Numerical Modelling of Compressed Masonry Column

A. Maroušková [1,a]

[1] *Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7/2077, Prague 6, 166 29, Czech Republic*

[a] *aneta.marouskova@fsv.cvut.cz*

Abstract: This paper deals with numerical modelling of unreinforced masonry (URM) column and masonry column reinforced (RM) by fiber reinforced polymer (FRP) wrapping. The heterogeneous model was chosen for the analysis under the assumption of linear – elastic behavior for all components simulating the state before damage. Both, the bricks and the mortar are modelled separately. The perfect adhesion was assumed between FRP external sheets and masonry support. The loading is applied through the prescribed vertical displacement at the upper surface. Stress distribution of URM and RM are mutually compared and discussed with the results obtained by experimental testing. For all simulations the commercial software package ABAQUS was used.

Keywords: finite element analysis; masonry; FRP sheet; perfect adhesion.

1 Introduction

This study deals with masonry columns with plan dimensions of 0.3 m x 0.3 m and a height of 1 m (according to the real column tested in laboratory). The column was constructed using P20 solid burnt bricks with dimensions of 0.29x0.14x0.065 m. Mortar joints with a thickness of 0.02 m were made with M2 mortar. The experimental program is part of a research project NAKI, which is being carried out at the Faculty of Civil Engineering, CTU in Prague.

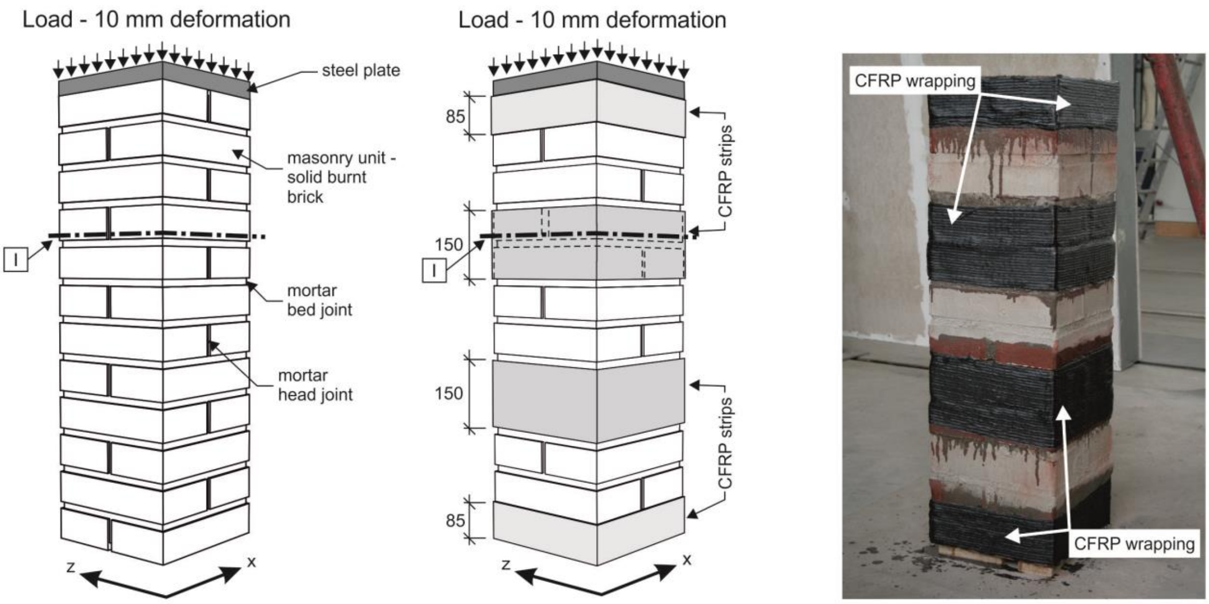

Fig. 1: Charts of URM and RM columns, photograph of real tested column.

Four external CFRP sheets (Fig. 1) were glued onto the column by means the epoxy resin – two sheets with a height of 85 mm were placed at the head and bottom of the column, another two with a height of 150 mm were placed at the column’s thirds [1,2].

2 Numerical Analysis

Numerical analysis of masonry structures became one of the most significant interest for global research program in last couple years. Experimental testing enables to follow up a visual response of loading structure, whilst the numerical simulation provides a possibility of disassembling the structure and looking “inside”. The obtaining further (numerical) outcomes helps to deeper understanding of structure’s behavior and its failure mechanism. Also, simultaneous process of experimental and theoretical parts of research enables mutual comparison of obtained results and better evaluation of damage character.

High requirements, such as non-invasion, reversibility, same appearance keeping, on architectural heritage’s protection can prevent an application of traditional strengthening and stabilization methods. FRP external sheets are one of the possible methods that is comply with these requirements. High tensile strength with low weight (thank to that no surcharge of structure appears) belongs to further advantages of FRP materials [1].

In general, modelling methods of FRP reinforcement and masonry support interface can be classified into several approaches. First approach is using zero-thickness interface elements, all the nonlinearities are concentrated along interface, while the components of masonry are usually modelled under the assumption linear-elastic behavior. An application of additional layer (layers) simulating the interface between FRP and masonry is another option. Masonry components can be assumed to behave linear-elastically or nonlinear material model can be adopted for them. The disadvantage of this method is the necessity of specifying enormous amount of materials’ parameters. The assumption of perfectly adherent FRP sheet can be considered as simplifying method although complex knowledge of the issue is necessary and this method can provide correct simulation of structure’s response.

2.1 The Issues of Numerical Modelling of Masonry

Masonry can be considered as heterogeneous material. The assembly of two materials with different mechanical properties (masonry units and mortar joints) causes masonry heterogeneity magnifying by the heterogeneous composition of masonry units and mortar themselves. Other effects, such as manufacturing, type of bond, damage or degradation further contribute to the heterogeneous nature of masonry. The assembly of the individual components, each of them has a huge variance of mechanical properties, together with influence of mortar joints makes from masonry numerical simulation a complex task.

Failure mechanism of concentrically compressed masonry column is accompanied by formation and growth vertical mostly tensile cracks. The behavior of unreinforced compressed masonry structures is strongly influenced by mutual interaction between masonry unit and mortar joints. The shape of solid burnt bricks can be considered as geometrically accurate, masonry has regular bond and more complaint mortar than masonry units in presented paper. The mortar’s compliance to greater transverse strain causes under concentric compressive load additional tensile stresses of masonry units (solid burnt bricks). Thus it has to be taken into account that the tensile cracking of compressed masonry column with regular bond is partially caused by compressive load and partially by mutual interaction [3].

2.2 Numerical Model

The heterogeneous model was chosen for the analysis under the assumption of linear – elastic behavior for all components simulating the state before damage. Linear – elastic parameters are shown in table 1. The accurate description (geometrically and materially) of all components results in complexity of numerical model, but on the other hand allows defining contact between two materials and following up the stress’s changes at interfaces. Only heterogeneous model, in which each components are modelled separately, is capable of expressing the influence of mortar joints.

The developed numerical model is composed from approx. 60000 finite elements - first order continuum (solid) elements (C3D8) for mortar and bricks discretization and linear membrane elements (M3D4) for reinforcement discretization. Maximal size of finite element’s edge was a third of masonry unit’s height. For brick-mortar interface, “hard” contact was assumed in normal direction and frictional behavior (with a friction coefficient of 0.6) in tangential direction. The simulation of RM was executed under the assumption of perfect adhesion between reinforcement and masonry support - masonry and composite were tied together through a standard constraint in ABAQUS program [4, 5]. The boundary conditions weren't applied directly on the masonry column, but there are two steel plates – one at the head of the column and another at the bottom of the column.

Tab. 1: Linear – elastic parameters of materials.

Material	Young Modulus E [GPa]	Poisson's coefficient ν [-]
Masonry unit	2.5	0.20
Mortar	0.5	0.15
Steel	210	0.30
FRP	140	0.33

2.3 Results

Numerical results are shown at the same spots - 1 cm over bed mortar joint, at the spot with CFRP sheet for RM column respectively. The stress distribution of RM column is significantly distinct from URM column. Maximal principal stress's trajectories of URM run along masonry units and cause transversal cracking of solid burnt bricks, whilst RM column's maximal principal stress's trajectories radically change direction as a result of CFRP wrapping. The cracking is concentrated close to masonry surface (reinforcement) and is converging at the corners of column.

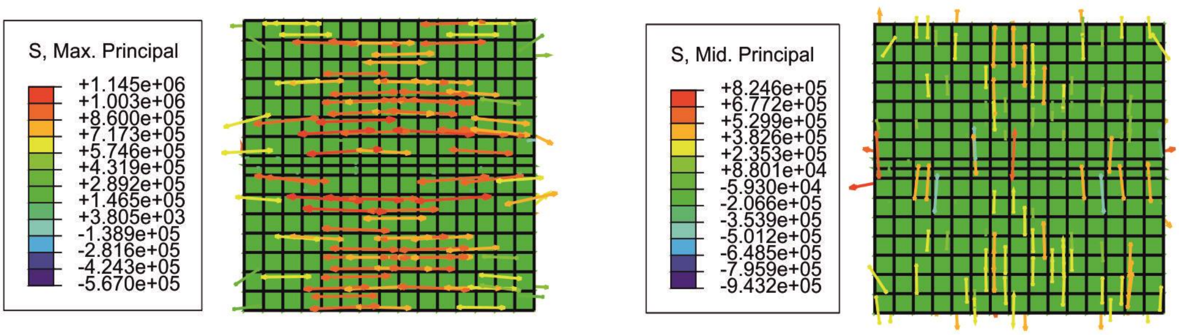

Fig. 2: Trajectory of max. and mid. principal stress along the cross section for URM column.

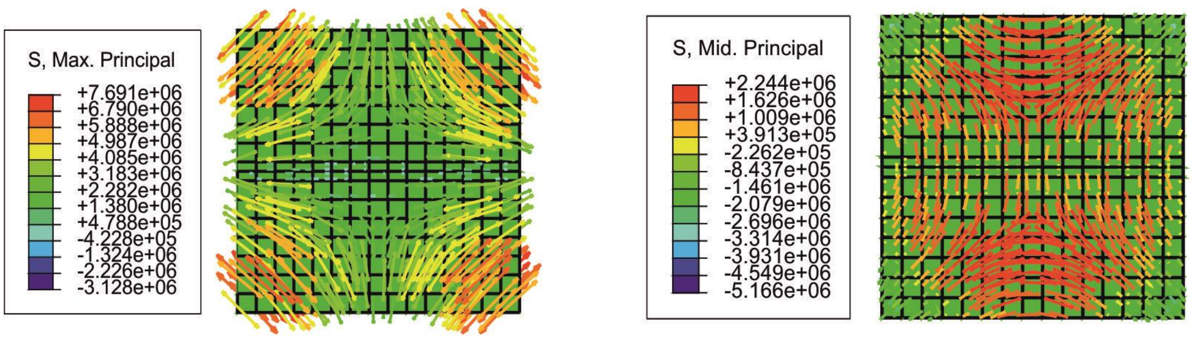

Fig. 3: Trajectory of max. and mid. principal stress along the cross for RM column by CFRP wrapping.

All laboratory tested column were disassembled after reaching the ultimate load. For both solved types – URM and RM column, the result from experimental testing clearly show cracking in direction of mid. principal stresses, normal to the direction of max. principal stresses respectively (Fig. 4).

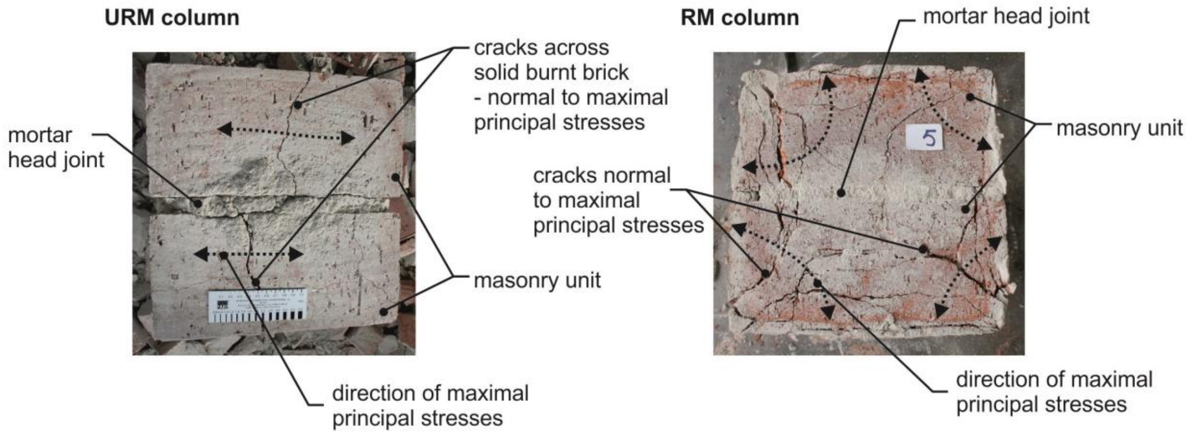

Fig. 4: Character of cracking of URM and RM column, experimentally detected.

3 Conclusion

The failure mechanism of compressed URM column is strongly influenced by mutual interaction between two materials with different mechanical properties – masonry units and mortar joints. For brick masonry, the mutual interaction causes additional transverse tensile stresses. CFRP sheets due to high tensile strength prevent the growth of horizontal deformation and vertical tensile cracks. It was shown that carbon CFRP sheets are efficient tool for increasing ultimate bearing capacity and rigidity of brick masonry [1,2]. CFRP sheets defend lateral strain and take over part of transversal tensile stresses. Reinforcement by CFRP wrapping significantly change stress distribution compared to URM column and transform failure mechanism of compressed masonry column.

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