STRENGTHENING SOLUTIONS BASED ON TEXTILE COMPOSITE FOR MASONRY STRUCTURES

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Masonry as a structural material has high compressive strength and versatility, in achieving different structural and architectural shapes with attractive features. Masonry walls, arches and vaults are frequently used as components of the monumental buildings, many of them belonging to the historical heritage. Since the tensile strength of masonry is very low, under certain loading conditions in particular concentrated and nonsymmetrical forces, the masonry elements are vulnerable to cracking and to various failure mechanisms. Previous theoretical and experimental studies carried out by our research team have proven that the use of textile composite materials has a favourable influence upon the structural response and the load bearing capacity of the construction elements. The results of an experimental study on the structural behaviour and failure mechanisms of unstrengthened and strengthened masonry curved elements are presented in this paper. The experimental results describe the mechanical behaviour of masonry arches and vaults under typical loadings for monumental buildings. The strengthening schemes of the walls and curved elements have been designed and applied on the members utilizing textile composite membranes sometimes connected through textile composite strips. The overall behaviour and the failure mechanisms have been certainly improved in all cases, especially in masonry arch and vault type elements.

Keywords: textile composite, strengthening solutions, masonry elements.

INTRODUCTION

Masonry structures are vulnerable to damage actions which arise from the natural hazards. The most destructive is the seismic force but other damaging actions produced by floods, tornadoes, fire [1], settlements or soil erosion could not be neglected. Masonry walls are constructed using two main components, mortar and brick units. The major function of mortar is to bond masonry units, to seal the spaces between them, and to bond the steel reinforcing bars in case of reinforced masonry. The mechanical behaviour of different types of masonry shows all the time a good compressive strength and a very low tensile strength.

To improve the behaviour of the masonry structures the engineers have used the traditional strengthening methods such as grout injection, stitching of large cracks and devastated zones with metallic meshes, bricks or reinforced concrete elements, structural repointing using steel reinforcements, etc. [2]. However traditional methods always lead to the increase of dead loads because of the section splaying of masonry structures, which represent an unfavourable situation in the case of the earthquake occurrence. For these reasons new solutions based on advanced polymeric composite materials have been applied avoiding the main shortcomings of the traditional solutions.
STRENGTHENING SOLUTION BASED ON TEXTILES COMPOSITES

Fiber reinforced polymeric (FRP) composite materials utilised in strengthening systems exhibit several convenient properties such as: high strength to weight ratio, acceptable stiffness, immunity to corrosion, compatibility and a good adherence to masonry blocks, etc. In Figure 1 some of the most efficient strengthening solutions based on FRP composite products for unreinforced masonry (URM) walls are illustrated.

![Figure 1. Strengthening solutions using FRP composites for URM: a. composite bars embedded in mortar joints; b. composite sheets bonded to wall surface; c. parallel FRP strips; d. cross arrangements of FRP composite strips; e. grid placement of FRP strips; f. carbon, glass or aramid fabric wet-out in polymeric resin; g. FRP meshes; h. spray-up technique using short fibres.]

An efficient strengthening solution using prestressed carbon fiber reinforced polymer strips proved to be the system presented by [3] achieving a closed prestressed area for the corners of historical masonry structures.

EXPERIMENTAL INVESTIGATIONS

An extensive experimental program has been initiated at the Faculty of Civil Engineering, the Technical University of Iasi to prove the efficiency of strengthening solutions based on FRP composites applied on curved masonry elements [4].

The experimental model has been made of masonry with normal bricks and mortars. Prior to construction of the model, preliminary tests on the material properties have been carried out. Tests have been performed on brick samples, mortars and bonding between textile glass fibre reinforced polymer (GFRP) strips, Figure 2a and masonry blocks, Figure 2b. A numerical modelling has been performed, Figure 2c, to characterize the bonding region.
The experimental tests have been performed on a universal testing machine, ZWICK/ROELL with displacement and force control. A summary of the test results is presented in Figure 3 where the stress-strain curves are illustrated. In all tests the stress-strain curves have been determined including the ascending branch up to the peak force and a descending segment showing the decrease of the loading force.

A preliminary test under static loading has been performed on the arch model, acted by vertical distributed loads and a horizontal force at the support level. In addition, a numerical analysis has been carried out to identify the maximum stresses and the maximum strains, Figure 4.
The numerical simulation gave a useful indication on the type and placement of the textile composite plates and the connecting composite strips, forming a pseudo-cage with beneficial effects on the structural response. In Figure 5 the main phases of making the strengthening solution are presented. The reinforcing textile GFRP strips are cut to size and the components of the polymeric matrix are selected and proportioned.

![Figure 5](image)

**Figure 5.** Application of strengthening solution on the masonry arch: a., b. components of the textile composite membrane; c. the masonry arch strengthened with inside and outside textile composite plates connected by transverse textile GFRP strips

The above presented experimental program has been extended to prove the suitability of GFRP strengthening solutions for masonry barrel vaults. A preliminary testing has been performed to evaluate the structural response of the unreinforced masonry barrel vault under static loading, Figure 6.

![Figure 6](image)

**Figure 6.** Masonry barrel vault under static loading

An additional numerical analysis, Figure 7, has been carried out to identify the main values of principal stresses and strains as well as their paths. Based on structural response under static loading and the numerical analysis it results that the strengthening system has been conceived, Figure 8.

![Figure 7](image)

**Figure 7.** Maximum principal stresses (left) and strains (right)
The experimental program has been extended to find out the structural response of the composite strips strengthened model under seismic action. The masonry vault model has been installed on the shaking table platform. Figure 9, having the following performance characteristics: the gravity load capacity=160 kN; the dynamic displacement amplitude=±15 cm; the frequency range=0.5÷50.0 Hz; the action type is triaxial (two in horizontal plane, one in vertical direction); the peak acceleration with a payload 100kN=± 3g and the maximum velocity= ±0.8 m/s.

The acquisition of the test data has been digitally performed, by simultaneously recording signals from 2 types of transducers: Dytran 3202A1 LIVM (accelerometer) and PT5AV (displacement transducer).

To evaluate the structural response under seismic load, the accelerograms of two representative earthquakes, Fig. 10a, 10b and an artificial accelerogram, Fig. 10c, have been imposed. The selected earthquakes were El Centro (1940), and Vrancea, Romania (1986). The amplitudes of the accelerations ranged between 0.1g and 0.41g for the El Centro earthquake and between 0.22g and 0.5g for the Vrancea earthquake.

Figure 8. The textile GFRP strips applied on the masonry vault

Figure 9. The strengthened barrel vault model on the shaking table [5]

Figure 10. The imposed accelerograms: a. El Centro-California, 1940; b. Vrancea-Romania, 1986; c. sine-sweep accelerogram
CONCLUSIONS

Glass fibre textile reinforced composite membranes and strips can be successfully applied to strengthen masonry arches and vaults of monumental buildings. Using the double sided system with transverse strips connecting the composite plates applied on the top and bottom side of the arch are effective systems for structural rehabilitation of masonry arch type elements. The improvement of the structural response of the double sided strengthened arch has also been materialized by appearance and development of four plastic hinges, beneficial for the load bearing capacity of the structural member. The development of crack pattern has also been enhanced leading to a more uniform distribution of cracks. There were no visible failures of the composite strips concluding that their load bearing capacity has not been fully utilized.

The masonry barrel vaults strengthened with GFRP composite strips subjected to static and dynamic loading have shown significant increase in strength and minimization of the displacements. Improved failure mechanisms have also been identified for different loading cases. Significant improvements have been noticed using GFRP composite strips, in both static and dynamic/seismic loading, showing an enhanced structural response.

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REFERENCES


