Saimaa University of Applied Sciences
Technology, Lappeenranta
Double Degree Programme
Civil and Construction Engineering

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STRESS DISTRIBUTION IN MECHANICALLY JOINTED TIMBER I-BEAM

Bachelor’s Thesis 2015

Abstract

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Stress distribution in mechanically jointed timber I-beam, 35 pages
Saimaa University of Applied Sciences, Lappeenranta
Double Degree Programme in Civil and Construction Engineering Technology
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The objective of the research was to study stress distribution in mechanically jointed I-beam section. The behavior of jointed beam with mechanical connectors was determined experimentally and theoretically. Theoretical calculations were made by 3D finite element modeling. This model considered the elasto-plastic behaviour of connectors and the orthotropic elasto-plastic behaviour of timber. Timber plasticity was considered for compression in parallel and perpendicular to grain directions. The experimental calculations included experimental tests of the jointed I-beam bending capacity and handling data received during the research.

The numerical results showed a good agreement with the experimental results. The comparison of the experimental and the numerical results showed the good capability of the analytical model to be used as a design approach for the mechanically jointed I-beam.

During the study the data from the science publications, university guides, data of the websites and experiment data were used.

Keywords: jointed timber section, mechanical connectors, deflection, normal stress, stress distribution, connectors for timber sections.

CONTENTS

1. INTRODUCTION

Timber is the only one building material that comes from a renewable resource. In contrast to other materials, it requires less energy for its manufacture and environmental pollution. In addition, it reduces the energy required to heat and cool the structure due to its insulating properties. Nowadays there are various types of timber elements that have been widely used in different constructions. As modern methods of construction demand new constructive decisions timber jointed elements are rapidly developing.

Composite timber elements represent a special type of structure that differ from the structures of other construction materials. By composite timber element jointed sections such as I-beam, hollow section beam or stressed beam or stressed skin panel are meant. Commonly used materials for the elements are glue laminated timber, laminated veneer lumber, plywood, oriented strand board, etc. The particular feature of the element is that the section is divided in to outer flange parts and intermediate thin web part. The elements are jointed by glue or mechanical connectors such as dowels, connector plates, nails, spikes, etc.

These two types of joints differently affect the process of design and analysis. Due to rigidity of glued connections the elements work as one single unit. This case is well covered by traditional beam bending theory. However, mechanical connectors work as flexible connections. Consequently, the slipping between member parts must be considered. The flanges will carry less of the applied bending moment through axial compression and tension of the flanges and more through individual bending of each flange and web panel. That is followed by decrease of shear stresses over the interface and increase of deflection.(3)

Particular attention in this study is generally paid to the stress distribution in such sections with mechanical connectors. The study is part of the bigger project that was held by Design Institute of Architecture and Construction

University. This project was made as a doctoral dissertation. The aim of the project is derivation of the differential equations that take into consideration partial composite action. To achieve this goal the following tasks were determined:

- development of analytical models for calculation of the flexibility coefficient and shear forces in the section;
- experimental determination of the flexibility coefficient, shear forces in the section, and the strain and stress in the beam;
- analysis and comparison of the results;
- introduction to the methodology for calculating the reduced rate of compliance.

This study concentrates initially on the analysis and comparison of the experimental and theoretical calculations of normal stresses in central section. The comparison will determine is the SCAD model appropriate for the further work on the project or not. The report is followed by experimental tests descriptions carried out on the beam sample and the beam model analysis by the program.

2. COMPOSITE TIMBER ELEMENTS

2.1 Composite timber elements

By composite timber element single elements that are connected to each other is meant. They are usually I-beams, hollow section beams or stressed skin panels. Basic configurations of composite section are presented in Figure 1. The particular feature of the elements is that the section is divided in to outer flange parts and intermediate thin web part.

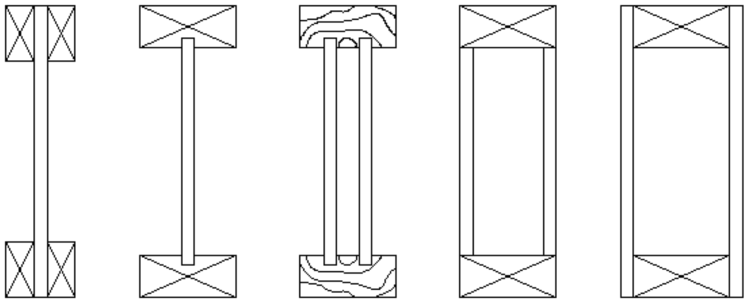


Figure 1. Cross-sectional profiles. I-beam, double I-beam, recessed beam, box beam.

The flanges are often made of sawn timber, glue laminated timber or laminated veneer lumber. Because of small element dimensions only few or very small material defects are acceptable. The flanges are carrying the stresses that are caused by bending moments and axial forces. (5)

The web panels are usually made of OSB, particleboard, plywood or fiberboard (hardboard). These are carrying the stresses caused by shear forces.
Sometimes it is necessary to reinforce web at joints and at the supports. All the reinforcement must be designed to bear shear forces. (5)

2.2 Connection requirements

Connections have to possess the following qualities:

- the sufficient bearing ability at a limited flexibility;
- reliability – ability to carry out the functions under the set conditions;
- durability;
- profitability, such as labour inputs, intensity of use and power consumption;
- local deformations in connections have to be absent or to be minimal.

Possible deformations of connections are presented in Figure 2. Plastic deformations of separate connections allow equalizing work of the connections that are under the same load. If there are no plastic deformations then the fragile destruction occurs.

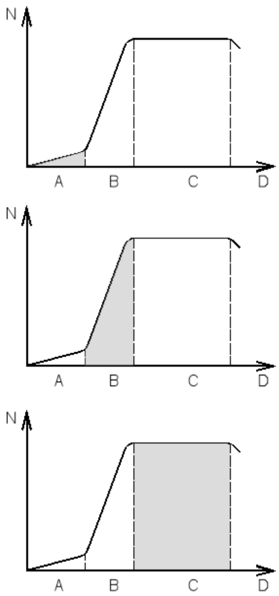


Figure 2. Possible deformations in connections (8)

A-type deformations in Figure 2 occur prior to the full loading. Considerable deformations of this type reduce quality of the connection. B-type deformations are elastic deformations. They are proportional to the load increase. The last type, type C, is a plastic deformation, that increases during the loading. These deformations help to find defects in proper time to repair the structure. (8)

Compressed timber element joints are the most simple and reliable due to efforts that are transferred directly from one element to another. In this case special working connections are not required.

2.3 Types of connection

According to EC 5 there are two methods that are used to assemble the composite elements:

- composite sections formed by using glued joints;
- composite sections formed by using mechanical joints.

Glued composite sections are assembled to serve as a single unit. A negligible slip between elements is typical for this case. Dowels, nails and screws assemble mechanically jointed composite sections. The slip between those section elements, on the contrary, is considered.

2.3.1 Glued connections

Glued connections completely provide rigidity of connection, but there is the shear along the junction. In some cases glue joints have tension perpendicular to the junction. It lowers the durability of the connections, so it should be limited. When jointing timber elements are connected without weakening their cross section. There are various ways to make glued connections. In Figure 3 the most common types of I-shaped joints are shown.

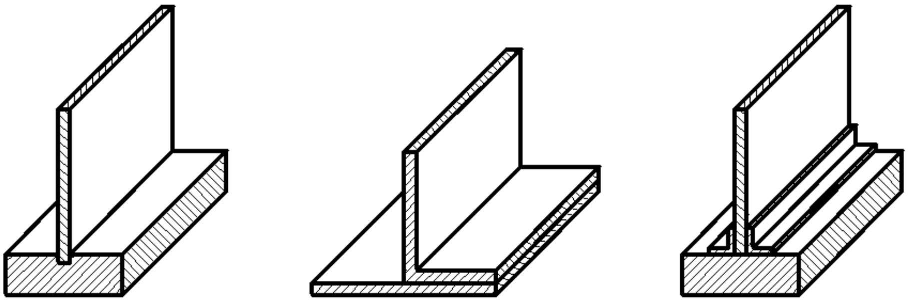


Figure 3. Types of glue connections.

On the one hand glued connections have the following advantages:

- simplicity of receiving one-piece connection and low cost of works on pasting;
- tightness, corrosion resistance and chemical resistance of connection;
- smaller tension concentration;
- smaller weight;
- smaller labor expenses.

But on the other hand there are also some disadvantages, such as :

- low durability;
- unsatisfactory work on an irregular tearing;
- fatigue of connection, reduction of durability;
- low heat resistance.

The basis of glued connection is glue and all the features of connection depend on it. There are five basic types of glues:

- Polyvinyl acetate (PVA) glue;
- Hide glue;
- Epoxy;
- Cyanoacrylate glue;
- Polyurethane glue.

Polyvinyl acetate (PVA) glue is the most common adhesive on the market. It comes in a variety of formulas depending on what types of materials are glued. PVA is a type of aliphatic resin. It is water based and non-toxic, has white or light yellow color. It has good freeze thaw resistance (4 cycles) and strong holding strength on wood. (11)

Hide glue is glue that is formed through hydrolysis of the collagen from skins, bones, tendons, and other tissues, similar to gelatin. It has some significant disadvantages such as thermal limitations, short open time, and vulnerability to microorganisms. But one the other hand hide glue joints are reversible and repairable unlike joints with PVA. (12)

Epoxy adhesives are very strong and highly waterproof, as well as being resistant to chemicals and changes in temperature than other common adhesives. Their strength is degraded at temperatures above 177 °C. They do not require pressure to effect a cure. And also there is no need the parts to be in intimate contact since only minimal shrinkage occurs during cure. (13)

Cyanoacrylates have a low shearing strength, which has led to its use as a temporary adhesive in cases where the piece needs to be sheared off later. It's also used in conjunction with another, slower, but more resilient adhesive as way of rapidly forming a joint, which then holds the pieces in the appropriate configuration until the second adhesive has set. (14)

Polyurethane (PUR and PU) is a polymer composed of organic units joined by urethane links. They have an extraordinary elasticity and elongation before the fracture occurs (up to 600%). Also exist rigid polyurethane adhesives, due to the high fracture resistance presented by these adhesives about 25 MPa. PUR glue is extremely weather-proof, and stable at temperatures from −40 °C to 100 °C. There are 3 different types of polyurethane adhesives or glues: 2 component Polyurethane adhesives (Pur 2C); 1 component Polyurethane adhesives curing by heat (Pur 1C - heat) - Rigid polyurethane; 1 component Polyurethane adhesives curing by moisture (Pur 1C - moisture) - Elastic polyurethane. (15)

The practical value of glues is defined by durability, thermal resistance, chemical and moist resistance and simplicity of technology. The choice of glue is made only after the comprehensive analysis of all these characteristics.

2.3.2 Mechanical connections

All the mechanical connections are constructed using two general fastener types – dowel and bearing. Dowel type fasteners: nails, screws and bolts that are shown in Figure 4 transmit either lateral or withdrawal loads. The latter is transmitted through friction or bearing to the connected materials. Bearing stresses developed between the fastener and the members of the connection transmits lateral loads. (1)

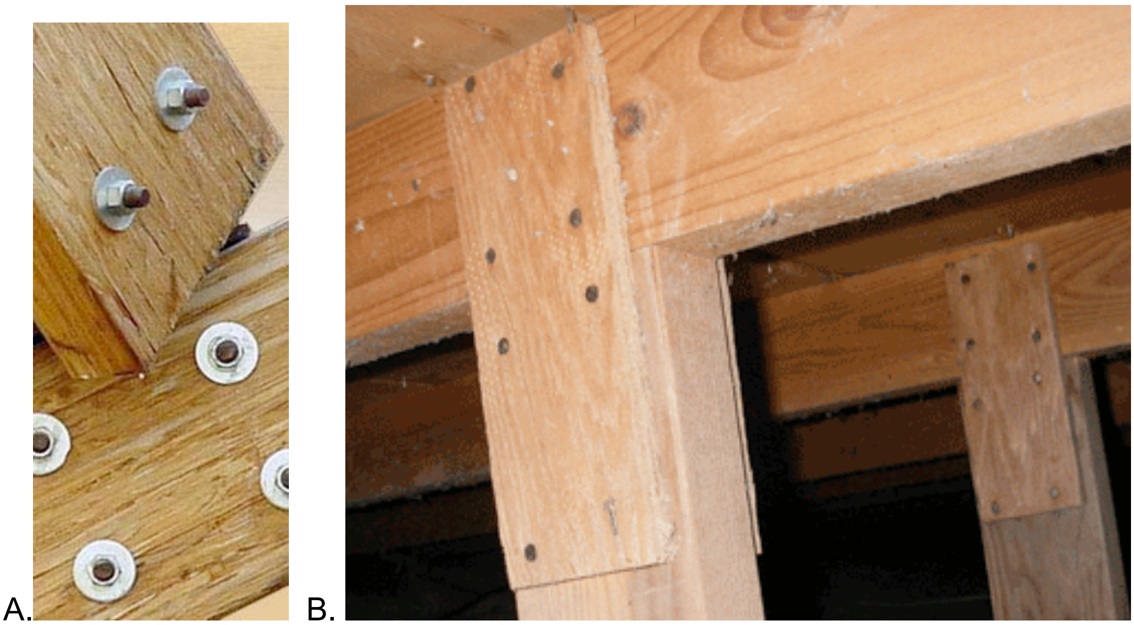


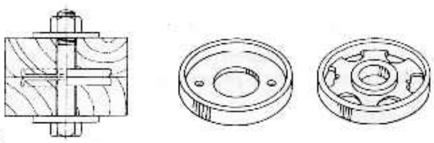
Figure 4. Dowel type fasteners. A-with bolts (16), B- with nails (17)

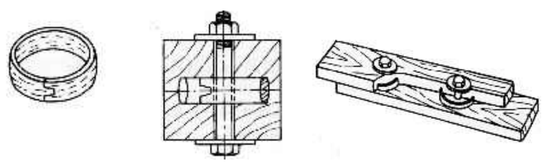
Nails are the most common mechanical fasteners used in constructions. There are many variations in types of nails as well as shapes, treatments, coatings, finishes, sizes, and qualities. They resist either lateral or withdrawal forces or a combination of the two.

Bolts are the most common wood fastener for connections where moderately high lateral strength is required. They are also used in tension connections where forces are applied parallel to the bolt axis. The bolts used for structural connections are standard machine bolts.

Other types of mechanical connectors are drift bolts and drift pins. These are long unthreaded bolts, steel pins, or steel dowels that are driven in prepared holes. Drift bolts have a head on one end while no head is provided on pins. Both are used in lateral connections for large wood members. They are not suitable for withdrawal connections because of their low resistance to withdrawal forces.

Bearing-type connections transmit lateral loads only. Bearing-type fasteners, such as shear plates and split ring connectors, transmit shear forces through bearing on the connected materials. (1) Bearing-type connections are shown in Figure 5.

A. 

B. 

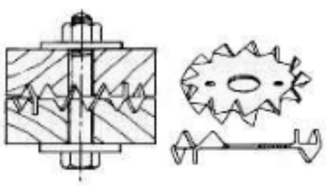
C. 

Figure 5. Bearing-type connections. A - split ring, B - double sided tooth plate connector, C - shear plates. (8)

Metal connector plates (metal plate connectors, steel truss plates, truss plates, or plates) are generally made of light gauge structural quality steel with zinc or zinc-aluminum alloy coatings or stainless steel. They have integral teeth and are manufactured to various lengths, widths, and thicknesses. They are designed to transmit lateral loads.

Timber connectors are steel, malleable iron, ceramic, or fiberglass rings or plates placed between members and partially inserted into each adjacent member held together by a bolt, lag screw, or spike grid. They are used in lateral connections only and provide the highest lateral strength of all fasteners because of the large bearing area provided by the connector.

Selection of a fastener for a specific design application depends on the type of connection and the required strength capacity.

In comparison with other types of connections, the mechanical ones have their advantages and disadvantages. The advantages of such connectors include the following characteristics:

- high reliability of connection;
- convenience of quality control;
- better resistance to percussions and vibration loads:
- better heat resistance;
- when dismantling details do not collapse.

The principal disadvantages are:

- higher value;
- higher material consumption;
- connected elements are weakened by openings;
- high percussions loadings at production;
- impossibility of difficult configuration connection.

Each connection must be designed to transmit forces adequately and provide satisfactory performance for the life of the structure without causing splitting, cracking, or excessive deformation of the wood members.

3. PRIMARY FEATURES OF MECHANICALLY JOINTED ELEMENTS

3.1 Flexibility of connections

The mechanical connectors of composite timber elements are flexible. Flexibility is ability of assembled elements to move relative to each other during the work of loaded construction.

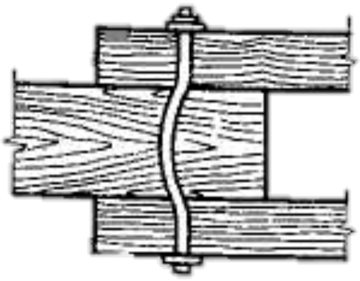


Figure 6. Flexibility of mechanical connector

Flexibility impairs work of component in comparison with the same single element. Also it reduces bearing capacity, increases deformation, modifies a character of stress distribution. That is why flexibility is relevant within composite element construction.

3.2 Partial composite action

All the built-up cross sections are quite common. If the parts are assembled by glue, they work as one single element, so the slip between section parts may not be much of trouble. But if the mechanical connectors are used, the slipping between member parts must be considered. Suppose that there are three composite beams subjected to bending, that are differently assembled: by mechanical connectors, by soft and thick glue layer. In the latter cases there is no composite action and full composite action correspondingly. These cases are covered by traditional beam bending theory. But in the first case partial composite action is taking place. By partial composite action is meant that the shear deformation between separate parts is considerable. According to Eurocode 5 the slip between parts is being considered.

3.3 Mechanically jointed beams according to Eurocode 5

In the case of flexible connections, the analysis procedure requires consideration of the interlayer slip between elements leading to the partial composite action. Based on linear behavior of the materials and shear connection calculations can be carried out according to Eurocode 5.

Calculation of load carrying capacity is based on the following assumptions:

- all the materials remain linear elastic;
- the beams are simply supported with a span l ;
- layers of section have equal deflections and radius of curvature;
- the assumption in bending theory, that plain cross-sections remain plain, holds for each layer;
- the deflections of the model can be counted only within *xz*-plane, so the cross-section must be symmetric about the *z*-axis;
- the spacing between the fasteners is constant;
- load is acting only in the *z*-direction, and external axial loads are negligible.

The Eurocode also determines spacing of the fasteners considering the slip between elements. If the spacing of the fasteners varies in the longitudinal direction, according to the shear force between s_{min} and s_{max} ($\leq 4s_{min}$), an effective spacing s_{ef} may be used as follows:

$$s_{ef} = 0,75s_{min} + 0,25s_{max} \quad (1)$$

Different types of sections are also considered in the Eurocode. In Figure 7 stress distribution for different section types is shown.

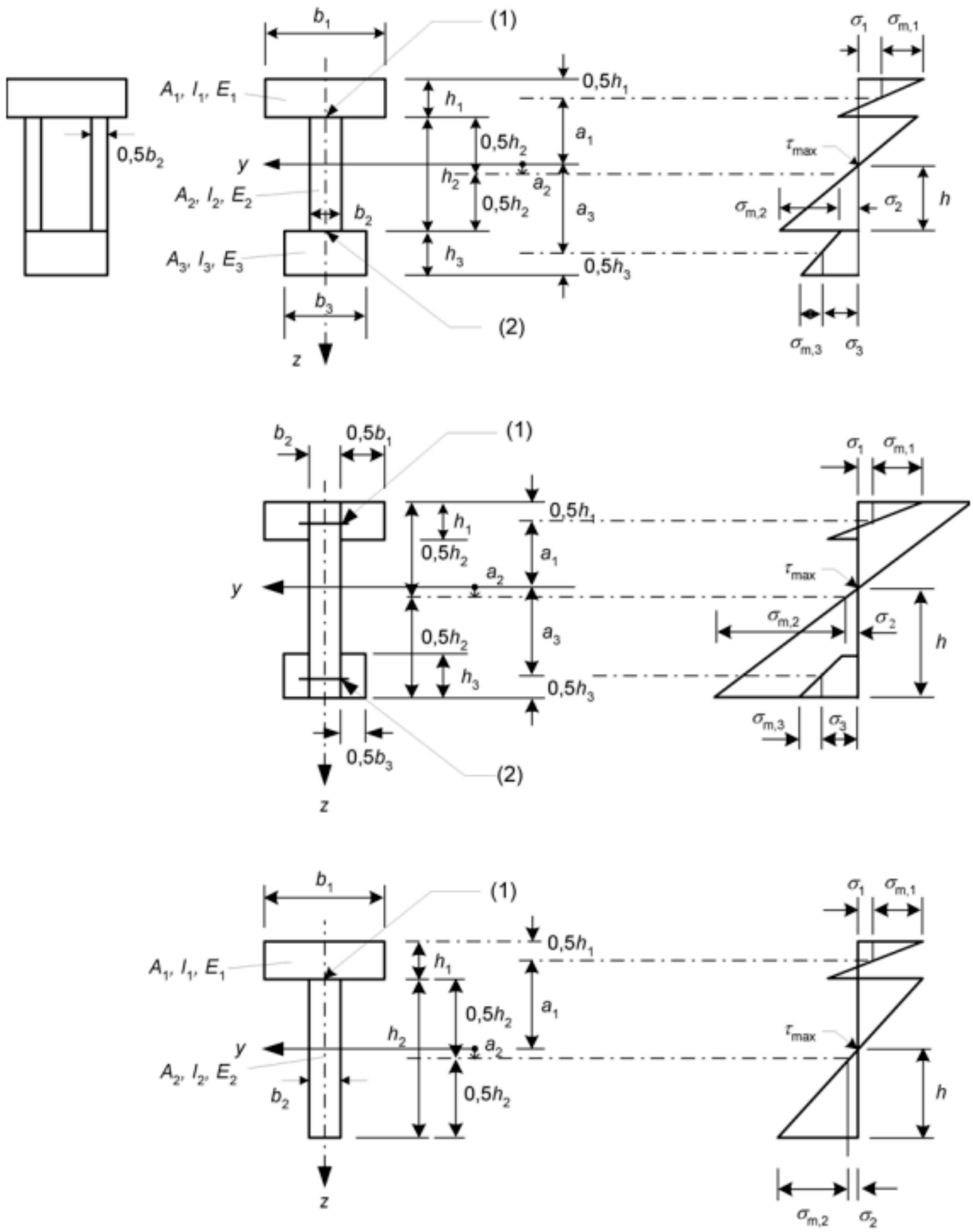


Figure 7. Cross-sections and distribution of bending stresses

The effective bending stiffness should be taken as:

$(EI)_{ef} = \sum_{i=1}^{3}(E_i I_i + \gamma_i E_i A_i a^2)$, where (2)

$A_i = b_i h_i$, - sectional area (3)

$$I_i = \frac{b_i h_i}{12}, \text{ - moment of inertia} \quad (4)$$

$$\gamma_2 = 1, \quad (5)$$

$$\gamma_i = [1 + \pi^2 E_i A_i s_i (K_i l^2)] \quad \text{for } i=1 \text{ and } i=3 \quad (6)$$

$$a_2 = \frac{\gamma_1 E_1 A_1 (h_1 + h_2) - \gamma_3 E_3 A_3 (h_2 + h_3)}{2 \sum_{i=1}^{3} \gamma_i E_i A_i}, \text{ - distance to center of gravity} \quad (7)$$

The normal stresses should be carried out as:

$$\sigma_i = \frac{\gamma_i E_i a_i M}{(EI)_{ef}}, \quad (8)$$

$$\sigma_{m,i} = \frac{0{,}5 E_i h_i M}{(EI)_{ef}}, \quad (9)$$

When the normal stresses are zero, the maximum shear stresses occur. In the web member the maximum shear stress should be taken as

$$\tau_{2,max} = \frac{\gamma_3 E_3 A_3 a_3 + 0{,}5 E_2 b_2 h_2^2}{b_2 (EI)_{ef}} V \quad (10)$$

4. The beam modeling in SCAD program

4.1 Basic information about SCAD program

The analysis of the deflected mode of a composite beam with mechanical connectors was carried out by the program SCAD complex. SCAD is a system, which is based on a finite element method and is intended for calculation of the deflected mode, durability, determination of own frequencies and forms of oscillation, etc. Within modeling it is possible to carry out the element analysis constructed on algorithms, that provides the maximum accuracy.

The program includes the various library of ready elements for modeling of the rod, lamellar, solid and combined structures, modules of the analysis of stability, forming settlement combinations of efforts, checks of a tension of structure elements according to various theories of durability, calculations of loads and displacements caused by loading combinations. The structure of a complex includes programs for sampling a reinforcement in reinforced concrete elements and checks of metal elements sections.

Calculating opportunities:

- high speed of calculation;
- the various library of final elements;
- effective methods of optimization of a matrix of rigidity.

The program is used mostly for selection of reinforcement in sections of elements of reinforced concrete structures for rod and lamellar element, for check of the carrying capacity and selection of steel elements sections.

4.2 Modelling

At first the analytical model of a beam in AutoCAD was created. The beam has 4 m long span and 660 mm high cross section. The scheme for calculations is shown in Figure 8. Hinge mounts were established at 700 mm from the both edges of the beam.

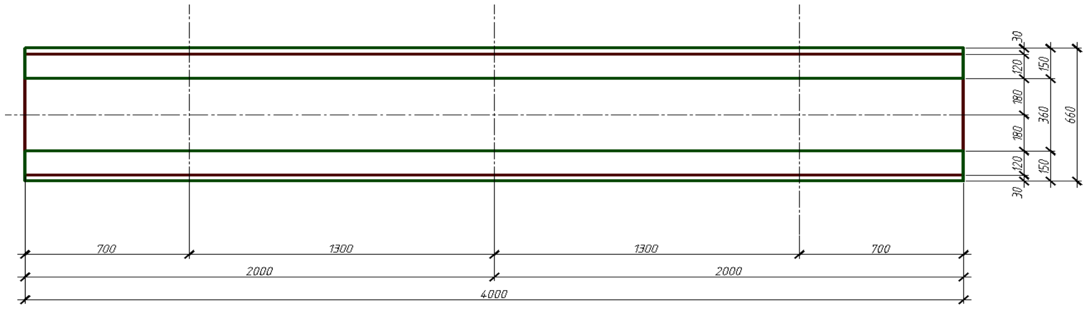


Figure 8. Scheme of the beam

As the further calculations were made by finite element method, the beam was divided into smaller elements in SCAD program that are shown in Figure 9.

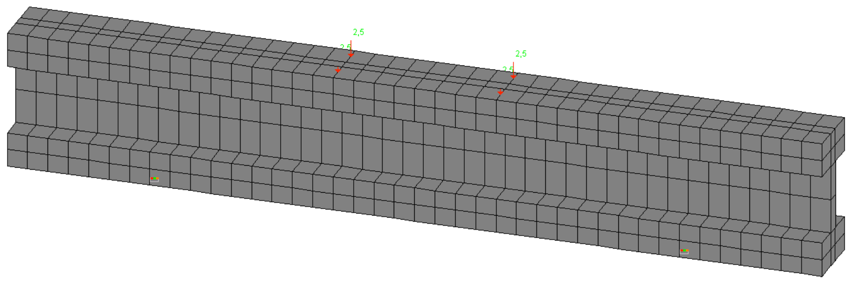


Figure 9. Analytical beam model in SCAD program

The SCAD program is mostly intended for calculations of steel or concrete elements. In order to provide the maximum compliance of the model to timber structure indicators of unit weight, elastic module and Poisson's coefficient were changed correspondingly to timber:

- unit weight, γ – 6 kN/m^3;
- elastic module, E – 10^4 MPa;
- Poisson's coefficient, μ – 0,13.

Mechanical connectors were conventionally replaced by bar elements with elastic orthotropic features. These transfer loads and stresses between section elements. It is shown in Figure 10, the timber element has rigidity number 144 and the connections – 55. Characteristics of the connections are following:

- unit weight, γ – 6,5 kN/m^3;
- elastic module, E – 2.8×10^4 MPa;
- Poisson's coefficient, μ – 0,018.

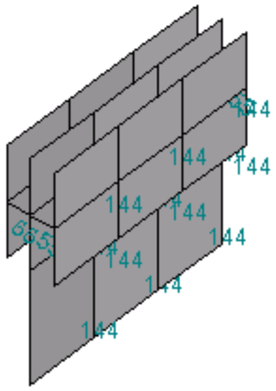


Figure 10. Beam cross-section in SCAD program

The loading was set in two points symmetrically at the center of the beam span, as it is shown in Figure 11. The axes of the supports are shown at 700 mm from edges of the beam. The various values of load were set (365 – 400 N).

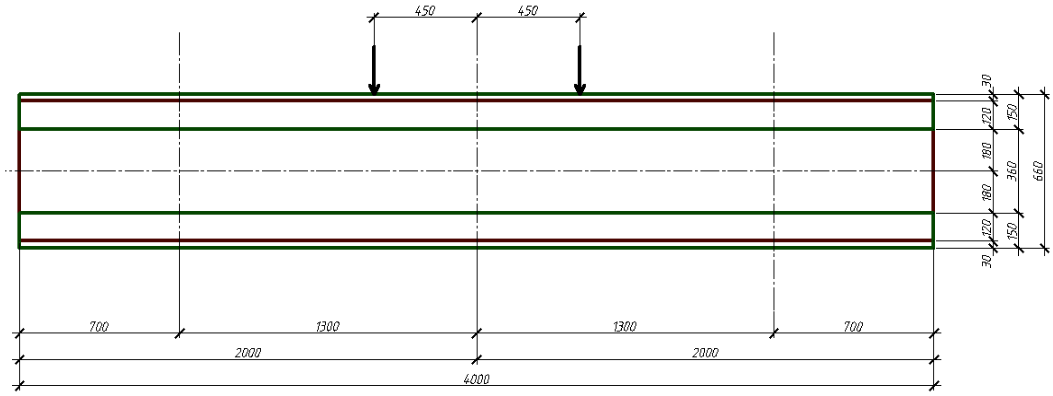


Figure 11. Loading scheme

After all the features of the model were set the calculation was carried out. And the following results were received.

4.3 Results

All the further results are shown at 400 N loading. Bending deformation of the beam is shown in Figure 12. The maximum value of the bending is in the middle of the span.

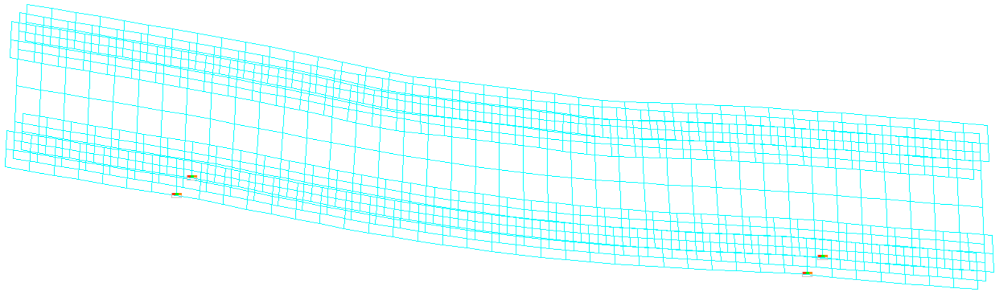


Figure 12. Scheme of deformation

The numerical value of deformation in SCAD is represented as displacement mosaic, which is shown in Figure 13. The maximum deflections are dark blue color and their value is 9,37 -10,41 mm. Zero deflection is light green and it is at the supports of the beam. It is also possible to see a small displacement of the beam edges. The table with the mosaic shows the range of the values for one color (the same for Figures 13 and 15).

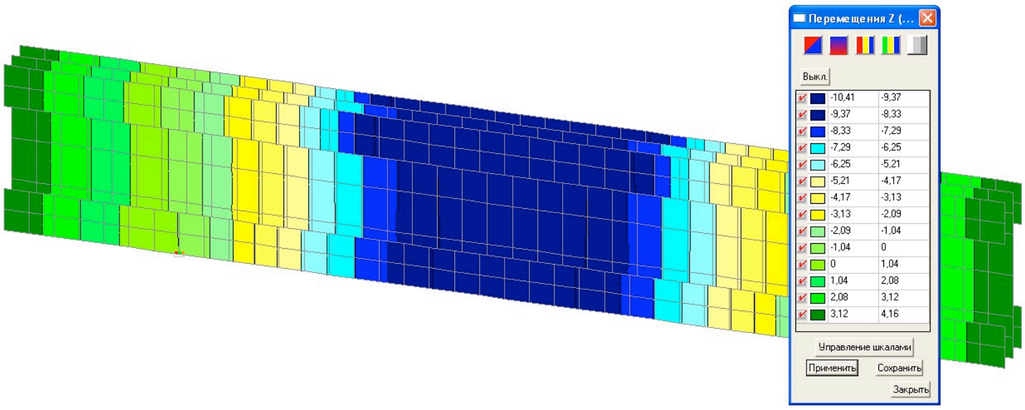


Figure 13. Mosaic of vertical displacement

SCAD also represents mosaic of normal stresses. Figures 14 and 16 show 3D view of the stresses mosaic along x and y axes correspondingly.

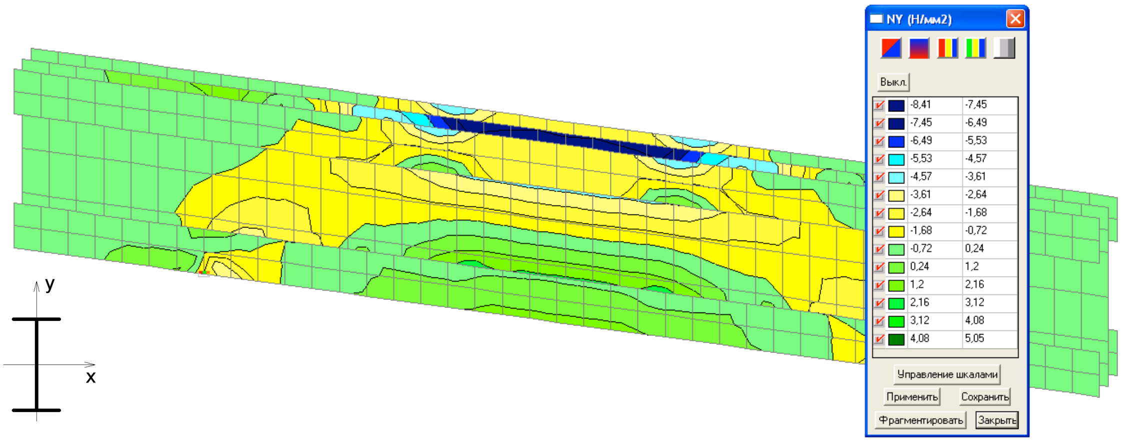


Figure 14. Scheme of normal stresses σ_x

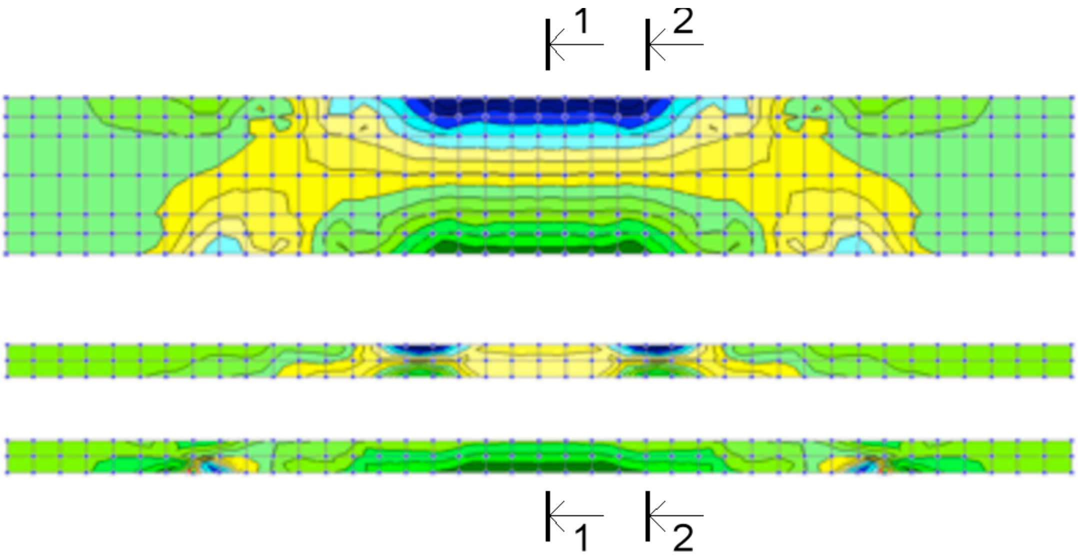


Figure 15. Scheme of normal stresses σ_x in the web and flanges (Sections 1 and 2 are shown in Figure 17)

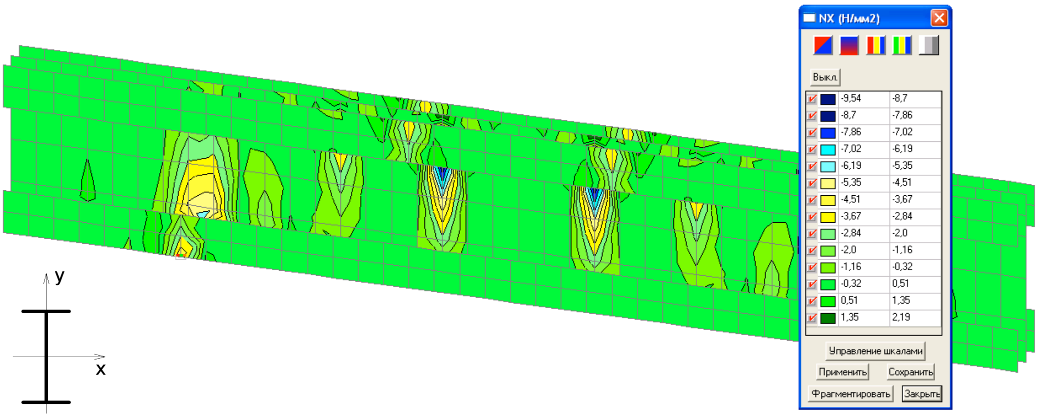


Figure 16. Scheme of normal stresses σ_y

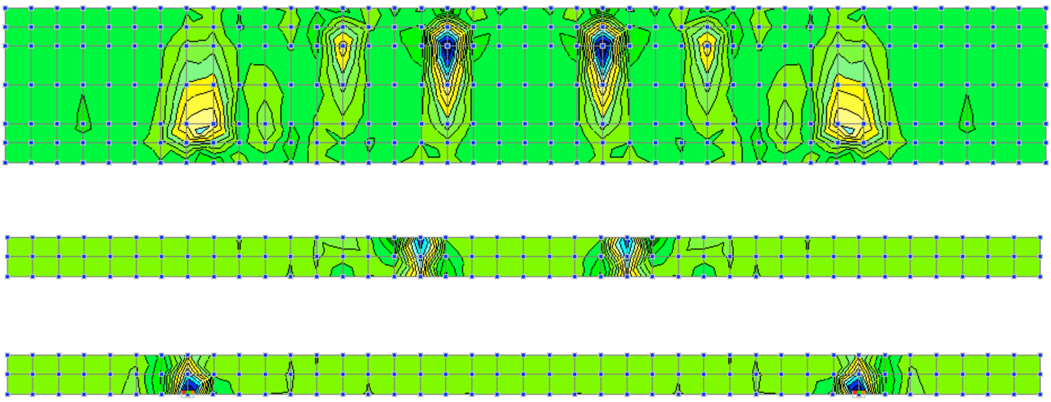


Figure 17. Scheme of normal stresses σ_y in the web and flanges

Figures 15 and 17 shows the separate mosaics of stresses in the web and flanges. The minimum stresses are dark blue and the maximum are dark green.

The values of the stresses are: maximum - 2,16 MPa and 5,05 MPa and the minimum - 6,49 MPa and 7,06 MPa for σ_x and σ_y correspondingly. The values are average due to small scale.

The maximum stresses are in the middle of the span. Figures 14 and 16 show that there are stresses in the web in the area of load impact. That means that from the flanges the stresses are transmitted to the web by connectors.

4.4 Conclusion

SCAD also allows to show a normal stress curve in the chosen section. In Figure 18 stresses in the middle of the span and in the area of load application are presented.

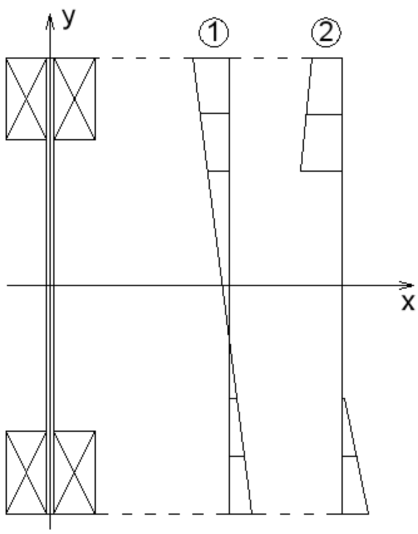


Figure 18. σ_x diagrams in the central section (1) and in the area of load application (2)

It is possible to see stress distribution in the section. In the central section the maximal stresses are located in the upper flanges of the I-beam. The stresses in the web can be explained by the flexibility of connections. Due to the slip of the elements the load is transmitted non-uniformly.

5. Testing procedures

5.1 Manufacturing a test specimen

In a laboratory the beam sample with mechanical joints was fabricated to be 660 mm high and 4000 mm long. It was made of four bearing beams (flanges) and a vertical cross-bar (web). A table-rotor was used to groove the flanges and a circular saw was used to cut the web and flange components into the required sizes.

Figure 19. LVL web and flanges.

As mechanical connectors of the section elements bolts at 30 cm intervals were used. At support the strengthened connection of the web and the flanges was provided by 3 additional bolts at 10 cm intervals. (Figure 20)

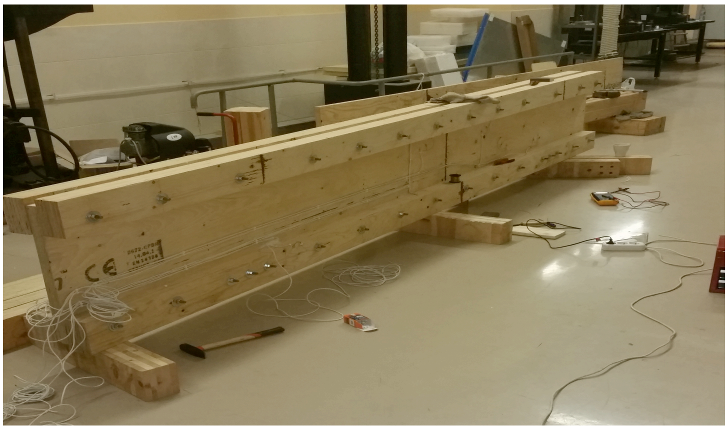


Figure 20. I-beam sample.

Strain gauge transducer

Deformation can be measured by using mechanical, optical, or electrical systems. In this survey a linear displacement sensor, called a strain gauge transducer, was employed for recording the deflection. Strain gauge transducers use a calibrated metal plate or beam that undergoes a small strain in one dimension. This mechanical deflection results in a small change in electrical resistance in the gauge wire. Kent and William (1999) state that electrical resistance of a strain gauge is remarkably stable when properly installed; however, improper installation of the gauge and its leads raises the transducer creep under load.

After the beam was assembled strain gauges were installed on its surface in special grooves. They were attached to the beam by glue. The stresses were measured in three planes, that is why the strain gauges were installed in three directions as it is shown in Figure 3. They were installed on the upper and lower flanges in positions of possible failure: above supports, in the middle of the span and at 30 cm from the supports.(9)

Deflectometers

Defelectometers are intended for the measurement of linear movements (a deflection of construction designs, a settlement of support, bases, etc.) of separate points of the structure, that is loaded by static loadings – a deflection of construction designs (farms, beams, plates) – and also to a settlement of support, the bases and other designs.

Deflectometers were installed by bolts as it is shown in Figures 22. They were installed almost in the same positions as gauges.

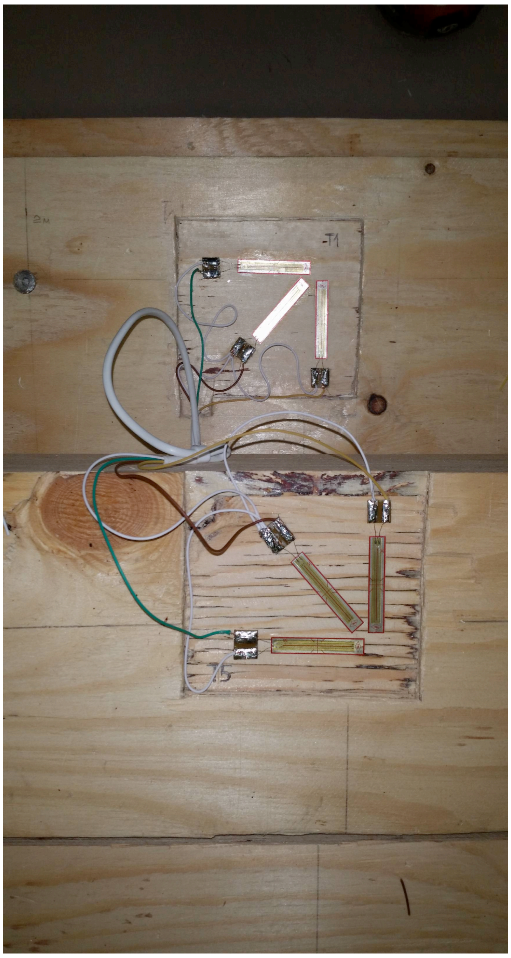


Figure 21. Strain gauges

Figure 22. Deflectometers

5.2 Testing procedures

Load testing

Methods of structural testing are improving rapidly. In metal structures, strains can be measured and associated to stresses, but this method is not applicable to the same extent to timber structures, due to the non-isotropic nature of timber and of timber products making it more difficult to test than more consistent materials such as steel or concrete. Nevertheless, it is possible to carry out meaningful load testing of timber or timber based structures. The purpose of static load testing is to determine the critical relation between loads and displacement. This in turn could define the capacity and safety of given structures. (3)

Structural test

The test apparatus was setup to evaluate the stiffness and strength of the beam. Stiffness is proportional to Young's Modulus of Elasticity, which is proportional to the load/deflection value. The strength of the material controls its suitability for the intended purpose, so the performance of the beam in bending, shear and bearing defines its potential applications.

The beam was simply supported at each end of a 4 m span and loaded at the 2 points of the top flange as shown in Figure 23. Loads and deflections at mid-span were recorded continuously. The loading machine was adjusted to 0.05 mm/s speed and beams were tested to no more than 25% of the maximum loading capacity of the profile, to avoid structural damage to the specimen. The curve of the loading is presented in Figure 25.

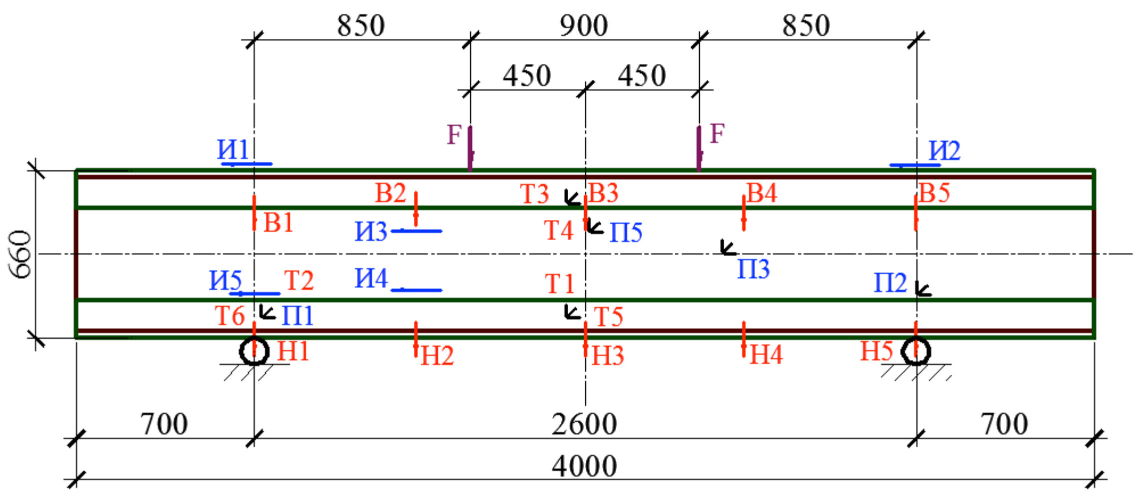


Figure 23. The scheme of test

B1 – B6, H1 – H5, T1-T6 are strain gauges, that are shown on Figure 3, И1 – И5, П1–П5 are deflectometeres, that are shown in Figure 4.

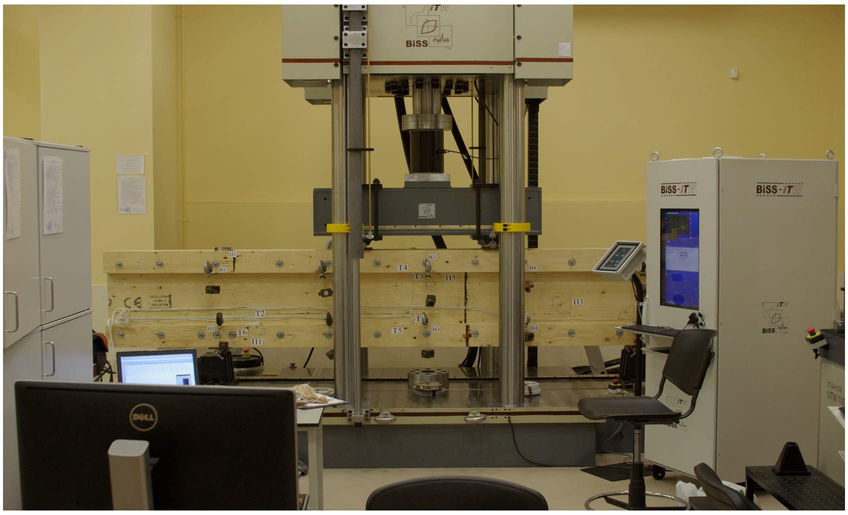


Figure 24.1. Testing LVL I-beam under two point bending.

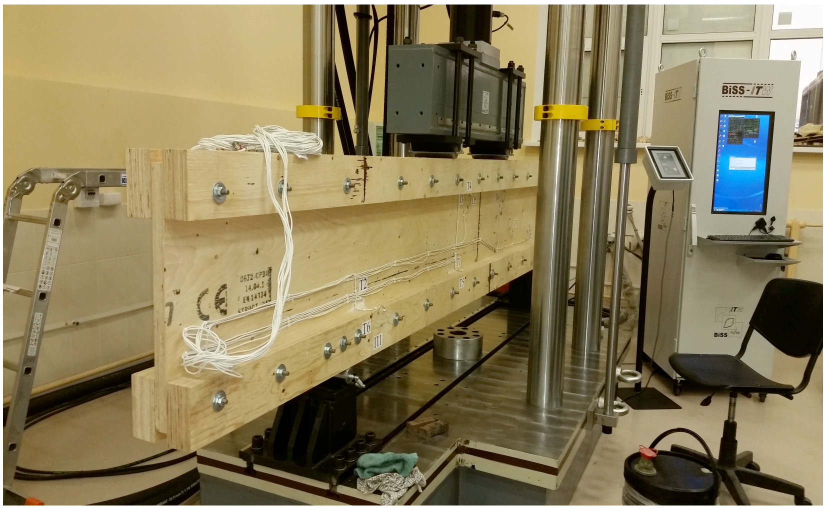


Figure 24.2. Testing LVL I-beam under two point bending.

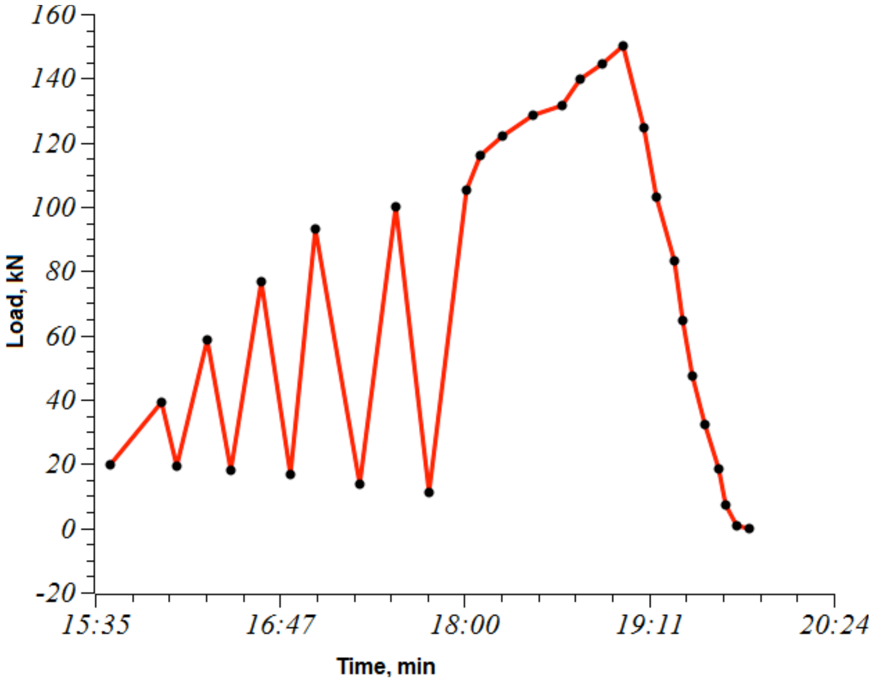


Figure 25. The diagram of the loading

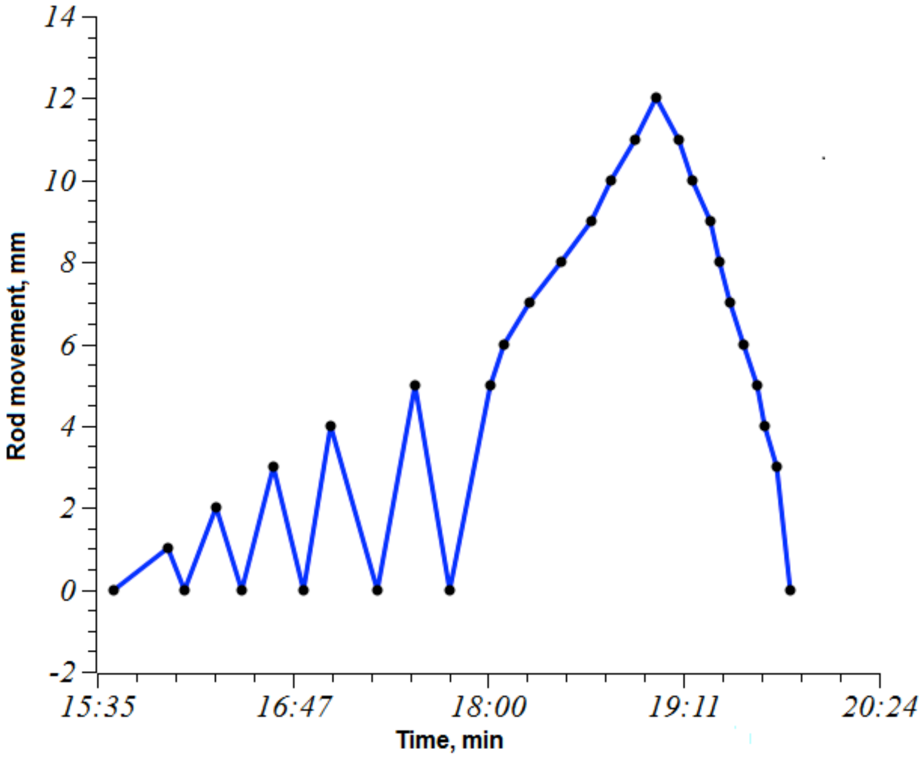


Figure 26. The diagram of the rod movements

In order to prevent untimely cracking of the beam the load was applied stepwise. Firstly, the beam was subjected to the 20 kN load, then it was increased to 40 kN, then decreased to 20 kN and then again increased to 60kN. There were six such steps of loading to 105 kN. The seventh step included the procedure of increasing the load to the maximum and then to unload the specimen. The value of the maximum load was 152 kN and the minimum (before the full unloading) – 17 kN. The maximum load in the experiment was determined so that the specimen would not crack. In Figure 26 the rod movement is shown. At the maximum loading the rod was moved approximately to 12,5 mm. Initial coordinate is the point of initial location of the stock before the loading. The relation of the rod movements and loading is shown in Figure 27.

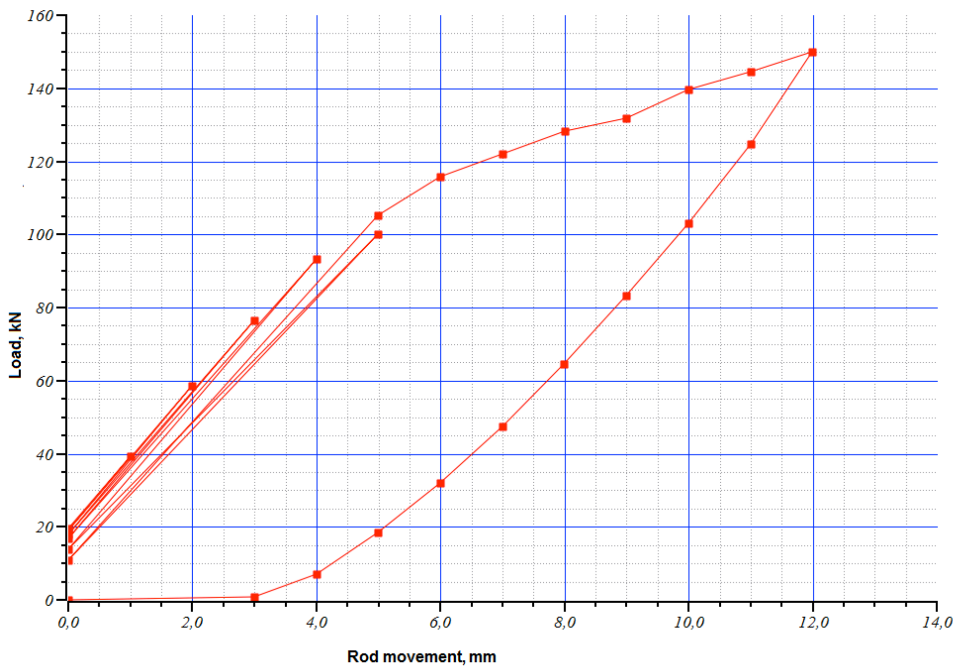


Figure 27. The diagram of the rod movements and loading dependence

The diagram also shows the stepwise loading of the specimen.

5.3 Test results handling

While the test was being made the shear was manually measured and the values of stresses were measured by machine. All the data were brought to the table. The following curves were made according to those values. Figure 28 shows the horizontal shear of grains between the supports and load application.

It is possible to see that the upper and the lower chords of the beam have almost identical shear curves with different values. The lower grains of the beam have bigger shear due to larger deflection of the lower beam chord that is shown in Figure 28.

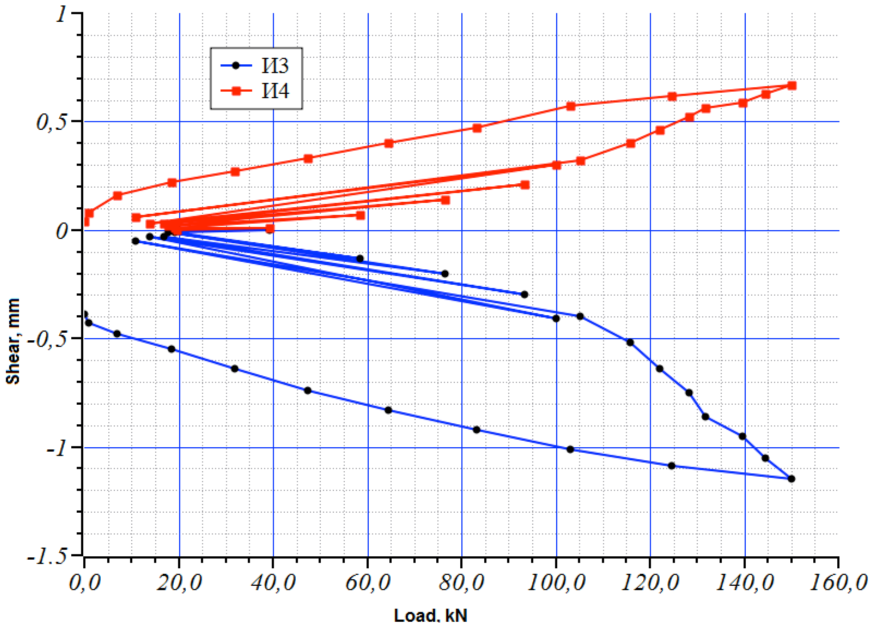


Figure 28. Horizontal shear

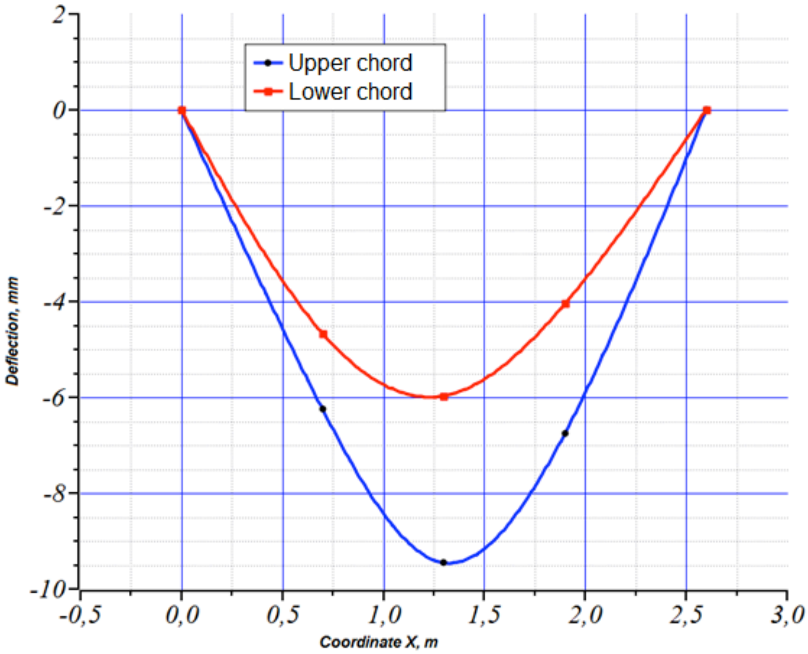


Figure 29. Deflection in the beam

The deflection of the upper chord, where the load is applied, is about 9,5 mm when in the lower chord it is 9 mm. In Figure 29 the difference of the deformation is shown in relation to coordinate X of the beam.

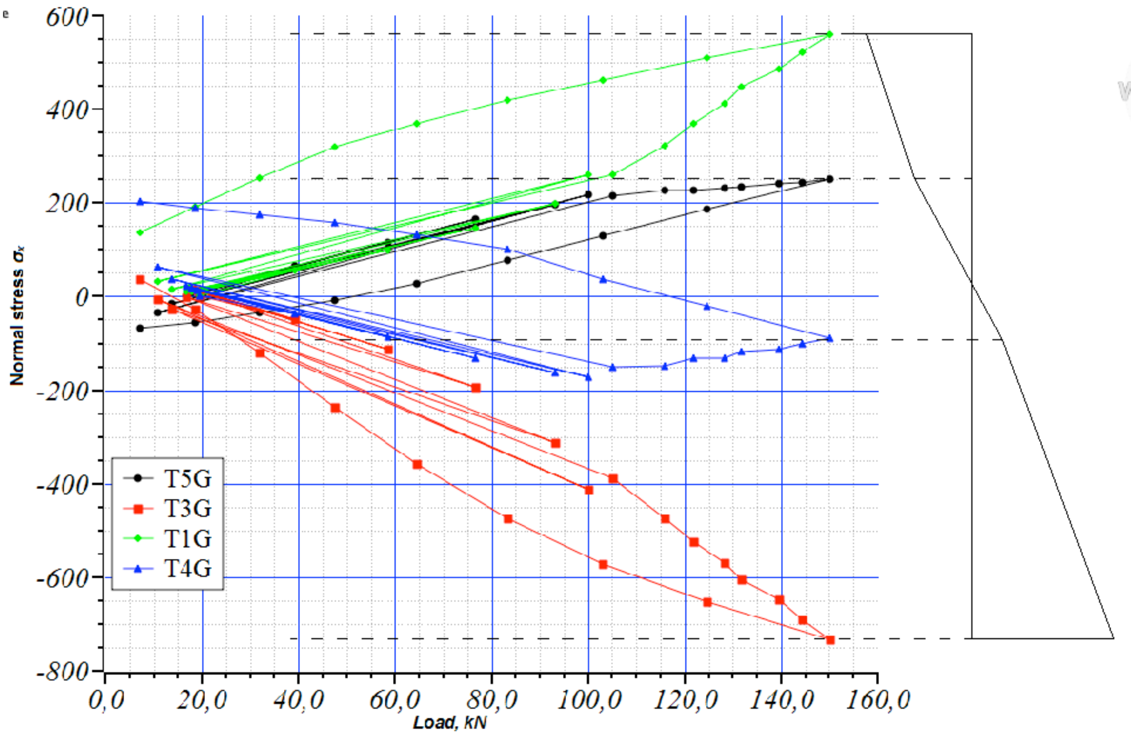


Figure 30. σ_x diagrams in the gauges

In Figure 30 the diagrams of central strain gauges are shown. The location of the gauges is shown in Figure 23. It is possible to see the location of σ_x stresses in different points of the section. For simplicity, values of the points in the chart are presented like in Figure 18. So the character of the stress distribution is the same as for SCAD model.

6. CONCLUSION

In the course of the work was performed 2 types of calculations. The first calculation included modeling of the beam by finite element method using the software system SCAD. Characteristic diagrams of the stress distribution in central section at a given load were obtained. The second calculation consisted

of two stages: the creation of the sample and its loading in the laboratory and analysis of the data received during the test. After the analysis the relations of the elements shear to applied load and stress distribution in the jointed section were determined.
Comparing the two stress diagrams in Figure 31 it can be concluded that the model made by SCAD software is adequate in relation to the results of the pilot studies, as the results convergence is achieved.

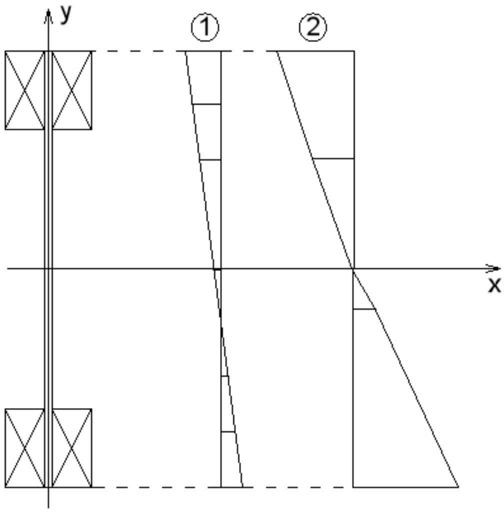


Figure 31. Stress diagrams. 1 - SCAD , 2 – experiment

The difference of the diagrams can be explained by differently applied loads. In program loads were applied in Newton, in experiment – kiloNewton. In program the load was lower because it was not determined the real load for the experiment. The later showed that the specimen can bear bigger loads, but in order to prevent the cracking the maximum load was established at 152 kN.

Also in the stress distribution diagram (Figure 17) it is possible to see a slight redistribution of the stresses. Due to the joints flexibilty normal stresses at load application are distributed irregulary on the beam web. That means that the slip between the elements must be considered in such sections.

All data obtained in the course of this work will be taken into consideration in further work on the project.

REFERENCES

1. Mechanical Connections in Wood Structures. http://www.woodcenter.org/docs/solti97c.pdf pp.3-5 (Accesed on 09.06.2015)

2. SNiP 11-25-80. Derevyannyye konstruktsii [Building code 11-25-80. Wooden structures]. (rus)

3. Roberto Crocetti, Marie Johansson, Helena Johnson, Robert Kliger, Annika Martensson, Bert Norlin, Anna Pousette, Sven Thelanerson, 2011. Composite timber elements. Design of timber structures-2011, pp. 5.1-5.48.

4. EN 1995-1-1:2004 (E) Eurocode 5 Design of timber structures Part 1-1: General – Common rules and rules for buildings 2004-11-01. Pp.26-29, 110-112.

5. Timber I-joists: applications and design: A brochure by TRADA. January 2000 p.42.

6. SP64.13330.2011 Derevyannyye konstruktsii, 2011 (New publication of SNiP 11-25-80)

7. Porteous Jack, Kermani Abdy, 2003. Structural Timber Design to Eurocode 5 https://books.google.ru/books?id=6rZqQKDMfF0C&pg=PT51&lpg=PT51&dq=Timber+I-Joist (Accesed on 04.06.2015)

8. Gappoev M., Guskov I., Ermolenko L., Linkov V., Serova E., Stepanov B, Filimonov E., 2004. «Konstruktsii is dereva i plastmass» (Wooden and plastic structures). Moscow: Moscow.

9. Karl Hoffmann. An Introduction to Stress Analysis and Transducer Design using Strain Gauges. HBM Test and Measurement www.hbm.com (Accessed on 30.05.2015)

10. Fisette P., 2000. The Evolution of Engineered Wood I-Joists. https://bct.eco.umass.edu/publications/by-title/the-evolution-of-engineered-wood-i-joists (Accessed on 23.05.2015)

11. Polyvinyl acetate http://www.woodworkbasics.com/pva.html_ (Accessed on 14.11.2015)

12. Animal glue http://www.shrunjing.com/folder/Animal%20glue100331.pdf (Accessed on 14.11.2015)

13. Bonding guide http://www.gurit.com/files/documents/bonding-guidepdf.pdf (Accessed on 15.11.2015)

14. WEICON http://www.weicon.com/en/download/prospekte/WEICON-Contact-Cyanoacrylate-Adhesives.pdf (Accessed on 15.11.2015)

15. Polyurethane adhesive http://www.adhesiveandglue.com/polyurethane-adhesive.html (Accessed on 15.11.2015)

16. http://alexschreyer.net/projects/dowel/ (Accessed on 26.11.2015)

17. Inspecting wood trusses http://www.ashireporter.org/homeinspection/articles/inspecting-wood-trusses/1213 (Accessed on 26.11.2015)