BEHAVIOUR AND CHARACTERISTIC OF CLAY BRICK MASONRY WALLETTES SUBJECTED TO COMPRESSIVE CYCLIC LOADS

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SUMMARY

In analysis of masonry structures in complex state of stress, usually carried out with usage of programmes based on FEM the most important is knowledge of the real mechanical material parameters. The detailed describing of the failure process of masonry structure needs the non-linear analysis, which should be based on the post elastic behaviour of masonry including the characteristic of the material degradation.

Tests of unreinforced clay brick masonry wall specimens subjected to cyclic axially compressive loads in both orthogonal directions are presented. Tested masonry wallettes were two types differ from each other overall dimensions. Moreover, in case of small specimens loading was realised in both orthogonal directions. The results of tests are presented and discussed.

INTRODUCTION

The linear elastic material models for masonry do not allow describing the post elastic behaviour of analysed structure, especially in case of dynamic or cyclic loads and influences. These types of loads are dominant not only in areas of coal and copper mining activity, but also in all terrains where urban transport is intensive. Therefore a more deep and advanced analysis of structures subjected to such influences is necessary.

This analysis of damaged or cracked structures or else a trial of damage mechanism description of considerably loaded constructions are not possible with usage of linear-elastic material model taken for masonry. In technical literature it is possible to find many different material models for describing the post-elastic behaviour of masonry or concrete (e.g. Lubliner et al. 1989, Lourenço et al. 1998, Jirásek and Bažant 2002). Some of them were implemented for professional numerical programmes based on FEM (e.g. ABAQUS). These programs make the simulation of construction failure possible on condition that earlier the model parameters will be experimentally determined.

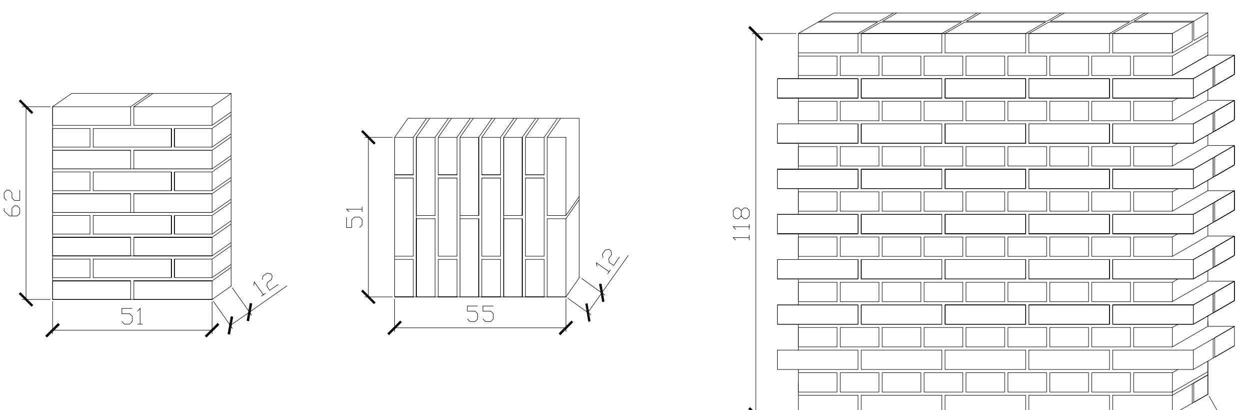
One of the more interesting material models is an elastic-plastic degradation model elaborated for concrete, well known in technical literature (e.g. Lubliner et al. 1989) as *Barcelona Model* (*BM*), which can be adopted for masonry.

The ductile-plastic material models do not describe such a property as brittleness. In real construction just brittleness has brought about micro-cracking and visible cracks. The accumulation of cracks in case of lack of plastic flow caused brittle cracks. The material degradation is beginning. This degradation is manifested by modulus of elasticity decreasing). Mentioned above *BM* model required among others, determination of hardening/softening characteristics separately for axially compression and tension of masonry and characteristics describing material degradation through recording of σ-ε relationship during cyclic compressive and tensile loading, as well.
Investigations of post-elastic behaviour of masonry have been conducted worldwide for many years, but obtained results are ambiguous. For example, Abrams 1985 has published tests results according to which the maximal compressive force for cyclic loading is 30% smaller than in case of axially static loading in one cycle. Naraine and Sinha 1989[1] and 1989[2] investigated masonry specimens under axially cyclic loading. The stress-strain relationships, where the loading curves were intersected with unloading curves of previous cycle. Such tests were repeated by Sinha and Senthivel 1999 and AlSchebani and Sinha 2000. According to those investigations the failure envelope determined for cyclic loading was overlapped with envelope getting for one cycle static compression. Senthilever and Uzoegho 2004 proposed the failure criterion for biaxial cyclic loaded brick masonry.
At Laboratory of the Faculty of Civil Engineering of Silesian University of Technology were carried out tests of unreinforced clay brick masonry wall specimens subjected to cyclic axially compressive loads in both orthogonal directions are presented. Two types of masonry wallettes, which differ from each other in overall dimensions, were tested. In case of small (compatible with EN 1052-1 regulations) specimens loading was realised in both orthogonal directions. The results of these tests are presented and discussed.

EXPERIMENTAL

In order to determine the behaviour and mechanical characteristics of masonry under cyclic loading and describe the influence of such type of loading on material degradation mode experimental tests of 14 masonry wall specimens were carried out. Three tests specimens, which differ from each other by shape and overall dimensions (see Fig.1), were used.

a) b) c)

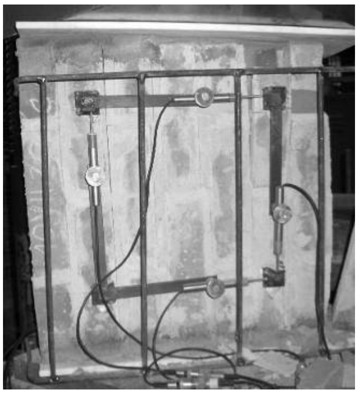


dimensions are in [cm]

Figure 1 Shape and overall dimensions of test specimens:
a) model **V** type; b) model **H** type; c) model **M** type

All these masonry wallettes were unreinforced and built of clay solid bricks (with mean value of masonry unit compressive strength f_b = 15 N/mm^2) and general-purpose cement-lime mortar M5 class (the mean value of mortar compressive strength f_m = 5 N/mm^2).
Totally were tested: 4 specimens type **V**; 4 specimens type **V** and 6 specimens type **M**. Masonry wallettes **V** and **M** types were subjected to axially compressive loads in direction perpendicular to bed joints, whereas models **H** type were compressed parallel to bed joints. One specimen of each series (reference specimen) was loaded statically in one cycle, but the rest of the specimens were subjected to compressive cyclic loads. All specimens were built before testing by qualified bricklayers.
On both sides of each wall a set of displacement measuring sensors was attached before test when wallette was located in the testing machine (with range from 0 up to 6000 kN) – as in Fig.2. The accuracy of these inductive sensors was 0,002 mm. To eliminate the friction between masonry specimens and the machine head a separator made of Teflon (10 mm thick) was used.

a)



b)

Figure 2 The masonry wallette type **H** (a) and **M** (b) with displacement measuring sensors in hydraulic testing machine – ready to test.

Masonry walls, except one of each series, were subjected to compressive cyclic loads. In the case of elements types **V** and **H** (small specimens – compatible with EN 1052-1 regulations) the first level of loading was 50kN and in every subsequent cycle it was increased by 50kN. The loading speed was ca. 2kN/s whereas large models, M type were loaded to 300kN, than 600, 900, 1200 kN, and in succession – up to failure – the loading level was growing up by 150kN. During each cycle, the loading was sustained ca. 2 – 3 minutes and than unloaded.

TEST RESULTS

The main results of presented investigations comprised values of cracking stresses σ_{cr}, ultimate stresses σ_u and corresponding strains ε_{cr} and ε_u presented in Table 1. In column 6 the correlation between σ_{cr} and σ_u stresses and number of cycles up to failure for each tested specimens is shown. For all specimens the number of cycles reached up to failure was quite similar, despite that the differences of shape and overall dimensions between small (**V** and **H** type) specimens and large wall models (**M** type) and differences between loading directions in case of both types of small specimens.

The comparison of compressive stresses corresponding with first crack appearance σ_{cr} and at failure σ_u is also very interesting. In case of small models type **V** the ratio is ca. 0.50 but when loading direction was parallel to bed joints (models **H** type) this ratio is very low and does not exceed 0.25. Some different situations are observed for walls **M** type. The σ_{cr}/σ_u ratio is about 0.6 and is greater than determined for small specimens **V** type loaded in this same direction. In presented tests the number of load cycles was quite similar for all types of specimens.

Table 1 Main results of investigations

Test specimen	σ_{cr} [N/mm²]	σ_u [N/mm²]	ε_{cr} $\times 10^{-3}$	ε_u $\times 10^{-3}$	σ_{cr}/σ_u	Number of cycles
V1	6.8	13.96	0.9	2.62	0.49	1
V2	6.5	13.04	0.95	293	0.50	16
V3	7.3	14.68	1.05	3,21	0.50	18
V4	6.9	11.43	1.15	2.95	0.60	15
H1	2.6	11.49	0.35	2.4	0.23	1
H2	2.3	11.11	0.48	3.35	0.21	16
H3	2.8	13.86	0.35	3.38	0.20	18
H4	2.2	9.92	0.45	4.0	0.22	14
M1	6.38	9.97	1.01	1.87	0.64	1
M2	5.55	9.72	0.96	2.45	0.57	15
M3	5.48	9.03	0.99	2.27	0.61	14
M4	6.15	9.94	0.91	2.55	0.62	15
M5	4.78	8.72	0.73	1.95	0.55	13
M6	5.96	9.89	0.96	2.61	0.60	16

All tested elements, apart from shape, overall dimensions and direction of loading (perpendicular or parallel to bed joints) fail in a similar manner by internal or set of vertical cracks (see Fig.3 and Fig.4). In case of internal crack appearance the masonry element was divided into two separate leafs.

Figure 3 Failure of **M** type model

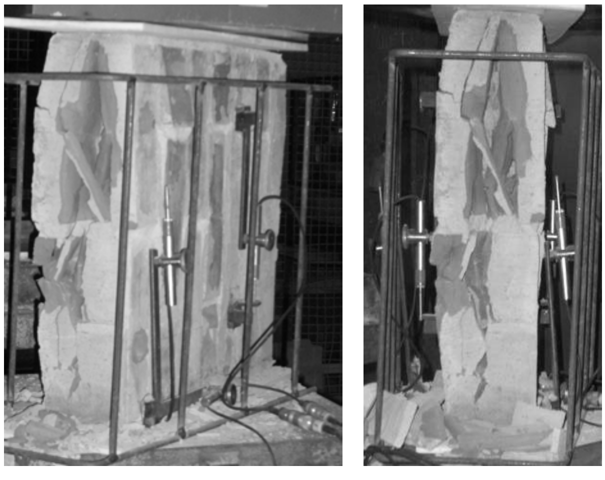


Figure 4 Failure of **H** type model

Typical stress-strain hysteresis determined in case of cyclic loading of small specimens **V** and **H** types is presented below in Fig.5. A significant influence of loading direction is observed. The degradation process in case of loading in direction parallel is as expected more significant. Unfortunately, the loading devices at the laboratory (hydraulic test machine with force, not displacement steering) didn't allow getting the falling branches of $\sigma - \varepsilon$ relationships but linking together the points of maximal stresses the envelope curves (see Fig.7 and Fig.8) have significant non-linear shape.

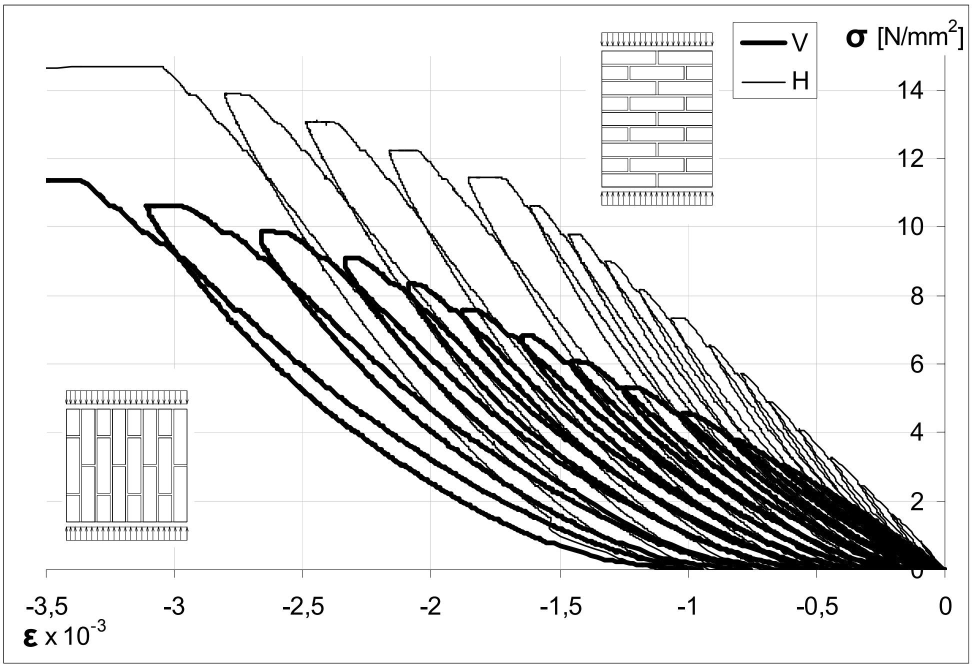


Figure 5 Typical stress-strain hysteresis for small models type **V** and **H**

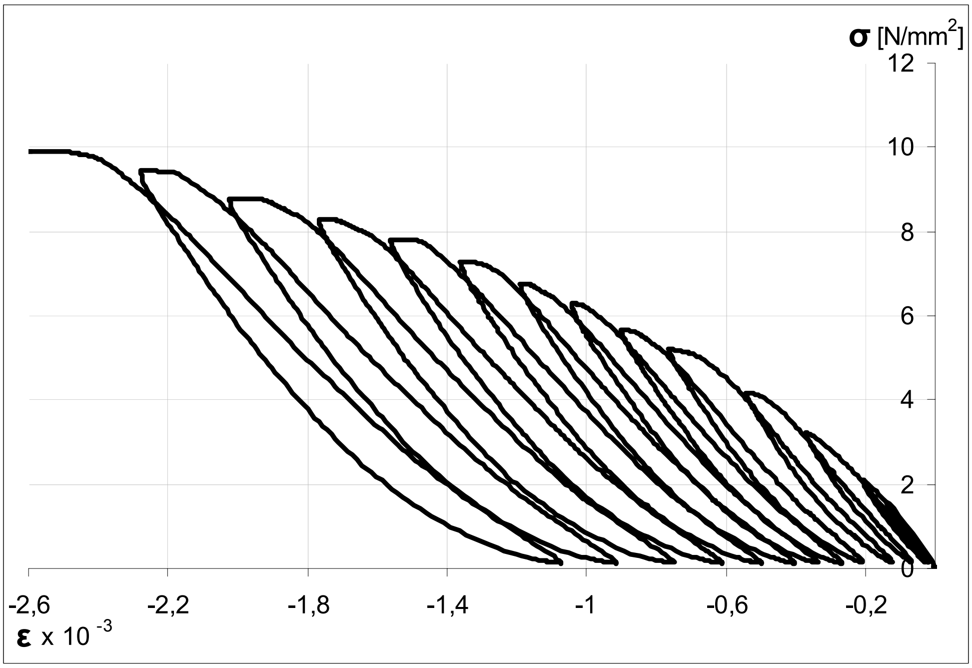


Figure 6 Typical stress-strain hysteresis for large model type **M**

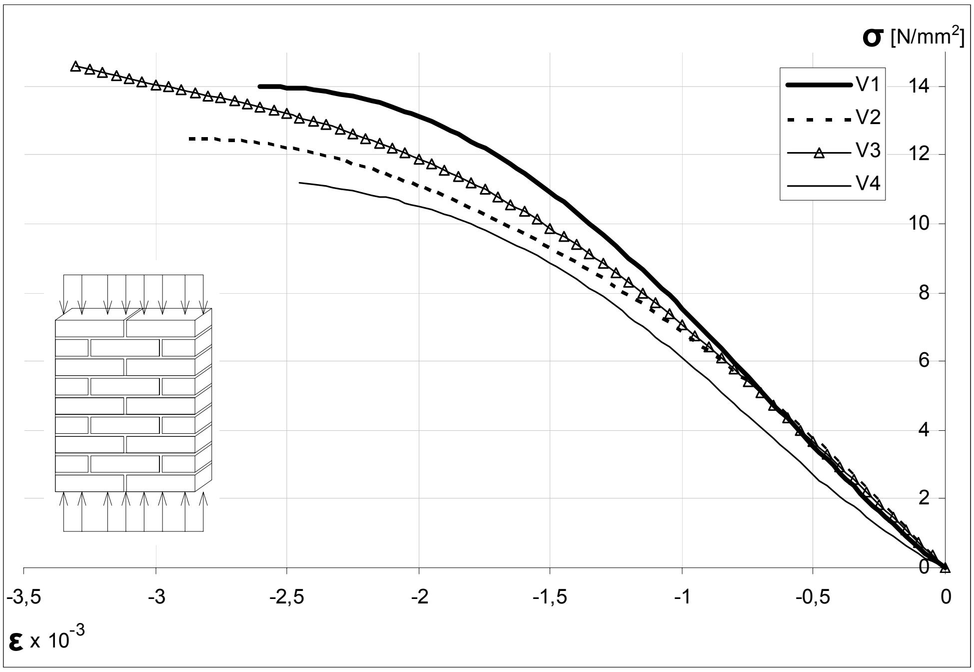


Figure 7 Envelope stress-strain curves for **V** type models

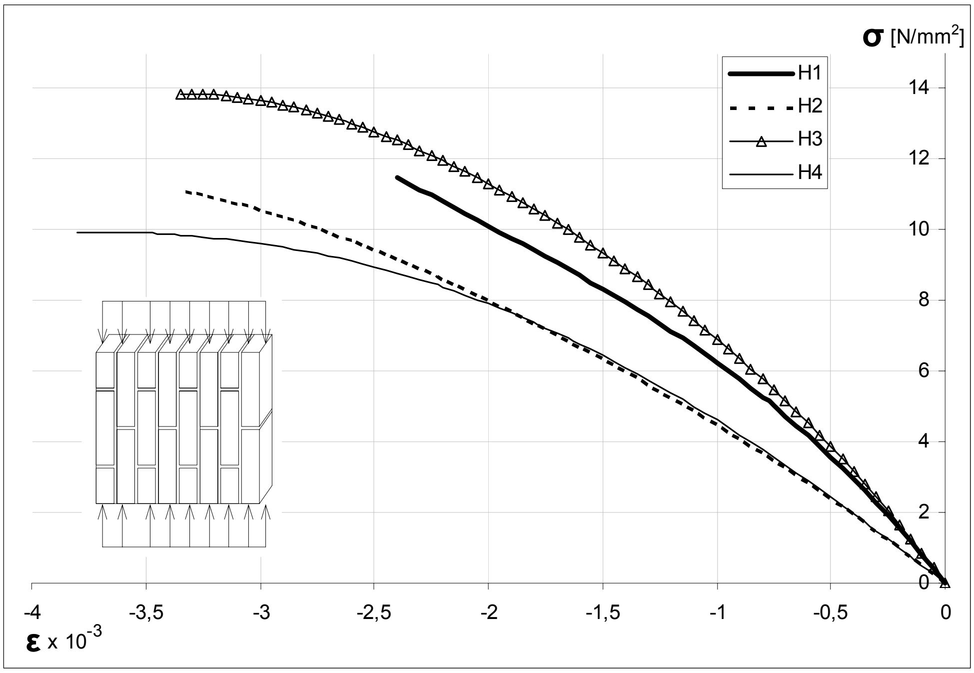


Figure 8 Envelope stress-strain curves for **H** type models

In Fig.7 and Fig.8 the thick continuous line represented specimen loaded statically in one cycle (reference specimens **V1** and **H1**). In case of models loaded perpendicular to bed joints, all envelopes σ - ε curves are located below the relationship determined in one cycle test. For **H** type specimens results of one wallette is above such line (see Fig.8).

Quite similar relationships were determined for wallettes **M** type. The typical stress-strain hystereses are presented in Fig.6 but obtained envelope σ - ε curves – in Fig.9. Generally, for

cyclic loading the degradation process is clearer than for wallette tested in one cycle (solid line for **M1** specimen) after reaching about 50% of final ultimate stresses.

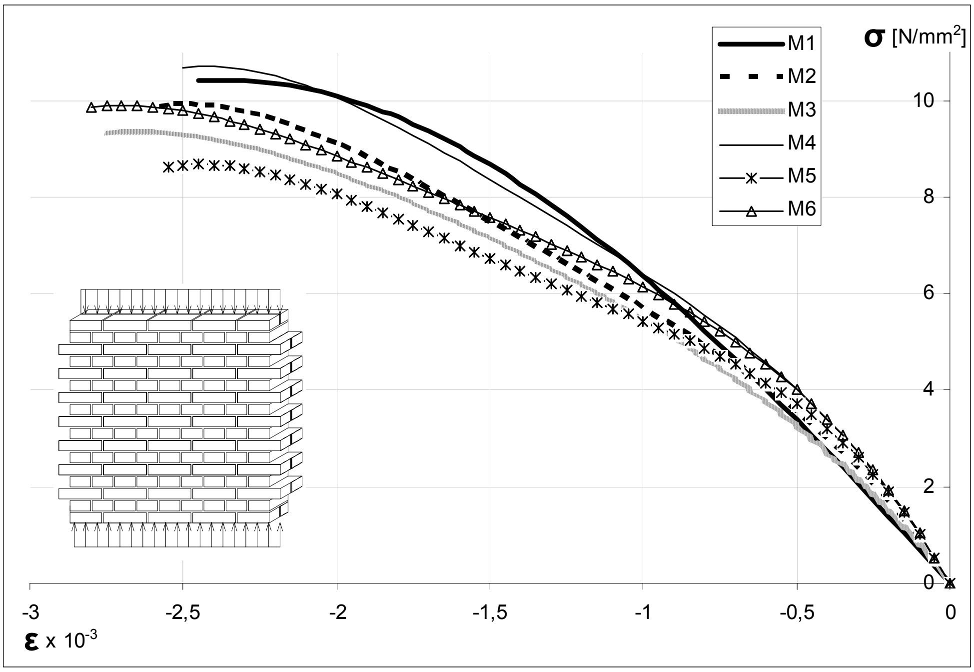


Figure 9 Envelope stress-strain curves for **M** type models

The comparison of envelope σ - ε curves (average relationships determined for all models of each series) for both directions of small specimens (**V** and **H** types) cyclic loading is shown below in Fig.10. The significantly greater strain deformations (faster stiffness degradation by reason of micro crack appearance) of models loaded parallel to bed joints are observed.

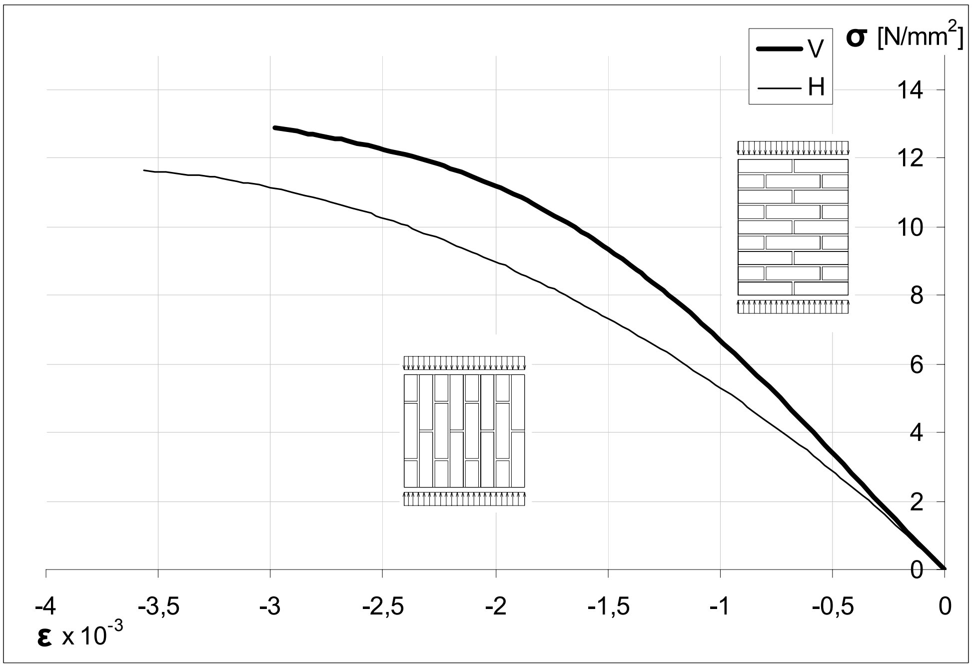


Figure 10 Comparison of envelope stress-strain curves for small specimens **V** and **H** types

In Fig.11 the comparison of envelope σ - ε curves (average relationships determined for all models of each series) for two types of models loaded in this same direction (small specimens **V** type and wallettes **M** type) is presented.

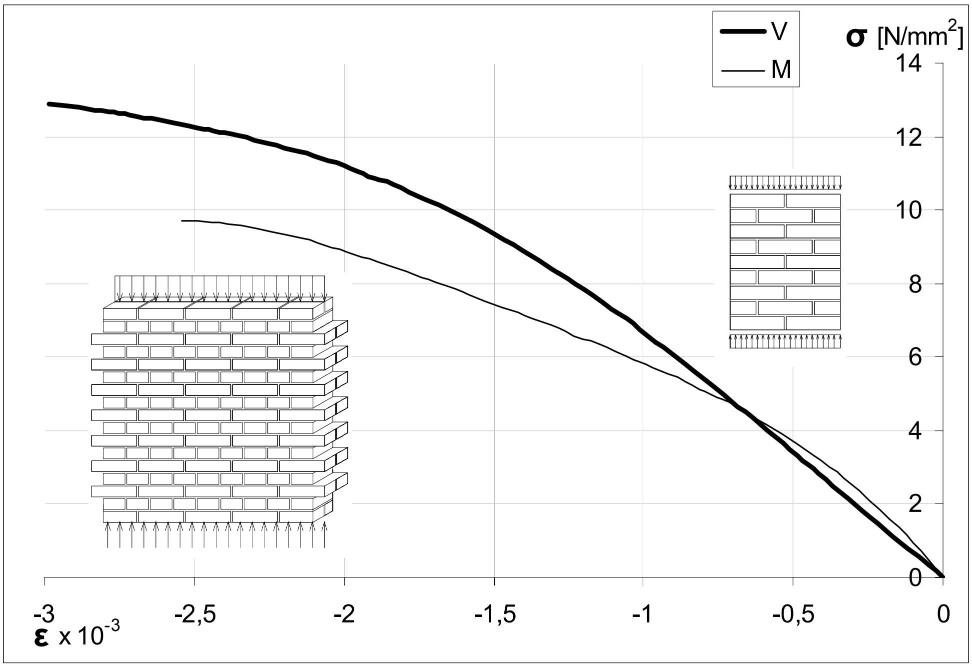


Figure 11 Comparison of envelope stress-strain curves for small (**V**) and large (**M**) wall specimens

Curves obtained for large walls for stresses corresponded with first cracks appearance are generally below those determined for small elements **V** type. In case of wallettes **M** type the masonry units arrangement determined internal longitudinal joint in every second layers caused some different stress distribution in masonry. Moreover, inaccuracy of brickwork must be connected with appearance of many internal micro cracks and other defects. As the result of such situation a faster stiffness degradation for that model is observed.

SUMMARY AND CONCLUSIONS

The outcome of presented results of laboratory experiments carried on 14 clay brick masonry walls of three types, loaded cyclically normal to the bed joint (models **V** and **M** type) and parallel to the bed joints, has revealed the following conclusions:

1. Failure of all tested specimens was brittle with the limited and very similar number of cycles – between 13 and 18 – apart from shape, overall dimensions and loading direction.
2. The failure mode, practically in each case apart from loading direction, was characterised by either vertical cracks appearance or divided by internal longitudinal crack specimen into two separate leafs.
3. A significant influence of loading direction on determined stress-strain hysteresis in case of cyclic loading of small specimens (**V** and **H**) types was observed. The degradation process in case of loading in direction parallel was more significant. All

envelopes σ - ε curves for this type of specimen were located below the relationship determined in one cycle test.

4. Quite similar relationships were determined for wallettes **M** type, especially for cyclic loading where the degradation process is more clear after reaching of compressive stresses about 50% of final ultimate stresses.
5. A clear influence of scale effect (shape and overall dimensions of test specimens) on behaviour and mechanical properties was stated. Envelope curves obtained for large walls were generally below those determined for small elements loaded in this same way.
6. All presented results and comments because of small number of tested specimens should be treated mainly from qualitative point of view. At this moment it is difficult to formulate more universal or qualitative conclusions. More test data, especially for other types of masonry units (hollow bricks and blocks) and mortar joints (thin bed joints) are needed.

Acknowledgement

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REFERENCE

Lubliner J., Oliver J., Oller S., Oňate E., “A plastic – damage model for concrete”, *International Journal of Solids and Structures*, vol.25, 1989, pp. 299-329.

Jirásek M., Bažant Z. P., “Inelastic Analysis of Structures”, John Wiley & Sons, 2002.

Lourenço P.B., Rot J.G., Blaauwendraad J, “Continuum model for masonry: Parameter estimation and validation”, *J. of Structural Engineering* (ASCE), vol. 124, No. 6, 1998, pp. 642-652.

Hibbitt, Karlsson & Sorensen, Inc. Documentation of ABAQUS v.6.3.1, Getting Started with ABAQUS/Standard: Interactive Version; ABAQUS/Standard User's Manual; ABAQUS/CAE User's Manual; ABAQUS Example Problems Manual; 2002.

Abrams D., Noland J., Atkinson R., “Response of clay unit masonry to repeated compressive forces”, *Proc. of the 7th International Brick Masonry Conference*, 1985, pp. 565-576.

Naraine K., Sinha S. N., “Behavior of brick masonry under cyclic compressive loading”, *J. of Construction Eng. and Management*, June 1989.

Senthivel R., Sinha S., “Behavior of calcium silicate brick masonry under cyclic uni-axial compression”, *Proc. of the 6th International Masonry Conference*, London 2002, pp. 412-422.

Sentilever R., Uzoegho H.C., “Failure criterion of unreinforced masonry under biaxial pseudo dynamic loading”’ *Joernaal van die Suid-Afrikaanse Institut van Siviele Ingekieurswese*, vol.46, No 4 2004, pp.20-24.

EN 1052-1:1998 Methods of test for masonry – Part 1: Determination of compressive strength.

Naraine K., Sinha S., “Loading and Unloading Stress-Strain Curves for Brick Masonry”, *J. of Structural Engineering* (ASCE), vol. 115, No.10, Oct. 1989, pp. 2631 – 2644.

AlShebani M.M., Sinha S., „Stress-strain characteristic of brick masonry under cyclic biaxial compression”, *J. of Structural Eng.* (ASCE), vol. 126, No. 9, 2000, pp. 1004-1007.