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Component Tests of Vitralock Installation System for Hollow Glass Blocks

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The paper is focussed on partition walls assembled from hollow glass blocks. These blocks gained popularity recently because of new development: new decors, wide range of colours, variable surface finishing and wide range of accessories make it attractive for architects. In addition, improvements in acoustic and thermal properties, improved fire resistance and further innovations lead to new applications. The traditional method of assembling is based on using of cement mortar and steel reinforcement leading in kind of reinforcement concrete structure. However, the growing popularity demands new, easier and faster installation methods as is the Vitralock system. It consists of two plastic elements and steel reinforcement. The elements are easily assembled, there is no need for special tools and skills. The performance of the system needs to be verified and reliable design model and application rules need to be prepared. Extensive test programme was carried out at Czech technical University in Prague. It include full-scale test of the wall loaded by horizontal load to evaluate the overall performance. The test is briefly described in the paper. In addition, component tests were performed to obtain properties of several parts of the system. These tests allow to build component finite element model which can be used to predict the response of the wall. Detailed description of these tests and basic information about the model is included here.

Keywords: Hollow glass block, Experiments, Component model, Finite element model

1. Introduction

Hollow glass blocks are used in building industry for more than a century. Originally, they were used in industrial buildings but soon new applications followed. They gained popularity in modern architecture of 1920-1930, again in 1960s and are getting increased popularity at present, see Fig. 1. This is caused by introducing new decors, using transparent and colored glass, various surface finish and wide range of accessories. Architect now can use the glass block in various applications in interior and exterior. The hollow glass blocks were always combined with reinforced concrete leading to traditional installation method. Ever growing popularity leads to demand of new, easier and faster installation methods to offer an alternative solution. The performance of these new systems needs to be verified to develop reliable design models and application rules.

Traditional installation of hollow glass blocks is carried out using cement mortar in similar way the walls from ceramic bricks are made. Reinforcing bars should be placed in the joints. This way a kind of reinforced concrete structure is created. The installation can be facilitated by using plastic spacers, however, it still requires experienced workers and precise planning. Hardening of the mortar is necessary which extends the construction time. For these reason, alternative methods are developed which allow installation without mortar or adhesives. Vitralock system by Seves is the optional method as it allows fast assembling procedure without the need for glue, mortar, special tools and skills (www.sevesglassblock.com).

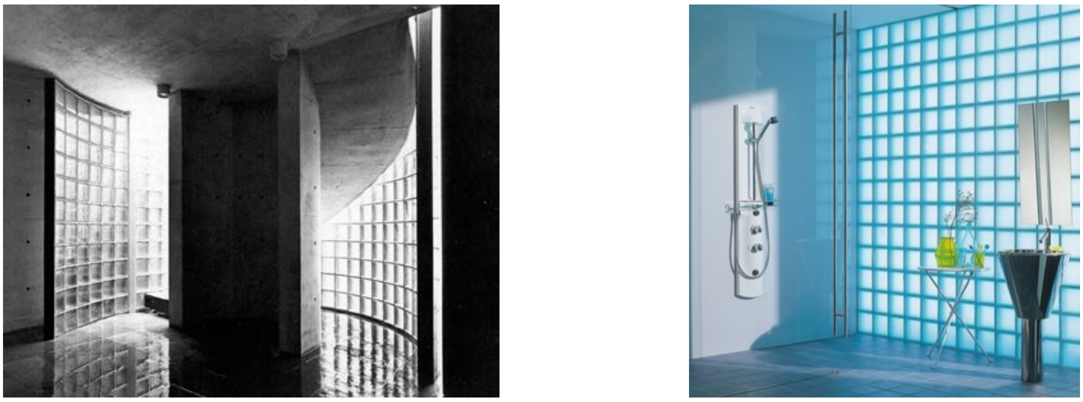


Fig. 1 Using hollow glass blocks in architecture: Osaka's Ishihara House, Tadao Ando, 1977, left, modern bathroom (www.sevesglassblock.com), right.

2. Full-scale test of the wall

2.1. Vitralock Installation System

Vitralock is dry installation system consisting of two plastic pieces, the spacer and the connector, see Fig. 2, which allows the assembling of the walls without mortar or glue. The connectors and spacers are made from plastic (polystyrene). They are assembled without need of special tools, just by click system to form a rectangular grid, see Fig. 3. The glass blocks are placed into openings o the grid. When necessary, the wall can be reinforced by steel bars placed in the spacers. The joints need to be filled by silicone or by grout for ceramic tiles to complete the assembling procedure.

Fig. 2 The elements of the Vitralock system, the spacer (left) and the connector (right).

Fig. 3a) Assembling of the wall, a) assembled spacers ready to accommodate the blocks, b) the first row of the blocks is finished.

The wall is not designed as load bearing structure considering the vertical load, it only resists its own weight. However, it might be loaded by horizontal forces as the wind pressure or horizontal forces induced by humans to barriers and even impact load. This leads to out-of-plane bending when the tension is resisted by the reinforcement and the compression by contact of the blocks and spacers. In case of small size of the wall (i.e. when the blocks are used for window glazing) the reinforcement might be omitted. In this case the tension is resisted by spacers and connectors only.

2.2. Full-Scale Test

Full scale test was performed in the laboratory of Czech Technical University in Prague in September 2016 (Sokol et al., 2017). Detailed information about the test is available (Fíla et al., 2016).

Purpose of the test was to obtain the response of interior partition wall exposed to horizontal load. The wall was assembled in the laboratory using 12 rows, each containing 14 glass blocks. The dimensions of the wall were 2.81 m (width) a 2.42 m (height), see Fig. 4. The wall was fixed to a timber frame made from 50×80 mm sections, each plastic spacer on the perimeter was connected by 4 screws 4×35 mm. Reinforcing bars 5 mm diameter were used on both surfaces, they were placed in horizontal direction on the tension side and in vertical direction on the loaded side. The joints were filled by grout for ceramic tiles.

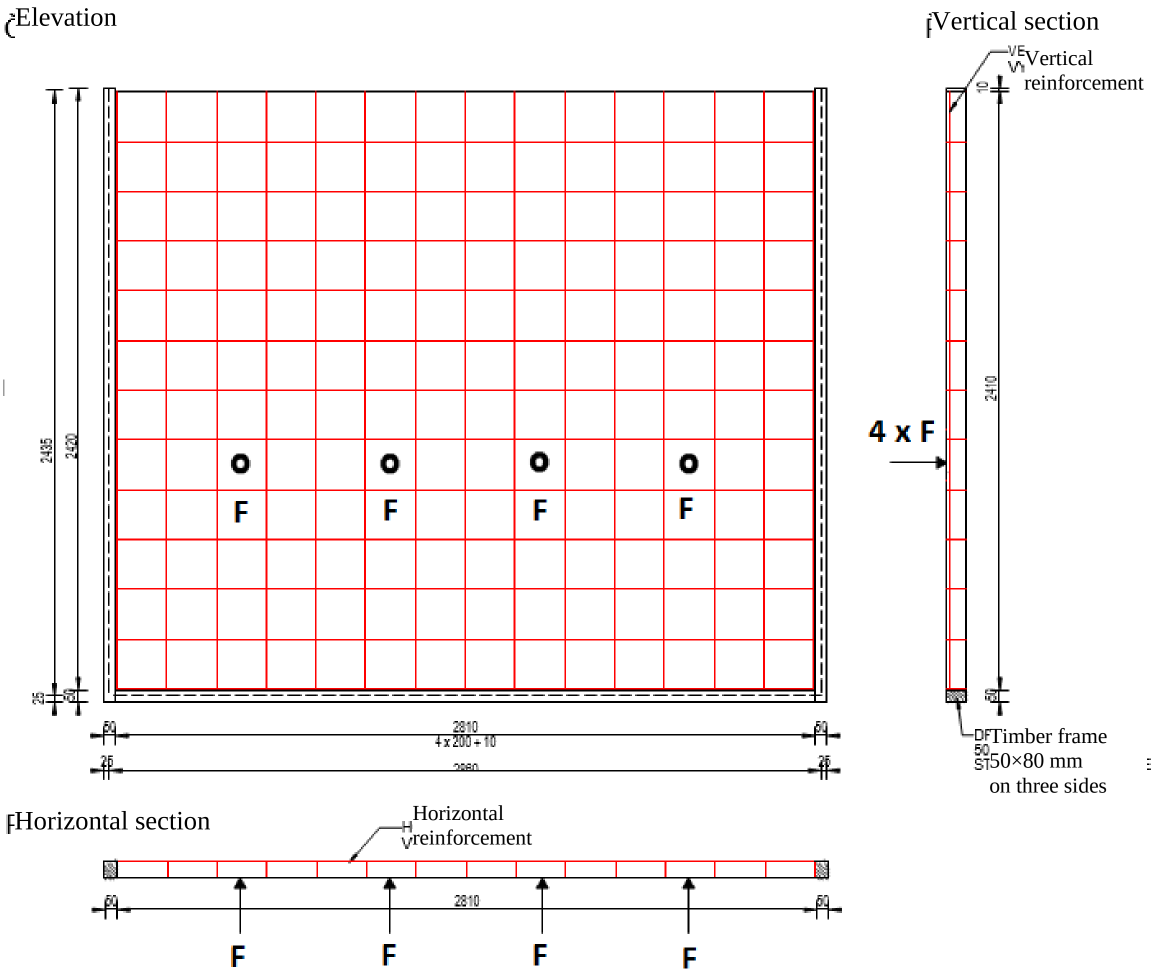


Fig. 4 Dimensions of the wall and load application.

The wall was loaded by horizontal load at height 900 mm above the floor, see Fig. 4 and Fig. 5b). The load was introduced by hydraulic jack and distributed by steel beams to 4 glass blocks. The test was deformation controlled, the load was applied in 22 loading-unloading cycles with increasing force. Horizontal deformations at 10 locations was measured during the test, see Fig. 6.

a) b)

Fig. 5a) The completed wall prior to filling of the joints, b) deformed wall during the test.

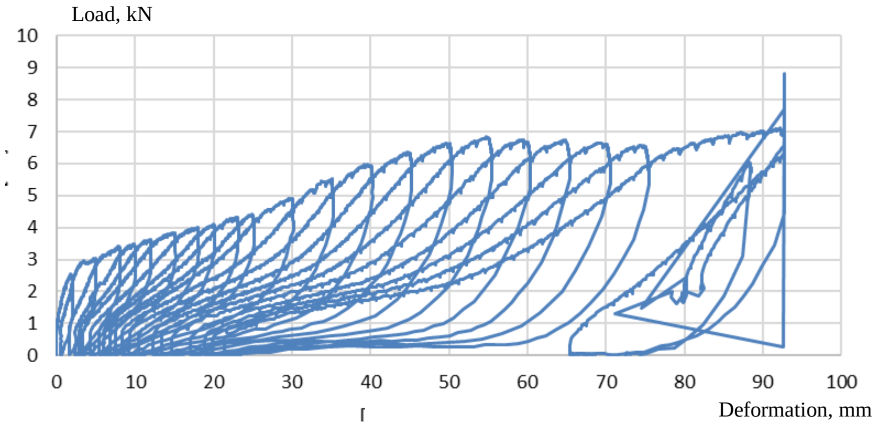


Fig. 6 Load - deformation diagram for the middle of the wall at height 900 mm.

The behaviour of the wall is linear for small deformations but significant non-linear response was found for higher loads. Assuming the limit for horizontal deformation is (according to EN 13116)

$$\delta_{lim} = \frac{L}{200} = \frac{2\,410}{200} = 12.0\ mm \tag{1}$$

and the total load to reach the limiting deformation is 3.58 kN, corresponding to 1.28 kN/m taking into account the width of the wall.

First crack in the grouted joint appeared at the horizontal deformation approx. 10 mm. It grew in the following load cycles. As the load increase, highly non-linear behaviour and significant permanent deformation was measured after unloading of each cycle, see Fig. 6. This is caused by plastic deformation of the connectors and slip of the reinforcement at the anchoring to the timber frame. However, the wall was able to resist the maximum load 8.8 kN (corresponding to 3.14 kN/m) which resulted in horizontal deformation of 93 mm when two hollow blocks were pushed out of the grid. This prevented further loading.

The full-scale test shows that the load to reach the limiting deformation is 1.28 kN/m which is beyond the requirement for barriers in public buildings (the characteristic value for categories B, C and D is 1.0 kN/m according to EN 1991-1-1 and National Annex for Czech Republic). The maximum load exceeds the design value of the horizontal load 2.1 times (the design load of the horizontal load applied to barriers is 1.5 kN/m according to EN 1991-1-1 and National Annex for Czech Republic). The test proved the hollow block wall assembled with Vitralock system is suitable for use in situations when horizontal load to the wall is applied.

3. Component tests

3.1. The component model

Prediction of the behaviour of the hollow block glass wall assembled with the Vitralock system is complicated as there is no analytical model available. In the case final element model would be used, it would be too complicated because of high number of parts (glass blocks, spacers, connectors, reinforcement), complex shapes and presence of contacts which open and close depending on the load.

Prediction of the wall behaviour can be made with component model. The idea of component model was introduced to joint modeling, especially to beam to column joints of steel structures (Wald, Steenhuis, 1993) (Jaspart, 1997), however, it can be easily applied for the hollow block wall. The principle of component modeling is very simple and the process can be described by these steps:

- Identifying the components. The structure should be decomposed to simple parts called components, whose parameters, i.e. strength, stiffness and deformation capacity can be easily obtained.
- Obtaining the force-deformation relationship for each component. The properties are represented as force-deformation relationship. This is usually done by simple calculation procedure based on analytical models. In approach described in this paper, however, the parameters are obtained by experiments (Polata, 2017).
- Assembling the components to obtain the response of the structural element. The assembling procedure is usually based on mechanical model consisting of rigid bodies connected by springs. In the simple case, the springs are linear which allows hand calculation of the properties of the structure. Interaction between the components is neglected and iterative procedure is therefore not required. To get more accurate response,

non-linear behaviour of the components needs to be considered. Hand calculation assembling procedure is not possible in this case but finite element modeling might be used.

Part of the component model is shown on Fig. 7. It shows one surface of the wall only while the other surface is identical. The only difference could be the reinforcement which is arranged either in horizontal or vertical direction.

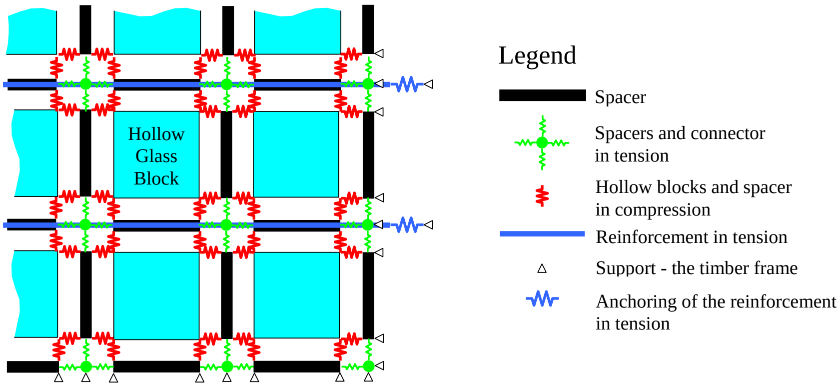


Fig. 7 Component model of lower right corner of the wall (one surface only is shown here).

3.2. The hollow blocks and spacer in compression

The purpose of the test is to obtain properties of the hollow glass block to spacer contact. For this purpose, two blocks and one spacer were stacked in the same way they are assembled in the wall. The load was applied to the upper block with help of thick steel plate to get uniform load distribution. Both blocks were padded by wood to avoid fracture on glass-steel interface. Deformation across the block-spacer-block contact joint was measured by laser extensometer, see Fig. 8.

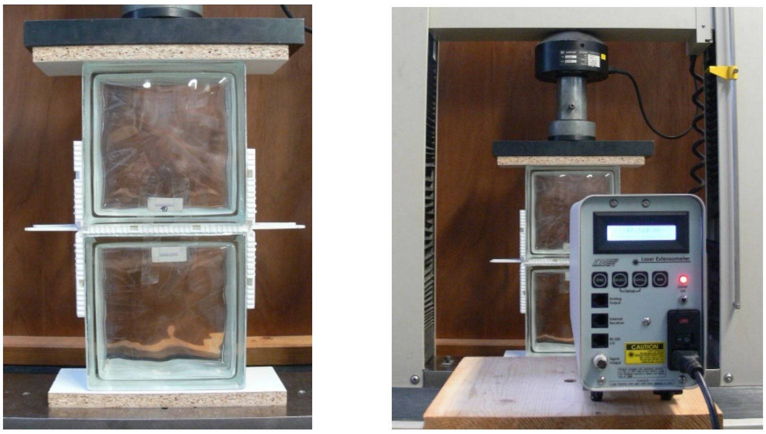
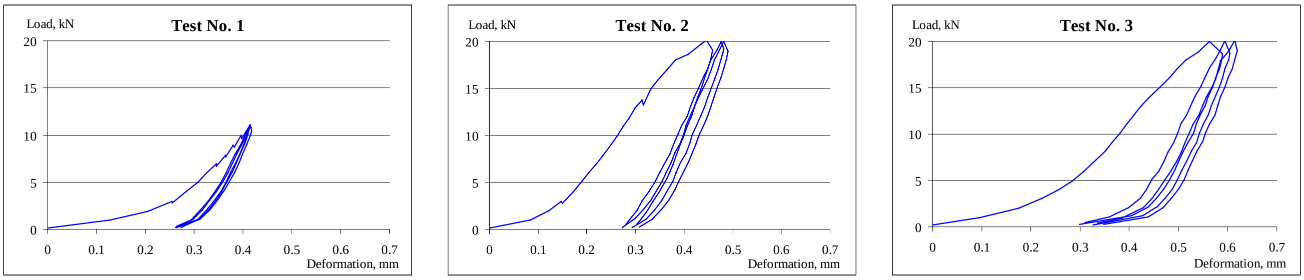


Fig. 8 The component "Hollow blocks and spacer in compression" during the test.

Three identical tests were performed. Each test specimen was loaded by three loading-unloading cycles up to 10 kN (test No. 1) or 20 kN (tests No. 2 and 3). The force-deformation diagrams are shown on Fig. 9. No collapse was reached during the tests therefore one glass block only was loaded to failure. The crushing load of the glass block was 27.43 kN. There was no damage of the spacers caused by the bearing stress even at the crushing load.



a) b) c)

Fig. 9 Experimental load-deformation curves of the component "Hollow block and spacer in compression".

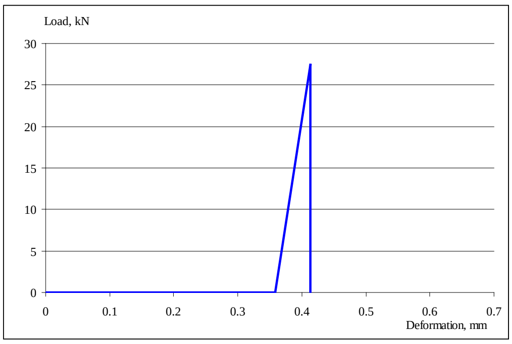


Fig. 10 Simplified force-deformation diagram of component "Hollow block and spacer in compression".

The simplified force-deformation diagram used for the component model is shown on Fig. 10. It exhibits small initial slip and brittle failure at the crushing load.

3.3. The spacers and connector in tension

This test is focused on evaluation of the properties of the connector to spacer "click-system" connection in tension. This component is very important in case the reinforcement is missing or, as an alternative, it is arranged in the other direction. In these situations, the tension is resisted by this component whose performance is critical for the performance of the wall.

The test specimen consisted of two spacers connected by one connector. The specimen was attached to steel elements by two pairs of M10 bolts. The steel elements allow clamping the specimen in the grips of the testing machine and avoid damage of the spacers made from plastic.

The displacement of the spacers was measured by extensometer, see Fig. 11. Results from five tests are available, see Fig. 12.

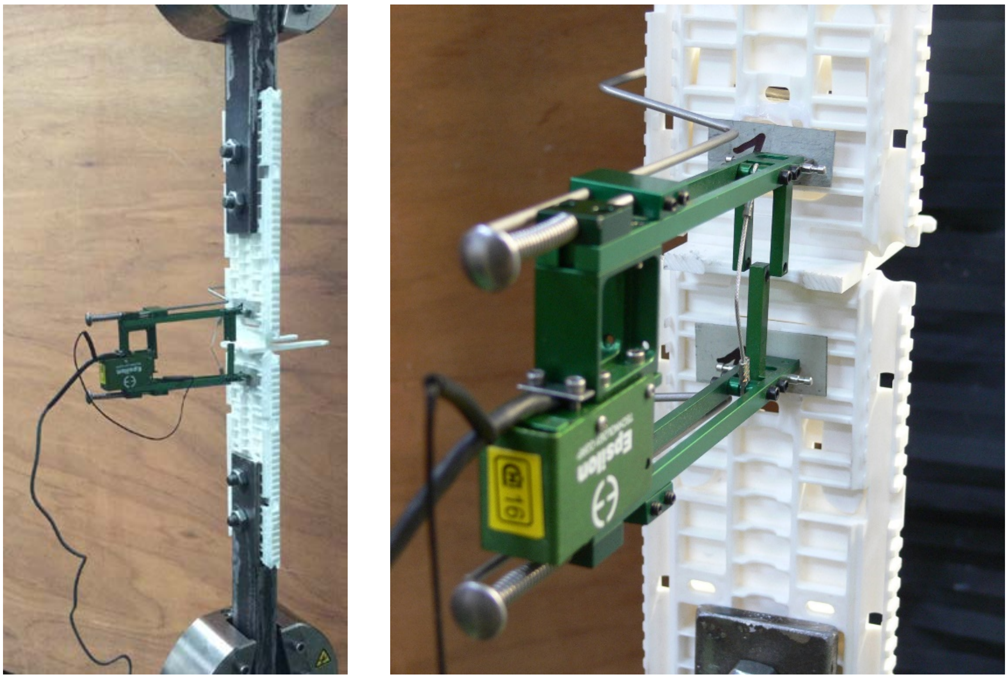


Fig. 11 The component "Spacers and connector in tension" during the test.

The specimen was loaded until failure. The failure was caused by breaking of the connectors in all the cases, see Fig. 12.

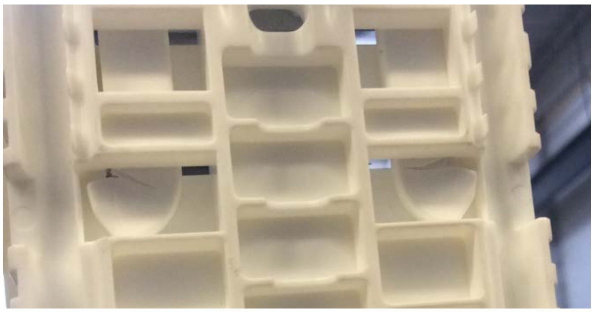


Fig. 12 The collapse mode of the component "Spacers and connector in tension".

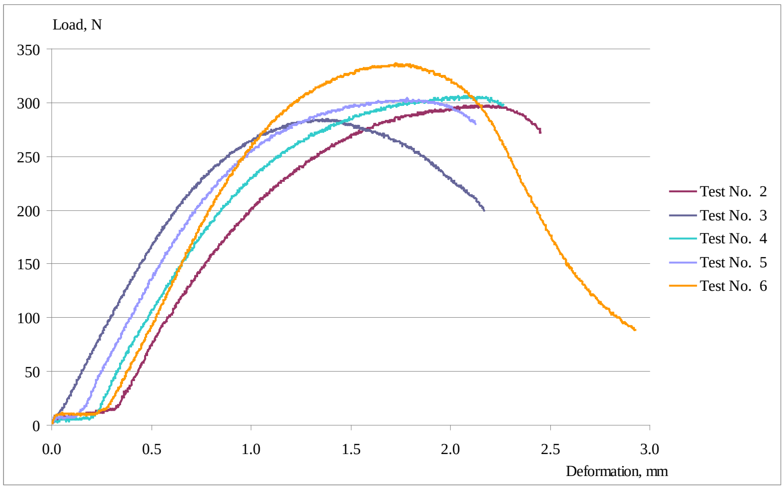


Fig. 13 Experimental force-deformation diagram of component "Spacers and connector in tension".

The initial slip, stiffness and resistance were calculated as average values of the five experimental curves. The simplified curve can be seen on Fig. 14.

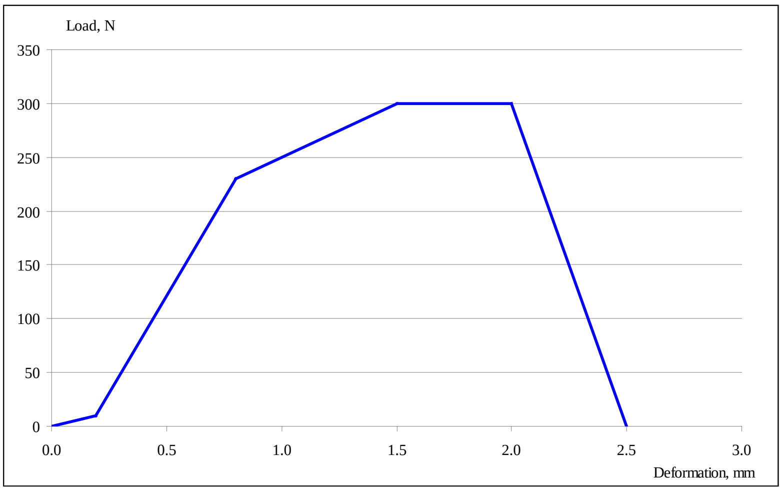


Fig. 14 Simplified force-deformation diagram of component "Spacers and connector in tension".

3.4. The reinforcement in tension

Reinforcement can be placed in the spacers to strengthen the wall. It can be located on both surfaces either in horizontal or vertical direction, but not both. Circular bars of diameter 5 mm are used. To prevent corrosion of the reinforcement, stainless-steel or zinc-coated bars are preferred.

The test described here is made with the specimens taken from the reinforcement used for full-scale test. The stress-strain diagram is shown on Fig. 15. with the conventional yield limit $f_{p,02}$ = 490 MPa and ultimate strength f_u = 540 MPa. The load at yield is approx. 9.6 kN.

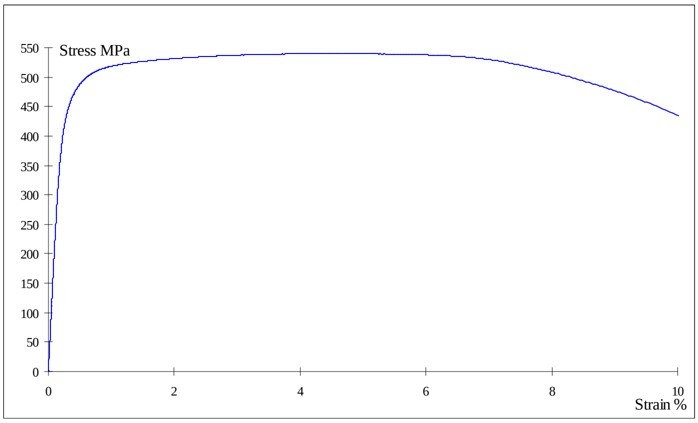


Fig. 15 Stress-strain diagram of component "The reinforcement".

The full-scale experiment proved the reinforcement is loaded below its yield limit because no failure of the reinforcement was observed, however, significant deformation of the reinforcement at the anchoring was found (Sokol et al., 2017).

3.5. Anchoring of the reinforcement in tension

According to assembling instructions, the reinforcement should be bended at 90 degrees at both ends. Precise length of the reinforcement between the L-shaped ends is necessary as it should fit tight inside the timber frame. The bars are clamped to the timber frame by the spacers, each spacer is fixed to the frame by 4 screws 4×35 mm (Fíla et al., 2016).

The component test was designed to get the load - deformation characteristics of the anchoring of the reinforcement. The reinforcement was approx 600 mm in length and was bended to L-shape and fixed to 50×80 mm timber sections with help of the spacers and screws, see Fig. 16. This assembly was completed by two glass blocks and tested. Tension was applied to the end of the reinforcement and displacement of its end relative to the glass blocks was measured by laser extensometer, see Fig. 17 for the test set-up.

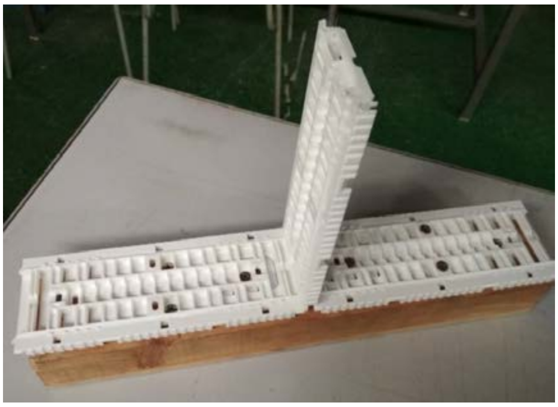


Fig. 16 The spacers are fixed to the timber frame.

The deformation of the reinforcement at the anchoring is caused by deformation of the spacer and its local damage at contact with the reinforcement at high loads. Significant deformation is caused by bending of the reinforcement, see Fig. 18.

The bearing of the L-shaped end in contact with the timber frame also contributes to the deformation, see Fig. 18. The same timber section was used for all six tests therefore local damage of the timber surface accumulated. This is the reason why the initial slip of the experimental curves is small for the first two tests but increase for the later (compare the curves for tests No. 1 and 6 on Fig. 19).

As the maximum load measured during the test is about 4 times smaller than yield load of the reinforcement, no yielding was observed. Collapse of the anchoring of the reinforcement was not observed but the reinforcement would be pulled-out of the anchoring while the L-shaped end was deformed at nearly constant load. Two plastic hinges would be created at the L-shaped end of the reinforcement as shown on Fig. 18. This indicates ductile behaviour of the anchoring.

Fig. 17 The component "Anchoring of the reinforcement in tension" during the test.

Fig. 18 Deformation and damage of the spacers and the reinforcement at anchoring (left), deformed reinforcing bar after the test (right).

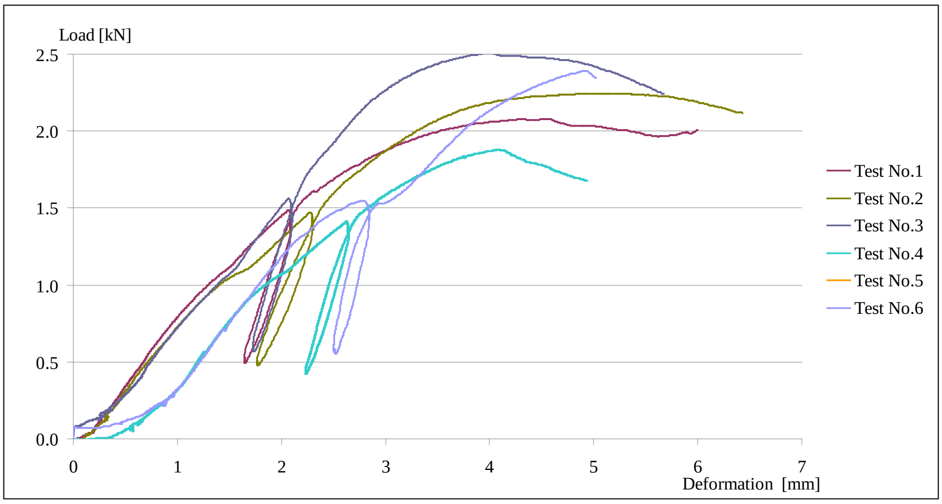


Fig. 19 Experimental force-deformation diagram of component "Anchoring of the reinforcement".

Simplified force-deformation diagram derived from the experiments is shown on Fig. 20. The initial slip used in the curve corresponds to the early tests.

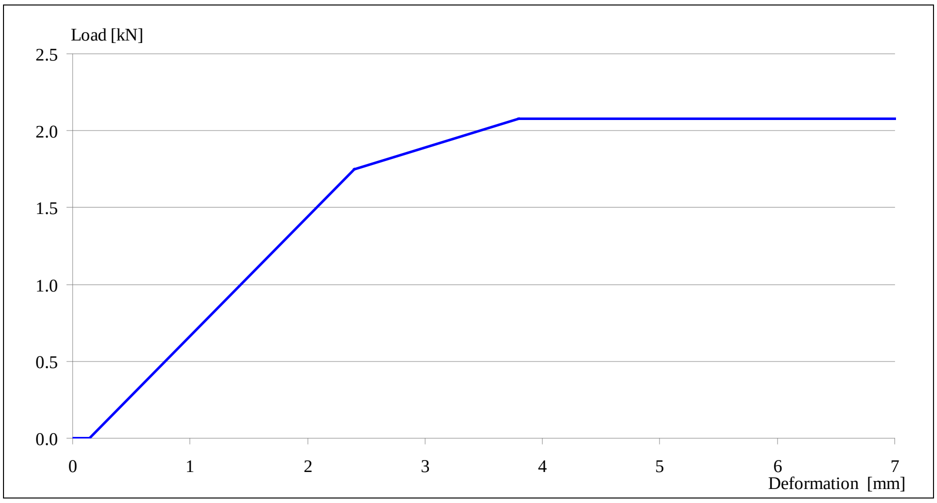


Fig. 20 Simplified force-deformation diagram of component "Anchoring of the reinforcement".

4. The Component Finite Element Model of the Wall

The experimental data described in the previous chapter were used in the component finite element model. The model was created in Ansys 18.2 software.

The model consists of the glass hollow blocks (SOLID 185 element type), spacers (SOLID 185 element type), connectors (COMBIN 39 element type) and reinforcement (LINK 180 element type). The wall was simply supported on the perimeter, no timber frame is included in the model. Anchoring of the reinforcement was introduced by COMBIN 39 element type. Properties of the components were derived from the simplified force-deformation diagrams presented in the previous chapter (Polata, 2017). The model of the full-scale test is shown on Fig. 21.

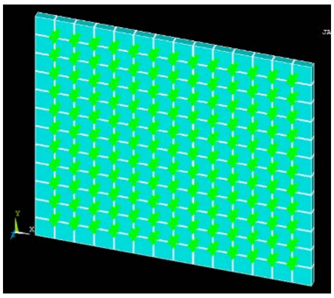


Fig. 21 Finite element component model of the wall, no boundary conditions are shown.

The wall was loaded by four equal horizontal forces located at the height 900 mm (in the middle of the 5th row of the glass blocks). The calculated horizontal deformation was compared to full-scale test, see Fig. 22.

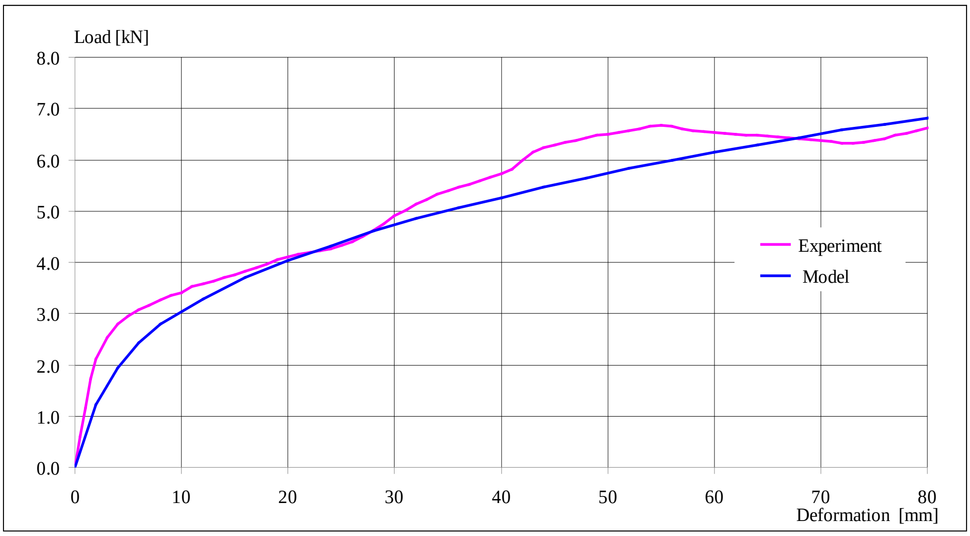


Fig. 22 Horizontal deformation of the wall, comparison of the measured and calculated values.

The model shows good accuracy and will be used in the following research. Creation of parametric study for various size and shape (square or rectangular) of the wall and reinforcement arrangement is planned. This study will be used as a background to prepare simple design model and design procedure for the wall assembled using the Vitralock system. However, further experiments are necessary as the wall without the reinforcement was not tested and the accuracy of the model could not be verified in this case.

5. Conclusion

Tests designed for evaluation of the properties of several components of wall assembled from hollow glass blocks and Vitralock system are described in this paper. The component properties (initial slip, stiffness, resistance, deformation capacity) are the necessary parameters for simple finite element model - the component finite element model. The model was compared to full scale test of the wall loaded by horizontal line load and exhibits good accuracy. Advantages of the model are easy assembling and short calculation time while it shows realistic response. Further development of the model is in progress.

Acknowledgements

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