International Symposium on Historical Earthquakes and Conservation of Monuments and Sites in the Eastern Mediterranean Region
500th Anniversary Year of the 1509 September 10, Marmara Earthquake
10 – 12 September 2009, İstanbul - Turkey

Reinforcement methodology applied in buildings damaged by the Azores earthquake

Ricardo S. Barros [1,2], João Guerra[1], Daniel V. Oliveira[2] and Humberto Varum [3]

[1] *University Fernando Pessoa, Portugal*
[2] *ISISE, University of Minho, Portugal*
[3] *University of Aveiro, Portugal*
e-mail: rsbarros31@gmail.com

INTRODUCTION

The Azores Archipelago (Figure 1) is formed by nine islands and some uninhabited islanders, it is part of the national territory of Portugal and it is located in the Atlantic Ocean at 1500 km west of Lisbon and 3400 km east of New York. All of islands have volcanic origin and are locate in the union of three major tectonic plates; the American plate, the African plate and Euro-Asiatic plate, being quite subjected to seismic phenomena.

Figure 1: Azores Islands.

The earthquake of July 9, 1998 was felt in three of the islands, Faial, Pico and S. Jorge. The epicenter was located at about 10 km North/Northeast of Faial island and about 2 km depth. The earthquake took place in the morning of July 9, 1998 at 5:19h with a Richter magnitude of 5,6. It caused a huge damage among the inhabitants, namely nine deaths and a hundred of wounded, 1700 people were dislodged, one and a half thousand of houses suffered strong damages, half of them without repair possibilities.

The most devastated area was the area of the Ribeirinha (Figure 2), in the Faial Island, the closest area to the earthquake epicenter. A vast part of the island constructions was destroyed, mostly because of the traditional weak seismic resistant constructions. The religious buildings, built with constructive methodologies similar to traditional buildings, suffered also great damages. The bridges also had great damages and the constructions closest to the epicenter were intensely damaged (Figure 3). The modern constructions didn't register several damages.

Figure 2: Ribeirinha church.

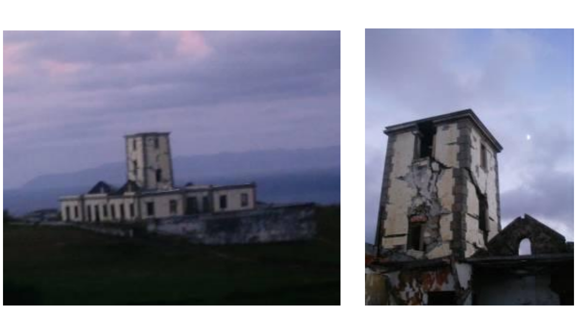

Figure 3: The epicenter closest construction.

REINFORCEMENT USING METALLIC ELEMENTS

After the earthquake, it became necessary to mobilize specialized teams to do the analysis of the buildings condition and to determine the best methodologies for rehabilitation and reinforcement. In spite of the existence of several seismic reinforcement methodologies, in the particular case of Azores, the most applied methodology was the use of metallic elements. Several metallic reinforcements were applied in Azores, namely the crowning belt, the trusses, foils, beams, irons ties and screwed connections.

The objective of using crowning belts, see Figure 4, was to distribute the seismic horizontal forces, to tie the façade walls enabling a box behavior, to distribute the vertical loads and to reduce the roof displacements, that is to say, to confine and improve the seismic behavior of the structure.

Figure 4: Crowning belt application (Barros et al. 2005).

The trusses component, Figure 5, is constituted by metallic profiles, of hollow rectangular section, usually prefabricated. This allows saving time in the work execution, as well as it facilitates the assembly. The metallic trellis receives the forces transmitted by the intermediate braces and it transfers them to the extremity supports, the two perpendicular walls in which it leans on.

Figure 5: Metallic trusses (Barros et al. 2005).

There were used a huge number of foil types (Figure 6) that can be used in the anti-seismic reinforcement. The folded foil is one of the most used types in the seismic reinforcement; it is a foil in elbow form that serves to support the wood beams, and at the same time allows to do the connection between the bottom walls and the floor.

Figure 6: Curve foil (Barros et al. 2005).

The metallic beams (Figure 7) were used to substitute the deteriorated pieces, or to reinforce weak areas of buildings. Their functions are similar to the beams applied in new buildings.

Figure 7: Metallic beams (Barros et al. 2005).

The iron ties (Figure 8 (a)) are usually made of stainless steel and work on tension, either having passive or active structural functions. However, their function, when used as an anti-seismic reinforcement, is usually passive, being activated only by an earthquake. The ties anchorage (Figure 8 (b)) is made by the external part of the walls, made through fastening bars usually in steel.

(a) (b)

Figure 8: Iron ties: (a) Iron ties; (b) Iron Ties anchorage (Barros et al. 2005).

The screwed connections (Figure 9) are connections made by metallic screws that allow connecting the metallic elements with the existent building structure. These are extremely important connections, because they allow guaranteeing the safety and the good behavior of the remaining metallic elements used in the seismic reinforcement.

Figure 7: Metallic beams (Barros et al. 2005).

The metallic connections among the roof structure are not usually the direct objective of the building seismic reinforcements, but they allow a good behaviour of the whole building. These connections are made through metallic foils, with screwed unions that permit to join the elements in the roof structure (Appleton, 2003). More comprehensive information on techniques and specific knowledge can be found in Barros et al. (2005)

CONCLUDING REMARKS

The Azores earthquake of July 9, 1998 was the most recent major earthquake registered in Portugal that caused several social and heritage damages, leading to a large rehabilitation process in the Azores archipelago.
The application of metallic elements allows precise and low intrusive seismic structural reinforcement interventions. It is understood that all reinforcement elements have different functions and are of extreme importance in the building seismic reaction improvement.

References

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