Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2017) 379-390

ECCOMAS Proceedia

COMPDYN 2017
6th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15–17 June 2017

INVESTIGATION OF STRENGTHENED MASONRY WALLS MADE OF EARTH BLOCK STRENGTHENED EXTERNALLY WITH GLASS AND STEEL FIBER MESHES UNDER CYCLIC LOADING

Ioanna PAPAYIANNI [1], Christina I. BATSOUKA [2], and Konstantinos KATAKALOS[1]

[1] School of Civil Engineering | Faculty of Engineering | Aristotle University of Thessaloniki
Thessaloniki, Greece
{papayian,kkatakal}@civil.auth.gr

[2] Interdepartmental Postgraduate Program "Protection, Conservation and Restoration of Cultural Monuments" | Faculty of Engineering | Aristotle University of Thessaloniki
Thessaloniki, Greece
christinabatsouka@gmail.com

Keywords: Stabilized-compressed Earth Blocks, Strengthening, Masonry wall, Glass-Steel Fiber Mesh, Cyclic Loading.

Abstract. *Structures constructed with materials from earth have attracted the interest of modern building designers because of many advantages that this old methodology is offering. The healthy internal climate and the low environmental footprint are the most significant advantages. In addition, there is an important asset of traditional earth block buildings in rural towns that need retrofitting to continue serving as houses. To this direction, externally bonded fiber meshes by using soil-based renderings, could provide a compatible and reversible method of strengthening. The experimental investigation of this study is focusing on constructing masonry wallet specimens with stabilized and compressed earth blocks and testing them under combined constant vertical with cycling horizontal loading, strengthened with and without externally bonded fiber meshes. Physio-mechanical characteristics of earth blocks have been determined. Two types of fiber meshes were used: glass fibers and stainless steel fibers. The bond between wall and fibers was achieved with soil-based renderings and a limited number of dowels (18) symmetrically embedded to the masonry with soil-based grout. Finally, three model walls were constructed and tested under horizontal cyclic loading sequence together with vertical normal stress of 1,1Mpa. The results showed that the strengthening methodology that was utilized was efficient and almost doubled the bearing capacity of the wall. Summarizing, it could be said that the use of earth blocks for construction purposes is a promising alternative methodology. The utilized strengthening technique proved to be efficient.*

Peer-review under responsibility of the organizing committee of COMPDYN 2017.
doi: 10.7712/120117.5427.18357

1 INTRODUCTION

Structures constructed with materials from earth constitute one of the largest ensembles of world architectural heritage. In Europe and in our case, in Greek rural towns, there is an important stock of traditional earth block buildings. Nowadays, most of them are in need of immediate restoration, due to extended damages, and retrofitting in order to keep their use as dwellings or introduce other compatible uses. The most common reason, why most of them have been abandoned from their owners is their vulnerability against earthquake and other physical phenomena, in contrast with other contemporary building materials, such us reinforced concrete. There are many researchers through time [1, 2, 3, 4, 5] who identify the typical pathology of such structures, which mainly derives from their low load bearing capacity while also from water and moisture action against earth material. On the other hand, studies over time [1, 6, 7] mention numerous advantages of building with earth. Low environmental footprint and the healthy internal climate are the most significant. During the last decades of the 20th century, earth-based material structures have attracted the interest of modern building designers, who reconsider this old methodology and are willing to revive it, in the light of bioclimatic architecture. However, they seem to be hesitant due to safety and functionality challenges. To this direction, optimization of earth building techniques via contemporary knowledge and technology is under request.

Different ways of producing new, more resistant earth building materials, via modifying earth's physio-mechanical properties, have already been examined by many researchers [8,9,10,11]. While, others have already conducted studies on alternative ways to improve the load bearing capacity of the whole earth structure [12, 13, 14, 15, 16, 17]. Both aspects have been subjects of studies at the Laboratory of Building Materials A.U.Th., with a special focus on compatible methods and materials restoring and further strengthening of historic earth block masonries [18, 1, 19, 20]. Those studies are reaching to the following two basic outcomes that are setting the base for the present paper. The first outcome concerns the use of stabilized-compressed earth blocks, which is preferable, rather than the traditional ones. The second outcome shows that strengthening of earth block masonry with externally bonded fiber meshes in synergy with soil-based rendering can be totally achieved. Both methods are efficient, compatible and reversible when in request of retrofitting historic earth block masonries.

This experimental research contributes to the further investigation of the efficiency of strengthening masonry specimens, constructed with stabilized and compressed earth blocks, with externally bonded fiber meshes, while also to the determination of an efficient way of applying the meshes to the masonry substrate, taking into account the prior experience [21, 22, 20].

2 EXPERIMENTAL PART

In this study, three masonry wallets were built with the use of stabilized-compressed self-produced earth blocks and soil-based bed mortar. One of the three wallets remained unstrengthened (T1: reference specimen), while the two others were strengthened with two types of fiber meshes (FRP); stainless steel fibers (T2: SRP specimen) and glass fibers (T3: GFRP specimen). In order to evaluate the seismic behavior of the masonry specimens, all three of them were tested to displacement controlled cyclic horizontal loading, under constant vertical compressive loading. The tests took place at the Laboratory of Experimental Strength of Materials and Structures of A.U.Th., using the available equipment.

2.1 Materials and Production

2.1.1. Earth blocks and wallets production

The materials used for the stabilized-compressed self-produced earth blocks were chosen after several laboratory tests. Specifically, after the analysis of the available clayey soil it was decided to stabilize it with the use of sand, cement and fly ash in appropriate ratio. The manufacture of the necessary amount of earth blocks was carried out in TECHNOBETON S.A. facilities, in a semi-automated way, using the laboratory-dictated recipe and following specific directions for the production, curing and drying conditions. Regarding the compression procedure, a hydraulic manual press was used, together with a custom-made mould designed by the research team. The exact composition and some mechanical characteristics of the produced earth block units of 19x9x8 cm^3 are given in Table 1.

Composition	σ_f (MPa)	σ_c (MPa)
soil 74%+sand 10%+cement 8%+ fly ash 8% by mass	2,24	8,44

Table 1: Composition and mechanical characteristics of stabilized-compressed earth blocks.

The materials used for the joint mortar of the wallet specimens were selected on the basis of two criteria: the compatibility with the earth blocks' mixture and the speed of its hardening. In Table 2 are presented the exact composition and the main characteristics of the mortar used in each specimen. It should be mentioned that the difference of the mortar's quality between the three wallets is a result of the manual and partial preparation of the materials during the constructional procedure. Every sub-mixture gave rectangular samples of 4x4x16cm^3 that were tested in order to determine the flexural strength (σ_f) of the mortars. The compressive strength (σ_c) was tested in the sub-segments of the rectangular samples, after the completion of the flexural test. Both tests held on after almost 20 days of curing.

Composition	Mortar ID	Water/Dry material	Expansion (cm)	σ_f (MPa)	σ_c (MPa)
soil 63%+sand 10%+ cement 27% by mass	K1	0,360	20,83	1,61	10,07
	K2	0,355	20,50	1,73	5,33
	K3	0,350	21,55	1,72	6,63

Table 2: Composition and mechanical characteristics of joint mortar.

The wallet specimens (80x78x9) cm^3 were built in the facilities of the Laboratory of Building Materials A.U.Th. by the research team. Their geometry can be described as single-wythe wallets, with 8 courses of earth blocks. Each course consists of 4 blocks arranged in a centric bonding. The thickness of mortar joints was about 1-1,5cm.

An estimation of the compressive strength of each wallet specimen was attempted, considering the mechanical characteristics of the wallets' individual materials and their geometry. The estimation was made according to Eurocode 6 expression about the calculation of the characteristic compressive strength (1), although it refers to other type of masonries except for the earth block ones, since there is no specific regulatory framework.

The equation of Eurocode 6 [23] is the following:

$$f_{ck} = K \, x \, f_b^{0.65} \, x \, f_m^{0.25} \quad (1)$$

where f_b = normalized compressive strength of the masonry unit and f_m= mean compressive strength of the masonry mortar.

To convert the compressive strength of the masonry unit (σ_c) to normalized compressive strength (f_b), it is multiplied by a factor which value was defined equal to 0,730.
The calculations and the results of the characteristic compressive strength of each specimen are shown in Table 3.

Specimen code	K factor	f_m (MPa)	f_b (MPa)	f_{ck} (MPa)
T1	0,55	10,40	6,16	3,96
T2	0,55	5,25	6,16	3,23
T3	0,55	6,92	6,16	3,51

Table 3: Calculation of characteristic compressive strength of specimens according to Eurocode 6.

2.1.2. Reinforcement materials

Regarding the reinforcement materials, two types of fiber meshes (FRP) were used; a bidirectional glass fibers mesh (GFRP) and a unidirectional stainless steel fiber mesh (SRP). Their technical characteristics are presented in Table 4.

Mesh type	Direction	Size (mm)	Tensile force (kN/m)	Elongation at failure (%)	Young modulus (GPa)	Weight Density (kg/m^2)
GFRP/FT	horizontal (weft)	18,1x14,3	77	4,1	80	0,36
	vertical (warp)	18,1x14,3	76	3,45	80	0,36
SRP/GST	main	5,5x5,5	235	>1,5	190	0,67

Table 4: Technical characteristics of fiber meshes [amended from Papayianni et al, 2016].

For the fixation of the meshes on the two wallets and the coating of all three, stabilized, soil-based mortar was used (Table 5). The selection of the renderings' mixture was guided by the requirement of good adhesion between the rendering and the substratum, without disrupting the moisture movement through the masonry's body, while also by the need for adequate workability of the mortar.

Composition	Water/Dry material
soil 70% + cement 30% + super plasticizer RHEOBUILD1-2 1% by mass	0,42

Table 5: Composition and water/dry material ratio of coating mortar.

The same mixture was also used for grouting, with the difference that the soil was further sieved in order to assure the grout's fluidity.

2.2 Experimental Tests of earth-block wallets

2.2.1. Strengthening technique

The strengthening technique included the application of fiber meshes in both sides of the two wallets (T2, T3). Regarding the fixation of the meshes, they were, at first, adhered to the wallets by soil-based coating mortar, and right after that, they got mechanically anchored to them by stainless steel bars of 4 mm diameter together with stainless steel washers and nuts, as described in Figure 1.

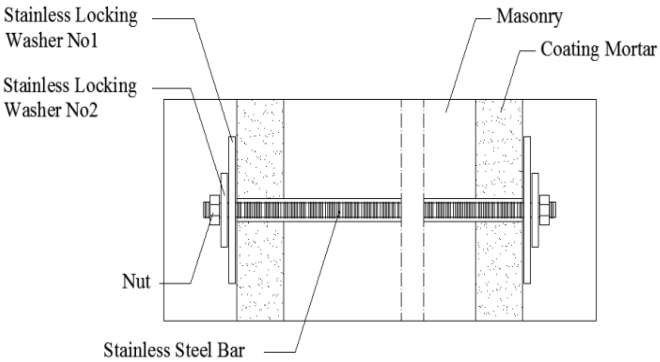

Figure 1: Mechanical anchorage applied on a wall section [20].

More especially, at first, a number of 18 holes of 6mm diameter were drilled symmetrically on the wallets to position the dowels (Figure 2). In order to develop sufficient adhesion between the rendering and the substratum, wetting the wallets' surfaces with highly diluted coating mortar, and drenching took place. A first layer of rendering was applied via a masonry trowel. Afterwards, the meshes were placed manually, via soft pressure against the rendered wallets. The procedure was completed after the necessary layering of the rendering, in order to reach 1,5cm thickness on each side. At last, grout was injected into the holes of the walls, where the stainless-steel bars were placed, with the use of a syringe. After hardening of the grout the stainless-steel washers and nuts were applied and the anchorage process was completed.

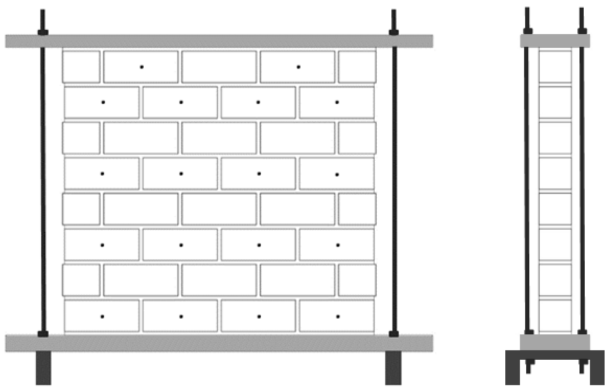

Figure 2: Wallets geometry and symmetrically drilled holes for the anchor.

It should be noted that the reference specimen (T1) was only coated with the coating mortar on both sides, following the same procedure, except the meshes application.

2.2.2. Experimental apparatus and test procedure

The shear strength tests of the wallets under in-plane cyclic horizontal load with combined constant vertical pressure was held at the Laboratory of Experimental Strength of Materials and Structures of A.U.Th, with the use of a steel framework. The wallets had to be mounted on a custom-made base with metal corners to be assured against horizontal sliding. The specimen was placed centrally to the engine load axis (Figure 3).

Figure 3: Steel framework and test pattern used for shear strength testing.

The test pattern consisted of a) hydraulic jacks and load cells applying the vertical and horizontal loading, b) a roller mechanism placed on the top of the wallet and, c) five electrical transducers (LVDT) for the measurement of displacements (Figure 4).

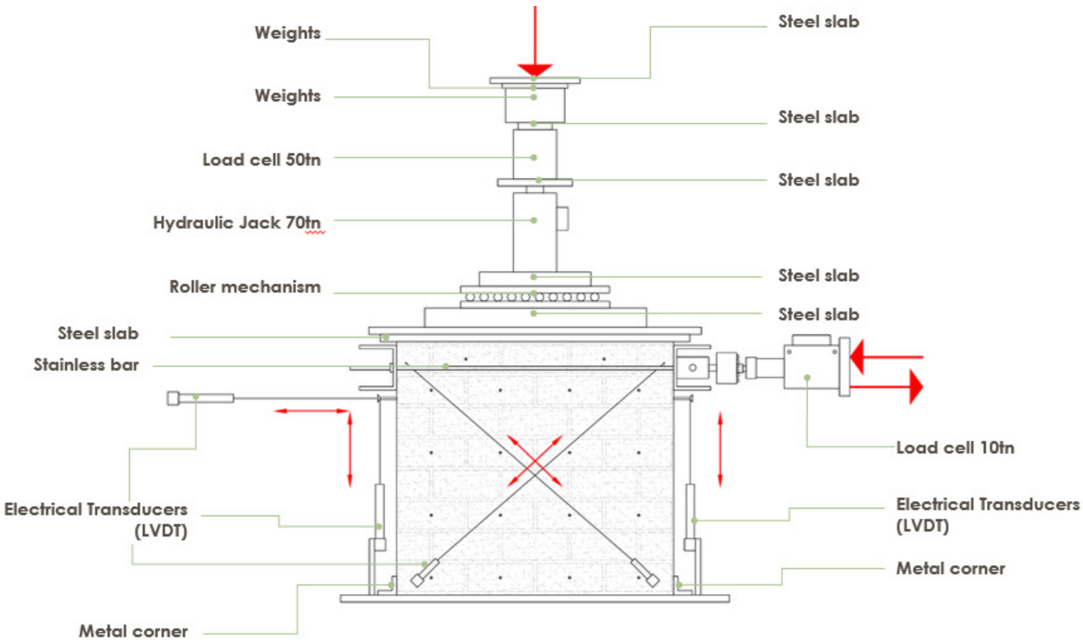

Figure 4: Experimental apparatus and test pattern used for shear strength testing.

Pre-compression under 8KN compressive axial force was applied to the wallets, while during the horizontal cyclic loading sequence the compressive force was increased tenfold, corresponding to vertical normal stress of 1,1Mpa.

The horizontal bearing loads and displacements of the tested specimens were being recorded via a data acquisition system. Curves representing the branches of loading and unloading of the successive cycles came as a result. Figure 5 presents the envelope curves that illustrate both the positive and negative horizontal load (KN) in relation to the horizontal displacements (mm) of each wallet. The shear strength test results have been compiled in Table 6.

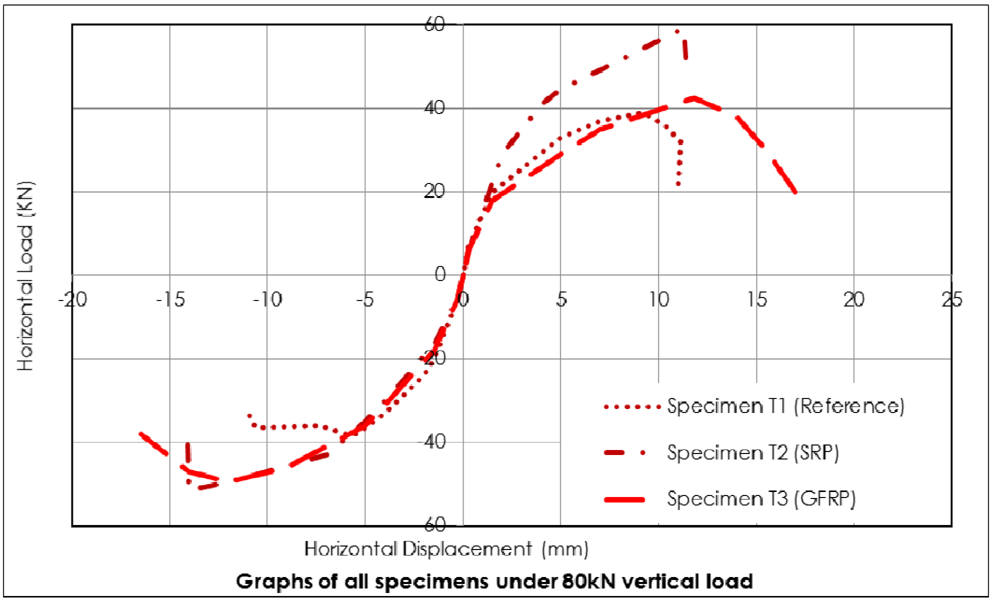

Figure 5: Horizontal Load/Horizontal Displacement envelope curves of all three specimens.

Specimen code	Fmax (KN)	Fmin (KN)	Max strain (mm)	Min strain (mm)
T1	39,0	-38,0	11,0	-11,0
T2	58,2	-50,6	11,4	-14,1
T3	42,4	-49,5	17,0	-16,5

Table 6: Shear strength test results: horizontal load (F max, min) and displacement capacity (max, min strain).

2.3 Results

Results were obtained through the evaluation of each wallet's failure mode and the interpretation of the horizontal load/horizontal displacement curves. The following interpretation leads to outcomes related to the strength, the displacement capacity and the energy absorption of each wallet.

2.3.1. Mode of Failure of tested wallet specimens

The failure mode observations were implemented after the deposition of the renderings and/or the fiber meshes from the wallets' surfaces, in order to increase the accuracy of the results.

Regarding the general failure mode of both specimens T1 (reference specimen) and T3 (GFRP specimen) the observations were quite similar, showing a complex shear and tensile failure mechanism. The mode and the succession of the cracks correspond to the typical response of masonries subjected to plate shear.

More especially, on the reference specimen (T1) cracking started from the compressed base corner on the one side and, afterwards, tension cracks were observed in the middle of the other side. At last, diagonal shear cracks appeared in both directions, causing partial detachment of the rendering from the wallet's surface and, further, joint and masonry unit failure. As shown in Figure 6, one side of the specimen suffered more severe cracking and mostly in diagonal direction, while in the rest of the specimen's body appeared smaller and shorter cracks with vertical or slightly diagonal direction.

Figure 6: Failure mode of specimen T1 during the test completion (left) and after the rendering's deposition (right). Cracks are marked with red (severe cracking/detachments) and blue (slighter/superficial cracking) color.

Regarding specimen (T3) the GFRP reinforcement was evaluated as successful. The main pathology that the masonry developed during the loading were cracking caused mainly by joint failure, local failure of some blocks, and detachment of the rendering along the zone between the middle and the base of the wallet. In the same zone and between the anchors, deformation of the glass fiber mesh appeared, as shown in Figure 7. The mesh's presence contributed to the reduction of the cracks' number and width, although the cracking progress had similarities to the unstrengthened specimen's.

The failure mode of T2 specimen showed that the lower half part of the wallet manifested the greater expansion. The same observation has been referred by other researchers [20] and thus should be further examined.

Figure 7: Failure mode of specimen T3 during the test completion (left) and after the rendering's deposition (right). Cracks are marked with red (severe cracking/detachments) and blue (slighter/superficial cracking) color. Expansion noticed at the lower half part of the wallet (middle).

It is also important to be mentioned that the deposition of the glass fiber mesh and the rendering from the wallet's body was easy, since both materials were turned into a block, causing minor harm to the substratum (Figure 8).

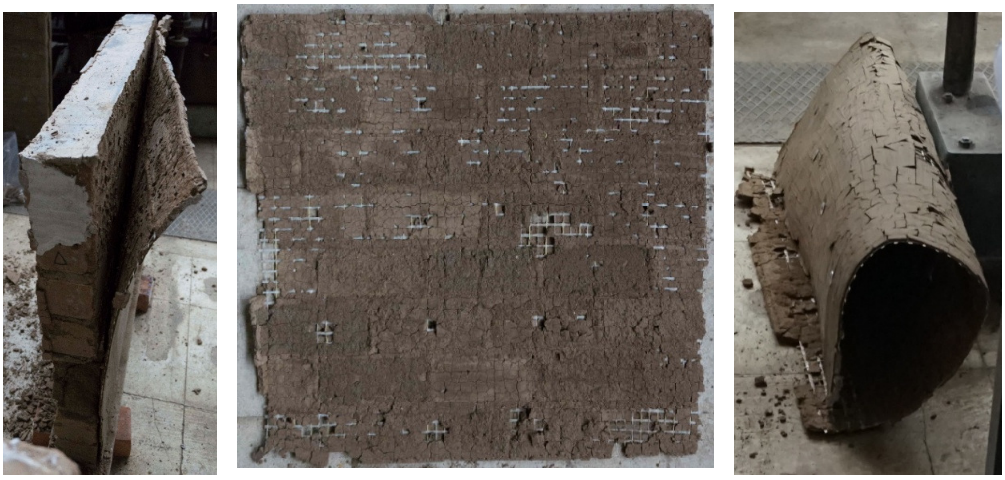

Figure 8: Deposition of the GFRP mesh together with the rendering, as a block, from the wallet's body.

As regards the last wallet (T3) which was strengthened with the SRP mesh, the failure mode could not be determined because of an unexpected interruption of the experiment, due to a constructional flaw that was related to the renderings application. The experiment was interrupted before any typical appearance of pathology, except of a local cracking and detachment of the rendering on the upper corner of the wallet, as shown in Figure 9.

Figure 9: Local pathology of the upper corner of the wallet after the experiment's unexpected interruption

2.3.2. Strength of tested wallet specimens

The comparison between the envelope curves of each specimen concluded to significant differences concerning their mechanical and flexural characteristics. The horizontal load capacity of the GFRP specimen (T3) appeared increased at a rate of 26,9% in comparison to the reference specimen. As regard to the SRP specimen (T2), it presented increased strength at least at a rate of 49,2%. However, due to the experiment's interruption, the recorded maximum horizontal load for specimen T2 did not correspond to the wallet's load capacity, but only to the "lower limit" of its strength. As a result, the actual rate of load capacity increase is supposed to be even higher. As expected, the use of the SRP mesh presented higher efficiency than the GFRP mesh, due to the better mechanical characteristics of the first one.

2.3.3. Displacements of tested wallet specimens

Regarding the horizontal displacement capacity of each wallet, the GFRP mesh (T3 specimen) contributed to a significant upgrade of a rate of 54,5% in comparison to the unstrengthened wallet. The SRP mesh increased the displacement capacity of the wallet specimen at least at a rate of 28,2%, although this rate does not represent the maximum possible displacement, due to the premature specimen's failure.

2.3.4. Energy absorption of tested wallet specimens

The energy absorption that took place during the shear strength testing of the wallets were graphically estimated, by use of the envelope curves. For both strengthened specimen, T3 and T2, there was a spectacular increase of energy absorption, at a rate of 70,1% and 50,0% respectively.

3 CONCLUSIONS

- With appropriate stabilization of the soil, the production of compressed earth blocks of mean compression strength of 8,44 MPa, i.e. normalized compression strength (Eurocode 6) of 6,16 MPa, was attained.
- The production of earth block wallets of a theoretical, calculated with the use of Eurocode 6 expressions, characteristic compressive strength of 3,57 MPa was attained. This strength value can be considered as comparable to the strength values of bricklaying masonries.
- During the shear strength test of wallet specimens under combined in-plane horizontal cyclic loading together with vertical constant compressive loading, it was proven that the strengthening technique of earth block masonries with attached SRP or GFRP meshes in both sides, which are fixed by soil-based renderings and local stainless steel anchors, is an efficient strengthening technique.
- The horizontal load bearing capacity of the strengthened specimens was increased more than 49%,compared to the unstrengthened one. An upgrade was, also, noted in horizontal displacement capacity, reaching the rate of 54,5%. Finally, the energy absorption during the shear test increased over 70%.
- It is an absolute prerequisite to establish a specific regulatory framework, which will allow the evaluation of the mechanical behavior of earth block masonries and will propose appropriate strengthening techniques for the increase of their load bearing capacity. The existence of such a regulatory framework is necessary both for retrofitting old earth block masonries and for constructing new safe earth-based buildings. The results of this research could be of use to the development of technological expertise related to the strengthening of earth block walls by using fiber meshes.

REFERENCES

[1] I. Papayianni, V. Pachta, Earth block houses of historic centers. A sustainable upgrading with compatible repair materials. *International Conference on Sustainable Synergies from Buildings to the Urban Scale (SBE16)*, 2016. Retrieved from: https://www.researchgate.net.

[2] R. Illampas, D.C. Charmpis, I. Ioannou, Laboratory testing and finite element simulation of the structural response of an adobe masonry building under horizontal loading. *Engineering Structures,* **80**, 362-376, 2014.

[3] M. Blondet, G. V. Garcia, M. S. Brzev, A. Rubinos, *Earthquake-resistant construction of adobe buildings: A tutorial [2nd Ed.]*, 2011. Retrieved from: http://www.world-housing.net.

[4] P. Oliver, Earth as a Building Material Today. *Oxford Art Journal*, ***5***(2*)*, 31-38, 1983. Retrieved from: http://www.jstor.org.

[5] P. W. Brown, J.R. Clifton, Adobe I: The Properties of Adobe. *Studies in Conservation,* **23**, 139-146, 1978. Retrieved from: https://www.researchgate.net.

[6] G. Minke, *Building with Earth - Design and Technology of Sustainable Architecture*. Germany: Birkhäuser-Publishers for Architecture, 2006.

[7] B. Berge, *The Ecology of Building Materials.* Oxford: Architectural Press, 2000.

[8] E. K. Anastasiou, I. Papayianni, S. Konopissi, M. Papachristoforou, Fly Ash - Red Mud Mixtures for Masonry Block Production. *1st Concrete Innovation Conference, Oslo, Norway,* 2014. Retrieved from: https://www.researchgate.net.

[9] F. Aymerich, L. Fenu, L. Francesconi, P. Meloni, Fracture behaviour of a fibre reinforced earthen material under static and impact flexural loading. *Construction and Building Materials,* ***109**,* 109-119, 2016.

[10] T. Galer, H. Guillaud, T. Joffroy, C. Norton, O. Salaza, *Compressed Earth Blocks - Manual of design and construction*: A Publication of Deutsches Zentrum Für Entwicklungstechnologien - GATE, a Division of the Deutsche Gesellschaft Für Technische Zusammenarbeit (GTZ) GmbH in Coordination with the Building Advisory Service and Information Network - BASIN. Vol. II. Braunschweig: Vieweg, 1995. Retrieved from EcoHabitar website: http://www.ecohabitar.org.

[11] R. Rahimnia, D. Heydari, The relationship between clay quantity of soils and mechanical strength of adobes stabilized by cement: An approach to conservation and modern materials, (n.d.). Retrieved from Academia website: https://www.academia.edu.

[12] M. Blondet, D. Torrealva, J. Vargas, J. Velasquez, N. Tarque, Seismic Reinforcement of Adobe Houses Using External Polymer Mesh. *First European Conference on Earthquake Engineering and Seismology,* Geneva, Switzerland, 3-8 September, 2006.

[13] D.M. Dowling, B. Samali, Low cost and low tech reinforcement systems for improved earthquake resistance of mud brick. Proc. Of *Getty Seismic Adobe Project 2006 Colloquium*, The Getty Conservation Institute, 22-33, 2009.

[14] P. Mayorca, K. Meguro, Proposal of an effective technique for retroffiting unreinforced masonry dwellings, Proc of *13th World Conf. on Earthquake Engineering*, Vancouver, Canada, 2004.

[15] J. Thomson, *Strengthening of structural elements of adobe constructions against seismic loads.* (Master's Thesis). Czech Technical University in Prague - Erasmus Mundus, 2011. Retrieved from: https://upcommons.upc.edu.

[16] L. Turanli, A. Saritas, Strengthening the structural behavior of adobe walls through the use of plaster reinforcement mesh. *Construction and Building Materials,* **25**, 1747-1752, 2011.

[17] L.E. Yamin, C.A. Phillips, J.C. Reyes, D. M. Ruiz, Seismic behavior and rehabilitation alternatives for adobe and rammed earth buildings. *The 13th World Conference on Earthquake Engineering,* Vancouver, B.C., Canada, August 1-6, 2004. Retrieved from: www.iitk.ac.in.

[18] I. Papayianni, Restoration of earth block building in vernacular architecture. Materials and techniques for their repair. *European Technology Platform Construction Aspects for Heritage Protection (ECTP*), Dubrovnik, Croatia, 2006.

[19] G. Bei, Earth Masonry: Experimental Investigation of physical and mechanical characteristics of units and wallets made with compressed earth blocks. (PhD).Aristotle University of Thessaloniki, Greece, 2004.

[20] I. Papayianni, M. Drygiannakis, G.M. Zarmpoutis, G. Mitolidis, K. Katakalos, Experimental study on retrofitting earth block masonry. *10th International Conference on Structural Analysis of Historical Constructions*, Leuven, 2016.

[21] G. Mitolidis, Experimental investigation of reinforced concrete beams strengthened with steel reinforced (SRP) and carbon fibre reinforced (CFRP) composites. (PhD). Aristotle University of Thessaloniki, Greece, 2009.

[22] K. Katakalos Experimental and numerical investigation of R/C beams strengthened externally with open hoop strips of either CFRP or SFRP with or without anchorage under monotonic or cyclic loadings. (PhD). Aristotle University of Thessaloniki, Greece, 2013.

[23] Eurocode 6 Design of Masonry Structures ; BS EN 1996-1 (2005) +A1:2012: Rules for Reinforced and Unreinforced masonry.

[24] I. Papayianni, G. Bei, Low Cost Construction with Stabilized Mud Bricks. Proceedings of *International Conference Modern Earth Building 2002,* Berlin, Germany, 80-90, 2002.

[25] G. Bei, Raw earth: an ancient and modern building material. (Master's Thesis). Katholicke Universiteit Leuven, Belgium, 1996.

[26] T. Kotak, Constructing cement stabilized rammed earth houses in Gujarat after 2001 Bhuj earthquake, Proc. Of *Int. Symp on Earthen Structures*, 62-71, Bangalore, 2007.

[27] I. Papayianni, M. Argyropoulos, B. Pachta, Consolidation of mud brick masonries with earth based grouts. Materials and application. Proc. *2nd Conf. of Anastylosis* (ETEPAM), Athens, Greece, 2009.

[28] R. Ramcke, Masonry in architecture. In A. Gabriel *et al. (Eds.), Masonry Construction Manual*, 8-53, Basel: Birkhäuser, 2001.