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Seismic behavior of strengthened URM masonry – an overview of research at ZAG

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Abstract

Four experimental campaigns performed at ZAG over almost a decade and dealing with strengthening of masonry using FRPs are briefly presented. The campaigns show in-situ tests on strengthened walls in an actual building, the cyclic shear laboratory tests where different materials and FRP layouts were explored, use of innovative flexible materials instead of mortar or epoxy, and finally the test of a full scale building model where all aspects of strengthening a building using FRPs are investigated.

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1. Introduction

Various technologies of strengthening the unreinforced masonry (URM) buildings are available. Although effective, the traditional strengthening techniques are time consuming and require that the users temporarily move out of their buildings. Therefore, strengthening methods based on using fibre reinforced polymers (FRP), which

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provide a simpler, faster and cleaner application, are replacing the traditional ones and their use is on the rise [1,2,3]. Additionally, the cost of many FRP materials has been steadily dropping and has become affordable.

An FRP coating consists of the fibres of the reinforcing FRP material which normally have high tensile strength. Different materials are used for the fibres (e.g. glass, carbon, aramid, basalt, etc.). The fibres themselves are inside a coating, which acts as the protecting cover for the FRPs and as the adhesive to the masonry. Despite its function as the adhesive, anchors for fixing the coating to the masonry are normally used. As in case of fibres, different materials are used for coating (e.g. epoxy resin, cement based mortar or even flexible polymers). The strengthening can be applied to different types of masonry (stone masonry, brick masonry, hollow clay masonry, etc.). Finally, the layout of the fibres on the surface of the wall can have many different configurations (vertical, horizontal, diagonal, it can be applied to one side or to both sides of the wall and there can be different densities anchors for anchoring the coating to the wall). The coating, the fibres and the masonry together constitute a complex composite system and the number of combinations of FRP materials, materials for coating and of layouts is virtually inexhaustible. The complexity of the composite system and high number of possibilities is perhaps one of the main reasons, why research in this field is so active and there is a lot of research in papers and conferences on this topic. Furthermore, some combinations appear to not work well together and are best avoided (e.g. coating without wrapping with glass or carbon fibres in epoxy on brick masonry [4]).

There has been a substantial amount of experimental research performed on this subject over several years at Slovenian National Building and Civil Engineering Institute (ZAG). In this paper this research will be briefly presented along with the main lessons learned. The research can be chronologically divided into four phases, and the structure of the paper follows these phases. The first tests were performed in-situ in a building that was about to be demolished [5]. It was a brick masonry building from 1935. Two walls were strengthened by wrapping them in carbon fibre fabric and using epoxy resin as the adhesive. In the second phase, presented in third section, a large series of walls were tested in laboratory using the cyclic shear tests. Different materials and especially different layouts of the FRP materials were used [4,6]. In the third phase, an innovative solution for gluing the fibres to the wall was used. A deformable material (called polymer PM) with elastic modulus of about 4 MPa was used and results were surprising [7]. Finally, a three storey model of a building was built in full scale and tested next to a reaction wall. The model was first tested in unstrengthened state up to considerable, but still repairable damage and then strengthened using glass fibre grids and cement based mortar. The model was then tested again, this time up to collapse. Similar laboratory experiments on multistorey buildings were performed by e.g. [7,8].

In the conclusions, the summary of the four experimental campaigns is presented.

2. In-situ cyclic shear tests [5]

A building in Ljubljana from 1935 (Fig. 1a) was about to be demolished and prior to the demolition the owners allowed us to perform destructive tests on the building. The walls of the building were built from so-called normal size (25 x 12 x 6.5 cm) solid bricks and lime mortar with small amount of cement. The building had reinforced-concrete slabs above the cellar, while all the stories above had timber floors. The thickness of the longitudinal walls was 51 cm in ground floor and 38 cm in floors above, whereas the transversal walls were 38 cm thick in the ground floor and 25 cm thick in floors above. The 12 cm thick partition walls were built of solid bricks. The construction is typical in Slovenia for the era between both world wars.

Compressive strength of bricks was measured on couplet specimens (11.3 MPa). Compressive strength (2.24 MPa) and elastic modulus (790 MPa) of masonry were measured on two full scale wall samples retrieved from the building.

Two walls (denoted as H1 and H2 in Fig. 1b) were selected for shear tests. First, the walls were tested in their original state using the test setup shown in Fig. 2a). The load was applied in the form of prescribed lateral displacements at mid-height of the walls. The walls were loaded and unloaded and the loading was gradually increased. The vertical load in the walls was estimated to 0.61 MPa and 0.44 MPa for walls H1 and H2, respectively. During the first phase of testing, the walls developed clear shear damage (Fig. 2b).

Then the walls were strengthened using carbon fabric and epoxy resin. Both walls were wrapped by three horizontal strips. In addition, wall H1 had diagonal strips on both sides, whereas wall H2 only had diagonal strips on one side of the wall. The layout of the fabric is shown in Fig. 2c. The strengthened walls were labelled H1w and H2w.