
Damage survey of the old nuclei of the Casbah of Delys (Algeria) and performance of preventive traditional measures in the wake of the Boumerdes 2003 earthquake

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Abstract:
This research work presents the damage recorded in the Casbah of Delys and stresses the performance of traditional structures with an emphasis on earthquake-resistant techniques that were tested during the Boumerdes earthquake of May 21st, 2003. Delys is a city located, within the stricken area by the Boumerdes 2003 earthquake, at about 170 Km east of the capital Algiers. It is one of the most ancient Casbah in Algeria. Previous to the Ottoman period, it was based in 1068 by the moors that fled Andalusia. The houses of the Casbah of Delys have their roofs made with assembled half-bricks, and although they look like, by certain structural elements (corbelling construction) and architectural style, the houses of the Casbah of Algiers which is ottoman. Delys lives today following the May 21st, 2003 earthquake, its third major earthquake. The first destructive earthquake was recorded during the year 42 BC and the second one was in the 17th century (1631). Also, it experienced on May 21st, 2003, the Boumerdes earthquake where many houses were damaged or destroyed. The structural damage assessment indicates the following kinds of failures: (1) total collapse and partial destruction of load bearing walls, (2) deep fissuring in the load bearing walls, (3) disconnection of the structural walls, (4) destruction of floors and roofs and (5) destruction of stairs and partition walls. Nevertheless, certain parts of houses that resisted the shaking were built according to Ottoman earthquake-resistant procedures as the corbelling construction.

Keywords: Performance, pathologies, Traditional preventive measures, Boumerdes earthquake, Casbah of Delys, Algeria.

1. INTRODUCTION

The Casbah of Delys is located, within the stricken area by the Boumerdes earthquake of May 21st, 2003, at about 170 Km east of Algiers. According to some historians, the Casbah of Delys is the oldest city of Algeria. Former to the Ottoman period, it has been founded in 1068 by the moors Muḥammad az al Daw’la Ibn Samadah that fled Tadless (Andalusia). The Mourabitine of Almeria (Spain) have hunted him [1]. During his reign, Delys thrived so much so that Al Idrissi praised it [2]. The design of the habitat and some architectural characteristics testify to this completed time. The city is at about 27 m above the Mediterranean Sea level and extends in an area of about 16.25 hectares. It counted in the past about 1000 houses and many fountains, ovens and fortresses. Rather different, the houses of the Casbah of Delys contain roofs made with assembled half-bricks, and although they look like, by certain structural elements (corbelling construction) and architectural (internal spaces), as the houses of the Casbah of Algiers. However, they remain different from those of Algiers by the absence of terraces and their roofs are covered by red tiles [3].

It was subdivided in 1844, at the time of the French occupation, in two parts separated by the main road
No.24. These are the lower Casbah, which covers about seven hectares and the higher Casbah about nine. Dellys lives today, following the Boumerdes earthquake of May 21st, 2003, its third major earthquake. The first destructive earthquake was during the roman era when it was called Rusuccuru in the year 42 BC. It was reported that the Casbah was completely destroyed, entirely devastated, its monuments were scattered in all the land between the villages of Taourga and Takdempt [3]. The second destructive earthquake occurred in the 17th century (1631) in the medieval times during the Ottoman regency and when it was called Tedelles. It was also destroyed again [4, 5, 6]. It was seriously affected again on May 21st, 2003 Boumerdes earthquake, where many houses were considerably damaged or completely destroyed [7, 8, 9].

The ancient neighbourhood built of stone houses with central courtyards, mainly dating back to Ottoman times (i.e. about 1520-1840), has been extremely damaged or destroyed by the 2003 earthquake. It was hard to find an alley without a collapsed building in the middle.

2. THE BOUMERDES EARTHQUAKE (ALGERIA, Mw 6.8) OF MAY 21ST, 2003

The Boumerdes earthquake of May 21st, 2003, which the magnitude was estimated at Mw 6.8, affected a considerable zone of about 150 km long between Algiers and Dellys and 40 Km wide (Fig. 1). This earthquake occurred at 18h 44min GMT (19h 44min local time). The epicentre was located at a depth of about 10 km [10]. The characteristics of the principal shock are shown in table 1 and figures 2 and 3.

The Boumerdes earthquake had generated some phenomena which are mentioned below:

− A tsunami has been generated which was propagated until the eastern Spanish coast where some of the boats had been damaged. According to witnesses, the sea was withdrawn as far as 150 m from the shore. [10] (Fig. 4).
− A massive destruction of the historical core especially in the lower part of the Casbah. The press reports that the Casbah of Dellys was completely destroyed and was in ruin, and that the environment is apocalyptic [7, 8, 9]. All of traditional constructions in masonry collapsed [7, 8]. The intensity attributed to the damage recorded at the historical centre was estimated at $I=X_{EMS-98}$ [14], because the majority of constructions in masonry of the class of vulnerability A, B and C [15] suffered damage of degree 5 (Fig. 5).
− The harbour suffered significant damage, cracks and an uplift of the seafloor of approximately 50 cm [12].

3. STRUCTURAL DAMAGE IN MASONRY CONSTRUCTIONS OBSERVED

All of the old nuclei of the Casbah of Dellys were built in traditional masonry made of stone [16, 17]. The earthquake had destroyed seriously all of the houses which were built before the Ottoman era.

The structural damage assessment indicates the following types of failures:

1. The total collapse of constructions (Fig. 6)
2. The destruction and collapse of load bearing walls (Fig. 7)
3. The deep fissuring in the load bearing walls (Fig. 8)
4. Minor cracks in the walls (Fig. 9)
5. The collapse of internal walls (Fig. 10)
6. The destruction of floors (Fig. 10)
7. The destruction of roofs as well as stairs (Fig. 11).

These several observed disorders are represented in the abacus of the major mechanism of destruction and rupture (major disorders) (Fig. 12) and are summarized in three essential points:

1. The total destruction whose principal cause was the rupture of masonries by extension and shear,
2. Rupture or disconnection,
3. The inclined cracks along the wall caused by the rod effect.

The less important observed damage are shown in the abacus of the mechanism of minor ruptures (minor disorders) and are summarized in what follows (Fig. 13):

1. Cracks of the piers (in cross in angles intersection),
2. Vertical cracks along the walls.
The load-bearing walls suffered the greatest damage, because they were not chained. Nevertheless, certain houses resisted the horizontal forces of earthquake. It is probably due to the good quality of construction techniques applied.

The massive destruction of the historical core could be aggravated by the fact that all the houses are joined together with a single wall. The frequency of the oscillations of two constructions accentuates the concentration of stresses in the wall. There is no other bracing system which can take part in the improvement of their earthquake-resistance such as the discharging arches or the “sabats”.

**Destruction of floors:**

Other disorders were observed on floors. Of course the floors of Delys are, like those of Algiers, made out of wood. They are on the other hand composed of, not squared beams, logs of olive-trees (presenting irregularities) which are transversely inserted in the walls. A particular roofing-strip is reinforced by a very dense bough of olive-trees, which comes to cover the beams (logs of olive-trees). Furthermore, beams are covered by stones (sandstone, grit stone) on which lay out a mortar.

**The destruction of roofs and stairs:**

In Delys, all the houses have wooden roofs covered with tiles. It is the one type of roof present in the historical center. The houses of Delys have this characteristic, which probably is Berber dating from the 10th century, and seemed to be as some constructions in Algiers going back to this same time (the Great and the Sidi Ramdan mosques of Algiers).

The roofs of Delys houses were built with the same materials as the floors. The load-bearing walls support beams, not squared shapes, in logs of wood (olive-tree). On the top of them is laying out the bough. Then the mortar is laid down and covered by the curved tiles.

The roofs are overloaded with stones, which is supposed maintain them during high winds. This additional overload increased the weight of the roofs and made them heavier and thus houses more vulnerable to lateral loads. The overload on load-bearing walls creates an inverted pendulum effect.

**4. DEDUCED EARTHQUAKE PATHOLOGIES**

The disorders observed on the walls find their origins in the main mentioned causes as follows:

− The bad quality of materials due to the age and the absence of maintenance.
− The bad implementation of masonry (quality of the code of practice).
− The absence of vertical and horizontal links to the junctions of the load-bearing walls.
− The absence of links between the load-bearing and partition walls.
− Heavy and insufficiently braced roofs.

The main causes of these disorders were the consequences of:

* Shear force in the plan of the walls (cracks in cross).
* Extension forces due to the inflection of the walls (vertical cracks).

The disorder observed on the floors is their rupture. It is due especially to:

* The old age of materials, rooted of olive-trees and cracks;
* The walls were not linked together.

The destruction of the roofs is on the one hand consequent of the inertia generated by the roof itself and on the other hand of the absence of bracing of the walls. This implies that there is no knowledge of repairing techniques by population.

**5. THE PERFORMANCE OF THE EARTHQUAKE RESISTANT TECHNIQUES USED THE OLD NUCLEI OF DELYS (ALGERIA) DURING THE 23 OF MAY 2003**
Some particular architectonic elements had a good seismic behaviour during this earthquake. Indeed those are the corbellings (called q’bu in Arabic) which are an ottoman heritage. The corbelling did not suffer any damage. All of them have resisted to the horizontal loads of earthquake (Fig. 14).

Their presence is systematic in each house of Delliys. They lay out on the higher floors such as corbellings of Algiers. The construction of the corbelling walls is quite similar to certain walls in the constructions of Algiers [18]. The walls are made with layers of bricks and wood or with the opus spicatum dressing. These procedures allowed a certain displacement during the shaking. Three types of constructive walls of the corbelling are present:

- Equal average a freestone masonry varying between 15x20x20cm, 15x30x25 and 15x40x50cm laid out alternatively the ones with the top of the others like brick. This disposition called “isodomic” because stone bases are equal thickness.
- The “opus mixtum” type where are superimposed in quasi regularly alternation the quarry-stone to an open-work opening called “oculus”.
- Another “opus mixtum” was also observed which masonry superimposed on logs of olive-trees.

The seismic behaviour of a wall having such stratification, had its barycentre lowered, recorded reduced the cracks [19]. Moreover, no corbelling suffered damage nor destroyed.

The walls having similar constructive techniques are less vulnerable to horizontal loads. They resist better the earthquake forces and suffered minimum damage because of the rod effect in wall does not appear. Therefore, the cracks decrease. Moreover, this laminated masonry has a subordinated earthquake-resistant function because it causes a drop in the total barycentre of the masses and, consequently, tends to make the earthquake-resistant function of the walls more significant.

6. CONCLUSION

The Boumerdes earthquake of May 21st, 2003, which has not only affected the whole of the Casbah of Delliys, but all the Boumerdes governorate and particularly the villages located all along the east coast up to the city of Algiers and extends to the south of this region at about 40 Km. This earthquake caused a great damage to historical masonry constructions, which are located in the lower part of the Casbah of Delliys. The seismic behaviour of the historical constructions proved to be more catastrophic, mainly those built before the Ottoman era.

The assessment of the listed damage varies from the simple crack to the total destruction of constructions, the rupture of the floors, roofs and staircases.

Moreover, this earthquake has also shown that certain structural and architectonic elements in the Casbah of Delliys are not so vulnerable for such earthquake. Their response to the horizontal loads proved as effective as expected. These elements are certain walls made of mixed apparatus and corbellings whose constructive technology is almost as similar as the walls of historical construction in the Casbah of Algiers. Indeed, the wall is made up of two materials, one rigid and the other flexible device. This stratification supports a good earthquake-resistant function.

The Boumerdes earthquake of May 21st, 2003 made it possible to check the seismic behaviour of certain constructive details on architectonic elements. In the absence of any laboratory test for the evaluation of the seismic behaviour of the traditional techniques, this earthquake played the role of a true laboratory of experimentation where there was no simulation but a quite real test.

On the basis of the result under the investigation of the historical sites of the Casbah of Delliys, it is recommended the following actions outlined below for the protection and rehabilitation of Cultural Heritage located in the seismically active zones.

1. Developing an intervention methodology for the preservation of historical monuments and sites based on science.
2. Producing an exhaustive "traditional techniques" catalogue, this includes the role and use of each technique as a practical tool.
3. Disseminating the knowledge acquired by the training of qualified workers in the field of preservation.
Acknowledgments:

This research work has been achieved for the requirement of my Doctorate degree ongoing at the Polytechnic School of Architecture and Urban Planning (EPAU) of Algiers, chaired by Professor D. Benouar.

I would like to express my sincere thank and deep gratitude to Prof. D. Benouar for his availability and fructuous discussions.

I would like also to give my thanks to the staff of the municipality of Delflys for their very much-appreciated assistance during the in-situ investigation.

I would like also to give my thanks to the military staff rather for their very much-appreciated assistance during the in-situ investigation.

Many thanks to Dr Assia Harbi Seismologist from CRAAG of Algiers for the elaborated map of intensity scale and to B. Foufa, architect who has carried out the 3D drawings of the details.

References:

17. Reinaich. (1892). "L'age de la pierre à Delflys (Algérie)". Bulletin Archéologique du Comité ; 496
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