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Failure Mechanism of Compressed Masonry Column

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Abstract. This paper deals with numerical analysis of masonry column under concentric compressive load. The heterogeneous model with the possibility of describing the contact between distinct materials was chosen for the numerical analysis. Mutual interaction between masonry unit (in this case solid burnt bricks) and mortar joints results in additional tensile stresses of the material with higher value of Young's modulus. Tensile vertical cracks following by loss of the structure's stability are caused not only from the contraction but also from the mutual interaction in contrast with compressed concrete pillars. For all simulations the commercial software package ABAQUS was used. Theoretically and experimentally obtained results are mutually discussed.

Introduction

The determination of required material characteristics entering the computation of masonry structure is very complex. Masonry consists at least of two components, in this case solid burnt bricks and one type of mortar. These components are considered as heterogeneous materials with huge spread of mechanical characteristic. Experimental part has proved quasi-brittle behaviour of mortar and brittle behaviour of solid burnt bricks in three-point bending test. For bricks, after the value of failure stress was reached the softening curve has directed straight down, on the contrary of mortar when the softening curve had gradient expressing the brittleness. Experimentally detected working diagram in compression of brick and mortar were characterized after first crack's appearance by mild hardening following by softening [1]. However even if all mechanical characteristic of the individual components are known, behaviour of masonry column as compact structure is influenced by several factors, such as manufacturing, the size and the shape of masonry unit, damage or degradation. To eliminate unknowns, the linear – elastic behaviour for all components simulating the state before damage were chosen for verification of the character of behaviour masonry column under concentric compressive load.

The modelled column with plan dimensions of 0.3 m x 0.3 m and a height of 1 m matches with 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.

Failure Mechanism of Masonry Column

Failure mechanism of compressed brick masonry column is characterized by the appearance and development of vertical tensile cracks passing in the direction of principal stresses and is accompanied by progressive growth of horizontal deformations. These cracks are caused by contraction and interaction between two materials with different mechanical characteristics [2, 3, 4]. As a result of this mutual interaction, 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".

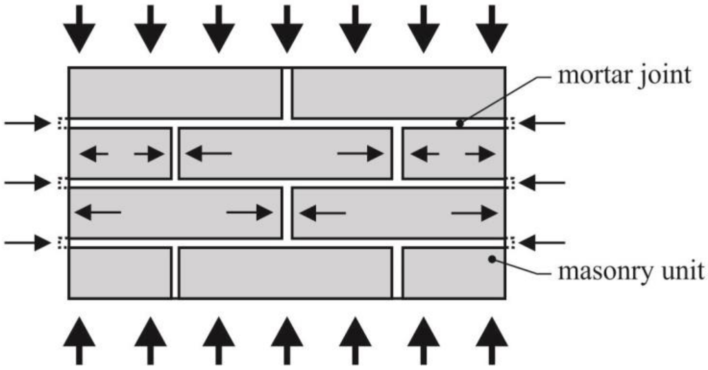

Fig. 1: Mortar-brick interaction

Intensive masonry unit-mortar interaction does not occur for example regular ashlar masonry with small differences in mechanical properties between masonry unit and binder. In that case, the failure mechanism is characterized by gradual local damage of masonry in compression.

Numerical Model

The heterogeneous model (all components are geometrically and materially accurate described) was chosen for the analysis under the assumption of linear-elastic behaviour for all components simulating the state before damage. Linear-elastic parameters are shown in table 1.

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	0.3

The maximal size of finite element's mesh was a third of masonry unit's height with refining for mortar joints matches with two finite element per mortar joint thickness. The chosen type of finite elements were three dimensional solid elements C3D8 – 8-node linear brick. For brick-mortar interface, "hard" contact was assumed in normal direction and frictional behaviour (with a friction coefficient of 0.6) in tangential direction.

The boundary conditions were applied on two steel plates positioned at the head and the bottom of the masonry column. Vertical load were applied in a form of displacement at the top surface of steel plate at the column's head and lower surface of bottom plate were rigidly fixed.

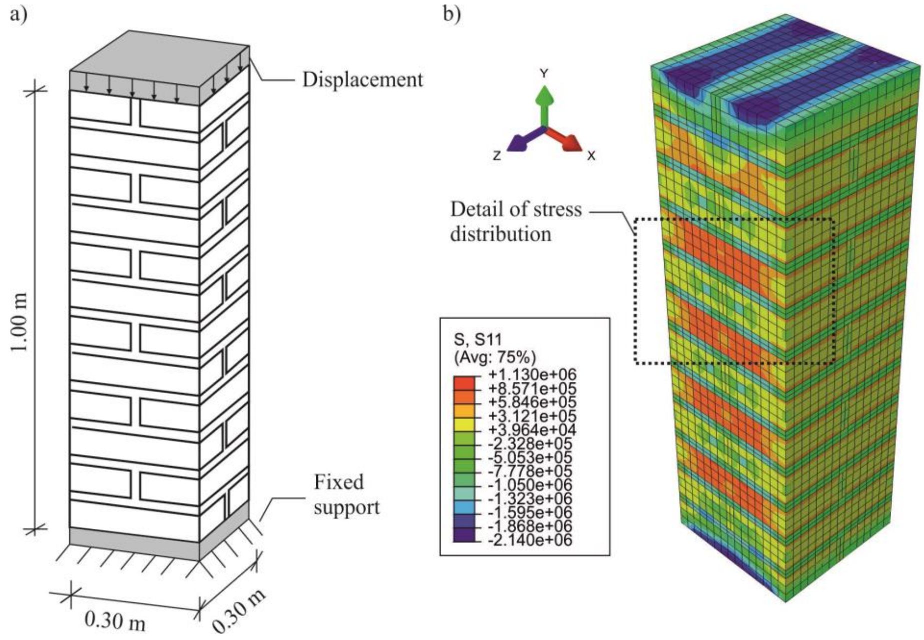

Fig. 2: Numerical model's scheme (a), horizontal stress distribution (b)

Discussion of Results

The horizontal stress (s11) distribution is evident from the results of numerical analysis. Figure 3 shows in detail one of the horizontal stresses, the second (s33) one is symmetric. The maximal principal stress's trajectories (combining primarily both horizontal stresses s11 and s33) run along masonry units and cause transversal cracking of solid burnt bricks. Direction of the crack thus matches with the middle principal stress's trajectories. Along the height of the column, cracks run in the direction of minimum principal stresses (almost corresponding to the vertical stress s22).

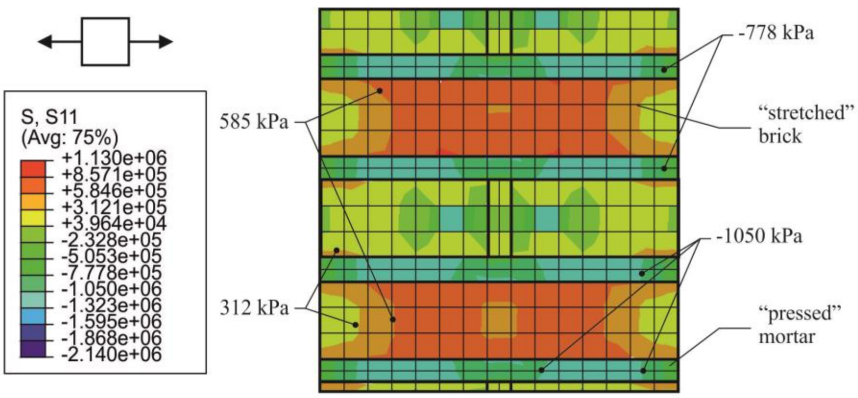

Fig. 3: Horizontal stress distribution in detail

Results from experimental testing are consistent with theoretically findings. Hairline cracks had appeared at the brick-butt joint interface. The vertical cracks approx. in a half of brick had firstly appeared in the middle part of the column. The next loading were accompanied by the appearance of other crack in the upper part and growth of cracks in the middle third of the column. Development of the cracks has resulted in large horizontal deformation and formation of several main continuous cracks causing the splitting of the column to the sub-parts.

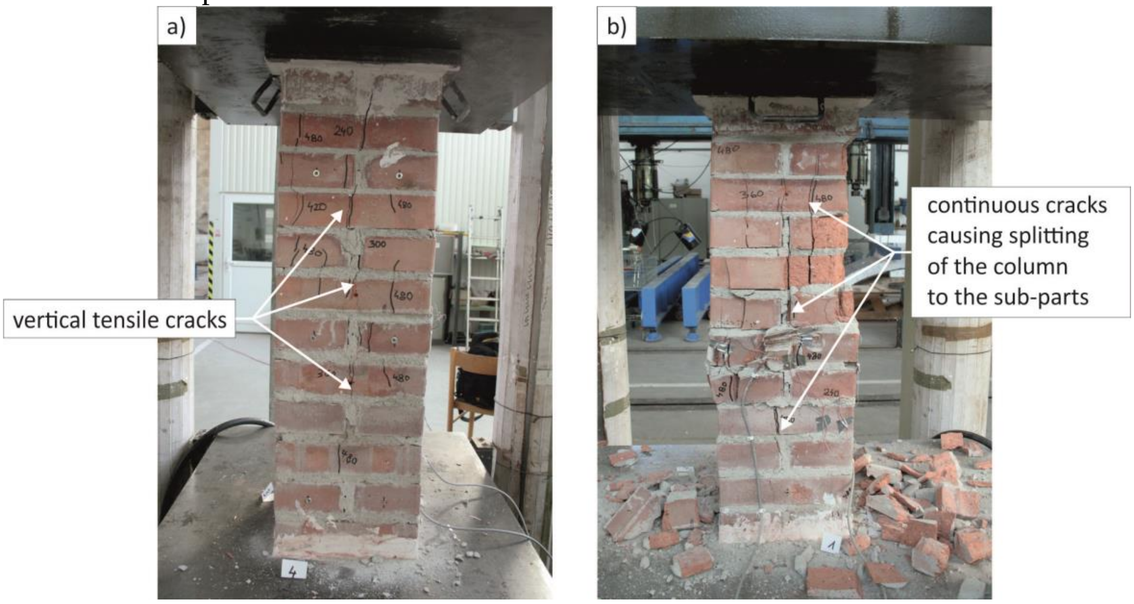

Fig. 3: Cracks distribution in the initial stage of loading (a), failure of the column after reaching the maximal stress (b)

Conclusions

The formation and growth of vertical tensile cracks in masonry units (bricks) due to the additional tensile stresses caused by lateral strain of more compliant mortar in bed joints and contractions precedes redistribution of stresses and failure of the structure. This type of failure mechanism corresponding with presented brick work masonry column under concentric compressive load was verified by stress distribution from numerical simulation and experimental testing.

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