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Alternative technology of constructing masonry structures designed for areas with increased seismic activity

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Abstract

The Czech Republic is a country which generally sees low seismic activity; however, this activity needs to be taken into account in ca 50% of the country's area with 10 districts being considered as having seismic activity higher than 0.08 g. In terms of masonry structures, this issue concerns mainly the execution of the head joints of the masonry and its reinforcement (both in the direction of the bed joint and in the perpendicular direction). All these technologies are rather difficult and expensive to implement. The research focuses on assessing the possibilities of constructing dry masonry and binding it with polyurethane foam. This method allows for significantly higher shear strength of the masonry and appears to be an interesting alternative in the area of constructing buildings in seismically active areas. The structure was stiffened by filling hollow masonry units with large cavities with polyurethane foam. The PUR foam was sprayed into the units during construction. The foam thus applied hardens perpendicularly to the bed joint of the masonry and, having expanded throughout the clay units, it functions as a binder and a stiffening component to the masonry as a whole. The initial shear and flexural strength of the masonry segments were determined. The newly developed method of filling the cavities of masonry units with PUR foam was compared with the conventional method of constructing masonry by means of bonding the blocks with mortar or PUR foam in the bed joints (with no cavities filled). The filling of the masonry unit cavities brought a significant increase in the shear and flexural strength of the masonry. This indicates the stiffness of the structure increased as well.

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Keywords: Clay masonry unit; masonry; seismicity; polyurethane foam; shear strength

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1. Introduction

Building design always emphasises the safety of building's users and inhabitants. Buildings are constructed so that they can resist (among others) damage by external factors that could endanger the function of the building as a whole. These factors include mainly weather effects but also random events, such as seismic activity. In areas, where such risks can occur, this factor must be taken into account during building design. If this threat is neglected, a possible earthquake could bring devastating consequences. This risk exists in the Czech Republic as well. There are areas where earthquakes occur [1], mainly in the Bohemian massif [2,3]. This is the reason why there is the effort to include seismic effect in the design of brick masonry composition in order to increase its resistance to mentioned events. This concerns mainly shear strength and sufficient stiffness of the walls as well as the whole structure.

Shear strength, being the main parameter connected with the earthquake resistance of masonry, was observed in masonry walls commonly used in the construction of civil and industrial structures. Increasing the shear strength of masonry concerns mainly the execution of bed and head joints as this provides stiffness to the structure [4,5].

2. Materials and methods

A way of improving the stiffness of a masonry structure is vertical and horizontal stiffening resulting in stiffer walls. These are the prerequisites for increasing the earthquake resistance. During construction with clay masonry units, other, new materials are used next to traditional mortar mixes (e.g. polyurethane foam (PUR), which is finding broad practical use).

The experiment was performed with clay masonry units with large cavities. These were clay masonry units with polished bed faces for precision wall construction. Their dimensions are 248/380/249 mm. These blocks are designed for both load-bearing and non-load-bearing exterior walls with the thickness of 380 mm.

These clay masonry units have large cavities, which offer possibilities for wall stiffening in the vertical direction. The stiffening was performed by means of a new method of filling the large-cavity clay masonry units with PUR foam with the result of binding the clay masonry units across several layers. The first stage involved determining the initial shear strength of the masonry according to EN 1052-3 [6] and in the second stage, the flexural strength test was performed according to EN 1052-2 [7].

The initial shear strength tests were performed on masonry fragments. This was a preliminary test for determining the performance of PUR foam in terms of vertical stiffening. Fig. 1 shows the placement of a specimen in the testing apparatus.

Fig. 1. The test sample for the determination of initial shear strength.

3. Results and discussion

The test specimens were made from three clay masonry units placed one on top of another and bound. The set of specimens was made with no binding in the bed joint; i.e. the polished bed faces of the clay masonry units were placed directly one on the other and the cavities inside the clay masonry units were filled with spray PUR foam. The masonry was constructed by filling two thirds of the height of the first clay masonry unit with the foam. Afterwards, another unit was placed directly onto the first and the cavities were filled to the same height as in the case of the first one. During this procedure, the foam expanded in the bottom unit and spread into the cavities in the top one. The spreading of the foam strengthened the whole masonry segment. The principle of stiffening the masonry lies in filling the clay masonry unit cavities with foam across the bed joint. This method appeared efficient in terms of increasing the earthquake resistance of the masonry.

The values of initial shear strength reached by the specimens after filling the hollow clay masonry units with PUR foam are in Table 1and are compared with commonly used masonry systems; i.e. with cement mortar and masonry PUR foam applied only in the bed joint as an alternative to cement mortar. Masonry with a thin layer of cement mortar and PUR foam in the bed joint is a commonly used masonry system today.

Table 1. Determination of initial shear strength.

Bed joint binder	Determination of initial shear strength (*N/mm²*)
Masonry mortar	0.19
Masonry polyurethane foam in the bed joints	0.12
Polyurethane foam in cavities	0.43

The determination of initial shear strength shows a positive influence of the wall stiffening across the cavities of the clay masonry units by means of spraying PUR foam. The shear strength reached was 0.43 N/mm^2, which is twice the value compared with masonry bound by conventional mortar or masonry PUR foam in the bed joint. This option, where the entire cavities are filled with foam, appeared suitable for increasing the wall stiffness without the need for additional stiffening by means of secondary reinforcement. Based on the tests of initial shear strength, the newly developed method of binding the hollow clay masonry units by filling them with PUR foam was also used in making test masonry fragments for determining the flexural strength of the masonry.

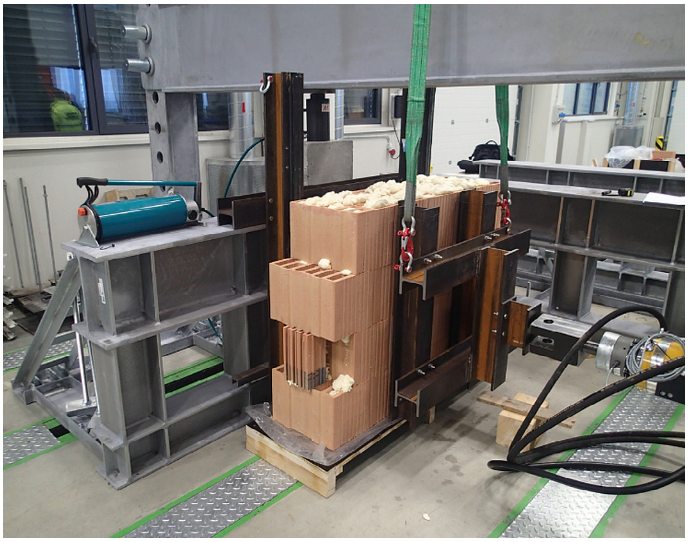

Fig. 2. Test masonry segment during the flexural strength test with the failure plane perpendicular to the bed joints.

This method of wall construction is very simple and efficient. Thanks to the expansion of the foam, the whole masonry fragment was strengthened. The principle of stiffening the masonry lies in spraying the PUR foam into the masonry unit cavities, which forms a firm foam structure in the cavities perpendicular to the bed joint. The test was performed in accordance with EN 1052-2 Methods of test for masonry – Part 2: Determination of flexural strength. The test takes place in two stages. In the first stage, flexural strength is tested with the failure plane perpendicular to the bed joints (Fig. 2) and in the second part, the masonry specimens are loaded by flexural stress with the failure plane parallel to the bed joints (Fig. 3).

Fig. 3. Test masonry segment during the flexural strength test with the failure plane parallel to the bed joints.

The flexural strength tests performed on the walls built from clay masonry units bound by PUR foam were evaluated as stress-strain curves with the failure plane perpendicular as well as parallel to the bed joints. The stress distribution was visually evaluated based on the tests performed and are shown in Fig. 4 and 5, where the stress is σ and the relative strain is ε.

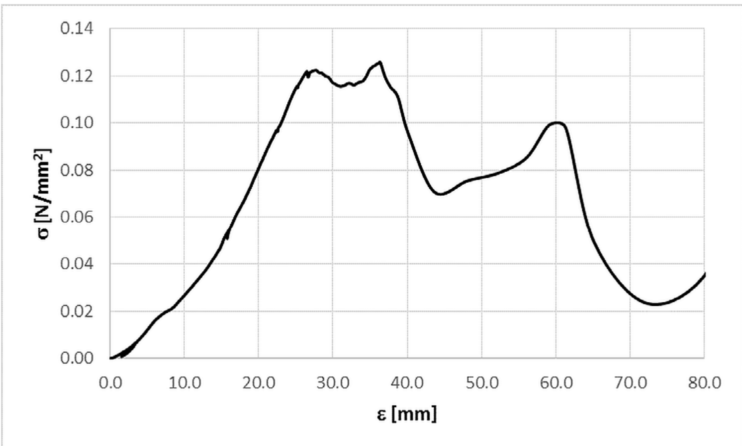

Fig. 4. Stress-strain curve of flexural strength with the failure plane perpendicular to the bed joints.

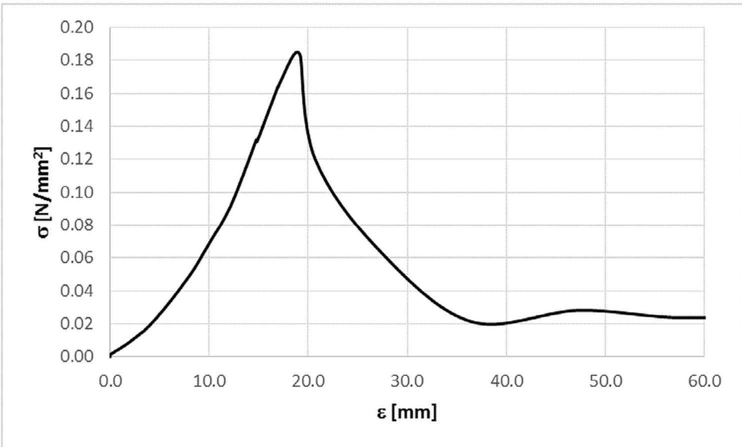

Fig. 5. Stress-strain curve of flexural strength with the failure plane parallel to the bed joints.

The values of flexural strength are listed in Table 2 together with values for the masonry built with traditional mortar or PUR foam in the bed joint.

Table 2. Determination of flexural strength.

Bed joint binder	Determination of flexural strength with the fracture plane perpendicular to the bed joints (*N/mm²*)	Determination of flexural strength with the fracture plane parallel to the bed joints (*N/mm²*)
Masonry mortar	0.09	0.13
Masonry PUR foam	0.09	0.13
PUR foam	0.13	0.18

The tests of the masonry fragments revealed the value of masonry flexural strength with the failure plane perpendicular to the bed joints to be 0.13 N/mm^2 and with the failure plane parallel to the bed joints the value was 0.18 N/mm^2. Compared with the masonry from units where PUR foam or mortar was used in the bed joint, the value of flexural strength with the failure plane perpendicular to the bed joints was 0.09 N/mm^2 and with the failure plane parallel to the bed joints it was 0.13 N/mm^2. In both cases, the measured value was higher. This indicates that the effect of the expansion of the PUR foam throughout the hollow clay masonry units strengthens the whole masonry fragment, which also indicates good behaviour in terms of earthquake resistance.

When the masonry fragment was being filled with the polyurethane foam, all the cavities in a clay masonry unit along the height of the fragment were filled. Another option could be only partly filling the units along the height of the structure; i.e. only in places where critical stress to the masonry occurs, in order to reduce the costs connected with the PUR foam consumption.

The achieved parameters of initial shear and flexural strength are very different for each masonry segment, depending on the shape of the units used and the system of bed joint binding. For this reason, it is only possible to compare those test walls, which are built from the same type of unit (only using a different construction method). Attempts at finding a literary source that deals with the stiffening of walls by filling them with polyurethane foam were also unsuccessful. Filling the units with PUR foam is only possible in the case of masonry with large cavities. Traditional clay masonry units typically have small cavities, which make them unsuited for the use in the experimental technology of being filled and bound using PUR foam.

4. Conclusions

The experiment examined the possibility of filling the entire volume of large-cavity clay masonry units with PUR foam. The initial tests with the masonry units, designed for masonry 380 mm thick, were performed during the experiment. The whole system was tested and basic mechanical properties determined; properties which were important in terms of seismic loading (initial shear strength and flexural strength).

The results of the tests performed on the masonry fragments and their comparison with the values given by the clay masonry unit manufacturer indicate an improvement in their static properties. The tests show a positive influence of filling the hollow masonry units with PUR foam. Polyurethane foam has a positive influence on the static function of the masonry and at the same time, it acts inside it as integrated insulation which suggests a promising combination. The results show that the technology of filling the entire volume of the hollow masonry units with PUR foam increases the initial shear strength by 126% compared with conventional masonry mortar. The flexural strength of the masonry increased by 44% with the fracture plane perpendicular to the bed joints and by 38% with the fracture plane parallel to the bed joints. This newly developed masonry system could be a partial substitute to additional structure stiffening by means of rods or stiffening bands, or it could be combined with these in order to reach an optimum balance in technical and financial terms.

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