53rd CONFERENCE ON EXPERIMENTAL STRESS ANALYSIS
Český Krumlov, Czech Republic, June 1–4, 2015

Numerical Analysis of Masonry Column Reinforced by FRP Wrapping

A. Maroušková [1,*]

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

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

Abstract: A numerical model for masonry columns reinforced by FRP wrapping is presented in this paper. Both, the bricks and the mortar are modeled as 3D continuum and to the interface between these two materials a non-linear contact law is assigned. The accurate 3D modeling of masonry units and mortar joints within the numerical model leads to high computational cost, but on the other hand, an appropriate analysis tool delivering detailed information about the behavior of masonry columns is obtained. External wrapping by carbon composite based strips and contact between strips and masonry is defined in the next step. The response and failure mechanism of masonry columns reinforced by CFRP wrapping can be investigated. For all simulations the commercial software package ABAQUS was used. By comparison with results from experiments [1], the performance of the numerical model is evaluated and the obtained numerical results are discussed.

Keywords: Numeric Analysis; Masonry; Reinforcement; FRP Materials; Finite Element Method.

1 Introduction

Masonry can be considered as heterogeneous, anisotropic and quasi brittle material. Its heterogeneity is mainly caused by the assembly of two different materials – masonry units and mortar. The composition of masonry units and mortar themselves results to further contribution to the heterogeneous nature of masonry, as well as manufacturing, damage, crack, degradation etc. All these influences cause an enormous scatter of mechanical characteristics of masonry. The presence of joints, which are usually the weakest parts of masonry, is responsible for the distinct directional properties (anisotropy). Failure of quasi brittle materials is characterized by microcracks formation, which precedes the appearance of continuous (dominant) crack, indicating the structural failure mechanism. Typical collapse mechanism of non-reinforced compressed masonry structures is accompanied by progressive growth of vertical macrocracks due to transversal tensile stresses [2].

2 Reinforcement by FRP Wrapping

This study deals with masonry columns with plan dimensions of 0.3 mm × 0.3 mm and a height of 1 mm (according to the real column tested in laboratory). The column was constructed using P20 solid burnt bricks with dimensions of 0.29 × 0.14 × 0.065 mm. Mortar joints with a thickness of 0.02 mm were made with M2 mortar (the declared strength of mortar is 2 MPa). The experimental program is part of a research project [1], which is being carried out at the Faculty of Civil Engineering, CTU in Prague.

The column was reinforced by wrapping with high-strength carbon fibers placed at 4 levels – at the column's toe and the column's head and in thirds of the column's height (Fig. 1). The ratio of Young's modulus of carbon fibers and Young's modulus of masonry is approximately 70:1. The test specimen was exposed to an increasing load up to their failure. Experimental research manifested a significant effect of masonry reinforcement by carbon fabrics on the ultimate bearing capacity and rigidity of compressed masonry column. FRP wrapping represents an efficient mean of stabilization of masonry column [3]. The carbon fabric prevents lateral masonry strain and assumes a significant part of transversal tensile stresses [4, 5].

Tab. 1: Linear – elastic mechanical properties of materials.

Model parameter/Material	Brick	Mortar	Steel	FRP
E [MPa]	2500	500	210000	140000
ν [-]	0.20	0.15	0.30	0.30

2.1 Numerical Analysis

Fig. 2 shows the chart of numerical model used for finite element analysis. Linear-elastic mechanical properties of materials are shown in Tab. 1. 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 assumption of perfect adhesion was considered for masonry-FRP strips connection in numerical analysis [6–8]. It was assumed that used epoxy glue is so rigid that failure occurs in the masonry. Option Tie Constraint was used for connection between masonry and composite in ABAQUS program [6]. The second order continuum (solid) elements (C3D20) with dimension equal to 0.02 mm were used for discretization of bricks and mortar. Linear membrane elements (M3D4) with dimension of 0.02 mm simulated the reinforcement. Vertical load in a form of pressure and the boundary conditions are not directly applied to masonry column, but there are steel plates at the top edge and the bottom edge of masonry column. The total number of finite element was 140256 and computational time was around 1.74 hour. For comparison, the computational time of unreinforced column was 0.92 hour.

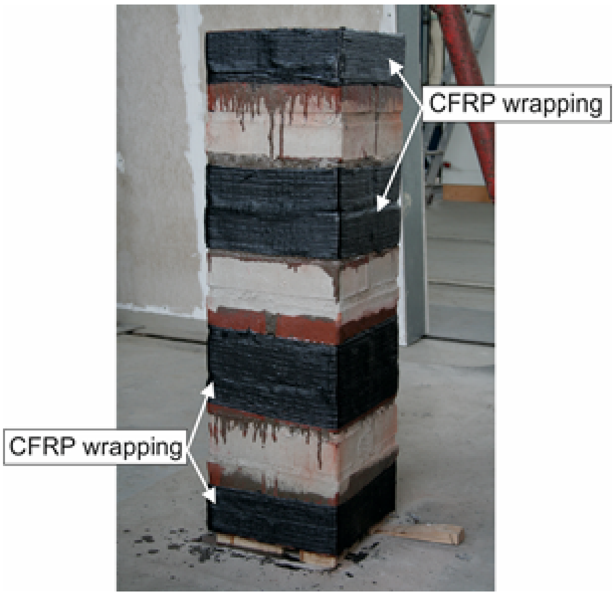

Fig. 1: Reinforcement of masonry column by CFRP wrapping.

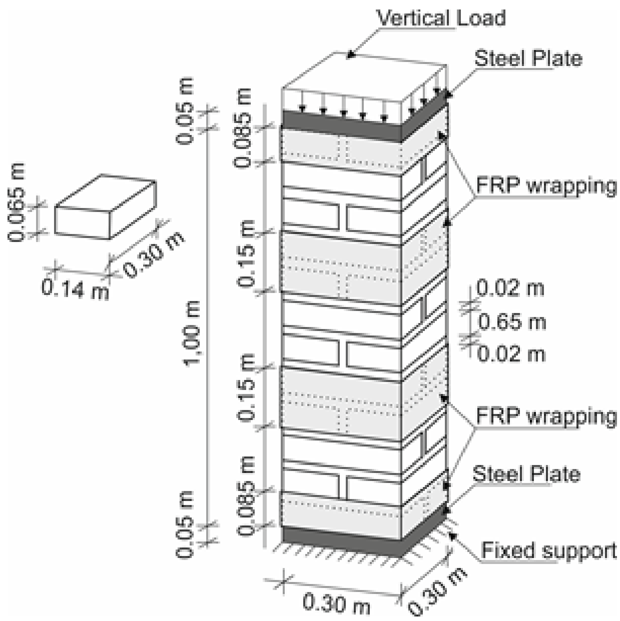

Fig. 2: Chart of numerical model.

Typical horizontal stress pattern of unreinforced masonry column is shown in Fig. 3a). Mortar that has a lower Young's modulus and has tendency to greater lateral strain, is transversely "pressed" and masonry units, on the contrary are transversely "stretched" (Fig. 3a, d) [2]. Reinforcement by FRP wrapping takes over part of horizontal tensile stresses and results in larger compressed part of masonry column than by unreinforced masonry column (Fig. 3b, e). Finite element analysis shows a redistribution not only in horizontal stresses, but also in vertical stresses although in the smaller scale. The vertical stresses are concentrated in FRP strips and in the unreinforced parts of masonry column (between FRP strips).

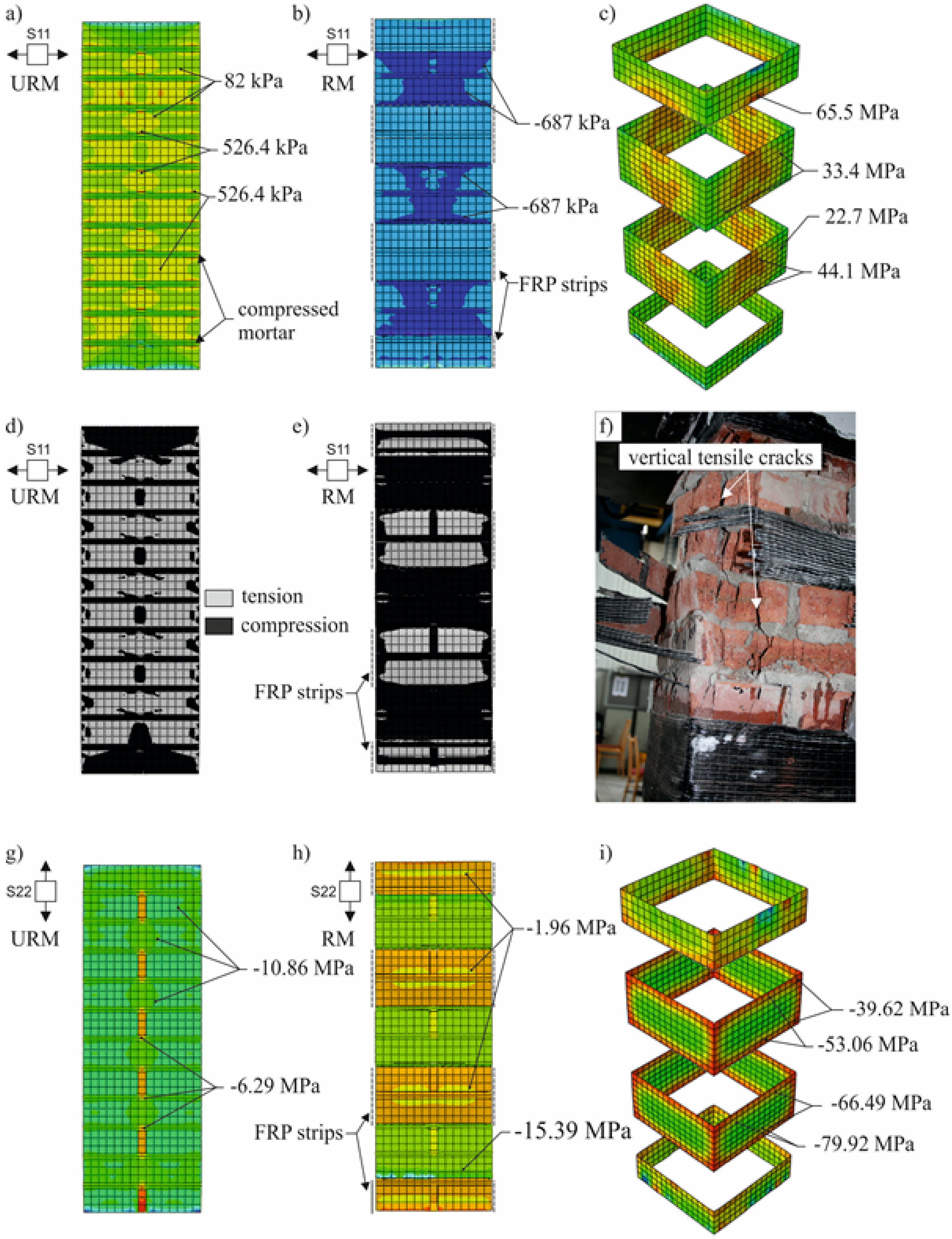

Fig. 3: Analysis of masonry column: a) Horizontal stress pattern of unreinforced column, b) Horizontal stress pattern of reinforced column, c) Horizontal stress pattern of FRP strips, d) Tension and compression areas of unreinforced column, e) Tension and compression areas of reinforced column, f) Characteristic failure of reinforced column, g) Vertical stress pattern of unreinforced column, h) Vertical stress pattern of reinforced column, i) Vertical stress pattern of FRP strips.

3 Conclusion

Simultaneous running of experimental research and numerical analysis allows comparison of experimental (physical) and mathematical (theoretical) results. Experiment works as a tool for verification of numerical model and numerical analysis on the other side helps with the understanding of failure mechanism of masonry.

The behavior of reinforced and unreinforced masonry column was investigated in this paper. The heterogeneous three-dimensional numerical model based on quadratic finite elements was developed under the assumption of perfect adhesion between masonry and FRP external sheets. The behavior of mortar, brick and reinforcement was assumed isotropic and linear elastic. Development of advanced non-linear numerical model can be outlined as a future goal. A plasticity-based model for mortar and brick requires further experimental testing. The material properties obtained by general experimental tests (for example three point bending) are not directly applicable to plasticity-based material model of mortar and brick requiring specific experimental tests (pure tension etc.) and their evaluation.

Acknowledgement

The results were obtained with support from research project DF12P01OVV037 - "Progressive Non-Invasive Methods of the Stabilization, Conservation and Strengthening of Historic Structures and their Parts with fibre- and nanofibre-based Composite Materials". The grant researcher is prof. Ing. Jiří Witzany, DrSc.

Gratefully acknowledgement belongs to Josef Füssl for supervising during my study internship at Institute for Mechanics of Materials and Structures, TU Wien.

References

[1] Research project NAKI DF12P01OVV037 "Progressive Non-Invasive Methods of the Stabilization, Conservation and Strengthening of Historic Structures and their Parts with fibre- and nanofibre-based Composite Materials". The grant researcher is prof. Ing. Jiří Witzany, DrSc.

[2] J. Witzany, T. Čejka, R. Zigler. Efficiency and Critical Points of Strengthening Masonry Structures with FRP, in proc.: The Third Asia-Pacific Conference on FRP Structures (APFIS 2012), Japan Concrete Institute, Tokyo.

[3] J. Kubát, J. Karas. The corner radius influence on the deformation behavior of brick pillars strengthened by CFRP confinement, in proc.: Proceedings of 16th International Conference on Rehabilitation and Reconstruction of Buildings (2014), Brno University of Technology, Brno.

[4] J. Witzany, T. Čejka, R. Zigler. Failure Mechanism of compressed short brick masonry columns confined with FRP strips, Construction and Buildings Materials 63 (2014) 180-188, doi: 10.1016/j.conbuildmat.2014.04.041.

[5] J. Witzany, R. Zigler. The Analysis of the Effect of Strengthening Compressed Masonry Columns with Carbon Fabric, in proc.: The 7th International Conference on FRP Composites in Civil Engineering (CICE 2014), International Institute for FRP in Construction, Vancouver.

[6] M. Mrozek, D. Mrozek, A. Warwrzynek. Numerical analysis of selection of the most effective configuration of CFRP composites reinforcement of masonry specimens, Composites: Part B 70 (2015) 189-200, doi: 10.1016/j.compositesb.2014.11.016.

[7] R. Fedele, G. Milani. A numerical insight into the response of masonry reinforced by FRP strips. The case of perfect adhesion, Composite Structures 92 (2010) 2345–2357, doi: 10.1016/j.compstruct.2010.03.014.

[8] R. Fedele, M. Scaioni, L. Barazzetti, G. Rosati, L. Biolzi. Delamination tests on CFRP-reinforced masonry pillars: Optical monitoring and mechanical modeling, Cement & Concrete Composites 45 (2014) 243–254, doi: 10.1016/j.cemconcomp.2013.10.006.