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Masonry Structures Confinement with Glass Fiber Reinforcement Polymers

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Abstract
The era of application the fiber-reinforced polymers (FRP) as a means of increasing the capacity of masonry through strengthening and confinement. Subject is addressed on strengthening of existing masonry structures. The new Codes and new methods are focused on improvement the behavior the masonry structures under the seismic load. In this study the four series are tested in different conditions and different parameters, focused on the behavior the masonry elements and behavior the infill concrete frames with masonry elements. The series of tests are models masonry columns with these variables: geometrical parameters; cross-section of columns and type of fibers. It is concluded that, in general confinement increases both the load-carrying capacity and the deformability of masonry almost linearly with the average confining stress. All the requested parameters are followed with the experimental works.

This paper discusses some of the pioneering research conducted by the author and his associates and provides examples of field applications where FRPs have been successfully used.

Keywords
FRP, strengthening, masonry structures, confinement

1. Introduction

The restoration and preservation masonry buildings, including historic buildings and existing buildings is the need for strengthening and retrofitting of the masonry parts of the structures. In older approach design purposes masonry is considered as homogeneous material but in reality it shows very complex heterogeneous and anisometric characteristics. New method analyses is based on the mathematical models but they need professional software and hardware for calculations. Many older masonry structures currently in use were designed and constructed with no consideration of many factors, recently changes in seismic requirements have left many URM (Un Reinforcement Masonry) buildings in need of strengthening. In many cases, these natural effects were not considered in ancient time. Since the advent of modern reinforced masonry construction, such reinforcement structures have been viewed as a significant liability when considering strengthening.

Significant research has been done on strengthening masonry components and their connections resulting in strengthening methods based on traditional materials, such as steel and concrete. These traditional techniques often create the additional load to structures and make it more risky. In same time it's usually very complicate for execution and on function of element position, and take long time for applied. The application of fiber reinforced polymers (FRP) for strengthening of masonry structures is relatively limited, depend of many factors. But in some of application the FRP materials is very beneficial having in mind its easy installation, low self-weight, high strength and ability to preserve the initial shape of the wall. Their light weight means that they do not alter the mass of a structure and thus the inertial forces from seismic excitation. This paper is an effort to collect the outcomes from previous researches that have been done on FRP application for masonry structures, its advantages and disadvantages and also some of examples of application based on our research works.

2. Fiber Reinforced Polymers

FRP's consist of high strength fibers embedded in a resin matrix. The fibers are usually Carbon (CFRP's), Glass (GFRP's) or Aramid (AFRP's). The fibers are strong – many times stronger than steel – in the longitudinal direction and generally weak laterally. Typically the fibers show no ductility, so FRP's are linear elastic to failure. The properties of FRP's are presented in many papers from different authors and are continually improving the main properties needed in. The role of FRP is on the combinations of fibers to provide non-linear responses to stress – attempts to achieve some "ductility" in the material.

FRP's not only have the advantage of very high strength over "conventional" materials, but are also light weight and highly durable in many environments. The light weight makes rehabilitation techniques much easier comparing with conventional materials and methods. The high durability is very attractive for applications where steel deteriorates rapidly (e.g. corrosion of reinforcing bars in bridges and other structural elements). But in process of hardening the resin slowly becomes brittle – often seen in plastic objects as they "weather" over the years when exposed to sunlight. Thus, FRP must be protected from exposure to direct sunlight – which can easily be achieved indoors and with paint. In our case study the protection of the resin is directly in relations with plastering layer inside and outside of strengthening the wall element.

2.1. FRP'S in masonry

Research into the use of FRP's in masonry has been reasonably wide ranging, with the same issues in mind as with concrete. From the durability perspective, GRFP's have been examined and propose such a possible strengthening material in wall construction .The use of GFRP to make the confinement in corners of walls is the proposal of authors in this paper. Such approaches might well be able to improve the ability of masonry not to disintegrate under seismic loading. However, there would be a need in design to have some component of the masonry fail in a stable manner at ultimate rather than some of actually methods.

2.2. Walls

Many authors and researcher propose the use of various FRP's to enhance masonry wall performance under quasi static or dynamic cycling loads. Initial work centered on bonding FRP's to the tension side of clay-brick beams subject to bending Large increases in both load and strain capacity to failure were observed, with the amounts depending on the quantity and type of the FRP used. Further testing followed, leading to reverse cyclic and quasi-static loading on brick walls with GFRP strips bonded to one side of the walls. The load capacity of the walls was increased comparing with common without strengthening wall. The walls increase the resisted deformations also comparing with common without strengthening wall.

The authors tested and analyses the three walls for different cases and different models in scope of increasing the load capacity and also increasing the level of deformations. For experimenting GFRPs were selected due to their lower modulus of elasticity, or such as to be compatible with the base material and to have a behaviour under load similar to that of novel type composite materials.

In our experiments the walls were prepared for different cases:

Case 1- with dimensions 100×100×12 cm, and to create the uniformity is just "closed" with steel frame profile U 140. The typical sample is presented in Figs. 1 and 2, such common sample without strengthening.

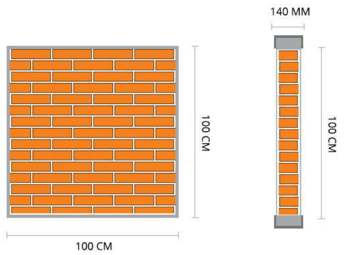

Fig. 1. Geometry of preparing wall for examinations


Fig. 2. Prepared walls for testing

In process of strengthening are prepared the following samples:
Case 2- wall strengthening with GFRP in diagonals, presented in Fig. 3.
Case 3- wall strengthening with mortar layer, presented in Fig. 4.

Fig. 3. Strengthening wall with GFRP


Fig. 4. Strengthening wall with layer of mortar

3. Experimental Program

The number of preparing models are examination in four series, according to the program for examinations:
- Common masonry wall –unreinforced
- Strengthening masonry wall with steel mesh and layer of mortar
- Strengthening of in fill frame with GFRP

3.1. Common masonry wall –unreinforced

Examinations of masonry elements is done according to the EN 771-1, focused on the physical and mechanical properties. The same clay elements are used in all our experiments. For behavior the clay elements in more than one layer, were examined starting from layers-block one to six, or from brick one to eight, as presented in Fig. 5 (a and b), depend of the different upper prepared surface for load applications.


a) b)

Fig. 5. Examination of clay masonry elements in layers

Beahavior of masonry elements under force in different layers is presented in Fig. 6.

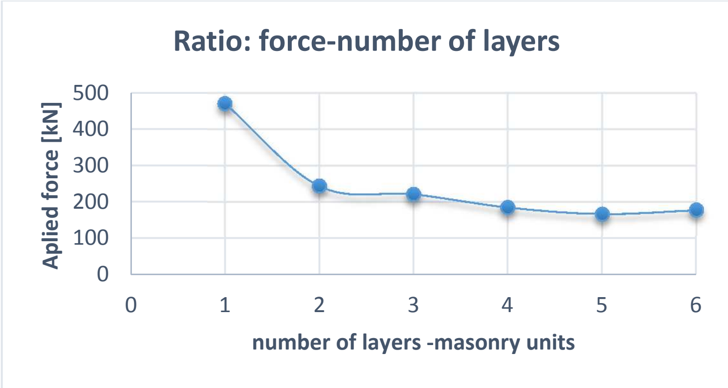

Fig. 6. Ratio: Force-number of layers of Clay Elements

3.1.1. Experimental setup

The main objective of testing was to record the stress-strain curve and to analyse the failure mode of masonry wall, which is under the horizontal and vertical loads, which increase incrementally. Of many experiments, we will present the procedure:

- Applied force: Horizontal-cyclic Loading

The LVDT are put in to measure the horizontal and vertical displacement during the load application. The behavior the masonry UN reinforcement wall is presented in Figs. 7 and 8.

Fig. 7. Measurement points and failure mode of wall

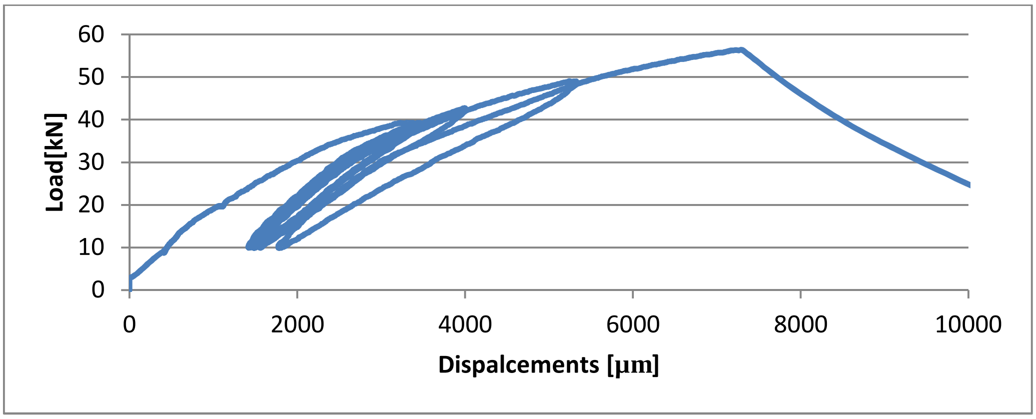

Fig. 8. Stress-strain diagram and maximum displacements

3.2. Strengthening masonry wall with steel mesh and layer of mortar

In scope of improvement the bearing capacity the method of reinforcement is focus on strengthening using the conventional method: strengthening using the plastering with mortar and steel mesh. Such a study case the wall is plastering with mortar in layer from t = 2.5 cm and reinforced with steel mesh Ø5/10 cm, and the applied horizontal and vertical force.

The behaviour under the applied force is presented in Fig. 9.

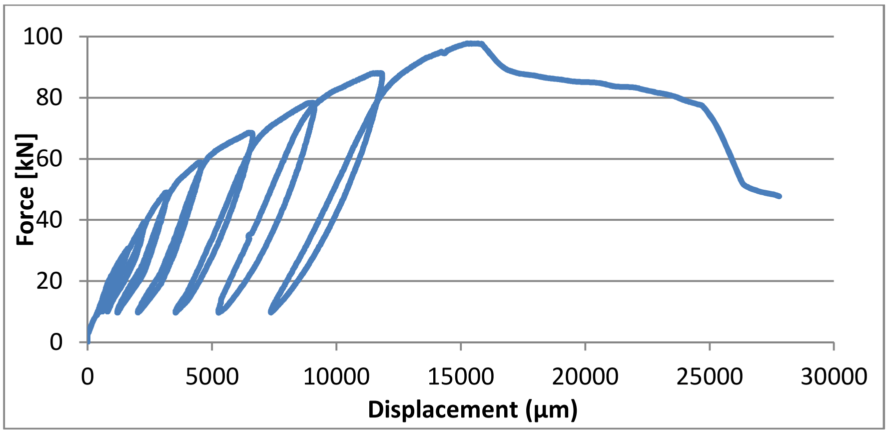

Fig. 9. Increase the capacity of reinforced wall with steel mesh and plastering mortar

3.3. Strengthening of in fill frame with GFRP

One of the new method based on the development of technology of materials is strengthening using the GFRP properties in composite material: wall with FRP. The GFRP are biaxial and are put in diagonal forms, according to the analytical analysis of failure mode.

Examinations of the masonry structure and behaviour are presented in Fig. 10 and 11.

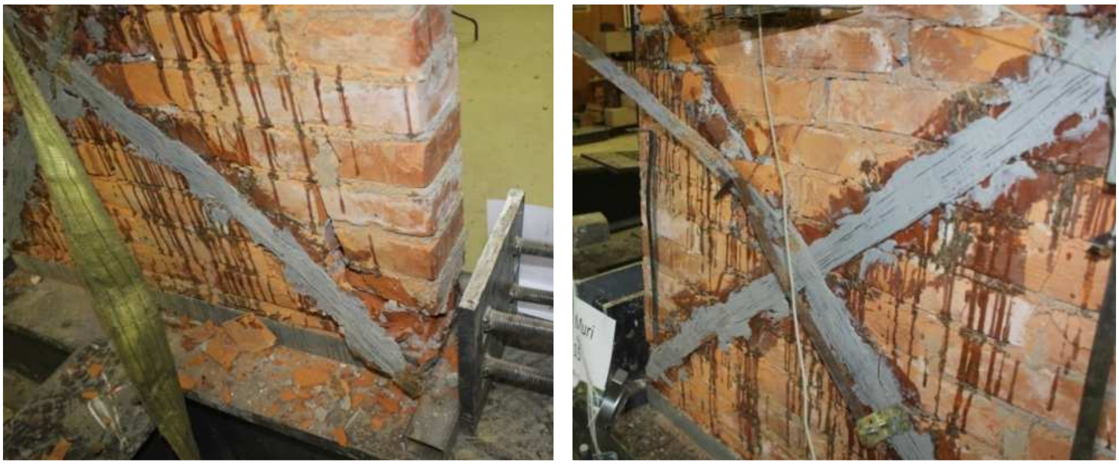

Fig. 10. Failure mode and delamination of GFRP

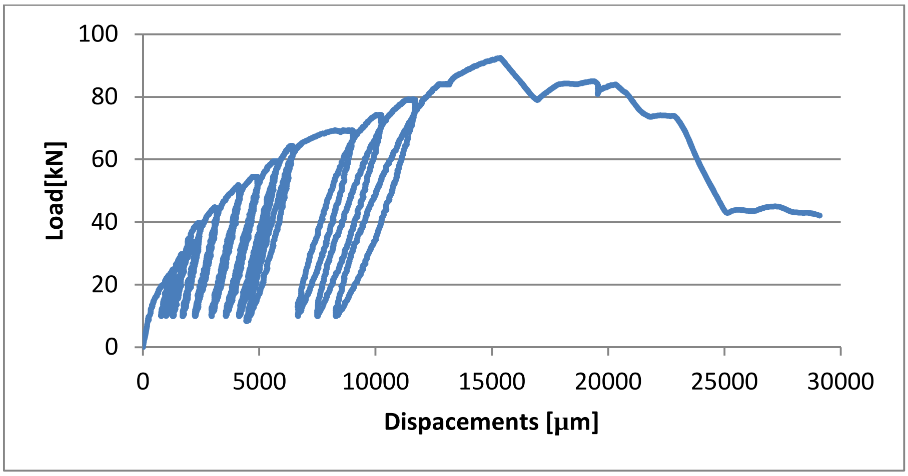

Fig. 11. Bearing capacity under cyclic loads

4. Discussion and Results

By examining the stress-strain curves and behaviours of the analysing models we can provide the main points for discussed:

- Comparing the results of three study cases-Masonry wall, Table 1.

Table 1. Comparing the output results between the three study cases

Case Study		1	2	3
Wall dimensions	m	1.0 × 1.0	1.0 × 1.0	1.0 × 1.0
Type of reinforcement		Without reinforcement	Mortar and steel mesh	GFRP-diagonals
Vertical Force	kN	75	75	75
Compressive Strength	N/mm^2	0.62	0.62	0.62
Horizontal Force	KN	56.3	97.8	92.7
Displacement in upper point	mm	7.5	15	15
Wall Bearing Capacity	%	1	1.74	1.65

The presented results in Table 1, present very clearly that using the different methods in strengthening the masonry walls will result with better behaviour and increasing the bearing capacity.

5. Conclusions

Confinement of masonry with GFRP or different methods its result on the strengthening the existing structures and properly design the new masonry structures, based on the behaviour under the cyclic loads.

The results are summarized as follows:

- Strengthening the walls with different methods is on the improvement the behavior the wall masonry structures, orients in displacement control.
  1. The strengthening with mortar results with increasing the bearing capacity for 1.74
  2. The strengthening with GFRP results with increasing the bearing capacity for 1.65
  3. Advance of strengthening with GFRP is based on the applications without secondary effects and with very few additional works

Test results developed in simple confinement for strength and ultimate strain, including the GFRP and other methods. Those models should attract further experimental verifications in future for masonry materials and to extend in other materials.

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