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SEISMIC VULNERABILITY OF STRATEGIC BUILDINGS IN ORAN (ALGERIA)

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ABSTRACT

Boumerdes earthquake of a magnitude of 6.8 struck the Boumerdes Prefecture on May 21, 2003. 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. Moreover, the earthquake disrupted health services, water supply lines, electricity, and communications in the region.

Second city socio-economic, capital of the west Algeria, a city rich in history and architecture, with a very dense urban fabric and housing achievements of urban and architectural value, Oran by its character, its nature, its geographical situation, constitutes a city of major potential hazard. its geographical situation, is a city at major and potential risk as all the northern Algeria.

The majority of buildings in Oran consist largely of masonry and reinforced concrete structures which are not, in general, conform to seismic design codes and represent therefore a great vulnerability vis-à-vis the seismic action.

The study of the seismic vulnerability of these buildings constitutes an important step for the reduction of human losses due to earthquakes in the city. This vulnerability can be reduced by preventive measures. In this paper, we present an overview of the vulnerability of buildings in Oran and show from examples the vulnerability of few strategic buildings. Two methods of calculation were used (push-over, ...). According to the preliminary study of the seismic vulnerability, these buildings are unsafe and thus seismic rehabilitation measures must be taken immediately.

1. INTRODUCTION

Earthquakes are one of the most destructive hazards. The northern Algeria which is in a zone of high seismicity is subject to this phenomenon. The last fatal earthquake occurred in Algeria Boumerdes May 21, 2003, was of magnitude 6.8, causing widespread destruction and 2,278 dead, 11,450 injured, 200,000 homeless.

Second socio-economical city and capital of Western Algeria; Oran is a city rich in history and architecture. Oran with its very dense urban fabric covers immense achievements of urban and architectural value. Oran by its character, its nature, its location, is a city exposed to significant seismic risk. The housing in Oran consists largely of masonry and reinforced concrete buildings which do not conform to the seismic design rules.

A seismic risk reduction policy should include the establishment of priorities to reduce the vulnerability of existing buildings based on the knowledge of actual urban fabrics. The complexity of vulnerability assessment requires a gradual approach from the urban scale [1] to the building scale [2].

The study of the seismic vulnerability is therefore a key step for the reduction of casualties from earthquakes in this city. The assessments carried out on certain structures showed the low resistance of this type of construction vis-à-vis the seismic action. This vulnerability can be reduced by preventive measures.

In this paper, we present an estimate of the vulnerability of buildings in the city of Oran based on analytical methods for vulnerability analysis and also by the establishment of the fragility curves by the nonlinear method ***"pushover"***.

2. SEISMIC RISK REDUCTION IN ORAN: THE ALGERIAN SITUATION

The extent of damage has encouraged researchers in the field of earthquake engineering to find solutions to reduce the seismic risk.

Algeria has inherited a large real estate, which is concentrated in large cities. It turns out that this ***Heritage*** is now in a very advanced state of degradation. The urban characteristics of Oran are a case study that can be generalized to all major cities of Algeria.

The city of Oran, like other Algerian cities, is facing major problems of **growth** and **management**. The current problem of its ***Heritage*** requires a strategy that will bring solutions to the state of degradation of the built environment.

Although Boumerdes is not a big city in Algeria such as Algiers, Oran, Constantine, Annaba, and Setif…., its earthquake clearly illustrates the damage that can be expected due to moderate or major earthquakes in urban areas.

In the aftermath of this tragedy (despite the lessons learned after the earthquake of El Asnam 1980), several personalities from the field of construction, researchers, media… have strongly criticized the structures built in Algeria and their construction methods. Thus, during the inspection of damaged buildings during our stay in the affected region, some of the main deficiencies in the design and construction methods have been discussed [3].

In the past, strong earthquakes shook the region of Oran. The most destructive occurred in 1790 (intensity X). And recent shakings recorded in Oran in 2008 and 2009 caused a great panic among the population. The strongest recorded quake with a magnitude of 5.3 caused few victims and caused the collapse of their buildings.

Thus, the objective of our work is to address all these concerns, namely the vulnerability of existing buildings, in order to reduce the seismic risk. This vulnerability poses significant problems of security in the event of an earthquake. It is therefore imperative to identify and record all vulnerable structures in the city of Oran, assess their seismic capacities and propose seismic retrofit methods for the exposed structures.

This research work is expected to take several years and is structured as follows:

- In the short-term, it is necessary to identify the vulnerability of buildings from the urban scale to the building scale.

- In the long-term we plan to develop a seismic damage index for different types of buildings in Algeria. This damage index has the potential to become a valuable tool in the decision of the structural evaluation and for a possible seismic rehabilitation.

3. BOUMERDES EARTHQUAKE

The latest devastating earthquake of the May 21, 2003 of magnitude 6.8 struck Alger-Boumerdes region causing widespread destruction of structures. The damage was estimated at 5 billion U.S.$.

From the inspection of the damaged buildings in the affected region, some of the main defects in the design and construction methods are shown in Figs 1 and 2. These defects discussed in a report [3] 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. Poor material quality and unsound construction practice,
6. Inappropriate anchoring of beam and slab reinforcement,
7. Use of irregular building configurations with discontinuities in mass, strength and ductility,
8. Use of weak materials for facades,
9. Old structures designed according to the old design code, before-1980,
10. The contractors are, for a number of them, reconverted manual workers with no skills,
11. Inexperience of young engineers who are not offered any further training,
12. The conditions of the soil are taken with ease,
13. Buildings are designed sometimes before even the ground is defined (adaptation on the ground),
14. Repetition, a practice intended to reduce the intervention of the architect and the engineer,
15. The pricing policy of social dwellings, and
16. The absence of town planning.

a/ Collapse of brick walls

d/ Story collapse of a building

c/ Pancake shape collapse

e/ Soft first story collapse of a private house

b/ Severe damage of a building

g/ Damage of pre-cast concrete panels

f/ Failure of a beam-column joint

h/ Break of bars inside a column

i/ Damage of a short column

j/ Failure at the column top

k/ Bad quality of concrete inside the apartments

l/ Lack of reinforcement bars causing failure at the column’s top level

Figure 1: Building damage caused by Boumerdes earthquake

Figure 2: Damage to RC silos showing cracks at different heights

4. ESTIMATION DU RISQUE ET ALEA SISMIQUE A ORAN

The city of Oran was founded in 902. Rare however are the still standing residential buildings inherited from the period prior to the French occupation (1830-1962). The development of urbanization in Oran followed an accelerated pace since 1831 and four main phases that have marked this evolution can be distinguished (see map below shown in Fig.3)

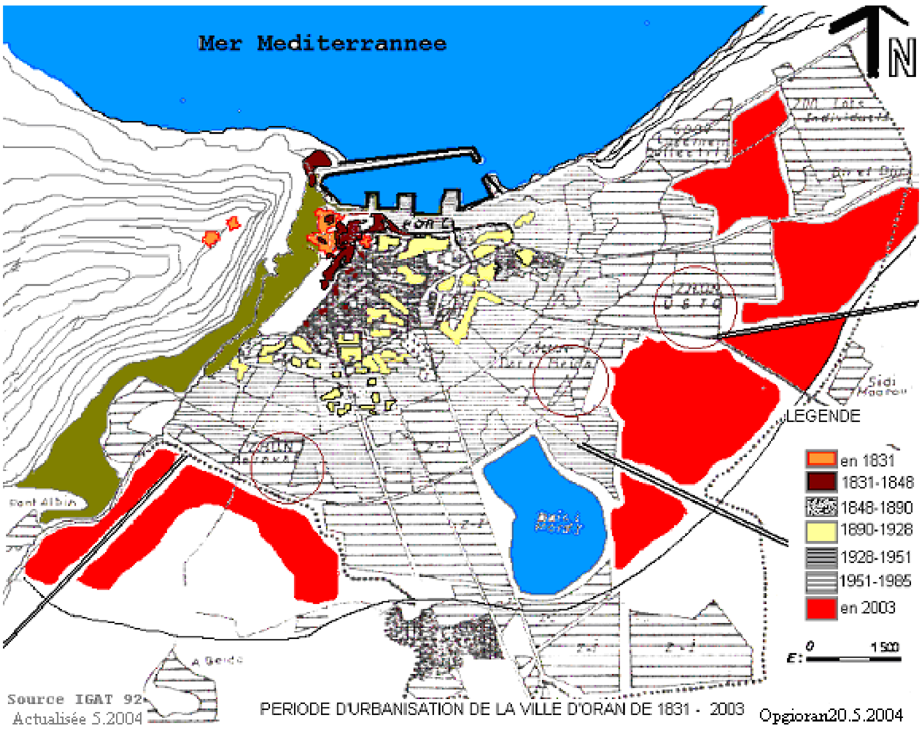

Figure 3 : The different of urbanization periods in Oran [4]

Oran covers immense achievements of urban and architectural value. A catastrophe in Oran can multiply dramatically the disaster consequences for three main reasons:

- The importance of the population density in urban areas,
- Concentration of craft, individual, commercial and cultural activities,
- Accumulation of buildings for individual or collective, and
- Accumulation of old buildings.

Figure 4 shows examples of building types of different ages from 1831 to 2010.

Figure 4: Example of building types of different age in the study area. **a** and **b** masonry (1860-1900); **c** masonry (1880-1910); **d** masonry (1910-1930); **f** reinforced concrete (1920-1950); **g** reinforced concrete (1950-1970); **h** reinforced concrete (recent construction) [1]

Figure 5 shows a spatial distribution of the dominant building typology per block of one area of the city of Oran [1]. This area was studied in 2009 by expert structural engineers from CTC (Technical Control of construction). The aim of the study was the evaluation of the conservation state of buildings and their capacity to resist permanent static charges (not considering seismic loading). The CTC approach was based on an expert judgment supported by a number of elements deriving from a visual survey from outside and inside every floor of each individual building. Most elements of construction are listed, their nature identified according to a pre-established grid form, including structural (infra- and super-structure) elements, non-structural elements, soil conditions, regularity in plan and elevation, etc.

Figure 5: Spatial distribution of the dominant building typology per block. The masonry dominates in the northern part of the area under study, while the southern part is comparatively recent with predominant reinforced concrete constructions [1]

Each element is defined by its type and its material and is classified into one of three classes, 1, 2, and 3. Class one (1) is allocated when the item is in good condition of preservation. The last class (3) characterizes bad preservation. The class (2) corresponds to the intermediate situation. This element-by-element classification is then aggregated at the building scale, leading to an overall classification into three different groups (green, orange, red). The CTC classified them in three groups labeled with three different colors (green, orange, red).

Furthermore Senouci [1] has carried out a study corresponding to the first step approach, i.e., a preliminary study of the seismic vulnerability and expected damage within an urban district of the city of Oran, based on a non-dedicated data base from a building survey previously performed for other purposes. The main goals of the study are twofold: (1) an assessment of the degree of uncertainty and robustness of such results through a comparison of the results derived from different urban vulnerability methods (GNDT 2; RISK-UE LM1; and VULNERALP 2.0) and (2) an assessment of the actual level of seismic risk in the city of Oran.

The city of Oran is affected by various risks such as earthquakes. This usually comes from two sources, the soil conditions and the state of the structures.

4.1. Soil related risk

This is due to the construction of certain parts of the city of Oran on an embankment. The main obstacles are the four ravines (natural cutting edge of cliff); a potential risk for landslide [5].

4.2. Structural state related risk

Oran's ***'heritage'***, particularly older districts experience an alarming situation due to the very advanced state of deterioration of its buildings. The number of deteriorated buildings is increasing, therefore the safety of property and people may no longer be assured. Fig. 6 shows the distribution of deteriorated strategic buildings by district. A survey operation of the ***'heritage'*** at high risk was carried around different parts of the city. A technical study of ***'heritage'*** was engaged where buildings were classified by degree of deterioration. The buildings have been classified into three categories according to their degree (grade) of deterioration; i.e. grades 1, 2 or 3. Among the 1990 identified buildings by the ***OPGI*** in 2005, 886 buildings are classified of a grade 1of deterioration, 783 buildings of grade 2 and 321 buildings of grade 3.

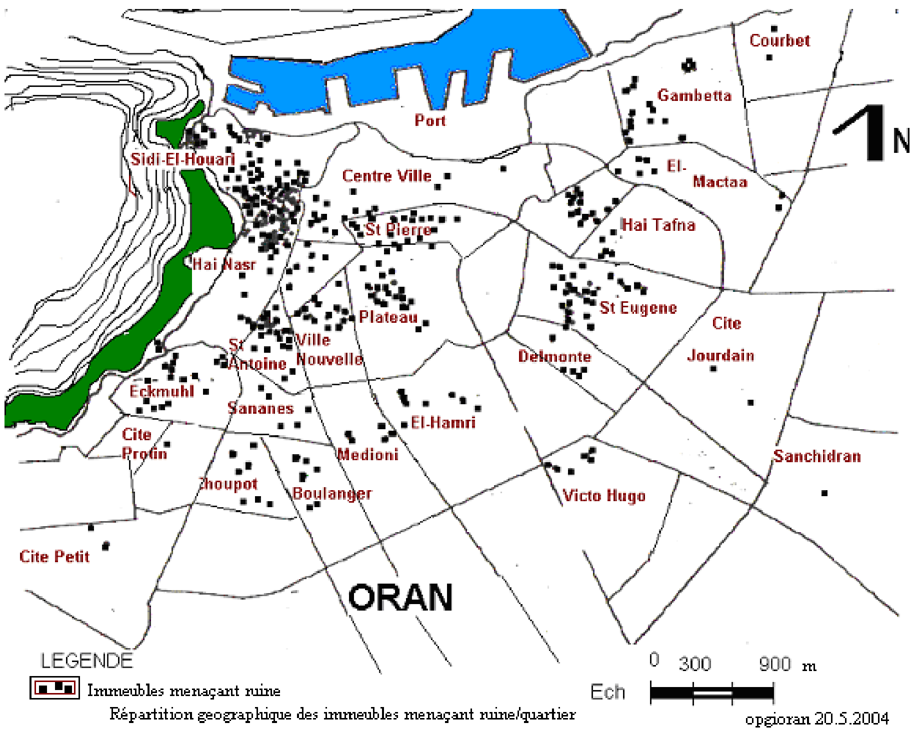

Figure 6 : Geographical distribution of buildings in advanced state of deterioration in Oran [4].

The minimum level of seismic protection granted to a structure depends on its destination and its significance vis à vis the objectives of protection set by the experts and needs. The seismic safety regulations allow for protecting people and the economic and cultural assets of the community. For this, a classification of structures according to their importance has been recommended. This classification recommended minimum levels of protection that a client can change only by outclassing the structure for increased protection, given the nature and purpose of the structure vis à vis the objectives.

For structures qualified as **strategic** buildings, they are vitally important and must remain operational after an earthquake. It is found that the number of **strategic** buildings which are deteriorated represents a percentage of 18% of the total deteriorated buildings in Oran.

4.3. Seismic hazard

During the twentieth century strong tremors were expressed by different intensities in the region of Oran. These data indicate that Oran and its region represent seismogenic source of strong earthquakes. According to the neotectonic data, this region is a tectonic node: area expressively destructive where morphostructures overlap which were taken by the different intensities of vertical movements. These earthquakes are related to morphostructures dislocations along their faults' border, while the maximum efforts are related to the nodes [6]. Two areas appear where the epicenters of strong shaking meet: Oran urban area extending to of the area Arzew-Mostaganem where we might suspect an accident along the Bay of Oran and Mascara area towards the south-west and north-east towards Relizane. Fig. 7 shows the tectonic map of the region of Oran [7].

Fig. 8 shows a map of the calculated maximum intensities in Oran region according to the maximum intensities of earthquakes that have affected the region of Oran within two hundred kilometers for the period 1900 to 1999 [8]. Figs 9a and b show the number of earthquakes for the period 1990-2003 versus magnitude and intensities in the region of, respectively.

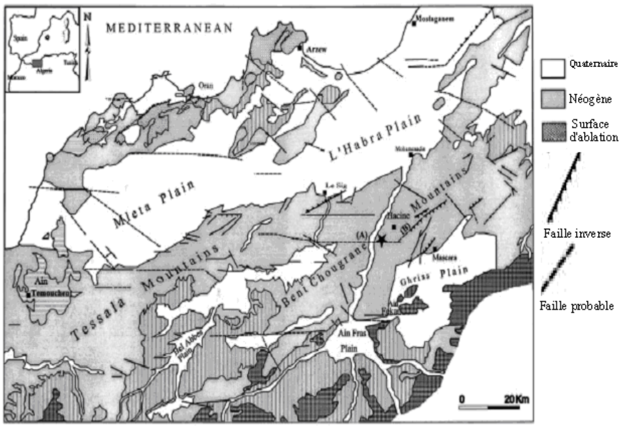

Figure 7 : The tectonic map of Oran region.

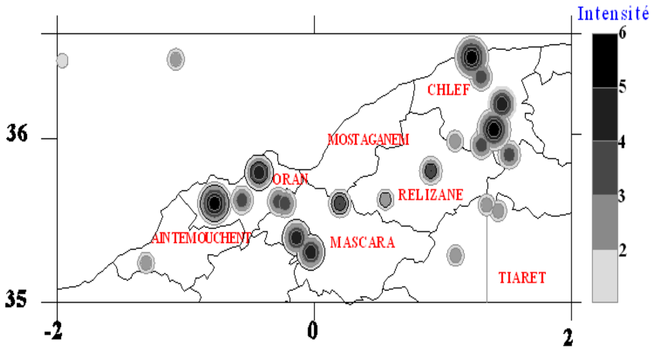

Figure 8: Map according to the maximum intensities of earthquakes in Oran region.

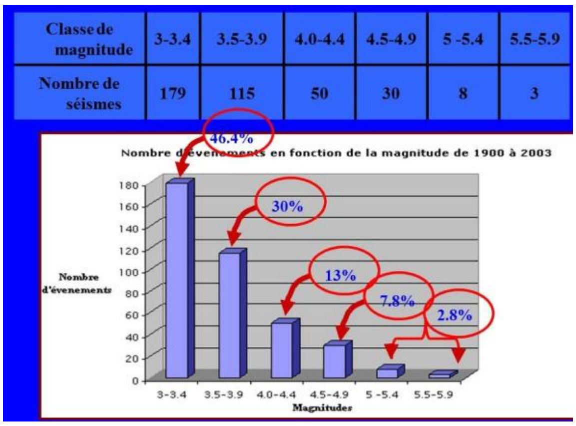

Figure 9a: Number of quakes vs magnitude in Oran (1990-2003)

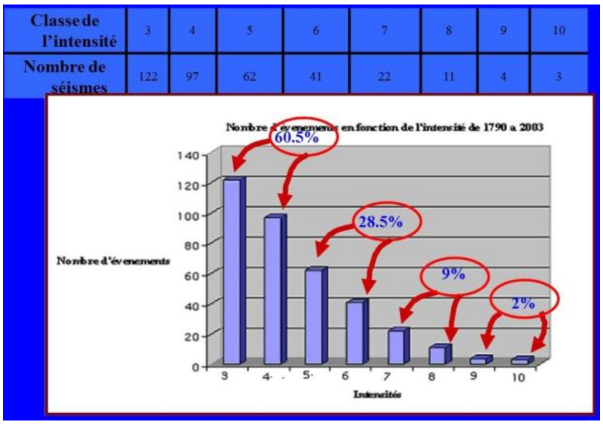

Figure 9b: Number of quakes vs intensity in Oran (1990-2003)

As for the hazard, this is defined as the probability of occurrence of an event in terms of intensity based on the European macroseismic scale. This scale ranks earthquakes based on their effects at a given location. Assessing the hazard is therefore computing, at a given site, the function of distribution of parameters characterizing an event; such as the intensity and the probability of occurrence.

For instance, for buildings the seismic hazard is expressed on the basis of classical terms of equations (1) and (2) below, defined by the United Nations. The components of the risk are shown schematically below:

$$\textbf{Risk} = \textbf{Danger} \times \textbf{Consequences} \quad (1)$$

$$\textbf{Risk} = \textbf{Hazard} \times \overbrace{\textbf{Vulnerability} \times \textbf{Value}} \quad (2)$$

5. VULNERABILITY ASSESSMENT OF EXISTING BUILDINGS IN ORAN

The objective is to achieve an overview of issues related to seismic retrofit of buildings: present different approaches to diagnose vulnerability to earthquakes and adopt an appropriate strategy of rehabilitation.

The evaluation of the seismic vulnerability of a building is based on the typology and the identified vulnerability factors (inventory). This includes the review of available documents, if possible, seeking information from people who participated in the construction of the project, a survey of vulnerabilities during a visual inspection inside and outside the site, and operation survey grids, covering:

- Architecture (configuration and architectural detail),
- The constructive,
- The construction detailing,
- The conservation status,
- The interaction with the built environment,
- The site.

It should also be noted that vulnerability increases with the intensity of the earthquake. We can evaluate it only for the retained maximum earthquake or for several seismic level of attack, usually three:

- Low Earthquake, corresponding to the degree VII of EMS 98 (European Macro Seismic) intensity scale or a peak ground acceleration as = 1 m / s ²;
- Moderate Earthquake, corresponding to the intensity VIII or as = 2 m / s ²;
- Strong Earthquake safe, corresponding to the intensity IX or as = 4 m / s ².

As for the level of performance, several levels of behavior can be searched for a given level of seismic attack. It seems appropriate to assess the ability of the structure at least in relation to two degrees of "performance": no-collapse and functionality.

As for the assessment methods, many approaches to assessing the vulnerability of structures to earthquakes have been proposed, particularly in countries with high seismicity (United States, Japan, Yugoslavia, Italy ...). As far as vulnerability assessment is concerned, in general a global vulnerability is estimated. For this purpose, the "weaknesses" identified are prioritized and a "grade" or coefficient characterizing the severity is assigned to them. Taking into account these weighted coefficients; terms which vary from one method to another, leads to predefined vulnerability levels of (overall 3 to 5). Depending on the degree of vulnerability, a decision for rehabilitation or not can be undertaken. The following situations may arise:

- Acceptable State; unnecessary strengthening of the building;
- State requiring economically strengthening feasible;
- Further study needed;
- Very high vulnerability, the economic feasibility of a building should be investigated.

Several methods for assessing the vulnerability of structures have been developed, such as:

1) Simplified method for the use of Architects (M. Zacek): [9]
2) Method proposed by the French Association of Earthquake Engineering (AFPS): [10]
3) Method "FEMA 310":
4) Method "ATC 40" [11]
5) Static non-linear methods: pushover analysis [12]
6) Displacement method FEMA 273: [13]
7) Method of spectrum capacity according to ATC 40

Figs 10 and 11 illustrate the condition of the building for each level of performance and capacity spectrum coefficients according to the FEMA 273 methods based on displacement and ATC 40 method, respectively.

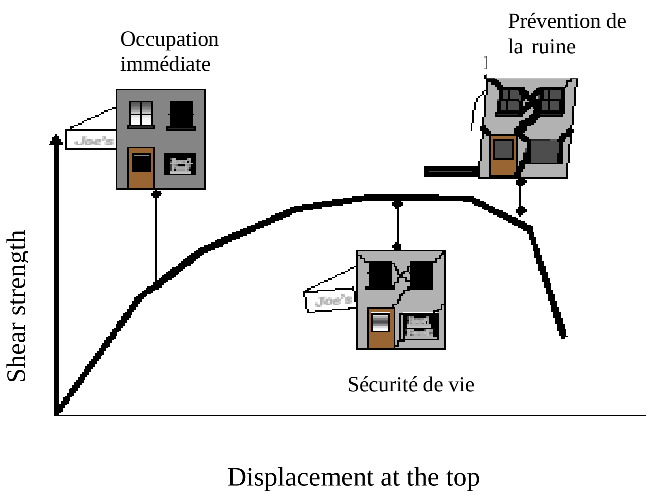

Figure 10: Building state for each performance level (FEMA 273).

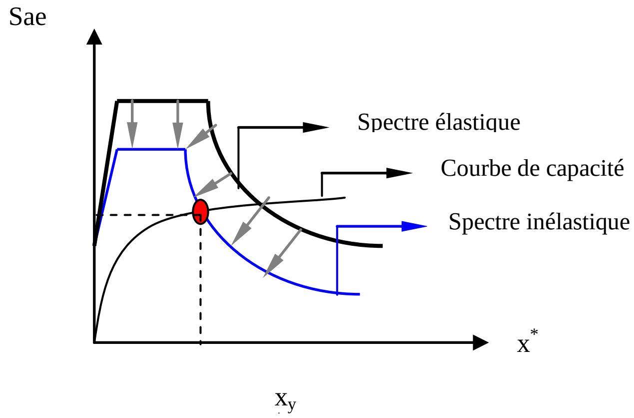

Figure 11 : Capacity spectrum (ATC 40)

6. CASE STUDY: VULNERABILITY STUDY OF A FEW STRATEGIC BUILDINGS IN ORAN [5,14]

As part of the vulnerability study of strategic buildings in the city of Oran, a structural check with regard to Algerian seismic code (RPA99 v.2003), a structural capacity calculation of the buildings and the required performance analysis due to earthquake accelerograms were performed.

To better simulate the dynamic response of the examined buildings, a non-linear dynamic analysis was performed. For this, three seismic records which are referential accelerograms were selected thanks to their broad band frequency content. These are shown in Table 1:

- Ulcinj Albatros N-S 1979;
- El Centro N-S-1940;
- Chenoua Cherchell 1989;

Table 1: Accelerations at soil level versus return period

	Return period (ans)		accelerograms
Types de séisme	100 ans	500 ans	
Proche	0.25g	0.40g	Cherchell
lointain	0.25g	0.40g	Ulcinj et El Centro

The dynamic analysis was carried out for two levels of seismic intensity. The level of maximum ground acceleration was given based on the return period of the earthquake considered likely to happen given the methodology adopted for the vulnerability study of strategic buildings.

For assessing the vulnerability of a few strategic buildings in the city of Oran, two analysis methods were used:

6.1. IZII Mthodology
This method was developed at the Institute of Engineering and Seismology in Macedonia and it is adopted in the seismic regulations of the former Yugoslavia. The method makes it possible to estimate the vulnerability of structures based on the capacity in terms of stresses and displacements for a linear and non-linear behaviors.

6.2. Pushover Analysis
This analysis is carried out using the software SAP2000 version.08 unlike the previous method. The pushover analysis gives us the capacity curve of the overall structure. Safety criteria established for the two levels of chosen seismic intensity are:

1. For a moderate earthquake, the structure should not suffer structural damages. The building must have an elastic behavior.

2. For a major earthquake, the structure can have a non-linear behavior; the structure behaves in the plastic range. The damage to structural elements must be acceptable and repairable.

To verify and satisfy the safety criteria mentioned above, it is necessary to assess the level of stress and displacement due to seismic records and the strength and deformability (displacement) capacities of the structure. For this purpose, several analyses and correlations were determined and compared by evaluating:

- The static and dynamic behavior of buildings based on the Algerian seismic on Regulations RPA99 Version2003,

- The strength and deformability (displacement) capacities of various buildings and their nonlinear dynamic responses are evaluated by different software.

6.3. Case study: Description of the structures [5, 14]
Several strategic buildings of the city of Oran were analyzed. In this paper two cases are presented:

Surgery ward at the Oran University Hospital (CHU)
The structure was built in the fifties. It consists of a ground floor plus four (04) floors as shown in Fig.12. Storey height is 3.40m. The total height of the building is 17.00m. The overall floor area of the building is (22x22) m². The building consists of a column-beam frame made of reinforced concrete and filled with masonry. Columns are (35x35) cm ², the main beams are (35x50) cm ² and the secondary beams are (35x40) cm ². The floors are thick ribbed slabs of about 12cm in thickness.

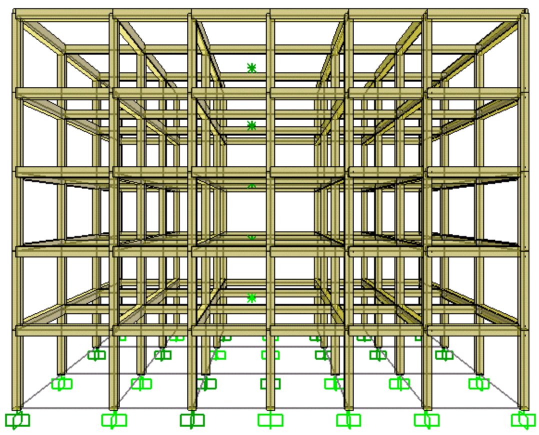

Figure 12: Surgery ward at Oran univ. hospital.

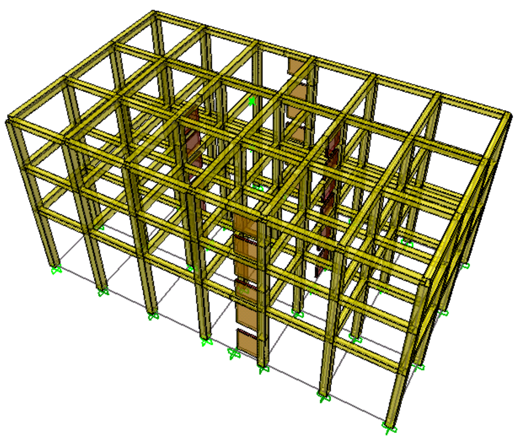

Figure 13: Fire department branch in Oran.

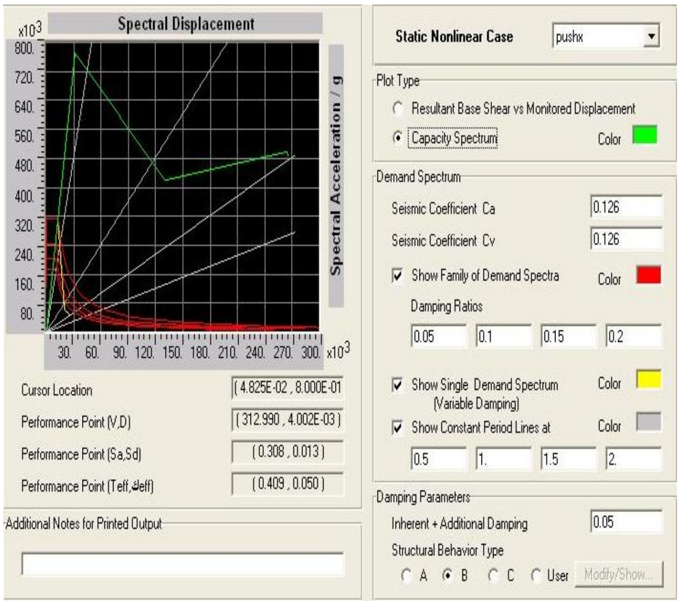

Fig. 14: Surgery ward at Oran univ. hospital (CHU): non-linear static analysis « pushover » ;

Oran Fire department branch

The structure was built in the eighties. It consists of a ground floor of a height of 4.5m plus two (02) floors as shown in Fig.13. Storey height is 3.40 m. The total height of the building is 10.62 m. The overall floor area of the building is (21x12) m². The building consists of a reinforced concrete structure frame braced by shear wall of thickness of 15 cm. Columns are (40x40) cm ², the main beams are (45x30) cm ² and the secondary beams are (30x30) cm ². The floors consist of hollow slabs of thickness of (16+4) cm.

6.4. Discussion of the results

Fig. 14 shows the non-linear ‘pushover’ analysis of one of the ward at the university hospital in Oran. Curves representing the structure’s capacity and performance point can be seen in the figure. The vulnerability assessment results of a few buildings of Oran lead us to conclude:

- The buildings’ initial design is not consistent with the current seismic regulations,

- The analysis revealed that the design of these structures may affect the functioning of these buildings, considering the group purpose for which they are assigned. This is due to the following:

- The building’s capacity to withstand a shear force is much higher than the required capacity derived from the RPA99 V.2003. Furthermore, almost all storeys behave in the elastic range recommended by the method. That is to say, a minimum of damage to the secondary structural elements (e.g. masonry) will be observed. The safety factor calculated for the different levels is greater than the minimum coefficient limited to 1.15 for all buildings and in both directions of excitation.

- However, the buildings have insufficient capacity as far as displacement and ductility are concerned for a major quake, while these structures do not satisfy the criterion of deformation for a few storeys.

In conclusion, for a major earthquake, these buildings do not meet the conditions of strength and deformability recommended by the methods used in this study for this group of structures (strategic building). In this case, the buildings can suffer non-repairable damage to structural elements under the effect of a major earthquake like that of Boumerdes. This can disrupt the utilization of buildings after an earthquake. For this, it is recommended to address this problem and to opt for a solution to strengthen these buildings.

However, buildings have a strength and deformability more or less acceptable for a low/moderate earthquake.

7. CONCLUSIONS, SUGGESTIONS & PERSPECTIVES FOR SEISMIC RISK REDUCTION

This research investigation has revealed the following:

1) Cross-method comparisons and correlations highlight a satisfactory agreement between mean damage estimates at the urban scale, despite significant scattering at the single building scale, and uncertainty levels which vary significantly from one method to the other [1].

2) The mean damage estimates among the three methods exhibit a very satisfactory agreement for RC buildings, and larger differences for masonry buildings. The VULNERALP 2.0 estimates are systematically larger, while RISK-UE LM1 most often provides the smaller ones [1].

3) For a major earthquake, the buildings which were investigated do not meet the conditions of strength and deformability recommended by the methods used in this study for this group of structures (strategic building).

Earthquakes will strike Algeria again during the next several years. The aftermaths of an event as tragically felt as the Boumerdes earthquake require a rigor, and rationality in their clarification. It is the responsibility of specialists qualified in urban planning, experts in the fields of civil and earthquake engineering and seismology, of psychologists but also of all those which have to design the environment and the corresponding buildings, dwellings in which the Algerians must live safely. There have been always tragedies caused by earthquakes in Northern Algeria. It is the time to find objective answers to objective problems.

There is absolutely a need for a national program for seismic risk mitigation which must include in the national development plan (sustainable development). The main actions of this national plan for seismic risk mitigation should be:

1/ Emergency preparedness and response capabilities

2/ Organizing and training volunteers for post-disaster damage assessment.

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/ Law ***MUST*** prohibit uncontrolled modifications to structural elements of existing structures, unless proper re-design study is carried out and submitted to the concerned authorities for approval.

5/ Deficiencies in the construction methods must be eliminated. Such deficiencies probably would not have led to the collapse of several buildings.

6/ The Algerian government should 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.

7/International cooperation with leading countries in the field of Earthquake Engineering such as Japan and USA, …….. is imperative.

8/ There is an urgent need for the evaluation of the seismic hazard zonation (microzonation) for the north of Algeria.

9/ Developing catastrophe-modeling solutions to insurers and corporations, with a focus on event-specific probabilistic modeling to quantify the seismic risk, is necessary nowadays.

10/ The extend of the damage has been accentuated due to the emergence of great urban cities and great concentrations of people. The anarchistic expansion of urban cities needs to be looked at seriously to mitigate the losses due to catastrophes caused by natural disasters.

Also:

- better evaluate and comprehend the seismic risk

- to promote scientific research and transfers of knowledge
- to develop networks for the prevention of the seismic risk as well as good mechanisms of coordination and mechanisms of exchange of information
- to sensitize the public (to better inform and better educate),
- to sensitize the media in order to establish an awakening population to the seismic risk and to better comprehend the regulations and laws that must be respected

Finally, since Oran inherited an important **'heritage'** which is in a very advanced state of degradation. This requires a strategy that will bring solutions to this degradation.

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