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Triplet Shear Tests on Retrofitted Brickwork Masonry Walls

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***Abstract*—**The main objective of this experimental study is to assess the shear strength and the crack behavior of the triplets built of perforated brickwork masonry elements. In order to observe the influence of shear resistance and energy dissipating before and after retrofitting applications by using the reinforcing system, static-cyclic shear tests were employed in the structural mechanics laboratory of Sakarya University. The reinforcing system is composed of hybrid multiaxial seismic fabric consisting of alkali resistant glass and polypropylene fibers. The plaster as bonding material used in the specimen's retrofitting consists of expanded glass granular. In order to acquire exact measuring data about the failure behavior of the two mortar joints under shear stressing, vertical load-controlled cylinder having force capacity of 50 kN and loading rate of 1.5 mm/min. with an internal inductive displacement transducers is carried out perpendicular to the triplet specimens. In this study, a total of six triplet specimens with textile reinforcement were prepared for these shear bond tests. The three of them were produced as single-sided reinforced triplets with seismic fabric, while the others were strengthened on both sides. In addition, three triplet specimens without retrofitting and plaster were also tested as reference samples. The obtained test results were given in the manner of force-displacement relationships, ductility coefficients and shear strength parameters comparatively. It is concluded that two-side seismic textile applications on masonry elements with relevant plaster have considerably increased the sheer force resistance and the ductility capacity.

***Keywords*—**Triplet shears tests, retrofitting, seismic fabric, perforated brickwork, expanded glass granular.

I. Introduction

THE considerable number of old masonry structures used for housing in Anatolia cities, most of which are part of the cultural heritage, are at risk for potential earthquakes due to lack of their ductility capacity and shear resistance. In order to enhance the seismic performance of load-bearing masonry walls and preserve these cultural heritages from the prospective strong ground motions, rehabilitation and retrofitting of unreinforced masonry structures should be a substantial subject in structural engineering. In this context, composite textile materials provide viable, effective solutions for strengthening masonry walls subjected shear stress caused by earthquake inertial forces. Several significant research studies on this subject were accomplished in different parts of the world [1], [2]. Many experimental setups and different wall components were used by researchers to fully understand the response mechanism of the reinforced masonry wall specimens and the crack pattern [3]-[5]. Within the scope of small scale tests, using various test methods, the behavior of brick-mortar interface under shear stresses, strength parameters, and deformability capacity are investigated carefully [6]-[8]. Experimental programs include full-scale specimens prepared for existing wall sizes as well as small-scale test samples [9], [10].

This paper focuses on the mechanical behavior of brickworks masonry walls before and after rehabilitation by using a textile retrofitting system. This system consists of alkali resistant glass-polypropylene fiber and expanded glass granular based plaster. In order to reveal the effect between single and two-sided seismic textile applications on the shear performance of masonry elements with relevant plaster, static-cyclic shear tests were employed on triplet specimens. In this experimental study, the thickness of the plaster layer for single and two-sided applications is considered as 2 cm and 1 cm, respectively.

Non-strengthening specimens named as reference samples are also examined and the results of these tests are compared with those of retrofitted specimens in terms of force-displacement relationships, ductility coefficients, and shear strength parameters.

II. Experimental Setup and Testing Procedure

In this study, all experimental tests were executed at the structural mechanics laboratory of Sakarya University. A vertical load-controlled cylinder having force capacity of 50 kN and loading rate of 1.5 mm/min. was applied perpendicularly to the triplet specimens to investigate the failure behavior of the two mortar joints under shear stress. Triplet shear tests were conducted on perforated brick blocks with and without seismic retrofitting.

A steel plate with a thickness of 12 mm was situated on the middle brick of the triplet specimen in order to reduce the influence of the bending moment and transmit the load properly to the mortar. For providing the stability of the test setup, the outer two bricks were also supported by two steel L profiles. The results of the experimental study are recorded by a displacement sensor integrated into the load cylinder.

Technical features of perforated bricks are given in the Table I. Each produced test set consists of a triplet of perforated brick blocks with three identical specimens (Fig. 1). Moreover, there are three sets of triplet specimens of which two of them were strengthened by using seismic fabric and its special plaster. The remaining one set of non-strengthening

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samples was evaluated as a reference.

TABLE I
PROPERTIES OF BRICK

Property	Unit	Value
Dimension	cm	19*29*13.5
Consumption	pcs/m^2	22-35
Gross Dry Unit Vol. Mass	kg/m^3	700
Net Dry Unit Vol. Mass	kg/m^3	1800
Pressure Strength	N/mm^2	10
Thermal Conductivity Factor	W/mK	0.32
Fire Resistance	-	A1
Tolerance Category	-	T1

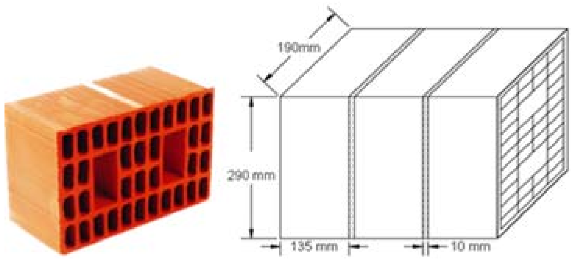


Fig. 1 Brick block and triplet specimen

The plaster and seismic fabric are implemented in two forms: Unilateral (D1G03) and bilateral (D1G04-T). Additionally, the thickness of plaster layer is equal to 2 cm for D1G03 and 1 cm (on each surface) for D1G04-T. The strengthening process is a combination of multi-axis hybrid seismic textile and special adhesive plaster (Fig. 2). This textile material comprises of alkali-resistant glass and polypropylene fibers.

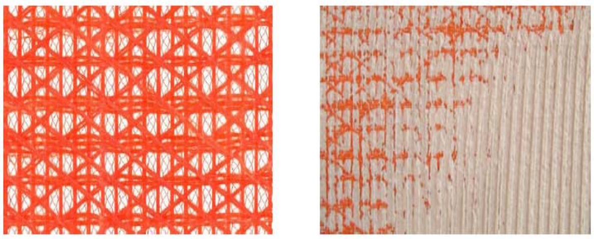


Fig. 2 The hybrid multiaxial seismic textile

The aim of this research is to observe the failure behavior and the mortar resistance under shear stresses of masonry units strengthened with composite material. For this objective, triplet shear experiments were performed for non-strengthened and strengthened test specimens. Test results of both types of specimens were compared with each other in terms of load-displacement relationship and deformation capacity.

Test device in which all experiments conducted and the scheme of triplet test are illustrated in Fig. 3. The relevant thickness parameters (t_s) used in the triplet shear test are t_{s1}=30 mm, t_{s2}=12 mm and t_{s3}=12 mm, respectively.

A code was given to each test group within the scope of the experiment program. Table II shows the name of the specimens with and without the textile composite material.

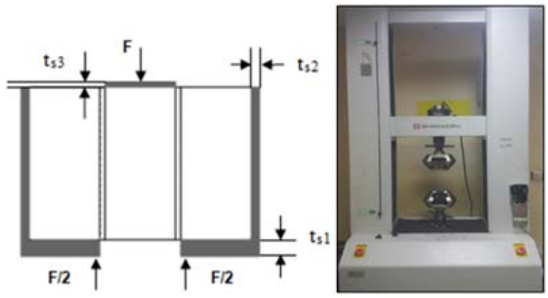


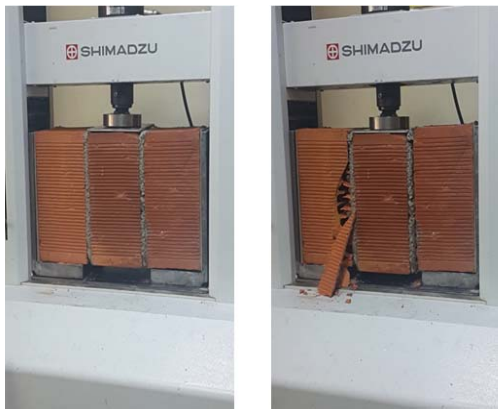
Fig. 3 Scheme of triplet shear test and test device

TABLE II
CODES OF TEST SPECIMENS

Name	Strengthening Situation	Plaster Type
D1R00	Reference	Without plaster
D1G03	Yes/Unilateral	Glass granular based
D1G04-T	Yes/Bilateral	Glass granular based

III. EXPERIMENTAL AND ANALYTICAL RESULTS

Firstly, the shear capacity was investigated without applying any plaster which was defined as the reference sample of the non-retrofitted masonry specimen. To describe this case, the non-strengthened control specimens are called as D1R00. Due to the fact that there are three specimens for each experiment set, each sample in the set is designated as D1R00-1, D1R00-2, and D1R00-3, respectively. Both initial and final states of failure under triplet shear test for D1R00-1 are given in Fig. 4.



(a) (b)

Fig. 4 (a) Initial state and (b) final state of D1R00-1

The maximum shear force F_{max} for this sample is obtained as 12200 N. The attained force-displacement relationship is illustrated in Fig. 5.

The shear strength, f_v is calculated according to EN 1052-3 [12] as given in (1).

$$fv = \frac{Fmax}{2A} \tag{1}$$

where $Fmax$ is the maximum value of the shear force and A is the cross sectional area of the joint. Additionally, characteristic value of the shear strength f_{vk} is calculated with (2):

$$fvk = 0.8 * fv \tag{2}$$

Similarly, triplet shear tests were performed for the D1R00-2 and D1R00-3 and the resulting crack forms are shown in Figs. 6 and 8, respectively.

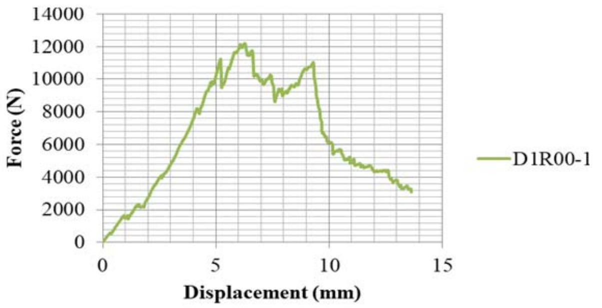


Fig. 5 Force-displacement diagram of the D1R00-1

(a) (b)

Fig. 6 (a) Initial state and (b) final state of D1R00-2

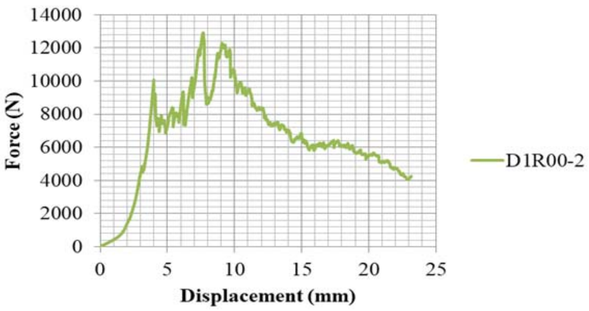


Fig. 7 Force-displacement diagram of the D1R00-2

As can be seen from Figs. 7 and 9, due to lack of ductility, the shear strength of the brick units suddenly decreased and brittle fractures occurred rapidly under stress. These damages are abrupt. The failure surface of specimen exhibits little degradation before the fracture occurs.

In this case, the shear strength, f_v are calculated as 0.117 MPa and 0.138 MPa by considering the experimentally obtained maximum force of 12920 N and 15316 N, respectively.

(a) (b)

Fig. 8 (a) Initial state and (b) final state of D1R00-3

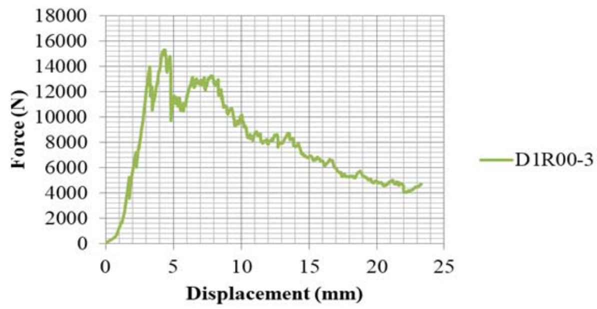
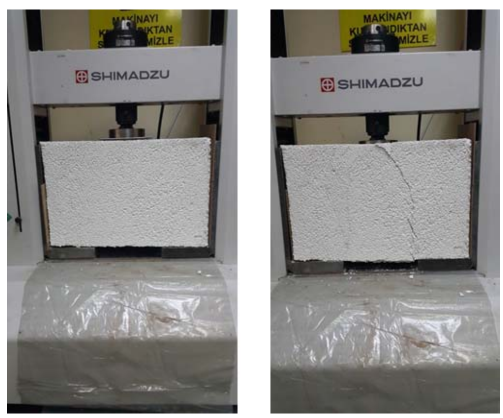


Fig. 9 Force-displacement diagram of the D1R00-3

In the second stage of the experimental study, the effect of the applied seismic textile and the plaster made of expanded glass granular on the shear capacity of mortar joints was investigated. Hereby, the one-sided retrofitted brick specimen with 20 mm reinforcing layer is named as D1G03 for triplet shear test. Firstly, D1G03-1 was tested. The crack pattern of this specimen can be seen in Fig. 10.



(a) (b)

Fig. 10 (a) Initial state and (b) final state of D1G03-1

The first cracks on the specimens under shear forces were experienced in vertical form and occurred in brick-mortar interface. When the imposed load reached close to the shear strength capacity of the specimen, the crack widths increased and the middle block separated from the joint plane.

As shown in Fig. 11, the maximum shear force F_{max} is obtained as 23033 N and the corresponding shear stress value f_v is calculated as 0.209 MPa for specimen of D1G03-1.

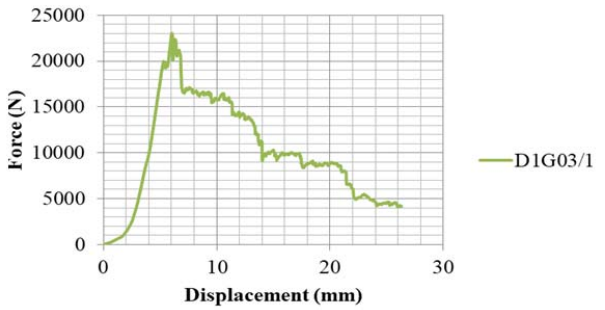
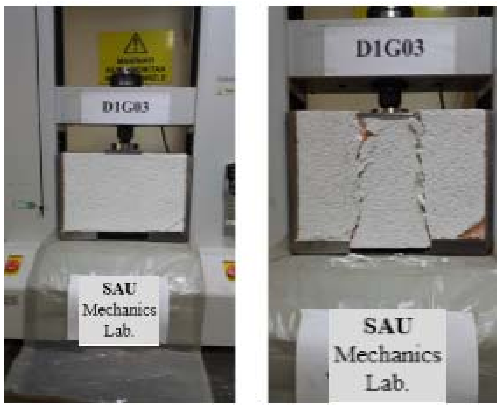


Fig. 11 Force-displacement diagram of the D1G03-1

For the D1G03-2 and D1G03-3 specimens; crack patterns, maximum shear loads and strength parameters were similarly determined. The failure mechanism of the test specimens under the vertical load is shown in Figs. 12 and 14. The maximum shear forces of the second and third sample of the D1G03 test set are equal to 24548 N and 29427 N, respectively (Figs. 13 and 15).



(a) (b)

Fig. 12 (a) Initial state and (b) final state of D1G03-2

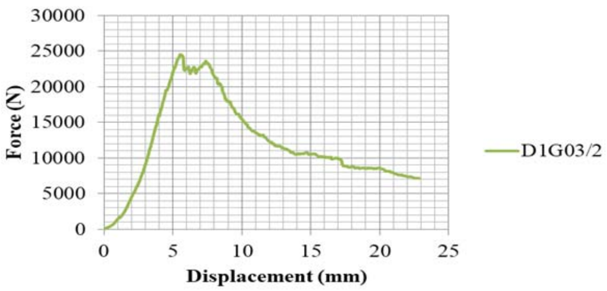
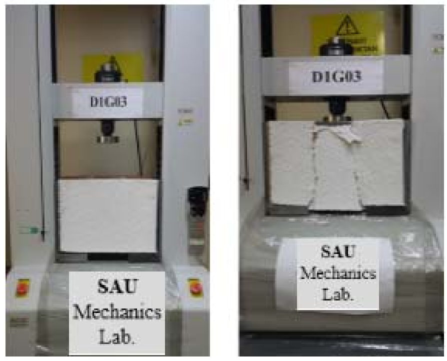


Fig. 13 Force-displacement diagram of the D1G03-2

The values of f_v are 0.220 MPa and 0.267 MPa for D1G03-2 and D1G03-3, respectively. Single-sided retrofitted triplets exhibited more ductile behavior when compared to the reference samples. Furthermore, it was clearly observed that the unilateral strengthening application significantly increased the shear capacity of the masonry building units. The measured value of F_{max} is 32611 N for this case. Also, f_v is calculated as 0.296 MPa. The curve of force-displacement relationship for D1G04-T/1 is depicted in Fig. 17.



(a) (b)

Fig. 14 (a) Initial state and (b) final state of D1G03-3

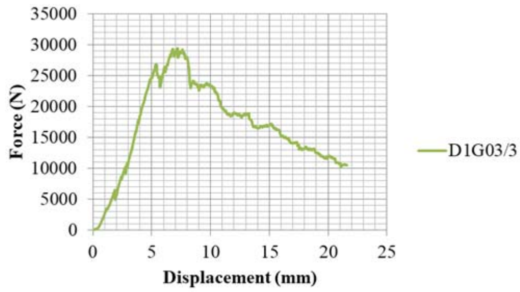
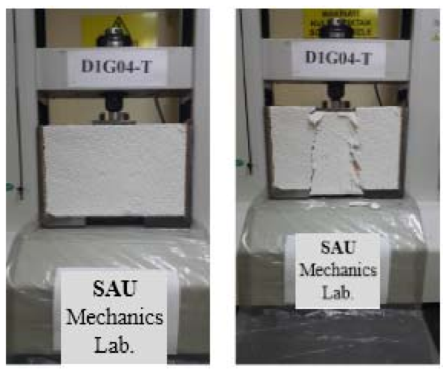


Fig. 15 Force-displacement diagram of the D1G03-3

In the final phase of the study, the above mentioned strengthening system was applied to both surfaces of the three specimens and the results were analyzed comparatively. The thickness of the plaster on each surface was considered as 1 cm. The experiment set was named as D1G04-T. Initial and final states of D1G04-T/1 under shear force were in Fig. 16.



(a) (b)

Fig. 16 (a) Initial state and (b) final state of D1G04-T/1

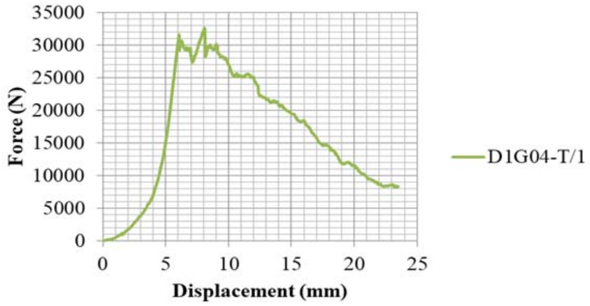
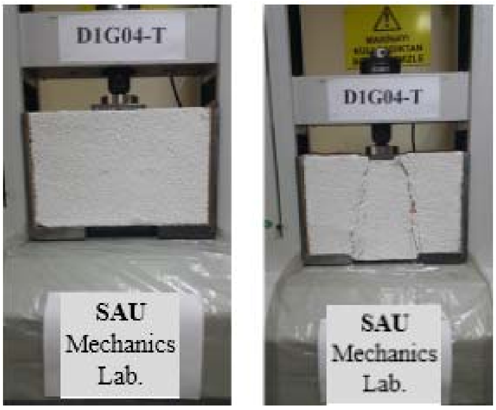


Fig. 17 Force-displacement diagram of the D1G04-T/1

The second and third specimens of the D1G04-T set were also tested. At all specimens in this experiment group, it was obviously seen that the damage started in a similar way to the D1G03 set (Fig. 18).



(a) (b)

Fig. 18 (a) Initial state and (b) final state of D1G04-T/2

The F_{max} values were determined for these specimens as 37544 N and 36394 N, respectively. The shear strengths were calculated as 0.340 MPa and 0.330 MPa, respectively. The experimental shear force-displacement curve for D1G04-T/2 and D1G04-T/3 are illustrated in Figs. 19 and 21.

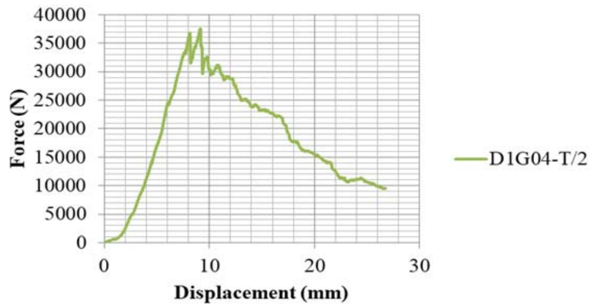
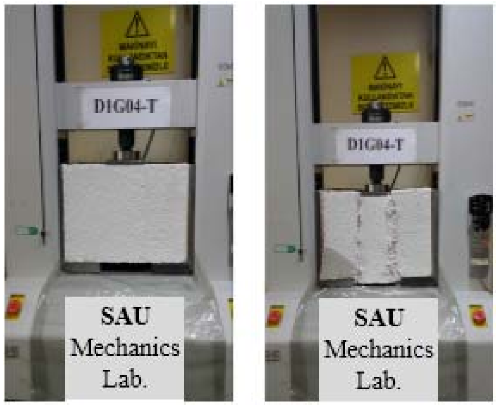


Fig. 19 Force-displacement diagram of the D1G04-T/2

The failure modes of all plastered specimens were similar due to vertical cracks in the direction of loading, which followed the interface between the bricks and joint mortar (Fig. 20).



(a) (b)

Fig. 20 (a) Initial state and (b) final state of D1G04-T/3

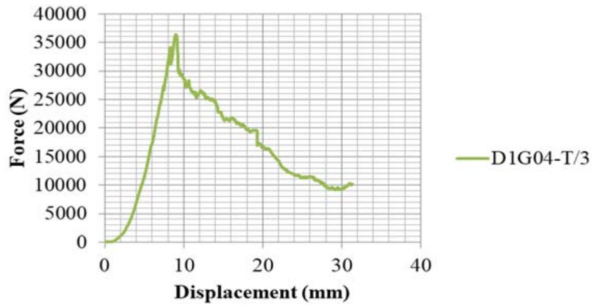


Fig. 21 Force-displacement diagram of the D1G04-T/3

Magenes and Morandi [11] calculated the ductility coefficients by idealizing the envelope curve obtained from the experiment with equivalent bilinear curves (Fig. 22). In a similar way, the energy-dissipation capacities of the samples were determined (3), with the force-displacement curves being idealized in this research.

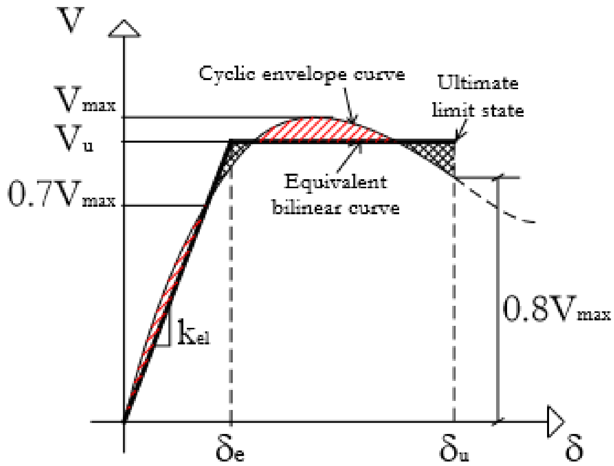


Fig. 22 Bilinear Idealization

$$\mu = \frac{\delta u}{\delta e} \quad (3)$$

The strength parameters calculated from the ultimate shear forces and obtained ductility coefficients of all considered specimens are given in Table III.

TABLE III
SHEAR AND DUCTILITY PARAMETERS OF SPECIMENS

Code	F_{max}	f_v	f_{vk}	μ
D1R00-1	12200	0.11 MPa	0,088 MPa	1.77
D1R00-2	12920	0.117 MPa	0,094 MPa	1.74
D1R00-3	15316	0.138 MPa	0,11 MPa	1.75
D1G03-1	23032	0.209 MPa	0,167 MPa	2.04
D1G03-2	24548	0.220 MPa	0,176 MPa	2.06
D1G03-3	29400	0.267 MPa	0,214 MPa	2.12
D1G04-T/1	32611	0.296 MPa	0,237 MPa	2.63
D1G04-T/2	37544	0.340 MPa	0,272 MPa	2.54
D1G04-T/3	36394	0.330 MPa	0,264 MPa	2.44

It is easy to see from the obtained ductility coefficients in Table III, D1G04-T coded samples exhibit a more ductile behavior compared to the other set of experiments (D1G03) and reference samples are insufficient in terms of load bearing capacity, shear strength and energy dissipation. The results of all triplet shear tests performed were compared in Fig. 23.

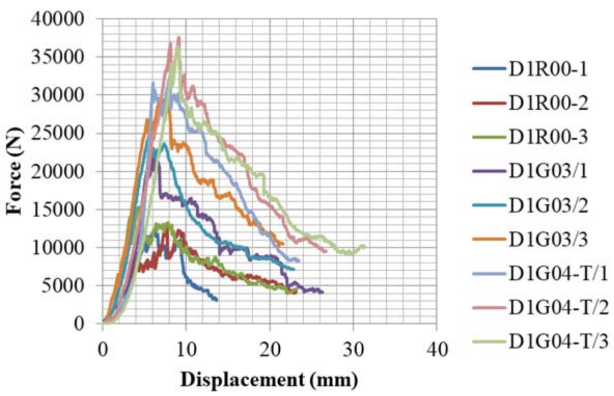


Fig. 23 Comparison of force-displacement diagrams

IV. CONCLUSIONS

In this study, the mechanical behaviors of brickwork specimens strengthened by seismic textile were investigated by triplet shear tests and compared with non-strengthening samples. It was emphasized that the earthquake performance of masonry structures can be improved by simple strengthening techniques, such as seismic fabric with expanded glass granular based plaster. At the end of all applied experiments, mechanical characteristics and failure mechanisms of brickwork masonry specimens after and before retrofitting were analyzed. The effects of seismic textile and relevant plaster on energy dissipation were also determined. Performances of strengthening with different plaster thickness were compared in terms of shear strength, ductility, and mechanism of failure.

The obtained results of the experimental investigations are given with respect to force-displacement curves comparatively for all considered test specimens. It is concluded that the single-sided reinforcing application provided enhancement in shear resistance of 68% and improvement in deformability capacity of 19%. However, two-sided reinforcing provided remarkable additional strength up to 168% and increase in ductility of 46%.

REFERENCES

[1] Wallner C., “Erdbebengerechtes Verstärken von Mauerwerk durch Faserverbundwerkstoffe Experimentelle und Numerische Untersuchungen”, *Ph. D. Thesis*, Karlsruhe Institute of Technology, Karlsruhe, Germany, (2008).

[2] Korany Y. and Drysdale R., "Rehabilitation of masonry walls using unobtrusive FRP techniques for enhanced out-of-plane seismic resistance." *Journal of Composites for Construction* 10.3 (2006): 213-222.

[3] Rizzo, S., “Triplet Shear Tests on Pumice Blocks BLG19 with and without the Seismic Retrofitting System Röfix SismaCalce”, *Final Report*, Karlsruhe Institute of Technology, Department Reinforced Concrete, Karlsruhe, Germany, (2015).

[4] Beattie, G., Molyneaux T.C.K., Gilbert M. and Burnett, S., “Masonry Shear Strength Under Impact Loading”, *9th Canadian Masonry Symposium*, Fredericton, NB, Canada, (2001).

[5] Corradi M., Borri A. and Vignoli A., "Experimental evaluation of in-plane shear behaviour of masonry walls retrofitted using conventional and innovative methods." *Masonry International* 21.1 (2008): 29.

[6] Lourenço P. B., Barros J. O. and Oliveira J. T., “Shear Testing of Stack Bonded Masonry”, *Construction and Building Materials*, 18, p.125-132 (2004).

[7] Alcaino P. and Santa-Maria H., "Experimental response of externally retrofitted masonry walls subjected to shear loading." *Journal of composites for construction* 12.5 (2008): 489-498.

[8] Oliveira, D.V.C., “Experimental and Numerical Analysis of Blocky Masonry Structures Under Cyclic Loading”, *Ph. D Thesis*, University of Minho, Portugal, 19-25 (2003).

[9] Münich J. C., “Hybride Multidirektionaltextilien zur Erdbebenverstarkerung von Mauerwerk; Experimente und Numerische Untersuchungen mittels eines erweiterten Makromodells”, *Ph. D. Thesis*, Karlsruhe Institute of Technology, Karlsruhe, Germany, (2010).

[10] Anglada, X. R., “Shear Tests on Masonry Triplets with Different Soft Layer Membranes”, *B.Sc. Thesis*, Swiss Federal Institute of Technology, Zürich, Swiss, 9-15 (2014).

[11] Magenes, G., P. Morandi, and A. Penna. "Enhanced safety and efficient construction of masonry structures in europe–d 7.1 c test results on the behaviour of masonry under static cyclic in plane lateral loads." *Report ESECMaSE D* s7 (2008).

[12] EN 1052-3, European norms for methods of test for masonry–Part 3: Determination of initial shear strength., 1996.