current buildings (also included in “RPA 99/2003”)
- More severe requirements for beam-column systems in order to lessen the future damages in this kind of reinforced concrete buildings; in addition to the new requirements introduced in “RPA 99/2003”, we have to think about other requirements and arrangements to make reinforced concrete columns and beam-column joints more seismic resistant.
- More training and better organization of the building staff and professions to improve quality in design and execution.

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