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STRENGTHENING OF UNREINFORCED MASONRY WALLS WITH COMPOSITE MATERIALS

BY

GABRIEL OPRIŞAN, N. ŢĂRANU and IOANA-SORINA ENŢUC

Unreinforced masonry (URM) is considered one of the oldest construction materials being until the end of XIXth century, the basic material for: foundations, walls, columns, volts, staircases, floor joists, roofs, retaining walls, drainage channels, barrages, etc. Construction with URM elements posses a series of advantages such as: fire resistance, thermal and acoustic insulations between interior and outside spaces, humidity resistance. However the URM elements have some significant inconveniences such as: large self weight (heaviness causes cracks in the other elements of the structures), reduced mechanical strengths in comparison with other traditional materials (steel and concrete), low tenacity, great manual labour consumptions, and vulnerability to earthquakes. Various factors cause deteriorations which must be overcome by strengthening solutions.

Some strengthening solutions based on fibre reinforced polymers (FRP) products applied directly on URM brick walls are presented in the paper.

1. Introduction

The first utilization of brick masonry units was mentioned by Egyptians in 10,000 B.C. while the Romans started using bricks in many of their structures 2,000 years ago. The Great Pyramid of Giza in Egypt is the first recorded use of mortar. Archeological excavations showed near Lake Hullen, Israel (9,000-8,000 B.C.), where drystone huts circular and semi-subterranean were found, as one of the oldest building construction. Brick manufacture was occurred in the middle of 1,600 and was patterned on English methods and practices.

Usually, masonry walls are constructed using two components: mortar and reinforcement. The most important property of mortar is the bond strength in comparison with concrete, where the compressive strength is crucial. The main functions of the mortar are: bonding of the masonry units and sealing of the spaces between them, enabling the dimensional variations in the masonry units, also ensuring the bond of steel reinforcement to the wall in case of reinforced masonry. The mortar provides an aesthetic and decorative effect if the joints between brick units have diverse colours [1].

Mechanical behavior of different types of masonry shows all the time a common feature: a very low tensile strength. A possible classification of stone masonry with different arrangements is illustrated in Fig. 1, while for brick masonry the most utilised arrangements are shown in Fig. 2.

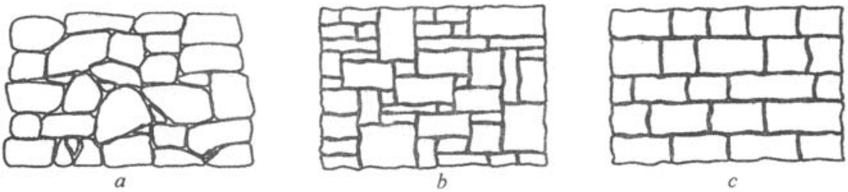

Fig. 1.- Different types of stone masonry: *a* – rubble masonry; *b* – ashlar masonry; *c* – coursed ashlar masonry.

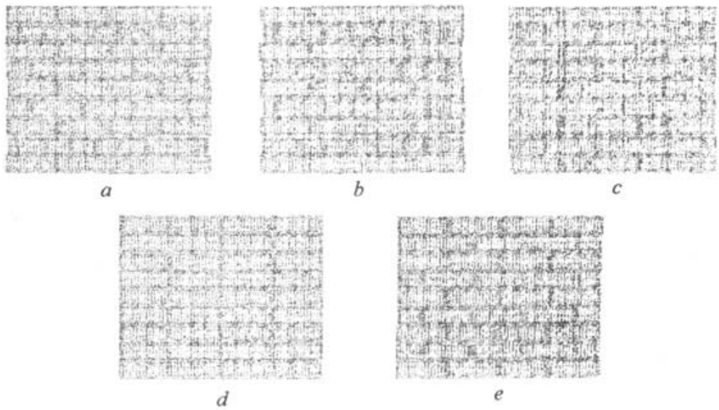

Fig. 2.- Different arrangements for a URM brick wall: *a* – American bond; *b* – english or cross bond; *c* – flemish bond; *d* – stack bond; *e* – stretcher bond [2].

Unreinforced masonry (URM) structures undergo damages due to inadequate foundation soil, uneven loads on the length direction of the URM wall, precarious design and execution, wind pressure and earthquakes, temperature variations, expansion and contraction due to the presence of moisture, etc. In fact, most type of failure encounting at URM walls were due to the lack of knowledge of the materials properties and of building construction details rendering which caused wrong choice or repair method and a weakness application of it.

Traditional strengthening techniques used to strengthen URM walls are: grout injection (the aim of this technique is to fill large and small voids and cracks to ensure the continuity of the masonry and its strength), stitching of large cracks and devastated zones with metallic, brick or reinforced concrete elements, external jacketing using shortcrete or monolithically procedure, external or internal post-tensioning using steel ties, structural repointing using steel reinforcement (repointing is a common name for a technique involving the application of short steel rods across cracks caused by creep of the masonry assemblage under long-term high level dead loads) [3], [9].

2. Advantages and Disadvantages of FRP Based Strengthening Solutions for URM Walls

From the diagrams illustrated in Fig. 3, the differences between the linear-elastic brittle behaviour of fibre reinforced polymer (FRP) composites and the ductile behaviour of steel can be noticed. Therefore, FRPs do not have the ductility that steel posses and their brittleness may limit the ductile behaviour of URM walls strengthened with FRP materials [4].

The tensile strength of FRP can exceed 3,000 MPa (compared to 400 MPa for reinforcing steel), FRP do not exhibit plastic yielding plateau as steel does and the behaviour of FRP is elastically up to an ultimate strain in the range of 1.5% to 3.5% (in comparison with a range of 15% to 25% for reinforcing steel).

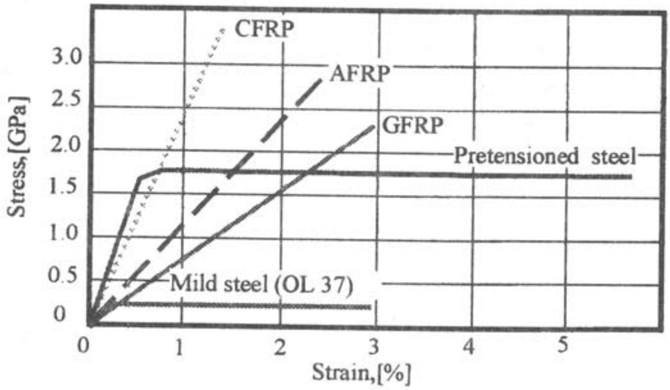

Fig. 3.– Stress–strain curves of different type of reinforced materials: CFRP – carbon fibre reinforced polymer; AFRP – aramid fibre reinforced polymer; GFRP – glass fibre reinforced polymer.

FRP composite materials exhibit several convenient properties, such as: high strength to weight ratio, acceptable stiffness, corrosion insensitivity, which are suitable for use as structural reinforcement. Fibre reinforced polymer applications are compatible with almost existing structural materials. The great majority of the investigations are the applications with reinforced concrete, but also masonry and wood have been combined with FRP to improve the load bearing capability of structural members.

A noticeable barrier concerning the use of FRP in Civil Engineering applications is their initial high material cost. Carbon and aramid fibres are resistant to many aggressive agents but glass fibres are susceptible to attack by the high alkalinity of concrete; therefore the designers must use alkali-resistant fibre glass with special chemical formulations.

3. Intervention at URM Using FRP

URM walls have in many cases insufficient ultimate capacities and/or serviceability performances, resulting from deficiencies due to lateral load variation, occupancy change, deterioration, construction or design errors. Load bearing walls are often sensitive to lateral cyclic actions, which may cause sudden loss of capacity and brittle failure due to instability; infill panels are also susceptible to pulling apart from floors or snap through during earthquakes or blasting shocks.

Some of the most efficient strengthening procedures using different FRP reinforcements [6] are presented in Fig. 4.

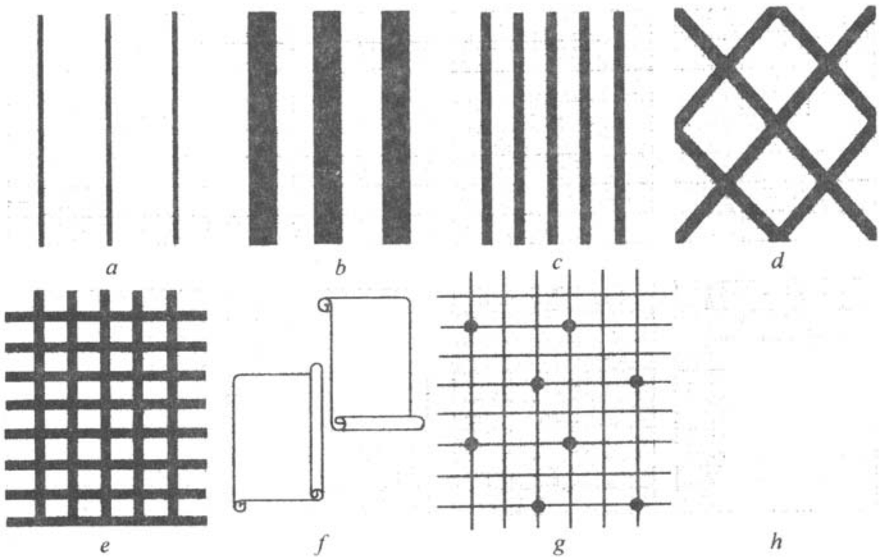

Fig. 4.– Strengthening procedures using FRP for URM: *a* – composite bars embedded near surface in joints; *b* – composite sheets bonded to wall surface; *c* – FRP plates; *d* – cross arrangements of FRP plates; *e* – grid disposition of FRP; *f* – carbon or glass fabric moisten in epoxy resin; *g* – FRP mesh; *h* – spray up technique.

The designer must observe all basic rules before rehabilitation or strengthening using FRP, namely [5]:

a) the as-built drawings including all past modifications, validated by field investigations;

b) the actual size of the masonry;

c) the actual properties of the existing materials including the surface tensile strength of the masonry;

d) the location, size and cause of cracks and spalls;

e) the location and extent of any corrosion of the reinforcing steel;

f) the quantity and location of the existing reinforcing steel;

g) the appropriate evaluation of the applied loads.

An innovative strengthening system to provide both direct tension and in-plane shear transfer from the wall to the floor slab and a strengthening system using glass or carbon fabrics bonded to perpendicular surfaces with a thickness and size designed for the required loading (Fig. 5) was tested at the University of California in Irvine [7].

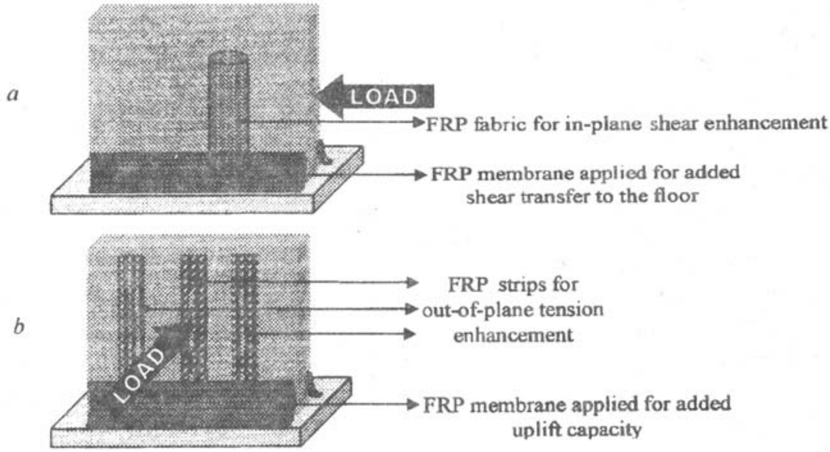

Fig. 5.– Strengthening system using FRP for URM brick walls: *a* – in-plane shear strengthening; *b* – out-of-plane tension strips (face loaded, single side application).

In 1997 T r i a n t a f i l l o u [3] proposed a concept of strengthening using FRP tendons around a masonry walls perimeter. Every side has two anchorages and a turn-buckle provided with two stainless steel thread rods (Fig. 6). The prestressing forces must be applied gradually in order to cramp the steel plate of anchorages.

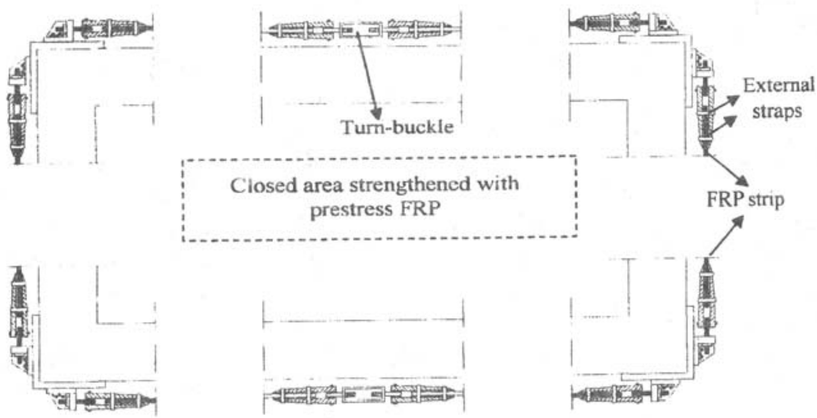

Fig. 6.– Circumferential prestressing of a structure with a single prestressed FRP tendon around the perimeter.

The extension of the FRP strengthening applications of URM has been performed through a series of experimental tests and practical demonstration projects. One of the earliest FRP strengthening application was performed in Zürich, where a six level building, built in 1930, was transformed after strengthening into an office building. The designer selected this FRP strengthening solution from three possible alternatives: demolishing and reconstructing a new fire wall, strengthening the existing wall by applying a reinforced shotcrete layer or strengthening the URM wall using the CarboDur (CFRP plates) strengthening system [8].

The solution based on FRP has been recommended by the following advantages of these strengthening techniques: no dimensional changing in URM wall thickness, its cost effectiveness resistance earthquake loads, easy of installation of the CFRP plate and a short time period of execution.

Presently, Romania possesses a rich cultural patrimony which includes orthodox churches made of URM stones beginning with the fourteenth century: Church of Cozia Monastery built in 1388, Radu Vodă Church built in 1570, Horezu Church built in 1692, Văcăreşti Church, in 1722, etc. Local researches in the strengthening domain of URM were performed using polymer grids, in vertical and horizontal plane of the wall. It was experimentally demonstrated that masonry walls reinforced with polymer grids with horizontal and vertical arrangement under seismic load no longer exhibit diagonal cracking in an X-shaped pattern. One of the great advantages of the polymer grids is that they are cost effective and easily applied *in situ*. In fact, polymer grids and FRP replaced succesfully massive reinforced concrete and steel reinforced strengthening solutions [9], [10].

4. Structural Overlay of URM Walls Using FRP

The procedure to strengthen the URM walls is unsophisticated. A thin glass or carbon fabric moisten with epoxy resin can be applied onto the surface of the URM wall to increase the stiffness and especially strength of the wall. The fibres can be oriented in one or more directions, and they are used as tension reinforcing for the wall, the followed purpose being the increase the in-plane and out-of-plane strength of the wall.

The repair materials used to strengthen the URM walls are: carbon or glass fibers sheets, epoxy resin for bonding the sheets to the URM wall, anchors for fixing the composite fibres sheets to the substrate, surface coatings. The necessary equipments used for this kind of intervention are: light chipping hammer or sandblasting equipment, brushes or rollers to apply the epoxy resin to the wall and to the fabric, protection glasses, gloves, etc.

The execution of the strengthening work with FRP includes the following phases [11]:

a) the existing cracks in the wall must be repaired using epoxy or grout injections;

b) spalls must be also repaired;

c) the wall surface should be prepared using sandblasting obtained the clean surface wall required by the manufactured of composite materials;

d) a thin layer of epoxy should be applied to the surface of the wall;

e) FRP fabric is saturated in epoxy and it is pressed into the epoxy binder with a roller (the number of layers and the fibres orientation should be in accordance with design requirements);

f) additional epoxy resin should be applied to ensure the complete coating of the fibres;

g) the fabric layers should wrap around the edges of the URM wall for a distance as recommended by the manufacturer;

h) anchors should be installed through the fabric along the perimeter of the wall to ensure the perfect adherence and tucks prevention;

i) after the epoxy curing the wall should be covered with a coating such as: paint, plasters or wallboard.

The categories of repairs for earthquake damage masonry wall are divided in three:

1° *Cosmetic repairs* – are those repairs that improve visual appearance.

2° *Structural repairs* – refers to the damaged elements with the intention of structural property restoring.

3° *Structural enhancement* – are the repairs that includes supplemental addition or removal and replacement of existing damaged components.

In Table 1 the repair procedures applied to URM walls in comparison with reinforced concrete and reinforced masonry walls are presented.

Table 1
Repair Procedures

Repair category	Material			Repair type
	Unreinforced masonry	Reinforced concrete	Reinforced masonry	
Cosmetic repair	√	√	√	Surface coating
	√			Repointing
		√	√*	Crack injection with epoxy
Structural repair		√	√*	Crack injection with epoxy
	√	√	√	Crack injection with grout
		√	√	Spall repair
		√		Rebar replacement
	√	√	√	Wall replacement
Structural enhancement	√	√	√	Concrete overlay
	√	√	√	Composite fibres
		√		Crack stitching

√* Epoxy injection not recommended for partially-grouted reinforced masonry.

5. Conclusions

The upgrading of existing URM walls using FRP systems represents a viable solution to improve capacity under in-plane and out-of-plane loading. FRP system offers an alternative to traditional strengthening methods, which is both simple and economical.

Further work is requiring to characterize materials, experimentally system behavior and to allow the development of the design guidelines for strengthening of the URM with FRP.

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Technical University "Gh.Asachi", Jassy,
Department of Civil and
Industrial Engineering

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CONSOLIDAREA PEREŢILOR DE ZIDĂRIE NEARMATĂ CU MATERIALE COMPOZITE

(Rezumat)

Zidăriile nearmate sunt considerate ca fiind cele mai vechi materiale de construcţii de la sfârşitul secolului al XIX-lea, fiind materiale de bază pentru: fundaţii, pereţi, arce, scări, planşee, acoperişuri, ziduri de sprijin, canalizări, baraje etc. Construcţiile din zidărie nearmată prezintă o serie de avantaje: rezistenţă la foc, asigură confort termic şi acustic atât în spaţiile din interior cât şi în exterior, rezistenţă la umezeală etc. În perioada de exploatare a zidăriilor nearmate s-au observat o serie de inconveniente: greutate mare (conduce la fisurarea celorlalte elemente de construcţie), rezistenţe mecanice slabe în comparaţie cu materialele tradiţionale (oţelul şi betonul), consum de manoperă ridicată, vulnerabilitate la apariţia seismelor.

Se prezintă câteva moduri de consolidare folosind compozite polimerice armate cu fibre, cu aplicaţii directe la zidăriile nearmate de cărămidă.