SHEAR STRENGTHENING OF UNREINFORCED MASONRY WALLS WITH VARIOUS TYPES OF COMPOSITE SYSTEMS

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***Abstract**: The shear strengthening of unreinforced masonry (URM) walls needs to be carried out through appropriate and effective techniques, compatible to the particular physical characteristics of the substrates. In this paper, various types of composite strengthening systems are presented and discussed. In recent years, the composite strengthening systems, especially those made with textile reinforced mortars (TRM), have received significant attention, due to their convenient mechanical properties and sustainability characteristics. Various analytical and numerical models have been developed to quantify the strength and deformation capacity improvement provided by the composite reinforcement to the URM walls. However, there is still a lack of works that examine the overall performances of the composite strengthening systems, including their limitations which are not thoroughly known, and, in some circumstances, may lead to buckling and out-of-plane failure of the URM walls.*

***Key words**: unreinforced masonry, composite strengthening systems, near surface mounted, externally bonded reinforcement, textile reinforced mortars.*

1. Introduction

The majority of existing historical masonry buildings has been constructed as unreinforced masonry (URM) structures. The design of these structures was focused mainly on the gravity loading and thus, many URM buildings are potentially vulnerable to earthquake loads. The URM walls take advantage of the adequate masonry compressive strength, and they behave satisfactorily as long as the loads are vertical. On the other hand, the shear response of URM walls is more complex and depends, mainly, on the nature of the mortar and the bricks. Furthermore, the stocky sequence of masonry units and the negligible tensile strength of the masonry material, makes these structures very brittle and with low ductility [1, 2].

The strengthening of the URM structures is an important issue and the design and the implementation of an appropriate reinforcing system represents the key aspects in order to achieve the required seismic performances in terms of energy dissipation capacity. The traditional strengthening techniques may not be very effective for historical masonry

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constructions, due to the high additional mass of the constituents and unsatisfactory mechanical attributes [3].

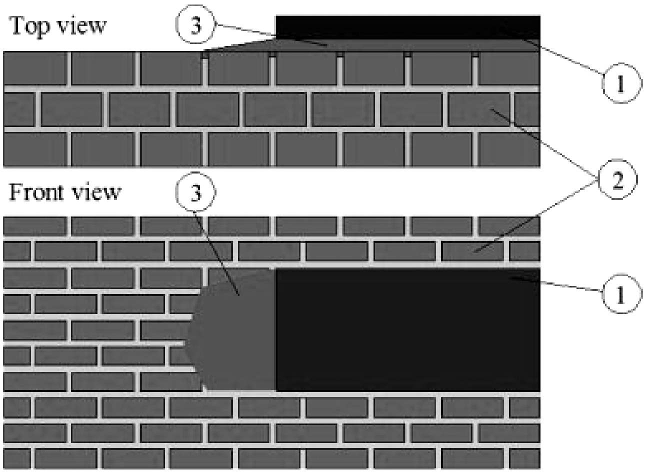
Strengthening URM structures with composite systems is a consolidated technique that has focused the research of several research teams in the last decades. The effectiveness of various composite products was analysed for different masonry elements (walls [4, 5], pillars [6, 7], arches, vaults and domes [8, 9]), under particular loading conditions: compression [10], static and cyclic shear [11, 12], static and cyclic bending [13, 14]. Based on various extensive experimental programs, the remarkable structural performances of the composite strengthening systems have been validated. According to these experimental programs, the bearing capacity can be improved with up to 100% in bending (thanks to the tensile contribution of composites) [15], over 20% in shear [16] and over 100 times in compression, in case of arches and domes [17].

A large share of the composite strengthening systems, designed for URM walls, are using fibre reinforced polymer (FRP) pultruded products that are manufactured under strict control procedures and visual inspection. Although these industrialised products have well controlled properties, their manual application into the strengthening system may result into structural deficiencies, usually associated with adhesive voids or inadequate curing. In order to overcome these drawbacks of the FRP strengthening systems, the textile reinforced mortar (TRM) composite, which is also referred to as textile reinforced concrete (TRC) or fabric reinforced cementitious matrix (FRCM), has emerged as an alternative strengthening technique. The application of TRM increases the shear strength of masonry walls, and it also improve the dominant failure mode. The TRM strengthened URM walls have a gradual prolonged failure, which is highly desirable, especially in the case of structures located in the earthquake prone areas [18].

2. Composite strengthening systems for URM masonry walls

2.1. Externally bonded reinforcement

The externally bonded reinforcement (EBR) technique (Figs. 1, 2) uses either pre-cured FRP composite laminates (bonded onto the masonry walls with a structural adhesive) or FRP sheets (applied by wet lay-up). The orientation of the FRP reinforcement can be horizontal, vertical, diagonal, or in a grid pattern. Furthermore, the strengthening system can be applied on one side or on both sides of the URM wall [19].



1 - FRP composite product (plates, grids, strips or shells);
2 - masonry; 3- adhesive.

Fig. 1. FRP Externally Bonded Reinforcement (EBR) applied to URM wall [19]

a)

b)

Fig. 2. FRP EBR strengthening technique applied to: a) Victor Slăvescu historical building; b) Laminates bonded on an URM wall [20]

2.2. Near surface mounted

The near surface mounted (NSM) strengthening technique uses FRP composite products, such of bars or strips that are bonded with structural adhesives into cuttings, in depth of masonry walls (Fig. 3).

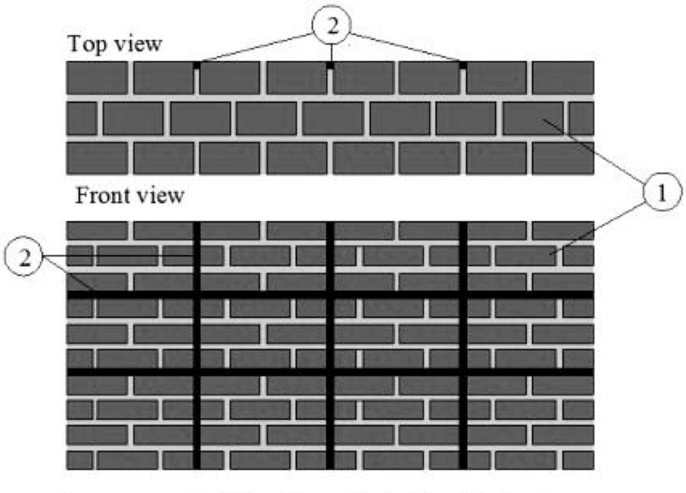


Fig. 3. Near surface mounted strengthening system applied to an URM wall [19]

2.3. Central core strengthening technique

The central core strengthened technique (Figs. 4, 5) involves drilling continuous straight vertical grooves through the head joints and the brick units and horizontally at the bed joints. After the drilling and the cleaning processes are finished, an epoxy primer is applied and the grooves are partially filled with an epoxy structural adhesive. The reinforcement used for this strengthening system consists of FRP rods installed in the grooves and encapsulated by an epoxy adhesive product. This strengthening system increases the URM wall capacity to resist in-plane and out-of-plane loading, but, at the same time, it creates regions of varying stiffness and strength properties.

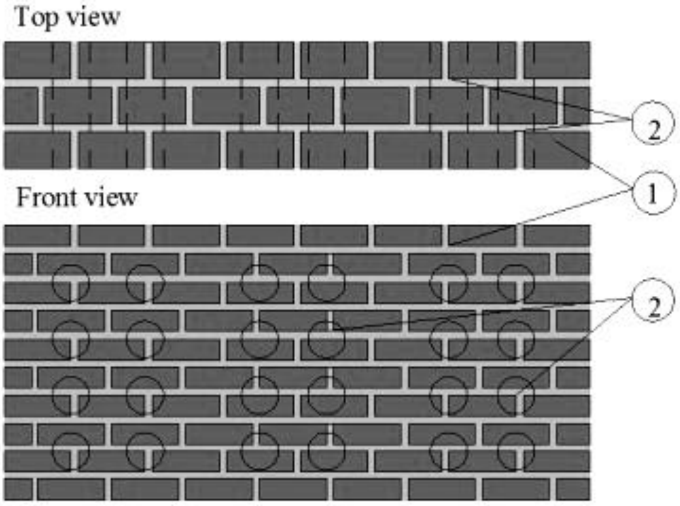


Fig. 4. Centre core strengthening technique applied to an URM wall [19]

a) b)

Fig. 5. Combined EBR and Central core strengthening techniques applied to: a) Palace Hotel, Govora; b) FRP EBR and central core reinforcements applied on an URM wall [20]

2.4. Textile reinforced mortars

The textile reinforced mortars (TRM) strengthening system uses a structural layer of engineered cementitious composite (ECC) that is fully or partially (only in the case of elements with complex geometry) bonded onto the faces of the URM walls (Figs. 6, 7). The TRM are usually composed of a dry fibre mesh, embedded in a cementitious matrix. This strengthening system is particularly well-suited for the reinforcement of masonry structures due to its high compatibility with the substrate, vapour permeability and durability against environmental agents.

Moreover, a TRM system has similar advantages to the ones of an FRP system, including high strength to weight ratio and corrosion resistance, but it overcomes some major FRP drawbacks, especially those related to the unsatisfactorily behaviour under elevated temperature and un-proper application on damp surfaces [18]. The flexural capacity of an URM wall strengthened with TRM is affected by several factors. The flexural capacity of the system can be improved by increasing the number of reinforcement and mortar layers. The type of the reinforcing fibre mesh influences the overall flexural capacity of the element, due to the dominant failure mode and bond strength associated with each type. In addition, the anchoring of the TRM system may help to increase the bearing capacity and ductility of the strengthened element, by delaying the development of the failure mode.

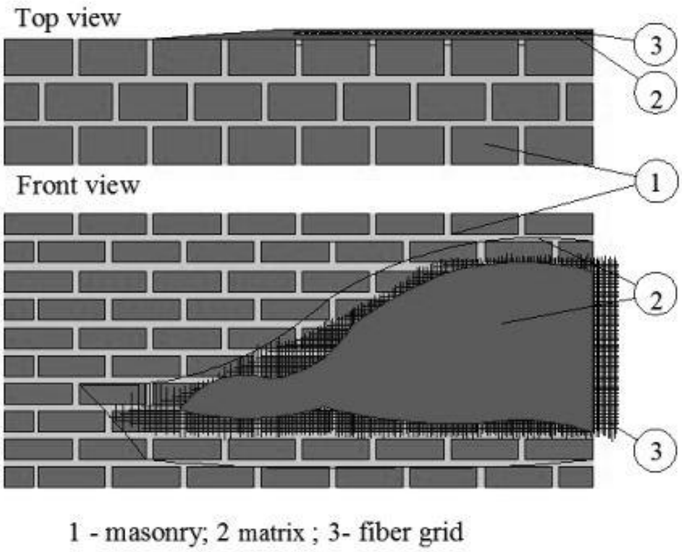


Fig. 4. Textile reinforced mortar applied to an URM wall [19]

a) b)

Fig. 5. Textile reinforced mortar applied to: a) Golia Monastery, Iași [21]; b) TRM applied on the monastery walls [20]

3. Conclusion

In recent years, the rehabilitation and strengthening of URM buildings has seen a remarkable development on the basis of new techniques and materials. In this study some of the shear strengthening techniques that are either suited for URM walls, or have been particularly designed for these structural elements are described. The history of past earthquakes showed that the URM buildings had performed the worst, developing un-repairing damages and also accounted for many life losses. In this frame, the already developed FRP strengthening techniques for plane / reinforced concrete, steel and timber members were also applied to masonry elements. However, the FRP composites have demonstrated unsatisfactory performance, when applied to URM structures that were located in high temperature environments, where the glass transition temperature of the resin is reached. This justifies the need to examine alternative strengthening techniques, such as the TRM systems. As it has been discussed in this paper, the TRM system has similar advantages to the ones of an FRP system, but it overcomes various FRP drawbacks, especially those related to the unsatisfactory behaviour at elevated temperature and un-proper application on damp surfaces.

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