# MASONRY FROM SMALL-FORMAT PRECAST UNITS

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## ABSTRAKT

Výstavba zděných konstrukcí je fyzicky náročná práce, avšak opakovatelnost pracovního postupu a pravidelnost zdiva vybízejí dlouhodobě k mechanizaci procesu zdění.

V úvodní části příspěvku jsou představeny možné alternativy mechanizace a technologie pro usnadnění a zvýšení efektivity zdění a na základě zhodnocení kladů a záporů uvedených systémů rozvedena myšlenka maloformátové prefabrikace a její montáž pomocí malých jeřábů. Praktickou částí výzkumu jsou mechanické zkoušky zdiva ze zděných prefabrikátů, kdy článek představuje první výsledky, a to z tlakové zkoušky. U zkušebních vzorků byla stanovena charakteristická pevnost zdiva v tlaku a popsán způsob porušení. Získané poznatky ze zkoušky byly porovnány s vlastnostmi tradičního zdiva. V diskusi je dále popsána rozvaha nad budoucími plány výzkumu na téma prefabrikace zdiva.

## KLÍČOVÁ SLOVA

Zdivo • Prefabrikace • Robotické zdění • Pevnost v tlaku • Vazba zdiva

## ABSTRACT

Bricklaying is a physically demanding job, but the repeatability of the workflow and the regularity of the masonry encourages the mechanization of the masonry process in the long term.

In the introductory part of the paper, possible alternatives of mechanization and technology to facilitate and increase the efficiency of masonry are presented, and the idea of small-format prefabrication and their assembly by small cranes is elaborated on the basis of an evaluation of the pros and cons of these systems. The practical part of the research is the mechanical testing of precast masonry, where the paper presents the first results, namely from a compression test. The characteristic compressive strength was determined for the test samples and the failure mode was described. The test findings were compared with the properties of traditional masonry. Further research plans on the topic of precast masonry are described in the discussion.

## KEYWORDS

Masonry • Precast production • Robotic masonry • Compressive strength • Masonry bond

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## 1. INTRODUCTION

The masonry process is one of the most physically exacting construction tasks. Bricklaying is a repeated movement of heavy objects over a long period of time – joining bricks together with mortar in a regular bond. The repeatability of the workflow and the regularity of the masonry construction make it seem perfectly suited for mechanization. The first attempts to mechanize bricklaying date back to the early 20th century, however it was not until the early 21st century that they became more widely used. Automatic masonry production lines are used in production halls for prefabrication of masonry and mechanization of masonry construction in the form of a robotic arm is applied on construction sites.

Precast masonry wall panels are produced using automated production lines by companies such as Redblocsystems®, Rimatem® or Rötzer® Ziegel Element Haus, which have been presented in more detail (Richterová 2021).

References to robotic masonry technology in the form of a robotic arm can be found in publications from the late $20^{th}$ century. Examples include the “BLOCKBOT”, a robot to automate construction of cement block walls (Slocum & Schena 1988), the prototype of a robotic bricklaying system from 1993 (Altobelli et al. 1993), the prototype of the mobile bricklaying robot “BRONCO” or the development of the “ROCCO” bricklaying robot system (Andres et al. 1994). In most cases, these systems ended up only on paper or in the form of a prototype that did not find application in practice. There are currently a handful of systems for automated bricklaying on the market that could become fully-fledged options for masonry construction.

- Hadrian X® by Fastbrick Robotics is the first mobile robotic blocklaying machine that can safely work outdoors in an uncontrolled environment. Construction of masonry using this robotic system is very fast and accurate and has already been used on several commercial construction sites abroad. The system consists of a boom (arm) that is mounted on the truck (FBR 2018).

Figure 1: *Hadrian X® by Fastbrick Robotics*

- SAM 100 by Construction Robotics is a mechanized masonry system that has found its application in practice since 2015. The system consists of a robotic boom, a mortar dispenser and conveyor belt that is mounted on a wheeled chassis (Construction Robotics 2022).


Figure 2: *SAM 100 by Construction Robotics*

- Dekmatic is a system developed by DEK in cooperation with the Department of Construction Technology at the CTU. The system enables robotic bricklaying and 3D printing on site (DEK 2023).

*Figure 3: Dekmatic by DEK in cooperation with CTU*

There are other systems to make bricklaying easier and more efficient, such as so-called bricklayer´s assistants. In the first instance, these are machines in the form of mini-cranes that can be used to more easily and faster moving especially large and heavy masonry elements within the construction (Construction Robotics 2022, Xella Group 2023). An interesting system for making the work of masons easier is the system named Exoskeleton by FRACO (Dutil, C. 2020). The system is based on a model that was developed for the military and is designed to reduce the strain on the mason´s muscles during the handling of masonry elements and the masonry process.

Figure 4: *Mini-crane by Xella*

Figure 5: *Exoskeleton by FRACO*

All these options have their pros and cons. Automated productions lines for prefabricating masonry in production halls are expensive and dimensionally demanding, and for precast masonry wall panels, it is necessary to think about transporting and assembling the precast panels with a crane as well. Robotic masonry technology, on the other hand, faces the challenges of applying mortar to the bricks and then achieving a clean mortar joint without human intervention. The behavior of mortar can be likened to that of a non-Newtonian fluid, which poses complications for brick laying using robotic masonry technology. It is therefore necessary to constantly check the flatness of the masonry. With robotic masonry technology, you also need to think about the logistics of the equipment needed on the construction site. The masonry assistants are only a relief for the masons, but compared to the two systems mentioned above, they are more portable due to their small size.
Based on the knowledge gained from these innovative options for masonry construction, the idea of small-format precast masonry was developed, where the small-format precast elements would be assembled on building site using small cranes. The small size of the precast units would greatly simplify transport logistics, ensure greater accuracy in the masonry wall area and the use of small cranes in combination with the precast units would ensure more efficient and less physically demanding job compared to the conventional method of masonry construction.

## 2. SMALL-FORMAT PRECAST UNITS MECHANICAL PROPERTIES OF MASONRY PART 1: COMPRESSIVE STRENGTH

A masonry wall is an assemblage of masonry units laid in a specified pattern and joined together with mortar. In terms of mechanical properties, it is characterized by good compressive strength, but the shear and bending strength of masonry is considerably lower. In the case of the assumption of masonry made of small-format precast masonry units, two different types of bonds are formed in the masonry. Therefore, it is advisable to verify the mechanical properties of the masonry structure made of these precast units. In the first phase of the research, the compressive strength of the masonry is going to be verified (described in this paper) and then shear and bending tests are going to be carried out to verify the remaining mechanical properties.

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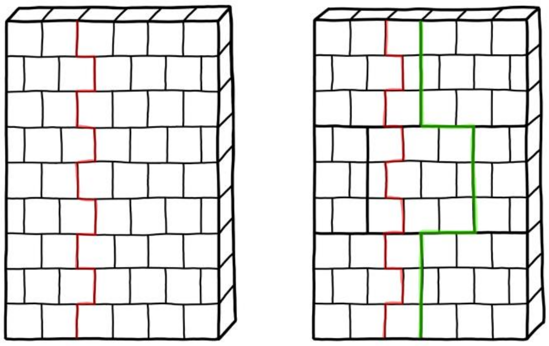

*Figure 6:* Bond(s) of masonry in traditional msaonry wall and in wall of small-format precast units

### 2.1. Test sample

Clay blocks of dimensions 300x249x247 millimeters were used to determine the initial compressive strength of masonry assembled from small-format masonry units. The average strength of the clay blocks used is 12.5 MPa. Cementless system masonry mortar was used to produce precast units (3x3 clay blocks) and also for the construction of test walls made of precast units. The compressive strength class of the mortar used is M1. The expected characteristic compressive strength of the masonry from the tests carried out was around 4,5 MPa. This value of compressive strength (value for traditional masonry) is based on the technical documentation of used clay blocks and mortar. Two samples of dimensions 1500x2250x300 mm were tested in total.

Table 1: *Basic data for compressive strength of masonry*

| Sample | Masonry wall | Precast units | Masonry unit: Clay block | | Bed joint: Cementless system mortar | Head joint: Polyurethane two-component reaction adhesive |
|---|---|---|---|---|---|---|
| | Dimension [mm] | Dimension [mm] | Dimension [mm] | $f_u$ [MPa] | Strength class | |
| A | 1500x2250 | 750x750 | 300x249x247 | 12.5 | M1 | Without mortar |
| B | 1500x2250 | 750x750 | 300x249x247 | 12.5 | M1 | With mortar between precast units |

### 2.2. Arrangement of the test

The samples were loaded at a rate of 2.025 kN/s according to ČSN EN 1052-1 and sensors were installed to monitor the deformation.

- The sensors marked 02 and 03 placed across the two bed joints of the precast units measured the vertical deformations.
- The sensors marked 06 and 07 measured the horizontal deformations at the head joint of the precast units.
- The sensors marked 08 and 09 measured the horizontal deformations at the interface of the two precast units.
- The sensors marked 04 and 05 measured the shear deformations at the head joint at the interface of the two precast units.

Gypsum targets in the panel surface were also made. A scheme of the test to determine the compressive strength of masonry is shown in Figure 7.

The resulting compressive strength of the masonry and the secant modulus of elasticity of the masonry were determined according to following equations (symbols are explained in Table 2 and 3):

$$f_i = \frac{F_{i,max}}{A_i} \quad (1)$$

$$f_k = \min\left[\frac{f}{1.2}; f_{i,min}\right] \quad (2)$$

$$E_i = \frac{F_{i,max}}{3\varepsilon_i A_i} \quad (3)$$


Figure 7: *Test scheme for determining the compressive strength of masonry*

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## 3. RESULTS

From the results obtained (Table 2, Figures 9 and 11) it is clear that the test sample B (the head joints between the precast units filled with polyurethane mortar) performed slightly better in the masonry compressive strength test. The measured deformations (measured up to a load value F = 1214.19 kN due to concerns about damage of the technical equipment) and the calculated values of the relative deformations are negligible in both cases and the failure mode of the sample (Figures 10 and 12) corresponds to the expected failure of the masonry under compression (Figure 8).

Secant modulus of elasticity of masonry was calculated from the measured strain values of sensor 02 and 03. These sensors measured vertical deformations over length of 1000 mm (see Figure 7). For the calculation of the modulus of elasticity, the measured deformations for stresses equal to one third of the compressive strength of the masonry according to ČSN EN 1052-1 were used.

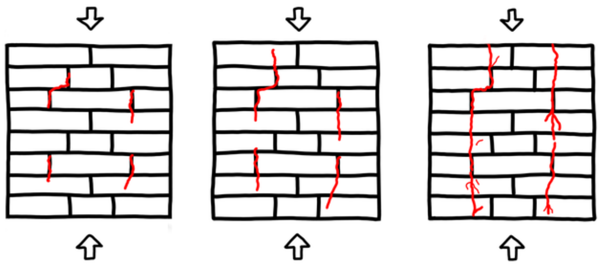

Figure 8*: Typical crack pattern of a compressed masonry wall*

Table 2*: Measurement results – Characteristic compressive strength of masonry (according to ČSN EN 1052-1)*

| Sample | Loaded cross-sectional area | The highest load force value achieved | Compressive strength of the masonry of the sample | Characteristic compressive strength of masonry [(1)] | |
|---|---|---|---|---|---|
| | $A_i$ [mm$^2$] | $F_{i,max}$ [kN] | $f_i$ [MPa] | $f_k = f/1.2$ [MPa] | $f_k = f_{i,min}$ [MPa] |
| A | 450 000 | 2140.56 | 4.76 | **3.97** | 4.76 |
| B | 450 000 | 2324.97 | 5.17 | **4.31** | 5.17 |

[(1)] Number of samples in each measurement = 1 test sample

f Average compressive strength of masonry

$f_{i,min}$ The lowest value of the compressive strength of the masonry of an individual masonry test sample

Table 3: *Measurement results – Secant modulus of elasticity of masonry (according to ČSN EN 1052-1)*

| Sample | Deformation sensor 02 | Deformation sensor 03 | Average deformation | Measured length | Relative deformations | Secant modulus of elasticity |
|---|---|---|---|---|---|---|
| | [mm] | [mm] | [mm] | [mm] | $\varepsilon_i$ [-] | $E_i$ [MPa] |
| A | 0.7837 | 1.0197 | 0.9017 | 1000 | 0.00090 | **1758.52** |
| B | 0.8753 | 0.6695 | 0.7724 | 1000 | 0.00077 | **2229.63** |

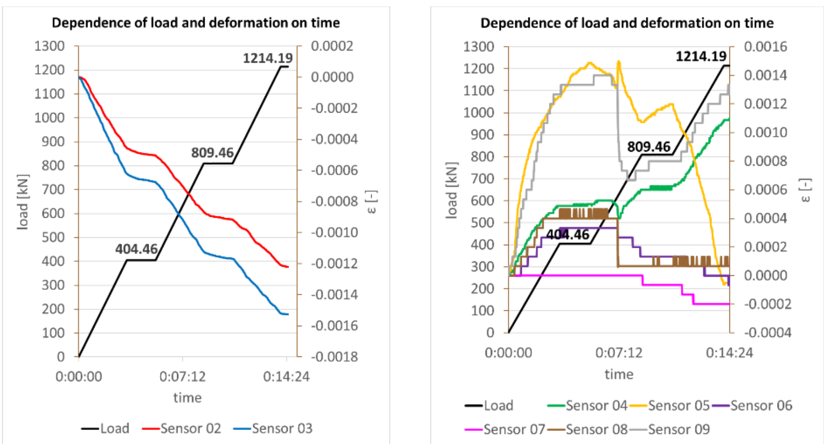


Figure 9: *Sample A – relative deformations*

Figure 10: *Sample A – failure mode*

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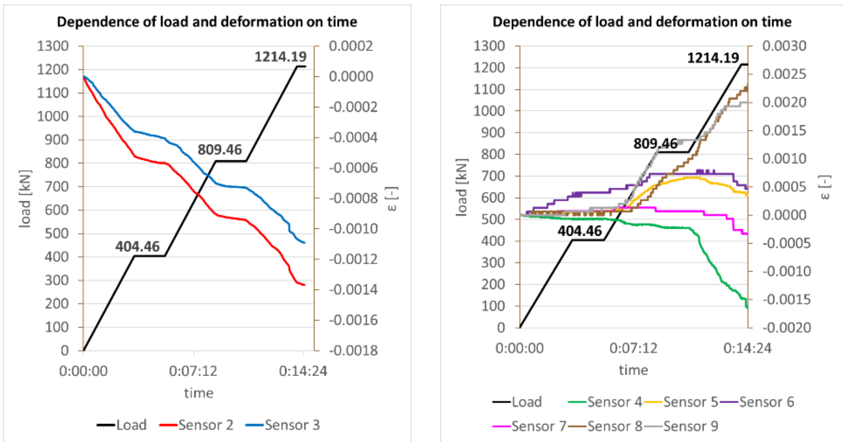


Figure 11: *Sample B – relative deformations*

Figure 12: *Sample B – failure mode*

## 4. DISCUSSION

Masonry is mainly used for the design of compressed structures; therefore, the compressive strength of masonry was investigated in the first phase of the research. The test carried out on the test samples did not show significantly different behavior compared to traditional masonry. In the first phase of loading, the first short tensile cracks appeared, followed by their extension through the individual masonry rows, and finally the formation of continuous crack when the load reached the ultimate limit.

The calculated values of the characteristic compressive strength of the masonry from the tests carried out are in favour of sample B. The calculated value of characteristic masonry strength for sample B is 4.31 MPa, which is approximately 5 % less than the declared value for traditional masonry stated in the technical data sheets. For sample A (without mortar in the head joints between the precast units), the difference is even slightly greater – a difference of approximately 10 % compared to traditional masonry. The resulting values of the characteristic compressive strength of the masonry obtained from performed tests need to be verified in detail on more test samples to obtain objective test results.

The measured deformations for both samples are very small and in the tenths of milimetres. The largest strain values were recorded by sensors 02 and 03, which measured vertical deformations (see Figure 7). The measured horizontal and shear deformations are completely negligible.

The results presented in Table 3 show that the application of mortar between the head joints of the precast masonry units has a relatively significant effect on the value of the modulus of elasticity of the masonry. For samples A and B, the final value of the modulus of elasticity of the masonry differs by more than 20 %, where the higher value belongs to sample B ($E_B$ = 2229.63 MPa)

However, situations can occur (wind, ground settlement, earthquakes) where masonry is subjected to tensile and shear forces. According to the character of masonry of the small-format precast units, different behavior of the masonry structure so constructed can be expected.

For the sample A, a relatively long head joint (tongue and groove) in masonry surface is formed, which represents a weak part of the masonry structure, particularly under the adverse loading conditions mentioned above. In sample B, the contact joints between the small-format precast units are grouted. With a suitable selected mortar – see (Richterová 2021) – it can be expected to achieve better results from the planned mechanical tests compared to sample A, or even traditionally constructed masonry.

In case of positive results from mechanical tests, small-format prefabrication of masonry using mini-cranes on site would be a good alternative to make construction more efficient and improve the quality of masonry buildings. In addition, the transportation, handling, and installation of small-format precast masonry would be considerably easier and more affordable compared to the construction of buildings made of precast masonry wall panels. Another advantage over wall precast panel is the ability to mechanically bind the precast masonry units in the corner of masonry construction.

## 5. CONCLUSIONS

The idea of constructing masonry buildings from small-format precast masonry units is a great way to achieve quality masonry construction in a faster time with easier logistics of precast masonry to the construction site. Compared to the construction of precast masonry wall panels, there would also be an elimination of additional handling and assembly components, which would be replaced by the mere presence of a mini-crane on construction site. The integrity of the masonry structure would be ensured by traditional bonding between the small-format precast masonry units – as opposed to the continuous joints of precast masonry wall panels.

The calculation relations and values in the standard ČSN EN 1996-1-1 are related to traditional masonry structures, there-

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fore it is necessary to verify the mechanical properties of masonry made of small-format precast units, to make sure that there is no significant change in the behavior of the masonry structure under compressive, shear and bending stresses. The first results obtained in the compressive strength test were positive, but it can be expected that in the case of shear and bending stresses the test results may not agree with the values of a traditionally constructed structure.

The shear and bending test of small-format precast masonry will be preceded by the design of concept of individual tests. Their subsequent aim will be to demonstrate the suitability of the small-format precast masonry concept for the constructions of masonry buildings.


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