# Compressed Brick Masonry Columns Strengthened by Textile Reinforced Concrete

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**Abstract:** The aim of presented article is to describe the influence TRC´s slim layer applied on compressed brick masonry columns. Simple application of TRC is not the only benefit of this solution. This solution stabilizes analysed columns and due to the confined higher maximum load-bearing capacity is achieved. Three tested columns, which two of them were strengthened, had height 1040 mm and plant dimension 300 x 300 mm. Burnt bricks 290 x 140 x 65 mm with declare compressed strength 30.0 MPa were joint by lime-cement mortar with compressed strength 5.0 MPa. Layer of approximately 10 mm of high strength cement matrix containing alkali-resistant glass textile reinforcement was applied around the columns. Compressive strength 100 MPa and flexural strength 15.7 MPa characterize used cement matrix, while AR-glass textile is characterized by 585 g/m$^2$ and windows´ size was 5.5 x 4.5 mm. The strengthening increased maximum force to 109 %, resp. 148 %, in compare to non-strengthened column.

**Keywords:** Masonry, compressed columns, strengthening, TRC, AR-glass textile reinforcement.

## 1 Introduction

Process of reparation, renovation, strengthening and stabilization of existing load-bearing structures has long history and development; used methods and materials reflected actual state of knowledge. The steel banding has been used for strengthening compressed load-bearing elements (concrete and reinforced concrete columns, masonry pillars) or bending load-bearing elements (wooden beams, reinforced concrete beams). In addition to steel the concrete, reinforced concrete or reinforced cement mortal are proven approaches of masonry´s strengthening. Strengthening of existing masonry columns takes place due to several reasons, mainly when the permanent load rise up (when the purpose of building is change) or when the masonry is breached (due aggressive environment, long-term overload, missing maintenance). More widespread use of newly developed composite materials (high performance concrete, glass, basalt or carbon composites) leads to their application in several areas, including strengthening. The wrapping of columns and pillars by GFRP (glass fibres reinforced polymer) or CFRP (carbon fibres reinforced polymer) increases their load-bearing capacity in compression [1]. The radius of column´s corner affects the final achieved strength [2]. Two times higher ductility showed reinforced concrete column strengthened by 40 mm of UHPFRC than traditional jacket from reinforced concrete (RC) and thickness of 60 mm [3]. The 350 x 350 x 3000 mm columns were strengthened in real condition (reconstruction of 80 years old factory). It should be noted, that the maximum load in kN of traditionally reinforced column was over 40% higher, than in the case of RC jacket. Benefit of this solution lies in higher resistance to earthquake action. Very promising material for strengthening masonry structures is textile reinforced concrete (TRC), which combines fine ground cement matrix and textile fabrics from high strength materials (carbon or glass). Several article deals with strengthening reinforced concrete by TRC [4] but masonry application is still not sufficient described; tensile characteristics of history masonry, in the context of earthquake, strengthened by TRC were investigated in [5]. There are two approaches to strengthening – wrapping, that maximizes the load-bearing capacity in compression or additional layer of concrete or cement mortar, which increases the cross-section that resist load action. The load transfer from structure has to be provided on the additional layer.

# 2 Description of Performed Experiments

Performed experimental program deals with the testing of bricks masonry columns strengthened by slim layer of textile reinforced concrete, where the textile fabrics were applied in two different ways. Columns were tested at 28 days after strengthening process by static load test.

## 2.1 Characteristics of Used Masonry

Following part describes properties of lime-cement mortal, brick´s units, masonry and textile reinforced concrete. Standard burnt bricks with dimension 290 x 140 x 90 mm were used; compressive strength of three specimens was tested ($f_u$) and the normalized mean compressive strength was calculated according to Eq. (1). Lime-cement prescription mortal with volume ratio 1:3:5 (cement, lime, sand 0/4 mm) was used and the mechanical properties ($f_m$ – compressive strength of mortal) were tested according to [6] on specimens 40 x 40 x 160 mm. Final characteristic strength of masonry was calculated according to equation (3). All these equations are available in [7].

$$f_b = \delta \cdot \eta \cdot f_u \quad (1)$$
$$f_b = 0.77 \cdot 1.0 \cdot 39.5 = 30.42\ MPa \quad (2)$$
$$f_K = K \cdot f_b^{0.65} \cdot f_m^{0.25} \quad (3)$$
$$f_K = 0.4 \cdot 30.42^{0.65} \cdot 5^{0.25} = 5.51\ MPa \quad (4)$$

$f_b$ – normalized mean compressive strength of masonry unit (brick)
$f_u$ – average compressive strength of masonry unit
$\delta$ – coefficient of masonry unit shape (0.77)
$\eta$ – coefficient of conditioning (equal to 1.0 for 6% humidity of masonry unit)
$f_k$ – characteristic compressive strength of masonry
$f_m$ – characteristic compressive strength of mortal
K = 0.4 (longitudinal joint, group 1, according to [7] CSN EN 1996-1-1)

## 2.2 Characteristics of Used TRC

TRC consists of two main parts – textile reinforcement and cement matrix. The cement matrix can be generally characterized as high performance concrete. Used cement matrix has been verified in several applications. The binder and filler consists of cement CEM I 42.5R, microsilica, silica powder ST6, silica aggregates in fractions 0.1/0.6, 0.3/0.8 and 0.6/1.2 mm. Due to the superplasticizer SVC 1035 the low water to cement 0.35 has been achieved. The compressive strength of this composite is 43.3 MPa at the age of 24 hours and 102.2 MPa at the age of 28 days [8], measured on cube specimens (100 x 100 x 100 mm). The flexural strength at the age of 28 days is 15.7 MPa.

The textile reinforcement was made by Adfors Saint-Gobain Company. This textile reinforcement can be used in concrete elements, wall reinforcement etc. The textile reinforcement has a lot of advantages and is made of glass fibres with high tensile strength. The textile reinforcement has alkali resistance surface due to safe use in concrete elements [9]. The textile reinforcement R 585 A 101, which is used in this experimental program, has basis weight 585 g/m2 and window´s size 5.5 x 4.5 mm. The window´s size of textile limits the maximum grain size of used cement matrix, in this case the maximum grain was 1.2 mm.

## 2.3 Strengthening Process

Two different ways of alkali-resistant glass textile reinforcement application were tested (in the angle of 45° and parallel to columns dimension). Two layers of glass-fibres textiles ADFORS R585 were applied on each side of columns. The scheme of application of textile reinforcement can be seen on Fig. 1 and Fig. 2. Fig. 1 shows first type of the textile reinforcement application and Fig. 2 shows second type of the textile reinforcement application. The strengthening process can be observed on Fig. 3. The strengthening process started after one month after columns´ production. Due to the character of bricks and their porosity, the surface was pre-wetted by spraying of water. First layer of fine ground cement matrix was applied on the surface of pre-wetted column and inside the concave masonry joints. The textiles were pressed into the layer of fine ground cement matrix. Slim layer of cement matrix finished the surface and creased the final surface. Columns were wrapped by foil to avoid the evaporation of water and eliminated shrinkage and creation of cracks.

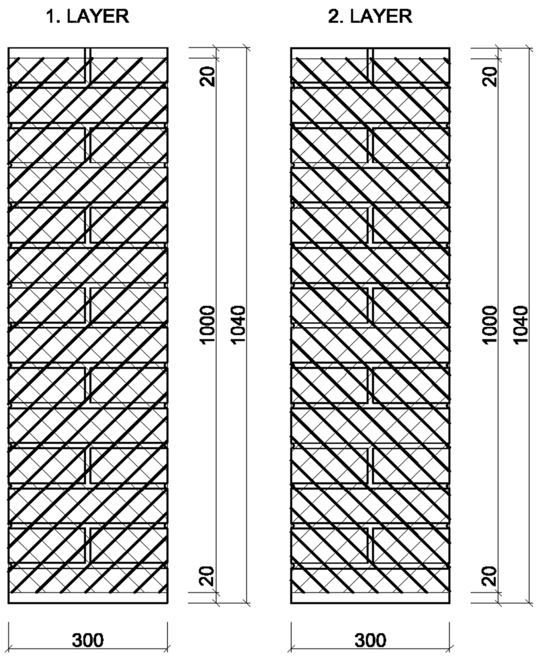


Fig. 1: First type of textile´s reinforcement application.

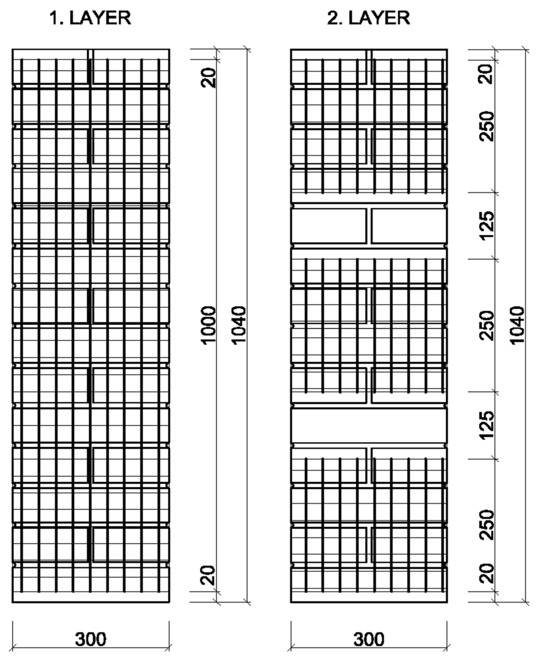


Fig. 2: Second type of textile´s reinforcement application.

## 2.4 Static Load Testing

Columns with dimension 300 x 300 x 1040 mm were tested at the age of 60 days (28 days after strengthening process). The hydraulic loading press INOVA 2000 was used for testing. The testing was controlled by linear increase of vertical deformation of loading plate (0.004 mm/sec). The evaluation of vertical force and the crosshead of the loading plate of the hydraulic press were recorded in time. The tested column in the loading press is shown in the Fig. 4.

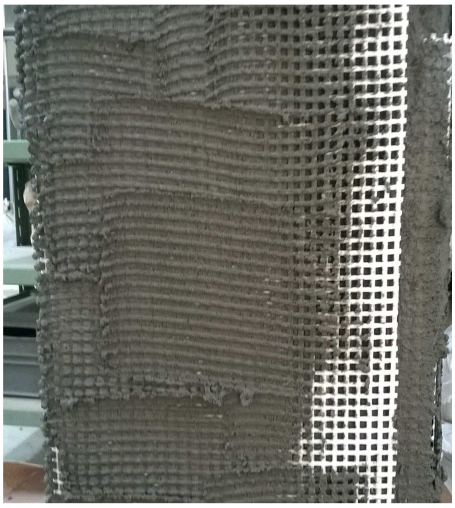

Fig. 3: Application of TRC on brick masonry column´s surface.

Fig. 4: Tested column in the loading press.

# 3 Results and Discussion

The obtained basic results are written in next Tab. 1. The table contains maximum value of vertical force in the second column, a ratio maximum force to characteristic force calculated from standards in the third column and a ratio maximum force to maximum force of non-strengthened column in the fourth column.

The maximal calculated force according standard CSN EN 1996-1-1 of non-strengthened masonry column is equal to 459.9 kN. The maximal force of the tested non-strengthened column reached 135 % of this value, which is 669.1 kN. First strengthened column reached 727.3 kN (147 % of the characteristic force) and second strengthened column reached 991.5 kN (200 % of the characteristic force). This experimental program was designed as a pilot testing to verify basic assumptions of strengthening by TRC. These results of two strengthened columns are spread due to not ideal technological approach in this pilot experimental program. First column strengthening was not geometrical great and this fact caused spread in the results.

We can see better resistance of strengthened columns, if we compare non-strengthened column and two strengthened columns. First column reached 109 % of maximal force on non-strengthened column and second column reached 148 % of maximal force on non-strengthened column.

Tab. 1: Obtained results from experimental program.

| Column | Maximum force - $F_i$ | $F_i$ / $F_k$ | $F_i$ / $F_{ref}$ |
|---|---|---|---|
| | [kN] | [%] | [%] |
| According to CSN EN 1996-1-1 | $F_i$ = 495.9 | 100 | 74 |
| Non-strengthened column | $F_{ref}$ = 669.1 | 135 | 100 |
| Strengthened column (45°) | 727.3 | 147 | 109 |
| Strengthened column (0°) | 991.5 | 200 | 148 |

Fig. 5: Tested strengthened column.

Fig. 6: Detail of collapsed strengthening layer and column after performed test.

The collapse of the non-strengthened column was regular like it was expected. The similar failure mode was developed on both strengthened columns. The collapse of the strengthened columns was caused by failure of the TRC layer in corner of the top of the column in both cases. The collapsed column it can be seen on Fig. 5 and detail of the collapsed corner it can be seen on Fig. 6.

The loading force and displacement of the load cell was recorded during testing. From obtained data for both strengthened columns is made a chart in Fig. 7. There is load cell displacement on the horizontal axis and force on the vertical axis. The linear increase of the force can be seen between 3.5 and 7 mm displacement. After linear area started cracking of the TRC strengthening around upper corner of the columns. The peaks of the curves indicate failure of the columns, which was caused by breaking the TRC layer on the upper corners of the columns.

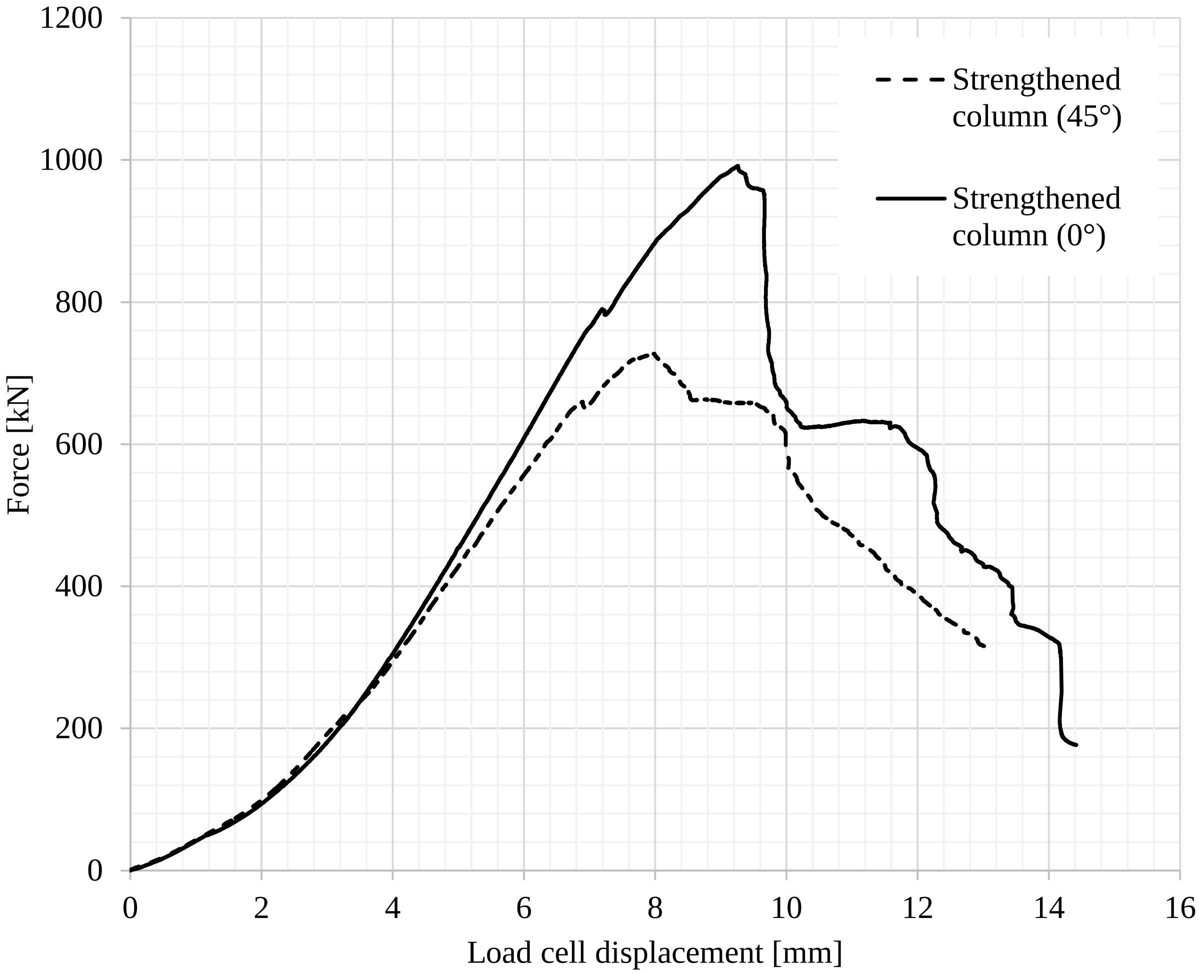


Fig. 4: Force x displacement chart of strengthened columns.

## 4 Conclusion and Further Research

The aim of this article is to describe pilot experimental testing of the masonry columns strengthened by thin layer of the textile reinforced concrete. Totally three columns with dimensions 300 x 300 x 1040 were made for the experimental program. Two of them were reinforced by two layers' of glass fibres textile reinforcement and cement matrix. The testing was controlled by linear increase of vertical deformation of loading plate (0.004 mm/sec). The maximum force of strengthened columns achieved 109 %, resp. 148 %, in comparison with non-strengthened column. These results are spread due to not ideal technological approach in this pilot experimental program. This experimental program was created for confirmation basic premises of strengthening of masonry by TRC. Anyway from the results we can conclude, that application of TRC seems to be a progressive solution for strengthening of compressed brick masonry columns and interesting alternative to conventional solution (reinforced concrete wrapping, application of CRF, GRF, etc.).

## Acknowledgement

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