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SEISMIC ASSESSMENT OF ANCIENT MASONRY BUILDINGS: SHAKING TABLE TESTS AND NUMERICAL ANALYSIS

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ABSTRACT

Ancient masonry buildings are one of the most vulnerable elements in the existing built heritage and were built for many centuries according to the experience of the builder, taking into account simple rules of construction and without reference to any particular seismic code. Still, in seismic areas, unreinforced masonry structures represent an important part of the building stock. The seismic assessment of ancient masonry buildings is difficult and depends on several factors. Besides the quality of masonry materials and the distribution of structural walls in plan, also the connection between the walls and floors significantly influences the seismic resistance.

An experimental program was carried out to assess the seismic vulnerability of a building typology that is believed to present the highest seismic vulnerability of the housing stock of Portugal ("gaioleiro" buildings). The program also aims at evaluating the efficiency of repairing solutions.

The ''gaioleiro'' buildings typology was developed between the mid 19th century and beginning of the 20th century, mainly in the city of Lisbon, and still remains much in use nowadays. This typology characterizes a transition period from the anti-seismic practices used in the ''pombalino'' buildings originated after the earthquake of 1755, see e.g. (Ramos and Lourenço 2004), and the modern reinforced concrete frame buildings. These buildings are, usually, four to six stories high, with masonry walls (thicknesses ranging from 0.30 m to 0.60 m) and timber floors and roof. The external walls are, usually, in rubble masonry with lime mortar.

The experimental program involved shaking table tests by imposing artificial accelerograms in two horizontal uncorrelated orthogonal directions, inducing in-plane and out-of-plane response of tested mock-ups; non-strengthened mock-up (NSM) and strengthened mock-up (SM). The methodology includes seismic tests on shaking table with increasing input excitations and characterization tests of the dynamic properties of the mock-ups before the first seismic test and after each of the seismic tests (Candeias 2009). The dynamic properties give inherent information of the mock-up and its evolution is related to the damage induced by a given seismic input.

The geometric properties of the non-strengthened mock-up result directly from the application of the scale factor to the prototype, resulting in a model 3.15 m wide and 4.8 m deep, with 0.17 m of wall thickness (Figure 1a). The interstory height is equal to 1.2 m. In the strengthened mock-up steel angle bars (internal surface) and plates (external surface) at the floor levels were used (Figure 1b). Additionally, timber elements to constrain the rotation of the timber joists were used. In the two top floors steel cables were also installed. Each floor has two pairs of steel cables connecting the middle of the façades to the corners of the opposite façades, leading the inertial forces in the out-of-plane direction of the façades to the plane of the gable walls. The main goals of the strengthening techniques adopted are to improve the connection between the floors and the masonry walls, mainly to the gable walls, and to prevent the global out-of-plane collapse of the façades.

Besides the seismic vulnerability assessment of the "gaioleiro" buildings through shaking table tests, a numerical model of the non-strengthened mock-up was also prepared and calibrated. The calibration of the numerical model was based on the comparison between experimental and numerical frequencies and MACs (Allemang 2003) of the first five modes shapes.

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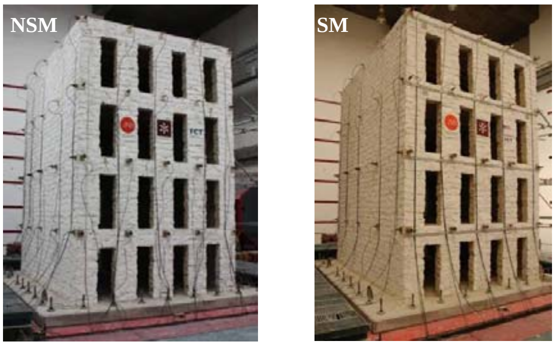

(a) (b)

Figure 1: (a) Non-strengthened mock-up; (b) strengthened mock-up

MAIN RESULTS AND CONCLUSIONS

The results of the shaking table tests showed that the façades of the non-strengthened mock-up present serious damage. The concentration of damage at the piers of the top floor is highlighted, where the horizontal cracks are related to its out-of-plane bending. The gable walls did not present any damage. The crack pattern of the strengthened mock-up shows that damage concentrates at the top floor and the lintels of the 1st and 2nd floors of the façades do not present serious cracking. Furthermore, the gable walls (4th floor) present diagonal cracks, indicating that part of the out-of-plane inertial forces of the façades were transferred to the gable walls. The vulnerability curves of the strengthened mock-up (Figure 2) show that the strengthening was efficient to reduce the seismic vulnerability of the mock-up. In the 4th seismic test (100% of the code amplitude) the strengthened mock-up presented a reduction of the damage indicator *d* (Mendes et al. 2010) of 35%, with respect to the original building.

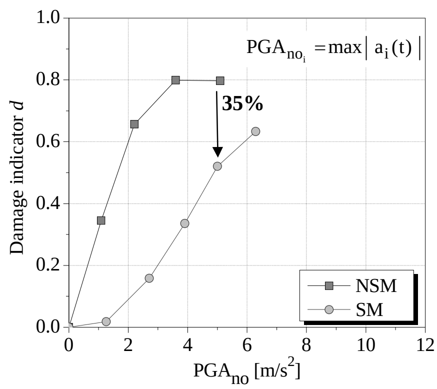

Figure 2: Vulnerability curves of the mock-ups

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