Analysis of Tri-axial Stress-strain Conditions of Pre-stressed Masonry Corner

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Abstract: During the revitalization of masonry structures the post-tensioning of masonry is used frequently for improving the structural mechanical properties. Masonry is heterogeneous material with varied material properties, in older buildings affected with different type of damage and that is why in engineering practice the intensity of pre-stressing is often designed according to engineering judgement of the designer. Mathematical modelling of post-tensioned masonry structures is very valuable. Authors are interested particularly in so-called micromodels and macromodels of masonry structures. Structural parts are analyzed using ANsys computer program. Mathematical model has been verified with testing. At VSB – Technical University of Ostrava unique equipment was designed for experimental testing of tri-axial state of stress and strain of pre-stressed masonry corner. Plan dimensions of the tested corner are 900 × 900 mm, the thickness of the wall is 450 mm and the height is 900 mm. Experiments started in 2011 with masonry corner made of clay bricks and general purpose mortar. Ongoing experiments and appropriate mathematical modelling should contribute to higher reliability of engineering computations of masonry structures.

Keywords: micromodel; macromodel; FEM, masonry structures, post-tensioning

1. Testing the Pre-stressed Masonry Corner

1.1. Motivation

Masonry structures are often historical buildings exposed at present to higher action than they were designed to, as a result of changing the use of the building or e.g. undermining and related change in soil-structure interaction (Cajka, Manasek, 2005). In engineering practice post-tensioning of masonry structure is used frequently because it is an effective method to enhance the static action and improve the rigidity of the building. Other advantages are that the existing cracks could be eliminated and the outward of the building does not change. Masonry is heterogeneous material with varied material properties, in older buildings affected with different type of damage and that is why the intensity of pre-stressing is often designed according to engineering judgement of the designer. From experience of practical design and also from available literature (Bazant, Klusacek, 2004) could be concluded that during the post-tensioning the failure occurs most often in the zone of pre-stressing force anchoring. Authors aim is to contribute to better understanding of post-tensioned masonry and therefore it was decided to perform the testing of tri-axial stress/strain conditions in post-tensioned masonry corner.

5th International Conference on Reliable Engineering Computing (REC 2012)
Edited by M. Vořechovský, V. Sadílek, S. Seitl, V. Veselý, R. L. Muhanna and R. L. Mullen

ISBN 978-80-214-4507-9. Published by Ing. Vladislav Pokorný − LITERA

1.2. DESCRIPTION

At VSB-Technical University of Ostrava unique equipment for was designed for testing of tri-axial stress/strain conditions, Fig. 1. Plan dimensions of the tested corner are 900 × 900 mm, the thickness of the wall is 450 mm and the height is 900 mm. It is possible to accomplish number of tests for different input parameters, e.g. using various materials (brick, mortar), laying out and number of pre-stressing bars, value of pre-stressing force, size and shape of anchoring plate, value of vertical load, number of brick layers or the thickness of bed joint, brick bond and the supporting of the masonry corner (simple, with slide joint and others). Deformation in network of points during the pre-stressing is measured. Possible tension-metrical measurements have not been fully accomplished yet.

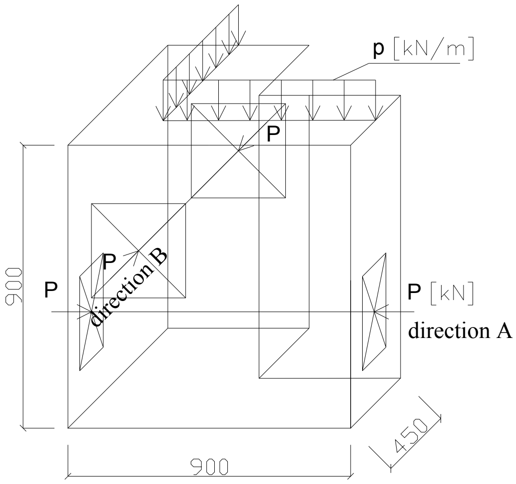

Figure 1. Testing equipment

Experiments started in 2011 with masonry corner made of clay bricks and general purpose mortar. Bricks were obtained from demolished building and limecement mortar was prepared from designed dry mixture. Pre-stressing was installed with two pre-stressing steel bars and square anchoring plates with dimensions 300 mm, 200 mm and 100 mm, the thickness is 10 mm. The strength of bricks and the mortar was checked in Faculty laboratory according to valid codes. Normalised mean strength of bricks was $f_b = 16.08$ MPa and mean strength of mortar f_m = 9.8 MPa. Characteristic strength of tested masonry is settled in (1) according to (EN 1996-1-1, 2005), where K is constant for different groups of bricks.

$$f_k = K.f_b^{0.7}.f_m^{0.3} = 0.55 \times 16.08^{0.7} \times 9.8^{0.3} = 7.6 \text{ MPa} \tag{1}$$

Masonry corner was exposed to vertical load 0.125 MPa and 0.250 MPa corresponding to vertical load in common building and arbitrary pre-stressing force 50 kN and 100 kN. Pre-stressing was installed in one direction and released, than in second direction and released and in the end in both directions. Only short-time deformations were measured. Primary pre-stressing force was settled according to recommendation that the pre-stressing force should cause the stress value of 10% vertical masonry strength.

1.3. Test Results

The deformations are measured in regular network of measuring points in two directions, network in the *direction A is* in Fig. 2.

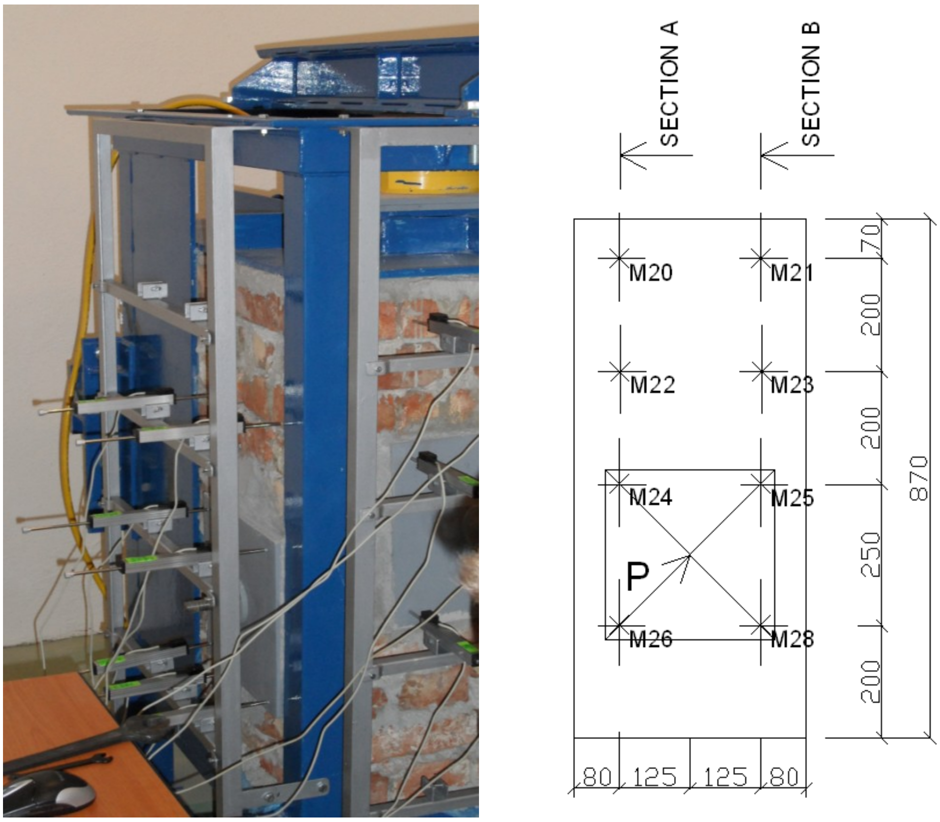

Figure 2. Network of deformation measuring points in the direction *A*

In the charts, Fig. 3 there are measured deformations in the direction A, section A and B (according to Fig. 2) for vertical load 0.125 MPa and pre-stressing force 100 kN in A direction anchored with square plate 0.3 × 0.3 m. Horizontal line indicates the location of pre-stressing force. Deformations in particular vertical section are unexpectedly higher in measuring points farther from the pre-stressing force. However the course of measured deformations in two symmetrical sections is similar. The same course of deformations is also in the Fig. 4 where there are deformations in the direction A for different dimensions of anchoring plates. Values in section A and section B are averaged. When anchoring the pre-stressing force with plate 0.150 × 0.150 m the stress is probably transferred more locally and the course of deformations is different. Possible inaccuracies could be caused also with uneven mortar joint under the anchoring plate. Analogous measurements were done also for pre-stressing in B direction and pre-stressing in both directions and the course of the deformations is similar. The deformations could grasp only the surface stress/strain conditions. Critical is distribution of pre-stressing in the whole cross-section. Tension-metrical measurements are planned in the newly bricked masonry corner.

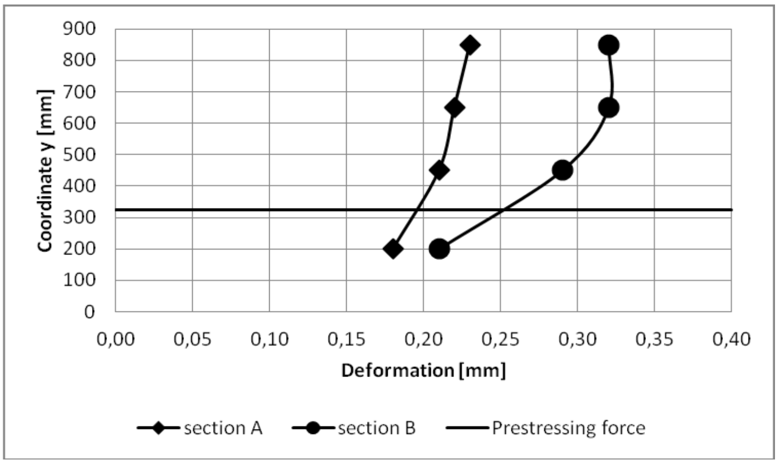

Figure 3. Deformations for pre-stressing 100 kN in the direction *A*, vertical load 0.125 MPa, anchoring plates 0.3 × 0.3 m

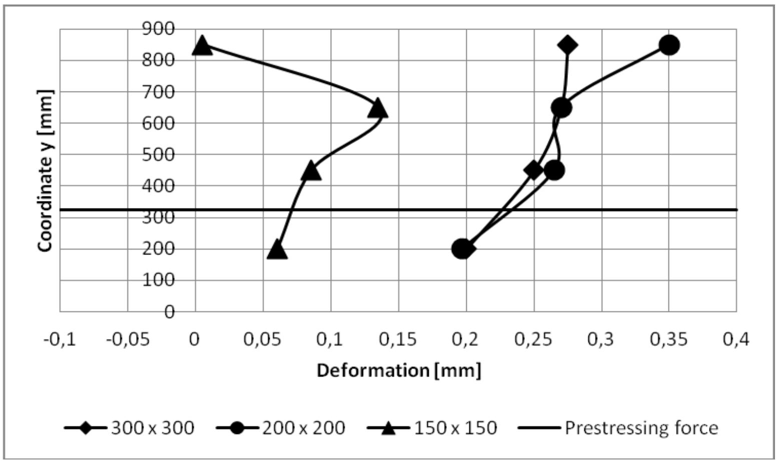

Figure 4. Average deformations for pre-stressing 100 kN in the direction *A*, vertical load 0.125 MPa

2. Masonry numerical modeling

2.1. BASIC WAYS OF MODELING

Complicated numerical modeling of masonry as anisotropic and heterogeneous material is connected with the main following factors:

- Different material properties of basic components (brick/mortar)

- Different dimensions of basic components (dimension of brick/dimension of mortar joint)
- Narrow dimension of mortar joint
- Geometrical arrangement of bricks
- Different structural response for different load action direction
- Interaction between components
- Quality of manufacturing
- Environmental influence

Investigation into masonry structures and into its mathematical modeling has brought number of different approaches, (Materna, Brozovsky, 2007). According to (Lourenco, 1996) there are three basic strategies, Fig. 5:

- *Detailed micromodel* – bricks and mortar are assumed as two different materials, with their real dimensions and real geometrical arrangement in the structure.
- *Simplified micromodel* – brick and surrounding mortar joints is assumed as one block. Material properties of bricks and mortar have to be simplified.
- *Macromodel* – masonry is assumed as homogenous material. It is necessary to determine the most fitting anisotropic material properties.

2.2. DETERMINATION OF HETEROGENEOUS MATERIAL PROPERTIES

Detailed micromodel, with its modeling of particular masonry components and geometrical arrangement, could be precise and accurate, but also very laboring and demanding the powerful computer. Modeling the whole structure in this way is inconceivable. Micromodel is useful for modeling of structural details or local action. Micromodel could be used for determination of heterogeneous material characteristics for macromodel, (Cajka, Kalocová, 2007). Part of the masonry wall micromodel is exposed to deformation load in different direction, Fig. 6, and from the result structural response F_x modulus of elasticity and shear modulus are determined (2). Input parameters for illustrative example and settled material heterogeneous parameters are listed in the Table 1.

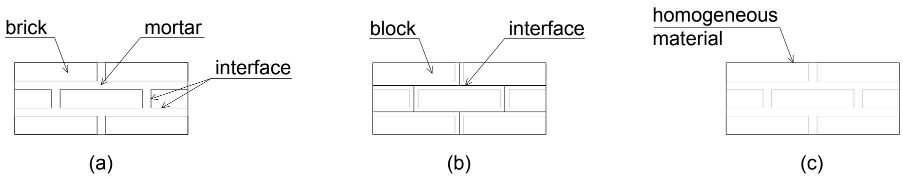

Figure 5. Basic way of masonry modeling

$$E_x = \frac{F_x \cdot L_x}{u_x \cdot A_x}, \qquad G_{xy} = \frac{F_{xy}}{\gamma \cdot A} \qquad (2)$$

Table I. Input and output parameters for illustrative example

	Material	*Modulus of Elasticity* [GPa]	*Shear modulus* [GPa]	*Poissons' ratio* [-]
Input	Bricks 290/140/65	15.00		0.15
	Mortar 10MPa	10.00		0.2
Output	Masonry *x* direction	13.96	3.65	0.202
	Masonry *y* direction	14.00	5.56	0.198
	Masonry *z* direction	13.84	4.30	0.197

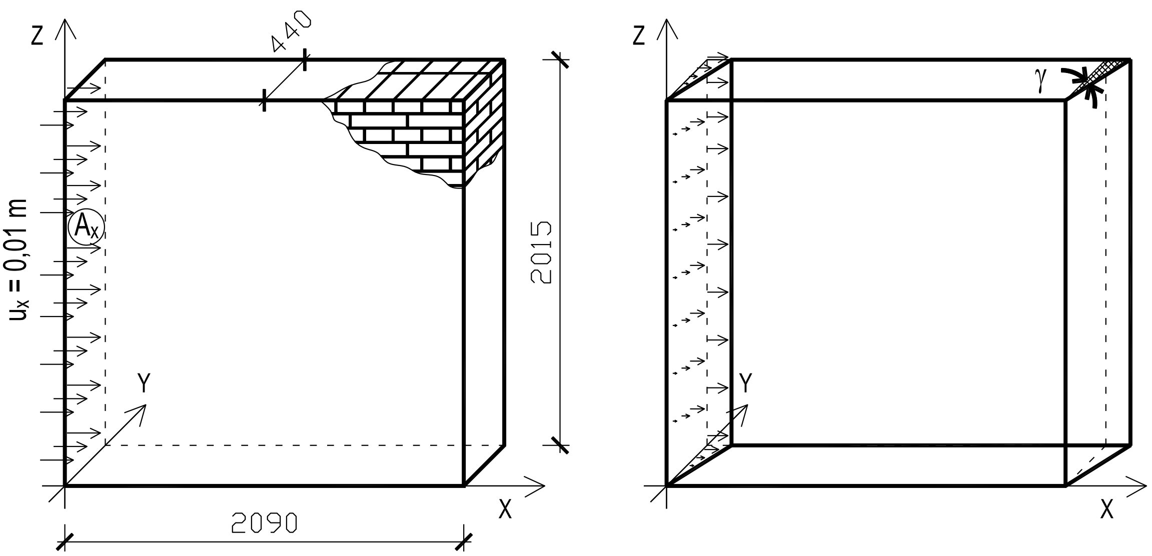

Figure 6. Masonry wall micromodel exposed to deformation load in x direction

2.3. MODELING OF TESTED MASONRY CORNER

Before the testing started the micromodel and macromodel of post tensioned masonry corner was prepared in ANsys computer program, Fig. 7. Elements Solid 45 are used for bricks, mortar, anchoring plates and also in macromodel. Pre-stressing is incorporated with the element Link8.

Micromodel and macromodel of masonry corner is made assuming the same conditions as in experiment, i.e. bricks 209/140/65 and lime cement mortar 10 MPa, vertical load 0.250 MPa and pre-stressing force 100 kN. In the Fig. 8 there are deformations in the section in location of upper pre-stressing bar. In macromodel the deformations (and consequently stress) are spread to larger area. In micromodel the deformation is concentrated in anchoring area and especially bricks and mortar adjacent to anchoring plate are affected. Deformation (and consequently stress) in micromodel corresponds with practical experiences with masonry post-tensioning. In case of masonry resistance is exhausted usually only bricks and mortar in anchoring area are affected while the farther components are not concerned.

Currently the mathematical model of masonry corner is improved so that it better fits the real structure. Presently it is possible to state that the settled deformations correspond to measured values approximately.

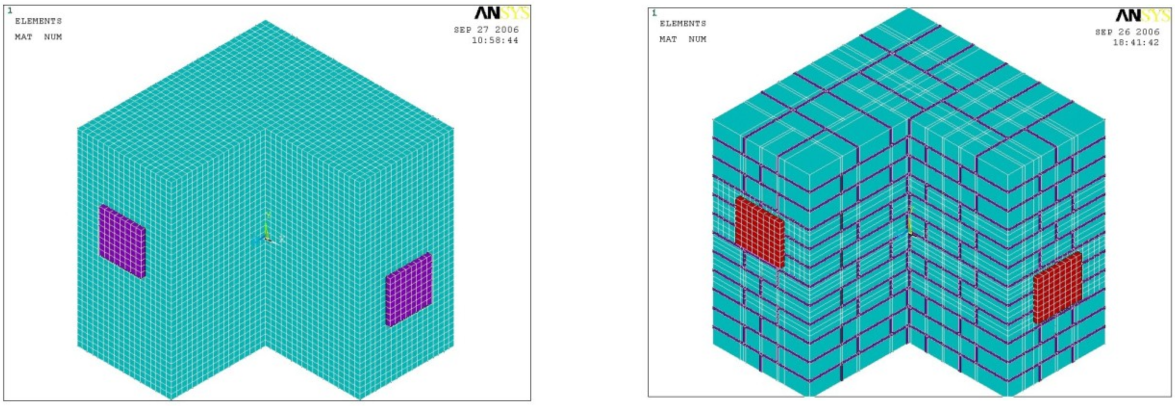

Figure 7. Macromodel and micromodel of post-tensioned masonry corner

Together with improving the mathematical model walling of new masonry corner is prepared again with clay bricks and general purpose mortar with lower strength.

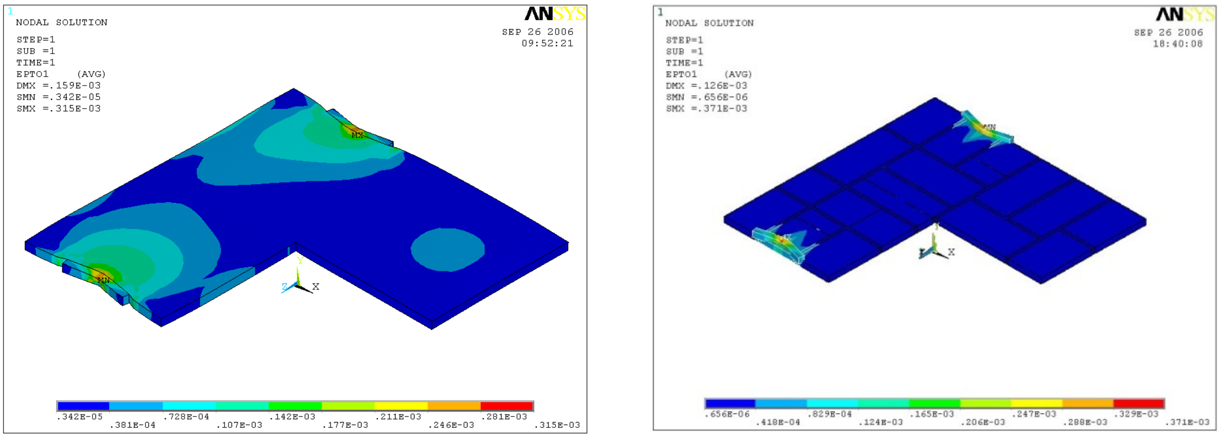

Figure 8. Macromodel and micromodel – deformation in section in place of upper pre-stressing bar

3. Conclusion

In the paper authors introduce the experimental testing of masonry corner exposed to tri-axial load and partial measured deformations. Masonry as heterogeneous and anisotropic material requires specific way of mathematical FEM modeling. Micromodel and macromodel of tested masonry corner is introduced. Ongoing experiments and following FEM modeling should contribute to better understanding of masonry strength characteristics and thus improve the structural reliability of masonry in case of post-tensioning.

Acknowledgements

This outcome has been achieved with the financial support of the Ministry of Industry and Trade of the Czech Republic, program TIP, project No. FR-TI2/746 Rheological sliding joint with thermo-controlled viscoelastic properties.

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