Acta Sci. Pol.
Architectura 23 (2024), 134–144

aspa.sggw.edu.pl ISSN 1644-0633 (suspended) eISSN 2544-1760 DOI: 10.22630/ASPA.2024.23.10

ORIGINAL PAPER

Received: 11.02.2024
Accepted: 19.03.2024

THE STRENGTH OF COMPLEX COMPRESSED REINFORCED CONCRETE STRUCTURES UTILISING HOLLOW CONCRETE BLOCKS

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ABSTRACT

Structures in which elements from different materials work together are successfully used in various combinations. Recently, new, effective construction materials and products have appeared. In complex or multi-component structures, elements made of materials with different physico-chemical or strain-strength characteristics should be sensibly combined for joint work. The more fully the properties of the components' materials are utilised, the more efficient the design itself is. By analysing global practice, it can be seen that small concrete blocks have become widespread. The use of masonry made of hollow concrete blocks in modern construction differs from traditional ones in that the void area (up to 70%) makes it possible to create complex high-strength load-bearing structures by filling them with monolithic reinforced concrete. This also enables speeding up the construction process itself and reducing the cost of work on the construction site. The purpose of the study was to examine the strength of centrally compressed columns composed of hollow blocks and concrete filling with different transverse and longitudinal reinforcements, as well as to improve their calculation methodology. Experimental studies of centrally compressed columns, with different percentages of reinforcement using hollow concrete blocks as permanent formwork, have been carried out. The article presents the results of the research on strength, but the results of the strain studies were not included in this work. The proposed method of calculating complex constructions can be applied in design practice. A good correlation was observed between the experimental results and the results of the analytical model.

Keywords: compression behaviour, reinforced concrete column, hollow concrete blocks

INTRODUCTION

When designing structures where various components, including blocks, masonry mortar, concrete filling voids and reinforcement work together, questions may arise as to how these structures relate to two building regulation documents: EN 1996-1-1:2005+A1:2012 (European Committee for Standardization [CEN], 2012) and EN 1996-2:2006 (CEN, 2006a).

In the building regulation documents EN 1996-1-1:2005+A1:2012 (CEN, 2012), EN 1992-1-1:2004 (CEN, 2004), EN 1996-2:2006 (CEN, 2006a), EN 1996-3:2006 (CEN, 2006b) and DIN 1053-3-1990 (Deutsches Institut für Normung [DIN], 1990), there is no binding information for the design of complex structures using hollow blocks, which indicates that the issue of their strength has been little studied. The lack of sufficient experimental

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and regulatory framework for the design of complex reinforced concrete structures utilising masonry from hollow blocks hinders the development of this field in construction.

According to the authors, paragraphs 3.6.1.2 (4) and 6.6.1 (4) of the EN 1996-1-1:2005+A1:2012 require adjustments.

Scientific research on the masonry work from hollow blocks is carried out in many countries, which confirms the relevance of the issue.

Studies and individual problems on the topic are presented in the works by Onishchik (1939), Matysek and Seruga (2005), Rudziński (2010), Drobiec (2016), Hasan, Saidi, Sarana and Bunyamin (2021), and Jafari (2021).

In the works by Popkow and Griniov (2006a, 2006b), the results of testing prisms made of hollow concrete blocks with different compositions of filling voids are presented. The masonry work from hollow blocks and the masonry work with concrete filling of different strengths and properties have been studied. Recommendations on the use of concrete filling are given, and the nature of the destruction is described.

In the work by Álvarez-Pérez, Chávez-Gómez, Terán-Torres, Mesa-Lavista and Balandrano-Vázquez (2020), mathematical models have been developed for calculating the compressive strength and elastic modulus of masonry prisms with hollow concrete blocks.

The works by Machado, Lübeck, Mohamad, Fonseca, and Barros da Silva Santos Neto (2019), and Syiemiong and Marthong (2020) study hollow concrete blocks of various configurations, with different mortar compositions in the joints, as well as examine how this affected the strength of the masonry.

In the works by Fahmy and Ghoneim (1995), Mohamad, Lourenc and Roman (2007), Jonaitis and Zavalis (2013), and Irnutan and Babota (2017), fragments of walls made of hollow concrete blocks of various configurations with and without concrete filling were tested, and the mechanism of wall destruction was studied.

In the work by Triwiyonoa, Nugrohoa, Firstyadia and Ottamaa (2015), fragments of walls made of hollow concrete blocks and strengthened with reinforced concrete were tested for out-of-plane bending. The ability to bend and the plasticity of the reinforced walls was increased by 5–16 times in relation to the non-reinforced walls.

The works by Pratyusha, Ashwin Thammiah, Aswath and Raghunath (2014), Bolhassani (2015), Calderón, Sandoval, Vargas and Araya-Letelier (2018), and Zhou, Du, Peng and Chen (2019) present the results of testing a fragment of a wall made of hollow concrete and ceramic blocks with separate sections of vertical and inclined reinforcement, where the voids of the masonry were filled with concrete of C20–C25 class.

In the work by Sandeep, Renukadevi, Manjunath and Somanath (2013), and Chi, Yang, Wang, Zhang and Quan (2019), the results of experimental studies and modelling of a wall fragment in the Ansys software with vertical reinforcement are presented. It is also possible to create prestressed masonry structures.

In the works by Thamboo (2018), and Thamboo, Zahra, Asad and Song (2021), the results of the analysis of calculations of reinforced masonry according to the Australian AS3700 (Standards Australia, 2018) and the British BS EN 1996-1-1:2005 (British Standards Institution [BSI], 2005b), BS 5628-2:2005 (BSI, 2005a) are presented.

The analysis of scientific works given above shows the insufficiency of research in the field of creating columns from concrete hollow blocks filled with reinforced concrete.

EXPERIMENTAL PROGRAM

Production of experimental columns

The experimental studies were carried out on specimens of columns with various reinforcement, as close as possible to the elements of full-scale structures in terms of cross-sectional dimensions, their reinforcement diagrams, and the composition of concrete.

Hollow concrete blocks from fine-grained concrete, made by vibropressing according to Besser technology, were used in all specimens of columns. A standard cement-sand mixture was used as a masonry mortar.

To prepare 1 m^3 of concrete mix, a composition consisting of PC500 portland cement (300 kg), 5–10 crushed stones (1,040 kg), medium sand (780 kg), C3 plasticizer (2.34 kg) and water (165 kg) was used.

As a transverse reinforcement of the joints between the blocks, grids made of reinforcement ∅5 S500 were used. The longitudinal reinforcement used reinforcement rods ∅14, of various classes of steel: S500 and S800.

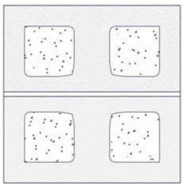
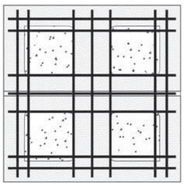
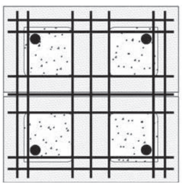
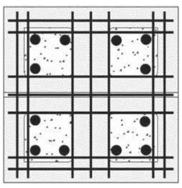
Table 1 shows the main characteristics of the materials used. Table 2 shows the types of specimen columns. In total, six types of columns were manufactured and tested, two identical specimens of each type.

Table 1. Characteristics of the materials, according to the test results of standard specimens

Average reduced prismatic strength of concrete		Joint solution strength	Longitudinal reinforcement rods			
			S500		S800	
blocks	fillings		yield strength	max. resistance	yield strength	max. resistance
MPa						
28.4	19.8	9.07	585	660	1 015	1 155

Source: own work.

Table 2. Characteristics of specimens

No	Cross-sections of specimens	Longitudinal reinforcement		Transverse reinforcement	Specimens
		steel grade	% of reinforcement		
1		–	–	–	k1
2		–	–	Welded mesh made of ∅5 S500 in each horizontal seam $\rho_{xy} = 0.39\%$	k2
3		S500	1.21		k3
4		S800	1.21		k4
5		S500	3.64		k5
6		S800	3.64		k6

Note: two specimens of each type have been manufactured and tested.

Source: own work.

The production of columns was carried out in the following order. The rods of the longitudinal reinforcement were fixed by manual electric arc welding to the lower steel plate. After concreting the lower head (Fig. 1a), two rows of blocks were laid out, with the installation of transverse reinforcement in horizontal seams and filling the voids with concrete. After finishing the masonry work, the formwork was installed, and the upper head was concreted (Fig. 1b), with the upper ends of the longitudinal reinforcement welded to the end plate.

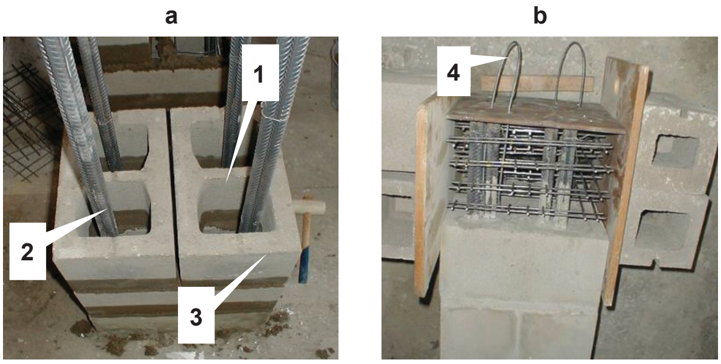


Fig. 1. Production of a specimen column

Source: own work.

Testing procedure

The specimens were loaded centrally, and the load transfer was carried out through pivotally mounted press plates.

The testing of columns after the concrete obtained strength in natural laboratory conditions was carried out at the age of at least 28 days in a PR-1000 hydraulic press.

Longitudinal strains were measured along each of the faces by means of dial indicators with a resolution of 0.01 mm fixed on a base of 600 mm. Mechanical strain gauges with a resolution of 0.001 mm and a base of 20 mm were used to measure the strains of the contact zone of the seam between the blocks. Additionally, dial indicators with a resolution of 0.002 mm and a base of 200 mm were fixed for measuring transverse strains on four faces. The reinforcement strains were measured on a base of 400 mm. The general view and the test scheme are presented in Figures 2 and 3. The cracking force was recorded on the scale of the press force gauge at the time of the formation of the first cracks. The crack opening width was measured at the level of the most stretched reinforcement using a reference microscope with an accuracy of 0.05 mm.

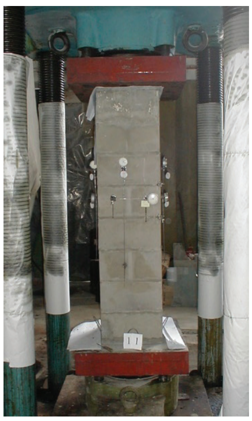
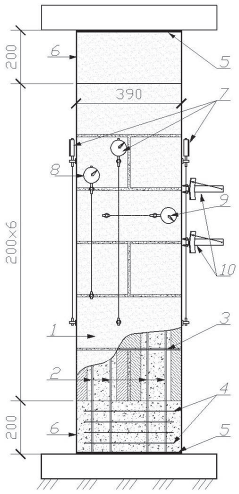


Fig. 2. General view of the testing of a specimen column

Source: own work.



1 – hollow concrete blocks
2 – longitudinal reinforcement rods
3 – welded reinforcing mesh in masonry seams
4 – welded reinforcing mesh monolithic head
5 – 16 mm thick steel support plate
6 – reinforced concrete support head
7 – mechanical strain gauge with a 0.01 mm scale resolution based on 600 mm for measuring concrete surface strains
8 – mechanical strain gauge with a 0.01 mm scale resolution based on 400 mm for measuring strains of longitudinal reinforcement
9 – mechanical strain gauge with a resolution of 0.002 mm based on 200 mm for measuring transverse strains of the specimen surface
10 – mechanical lever strain gauges with a resolution of 0.001 mm based on 20 mm for measuring strains in the seam area

Fig. 3. The design of a specimen column with the placement of mechanical strain gauges

Source: own work.

The loading was carried out with a short-term mode of a stepwise increase in the load by 10% with the exposure at the level of each step for 12–15 min. In the steps preceding the exhaustion of the bearing capacity, the increase in the load was reduced to 5%. Readings from measuring instruments were recorded before and after the application of the load in consecutive stages. Measurements of the most important strain parameters were carried out before applying loads of the maximum load-bearing capacity of structures, as determined by the maximum reading of the control arrow of the press force meter.

RECOMMENDATIONS FOR THE CALCULATION OF COMPLEX COMPRESSED STRUCTURES

In the strain calculation model, the equilibrium condition for determining compressive strength is taken as:

$$\sigma_c(\varepsilon) \cdot A_c + \sigma_k(\varepsilon) \cdot A_k + \sigma_s(\varepsilon) \cdot A_s = N. \tag{1}$$

The first three terms are the forces from: concrete filling, concrete blocks, and reinforcement, respectively.

When compressing complex reinforced concrete elements at all stages of loading, all components are strained together:

$$\varepsilon = \varepsilon_k = \varepsilon_c = \varepsilon_s. \tag{2}$$

The condition (2) enables calculations of a complex compressed reinforced concrete element under the known strain laws of its components. To calculate the strength, we used the following analytical dependencies:

– for concrete (Hognestad, 1951):

$$\sigma_c(\varepsilon) = f_c \cdot \left[2 \cdot \left(\frac{\varepsilon}{\varepsilon_{c1}} \right) - \left(\frac{\varepsilon}{\varepsilon_{c1}} \right)^2 \right]; \tag{3}$$

– for masonry of hollow concrete blocks (Onishchik, 1939):

$$\sigma_k(\varepsilon) = \mu \cdot f_k \cdot [1 - e^{(-0.9 \cdot \varepsilon \cdot \alpha)}]; \tag{4}$$

– for reinforcement:

$$\sigma_s(\varepsilon) = \varepsilon \cdot E_s. \tag{5}$$

Thus, the calculation is based on dependencies (3)–(5) that establish a relationship between stresses and strains: concrete, reinforcement, and masonry. The criterion for exhaustion of strength is the achievement of strains in the specimens, at which the total compressive force (concrete, blocks and reinforcement) reaches the maximum value.

Considering the above, it is proposed to calculate the strength of complex compressed reinforced concrete structures utilising hollow concrete blocks by using the dependence in the form of a formula:

$$N = A_{cmk} \cdot f_{cmk,eff} \cdot \left[2 \cdot \left(\frac{\varepsilon}{\varepsilon_{cmk.1,eff}} \right) - \left(\frac{\varepsilon}{\varepsilon_{cmk.1,eff}} \right)^2 \right] + \varepsilon \cdot E_s \cdot A_s, \tag{6}$$

where $f_{cmk.eff} = f_{cmk} + \phi_0 \cdot \rho_{xy} \cdot f_{yd,xy}$, (7)

where $f_{cmk} = \dfrac{f_k \cdot A_k \cdot \lambda_k + f_c \cdot A_c}{A_k + A_c}$, (8)

where $\phi_0 = \dfrac{1}{0.23 + \psi}$, (9)

where $\psi = \dfrac{\rho_{xy} \cdot f_{yd,xy}}{f_{cmk} + 10\,\mathrm{MPa}}$, (10)

in which:
A_s – area of compressed reinforcement [mm^2 (in.^{2})],
A_c – area of compressed concrete filling [mm^2 (in.^{2})],
A_k – area of compressed masonry [mm^2 (in.^{2})],
A_{cmk} – area of concrete filling and masonry [mm^2 (in.^{2})],
ρ_{xy} – reinforcement of transverse reinforcement [%],
ε – longitudinal deformations of specimens [%],
ε_{c1} – longitudinal deformations of concrete at the peak point [%],
ε_k – longitudinal deformations of masonry [%],
ε_c – longitudinal deformations of concrete filling [%],
ε_s – longitudinal deformations of reinforcement [%],
σ_c – stresses in the concrete filling [MPa],
σ_k – stresses in the masonry [MPa],
σ_s – armature stresses [MPa],
N – total longitudinal compression force [kN],
f_c – characteristic compressive (cylinder) strength of concrete [MPa],
f_k – characteristic compressive strength of masonry [MPa],
$f_{yd,xy}$ – yield strength of the steel reinforcement grids [MPa],
f_{cmk} – reduced strength of the complex section [MPa],
$f_{cmk,eff}$ – reduced strength of the complex cross-section reinforced with transverse reinforcement [MPa],

λ_k – masonry utilisation factor (λ_k = 0.80),
α – elastic characteristics of masonry (α = 780),
ψ, ϕ_0 – dimensionless coefficients.

RESULTS AND DISCUSSION

The specimens of columns without reinforcement (k1) were loaded until destruction, and the nature of the destruction was similar to that of conventional concrete prisms. Longitudinal cracks appeared at a load level of about 0.7–0.9 of the limit, along the entire height of the specimen, then the column was broken into separate vertical blocks. The destruction of centrally compressed specimens occurred in a brittle manner with the fragmentation of concrete.

The specimens of columns with transverse reinforcement (k2) were loaded until destruction. Longitudinal cracks occurred at a load level of 0.85–0.95 of the limit. The transverse grids limited the development of longitudinal cracks. The destruction of the specimen occurred due to the exhaustion of the bearing capacity of the concrete between the grids. The destruction occurs in a more plastic manner, compared to the specimen k1.

The destruction of the columns with S500 longitudinal reinforcement (k3, k5) proceeded smoothly, and longitudinal cracks appeared on the concrete surface around the longitudinal reinforcement. The destruction occurred with the loss of stability and buckling of the longitudinal reinforcement bars. The plane of the destruction, in most cases, was at an angle with a vertical axis of the order of 30–35° and usually coincided with previously formed longitudinal cracks. The buckling radius of the longitudinal reinforcement at the stage of destruction was small (90 mm). With a reinforcement of 1.21% (k3), buckling occurs on a segment limited by the transverse grids.

The initial stages of the destruction of the column specimens with S800 longitudinal high-strength reinforcement (k4, k6) was like the destruction of samples k3 and k5. The destruction occurred with the loss of stability and buckling of the longitudinal reinforcement bars. The plane of destruction, in most cases, was at an angle with a vertical axis of the order of 15–25° (i.e., during the destruction, almost all of the reinforcement was exposed). The radius of buckling of the longitudinal reinforcement at the stage of destruction was large (900 mm), and the reinforcement lost stability along the entire height of the specimen, bursting the grids with a scattering of concrete fragments.

The rods lost their stability within the middle section of the length of the structures and between the fixing points at their intersection with the transverse grids. The forms of bending are shown in Figure 4. The average strength of the columns is shown in Figure 5, while the destruction of the column specimens is shown in Figure 6.

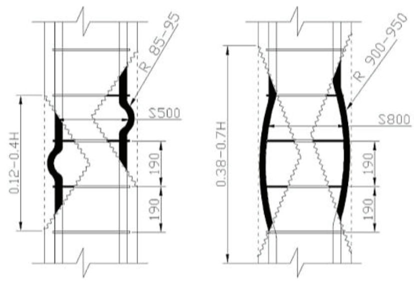


Fig. 4. Types of stability loss with longitudinal reinforcement of S500 and S800

Source: own work.

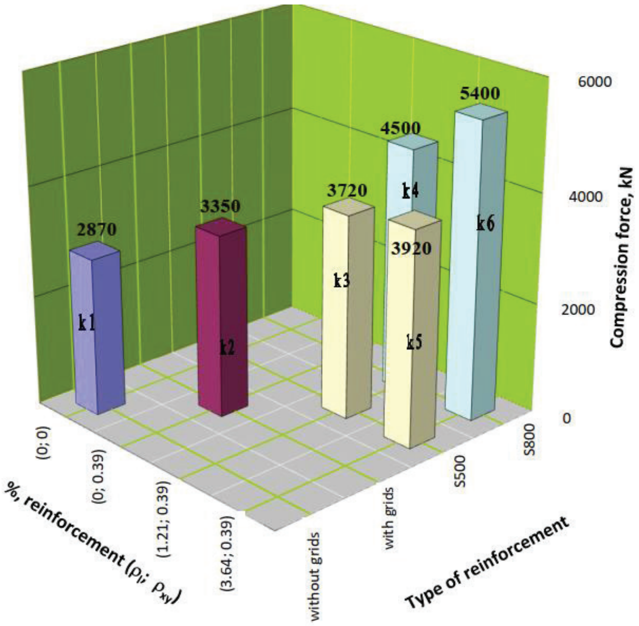


Fig. 5. Strength of specimens with different reinforcement

Source: own work.

Fig. 6. The nature of the destruction of the columns

Source: own work.

When comparing the results of the theoretical calculation of strength and the experimental data, satisfactory convergence was revealed (Table 3).

Table 3. Comparing the results

Sample	N_{Rd} [kN] (experimental data)	Using the formula (6)	
		N [kN]	N_{Rd}/N [kN]
k1	2 870	2 690	1.07
k2	3 350	3 300	1.02
k3	3 720	3 715	1.00
k4	3 920	3 865	1.01
k5	4 500	4 460	1.01
k6	5 400	5 305	1.02

Source: own work.

CONCLUSIONS

1. Transverse and longitudinal reinforcement of complex compressed reinforced concrete structures increases the levels of cracking. The destruction of a column begins with a decrease in its volume, then a subsequent increase due to the formation of microcracks and further destruction.
2. The analysis of experimental complex reinforced concrete structures with S800 high-strength reinforcement indicates the possibility of the full use of the mechanical properties of reinforcing steel.
3. To calculate the strength of complex compressed reinforced concrete structures, it is proposed to use dependence 6, which considers the descending branch of the strain diagram of concrete components and the processes of redistribution of forces in the presence of high-strength steel as part of the reinforcement section.
4. Based on the conducted experimental and numerical analysis, the authors of the article propose to change the wording of paragraphs 3.6.1.2 (4) and 6.6.1 (4) in the EN 1996-1-1:2005+A1:2012 "When a compression zone contains both masonry and concrete infill, the compressive strength should be calculated using a stress block based on the compressive strength of the weakest material" should be replaced with "When a compression zone contains both masonry and concrete infill, the compressive strength should be calculated proportionally for each material making up the total cross section".

REFERENCES

Álvarez-Pérez, J., Chávez-Gómez, J. H., Terán-Torres, B. T., Mesa-Lavista, M. & Balandrano-Vázquez, R. (2020). Multifactorial behavior of the elastic modulus and compressive strength in masonry prisms of hollow concrete blocks. *Construction and Building Materials*, *241*. https://doi.org/10.1016/j.conbuildmat.2020.118002

British Standards Institution [BSI], (2005a). *Code of practice for the use of masonry. Structural use of reinforced and prestressed masonry* (BS 5628-2:2005).

British Standards Institution [BSI], (2005b). *Eurocode 6. Design of masonry structures. General rules for reinforced and unreinforced masonry structures* (BS EN 1996-1-1:2005).

Bolhassani, M. (2015). *Improvement of Seismic Performance of Ordinary Reinforced Partially Grouted Concrete Masonry Shear Walls*. National Science Foundation (NSF) Grant Report 1208.

Calderón, S., Sandoval, C., Vargas, L. & Araya-Letelier, G. (2018). Behavior of partially grouted reinforced masonry shear walls built with concrete blocks and clay bricks: a comparative study. In A. Taliercio & S. Garrity (Eds), *10th International Masonry Conference*, Milan, Italy, July 9–11, 2018. https://www.researchgate.net/publication/326343973

Chi, B., Yang, X., Wang, F., Zhang, Z. & Quan, Y (2019). Experimental Investigation into the Seismic Performance of Fully Grouted Concrete Masonry Walls Using New Prestressing Technology. *Applied Sciences*, *9* (20), 4354. https://doi.org/10.3390/app9204354

Deutsches Institut für Normung [DIN], (1990). *Reinforced masonry, design and construction* (DIN 1053-3) [in German].

Drobiec, Ł., Jasiński, R., Piekarczyk, A., Mazur, W., Rybarczyk, T., Chojnowski, J., Janiak, R. & Kwaśniak, J. (2016). *Projektowanie konstrukcyjne ścian z betonu komórkowego* (zeszyt 2, część 1). Warszawa: Stowarzyszenie Producentów Betonów.

European Committee for Standardization [CEN], (2004). *Eurocode 2. Design of concrete structures. Part 1-1: General rules and rules for buildings* (EN 1992-1-1:2004).

European Committee for Standardization [CEN], (2006a). *Eurocode 6. Design of masonry structures. Part 2: Design considerations, selection of materials and execution of masonry* (EN 1996-2:2006).

European Committee for Standardization [CEN], (2006b). *Eurocode 6. Design of masonry structures. Part 3: Simplified calculation methods for unreinforced masonry structures* (EN 1996-3:2006).

European Committee for Standardization [CEN], (2012). *Eurocode 6. Design of masonry structures. Part 1-1: General rules for reinforced and unreinforced masonry structures* (EN 1996-1-1:2005+A1:2012).

Fahmy, E. H. & Ghoneim, T. G. M. (1995). Behaviour of concrete block masonry prisms under axial compression. *Canadian Journal of Civil Engineering*, *22*, 898–915. https://doi.org/10.1139/l95-107

Hasan, M., Saidi, T., Sarana, D. & Bunyamin, (2021). The strength of hollow concrete block walls, reinforced hollow concrete block beams, and columns. *Journal of King Saud University – Engineering Sciences*, *34* (8), 523–535. https://doi.org/10.1016/j.jksues.2021.01.008

Hognestad, E. (1951). Study of Combined Bending and Axial Load in Reinforced Concrete Member. *University of Illinois Engineering Experiment Station Bulletin*, *399*. Retrieved from: https://core.ac.uk/download/pdf/4814295.pdf [accessed: 09.02.2024].

Irnutan, R. A. & Babota, F. (2017). Autoclaved Cellular Concrete (ACC) Masonry with Vertical Hollows Confined with Disperse Reinforced Concrete. *10th International Conference Interdisciplinarity in Engineering INTER-ENG 2016. Procedia Engineering*, *181*, 300–307. https://doi.org/10.1016/j.proeng.2017.02.393

Jafari, S. (2021). *Material characterisation of existing masonry: A strategy to determine strength, stiffness and toughness properties for structural analysis*. Delft University of Technology, Delft.

Jonaitis, B. & Zavalis, R. (2013). Experimental Research of Hollow Concrete Block Masonry Stress Deformations. *11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013. Procedia Engineering*, *57*, 473–478. https://doi.org/10.1016/j.proeng.2013.04.061

Machado, J. F., Lübeck, A., Mohamad, G., Fonseca, F. S. & Barros da Silva Santos Neto, A. (2019). Compressive strength of masonry prisms under compression according to Eurocode 6 – EN 1996-1-1 (2005). In *Conference: 13th North American Masonry*, Salt Lake City/EUA, June. https://www.researchgate.net/publication/333731008

Matysek, P. & Seruga, T. (2005). *Konstrukcje murowe. Przykłady i algorytmy obliczeń z komentarzem*. Kraków: Wydawnictwo Politechniki Krakowskiej.

Mohamad, G., Lourenc, P. B. & Roman, H. R. (2007). Mechanics of hollow concrete block masonry prisms under compression: Review and prospects. *Cement & Concrete Composites*, *29*, 181–192. https://doi.org/10.1016/j.cemconcomp.2006.11.003

Onishchik, L. I. (1939). *Kamennyye konstruktsi promyshlennykh i grazhdanskikh zdaniy* [*Stone structures of industrial and civil buildings*]. Moskva: Gosstroyizdat.

Popkow, J. & Griniov, V. (2006a). Compressed prefabricated monolithic structures based on concrete vibropressed hollow stones. *Construction Science and Technology. Minsk*, *4* (7), 52–57. https://elib.psu.by/bitstream/123456789/26650/5/8-16.pdf

Popkow, J. & Griniov, V. (2006b). Determination of the strength of compressed complex structures based on concrete vibropressed hollow stones. Prospects for the development of new technologies in construction and training of engineering personnel of the Republic of Belarus: *Collection of articles of the XIV International scientific and practical seminar. Minsk: BNTU*, *1*, 135–140.

Pratyusha, M. N., Ashwin Thammiah, K., Aswath, M. U. & Raghunath, S. (2014). Ultimate moment carrying capacity of reinforced hollow concrete block masonry. *Bulletin of ACCE*, *31* (1), 22–27. Retrieved from: https://www.researchgate.net/publication/347331969

Rudziński, L. (2010). *Konstrukcje murowe. Remonty i wzmocnienia*. Kielce: Politechnika Świętokrzyska.

Sandeep, Renukadevi, M. V., Manjunath, S. & Somanath (2013). Influence of reinforcement on the behavior of hollow concrete block masonry prism under compression – an experimental and analytical approach. *International Journal of Research in Engineering and Technology*, *November.* Retrieved from: https://www.researchgate.net/publication/343826661

Standards Australia (2018). *Masonry Structures* (AS3700:2018).

Syiemiong, H. & Marthong, C. (2020). Effect of mortar grade on the uniaxial compression strength of low-strength hollow concrete block masonry prisms. *Materials Today: Proceedings*, *28* (Part 2), 842–845. https://doi.org/10.1016/j.matpr.2019.12.309

Thamboo, J. (2018). Reinforced Masonry, An alternative to Reinforced Concrete. *Conference Paper*, *March*. Retrieved from: https://www.researchgate.net/publication/347946205

Thamboo, J., Zahra, T., Asad, M. & Song, M. (2021). Improved design provisions for reinforced concrete block masonry walls under axial compression. *Construction and Building Materials*, *October*. Retrieved from: https://www.researchgate.net/publication/355406340

Triwiyonoa, A. B., Nugrohoa, A. S., Firstyadia, A. D. & Ottamaa, F. (2015). Flexural strength and ductility of concrete brick masonry wall strengthened using steel reinforcement. *The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5). Procedia Engineering*, *1*, 940–947. https://doi.org/10.1016/j.proeng.2015.11.124

Zhou, X., Du, J., Peng, Q. & Chen, P. (2019). Hollow block masonry wall reinforced by built-in structural configuration: Seismic behavior analysis. *Soil Dynamics and Earthquake Engineering*, *126*, 105815. https://doi.org/10.1016/j.soildyn.2019.105815

NOŚNOŚĆ ŚCISKANYCH KONSTRUKCJI ZESPOLONYCH Z WYKORZYSTANIEM WIBROPRASOWANYCH PUSTAKÓW BETONOWYCH

STRESZCZENIE

Struktury, w których elementy z różnych materiałów współdziałają ze sobą, są z powodzeniem stosowane w różnych połączeniach. W ostatnich czasach pojawiły się nowe skuteczne materiały budowlane i produkty. W konstrukcjach zespolonych lub wieloskładnikowych elementy wykonane z materiałów o różnych właściwościach fizykochemicznych lub wytrzymałościowych należy rozsądnie łączyć w celu ich optymalnego współdziałania. Im pełniej wykorzystane są właściwości materiału komponentów, tym bardziej efektywna jest sama konstrukcja. Małe bloki betonowe stały się szeroko rozpowszechnione, co zaobserwowano dzięki analizie światowych doświadczeń. Zastosowanie muru z pustaków betonowych w nowoczesnym budownictwie różni się od tradycyjnego budownictwa tym, że powierzchnia pustki (do 70%) umożliwia tworzenie zespolonych konstrukcji nośnych o większej wytrzymałości poprzez wypełnienie ich monolitycznym betonem zbrojonym. Umożliwia to również przyspieszenie samego procesu budowlanego i obniżenie kosztów pracy na placu budowy. Celem pracy było zbadanie nośności centralnie ściśniętych słupów z pustaków z wypełnieniem żelbetonem, a także udoskonalenie metodologii obliczeniowej. Przeprowadzono badania eksperymentalne centralnie ściśniętych słupów o różnym procencie zbrojenia z wykorzystaniem pustaków jako szalunku stałego. W artykule przedstawiono wyniki badań wytrzymałości i nośności, nie uwzględniono w nim wyników badań odkształceń. Proponowana metoda obliczania zespolonych konstrukcji może być stosowana w praktyce projektowej. W trakcie badań zaobserwowano dobrą korelację między wynikami eksperymentalnymi a wynikami modelu analitycznego.

Słowa kluczowe: ściskanie betonu, słup żelbetowy, pustaki betonowe