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LABORATORY MEASUREMENT OF DEFORMATIONS OF BIDIRECTIONALLY PRESTRESSED MASONRY

LABORATORNÍ MĚŘENÍ DEFORMACÍ OBOUSMĚRNĚ PŘEDPJATÉHO ZDIVA

Abstract

This paper deals with laboratory measurements of deformations in the place exposed to local load caused by pre-stressing. The measurements are made at the masonry corner built in the laboratory equipment. The laboratory equipment was designed at Faculty of Civil Engineering VSB-TU Ostrava for measurement tri-axial stress-strain conditions in masonry. In this masonry corner two pre-stressing bars are placed. These bars are in different height and are anchored to the anchor plates, which transfer pre-stressing forces to the masonry. The masonry was pre-stressed in the both directions. The specimen for laboratory testing is performed in the proportion to the reality of 1:1.

Keywords

Masonry, pre-stressing, deformation, measurement.

Abstrakt

Tento článek se věnuje laboratornímu měření deformací v místě lokálního namáhání zdiva od předpětí. Měření jsou prováděna na zděném rohu, který je vestavěn do laboratorního zařízení. Laboratorní zařízení bylo navrženo a vyrobeno na Stavební fakultě VŠB a je určené pro měření trojosé napjatosti zdiva. Ve zděném rohu jsou vloženy dvě předpínací tyče umístěné v různých výškách a upevněny do kotevních desek, které slouží pro přenos předpínacích sil do zdiva. Zdivo bylo předpínáno v obou směrech. Zděný roh je proveden v poměru ke skutečnosti 1:1.

Klíčová slova

Zdivo, předpětí, deformace, měření.

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1 INTRODUCTION

Rehabilitation with additional preload is examined in detail in reinforced concrete structures, but masonry structures are not. The problem is determining the strength especially with regard to the current state of the masonry, the nature and extent of damage. More difficult is the determination of values of tensile forces [1;2].

In the literature we can find the recommended values for the ratio of prestressing force and masonry compression strength perpendicular and parallel to the bed joints based of experiments. According to German research [3] is possible to choose the value of the prestressing force in size from 0.10 to 0.15 strength of masonry perpendicular to bed joints. This range is determined using a graph, where the strength of masonry depends on the percentage of completion of vertical joints with mortar. Quality of vertical joints filled with mortar in masonry decides on the overall strength of masonry. The less well joints are filled, the lower is the strength of masonry. According to [4;5] the tensile strength of the selected size is about 1/10 masonry compression strength perpendicular to a bed joints. According to [6] the masonry compressive strength parallel to the bed joints acquire from 0.1 to 0.85 times the strength of a loading perpendicular to the bed joints. According to the results of the work [7] the values range from 0.1 to 0.25 masonry strength perpendicular to the bed joints. This range is dependent on sufficient information about masonry and especially its quality filling vertical joints with mortar. For walls with a well filled joints are considering the value of 0.7 to 0.8 with the fact, that this value should not be exceeded.

More detailed information to calculate the tensile strength or the analysis of stress in the anchor plates are not in the current technical standards listed.

Prestressing force in the experimental measurement of deformations, described in this article are chosen safely with regard to the quality of filling joints with mortar as 10, 20 and 30% of the compressive strength of masonry perpendicular to bed joints. The purpose of this testing is not only the actual deformation measurement, but also monitoring the behavior of masonry at the local strain of gradually increasing preload.

The tests simulate the behavior of masonry reinforced prestressing cables at the moment of introduction of preload, it is the short-term tests.

2 MEASUREMENT PROCEDURE

2.1 The course of walling and determination of material characteristics

Laboratory equipment for testing three-axis stress is a steel structure with dimensions 900 × 900 × 1550 [8]. In it is built brick corner with a height of 850 mm (11 rows of bricks). Wall thickness is 440 mm.

Fig. 1: Laboratory equipment and location prestressing bars in the masonry

Were used bricks CP 290x140x65, P15 and like fasteners material was used cement mortar M5 (easily available mortar for masonry), mixed with sand in the ratio 1:1. The intention of mixing mortar and sand was to obtain mortar with a lower strength, which better correspond to the quality of lime mortar for existing buildings rehabilitated, which reached strength 0 - 0,4MPa.

To test the strength of masonry elements were selected 10 samples (whole bricks) that were tested according to the standard [9]. The average compressive strength of brick was set to 12.87MPa. From this value is then derived normalized mean compressive strength of masonry element $fb = 9.9$ MPa. In the course of masonry were gradually removed 6 samples mortars, which were tested according to [10]. Samples were all the time maturing in the same climatic conditions as brick corner. The average compressive strength of mortar $f_m = 0.653$MPa.

Tested brick corner is considered as part of the existing structure and therefore the calculation of the characteristic strength of masonry in compression is followed according to [11] – Assessment of existing structures, which refers to the determination of the strength characteristics to the previously applicable standards, for masonry for example, already invalid standard [12]. To calculate the characteristic compressive strength of masonry perpendicular to bed joints then it holds:

$$f_k = K \cdot f_b^{0,65} \cdot f_m^{0,25} \tag{1}$$

The constant K depends on the type of masonry and a group of bricks of elements and according to [12] is equal to 0.4. The resulting characteristic compressive strength of masonry perpendicular to the bed joints is $f_k = 1.59$MPa.

During the masonry walls were inserted into two prestressing bars at different heights, see Fig.1. Both tensioning rods were marked according to the direction in which it is placed (direction A and direction B). In the direction of A was placed at a height of 370 mm, the B was placed at a height of 500 mm. After the final brick walling around the corner, the upper part of the structure aligned layer of mortar and it settled spreading steel plate with a thickness of 12 mm with welded steel reinforcements to ensure even load masonry. Post-tensioning rods are planted steel anchor plates on a layer of mortar for leveling the surface of the wall.

2.2 Loading of test sample

After 28 days it was masonry ready for load and deformation measurement. In the first phase settled the loading equipment. Vertical load was introduction on using a hydraulic cylinder, which is placed between the plate and the load distribution I profile bolted for laboratory equipment. The sample was loaded vertical uniformly distributed load of 0.1 MPa.

Prestressing force was brought in prestressing rods also by hydraulic cylinders through the anchor plate of size 300 x 300 mm and a thickness of 10 mm. The values of tensile strength are given in Tab. 1. Measured deformations were recorded using potentiometric sensors attached to laboratory equipment, identified as connected to the measuring station. In each direction was fixed total of eight sensors, in the direction A sensor labeled M21 to M28 and in the direction B labeled M1 to M8. The placement of individual sensors in both directions is shown in Fig. 2.

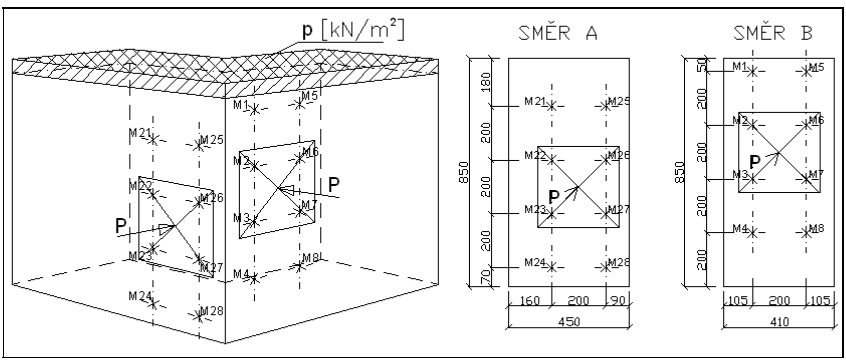

Fig.2: Schematic layout of measuring sensors in the direction A and B

Prestressing rods were conducted gradually. The sample was weighted prestressing force by the size 10%, 20% and 30% of the masonry compression strength perpendicular to the bed joints, always in the direction A, then in the direction B.

In Tab. 1 shows the input values of load masonry. The first column shows the percentage values, the second is values voltage in the anchorage areai, derived from the characteristic compressive strength of masonry perpendicular to bed joints, in the third column lists the size of prestressing forces, brought into the masonry through anchor plate of size 300 x 300 mm. Surface anchor plate and the surface of masonry anchor plate is considered without weakening hole, which was left for the passage of the prestressing rods, inasmuch as dimensions hole are negligible.

Tab. 1: Input values for anchoring plate with dimension 300 x 300 mm, area A = 0.09 m^2

	Stress [kPa]	Prestressing force [kN]
10 %	159	14.3
20 %	318	28.62
30 %	477	42.93

3 RESULTS OF DEFORMATIONS

The course of the resulting distortions can be seen in the graphs in Fig. 3 and Fig. 4. The x-coordinate of the values of deformation with a negative sign of the pressure bearing plates on masonry. The resulting deformations are obtained by averaging the measurements in vertical sections M21 ~ M24 and M25 ~ M28 in the direction A (Fig.3) and M1 ~ M4 a M5 ~ M8 in the direction B (Fig.4). The vertical axis is the vertical coordinates of the location of each sensor according to Fig.2. All sensors were placed on bricks or anchor plates, but not in the mortar joint. Horizontal line in the graph indicates the location of the prestressing force. In the direction A is the height of the prestressing force 370 mm and in the direction B is the height of prestressing force 500 mm.

As is evident from Fig. 3, the shape deformation of walls in the direction A at the tensioning rod corresponds to a significant stress concentration directly under the anchor plate, while above and below the anchor plate deformations are smaller. Courses of deformation are approximately at equal distances for each size prestressing forces.

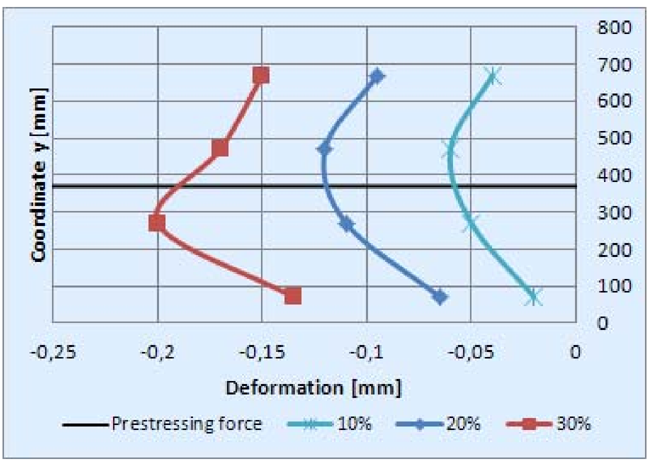

Fig.3: The courses of deformation in the direction A

More interesting is the process of deformation in the direction B (Fig. 4). The resulting process deformation is likely to be affected have already applied prestressing force in the direction A.

Prestressing force at a load of 30% of the masonry compression strength perpendicular to the bed joints is evident, that likely contribute to deformation and greater compression buffer mortar M5 (thickness 30 mm) under anchor plates, or poor completion vertical mortar joints. Excessive deformation in the direction B at the bottom of the walls were probably due to the load of the prestressing force in the direction A, because approximately the same level is a distributive plate, respectively its lower part, which could cause a displacement layer of bricks.

The results show that it would be appropriate to make the same measurement with the gradual prestressing in reverse order, ie the first direction B and then the direction A, in order to verify the accuracy of the results achieved, their control and test hypotheses.

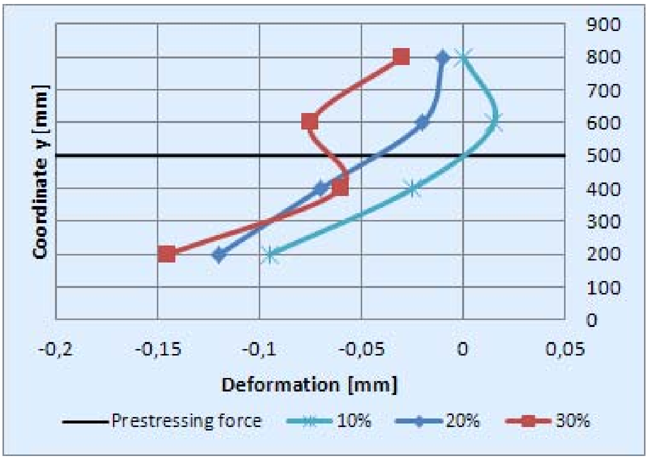

Fig.4: The courses of deformation in the direction B

4 CONCLUSION

This paper describes the laboratory measurement of deformations on prestressed masonry corner. The introduction deals with determining the size of prestressing forces, which were selected for laboratory measurements safely given on the quality of filling joints with mortar. The sample was loaded with vertical loads and then prestressing force in two directions. Deformations are plotted for different sizes of masonry tensile forces in the two directions. In preparation for the measurement of brick corner using larger tensile forces of up to 50% of the compressive strength of masonry perpendicular to bed joints. Are prepared samples for determination of modulus of elasticity of brick and mortar, for future comparison with numerical modeling program on the principle of FEM [13;14;15;16;17].

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REFERENCES

[1] ČAJKA, R. Strengthening of Historical Structures on Flooded and Undermined Territory. *International Geotechnical Engineering,Saint Petersburg.* 17-19. September 2003, Russian, ISBN 5-93093-204-2.

[2] ČAJKA, R. Lifetime Enhancement of Historical Structures on Flooded and Undermined Territory. *Integrated Lifetima Engineering of Buildings and Civil Infrastructures, and International Symposium ILCDES 2003.* 1-3. December 2003, Kuopio, Finland, ISSN 0356-9403, ISBN 951-758-436-9.

[3] SCHUBERT, P.; HOFFMANN, G. Druckfestigkeit von Mauerwerk parallel zu den Lagerfugen. *Mauerwerk-Kalender 1994*, Ernst Sohn & Berlin 2004.

[4] BAŽANT, Z.; KLUSÁČEK, L. Structural Analysis at Redevelopment of Buildings. VUT Brno, 2004.

[5] KLUSÁČEK, L.; BAŽANT, Z. Structures Post-tensioning in Relation to Subsoil. *Sborník příspěvků 13. mezinárodního semináře 2008*, Ostrava 2008. VŠB-TU Ostrava 2008, s. 21 – 26. ISBN 978-80-248-1715-6.

[6] KOŠATKA, P.; LORENZ, K.; VAŠKOVÁ, J. *Masonry structures 1.* ČVUT Praha, 2006.

[7] ŠULÁK, P. Long – term Monitoring of Post-tensioned Structure. *Sborník příspěvků 13. mezinárodního semináře 2008*, Ostrava 2008. VŠB-TU Ostrava 2008, s. 27 – 33. ISBN 978-80-248-1715-6.

[8] MYNARZOVÁ, L. Static Analysis of Masonry Structures *Dissertation thesis 2009.* VŠB-TU of Ostrava 2009. ISBN 978-80-248-2064-4.

[9] ČSN EN 1052-1 Methods of Test for Masonry, Part I, Determination of Compressive Strength, Český normalizační institute, 2000.

[10] ČSN EN 1015-11 Methods of Test for Mortar for Masonry, Part 11: Determination of Flexural and Compressive Strength of Hardened Mortar, Český normalizační institut, 2000.

[11] ČSN ISO 13822 Bases for design of structures - Assessment of existing structures. Český normalizační institut, 2005.

[12] ČSN P ENV 1996-1-1: Design of masonry structures - Part 1-1: General rules for buildings - Rules for reinforced and unreinforced masonry. Český normalizační institut, 1996.

[13] ČAJKA, R., KALOČOVÁ, L. Modeling and Analysis of Post–Tensioned Masonry. *The eleventh International Conference on Civil, Structural and Environmental Engineering Conputing.* 18-21. Septenber 2007, St. Julians, Malta 2007, ISBN 978-1-905088-17-1.

[14] ČAJKA, R., KALOČOVÁ, L. Progressive approach to the analysis of post-tensioned masonry structures using FEM. In EngOpt 2008 - *International Conference on Engineering Optimization.* Rio de Janeiro 1-5. Juni 2008. Ed. J. Herkovitz, A. Canelas, H. Cortes, M. Aroztequi, 2008. ISBN 978-85-7650-152-7.

[15] GIORDANO, A., MELE, E., DE LUCA, A. *Modelling of historical masonry structures: Comparison of different approaches through a case study.* Engineering Structures. July 2002, ISSN: 01410296, DOI: 10.1016/S0141-0296(02)00033-0

[16] MATERNA, A., BROŽOVSKÝ, J. Constitutive model for two-dimensional modeling of masonry. In *proceedings of the Eleventh International Conference on Civil, Structural and Envirinmental Engineering Computing 2007,* Malta 2007.

[17] ZUCCHINI, A., LOURENCO, P. B. *A micro-mechanical model for the homogenisation of masonry*. International Journal of Solids and Structures. Juni 2002, DOI: 10.1016/S0020-7683(02)00230-5

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