

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Robertas ZAVALIS

STRESS STATE ANALYSIS OF CALCIUM SILICATE HOLLOW BLOCK MASONRY UNDER COMPRESSION

SUMMARY OF DOCTORAL DISSERTATION

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Scientific Supervisor

Assoc Prof Dr Bronius JONAITIS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

The dissertation is being defended at the Council of Scientific Field of Civil Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Romualdas KLIUKAS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

Members:

Dr Valentin ANTONOVIČ (Vilnius Gediminas Technical University, Technological Sciences, Materials Engineering – 08T),

Dr Raimondas BLIŪDŽIUS (Kaunas University of Technology, Technological Sciences, Civil Engineering – 02T),

Prof Dr Habil Gintautas DZEMYDA (Vilnius University, Technological Sciences, Informatics Engineering – 07T),

Prof Dr Juozas VALIVONIS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

Opponents:

Assoc Prof Dr Darius BAČINSKAS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T),

Prof Dr Habil Vytautas STANKEVIČIUS (Kaunas University of Technology, Technological Sciences, Civil Engineering – 02T).

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Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.

Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;

e-mail: doktor@vgtu.lt

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Robertas ZAVALIS

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Mokslinis vadovas

doc. dr. Bronius JONAITIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Statybos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. dr. Romualdas KLIUKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Nariai:

dr. Valentin ANTONOVIČ (Vilniaus Gedimino technikos universitetas, technologijos mokslai, medžiagų inžinerija – 08T),

dr. Raimondas BLIŪDŽIUS (Kauno technologijos universitetas, technologijos mokslai, statybos inžinerija – 02T),

prof. habil. dr. Gintautas DZEMYDA (Vilniaus universitetas, technologijos mokslai, informatikos inžinerija – 07T),

prof. dr. Juozas VALIVONIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Oponentai:

doc. dr. Darius BAČINSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T),

prof. habil. dr. Vytautas STANKEVIČIUS (Kauno technologijos universitetas, technologijos mokslai, statybos inžinerija – 02T).

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Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.

Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;

el. paštas doktor@vgtu.lt

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Introduction

Topicality of the problem

Hollow calcium silicate blocks become ever more popular in masonry construction. Evidence to their wide application lie in the production scale of such units, as well as in recommendations for construction organisations, in Lithuania and its neighbour states, to employ them for construction purposes.

Many countries carry out large-scale and exhaustive masonry properties and behaviour tests. These tests mostly focus on conventional masonry, i.e. brick, ceramic and concrete block masonry. However, behaviour tests of hollow calcium silicate block masonry are performed rather rarely.

Numerical modelling is increasingly used to investigate masonry behaviour under loads and analyse state of stresses. For this purpose, it is necessary to assess properties of masonry units and mortar as accurately as possible. Research revealed that properties of bed joint mortar greatly differ from those determined by investigating control samples. It is influenced by a contact zone of bed joint mortar with a masonry unit. However, there is no methodology on how to assess mechanical properties and other parameters necessary for numerical masonry model development of the set masonry units and bed joint mortar.

Topicality of the work

Masonry unit construction solutions, mortar bed joints, and contact zone between masonry components have major influence on the state of compressive masonry stresses and deformations. While analysing compressive masonry stress-strain state, especially when applying numerical modelling, it is important to assess masonry unit, bed joint and their contact zone parameters as accurately as possible.

Research object

Stress-strain state of hollow calcium silicate block masonry under short-term static compressive load.

Main objective

Main objective of the thesis – to analyse impact of bed joints on compressed masonry stress-strain state by applying the numerical modelling method and experimental research.

Main tasks

In order to achieve the aim of the thesis, the following tasks were set:

1. Review experimental and theoretical compressive masonry stress-strain state research.
2. Determine influence of bed joints on masonry stress-strain state by carrying out experimental research of hollow calcium silicate block masonry.
3. Experimentally determine parameters of calcium silicate hollow blocks and bed joint mortar, as well as their contact zone, used for numerical masonry micro-modelling.
4. Compare experimental research results with numerical micro-modelling and results of analytic compressed masonry mechanical properties calculation method results.
5. Specify estimation methods for compressive strength and Young's modulus of masonry made of hollow calcium silicate blocks.

Methodology of research

Hollow calcium silicate block masonry samples are tested under short term compressive load. Compressed calcium silicate blocks and their masonry behaviour are investigated by applying numerical micro-modelling. Analytic calculations of masonry compressive strength and Young's modulus are carried out.

Scientific novelty

The research revealed results new to the science of engineering

1. Bed joints impact on mechanical properties of compressed calcium silicate block masonry (compressive strength and Young's modulus) was assessed.
2. Calcium silicate block masonry bed joint mechanical properties were investigated and analytically described.
3. Assessment suggestions for masonry units and bed joints' parameters, used in masonry stress-strain state analysis, by applying numerical micro-modelling, were presented.
4. Methodology specification suggestions for determining calcium silicate hollow block masonry compressive strength and Young's modulus calculations according to LSTEN 1996-1-1 were presented.

Practical value

Hollow calcium silicate block masonry behaviour under short-term compressive static load, and impact of bed joints on stress deformations state of such masonry were analysed. Mortar bed joint generalised Young's modulus,

which assesses contact zone between the mortar and masonry units (blocks), was determined. Methodology, which allows specifying mechanical properties of set masonry units and mortar bed joint, was suggested.

The research proved that numerical modelling, when applying specified masonry unit and mortar properties, can be successfully used for determining the masonry Young's modulus, without performing experimental research (not applying disruption methods).

Suggestions for specifying calcium silicate hollow block masonry compressive strength, and Young's modulus calculating methods in accordance with LSTEN1996-1-1 were presented.

Defended propositions

1. Deformation of mortar bed joint is up to 10 times higher than the mortar control sample.
2. Young's modulus of masonry can be estimated up to 25% more accurate by analytical and numerical methods, when generalized bed joint Young's modulus is evaluated.
3. Empirical coefficient should be reduced, when the characteristic compressive strength of hollow calcium silicate 1 and 2 group block masonry according EC6 is calculated.

The scope of the thesis

The dissertation consists of introduction, three chapters, general conclusion and a list of references. The total scope of dissertation – 136 pages, 74 pictures, 19 tables and 131 references.

1. Masonry stress-strain state analysis and review of numerical masonry modelling

The performed scientific literature analysis reveals that the main factors influencing mechanical properties of masonry are mechanical properties of masonry units and mortar joints as well as their geometrical parameters. A number of theoretical and experimental ceramic brick or block masonry behaviour research data can be found in literature; however, there is relatively little data on hollow calcium silicate block behaviour and effect of the above-mentioned factors.

Thickness of bed joints as well as mechanical properties of mortar has a tangible effect not only on mechanical properties of masonry, but also on masonry behaviour. Due to partial hydration of cement in bed joint mortar and transverse deformation confinements, mechanical properties of bed joint mortar differ from properties determined while testing control mortar samples.

However, there is no methodology, which would allow determining mortar properties in the bed joint with regard to the contact zone.

Recently, while investigating masonry stress-strain state, major attention was focused on numerical modelling. In order to perform numerical analysis of compressed masonry, it is imperative to assess mechanical properties of masonry units and bed joint mortar as precisely as possible.

2. Experimental research of calcium silicate hollow block masonry

Masonry components (mortar, masonry units), samples and their preparation, as well as methodology of performed research are described in this chapter. Hollow calcium silicate block masonry samples' research results are presented, and effect of different factors on mechanical properties of masonry is analysed.

Hollow calcium silicate masonry units of two kinds B120 and B180 were used in the experimental research (Fig. 1, a). Geometric parameters, as well as main mechanical properties of the masonry units are presented in table 1.

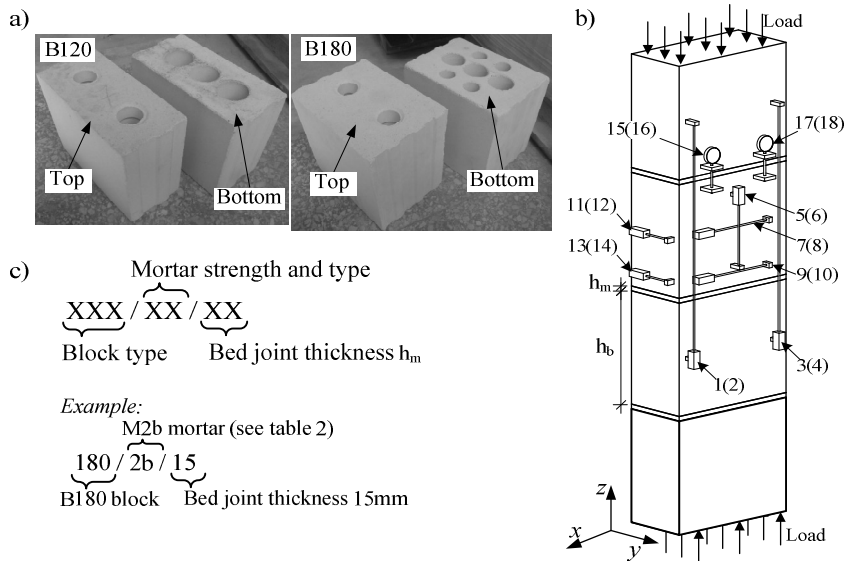


Fig. 1. Experimental tests a) used block types, b) the scheme of masonry sample tests and arrangement of the measurement equipment, c) sample series name explanation

Samples were set using masonry mortar of five different strengths. Two kinds of mortar were employed: general purpose mortar (M1b, M2b and M3b) and thin layer masonry mortar (M1p and M2p). Samples were grouped into series; each series consisted of three samples. Summary of experimental programme is presented in table 2. The meaning of series codes employed in the research is explained in the figure (Fig. 1, c).

Samples are tested under short-term static load, speed of the load is controlled (0,5 kN/s), so that the sample fails in 13–30 min. Experiment and measurement equipment schemes are presented in the figure (Fig. 1, b).

Table 1. General properties of masonry units

Masonry unit	Dimensions, mm			Hollowness, %	Compression strength $f_{c,b}$, N/mm ²	$A_{net}^{(1)}$, cm ²
	length	with	height			
B120	250	120	238	18,9	17,0	230,2
B180		180		19,7	22,9	342,1

(1) – area of block bottom surface

Table 2. Composition of the research program

	General purpose mortar									Thin layer mortar			
	M1b (7 N/mm ²) ⁽¹⁾			M2b (13 N/mm ²) ⁽¹⁾			M3b (33 N/mm ²) ⁽¹⁾			M1p (7 N/mm ²) ⁽¹⁾		M2p (17 N/mm ²) ⁽¹⁾	
										N ⁽²⁾	D ⁽³⁾	N ⁽²⁾	D ⁽³⁾
Block type \ h_m , mm	5	10	15	5	10	15	5	10	15	3	3	3	3
B120	3	3	3	-	-	-	3	3	3	-	-	-	-
B180	3	3	3	3	3	3	3	3	3	3	3	3	3
Total amount of specimens													57

(1) – mortar strength under compression

(2) – blocks were not moistened before laying them

(3) – blocks were moistened before laying them

Experiments revealed that bed joint thickness has the greatest effect on calcium silicate hollow block masonry compressive strength, when weak, up to 7 N/mm² strength, general purpose mortar is used. The highest compressive strength of masonry was achieved when the above-mentioned strength mortar joint thickness was 10 mm. When the bed joint thickness was thinned to 5 mm and thickened to 15 mm, compressive strength diminished by 10% and 15% respectively (Fig. 2).

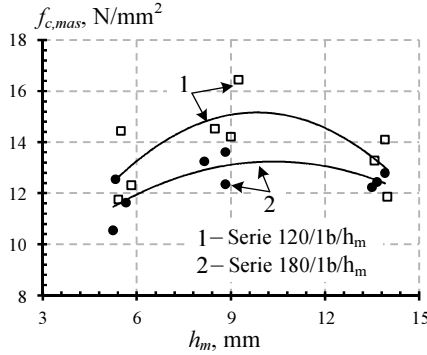


Fig. 2. Relationship between masonry compressive strength and thickness of bed joint while applying 7 N/mm² (M1b) general purpose mortar

When reducing mortar joint thickness, the mortar joint influence on compressive masonry strength diminishes, as tensile stresses within the masonry unit diminish in the transversal direction, thus compressive masonry unit's strength is employed in a more efficient manner. The fact that upon reducing mortar joint height, tensile stresses acting in transversal direction within the masonry unit are reduced is proved by masonry unit transversal deformations (Fig. 3).

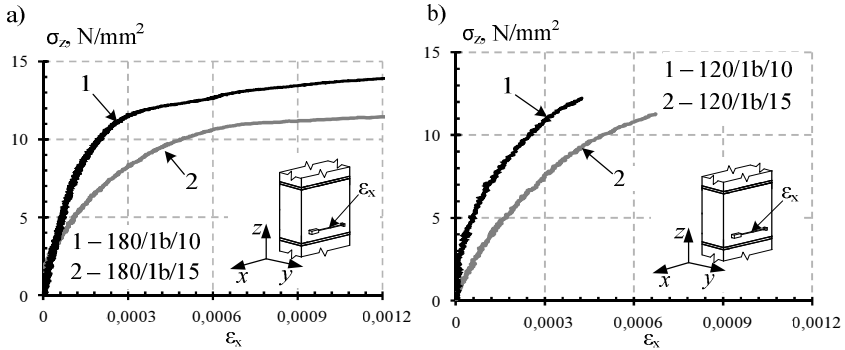


Fig. 3. Tensile transversal deformation (ϵ_x) dependence on vertical (σ_z) stresses when different thickness of bed joints are used a) B180 block masonry, b) B120 block masonry

Upon reducing mortar bed joint thickness to 5 mm, compressive strength of masonry decreased. Such decrease was influenced by a technological factor. Due to imperfection of the mortar joint (uneven thickening), compressive stresses were distributed unevenly, stress concentrations appeared, thus, samples failed under lower average vertical compressive stresses.

When stronger general purpose mortar (13 N/mm^2 and 33 N/mm^2) was employed, impact of bed joint thickness on compressive strength of masonry is slight.

Compressive strength of mortar also influences compressive strength of masonry. Average compressive strength of B120 and B180 masonry samples increased from 10% to 29%, upon increase of general purpose mortar strength from 7 N/mm^2 to 33 N/mm^2 (M1b to M3b respectively). The most significant increase in compressive strength was acquired when strength of mortar increased from 7 N/mm^2 to 13 N/mm^2 .

Compressive strength increase of B120 and B180 block masonry, when thickness of a bed joint is altered, is similar.

The research revealed that deformations of the bed joint and mortar control samples are significantly different (Fig. 4). Average compressive stresses of the bed joint, presented in diagram (Fig. 4), are calculated considering bed face of the blocks A_{net} (Table 1). Research shows that longitudinal deformations of the bed joint mortar, with stresses at $0,33\sigma_{\max}$, are up to 10 times higher than longitudinal deformations of mortar control samples. This difference depends on the masonry unit material used, deformational properties of mortar, and thickness of a bed joint.

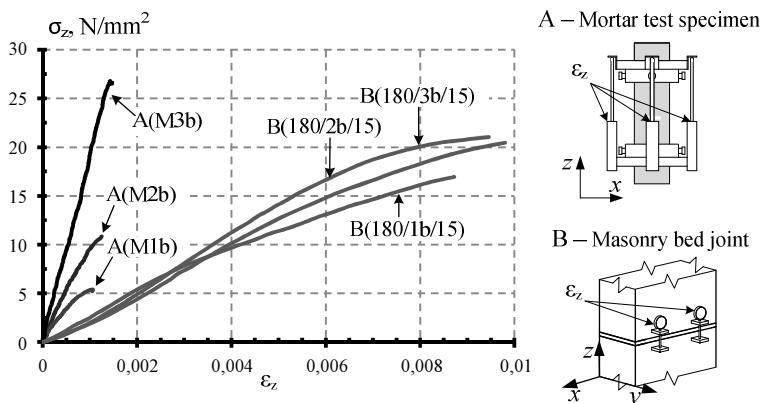


Fig. 4. Characteristic mortar test specimen (A) and bed joint (B) stress strain curves

3. Assessment of experimental research and theoretical methods

Experimental research results and results of numerical modelling and analytic masonry and masonry units' mechanical property calculation methods are compared in this chapter. Generalised bed joint Young's modulus is determined. Its calculation formula is suggested.

Generalised bed joint Young's modulus is tailored to hollow calcium silicate block compressive masonry deformational properties' analysis by employing analytical formulas and applying detailed numerical micro-modelling. Recommendations for mechanical properties determining specification in accordance with LST EN 1996-1-1 were provided.

Analysis of calcium silicate blocks mechanical properties

Numerical models were developed for mechanical properties analysis of B120 and B180 block units. The model assesses non-linear mechanical characteristics of materials, parameters of which were described using recommendations suggested in the current thesis or those provided by other authors.

Quite accurate results of blocks' mechanical properties were acquired by applying numerical modelling (Fig. 5). B120 and B182 blocks compressive strength values are lower only by 3% and 6% respectively than the average values determined by means of experimental research, and Young's modulus values are slightly (up to 3%) different from the average Young's modulus values determined by experiments.

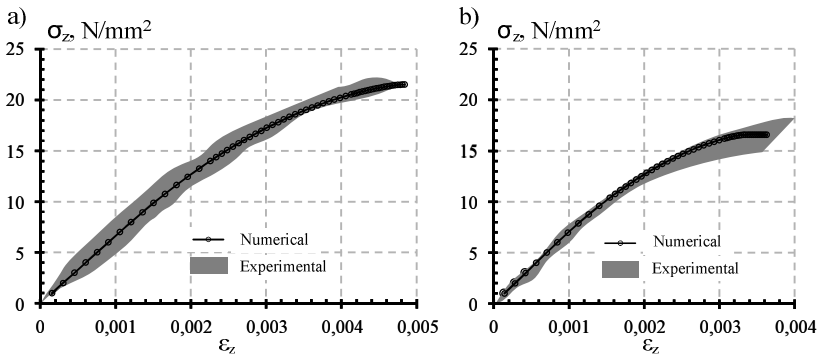


Fig. 5. Result comparison between experimental and numerical tests of calcium silicate blocks: a) B180; b) B120

Determining generalised bed joint Young's modulus

Generalised bed joint Young's modulus can be estimated by removing masonry unit deformation from the overall masonry deformation. Overall masonry deformation consists of masonry unit deformation and mortar joint deformation (Fig. 6):

$$\Delta h'_{sum} = \Delta h'_b + \Delta h_m, \quad (1)$$

here $\Delta h'_{sum}$ – vertical masonry deformation, $\Delta h'_b$ – vertical masonry unit deformation, Δh_m – vertical mortar joint deformation.

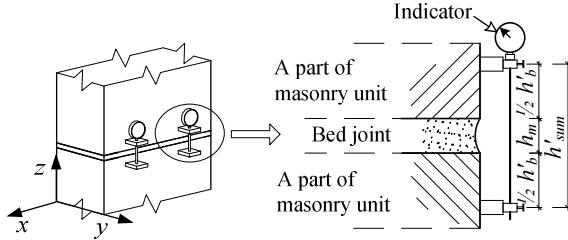


Fig. 6. The scheme of determination generalized bed joint Young's modulus

Having applied several alterations, generalised mortar bed joint Young's modulus, which considers mortar and block contact zone influence, can be received from formula 1 and the Hooke's law:

$$E_{m,s,obs} = \frac{h_m E'_{mas} E'_b}{E'_b (h_m + h'_b) - E'_{mas} h'_b}, \quad (2)$$

here E'_{mas} – masonry's Young's modulus (according Fig. 6), h'_b – a part of masonry unit included in to h'_{sum} zone (Fig. 6), E'_b – masonry unit Young's modulus, $E_{m,s,obs}$ – generalised bed joint Young's modulus determined from experimental data.

In accordance with the experimental research results, empiric formula, which allows determining generalised bed joint Young's modulus, is acquired:

$$E_{m,s,cal} = \frac{E_m (0,75 E_m - 2) + h_m (9 - 0,45 E_m) - 32}{110 + E_m (E_m - 15,5)}, \quad (3)$$

here $E_{m,s,cal}$ – calculated generalised bed joint Young's modulus. In this equation, mortar Young's modulus E_m dimension is GPa and height of the bed joint is h_m – mm.

Generalised bed joint Young's modulus application

The generalised mortar bed joint Young's modulus, calculated according to the suggested formula 3, was tailored for estimating masonry Young's modulus in accordance with the dependences described in literature:

Masonry Young's modulus E_m employed in these formulas is substituted with the generalised Young's modulus $E_{m,s,cal}$ estimated using formula 3. The acquired calculation results are presented in the diagram (Fig. 7).

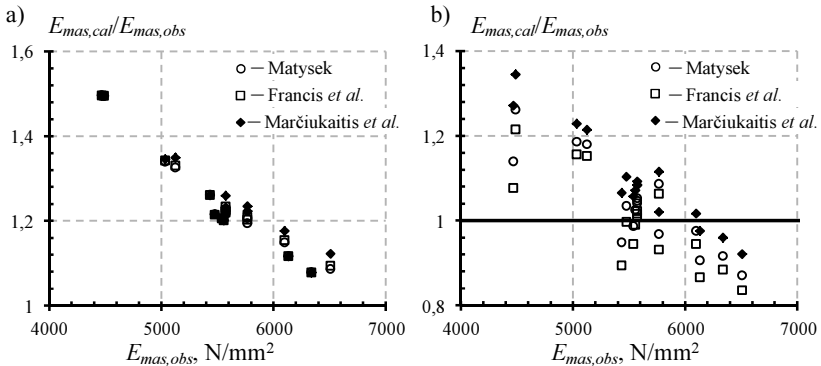


Fig. 7. The comparison of experimental and analytical test result of masonry Young's modulus when: a) mortar Young's modulus is evaluated; b) generalized Young's modulus of bed joint is evaluated

Comparison of analytic masonry Young's modulus calculation methods revealed that considering generalised bed joint Young's modulus, in accordance with the suggested formula 3, the acquired results are 15–24% more contiguous to the experiment results (Fig. 7, b), than when mortar control samples Young's modulus is employed (Fig. 7, a).

Masonry Young's modulus is also determined by applying numerical detailed micro-modelling method. While developing numerical detailed masonry micro-model, generalised bed joint Young's modulus $E_{mas,obs}$ was applied. Result comparison of experimentally determined $E_{mas,obs}$ Young's modulus and $E_{mas,num}$ Young's modulus determined using numerical modelling methods values, was presented (Fig. 8).

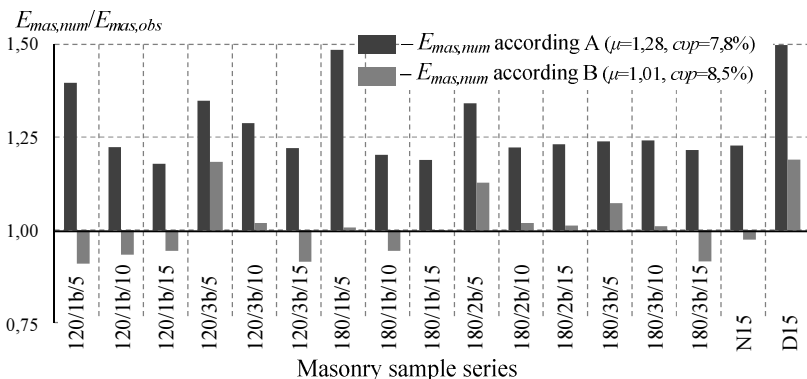


Fig. 8. Result comparison of numerical calculation of masonry Young's modulus when A – mortar Young's modulus is evaluated, B – generalized Young's modulus of bed joint is evaluated

The research indicates (Fig. 8) that when generalised bed joint Young's modulus is employed, acquired masonry Young's modulus values are 9%–32% more contiguous to experimental masonry Young's modulus values.

Determining calcium silicate hollow block masonry mechanical properties in accordance with EC6

While analysing methods to determine mechanical properties of masonry according to EC6, results of calcium silicate block masonry research carried out at VGTU are additionally investigated. Calcium silicate blocks of different strength and hollowness were employed in this research. Masonry samples were set and tested in accordance with LST EN 1052-1 requirements. Sample group descriptions are provided in table 3.

Table 3. The description of specimens groups

Name of specimens group	Number of specimens	Mortar type	Masonry units applied	Group of masonry units (accord. EC6)
SB1-1	2 ⁽¹⁾ (6 ⁽²⁾)	General purpose mortar $h_m = 8-12$ mm	SB120	1
SB1-2	3 ⁽¹⁾ (9 ⁽²⁾)		SB248	2
SB2-1	2 ⁽¹⁾ (6 ⁽²⁾)	Thin layer mortar $h_m \leq 3$ mm	SB120	1
SB2-2	3 ⁽¹⁾ (9 ⁽²⁾)		SB248	2
M-1	10 ⁽¹⁾ (30 ⁽²⁾)	Thin layer mortar $h_m \leq 3$ mm	M15, M25	1
M-2	5 ⁽¹⁾ (15 ⁽²⁾)		M18	2

(1) – number of series in group

(2) – total number of specimens in group

Masonry construction design norms EN 1996-1-1 (EC6), recommend determining characteristic compressive strength of masonry by experiments, testing masonry samples according to EN 1052-1 standard requirements.

Otherwise, characteristic compressive strength of masonry f_k in accordance with EC6 is estimated by applying the empiric formula, which is generally expressed in the following way:

$$f_k = K \cdot f_b^\alpha \cdot f_m^\beta, \quad (4)$$

here f_b – normalized compressive strength of a masonry unit (masonry unit class is associated with this strength), f_m – the mean compressive strength of mortar (compressive strength class), K – empirical coefficient evaluating a type of a masonry unit, hollowness, a type of material and other factors, α and β – empirical indexes evaluating influence of a type (kind) of mortar and thickness of a bed joint h_m .

Research (Table 3) data analysis revealed that characteristic compressive strength values of calcium silicate block masonry, estimated according to formula 4, are often higher than those determined by experiments (Fig. 9, a).

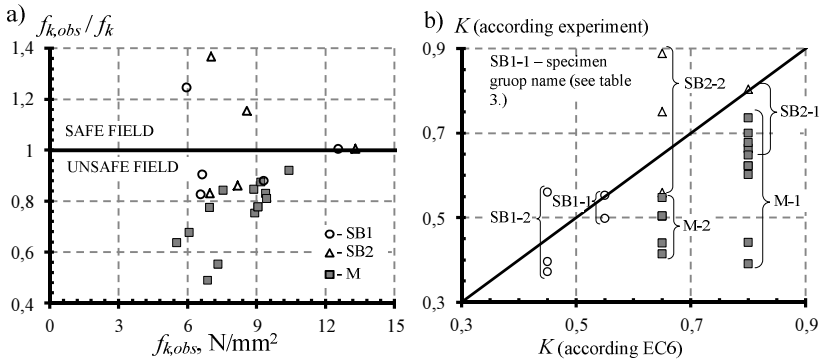


Fig. 9. Experimental results (according tabale 3) a) The variation of experimental to theoretical characteristic masonry strength values $f_{k,obs}/f_k$ ratio with experimental characteristic masonry strength value $f_{k,obs}$; b) relationship between empirical coefficient K , determined in accordance with EC6, and obtained from experiments

The diagram (Fig. 9, b) indicates that hollow first and second group calcium silicate block masonry with thin layer mortar bed joints K coefficient values should be considered lower than values presented in EC6. According to the results of experimental research it is offered to calculate the characteristic compressive strength of masonry which is produced from 1st and 2nd group hollow calcium silicate blocks with thin layer mortar bed joints using reduced

empirical coefficient K . It could be reduced multiplying its value by correction coefficient depending on mortar strength β_K . According to the results of experimental research the coefficient $\beta_K = 1$ when thin layer mortar strength $10 \leq f_m \leq 20 \text{ N/mm}^2$, and $\beta_K = 0,75$ when $f_m < 10 \text{ N/mm}^2$.

Simplified masonry Young's modulus determining formulas are usually applied in practice. Masonry Young's modulus is expressed through characteristic compressive strength of masonry and masonry Young's characteristics (EC6). However, EC6 does not indicate what Young's characteristics values should be employed when different masonry unit types are used. It was estimated that average elasticity characteristics value of hollow calcium silicate blocks with general purpose mortar equals 521 and for the thin layered mortar masonry 511. Thus, it is recommended to apply masonry elasticity characteristics of 500 for calcium silicate 1st and 2nd group block masonry.

General conclusions

1. Influence of bed joints thickness on masonry stress-strain state by carrying out experimental research was determined. The greatest up to 15% mortar joint thickness effect on masonry compressive strength was determined when general purpose mortar with strength of up to 7 N/mm^2 is used. When stronger general purpose mortar (13 and 33 N/mm^2) is used, impact of bed joint thickness on compressive strength of masonry is insignificant and accounts for up to 3%.
2. Influence of mortar compressive strength on masonry stress-strain state was determined. Masonry compressive strength increase changes unevenly when mortar strength is increased. The increase constitutes the main part of the alteration in the compressive strength of masonry, up to 70%, when mortar strength is increased from 7 N/mm^2 (M1b) to 13 N/mm^2 (M2b). The first crack opening load and ultimate load ratio increased from 0,55 to 0,85, when mortar strength was increased from 4 N/mm^2 to 24 N/mm^2 .
3. Research revealed that longitudinal compressive deformations of mortar bed joints, when stresses constituted 33% of maximum stress, are up to 10 times higher than relative mortar control sample deformations. This alteration is determined by joint mortar deformation properties and contact between a masonry unit and mortar. Deformation properties of a mortar joint are suggested to be assessed by applying generalised bed joint Young's modulus.
4. It is recommended to calculate generalised Young's modulus of a bed joint in first group calcium silicate hollow block masonry with general purpose cement mortar, when bed joint thickness alters from 5 to 15 mm, and

mortar Young's modulus (established while testing control samples) alters from 6 to 18 GPa according to the suggested formula. This dependence is also applicable for determining generalised bed joint Young's modulus in thin layer mortar masonry, when joint height is not lower than 2 mm, and mortar Young's modulus is no lower than 8 GPa.

5. Analytical masonry Young's modulus calculation methods comparison revealed that upon assessing generalised bed joint Young's modulus, according to the suggested formula, acquired results are 15–24% more accurate, than when mortar control samples Young's modulus is applied.
6. Stress and deformations curve of compressed masonry units is acquired by applying detailed numerical micro-modelling method; the curve is used to determine compressive strength of blocks and their Young's modulus. Estimated compressive strength values of the blocks were up to 6% lower than those determined by experiments, whereas Young's modulus values differed slightly up to 3%.
7. Detailed numerical micro-model can be employed for determining Young's modulus for calcium silicate hollow block masonry, when generalised bed joint Young's modulus is assessed. By applying numerical modelling, estimated masonry Young's modulus values are about 18–50% higher, if mortar Young's modulus established from control samples is employed. Considering generalised bed joint Young's modulus, the difference between the numerical model and experimental results is about 9–18%.
8. Upon completing experimental research result analysis, suggestions for assessing mechanical properties of masonry according to EC6 were provided. Elasticity characteristics of 1 and 2 group calcium silicate hollow block masonry is recommended to be set at 500 in construction internal forces and loadbearing strength calculations. While calculating characteristic compressive strength 1 and 2 group calcium silicate block masonry with thin layer mortar, it is recommended to apply reduced empiric coefficient.

List of published works on the topic of the dissertation In the reviewed scientific periodical publications

Zavalis, R.; Jonaitis, B. 2011. Mūro gaminių ir gulsčiųjų siūlių įtempių deformacijų būvio ypatumų analizė, *Engineering Structures and Technologies* 3(3): 105–111. ISSN 2029–2317. (ICONDA; Proquest; EBSCOhost)

Zavalis, R.; Jonaitis, B. 2013. Numerical and experimental analysis of grouted hollow block masonry under compression, *Engineering Structures and Technologies* 5(2): 45–53. ISSN 2029–882X. (ICONDA; Proquest; EBSCOhost)

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About the author

Robertas Zavalis was born in Skuodas, on 4 of May 1984. He began his studies at Vilnius Gediminas Technical University in 2003. The first degree of civil engineering gained in 2007 from the Faculty of Civil Engineering. From the same faculty he gained a diploma of Master of Science of Civil Engineering in 2009. In 2009–2013 was PhD student of Vilnius Gediminas Technical University in Reinforced Concrete and Masonry Structures Department. Robertas Zavalis in 2010 was on internship at Minho University (Portugal).

GNIUŽDOMO TUŠTYMĖTŲJŲ SILIKATINIŲ BLOKŲ MŪRO ĮTEMPIŲ BŪVIO ANALIZĖ

Problemos formulavimas

Mūro statyboje vis plačiau naudojami tuštymėtieji silikatiniai blokai. Apie jų platų naudojimą liudija gamybos mastai ir rekomendacijos, teikiamos statybinėms organizacijoms dėl blokų naudojimo ne tik Lietuvoje, bet ir kitose kaimyninėse valstybėse.

Daugelyje šalių atliekami platūs ir išsamūs mūro savybių bei elgsenos tyrimai. Jie daugiausia atliekami su tradiciniu mūru, t. y. naudojant plytas ar keraminius ir betoninius blokus. Tačiau tuštymėtųjų silikatinį blokų mūro elgsenos tyrimų atliekama palyginti nedaug.

Mūro elgsenai, veikiant apkrovoms, tirti ir įtempių būviui analizuoti vis dažniau taikomi skaitiniai modeliai. Tam būtina kuo tiksliau įvertinti mūro gaminių ir skiedinio savybes. Tyrimais įrodyta, kad skiedinio savybės

gulsčiojoje siūlėje gerokai skiriasi nuo savybių, nustatytų bandant kontrolinius bandinius. Tam įtakos turi skiedinio, esančio siūlėje, sąlyčio zona su mūro gaminiu. Tačiau nėra bendros metodikos, kaip tiksliau įvertinti sumūrytų mūro gaminių ir skiedinio gulsčiojoje siūlėje mechanines savybes bei kitus parametrus, reikalingus mūro skaitiniam modeliui sudaryti.

Darbo aktualumas

Gniuždomojo mūro įtempių ir deformacijų būviui bei mechaninėms savybėms didelį poveikį turi konstrukciniai mūro gaminių sprendiniai, gulsčiosios skiedinio siūlės ir mūro komponentų sąlyčio zona. Analizuojant gniuždomojo mūro įtempių ir deformacijų būvį, ypač taikant skaitinius modelius, svarbu kuo tiksliau įvertinti mūro gaminių, gulsčiųjų siūlių ir jų sąlyčio zonos parametrus.

Tyrimų objektas

Trumpalaikie gniuždomąja statine apkrova veikiamo silikatinų tuštymėtųjų blokų mūro įtempių deformacijų būvis.

Darbo tikslas

Pagrindinis šio darbo tikslas – eksperimentiniais tyrimais bei taikant skaitinio modeliavimo metodą išanalizuoti gulsčiųjų siūlių poveikį gniuždomojo mūro įtempių deformacijų būviui.

Darbo uždaviniai

Darbo tikslui pasiekti keliami šie uždaviniai:

1. Atlikti eksperimentinių bei teorinių gniuždomojo mūro įtempių ir deformacijų būvio tyrimų apžvalgą.
2. Nustatyti gulsčiųjų siūlių poveikį mūro įtempių ir deformacijų būviui, taikant gniuždomojo silikatinų tuštymėtųjų blokų mūro eksperimentinius tyrimus.
3. Eksperimentais nustatyti silikatinų tuštymėtųjų blokų ir skiedinio gulsčiojoje siūlėje bei jų sąlyčio zonos parametrus, naudojamus skaitiniam mūro mikromodeliavimui.
4. Eksperimentinių tyrimų rezultatus palyginti su skaitinio mikromodeliavimo bei analitinių gniuždomojo mūro mechaninių savybių skaičiavimo metodų rezultatais.
5. Patikslinti gniuždomojo silikatinų tuštymėtųjų blokų mūro stiprio ir tamprumo modulio apskaičiavimo metodus.

Tyrimų metodika

Trumpalaike statine gniuždomąją apkrova bandomi tuštymėtųjų silikatinių blokų mūro fragmentai. Gniuždomųjų silikatinių blokų ir mūro iš jų elgsena tiriama taikant skaitinius mikromodelius. Atliekami mūro gniuždomojo stiprio ir tamprumo modulio analitiniai skaičiavimai.

Darbo mokslinis naujumas

Tyrimais gauti inžinerijos mokslui nauji rezultatai:

1. Įvertintas gulsčiųjų siūlių poveikis gniuždomojo silikatinių blokų mūro mechaninėms savybėms (gniuždomajam stipriui ir tamprumo moduliui).
2. Iširtos ir analitiškai aprašytos silikatinių blokų mūro gulsčiųjų siūlių mechaninės savybės.
3. Pateikti mūro gaminių ir gulsčiųjų siūlių parametrų, naudojamų mūro įtempių ir deformacijų būvio analizei, taikant skaitinius mikromodelius, vertinimo pasiūlymai.
4. Pateikti pasiūlymai, kaip patikslinti silikatinių tuštymėtųjų blokų mūro gniuždomojo stiprio ir tamprumo modulio skaičiavimo pagal LST EN 1996-1-1 metodiką.

Darbo rezultatų praktinė reikšmė

Išanalizuota tuštymėtųjų silikatinių blokų mūro, gniuždomo trumpalaike statine apkrova, elgsena ir gulsčiųjų siūlių poveikis tokio mūro įtempių deformacijų būviui. Nustatytas skiedinio gulsčiosios siūlės apibendrintas tamprumo modulis, įvertinantis sąlyčio zoną tarp skiedinio ir mūro gaminių (blokų). Pasiūlyta metodika, leidžianti patikslinti sumūrytų mūro gaminių ir skiedinio gulsčiosios siūlės mechanines savybes.

Tyrimais įrodyta, kad skaitiniai modeliai, taikant patikslintas mūro gaminių ir skiedinio savybes, gali būti sėkmingai naudojami mūro tamprumo moduliui nustatyti, neatliekant mūro fragmentų eksperimentinių tyrimų (nenaudojant ardymo metodų).

Pateikti pasiūlymai, kaip patikslinti silikatinių tuštymėtųjų blokų mūro gniuždomojo stiprio ir tamprumo modulio skaičiavimo metodus pagal LST EN 1996-1-1.

Ginamieji teiginiai

1. Skiedinio gulsčiosios siūlės deformacijos iki 10 kartų didesnės nei skiedinio kontrolinių bandinių.

2. Įvertinus apibendrintą gulsčiosios siūlės tamprumo modulį galima iki 25 % tiksliau apskaičiuoti mūro tamprumo modulį analitiniais ir skaitinio modeliavimo metodais.
3. Apskaičiuojant tuštymėtųjų silikatinių 1 ir 2 grupių blokų mūro charakteristinę gniuždomąją stiprį pagal EC6, būtina redukuoti empirinį koeficientą.

Darbo apimtis

Disertaciją sudaro įvadas, trys skyriai ir rezultatų apibendrinimas, naudotos literatūros sąrašas, autoriaus publikacijų sąrašas disertacijos tema. Darbo apimtis yra 136 puslapiai, 74 paveikslai, 19 lentelių ir 131 literatūros šaltinių sąrašas.

Pirmame skyriuje pateikta literatūros apžvalga. Nagrinėjamas statine gniuždomąją apkrova veikiamo mūro įtempių deformacijų būvis. Aprašomi mūro elgsenai poveikį turintys veiksniai. Analizuojamas minėtų veiksnių poveikis mūro stiprumui ir deformacinėms savybėms. Aptariami mūro skaitinio modeliavimo pritaikymo būdai. Apžvelgiami pagrindinių modeliavimo metodų principai ir irimo kriterijai taikomi mūro skaitiniame modeliavime.

Antrame skyriuje aprašomi eksperimentiniai mūro komponentų ir mūro tyrimai bei tyrimų rezultatai. Aprašomi mūro komponentai (skiediniai, mūro gaminiai), bandiniai ir jų paruošimas bei atliekamų eksperimentų metodika. Pateikti tuštymėtųjų silikatinių blokų mūro fragmentų tyrimų rezultatai bei analizuojamas įvairių veiksnių poveikis mūro mechaninėms savybėms.

Trečiame skyriuje palyginti eksperimentinių tyrimų rezultatai su skaitinio modeliavimo ir analitinių metodų mūro bei mūro gaminių mechaninių savybių skaičiavimo rezultatais. Nustatytas gulsčiųjų siūlių apibendrintas tamprumo modulis. Pasiūlyta priklausomybė jo apskaičiavimui. Gulsčiųjų siūlių apibendrintas tamprumo modulis pritaikytas tuštymėtųjų silikatinių blokų gniuždomojo mūro deformacinių savybių analizei naudojant analitines priklausomybes bei taikant detalų skaitinį mikromodeliavimą. Pateiktos rekomendacijos mechaninių savybių nustatymo pagal LST EN 1996-1-1 patikslinimui.

Darbo pabaigoje pateiktos bendrosios išvados.

Bendrosios išvados

1. Eksperimentiniais tyrimais nustatytas gulsčiosios siūlės storio poveikis mūro įtempių ir deformacijų būviui. Didžiausias, iki 15 %, skiedinio gulsčiosios siūlės storio poveikis mūro gniuždomajam stipriui nustatytas, kai skiediniui naudojamas iki 7 N/mm^2 stiprio bendrosios paskirties skiedinys. Naudojant didesnio stiprio bendrosios paskirties

- skiedinius (13 ir 33 N/mm^2), gulsčiosios siūlės storio poveikis mūro gniuždomajam stipriui sudaro iki 3% .
2. Nustatytas gulsčiosios siūlės skiedinio stiprio poveikis mūro įtempių ir deformacijų būviui. Mūro gniuždomojo stiprio prieaugis, didinant skiedinio stiprį, kinta netolygiai. Didžiąją mūro gniuždomojo stiprio pokyčio dalį – iki 70% – sudaro prieaugis, kai skiedinio stipris padidinamas nuo 7 N/mm^2 (M1b) iki 13 N/mm^2 (M2b). Padidinus skiedinio stiprį nuo 4 N/mm^2 iki 24 N/mm^2 , pirmojo plyšio atsivėrimo apkrovos ir ribinės apkrovos santykis padidėja nuo $0,55$ iki $0,85$.
 3. Tyrimais nustatyta, kad gulsčiosios skiedinio siūlės išilginės gniuždomosios deformacijos, kai įtempiai sudaro 33% maksimalių įtempių, yra iki 10 kartų didesnės už skiedinio kontrolinių bandinių santykinės deformacijas. Šį pokytį lemia skiedinio siūlės deformacinės savybės ir mūro gaminio bei skiedinio sąlytis. Skiedinio siūlės deformacinės savybės siūloma vertinti taikant apibendrintą gulsčiosios siūlės tamprumo modulį.
 4. Pirmos grupės silikatinių tuštymėjų blokų mūro su bendrosios paskirties cemento skiediniu apibendrintą gulsčiosios siūlės tamprumo modulį, kai gulsčiosios siūlės storis kinta nuo 5 iki 15 mm , o skiedinio tamprumo modulis (nustatytas bandant kontrolinius bandinius) – nuo 6 iki 18 GPa , rekomenduojama skaičiuoti pagal autoriaus pasiūlytą formulę. Ši priklausomybė gali būti pritaikyta ir mūro su plonasluoksniu skiediniu apibendrintam gulsčiosios siūlės tamprumo moduliui, kai siūlės aukštis ne mažesnis nei 2 mm , o skiedinio tamprumo modulis ne mažesnis nei 8 GPa , nustatyti.
 5. Analitinių mūro tamprumo modulio skaičiavimo metodų palyginimas parodė, kad, įvertinus apibendrintą gulsčiosios siūlės tamprumo modulį pagal siūlomą formulę, gaunamos 15 – 24% tikslesnės reikšmės nei tada, kai naudojamas skiedinio kontrolinių bandinių tamprumo modulis.
 6. Taikant detalųjį skaitinį mikromodeliavimo metodą, gaunama gniuždomų mūro gaminių įtempių ir deformacijų kreivė, iš kurios nustatomi blokų gniuždomasis stipris ir tamprumo modulis. Apskaičiuotos blokų gniuždomojo stiprio reikšmės iki 6% mažesnės už nustatytas eksperimentais, o tamprumo modulio reikšmės skyrėsi nedaug – iki 3% .
 7. Detalusis skaitinis mikromodelis gali būti pritaikytas silikatinių tuštymėjų blokų mūro tamprumo moduliui nustatyti, kai įvertinamas apibendrintas gulsčiosios siūlės tamprumo modulis. Taikant skaitinį modelį, apskaičiuotos mūro tamprumo modulio reikšmės apie 18 – 50%

didesnės, kai naudojamas skiedinio tamprumo modulis, nustatytas iš kontrolinių bandinių. Įvertinus apibendrintą gulsčiosios siūlės tamprumo modulį, skirtumas tarp skaitinio modelio ir eksperimentinių rezultatų sudaro apie 9–18 %.

8. Atlikus eksperimentinių tyrimų rezultatų analizę pateikti mūro mechaninių savybių vertinimo pagal EC6, pasiūlymai. Skaičiuojant konstrukcijų įrašas ir laikomąją galią, silikatinių 1 ir 2 grupių tuštymėtų blokų mūro tamprumo charakteristiką rekomenduojama priimti lygią 500. Apskaičiuojant tikslių matmenų silikatinių blokų mūro su plonasluoksniu skiediniu charakteristinį gniuždomąjį stiprį, rekomenduojama taikyti redukuotą empirinį koeficientą.

Trumpos žinios apie autorių

Robertas Zavalis gimė 1984 m. gegužės 4 d. Skuode. 2007 m. įgijo statybos inžinerijos bakalauro laipsnį, o 2009 m. įgijo statybos inžinerijos mokslo magistro laipsnį Vilniaus Gedimino technikos universiteto Statybos fakultete. 2009–2013 m. – Vilniaus Gedimino technikos universiteto Gelžbetoninių ir mūrinių konstrukcijų katedros doktorantas. 2010 m. buvo akademinėje stažuotėje Minjo universitete (Portugalija).

Robertas ZAVALIS

STRESS STATE ANALYSIS OF CALCIUM SILICATE
HOLLOW BLOCK MASONRY UNDER COMPRESSION

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Robertas ZAVALIS

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Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
<http://leidykla.vgtu.lt>
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius