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Post-Stabilization of Damaged Stone Full Scale Column Using External CFRP

J. Kubat [1,*]

[1] *CTU in Prague, Faculty of Civil Engineering, Czech Republic*
[*] *jan.kubat.2@fsv.cvut.cz*

Abstract: This paper deals with the effectiveness of CFRP confinement externally bonded on surface of damaged stone masonry column. The experimental measurement carried out within research project DF12P01OVV037 [1] includes the mechanical behavior, the specimens strength and the failure modes. The results showed that the CFRP confinement may be considered as an effective stabilization technique able to increase the structural safety of damaged stone masonry columns.

Keywords: Stone Masonry; Stabilization; Confinement; Damaged Masonry; CFRP.

1 Introduction

Experimental and theoretical research of compressed masonry structures' retrofitting with CFRP-based materials performed in the last 20 years was primarily focused on the applications in the field of reinforcement masonry structures in terms of load bearing capacity [2–4] and seismic safety [5, 6], to a lesser extend in the field of stabilization of damaged masonry [7]. The majority of research studies focus on brick masonry [8–10], while only few also deal with stone masonry [11, 12]. The executed experimental verification of damaged stone masonry column confined with CFRP will provide boundary conditions for numerical analysis of masonry structures, in particular for the historical stonework structures [13]. For the comparison with the confined and unconfined undamaged columns' behavior were used another specimens from the experimental program [1].

2 Description of the Experimental Investigation

2.1 Material Characteristics

The mechanical properties of the used materials were obtained by experimental tests. Masonry units used for walling were consist of fine sandstone (75 %) and marly limestone (25 %). The both kind of stones were widespread used to build the masonry structures in Bohemia.

The density of stone units were determined from 12 random selected specimens. The compressive strength was determined by loading tests on 8 drill cored specimens with 50 mm diameter. The three point bending tests was used for determination of flexural strength of 6 sawn specimens dimensions $50 \times 50 \times 160$ mm. In order to measure the flexural and compressive strength of the mortar, three mortar specimens with dimensions $40 \times 40 \times 160$ mm were loaded to determine the flexural strength. The half-specimens were used to determine compressive strength. Stones and mortar testing was performed in displacement-control mode using 100 kN universal testing machine. The obtained values of density, compressive and flexural strength are shown in Tab. 1.

Tab. 1: Material properties of masonry units and mortar.

Type of masonry unit	Density[kg/m^3]	Compressive strength [MPa]	Flexural strength [MPa]
Fine sandstone	1890 - 2100	19.51	5.22
Marly limestone	1490 - 1790	23.89	6.96
Cement-lime mortar	-	2.70	1.28

2.2 Test Setup

Experimental measurement was performed on full scale column having dimensions of $0.54 \times 0.55 \times 1.70$ mm. which was made of fine sandstone and marly limestone masonry units and cement-lime mortar. Specimen was built as a coursed irregular masonry with continuous bed joints. Specimen was built and confined by experienced mason.

In the first phase, the column was loaded by monotonic increasing load up to appearance and development first vertical cracks. The range of damage by concentric loading is shown in Fig. 1. After this phase, the column was confined by carbon fabric situated on heel and head of column and in the middle thirds of height. The second loading phase was executed up to the failure of the specimen. During both of phases, 12 vertical and horizontal LVDTs and 9 strain gauges were used to describe the mechanical behavior. Deformation behavior is well described in chapter three.

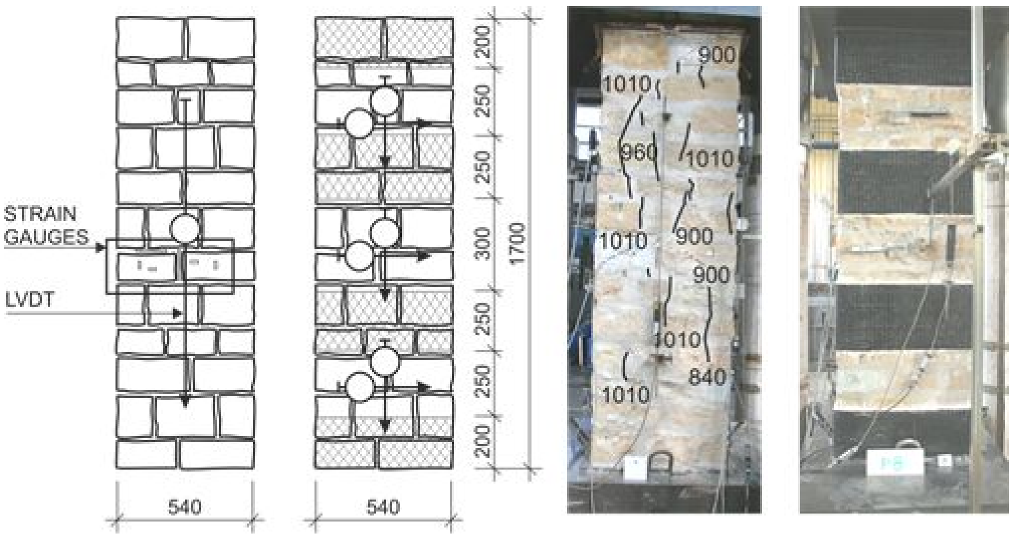

Fig. 1: Scheme of LVDT and strain gauges positions on columns before and after CFRP confinement and pictures of damaged columns before and after CFRP confinement.

2.3 Failure Modes

Before the stabilization, unconfined column was damaged mostly in the middle third of height with vertical oriented tensile cracks. All four sides of the column were uniformly damaged, which indicates the regular bond of masonry units and minimum of imperfections during the execution. Cracks with thickness up to 2 mm were situated on the interface stone-mortar and further cracks were observed in both kind of the stones. By the value of load equal 1010 kN, responding to the stress 3.40 MPa, the horizontal and vertical deformations were still growing, new cracks were observed and loading was stopped. After loading, column were confined by four strips CFRP sheets glued onto the modified surface. After confinement work, the column was loaded by the same loading scheme as before up to the failure. The total failure occurred when the load value was 1480 kN, i.e. 4.98 MPa.

In the Fig. 2 are shown the photos three failure modes of stone unconfined and confined masonry columns. The first failure mode related to non-confined stone column is characteristic by vertical tensile cracks which divide the cross-section to parts. The second failure mode (see the Fig. 2a) may occurs as a compressive crushing between non-damaged CFRP strips in the middle of column's height. The third type of failure is caused by the lateral cracks developed after CFRP strips damage.

The collapse of experimentally tested column was immediately preceded by the damage of the carbon strips wrapping. One of the intermediate strips was partially damaged at the corner's edge of column. The other one was damaged in the epoxy glue overlapped joint of CFRP strip.

(a) tensile failure of URM column and compressive failure of confined column between CFRP strips

(b) lateral tensile failure of column due to damage of CFRP confinement

Fig. 2: Photos of different failure modes of stone masonry columns.

3 Discussion of Results

The experimentally obtained results of damaged stone columns stabilized by CFRP confinement (despite one experimental specimen only) lend themselves to drawing the following conclusions about the effect of the CFRP confinement of damaged masonry columns:

- Up to the first cracks load level of unconfined masonry, vertical and horizontal deformation behavior of columns before and after CFRP confinement was similar for undamaged and also for damaged stone columns.

- The deformation behavior started to be divergent after appearance of the first observable cracks. The experimentally obtained load-displacement diagrams (Fig. 3) of undamaged column confined before loading show "activation of CFRP confinement". This positive state is characterized by the continuing linear branch of vertical and horizontal load-displacement diagrams. The inclination of the branches was slightly lower than the branch corresponding to linear undamaged state.

- The positive phase of activating confinement wasn't obvious on experimentally obtained load-displacement diagrams of column with initial cracks confined with CFRP (Fig. 4).

- The ultimate load of undamaged confined column reached value of 227 % of unconfined column. Vertical and horizontal deformation of confined undamaged masonry were linear approximately in the load range of 360 kN – 920 kN due to CFRP activating. In terms of deformation behavior, difference of increase of vertical and especially horizontal displacement of unconfined and confined column. The vertical and horizontal displacement of confined column was 28.5 % and 4 % respectively, compared to unconfined column during the load level corresponding to ultimate load of unconfined column.

- Ultimate load comparison of column loaded up to cracks development and confined column with the initial crack isn't obviously possible. Confined column reached (at the comparative load level - 1000 kN) lower deformations in both directions. Vertical displacement was 71 % and horizontal displacement was 42 % compared to the same column before confinement.

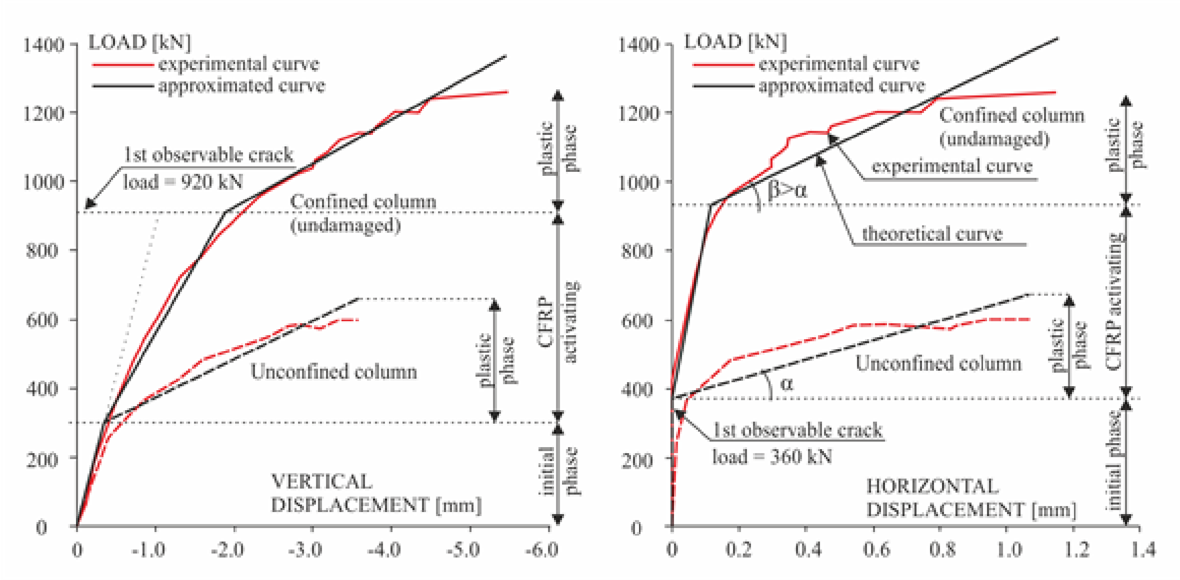

Fig. 3: Load-displacement diagram of non-confined and confined undamaged stone masonry columns.

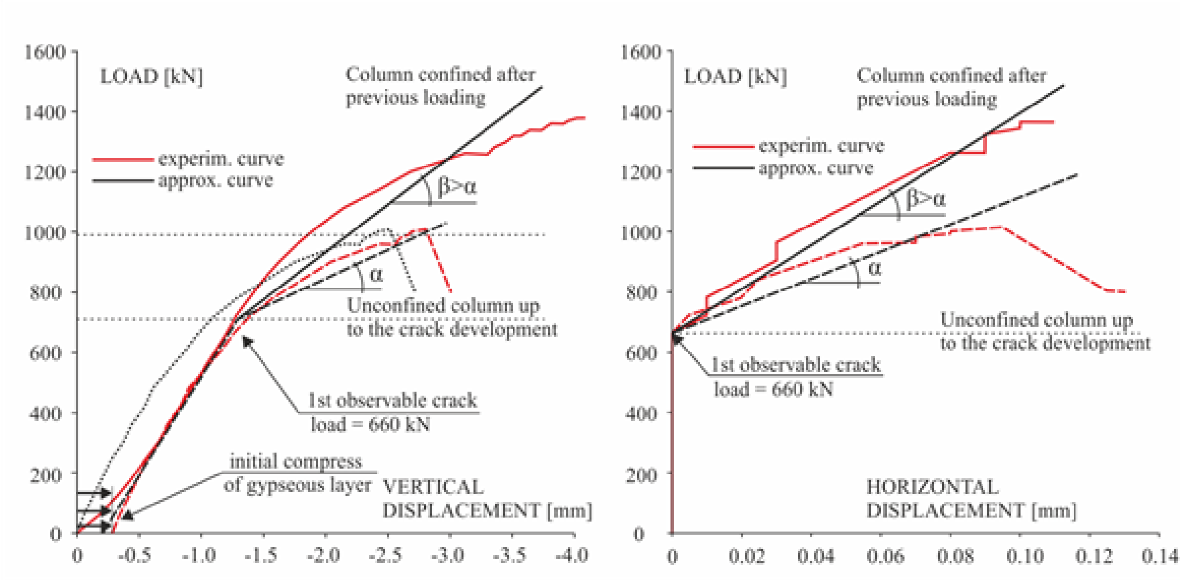

Fig. 4: Load-displacement diagram of damaged stone masonry column confined with CFRP.

4 Conclusion

The problem of post-stabilization of existing damaged masonry, especially historical stonework, is often encountered by engineers and other technicians. In this case effectiveness of stabilization depends on range of damage as well as failure mode. The type of masonry bond is also very important.

The experimentally obtained vertical and horizontal deformation behavior of pre-loaded (undamaged) and post-loaded (damaged) stone column confined with CFRP show low increase of load-bearing capacity due to absence CFRP activation phase in the case of retrofitting damaged column. Nevertheless CFRP confinement positively manifested in terms of reduction of further deformations stone column.

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