Investigation of the 1716 Algiers (Algeria) earthquake from historical sources

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ABSTRACT: This research work presents the consequences of the 1716 Algiers earthquake. The damages records are collected from the ottoman files, consular mails, scientists and travellers of the 18th century. The 1716 Algiers earthquake is one of the most significant historical event having affected the city ($I = IX$ MSK). Indeed several sources describe it and give significant information about the scope of the damage recorded. These entire documentaries sources and in particular those of Ottoman regency were carefully studied and analyzed allowing us to have supplement information on this earthquake. This research work makes it possible to have a clear vision on the damage as well as on the vulnerability of the predominant constructions in Algiers. The information obtained, constitute an excellent damage database which will make enable us to work out the future seismic scenarios to protect cultural heritage of the old nuclei of Algiers and eventually other historical sites with the same characteristics.

1 INTRODUCTION

1.1 The structure of the EMS-98 scale

The Macroseismic Scale used for the classification of the damages degrees on traditional buildings of Algiers dating from the 18th century is the European Macroseismic Scale (EMS-98) with twelve degrees. This scale takes in charge historical earthquake. The EM-98 intensity scale, like the MSK scale which preceded it, is one of a family of intensity scales which originated with the widely used simple ten degree scale by Rossi and Forel; this was revised by Mercalli, subsequently expanded by Cancani to twelve degrees, and then defined in a very full way by Sieberg as the Mercalli-Cancani-Sieberg (MCS) scale. It is this scale which forms the starting point not only for the MSK/EM-98 scale, but also for the numerous versions of the “Modified Mercalli” scale. The major difference between the EM-98 scale and other intensity scales is in the detail with which different terms used are defined at the outset, in particular, building types, damage grades, and quantities.

1.2 Building types and vulnerability classes

The European Macroseismic Scale incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake generated shaking (vulnerability) has been employed in order to give a robust way of differentiating the way in which buildings may respond to earthquake shaking. The Vulnerability Table is an attempt to categorise in a manageable way the strength of structures, taking both building type and other factors into account.

The MSK scale defined building classes by type of construction as a simple attempt to express the vulnerability of buildings. Accordingly, six classes of decreasing vulnerability are proposed (A to F) of which the first three (A, B and C) represent the strength of a “typical” adobe house, brick building and reinforced concrete (RC) structure they should be compatible with building classes A to C in the MSK-64 and MSK-81 scales. Classes D and E are intended to represent approximately linear decreases in vulnerability as a result of improved level of earthquake resistant design (ERD), and also provide for well-built timber, reinforced or confined masonry and steel structures, which are well-known to be resistant to earthquake shaking. Class F is intended to represent the vulnerability of a structure with a high level of earthquake resistant design (see annexes).

1.3 Damage grades

The way in which a building deforms under earthquake loading depends on the building type. In this work the type of structure is the masonry with bricks and stones. This structure represents the A and B classes of
vulnerability. As a broad categorization we can group buildings in five grades.

Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage).
Grade 2: Moderate damage (slight structural damage, moderate non-structural damage).
Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage).
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage).
Grade 5: Destruction (very heavy structural damage).

(See annexes).

1.4 Quantities

The use of quantitative terms (“few”, “many”, “most”) provides an important statistical element in the scale. It is necessary to confine this statistical element to broad terms, since any attempt to present the scale as a series of graphs showing exact percentages would be impossible to apply in practice and would destroy the robustness of the scale. The definition of quantity has been presented, very deliberately, in graphical format to emphasise the way these numerical categories are blurred rather than sharply defined. In such a case as a precisely determined quantity falls into an overlapping area, the user should consider the implications of classing it as one category or the other, in terms of which would be more consistent with any other data available for the same place.

1.5 Assessing intensity from historical records

The term “historical data” is frequently used to mean descriptions of earthquake effects from historical records, that is, written sources prior to the instrumental period (before 1900). Historical accounts often report in detail damage to special monumental buildings (castles, churches, palaces, towers, pillars, mosques, and so on). Less frequently do they report the effects on ordinary buildings, which are the only ones which can be used within the framework of the scale. With regard to ordinary buildings, the vulnerability classes of traditional houses range in most cases from A to B, even to C and D (wooden structures). With regard to ordinary buildings, the vulnerability classes of traditional houses range in most cases from A to B, even to C and D (wooden structures). Very little is known from the general literature about building types in Europe and Maghreb up to the 17th century, except for the obvious facts that people used the materials nearest to hand, and that the richer the owner, the better-built and better-maintained his house was likely to be. But in the Middle Ages, certainly, most houses in many parts of Europe were made of wood, and in the Maghreb they were made of stone and adobe brick.

2 THE MEDINA OF ALGIERS AT 1716

In 1716, Algiers showed the typical characteristics of a medieval Moslem Maghreb cities such as Fez (Morocco) and Tunis (Tunisia) (Le Tourneau 1949). Indeed, the blocks are of various sizes and contain a several number of houses. The parcels are fully built; the houses are overlapping and leaning against each other forming a compact unit. In addition, a great number of narrow and short streets were covered by galleries on top of which the houses extended and thus, created roofed passageways called “Sabat”. In Algiers, just a main street crossed the city from the south to the north in the lower part of the city. Algiers was surrounded by walls built before 1517, was pierced by five gates with twelve batteries (figure 1).

3 TYPOLOGY OF CONSTRUCTIONS AT THE 18TH CENTURY

According to various historical sources (Haedo 1578–1580, Shaw 1808 & De Grammaye 1670) in Algiers, all houses look alike, most of them have a central patio or square courtyard surrounded by rooms. This type of house is called “Dar”. A gallery supported by columns with horseshoe pointed arches surrounds this courtyard called “wast al dar”. A great number of the palaces and houses have three levels. Houses with courtyard develop another type of dwelling, which is called “Dar shebak”, house with metal grid, where dimension of the courtyard is reduced. This grid represents only a tiny vertical opening for daylight. Furthermore, we can find houses called “Alwi”, because of constraint of the site giving narrows plots. So, they do not neither “patio” nor grid. As a consequence, this houses open towards external sance. These are generally situated on the border of the streets (figure 2). The number of houses was estimate at 5000 (De Paradis 18th century) and are about 800 today (Cellule Casbah 276
2003). Religious buildings as mosques, military and government buildings are well built (Devoulx 1875).

The vertical structure of buildings is made up of masonry walls with a thickness varying from 10 cm for the poorest quality to 90 cm and more for defence structures. The masonry walls are built out of brick masonry bound by a lime mortar (figures 3, 3a & 3b).

The horizontal structure as floors and terraces were out of squared or not squared wood. All houses are covered with terraces and they all are bleached with lime (figures 4).

4 CONSTRUCTION ELEMENTS OF THE DAMAGE

Traditional vertical structure, built mainly to support their own weight as well as the weight of floors and terraces (case of Algiers) and at the most to resist to the wind action. These structures are particularly vulnerable to seismic effects when they are not bonded horizontally. In the other hand, the shape, size, weight and materials of horizontal structure have a great influence on the level of seismic damage.

As a general rule, the vulnerability of the common constructions (houses) can be assessed in term of vulnerability classes A and B of EMS-98 intensity scale (Gru/enthal 1998) with reference to ordinary buildings. The vulnerability of monumental buildings, as the religious one, can not be easily assessed in terms of vulnerability classes of EMS-98 intensity scale, as the classes are conceived with reference to ordinary buildings.

In general, it is well known that mosques as important monument can be very vulnerable.

In the case of Algiers, the importance of such buildings may imply that some care should be take for their construction, suggesting vulnerability of classes D which represents the reinforced masonry.

5 DAMAGE DISTRIBUTION

The earthquake of 3 February 1716, which caused the largest seismic catastrophe from the Mitidja plain to the Cheliff plain (southeast of Algiers), was studied by Ambraseys and Vogt (Ambraseys & Vogt 1988). French and Foreign British archives and Sources for seismological purpose were used in that study.

The historical documentary sources on earthquake effects in Algiers are spread among different archives and libraries (French, British, Simancas and Ottoman).
Figure 3. Masonry typology.

Figure 3a.

Figure 3b.

Figure 4. Floor made of wood.

The ottoman files, refers to ruinous state of the city, this sources describing the damage in a useful way to quantify it are, unfortunately, dispersed in the different registers (financials and fiscal records, domanial and successional acts). There is not any published report containing details on damaged buildings.

Sources available so far do not detail mapping of damage, as performed for instance in the case of some cities in Italy (Guidoboni & Boschi 2001, Moroni et al. 1999). No official on historical detailed damage survey exist in Algeria.

Actually, such surveys are usually found when the intensity does not exceed 9 MCS, that is, when a significant part of damaged buildings can be repaired.

February 3, 1716, in the middle of morning, at 9h 45 mn (local time) a destructive earthquake shook Algiers and its adjacent regions. Houses collapsed and many others were damaged in the city, even the country houses suffered considerable damages and some of them collapsed (Ottoman Archive 1716,
Anonymous manuscript no date, French Archives 1716, Gazette de France 1716, Comelin 1720 & Ibn Redjeb 1740). Not only the poorest houses but also solid construction, such religious one as the mosques (Great Mosque of Algiers, Sha’ban Khudja mosque) suffered extensive cracking of walls and partial collapse of cupola, therefore they needed to be repaired in 1735 (Devoulx 1870 & Barges 1877) and palaces as Dar Aziza where the first floor collapsed, and the great palace where walls suffered extensive cracking.

On February 26, a violent commotion, damaged what resisted to the first shock.

For this earthquake, Roussel (1973) have assigned an intensity \( I = X \) MM, while Ambroseys and Vogt (1988) have assigned that this intensity could not be reached because no solid construction was damaged and they give \( I = 7 \) MSK. In this study, we assess intensity \( I = 9 \) EMS, on the basis of the assumption that the houses stock and the mosques are respectively equally distributed between vulnerability classes A and B and vulnerability classes D.

An anonymous map (Algiers 1830), in absence of any map dating from the 18th century, can be used as a reliable reference for the earthquake situation.

6 DAMAGE TO MINOR BUILDINGS (HOUSES)

Damage description for the earthquake of February 3, 1716 is available for 240 minor buildings (houses) and 4 monumental buildings (mosques and palaces). For all these constructions, they are detailed and concerned damage caused by this earthquake. All of them have been classified in term of EMS-98 damage grades.

According to the various historical sources (cited above) and in particular, those of the ottoman files, various damages due to earthquake were emphasized and they were of three types:

6.1 The total collapse of the houses

According to the analysis of the ottoman files (domanial acts 1716) [8], Comelin (1720), Delphin (1922), Shaw (1808) and Carette (1850), 200 houses collapsed, most of the dwellings were ruined and part of the city was thrown to the ground. According to Tassy (1830) and Burzet (1866–1869), the country houses or houses of the fahs around Algiers collapsed completely at a distance of about 3 km around the city. Carette and Burzet reported that the aftershock of 26 February added damaged to most of the houses, which did not collapse totally after the main shock.

The grade of damage 5 was assessed.

6.2 Destruction of the walls

According to the ottoman files (1716), many houses were damaged and repairs were conducted.

The grade of damage 3 was assessed.

6.3 Rupture of floors

According to the ottoman files (1716), related to the cadastral acts, it was revealed that many first floors of the houses collapsed following the earthquake. Comelin (1720) reported on the event: “...The house of the ambassador of France was one of the most beautiful of Algiers. It did have three floors before the last earthquake, now only two floors remain”.

The grade of damage 4 was assessed.

7 DAMAGE TO MONUMENTAL BUILDINGS (MOSQUES AND PALACES)

There is no detailed report on damaged monumental buildings. The information is consigned in the registers of the religious buildings (claim of real estate). These registers defer all the operations of maintenance, which took place regularly on the damaged buildings by the catastrophes (earthquake, floods, war...). It result from it that only two damaged mosques by the 1716 earthquake had been described:

The great Mosque of Algiers (Djama’ al kabir) presented several cracks on the north-west walls or the “qibla” walls (Devoulx 1946), and the reparations took place only in 1732 (Barges 1877). The grade of damage 2/3 is assessing.

The cupola of Sha’ban Khudja mosque collapsed. The grade of damage 3/4 is assess.

It was said that many palaces were destroyed or severely damaged. The first one related is “Dar ‘Aziza” palace, which was the French Embassy. The Consul Clairembaut (French Archive 1716) and later Comelin (1720) described the damage. All the higher floor of this large house fell down. The damage was thus significant in this residence. The degree of damage assessed was 4. The second one is “Dar al Sultan” called “Al Djenina” palace, which was at that time the residence of the regency and the government palace. According to Klein (1937), this palace suffered many cracks that have constrained the “Dey Ali Shaush” to leave precipitately the palace with its court to find a provisional refuge in “Burdf Mulay Muhammad” called later “fort de l’étoile”. The grade of damage 2/3 is assessing.

Synthetic information: collapsed, destroyed, several cracks, referring to cumulative effects of the 1716 earthquake, are available for the remaining 240 houses, 2 religious buildings and 2 palaces.
Table 1. Assessment and damage grade of minor building after the 1716 Algiers earthquake.

<table>
<thead>
<tr>
<th>Type of damages</th>
<th>Slightly damages</th>
<th>ID. Destruction of floors</th>
<th>ID. Several cracks</th>
<th>Total collapse</th>
<th>Total damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grades</td>
<td>2</td>
<td>4</td>
<td>3/4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Houses</td>
<td>68</td>
<td>24</td>
<td>15</td>
<td>8</td>
<td>130</td>
</tr>
<tr>
<td>Houses</td>
<td>86*</td>
<td>13*</td>
<td>9*</td>
<td>7*</td>
<td>115</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>162</strong></td>
<td><strong>37</strong></td>
<td><strong>24</strong></td>
<td><strong>14</strong></td>
<td><strong>245</strong></td>
</tr>
<tr>
<td>%</td>
<td><strong>67.5%</strong></td>
<td><strong>15.40%</strong></td>
<td><strong>8.33%</strong></td>
<td><strong>5.40%</strong></td>
<td></td>
</tr>
</tbody>
</table>

* indicate the houses, which has been not located in the map

Table 2. Assessment and damage grade of important building after the 1716 Algiers earthquake.

<table>
<thead>
<tr>
<th>Important Buildings</th>
<th>Slightly Damages Cracks in the walls Grade 2/3</th>
<th>Important Damages Several cracks Grade 4</th>
<th>Destruction of the first floor Grade 4/5</th>
<th>Total Collapse Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Mosque of Algiers</td>
<td>x</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Shaban Khudja Mosque</td>
<td>–</td>
<td>x</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Dar Aziza Palace</td>
<td>–</td>
<td>–</td>
<td>x</td>
<td>–</td>
</tr>
<tr>
<td>Dar al Sultan Palace</td>
<td>x</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 5.
Figure 6. Recorded damages of the 1716 Algiers earthquake.

Damage grade 5 is assigning when the description clearly reported “total collapse”.
Grade 4 is assigning when the sources simply reported “collapse”.
Grade 2/3 is assigning when the sources reported “slightly damage”.
The summary of damage is reported in Tables 1 and 2.
The identification of the buildings is performing on the historical map of Algiers (figure 5).

8 CONCLUSION

The severity of Algiers’ destruction caused by the 1716 earthquake probably explain the absence of historical sources, e.g. in the form of damage surveys, that would allow us to map the distribution in the whole city. The interpretation of the available source (ottoman files) describing the damage, limited to the houses which were managed by the religious institution, must take into account that it is only a partial interpretation of the effects of this great earthquake.

The study of Roussel (1973), comes to the conclusion that the intensity assessed in Algiers considering damage is X MM. On the other hand the study of Ambraseys and Vogt (1988), suggesting an investigation of the seismicity of the region of Algiers, concludes that it is improbable that the intensity reaches X MM because no great building was damaged.

Whereas, in this study the intensity assesses is \( I = 9 \) EMS-98 because of the damages of important buildings.

Damage to 240 minor buildings and 4 important buildings was assessed in term of EMS-98 intensity.

This data, though not useful for detecting possible amplification or desamplification areas, can provide useful informations on the vulnerability of the serving buildings and serve as an input for evaluating the ground shaking.

Annexes:

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Vulnerability Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>rubble stone, fieldstone</td>
<td></td>
</tr>
<tr>
<td>adobe (earth brick)</td>
<td></td>
</tr>
<tr>
<td>simple stone</td>
<td></td>
</tr>
<tr>
<td>massive stone</td>
<td></td>
</tr>
<tr>
<td>unreinforced, with manufactured stone units</td>
<td></td>
</tr>
<tr>
<td>unreinforced, with RC floors</td>
<td></td>
</tr>
<tr>
<td>reinforced or confined</td>
<td></td>
</tr>
<tr>
<td>frame without earthquake-resistant design (ERD)</td>
<td></td>
</tr>
<tr>
<td>frame with moderate level of ERD</td>
<td></td>
</tr>
<tr>
<td>frame with high level of ERD</td>
<td></td>
</tr>
<tr>
<td>walls without ERD</td>
<td></td>
</tr>
<tr>
<td>walls with moderate level of ERD</td>
<td></td>
</tr>
<tr>
<td>walls with high level of ERD</td>
<td></td>
</tr>
<tr>
<td>steel structures</td>
<td></td>
</tr>
<tr>
<td>timber structures</td>
<td></td>
</tr>
</tbody>
</table>

\[\text{most likely vulnerability class; } \equiv \text{ probable range; } \equiv \text{ range of less probable, exceptional cases}\]

Damages Classification after the EMS 98.
Quantities after the EMS 98.

**Classification des dégâts aux bâtiments en maçonnerie**

**Degré 1:** Dégâts négligeables à légers (aucun dégâts structural, légers dégâts non structuraux)
Fissures capillaires dans très peu de murs. Chute de petits débris de plâtre uniquement. Dans de rares cas, chute de pierres dissécutées provenant des parties supérieures des bâtiments.

**Degré 2:** Dégâts modérés (dégâts structurels légers, dégâts non structurels modérés)
Fissures dans de nombreux murs. Chutes de grands morceaux de plâtre. Effondrement partiel des cheminées.

**Degré 3:** Dégâts sensibles à importants (dégâts structurels modérés, dégâts non structurels importants)
Fissures importantes dans la plupart des murs. Les tuiles des toits se détachent. Fractures des cheminées à la jonction avec le toit; défaillance d'éléments non structurels séparés (cloisons, murs pignons).

**Degré 4:** Dégâts très importants (dégâts structurels importants, dégâts non structurels très importants)
Défaillance sérieuse des murs; défaillance structurale partielle des toits et des planchers.

**Degré 5:** Destruction (dégâts structurels très importants)
Effondrement total ou presque total.

Damages classification after the EMS 98.

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