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Seismic evaluation of old masonry buildings. Part II: Analysis of strengthening solutions for a case study

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Abstract

This paper describes the application of the iterative method described in Part I (Cardoso R, Lopes M, Bento, R, Seismic Evaluation of Old Masonry Buildings. Part I: Method Description and Application to a Case Study, Engineering Structures, 2005) to the seismic strengthening design of irregular block masonry structures. The method was applied to an old masonry building from the city of Lisbon, which includes a three-dimensional wood structure braced with diagonal elements, aiming at providing seismic resistance to the building. Three different strengthening solutions were defined, based on the collapse mechanism obtained. This paper presents the analysis performed for each solution and the discussion regarding its qualitatively and quantitatively effects in the seismic structural behaviour: the identification of the expected collapse mechanism after strengthening and the seismic intensity for which it occurs. This is necessary to define the more efficient and economic strengthening strategies.

Keywords: Seismic vulnerability; Old masonry buildings; Strengthening; Wood structure

1. Introduction

The importance of the preservation of the cultural heritage and the functions that old masonry structures still maintain in our days justify the concern about their structural safety, including under earthquake actions. Recent earthquakes showed a deficient performance of masonry buildings under seismic actions and Portuguese buildings are not expected to be an exception.

A ‘Pombalino’ building, which is a typical old masonry building from Lisbon Downtown built after the 1755 Lisbon Earthquake, was analysed (Part I) and its expected collapse mechanism due to seismic actions was identified. The methodology proposed allowed simulating, by an approximate manner, the non-linear behaviour of irregular block masonry structures with structural timber elements. Each iteration comprises a linear elastic dynamic analysis by response spectrum, scaled by a factor γ_{sis} to define the seismic action associated to each damage state. The value of this factor at the collapse of the structure, γ_{sis}^{max}, quantifies its potential seismic performance, and is directly comparable to a safety factor. The low value of factor γ_{sis}^{max} obtained ($\gamma_{sis}^{max} = 0.25$) justifies the concern about the seismic performance of these structures and the need to improve their seismic resistance. Note that the values of γ_{sis}^{max} mentioned in this paper are not multiplied by the q-factor (or force reduction factor), as it would be necessary to evaluate the seismic intensity at collapse. As discussed in Part I, it was considered that a value of $q = 1.5$ could be reasonable for these type of building if the collapse would take place after significant horizontal displacements of the interior ‘gaiola’ walls. The energy dissipation capacity of these walls was already been observed experimentally [1], as mentioned in Part I.

The rupture of relevant structural elements (masonry cracking and the rupture of connections) was introduced in the model in each step of calculation, until the collapse. This procedure allowed identifying the weakest links of the structure, mainly the connections between interior ‘gaiola’

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walls and its perpendicular masonry walls, providing useful information to the seismic strengthening design. The rupture of the relevant structural elements mentioned allowed identifying the fall out-of-plane of the front façade as the expected collapse mechanism.

The iterative method previously described was also used to analyse the effects of three different strengthening solutions, usually adopted in seismic strengthening. The expected collapse mechanism was identified and the corresponding factor $\gamma_{\text{sis}}^{\max}$, was used to quantify the efficiency of the solution by comparing it with the one obtained for the original building, before strengthening. The solutions studied are described further in this paper.

The effects on global behaviour of each strengthening solution will be discussed, aiming at providing information to the definition of the more adequate strategies to improve the seismic resistance of old masonry buildings.

2. Description of the building and numerical model

'Pombalino' buildings are old masonry buildings that can be identified by the presence of a three-dimensional timber structure named 'gaiola pombalina' enclosed in interior masonry walls above the first floor. The wood structure of 'gaiola' is like a birdcage made of vertical and horizontal elements braced with diagonals named St Andrew's Crosses. The other interior walls are partition walls made of wooden panels and should not be considered as having structural functions.

The first floor is composed of a system of vaults made of regular masonry blocks and stone arches and the foundations include short and small diameter woodpiles connected by a wood grid. Floors above the first are wood slabs and should be considered as flexible diaphragms, and the roof is made with timber truss and ceramic tiles and may include window openings. A more detailed description of 'Pombalino' buildings can be found in [2].

A commercial program was used (SAP2000® [3]) and the numerical model of the structure is described in Part I.

The masonry of the exterior walls is made of irregular blocks of calcareous stone and lime mortar with very poor strength capacity. The Young's modulus, E, adopted for the structural materials were 600 MPa for masonry, 8000 MPa for timber and 3000 MPa for stone. The Poisson coefficient of all materials was assigned the value 0.2.

According to the Portuguese Code [4], a uniform service load (1.2 kN/m^2) acting at all the floors was considered. As previously described, linear dynamic modal analysis was performed by response spectrum. The seismic action was based on the response acceleration spectrum also defined in the mentioned code, acting along the two horizontal directions.

3. Strengthening solutions adopted

According to the study of the building presented in Part I, the expected collapse mechanism of the building is the fall out-of-plane of the front façade at the top floor, eventually bringing down other parts of the building. Therefore, the primary concern of the studied strengthening solutions, which are presented in Fig. 1, is to increase the building resistance to this mechanism.

The connections between 'gaiola' walls and masonry exterior walls (identified in Fig. 2) play an important role

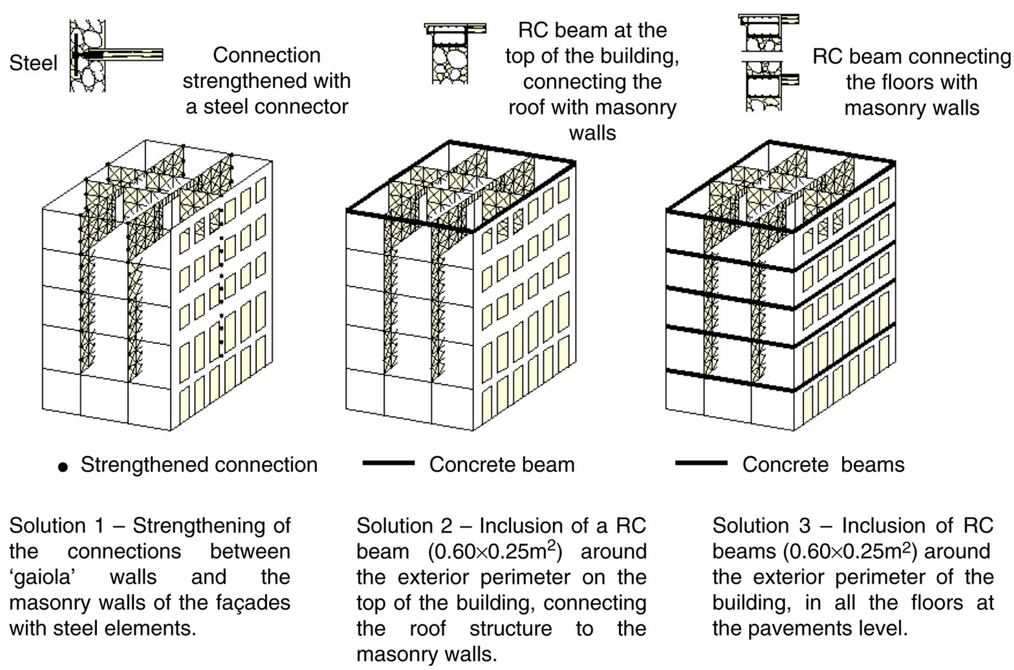

Fig. 1. Strengthening solutions adopted.