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ANALYSIS OF REHABILITATION SOLUTIONS FOR MASONRY BUILDINGS

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Abstract: *Masonry is the oldest technique in construction, therefore masonry buildings are the most widespread structures in Europe. Although many of these buildings exceeded a long time ago their life span for which they were designed, many of them are still in use, while the minimum requirements of comfort and safety are nowadays much more demanding leading to the need for adaptation of housing to new regulatory requirements through a proper rehabilitation. The strengthening of old masonry buildings is an important issue since these buildings constitute the historical centres of many cities and thus deserve attention from the state authorities for preservation purposes. Some strengthening solutions will be discussed based on two different study cases.*

Key words: *old masonry building, reversible rehabilitation solutions*

1. Introduction

With masonry being the oldest construction technique, old masonry buildings are an important part of the building stock of most European cities. These buildings are still being used even if they exceeded a long time ago their life span, so the repairing, strengthening, and restoration of existing buildings in seismic zone is sustained by necessity to extend the life of structures. 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 [1,2, 8,9].

At the same time, the preservation of the building heritage in Romania and concern for the seismic risk are increasingly present in Romanian society with particular attention to old buildings. Because of masonry’s poor resistance to tensile stresses, the masonry elements are very little resistant to shear stresses and compression that arises when the structure is subject to seismic action. However it is difficult to measure and characterize the seismic vulnerability of these buildings because each case is a new problem.

Old masonry buildings have common pathologies that are mainly related to their age. For instance the wood can be damaged due to the changes and exposure to humidity. It can have fungus attack or insect attack. On the other hand masonry can be also damaged. In this case, the most important pathologies have structural origin and can be translated into desegregation, crushing, fracture and cracking. The most common causes are related with foundation settlements, movements of thermal origin, horizontal thrusts transmitted by inclined roofs or arches, the existence of concentrated and high loads (generally

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associated with adaptation of building to new usages) and earthquakes which have considerable influence in a material that is both heavy and brittle [3], [4].

In spite of the presence of the anti-seismic provision *Gaiola* in the buildings increasing global stiffness and resistance, a bad behaviour of these buildings for seismic actions can be expected due to the following reasons: (i) the combined effects of age and of lack of maintenance leading to the degradation of structural materials, that decrease local and global stiffness and strength; (ii) the high number and variety of negative structural changes that these structures suffered during service time [5,10].

The rehabilitation solutions of two old masonry buildings will be discussed in this paper, one of the structures located in Lisbon, Portugal and the other one in Timisoara, Romania.

2. Case Studies

2.1. Rehabilitation of an Old Masonry Building in Lisbon

The studied building is located in Alfama District, Lisbon, built in the nineteenth century and it's classified as a *Pombalino* building. *Pombalino* Buildings are masonry buildings which include an anti-seismic provision consisting of an interior three-dimensional braced timber structure named *Gaiola* enclosed in masonry walls, aiming at providing resistance to horizontal forces [6], [7].

The vertical structure of the building consists of exterior masonry walls and *frontal* walls. In general, the internal walls supporting the floor are *Pombalino* walls. At the ground floor, the constructive system consists of masonry walls and vaults. The inner vertical structure of the upper floors consists of *frontal* and partition walls which represent the *Gaiola* system.

Regarding the horizontal structure, all floors are timber slabs supported by timber beams that are oriented in the perpendicular direction to the facade. The roof structure consists of timber trusses, has window openings and it's supported by the external masonry walls and the interior *frontal* walls.

State of degradation

In 2004, it underwent a reinforcement of the foundations of the façade walls, which presented cracks and settlements related to the decompression phenomena of the soil. This intervention consisted in the execution of micro-piles.

After a diagnostic study was performed, evident signs of large deformations, both at the level of the floors and at the level of the frontal walls, were identified. These deformations were caused by two main factors: the first one is related to the phenomenon of decompression and decompression of the constituent sands of the foundation soil and the second one by the lack of vertical continuity of the frontal alignments at the ground level.

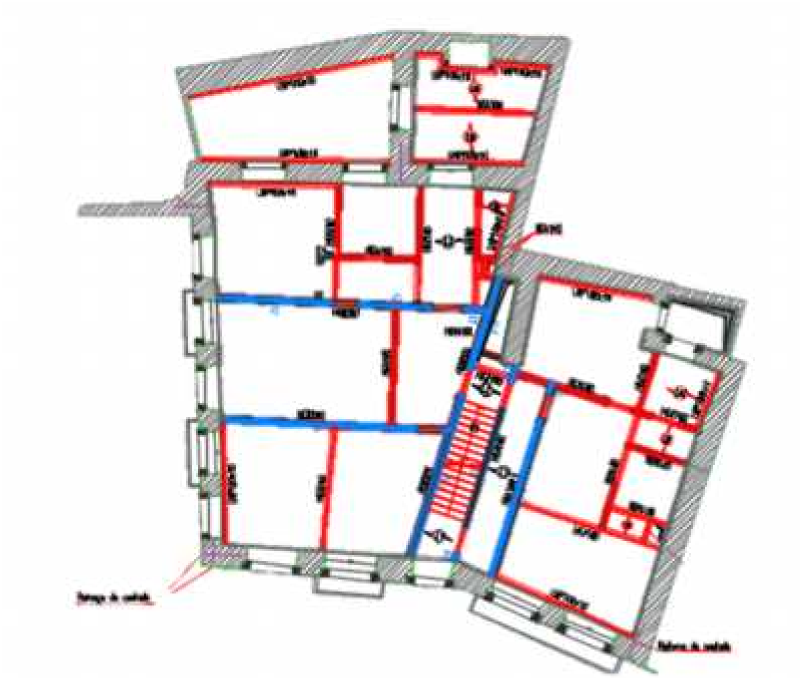

Fig. 1. *Plan of the analysed building*

Strengthening Interventions

The large deformations of the existing floors and the lack of continuity of the vertical alignments at the ground level and the deformations of some frontal walls, led to the decision to completely demolish the interior, with only existing masonry walls remaining. Thus the solution involves the reconstruction of the frontal walls needed to support the floors in the same alignments as those already existing and the reconstruction of the existing staircase as it is.

The strengthening solution for the remaining masonry walls was a reinforced concrete plaster which allows to provide the masonry with sufficient strength to absorb the traction that arises when the building is subject to seismic actions, in addition to ensure a confinement for vertical loads.

At the crown of all maintained walls a reinforced concrete lintel cast was executed, that serves not only as a belt but also as a support for the new roof cover.

The kitchen and bathroom floors consist of a mixed steel-concrete slab supported by steel profiles HEA 160 linked to the frontal walls while the link to masonry walls is made by LNP100 steel profiles. The rest of the floors are timber slab supported in the same way as the mixed steel-concrete slabs. The existing roof was also demolished and replaced by a new structure, consisting of main steel profiles and secondary wood elements.

In order to assess the seismic global response of the analysed buildings, a three-dimensional model was defined based on the equivalent frame model approach considering the commercial software 3Muri (S.T.A.DATA s.r.l., release 10.9.1.7) [8].

The building structures capacity curves were determined by incremental nonlinear static (pushover) analysis, neglecting the out-of-plane behaviour of the walls (the code assumes that the global building response is governed by the in-plane behaviour of walls).

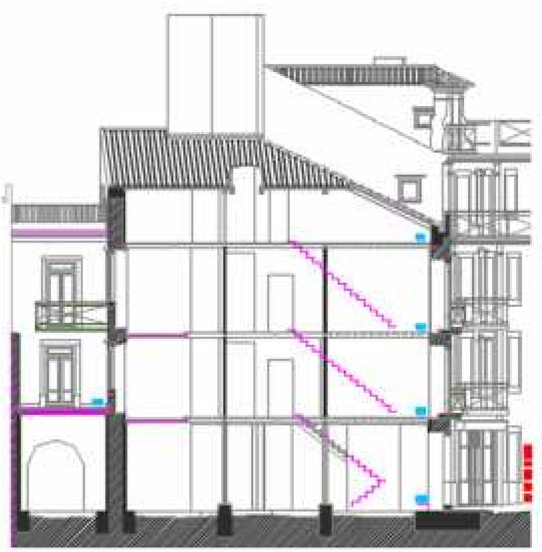

Fig. 2. *Cross section of the analysed building*

Based on the results obtained we can notice that the stiffness and strength of the building is a little bit higher in y direction. On the other hand, the ductility of the system is higher on the X direction. In both directions piers are very slender (due to the opening's configuration) and with a very moderate coupling provided by spandrels.

Comparing the results obtained with the two lateral load patterns, it can be seen how the triangular load pattern is more demanding than the uniform load pattern, since the curves run below the later ones.

Timber floors are typically flexible and they were replaced, in agreement with the conservation principle, with new ones to increase their in-plane stiffness that enables the horizontal forces to be redistributed between the failing walls to the adjacent remaining walls, therefore the structure should behave like a box. In this case, the structure has a different behaviour because of the connection among different elements and it exhibits a soft story failure mode.

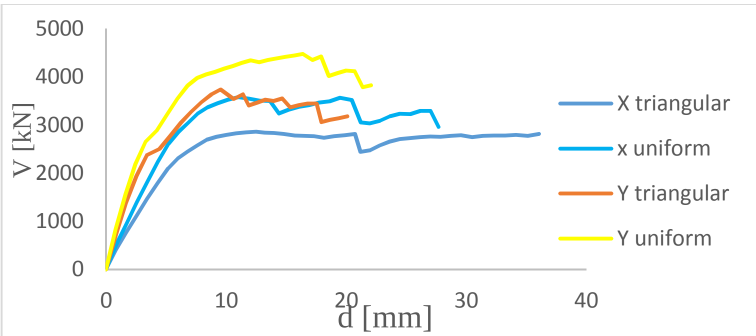

Fig. 3. *Pushover curves in the two directions for both uniform and triangular load patterns*

The global structural performance of the structure is affected by the efficiency of floor-wall and beam-wall connections.

2.2. Rehabilitation of the *Banatul Museum,* Timișoara

The Banatul Museum (Fig. 4) is one the most important historical building in Timisoara, Romania. The first site of the Huniade-Castle is mentioned in the XIV century. Bad soil conditions and soil water level had affected the castle building which was re-erected or rehabilitated many times: in the period 1720-1750 timber pilot foundations were used; in 1848 it was destroyed by fire and rebuilt in 1850-1856 in the present-day form.

Some rehabilitation were performed during this century as in 1903-1906 by utilisation of bricks as sub-foundations for walls as well as stiffening of some pillar foundations by utilisation of reinforced concrete piles and reinforced concrete floors in 1956-1963 (Hall2).

The presence of eight reinforced concrete piles around each existing pillar foundation of the Hall 2 contributes to a stabilisation of the three columns. After 40 years, the settlement of Hall 2 columns was insignificant as compared to the settlement values of 24-39 mm under walls. The data concerning settlement were obtained by topographic surveying on markers displaced on the building in 1959. In 1980 there was performed a building maintenance, with filling up the cracks, but after a few years the cracks are still present in building structure.

The structural composition of the building consists of:

- vertical members which were built of longitudinal and transversal masonry walls with different width 60-240 cm and stone/brick pillars of 98x98 cm (Hall 1) and of 160x160 cm (Hall 2);
- horizontal members consist of brick arches as domical vaults over the first and second level and wooden board over the third level.

Fig. 4. *The Banatul Museum building*

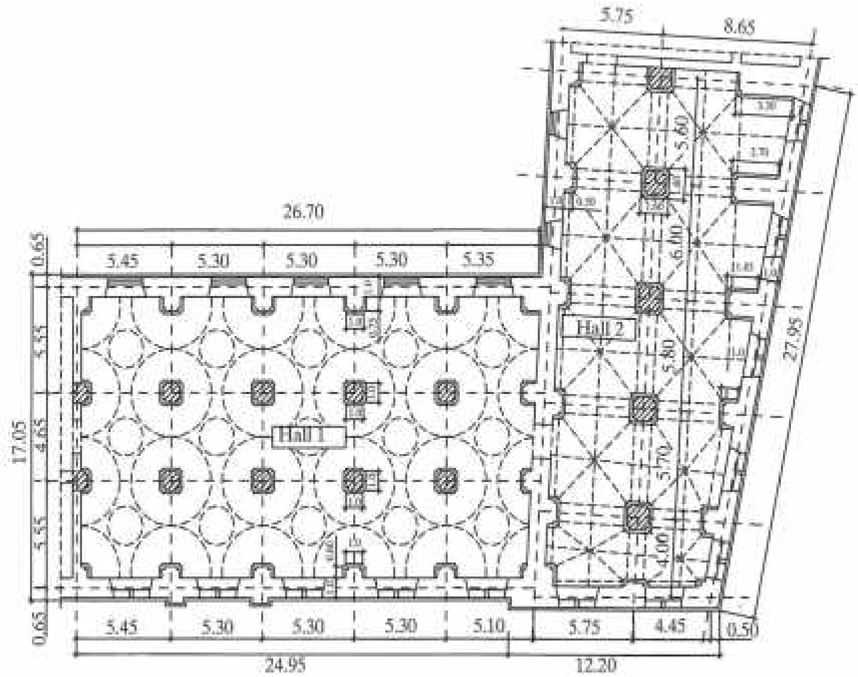

Fig. 5. *Horizontal section at second story through Hall 1 and Hall 2*

State of Degradation

The main damages of the actual structure of the building are located inside the Halls 1 & 2 and are characterised by cracks in the masonry walls: maximum width of 5 cm at upper part (Hall 1) as well as in the brick arches, especially in the vault head (5-8 mm). Such cracks were caused by both, earthquake actions and soil settlement due to bad soil, non-uniform foundations and soil water level.

Strengthening Interventions

The rehabilitation of the foundations soil represents an important step for improve the structural safety at different actions. The soil characteristics are increased by infilling a bentonite-cement slurry. The infilling material has to act as: soil stabilisation under and around foundations; to infill the holes and joints of the existing foundations. The injection with the bentonite-cement slurry is used between 1.5 and 8.5 m levels.

The foundation ground was improved by injections with bentonite solution, the foundations were strengthened by interior and exterior reinforced concrete plaster and a reinforced concrete slab on the ground floor was provided.

The following rehabilitation solutions were applied for the structure:

- reinforcement of the cracks in vaults and arches withepoxy-resin-based injections and Carbon Fiber Reinforced Polymers(CFRP) plaster;

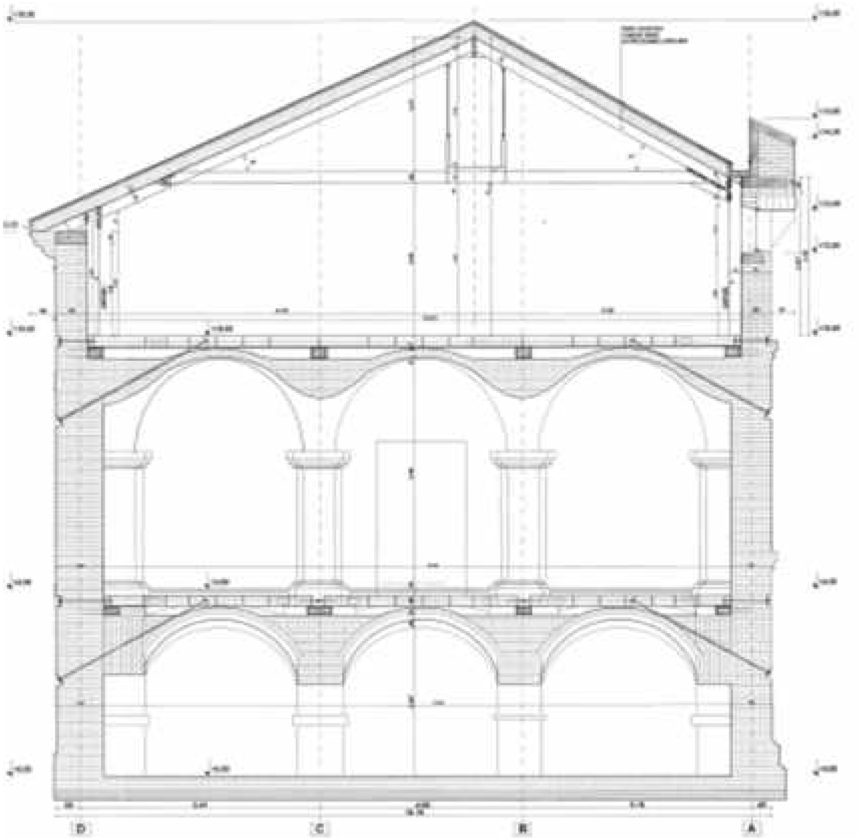

Fig. 6. *Cross section of Hall 1*

- under the floor above de ground floor and first floor, some transversal pre-tensioned tie-rods consisting of UNP 260 profiles were introduced, supported by reinforced concrete perimeter plaster and anchored in the exterior walls (Fig. 6);
- strengthening of arches and vaults (Hall 1 first and second floor, Hall 2 first floor) by introducing oblique pre-tensioned tie-rods anchored in the exterior walls and to the transversal tie-rods., which prevent the development of existing cracks and the development of new ones (Fig. 6);
- at the crown of the perimeter walls a reinforced concrete lintel cast was executed, that serves not only as a belt but also as a support for the new roof cover consisting of a steel frame structure;
- at hall 2 second floor a reinforced concrete slab was casted.

All the rehabilitation solutions were designed to be reversible, according to preservation principle of historical buildings. As a first observation on analysingthe rehabilitated structure, the influence of the tie-rod elements is reducing the bending force and further on the eccentricity of the structure. Secondly, the discharge of the earth filling above the vaults and the demolishment of the existing partition walls on the second floor reduce the bending and axial forces by 30-50%, but the eccentricity of the structure remains similar.

A further numerical study will be performed to asses the seismic performance of the building after strengthening.

3. Conclusions

When strengthening an old building, one must focus first on understanding how it is working, assessing its performance for gravity and seismic loads. Then, the problems and/or pathologies must be encountered and only then one can start prescribing the necessary solutions for the rehabilitation or strengthening. It's essential to improve the connections between the structural elements (for example, between the floors and walls and between the roof and the top of the walls. It's also important in any building to strengthen its floors given the wooden floors are flexible in plan while the masonry is rigid and thus they do not transmit forces between parallel walls. The whole structure should behave like a box where all the structural elements are having similar displacements and moving together.

In case of rehabilitation of a historical building the final decision has to take into account the architectural requirements, among them, the geometrical proportions and the principal fronts. These requirements were fulfilled by the rehabilitation projects of the two study cases.

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