CONTRIBUTION TO THE STUDY OF THE SEISMIC VULNERABILITY OF MASONRY ARCHITECTURAL HERITAGE USING NUMERICAL MODELING

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Abstract:

The protection of the architectural heritage from seismic risk is now a major challenge. As a result, the objective of this research is to establish a methodology for studying the seismic vulnerability of masonry buildings, which represent a significant percentage of Algeria's heritage. Since the hypothesis of the possibility of a major earthquake is not negligible, assessing the vulnerability of our built heritage is becoming a major issue. Especially when it is a real estate asset that is still functional, in use and home to a significant number of residents. This research work presents the results of a study on the seismic vulnerability of existing buildings with unchained masonry located in the city of Algiers, an area of high seismicity (III). What motivated our research was the fact that according to the RPA2003 regulation, masonry is a construction system that is not recommended in cities like Algiers. These are structures built at a time when no official text provides a framework for justifying a construction in terms of earthquakes and well before the appearance of the first Algerian seismic code. In order to avoid costly and unnecessary reinforcement after each seismic event, a method based on SAP 2000 numerical analysis and modeling tools was proposed. In addition, an example of a masonry building was taken to better define the method. The results of this study confirm the important role played by modeling tools in determining the level of seismic vulnerability of older buildings.

Key words: Architectural heritage; Seismic vulnerability; Numerical analysis; Masonry; RPA2003 regulation
Introduction

At each major seismic event, there is a renewed interest in safeguarding and preserving the built heritage from this natural risk. Algeria has experienced three major earthquakes throughout its history: the first is the El Asnam earthquake in Chleff on 9 September 1954 and the second on 10 October 1980 in the same city, and recently the Boumerdès earthquake on 21 May 2003. These events have certainly contributed to this growing interest.

Before the violent earthquake of 9 September 1954, there were no regulations on seismic construction (GSC, 2003). The expert report showed that most of the buildings damaged by previous earthquakes were not seismically designed, because they were built before 1970 and could not benefit from the Algerian seismic code.

Today, in cities in northern Algeria in general, and in Algiers in particular, the probability of a major earthquake occurring is not zero (Davidovici, 1999). As a result, the numerical modeling of older buildings plays a key, albeit difficult to analyze, role in preventive decision-making and in the choice of action to be taken.

In this article, we will try to develop a method to study the seismic vulnerability and level of damage of existing masonry structures. This study integrates the CSI digital analysis tool; example SAP2000 (CSI, 2004) in the analysis process. In the context of the renovation or rehabilitation of old buildings, this type of initiative is currently only rarely implemented. And bearing in mind, the use of modeling software will certainly be beneficial in the process of preserving built heritage, especially the most vulnerable.

The architectural heritage of the city of Algiers

Identification of constructive typologies

On the scale of the Algiers agglomeration, there are three main periods relating to three modes of construction (Petruccioli) (Table 1):

- Until 1920: predominance of traditional masonry construction systems: stone and/or brick walls, wooden floors and/or vaults, such as historic centers and old districts.

- Between 1920 and 1955: stone and/or brick masonry constructions with reinforced concrete slab floors.

- From 1955 onwards: with the exception of Fernand Pouillon's buildings, all the buildings designed after this year is made of reinforced concrete. A constructive system imposed by prefabrication and mass construction.
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Table 1. The constructive typologies of the built heritage of the city of Algiers (Colloquium, 1987)

<table>
<thead>
<tr>
<th>Typology</th>
<th>Constructive system</th>
<th>Location</th>
<th>Year of completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historic centre</td>
<td>Brick load-bearing wall</td>
<td>Kasbah</td>
<td>Until 1830</td>
</tr>
<tr>
<td>Old quarter</td>
<td>Stone load-bearing wall</td>
<td>- Mustapha</td>
<td>Before 1920</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Bab El Oued</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Downtown area</td>
<td></td>
</tr>
<tr>
<td>The 1st HLM</td>
<td>- Masonry</td>
<td>- HLM Champ de manœuvres</td>
<td>1920-1930</td>
</tr>
<tr>
<td></td>
<td>- Building in open islets</td>
<td>- Cité Bobillot</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cité Verdun</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cité la Consolation</td>
<td></td>
</tr>
<tr>
<td>The resettlement cities</td>
<td>Masonry</td>
<td>- Djenan El Hassen</td>
<td>1950-1960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Diar El Kef</td>
<td></td>
</tr>
<tr>
<td>Pouillon's buildings</td>
<td></td>
<td>- Diar Es Saada</td>
<td>1953-1958</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Diar El Mahçoul</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Climat de France</td>
<td></td>
</tr>
</tbody>
</table>

Description of structural characteristics

It can be seen that a large part of the real estate heritage of the city of Algiers is built in masonry (Table 2). The materials used in traditional walls are fairly resistant to compression and have little or no tensile strength (Jeannet, 2001). These masonries are rarely linked. Thus, the tensile forces applied to these walls cause either deformations (tilting) or the appearance of cracks. Whether it is stone or brick masonry, the appearance of cracks is a common phenomenon over time.

These buildings are still functional and in service, hence the importance of assessing their seismic vulnerability. Indeed, a simple seismic event can cause irreversible human and material losses.
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Table 2. Structural characteristics of real estate assets (Colloquium, 1987)

<table>
<thead>
<tr>
<th>Typology</th>
<th>Location</th>
<th>Vertical element</th>
<th>Horizontal element</th>
<th>Plan configuration</th>
<th>State of conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry</td>
<td>- Quartier Mustapha - Bab El Oued</td>
<td>Stone load bearing wall</td>
<td>- Brick roof - Wooden flooring</td>
<td>- Insulated buildings - Buildings in blocks</td>
<td>- There is very often a lack of maintenance - Obsolete structures</td>
</tr>
<tr>
<td></td>
<td>- Quartier El Kitani - Bd Zirout Youcef - Bab Azzoun - Basse Casbah</td>
<td>Block loadbearing wall of tuff</td>
<td>- Hollow body -Concrete slab</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Bab Azzoun - Kasbah</td>
<td>Solid brick wall</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vulnerability assessment of buildings

State of the art on seismic vulnerability assessment methods

Before developing our working method, a reminder of the current methods for assessing the seismic vulnerability of masonry structures is necessary. Indeed, two methods of assessing seismic vulnerability can be distinguished (Merazka Ghribi, 2012):

- Evaluation method based on the European macro-seismic scale (EMS-98)
  - RISK-EU method
  - VULNERALP method
  - FaMIVE (Failure Mechanisms Identification and Vulnerability Evaluation)

- Score-based evaluation method
  - FEMA (Federal Emergency Management Agency) method
  - National Research Council of Canada Scoring Method
  - GNDT method

A set of programs and software designed to evaluate existing structures. These methods are based on visual observation of damage resulting from previous earthquakes. Thus, they are not effective if the structure is not damaged and does not have any apparent pathology.

Proposed evaluation methodology
This work proposes to use a robust and original alternative for the simulation of masonry structures (Remki, 2010). It consists of three stages: preliminary study, diagnosis and numerical modeling, the latter to enrich current assessment methods.

We have opted for the specialized analysis software SAP2000 as a digital tool in order to achieve more accurate results. This software is considered as one of the most powerful finite element calculation software to solve the static and dynamic problems of different structures under the effect of different seismic excitations. The method is summarized as follows (Figure 1):

![Diagram](image-url)  
**Figure 1** - Methodology for studying the vulnerability of masonry constructions
Application example: residential building

**Description of the work to be studied**

The example chosen has significant heritage value. It is a residential building located in El Madania, designed in the 1950s. It is an insulated block with a rectangular shape, and occupies a floor area of 252.89 m²; overall the building is built on five levels with 40 cm thick stone masonry load-bearing walls and 15 cm thick brick interior walls (Figure 2).

![Design view of a typical floor showing the wall lines in both x-x and y-y directions and an elevation view of the building](image)

**Figure 2**—Design view of a typical floor showing the wall lines in both x-x and y-y directions and an elevation view of the building

**Expertise of the work**

The various visits made to the site revealed the following:

- Deterioration of the concrete, revealing the reinforcement of the floors at the level of the balconies.

- Alteration of building stones: loss of material (perforation, pitting, disintegration and erosion), color change (crusts and crushing) and biological colonization (lichens and mosses).

- Loss of material (coating) due to infiltration of rainwater.
The facades of the buildings appear dull, which gives off a hideous character and offers visitors an unpleasant view.

However, no cracks or deterioration in the walls were observed that would indicate vulnerability to seismic risk.

**Verification of the structure according to RPA code 99 -Version 2003** (RPA, 2003)

**Determination of the calculation parameters according to RPA 99 -Version 2003**

- Zone III: high seismicity
- Site S3: movable site
- Use group: 1B; major works
- Constituent materials: walls or walls; masonry
- Bracing system: load-bearing walls
- Zone acceleration coefficient: $A = 0.30$
- Quality factor: $Q = 1.35$
- Behavior coefficient: $R = 3.50$
- Characteristic period 1: $T_1 = 0.15$
- Characteristic period 2: $T_2 = 0.50$
- Critical damping percentage: $\xi = 10.00$
- Damping correction factor: $\eta = 0.76$

**Determination of the mechanical characteristics of materials**

The stone:
- Density: $d=2.7t/m^3$
- Modulus of elasticity: $E=2000\,000\,Kpa$
- Shear modulus: $G=500\,000\,Kpa$
- Compressive stress: $\delta_c=1500\,Kpa$
- Tensile stress: $\sigma_t=40Kpa$

**Method usable according to RPA 99/Version 2003**

The calculation of seismic forces can be carried out using three methods:

- By the equivalent static method
- By the spectral modal analysis method
- By the dynamic analysis method using accelerograms

**Modeling of the building by the SAP 2000 v15 software**
SAP2000 is software for the design and calculation of engineering structures particularly adapted to buildings and civil engineering works. It allows modeling steps (geometry definition, boundary conditions, structure loading, etc.) to be performed in a totally graphical, numerical or combined manner, using the countless tools available (CSI, 2004).

Briefly, the steps to follow are summarized as follows (Figure 3):

- **Step 01**: Definition of the geometry of the plan and elevation model (2D and 3D): The first step is to define the geometry of the structure to be modeled.
- **Step 02**: Specifying the properties of the elements (walls and floors): The second step consists in entering material data and calculation parameters into the software.
- **Step 03**: Assignment of loads (static and dynamic), combinations of actions and determination of supports.
- **Step 04**: Determination of the type of loading: by response spectrum or by accelerogram (time history).
- **Step 05**: Start the analysis execution.
- **Step 06**: Visualization and exploitation of the results.
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Figure 3-Modelling steps with SAP2000 software

Interpretation of the results

The numerical model showed that the capacity of the structure and the inter-floor displacement of the structure do not exceed the recommendations required by RPA99/Version 2003. Thus, in this case, no reinforcement or consolidation is necessary.

Conclusion

The numerical model, even if it only represents an approximation of the behavior of a building under the effect of a real earthquake, is an essential tool for decision support in the renovation or rehabilitation of old building heritage.

The use of computer technology in this research, in connection with the new techniques recently introduced in the field of architectural heritage conservation, will make it possible, on the one hand, to verify the seismic resistance of buildings and, on the other hand, to contribute to the rediscovery of the seismic performance and potential of our heritage.
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