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STRENGTHENING AND REHABILITATION CONVENTIONAL METHODS FOR MASONRY STRUCTURES

BY

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Abstract. The study and development of rehabilitation and strengthening methods for masonry structures is a permanent concern of civil engineers, because of the high proportion of existing structural masonry and their vulnerability to exceptional loads, especially from seismic action. This paper presents an overview of existing methodologies for strengthening and rehabilitation of masonry structures using traditional materials.

Key words: strengthening methods; repairing techniques masonry structures; traditional materials.

1. Introductions

Buildings made of masonry structural system remain one of the most vulnerable classes of structures. In the last decades numerous studies have been conducted concerning ways for strengthening and rehabilitation assessment for masonry structures. These studies helped to develop new design codes, guidelines and handbooks like: FEMA 356. 2000. (also ASCE 41-06) – Seismic Rehabilitation Prestandard, FEMA 172, 1992, NEHRP Handbook for Seismic Rehabilitation of Existing Buildings, Australian Standard: AS 3826 – 1998

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Strengthening Existing Buildings for Earthquakes, NZSEE. 2005 – Assessment and Improvement of Structural Performance of Buildings in Earthquakes, P 100-3/2008 Eurocode 8, SR 1991-1-7, 2006, Eurocode 1.

The aim of this paper is to present a classification of building strengthening technologies considering their goal, materials and the criteria used to verify their effectiveness, analysing these conventional retrofitting methods using traditional materials.

The main objective of a civil engineer is to improve the bearing capacity of the structural elements. *Prior* to strengthen a masonry structural element, the causes of the element degradation must be fully understood.

Among the damage factors for masonry structures are: structural problems or distress which result from unusual loading or exposure conditions, inadequate design or poor construction practices. Distress may be caused by overloads, fire, foundation settlement, deterioration resulting from abrasion, fatigue effects, aging of the component materials in time (mortar destruction), poor maintenance of the building, design or construction errors, aggressive environments, etc. (Islam, 2008).

It is impossible to conceive the strengthening of masonry structures without fully understanding the ways they are affected by earthquake action. A practical knowledge of structural behaviour is essential as masonry structures are characterized by a complex behaviour under dynamic loads. Studies related to the effect of previous earthquakes on these types of construction revealed that masonry structures are more prone to damage than reinforced concrete structures or metal ones.

Repairing/strengthening means to increase one or more than one of the following parameters: tensile capacity, shear capacity, flexural capacity, member stability, compressive capacity, ductility, energy dissipation, strength or stiffness or both.

2. Strengthening Methods Using Traditional Materials

The repairing and retrofitting of existing masonry structures are traditionally accomplished by using conventional materials and constructions techniques. The rehabilitation methods can be of two kinds: repairing technique, when the purpose is to restore the load bearing capacity of the masonry elements, and strengthening techniques, when the purpose is to increase the load bearing capacity.

A large number of research programs were carried out around the world, with the purpose of studying the performance of the repair and/or strengthening methods of masonry structures. In the next section of this paper the most common solutions as well as the improvement of safety behaviour in case of seismic action are presented.

2.1. Restoration Using Masonry Replacement

a) *Masonry replacement technique using similar materials; use of concrete*. The strengthening solution consists in replacing all the affected areas of the walls where major deterioration has occurred (local areas affected by deterioration of the blocks and mortar) with similar materials to the original structure. In case of necessity of using high strength materials it will be taken into account some special areas like corners, where stress concentration can appear. The main objectives of this method are: preserving of the mechanical efficiency and improving of the continuity of the masonry structures (Budescu *et al*., 2001)

b) *Strengthening masonry using wall buttresses*. The strengthening technique consists in adding additional supports (buttress) in vertical plane of vulnerable walls to out-of-plane loads (Fig. 1). The distance between buttresses should not be gather than 5 m and these should be connected with steel connectors anchored into the existing wall. The main advantages of this solution are: preventing the failure mechanisms related to the lateral deformations and a good behaviour in case of horizontal forces (Bothara & Brzev, 2011).

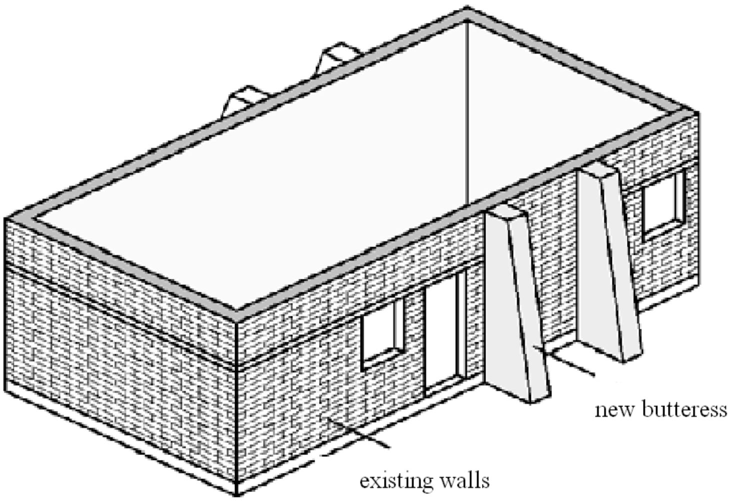

Fig. 1 – Strengthening an existing wall with buttresses.

2.2. Techniques Concerning Crack Treatment

a) *Repointig*. The strengthening solution is based on improving and reinforcing the damaged mortar joints due to leaking roofs or gutters, capillarity actions causing rising damp, extreme weather (freeze/thaw cycles), cracks along the joints due to differential settlements. The decision of repointing is related to some obvious signs of deterioration, such as disintegrating mortar, cracks in the mortar joints, missing bricks and stones, damp walls or damaged plasterwork. The technique consists in removing, cleaning, washing, filling the mortar joints with a new mortar (Fig. 2). This mortar should be compatible with the properties of the masonry units, resistant to agents of deterioration and it should have almost the same mechanical properties and durability as the original one. The main targets are: increasing the compressive and the shear strength, improving the appearance and reduction of deformation. (Mack & Speweik, 1998; Hassapis, 2000; Secondin, 2003).

Fig. 2 – Steps for repointing strengthening intervention.

b) *Structural repointing*. The strengthening actions consist in using steel reinforcement which involves the application of short steel rods across cracks caused by creep of the masonry assemblage under long-term high level dead loads (Fig. 3). This technique offers some advantages as reduced surface prepa-

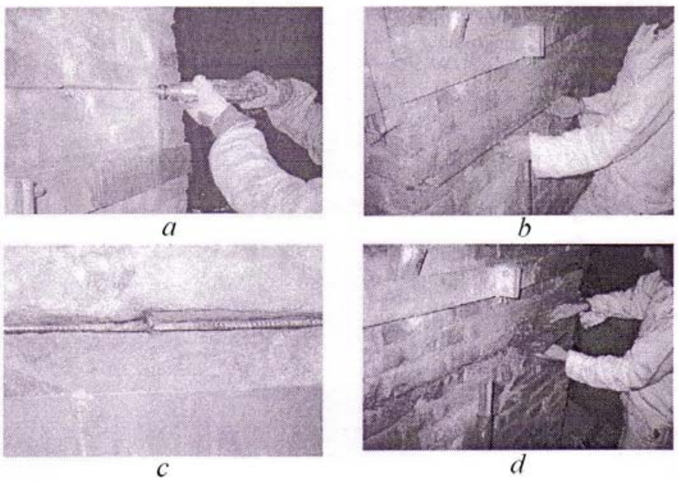

Fig. 3 – Steps for reinforced repointing strengthening intervention (Islam, 2008).

ration and preservation of aesthetics, the application of steel bars in the mortar matrix across the joint cracks. The main targets are: restoring the integrity and/or upgrading the shear and/or flexural capacity of walls, confining effect on the walls and improvement of the tensile behaviour of masonry due to steel anchorages in masonry (Islam, 2008).

c) *Covering and injecting the cracks*. The strengthening method consists in covering, injecting the mortar into the walls for anchoring, bonding the missing parts, increasing strength and stiffness of the wall by solid filling of hollows in masonry with cement mortar, fluid cement mortar or grout (depending on the size and density of the cracks) (Fig. 4). It is very important to assure a perfect filling and to avoid later contractions (shrink-back) after the water is absorbed from the mortar. The effectiveness of the strengthening technique depends on the mechanical properties (high tensile strength, high bond to mortar units) of the new injected material, and its chemical and physical compatibility with the original masonry. The main targets are: restoring the initial stiffness and improving lateral resistance of the retrofitted walls to in plane loads, filing existing cavities and internal voids to make the masonry more homogenous, to prevent displacements during earthquake actions and sealing possible cracks (Jeffs, 2000; Budescu *et al.*, 2001; ElGawady *et al.*, 2004).

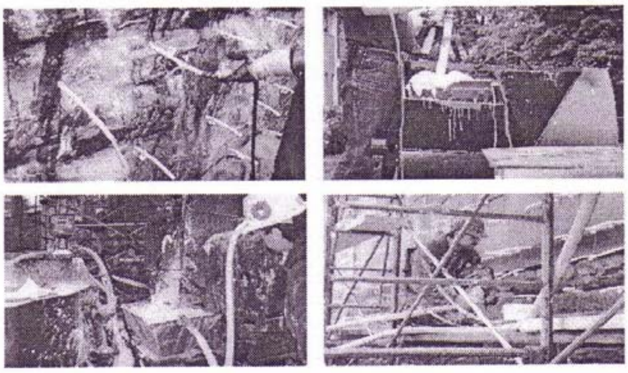

Fig. 4 – Technology of cracks injecting grout (Jeffs, 2000).

d) *Pinning-repairing cracks using steel pins.* The strengthening actions consist in inserting steel pins into holes drilled through the face of the masonry. After inserting the steel pins, epoxy resin or cement grout is injected in order to provide bonding of reinforcing bars to the masonry elements and to establish the load transfer mechanism. Pinning can be used to fix weak areas of masonry to the main structure, to stitch cracks, provide alternative routes for loads, and to improve the stability of the substrate. The main targets are: re-establishing the structural strength and its original appearance (Shrestha *et al.*, 2010; Glavan, 2004).

e) *Stitching – sewing large cracks*. The strengthening actions consist in sewing, tying together of cracked or damaged areas of masonry using different materials. One of the most common applications of stitching is to re-tie a wall on each side of a crack using steel ties laid into joints at different intervals. Sewing involves also injecting mortar in order to form a bonded contact between the reinforcement and the masonry elements as well as to prevent metal corrosion. The main targets are: increasing the mechanical properties and the element ductility (Trujilio Leon, 2007; Islam, 2008).

2.3. Technique Regarding Surface External Treatments

a) *Walls reinforcing overlays, jacketing*. The strengthening actions consist in the application of self-supporting reinforced concrete cover or a cement mortar matrix reinforced with independent bars, surrounding the structural elements. It is applied to elements subjected to high compression stresses and lateral deformation. Jacketing wall surfaces must be interconnected by means of through-wall anchors. The overlay starts from the foundations through a belt of reinforced concrete in order to ensure an effective transmission of loads to the soil. Overlays are not conceived to work independently, but they are designed to undertake the loads from the reinforced structure. With this view, the reinforcement is fixed to the masonry wall with steel connectors and staples, and the overlays are connected through the mortar ribs which are formed in the mortar joints. It is known that the effectiveness of the intervention is better when jacketing is applied on both sides of the wall, with diffuse connections. The main targets are: improving strength and stiffness, providing additional strength to seismic loads, obtaining a continuous confinement, a monolithic behaviour of the element (*Guide lines*..., 2006).

b) *The shotcrete technique*. The strengthening actions consist in spraying overlays made of a mixture from a mineral matrix onto the surface of a masonry wall over a mesh of reinforcing bars. The thickness of the shotcrete can be adapted according the requirements for the protection to seismic actions. The shotcrete overlay is usually reinforced with a welded wire fabric to the approximately minimum ratio for crack control. In order to transfer the shear stress on the entire surface of the shotcrete, shear dowels are fixed using epoxy resins or cement grout in holes drilled into masonry wall. However, there is no consensus regarding the bonding between the bricks and the shotcrete material or the need of using the anchor system (different diagonal tests shows that are not major improvements of the response to brick-shotcrete bonding). Moreover, it is recommended wetting the masonry surface before applying the shotcrete. This treatment does not affect the cracking or ultimate load, it only limits extended the inelastic deformations. The main targets are: increasing the ultimate load of the retrofitted walls, increasing of the capacity to axial loads and also to lateral ones, significant development of the energy dissipation mechanism, improving stability (El Gawady *et al.*, 2004).

c) *The ferrocement technique*. The strengthening actions consist in an orthotropic composite material matrix based on cement mortar of high resistance and multiple layers of steel meshes. The tensile strength of the ferrocement depends on the nature of the mesh, on the orientation and the thickness of the reinforcement. The main targets are: improving the behaviour to in plane and out-of-plane loads, the mesh increase in plane inelastic deformation capacity, ferrocement improves out-of-plane stability and arching action (Ţăranu, 2006; Singh & Paul, 2006).

d) *Rehabilitation using seismic bands technique*. The strengthening actions consist in applying a continuous band called *ring beam* or *collar beam* made of reinforced concrete at different levels of the building which provides horizontal bending strength preventing out-of-plane collapse of the walls. Horizontal bands should provided as follows: lintel band incorporates in itself all door and window lintels; roof and floor band it is required where timber or steel floor/roof structure has been used; gable band; sill band just below the window openings (Fig. 6). The main targets are: preventing shrinkage, temperature and settlement cracks, improves seismic safety of masonry buildings (Bothara *et al.*, 2002; Arya, 2005).

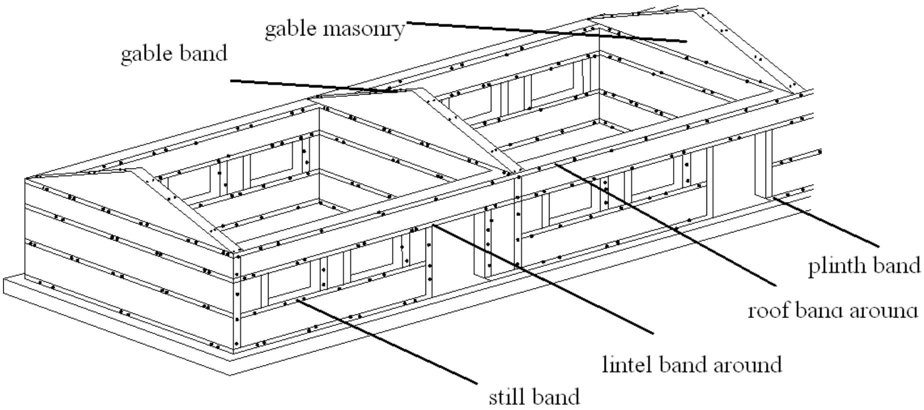

Fig. 6 – Strengthening bands at different levels.

2.4. Techniques Regarding External Reinforcement

a) *External steel plate reinforcement*. The strengthening actions consist in placing diagonal and vertical stripes on both sides of the element. Steel plates can be used as external reinforcement for unreinforced masonry buildings or lightly reinforced masonry walls. This method was studied by Taghadi *et al.*

(2000), and it follows the behaviour of the tested specimens to-in-plane actions, obtaining an increase of strengthening to this type of actions and it provides energy dissipation mechanism. The main targets are: preventing disintegration, increasing lateral resistance and improving ductility (El Gawady, 2004).

b) *External reinforcement using steel bars*. The strengthening actions consist in assembling of steel bars horizontally under the floors and roof levels in the main directions of the structure and connected to the walls by using anchor plates. This increases the development of the three-dimensional behaviour of the structure, improving connectivity between parts or subsystems of the structure, and supplying their unsatisfactory behaviour in case of out of plane loads. To ensure a good behaviour, the bars should have a proper thickness. The usual application of this technique is used in case of masonry structures with poor interconnections between the intersecting walls and in case of flexible roofs and floors (to increase stiffness to these diaphragms). The main targets are: improving the overall structural behaviour by ensuring seismic cooperation between structural elements (Islam, 2008; Kaya, 2009, Bothara & Brzev, 2011).

c) *External reinforcement using post-tensioning steel tie-rods*. The strengthening actions consist in the application of post-tensioning steel ties which involves the application of a compressive force on the masonry wall meant to experience tensile stresses under the effect of gravity or other external actions, lateral forces. This technology is mainly used for monument consolidation. Post-tensioning tie rods are usually made of treated steel bars. The steel bars, compared with polymer fibre reinforcements, have relaxing or residual deformations, as well as an adverse resistance/weight ratio. Another major disadvantage of steel bars is corrosion. But when using these consolidation methods with steel tie rods, tubes can be used for the tie rods. After post-tensioning and anchoring, the tubes are filled with grout or other materials that prevents corrosion. The main targets are: avoiding or closing cracks, improves lateral strength of unstrengthened specimens to-in-plane and out-of-plane loads (El Gawady, *et al*., 2004; Islam, 2008).

d) *External reinforcement using timber type wood elements*. The strengthening actions consist in: applications of timber wood on the external sides of the wall, locally or to the whole surface of the structure. This type of consolidation has been used mainly in Greece and the Mediterranean area ever since 5000 years ago. To observe the improvements of reinforced masonry structures using this system, tests for compression and diagonal compression (shear) were carried out. The chosen reinforcement method was the most commonly used in their case, two longitudinal wood plates, parallel to the two sides of the masonry wall connected by steel connectors with the two transversal reinforcement elements. The experimental results led to the following conclusions: the favourable effect of the reinforcement with wooden elements consists in the increasing of the shear load capacity of the masonry walls , the moderate increase of the ultimate load up to 20% due to the lateral confinement provided by the connection between the wood elements and the masonry. A significant influence on the metal connectors in the failure mode is also noticed. However, when adopting such a rehabilitation technology, there should be taken into consideration the aggressions to which the wood is subjected: rot, decay, etc. The main targets are: increasing ductility and obtaining a better behaviour of structure adding wood timbers that can take over tension (Vintzileou & Skoura, 2009).

e) *External reinforcement using pipes bracing system*. The strengthening actions consist in introducing prefabricated pipes into the ground (about 5 m deep), connected through the floors on each level. The lateral forces, especially caused by the seismic action, are transferred using this system from the floors to the foundation soil. To assess the performance obtained with the system, a series of tests were performed. 2 to 4 pipes with different diameters and thicknesses where mounted at the level of each floor giving special attention to the connecting mode, because of the transfer of the seismic force which takes place at this level (Fig. 7). The connection is made using steel profiles or reinforced concrete members. The floors are reinforced with bars arranged in an X shape and/or a layer of reinforced concrete. The results show that this system brings considerable contributions to the rigidity, strength and ductility of unreinforced masonry buildings (Mahmoudi & Ebadi, 2010).

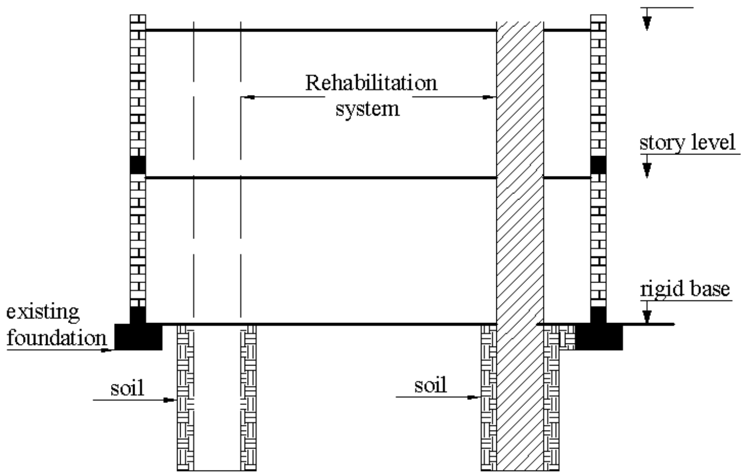

Fig. 7 – Pipe bracing system.

2.5. The Confinement Technique

a) *Masonry reinforcement using reinforced concrete tie columns*. The strengthening actions consist in: placing reinforced concrete tie-columns and tie-beams in unreinforced masonry walls which became confined. Masonry confined with reinforced concrete is also called the *weak framework*. In Europe, Eurocode 8 recommends this technique for masonry structures. In China this method is also used for the rehabilitation of masonry buildings. However, it is not easy to place the confinement in a masonry building already constructed. The basic characteristic of the confinement of a masonry structure is to achieve the vertical reinforced concrete elements, called *the tie-columns*, which are designed to confine the walls at all corners, in the areas where they intersect, as well as above the openings of the doors and the windows. To be effective, the tie-columns should intersect with the belts at the floors level. Study reveals that the tie-columns without belts do not show significant improvement of the walls behaviour. Confinement prevents decay and improves the ductility and the energy dissipation effect of the unreinforced masonry buildings, but with a limited effect in terms of load capacity. However, the real effect of confinement depends on the relative stiffness between the infill masonry wall and the framework and less on the properties of the materials. The effect of confinement can be neglected until cracks appear. However, in case of unreinforced masonry walls, confinement effect represents the increased resistance to cracking. In case of ultimate strength, the results are an increase to lateral actions. caused because of the lateral deformations and the energy dissipation limits are also increased. The main targets are: reducing out-of-plane bending effects in the walls, preventing disintegration, improving ductility and energy dissipation (El Gawady *et al*., 2004).

3. Conclusions

Conclusions of the presented study on strengthening and rehabilitation of masonry structures are that typical repairs may be classified according to their effects. These are divided into three categories as follows:

a) Cosmetic repairs that improve the appearance, restores the non-structural properties and weather protection of the component damaged; such as repointing, pinning.

b) Structural repairs that intend to restore structural properties of the components, namely: injections of cracks, structural repointing.

c) Structural strengthening, consisting in repairing of some parts of a structure or entire structure with the results of restoring load capacity or additional strength, or removal and replacement of existing damaged components. The main target is to replace the structural damaged components rather than to restore them, by adding new components like bands, overlays, etc.

The identification of the most effective intervention techniques requires an assessment of the seismic vulnerability and potential collapse mechanisms of the building due to constructive and technological deficiencies. Within a range of structurally efficient seismic retrofit upgrade options, considerations on cost and invasiveness will dictate the selection of the most appropriate solution, based on a case-by-case evaluation.

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METODE CONVENŢIONALE DE CONSOLIDARE ŞI REABILITARE A CONSTRUCŢIILOR DIN ZIDĂRIE

(Rezumat)

Studiul şi dezvoltarea metodelor de consolidare şi reabilitare a structurilor din zidărie reprezintă o preocupare permanentă a inginerilor constructori, datorită proporţiei ridicate a structuriilor de rezistenţă din zidărie existente şi a vulnerabilităţii acestora la solicitări excepţionale, în special din acţiunea seismică. Se expune o prezentare a metodologiilor de consolidare şi reabilitare a structurilor din zidărie existente prin metode ce folosesc materialele tradiţionale ca sisteme de reabilitare.