Stability of Wall Panels with One-Sided Board Sheathing for Timber Structures

J Celler¹, J Dolejš¹, J Pošta² and R Jára²

¹ CTU, Faculty of Civil Engineering, Department of Steel and Timber Structures, Thakurova 7, 166 29 Praha 6 – Dejvice, Czech Republic
² CTU, University Centre for Energy Efficient Buildings, Trinecka 1024, 273 43 Bustehrad, Czech Republic

jiri.celler@fsv.cvut.cz

Abstract. The subject of this paper is a new knowledge in experimental and numerical analysis of the stability of the wall panels with one-side board sheathing. The reinforcement of the panel is provided by means of glued timber composite I-shaped element consisting of a web made of a wood-based desk – OSB board embedded into flanges of solid timber. At present, the design of wall panels with I-shaped cross-section stiffeners and double-sided sheathing is based on test results and simplified analytical calculation. For the design of wall panels with I-shaped cross-section stiffener rib and one-sided board sheathing, a reliable procedure for determining the buckling load bearing capacity has not been described so far. It is assumed that the base of this work can be used for more effective material use of subtle light timber frames. By optimization of the supporting structure, increased heat-technical properties will be effectively achieved. New outputs of experimental analysis on wall panels in real dimensions, as well as material tests of individual components such as solid wood, OSB board and staples will be presented in this paper. Moreover, this paper presents the results of detailed numerical analysis, which are validated on the basis of the experiments performed.

1. Introduction

The stiffener rib is mostly made from elements with classical rectangular cross section in light timber frames. Nowadays the modern woodworking technologies enable to use the elements composed of different materials and several parts – the substance is a glued timber composite element with I-shaped cross section consisting of a web made of a wood-based desk embedded into flanges of solid timber or glued laminated timber. The use of these elements as a reinforcement in wall and ceiling panels have several advantages over classical studs and beams with rectangular cross section: saving material, high load bearing capacity, lower weight for easier handling, easier realization of holes for installations, elimination of thermal bridges in the construction of wall, ceiling and roof and also excellent shape and dimensional stability.

Elements with an I-shaped cross section with different cross-sectional height are presented in Figure 1. The reduction of the thermal bridge at the point of the I-stud is also shown in Figure 1.
2. The aim of the research

Currently, the design of wall panels with an I-shaped cross-section stiffener and one-sided board sheathing is performed on the basis of the results of the experimental tests and the simplified analytical calculation. In the case of wall panels with one-sided board sheathing, the mechanism of the behaviour of these panels and the mode of failure is not fully explored until now. The main aim of this work is to describe the behaviour of the above-mentioned system, to create a reliable numerical model and to elaborate a parametric study using experimental and numerical analysis. The output of the work will be the design model and the tables for design for the one-sided board sheathing systems with an I-shaped cross-section stiffener.

3. Experiments

3.1. Preparation of the experiment

Analytical calculation and numerical model were created for the purpose of the preliminary estimation of the behaviour of the wall panels with an I-shaped cross-section stiffener and one-sided board sheathing before performing experiments. The particular steps which have been performed before the experiment such as: the selection of the parameters of the structure, the process and the chosen methods of calculation for several ways of possible buckling cross-section of the wall panel according to [2] and [3], the results and comparison of these different methods of analytical calculation were presented in [4]. Several possible methods of buckling cross-section of the wall panel or free flange are shown in figure 2. The article [4] also describes a numerical model, creation of a model and analysis results. These results showed important parameters that need to be taken into account when designing the experiment. The numerical model is shown in figure 2.

The choice of the bearing I-stud for the design and assessment of the load-carrying capacity was performed with regards to the current requirements for heat-technical properties of exterior perimeter walls. It was especially crucial to consider the values of the coefficient of heat transfer $U$ [W/m²K] across the walls that corresponds to normative values for low-energy and passive houses.

Since the support I-stud is created in the form of solid element, the system thermal bridges are created in the structure. At present, the interruption of these thermal bridges is most often performed by application an external thermal insulation system. On the basis of calculated values of the thermal transmittance, I-studs with a cross-sectional height of 240 mm and 300 mm were selected.
3.2. Experiments

Static tests on wall panels of real dimensions with a stiffener made of wood-glued composite element with I-shaped cross section and one-sided board sheathing were designed and performed within the experimental part of the work. The test set up, the dimensions of each components and of the whole sample and method of load are shown in figure 3.

Specimens were prepared and the series of tests carried out. The wall panels with the dimensions of 1250 × 3000 mm were tested. I-studs with cross-sectional height of 240 mm (3 samples) and 300 mm (3 samples) were used. I-studs are composed of flanges of solid timber strength class C24 with a cross-section of 58 × 45 mm and a web made of an OSB board 10 mm thick. The sheathing made of an OSB
board 15 mm thick was attached to the I-stud using staples (distance 100 mm, 150 mm or 200 mm). Overall depth of cross-section is 255 mm and 315 mm. The top and bottom frame plates were made of an OSB board 22 mm thick. This specimen was placed to the test area gate and loaded, figure 4.

Before the experiment, the imperfections of the free flange were measured. Direction of deflection of free flange was estimated based on measured imperfections.

The displacements were measured by linear potentiometric sensors. The sensors were installed to the structure. These sensors measured firstly the horizontal displacements of the free flange in the plane of the wall at five points and secondly horizontal displacements of prisms on the edges of sheathing from the plane of the wall at three points.

Loading of the wall panel was controlled by deformation or, in other words, displacement of the loading cylinder at a speed of 2 mm / min. During the experiment, the wall panel was deformed according to the assumptions of the numerical 3D model and the I-studs always deviated in the direction of measured imperfections as expected.

3.3. Experiment results

The sheathing from OSB board was attached to the flange of I-stud by steel staples. The distance of the staples was 100, 150 and 200 mm. Deformation process during wall panel loading was occurring through these steps: the I-stud always began to slightly rotate, the steel staples started to be pulled of the rigid flange, the gap began to appear between the sheathing from OSB board and the attached flange and the free flange began to slightly deviate in the half-height of the I-stud in the plane of the wall panel.

The collapse of construction and decrease of the exerting force were different depending on the distance of the staples. In the case of higher distance of staples, collapse is usually caused by the pulling and stretching of the steel staples and the I-stud deviate in the plane of the wall. In the case of lower distance of staples, the staples kept the rigid flange of I-stud and a collapse of the construction was caused by buckling of the free flange in the plane of the wall panel.

The maximum force at the I-stud with a cross-section height of 300 mm was reached in a range of 330 to 400 seconds and the maximum force at the I-stud with a cross-section height of 240 mm was reached in a range of 410 to 465 seconds.

The force depends on the horizontal displacement of the free flange at half the height of the I-stud is shown in figure 5.
Figure 5. Load-deflection curve.

The shape of the curves is partly dependent on the initial imperfections and also on the distance of fasteners which connect the sheathing OSB to the flange of I-stud. The measured initial imperfections and distances of staples for each samples are shown in the right side in figure 5.

Good concordance between experiment and numerical model has been confirmed after the experiments. Wall panels were collapsed in expected ways. The maximum force detected during the experiment was higher by 40% than expected load-bearing capacity calculated according to preliminary analytical calculation. From the results of the experiments can be concluded that the I-stud with cross-sectional height of 240 mm has a higher load-carrying capacity than the I-stud with cross-sectional height of 300 mm which is more susceptible to loss of stability buckling of free flange.

4. Material tests
The material tests were performed for wood and OSB boards. For wood samples, moisture was measured as well as flexural strength, dynamic modulus of elasticity, static modulus of elasticity. For samples from OSB boards, the static modulus of elasticity and flexural strength were measured.

4.1. Moisture
During the experiments, the wood absolute moisture was measured at several points on the wall panel using the absolute moisture meter, type T510 with head, type TS 070, figure 6. The average value of moisture was 7.4%.

4.2. Modulus of elasticity
The samples were sectioned into smaller specimens 500 mm long with rectangular cross section 58 x 45 mm after the experiment, figure 5. The specimens were measured and their weight was determined. The density was assessed and the average value was 425 kg/m³.
4.2.1. Dynamic modulus of elasticity. The dynamic modulus of elasticity was measured using two devices with two different methods: device Fakopp and Sylvatest, figure 6. Time passage of shock and acoustic waves through the specimen was the result of the measurement. Based on this time, the speed of passage wave through the specimen was determined. Subsequently, the dynamic modulus of elasticity was calculated, figure 6. The average values of modulus of elasticity are: Fakopp device 15817 MPa, Sylvatest device 14135 MPa. Measurements were performed between the foreheads of the specimens.

The comparison of the results for the shock wave method and the ultrasonic method is shown in figure 7. The correlation coefficient "R" between these methods was 0.987.

Similar research was carried out by Pošta [5]. He also measured the correlation coefficient between the dynamic modulus of elasticity measured by Fakopp and Sylvatest. His result was $R = 0.94$. He placed the sensors of both devices on the upper surface of the specimens at an angle of 45°.
By comparing the results of correlation coefficients it can be stated that by measuring with sensors applied to the foreheads of the specimens, the same or higher correlation rates are achieved than with the sensors attached to the upper surface of the samples.

4.2.2. Static modulus of elasticity. The modulus of elasticity was also determined by static destructive tests on the same samples on which the dynamic modulus of elasticity was measured. The four-point bending test was used. Measurements were carried out on the loader machine MTS. The test scheme is shown in figure 8. The average value of the static elastic modulus is 10635 MPa.

![Figure 8. Schema of four-point bending test.](image)

4.2.3. Comparison dynamic and static modulus of elasticity. Correlation between the elastic modulus performed from dynamic tests (device Fakopp: $E_{DYN,F}$ and device Sylvatest: $E_{DYN,S}$) and static tests: $E_{STAT,C}$ was determined to evaluate the accuracy of all used methods. The results show a good correlation between the methods. Correlation coefficients are presented in table 1.

| Correlation coefficient "R" | Dynamic modulus of elasticity | Static modulus of elasticity $E_{STAT,C}$ |
|-----------------------------|------------------------------|------------------------------------------|
| $E_{DYN,F}$                 | 0.90                         | 0.90                                     |
| $E_{DYN,S}$                 |                              |                                         |

The obtained correlation coefficients can be compared with data from similar measurements from other authors: Pošta [5] reached a correlation of 0.80 and for example Dolejš [6] reached a correlation of 0.87.

4.3. Flexural strength
The flexural strength of wood $f_{m}$ was determined from the same static destructive tests as the static modulus of elasticity. The average value of flexural strength was 50.2 MPa.

4.4. OSB board
Similarly, mechanical properties for OSB boards were determined: the average value of the modulus of elasticity in the fiber direction was 8280 MPa and perpendicular to the fibers 2596 MPa. The average value of the flexural strength in the direction of the fibers was 26.5 MPa and perpendicular to the fibers 12.6 MPa.
5. Test of connection
Steel staples of the same type that were used for experiments on wall panels in real dimensions were tested. The material used to assemble the samples (wooden prisms and OSB boards) was cut from the wall panels after the experiments on wall panels in real dimensions was completed. A compression test to determine shear capacity of staples was performed. The samples, placement in the MTS loader and deformed sample are shown in Figure 9.

![Figure 9](image)

**Figure 9.** The samples for test (on the left), placement in the MTS loader (in the middle) deformed sample (on the right).

6. Conclusion
At present, a more detailed numerical model of the wall panel with the I-shaped reinforcement and one-sided board sheathing is being prepared. The numerical model is created in the Ansys program. This numerical model will be validated on the basis of all the above described material tests and the parameters of the individual materials and parts of the model. It is assumed that the conclusions of this work can be used for more effective material use of subtle light timber frames. By optimization of the supporting structure, increased heat-technical properties will be effectively achieved.

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