



Kęstutis GURKŠNYS

**DEVELOPMENT AND TESTING
OF COMPOSITE TIMBER-CONCRETE
BEAMS AND CONNECTORS**

**Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)**

1241

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2001–2005

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The dissertation will be defended at the public meeting of the Council of Scientific Field of Civil Engineering in the Senate Hall of Vilnius Gediminas Technical University at 1 p.m. on 28 February 2006.

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The summary of the doctoral dissertation was distributed on 27 January 2006.

A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, Vilnius, Lithuania)

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Kęstutis GURKŠNYS

**KOMPOZITINIŲ MEDIENOS-BETONO
SIJŲ IR JUNGIŲ KŪRIMAS IR BANDYMAI**

Daktaro disertacijos santrauka
Technologijos mokslai, statybos inžinerija (02T)



Disertacija rengta 2001–2005 metais Vilniaus Gedimino technikos universitete.

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Disertacija ginama Vilniaus Gedimino technikos universiteto Statybos inžinerijos mokslo krypties taryboje:

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Disertacija bus ginama viešame Statybos inžinerijos mokslo krypties tarybos posėdyje 2006 m. vasario 28 d. 13 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

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Disertacijos santrauka išsiuntinėta 2006 m. sausio 27 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, Vilnius, Lietuva)

VG TU leidyklos „Technika“ 1241 mokslo literatūros knyga

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GENERAL CHARACTERISTIC OF THE DISSERTATION

Topicality of the research. Recently more and more buildings of light structures have been built in Lithuania as well as in other European and world countries. Nevertheless, timber products are not widely used for floors in this share of construction market. Traditional light timber frame floors are characterized by vibrations, acoustic transmission and low fire resistance. The above-mentioned problems can be rationally solved by using timber-concrete composite (hereinafter TCC) floors. In comparison with entirely timber floors such type of floors are characterised not only by increased strength and stiffness but also by increased fire resistance and better sound insulation. In comparison with reinforced concrete floors manufactured of non-regenerative sources TCC floors are lighter and more economic. These characteristics stimulate usage of TCC floors in newly built buildings. It should also be noted that usage of timber in building structures instead of concrete or steel could substantially decrease energy demand and emission of carbon dioxide during production.

In this work author presents TCC structural solution when thin-webbed beams (I-joists) used for timber floor beams instead of solid or glued rectangular beams. Thin-webbed beams are without upper flange of structural timber. Embedding in concrete a part of web of oriented strand board (hereinafter OSB) connects the OSB web and the concrete slab.

This concept allows to save structural materials and production costs. Nevertheless, not so many researches in the world were made on the behaviour on such type of composite structures, both the new proposed TCC beams and the groove and tongue connection between concrete and OSB web as the main components of TCC. Therefore both theoretical and experimental investigations were introduced into the programme and they were carried out for analysis of the behaviour of the new proposed type of TCC beams and their joints as well as for development of design methods remains relevant.

Main objective. To apply timber thin-webbed beams for development of new type of timber-concrete composite floor including their interconnection, to analyse their behaviour and to develop the design methods in order to increase the efficiency of TCC floors in their practical application for dwelling housing.

Methodology of research is associated with experimental study and theoretical assessment a behaviour of TCC beams comprised of concrete slab and timber thin-webbed beam and a connector suitable for connection of these beams between concrete and OSB into one structural unit. Short-term tests of beams and connectors of natural size were performed for establishment of their main mechanical properties and statistical parameters necessary for adaptation of the design algorithm based on known gamma and section reduction methods.

Main tasks. In order to achieve the main objective, the following problems have to be solved:

1. Reviewing the types of prevalent TCC floor interlayer connectors and evaluating their peculiarities;
2. Developing the embedded connection (by analysis of different types of concrete dowel connectors) between concrete slab and OSB web;
3. Establishing by tests the mechanical characteristics of different types of concrete dowel connectors due to different OSB thicknesses and distances between connectors;
4. Analysing the peculiarities, design methods and their characteristics of TCC floors;
5. Developing a new structural type of TCC floor;
6. Preparing and performing experimental researches of a new composite beam;
7. After evaluation of the results of theoretical and experimental researches developing the design methods for the new proposed composite beam under uniformly distributed symmetrical load.

Scientific novelty

1. A new type of TCC structure has been developed on the base applied effective thin-webbed timber beams;
2. A new type of an embedded connection between a concrete slab and an OSB web using a “sleeved” steel connector of has been developed;
3. Rational dimensions of the embedded connection between a concrete slab and a OSB web as well as the values of resistance and slip stiffness of the connector have been established by experimental investigations;
4. New results of experimental researches on structural behaviour of TCC beams under symmetric loads have been obtained and analysed;
5. The design method for the developed a new type of timber-concrete composite floor under uniformly distributed symmetrical load have been developed.

Approbation and publications. The main results of this work were submitted in five scientific technical conferences. Nine papers were published on the topic of the dissertation and two of them were published in the magazines from the list approved by the Department of Science and Higher Education (see 21–22 p.).

The scope of the scientific work. The thesis written in Lithuanian consists of general characteristics, list of notations, five main chapters, general conclusions, 70 pictures, 15 tables and list of references and annexes. The total scope of the dissertation is 157 pages.

CONTENT OF THE WORK

1. Timber-Concrete Composite Construction. In this chapter historical review of TCC structures, TCC solutions and their advantages were briefly outlined.

When the span length of the composite floor is up to 6 m, joist elements are made of integral rectangular cross-section timber (Fig 1a). When the span of the timber-concrete composite floor is from 6 to 10 m, joist elements are usually made of glulam timber (Fig 1b). Composite cross-section of I-joists can also be perfectly used for timber floor beams instead of glued rectangular beams. A structural solution connecting composite timber I-joist with concrete slab (Fig 1c) is presented in several scientist works and in I-joist manufacturer's editions. Nevertheless, the structural properties of the top compressive flange of I-joist are not efficiently used in a cross-section of such composition. In this work author presents the structural concept of TCC floor in which I-joists are without the top flange from structural timber. Embedding in concrete a part of web connects the OSB web and the concrete slab (Fig 1d).

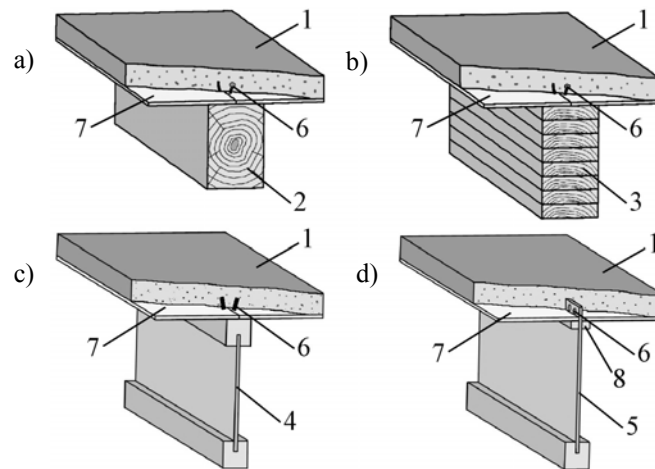


Fig 1. Structural concept of TCC joisted floor

1 – concrete; 2 – solid timber beam; 3 – glulam timber beam; 4 – timber I-joist; 5 – timber I-joist without the top flange; 6 – connectors; 7 – slab formwork (timber boards); 8 – timber planks for slab formwork

2. Calculation Model for Timber-Concrete Composite Beams. In this chapter framework model, finite element model, exact solution of differential equations by J. Natterer and M. Hoefft, gamma method and their advantages and

disadvantages are reviewed. Design method for proposed new TCC beams is given.

The load acting on TCC joist floors cause normal and shear stresses in concrete slab, timber flange and web as well as shear forces in the connections between the web with the concrete slab and timber flanges. The shear forces that are in equilibrium with the internal forces of the components N_i depend on the mechanical index of the interlayer connection – slip stiffness k . Stiffness of connection determines the distribution of stresses in the cross-sections of the separate components of TCC joist floor (Fig 2). Author assumed that the connection of the timber flange and the web of I-joist are absolutely rigid, ie there is no slip between these components. Therefore, the distribution of stresses in cross-section may be analysed as depending only on the stiffness of the web and concrete slab connection.

When no connectors are used in the connection (fully slip joint) between the web and the concrete slab of TCC joist, the components will be only on action of bending moment $M_{i,max}$ (Fig 2a), ie mainly two independent flexural members will operate.

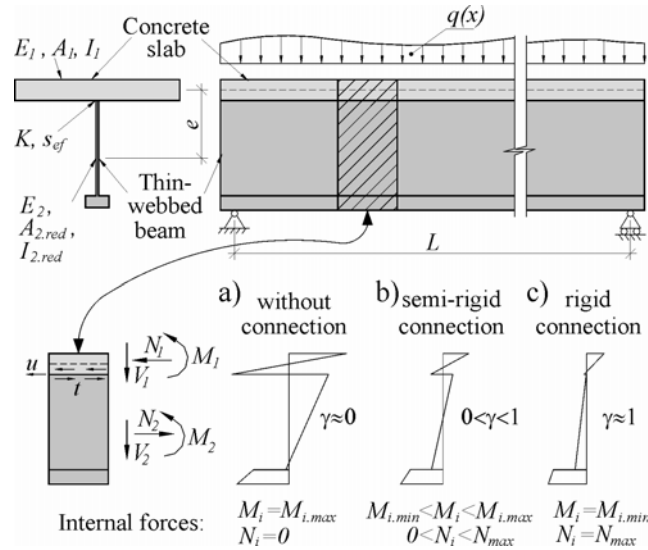


Fig 2. Distribution of stresses in TCC joist cross-section depending on connection stiffness

The semi-rigid connection does not ensure absolute interaction between the cross-section components and its stiffness depends on the value of the slip between the connecting components (Fig 2b).

The rigid connection ensures absolute composite interaction between components, ie when there is no slip between timbers and concrete, the components are under action of the maximal axial force N_{max} and minimal bending moment $M_{i,min}$ (Fig 2c).

The rigid connection having infinite slip stiffness and the connection (without connectors) having a zeroed slip stiffness define the upper and the lower limits of slip stiffness of the connection.

In practice it is very complicated to implement rigid connections between timber and concrete, therefore the effect of connection slip has to be evaluated in the design of TCC beams.

The Lithuanian standard for design of timber structures STR 2.05.07:2005 covers a method for design of flexural compound structures with mechanical connections. However the reduction coefficients given in this method for moment of resistance and moment of inertia do not evaluate the connector's mechanical characteristics. For engineering calculation of the proposed new type TCC beam author offers to use a known simplified design method. This method is also called as “ γ -method” and is based on the analytical concept of differential equations derived by K. Mohler in 1956 and given in Eurocode 5. It was developed for simply supported beams with constant slip stiffness subjected to loads giving a bending moment varying sinusoidally, because in this case the differential equation of partial composite action has a simple analytical solution.

For simplification of calculation the presumption about the OSB web and flange of timber glued together to form a structural unit is taken. This can be done by regarding the whole profile of thin-webbed beam as one homogeneous material with the same properties as the flange material. The contribution from the web of OSB must then be reduced proportionally to the ratio of the modulus of elasticity of OSB and timber. Under this presumption effective cross-section area $A_{2,red}$ and effective moment of inertia $I_{2,red}$ calculated as:

$$A_{2,red} = A_2 + \frac{E_3}{E_2} \cdot A_3, \quad (1)$$

$$I_{2,red} = I_2 + A_2 \cdot a_2^2 + \frac{E_3}{E_2} \cdot I_3 + \frac{E_3}{E_2} \cdot A_3 \cdot a_3^2, \quad (2)$$

here A_i – area of components; E_i – modulus of elasticity; I_i – moment of inertia; a_i – distance between the centres of gravity of the components and the centre of reduced cross section; components' index: 2 – timber; 3 – OSB.

The effective bending stiffness of TCC beams according to γ -method is calculated as:

$$EI_{ef} = E_1 \cdot I_1 + E_2 \cdot I_{2,red} + \gamma \cdot S, \quad (3)$$

$$S = \frac{E_1 \cdot A_1 \cdot E_2 \cdot A_{2,red} \cdot e^2}{E_1 \cdot A_1 + E_2 \cdot A_{2,red}}, \quad (4)$$

here e – distance between the centre of gravity of concrete and the centre of reduce cross section of timber; γ – coefficient of efficiency of the interlayer connection calculated as:

$$\gamma = 1 / \left(1 + \frac{\pi^2 \cdot S}{k \cdot L^2 \cdot e^2} \right). \quad (5)$$

The slip stiffness k of the TCC connection is calculated from the slip modulus K and the spacing s_{ef} between the connectors as:

$$k = K / s_{ef}. \quad (6)$$

The spacing s_{ef} varies uniformly according shear to force between s_{min} and s_{max} with a condition that $s_{max} \leq 4 \cdot s_{min}$:

$$s_{ef} = 0.75 \cdot s_{min} + 0.25 \cdot s_{max}. \quad (7)$$

Slip modulus of connector is the ratio of the force F acting on the connection and its displacement u . Slip modulus of connectors of timber structures K_{ser} is used in calculations of the limit state of serviceability. When the ultimate limit state is checked in calculations the slip modulus K_u is equates to two thirds of the respective value of K_{ser} .

The design normal stresses according to the γ -method are calculated as:

$$\sigma_{1,N,d} = \frac{M_d(x) \cdot \gamma \cdot S}{e \cdot EI_{ef} \cdot A_1}, \quad \sigma_{1,M,d} = \frac{M_d(x) \cdot E_1 \cdot h_1}{EI_{ef} \cdot 2}; \quad (8)$$

$$\sigma_{2,N,d} = \frac{M_d(x) \cdot \gamma \cdot S}{e \cdot EI_{ef} \cdot A_{2,red}}, \quad \sigma_{2,M,d} = \frac{M_d(x) \cdot E_2 \cdot h_2}{EI_{ef} \cdot 2}; \quad (9)$$

$$\sigma_{3,N,d} = \frac{M_d(x) \cdot \gamma \cdot S}{e \cdot EI_{ef} \cdot A_{2,red}} \cdot \frac{E_3}{E_2}, \quad \sigma_{3,M,d} = \frac{M_d(x) \cdot E_3 \cdot h_3}{EI_{ef} \cdot 2} \cdot \frac{E_3}{E_2}. \quad (10)$$

The ultimate limit state for the concrete subjected to combined bending and compression/tension should be verified with the following linear elastic condition:

$$\begin{cases} \sigma_{1,c,d} = \sigma_{1,N,d} + \sigma_{1,M,d} \leq f_{c,d} \\ \sigma_{1,t,d} = \sigma_{1,N,d} - \sigma_{1,M,d} \leq f_{ctm,d} \end{cases}, \quad (11)$$

here $f_{c,d}$ and $f_{ctm,d}$ – respectively design compressive strength and design axial tensile strength of concrete.

The ultimate limit state for the timber subjected to combined bending and tension should be verified by expression (12).

$$\frac{\sigma_{2,N,d}}{f_{t,d}} + \frac{\sigma_{2,M,d}}{f_{m,d}} \leq 1.0 , \quad (12)$$

here $f_{t,d}$ and $f_{m,d}$ – respectively design tensile strength and design bending strength of timber.

The stress of OSB shall satisfy the following condition:

$$\sigma_{3,t,d} = \sigma_{3,N,d} + \sigma_{3,M,d} \leq f_{t,w,d} , \quad (13)$$

here $f_{t,w,d}$ – design tensile bending strength of OSB.

The longitudinal shear flow $t(x)$ between concrete and OSB and the resulting load $T(x)$ on a connector are calculated as:

$$t(x) = V(x) \cdot \frac{\gamma \cdot S}{e \cdot EI_{ef}} , \quad (14)$$

$$T(x) = V(x) \cdot \frac{\gamma \cdot S}{e \cdot EI_{ef}} \cdot s_{ef} = t(x) \cdot s_{ef} . \quad (15)$$

The load-bearing capacity of the shear connectors is verified by:

$$T(x) \leq T_{R,d} , \quad (16)$$

here: $T_{R,d}$ – the design shear resistance of the connector.

For a simply supported TCC beam under uniformly distributed load $q(x)$ the instantaneous deflection in the middle of the span is calculated as:

$$w_{inst} = \frac{5}{384} \frac{q(x) \cdot L^4}{EI_{ef}} . \quad (17)$$

Displacement of TCC interconnection between OSB web and concrete slab is calculated as:

$$u(x) = V(x) \cdot \frac{\gamma \cdot S}{e \cdot EI_{ef}} \cdot \frac{1}{k} = \frac{t(x)}{k} . \quad (18)$$

3. Connectors of embedded connection of TCC beam. In this chapter suitable connectors for embedded connection are analyzed. Four types of connectors with mechanical, dowel action, adhesion and interface friction were presented and their construction behaviours, advantages and disadvantages were analyzed.

In the new type of TCC beam, the timber web is connected with the concrete slab by embedding a part of it into the concrete slab. Moreover, Ø25 mm holes are drilled in the embedding part of the web that is let in for forming a concrete dowel after casting them with concrete mix. Failure of such kind of connection under action of longitudinal shear forces can occur in the following cases:

1) After local compression of the web contact with the concrete dowel surface;

- 2) After cutting the web between the concrete dowels;
- 3) After cutting the concrete dowel.

Preliminary calculations indicated that such connection, as a rule, fails because the web cuts the concrete dowel, the concrete shear resistance being too small. Therefore the concrete dowel of the connection was strengthened by inserting additional steel connector into the hole of the web prior to concrete casting.

Two types of connectors were analysed for TCC beam connections. Connector of type I: 3 mm diameter 100 mm long steel reinforcing bar (Fig 3a).

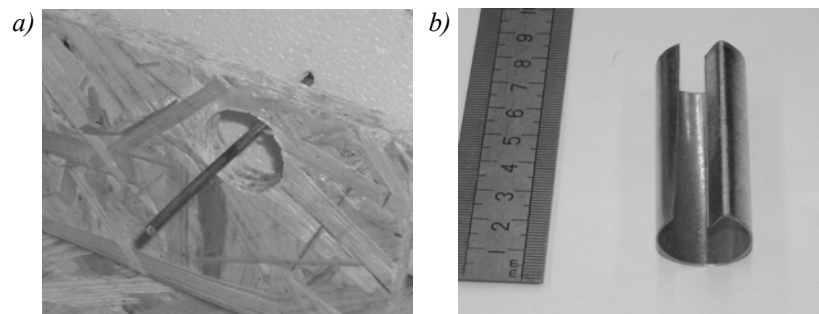


Fig 3. Type of connectors: a – reinforcing bar; b – “sleeved” connector

Connector of type II: “sleeved” metal connector (Fig 3b) made of 0.5 mm thick, 60 mm wide and 72 mm long steel strip, which with a special rig was rolled into a tubule (external diameter 25 mm with longitudinal gap).

4. Experimental results of TCC beams and connectors

The main objectives were to select a rational connector for TCC beam that would ensure a reliable connection between concrete and OSB and establish the peculiarities of behaviour and the modes of failure of this connection and the TCC beam itself. For this purpose models of structures were tested in specially made test beds using quasi-static loads. The tests were performed at the laboratories of the Department of Steel and Timber and of Strength Mechanics of VGTU.

Tests of connectors. The goals of the research:

1. To estimate by tests the mechanical properties of reinforcing bar and “sleeved” connectors and according to these results to choose the best suitable connector for embedding connection between OSB web and concrete slab (primary tests see in Fig 4);
2. To estimate by tests influence of properties different thicknesses of OSB and distances between holes on connectors’ mechanical (primary tests see in Fig 4);

3. To estimate by tests the mechanical properties of connector, which was used in tests of TCC beams (finally tests see in Fig 5).

Short-term push-out tests of connections between the OSB web and concrete part were performed according to the requirements of LST EN 26891.

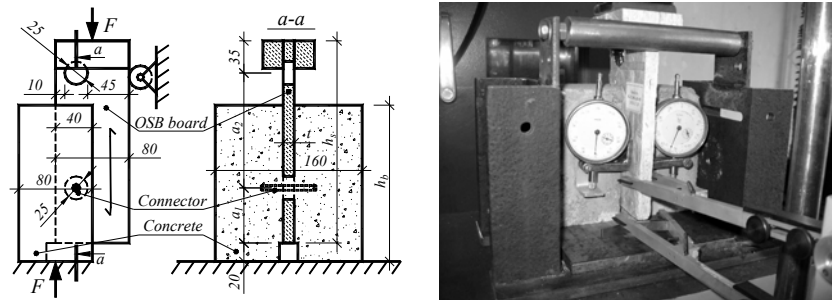


Fig 4. View on specimens and test equipment

In primary tests such parameters for each type of connector were used:

- thickness t of OSB of class III was 10 mm and 12 mm,
- distance a_2 between holes was 75 mm, 100 mm and 125 mm.

On the sides of OSB web the 20 mm thick and 30 mm wide lateral OSB stiffeners were glued at the places of application of concentrated load. These strips stiffened the OSB web and decreased the bearing strains.

A 20 mm gap was formed in the area of the bearing surface of the concrete part of the specimen to let the slab free slip during the test.

The concrete compressive strength conformed to the class C20/25 (after 28 days it mean was 25.85 N/mm^2). During the concrete hardening period the specimens were kept at indoor temperature and humid environment under polythene mantles.

Push-out tests of TCC specimens were performed using the testing equipment TIRA TEST 2300 with measuring devices. The slip between the OSB and concrete part was measured using two mechanical clock-type indicatory tensometers IGM-1 and linear voltage displacement transducer (hereinafter LVDT) (Fig 4).

Different distances between the holes of the specimens have no effect on the value of critical force and slip modulus.

In specimens with 12 mm thick OSB the critical load was 1.4–1.8 times higher then in the specimens with 10 mm thick board. Nevertheless, there is almost no difference between their resistances determined at the 2 mm ultimate strain.

The slip modulus of specimens with “sleeved” connectors was 1.1–1.4 times higher than of the specimens with rebar connectors.

It shall be noted that OSB-3, which was used for timber part of samples, swelled when submerged into concrete mix during concrete casting and during the concrete hardening when moisture evaporated a 1 mm gap formed at the contact place of OSB and concrete.

The experimental investigation of OSB-concrete connections and analysis of the results showed that “sleeved” connectors are more suitable for the connection between the web and concrete slab of a timber-concrete composite thin-webbed beam structure.

In finally tests the mechanical properties of connectors, which was used in test of TCC beams were defined.

Push-out tests of TCC specimens were performed by the testing equipment ZIM P10 with 10 tonne capacity load cell, and with DIGICON 2000 control console. The slip between the OSB web and concrete part was measured using four LVDT (see Fig 5).

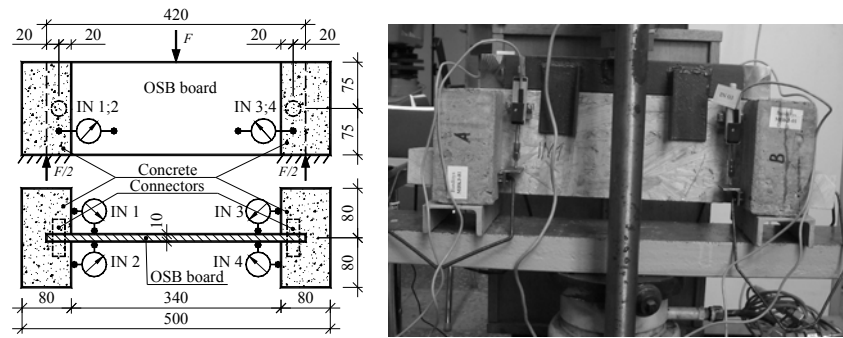


Fig 5. View of specimens and test equipment

The fine-grained concrete mix of mobility class S4 was made in UAB “Palmusta”. The concrete compressive strength conformed to the class C30/37 (after 28 days it mean was 39.68 N/mm²). During the concrete hardening period the specimens were kept at indoor temperature and humidity under polythene mantles.

The tongue part of the web to be set into concrete was covered with polyurethane varnish.

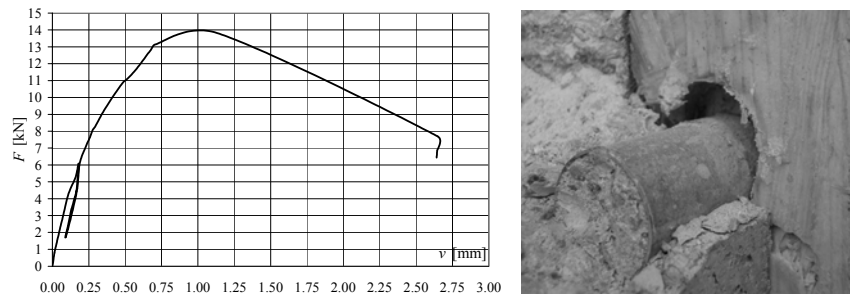
The mean values of the test results are presented in Table 1. The values indicated: F_{max} – experimental load-bearing capacity of the connection corresponding to the maximal value of load acting on the specimen; v_i – experimental initial slip of the connection under $0.4 \cdot F_{max}$; v_e – experimental elastic slip of the connection under $0.4 \cdot F_{max}$; K_s – slip modulus of connection i.e. the ratio between of the force $0.4 \cdot F_{max}$ and force indicating the connection slip.

Table 1. Test results of “sleeved” connectors

Number of specimens	F_{max} [kN]	v_i [mm]	v_e [mm]	K_s [kN/m]
10	14.21	0.202	0.144	29 788

The failure of specimens occurred in OSB web at the opening due to bearing of OSB web (Fig 6).

Load-slip curves of the most of specimens complied with the plastic behaviour, i.e. any sudden failure of connections was observed (Fig 6).

**Fig 6.** Load-slip curve for specimens and failure of failure in specimen connection

Test of TCC beams. The goals of the research were establishment by tests the TCC beams load-bearing capacity and evaluate their behaviour.

Thin-webbed timber beams of composite beams were manufactured at UAB “AHL” plant in November 2004 according to the agreement on implementation of innovations IDS002. 10 mm thick OSB-3 boards were used for thin-webbed timber beam web. In the beam itself these boards were connected with the help of cover boards that were manufactured of the same 10 mm thick OSB-3 board. At the edge of OSB board a chord of pine planks (cross-section 90x45 mm) was glued. It shall be noted that in samples KMBS 01; 02; 03; 04 the chord of planks had finger joints at two places, whereas KMBS 05 chord was of solid timber. The beam web was set into the bottom chord for 20 mm. The finger joints of timber chord, connections between the beam web with timber chord and cover plates were glued at “AHL” plant with the glue LIPALAS D2.

Prior to setting “sleeved” connectors into the openings of the web, the tongue part of the web to be set into concrete was covered with polyurethane varnish. This protection helped to avoid swelling of OSB during concrete casting and hardening.

The 80 mm thick concrete layer of TCC beam was formed by compaction the mix with an electric internal vibrator P14. The concrete part was additionally reinforced with Ø4 S240 class steel reinforcement mesh.

In order to simplify and facilitate the process the TCC beams were manufactured and as simply supported elements tested in upside-down position.

Five composite beams were tested until rupture. The distance between beam supports was 6.4 m. The bending moment was generated by loading the beam with vertical forces. For generation of vertical forces one hydraulic jack was used (maximal load capacity of the jack 10 t) as well as a subsidiary metal beam that distributed this force into two equal parts. The secondary beam was supported on the concrete part of TCC beam via simply supports with distribution cross-arms (Fig 7, 8). The force created by hydraulic jack was monitored by control panel DIGICON 2000 and software PROTEUS 2.5.3. The deformations, slips and displacements of TCC beams were measured using LVDT (Fig 9).

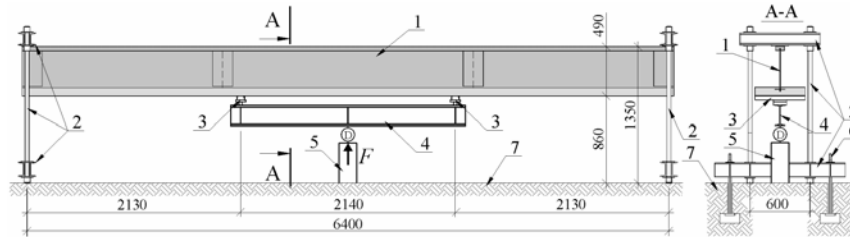


Fig 7. Test arrangement: 1 – experimental member; 2 – support with stringers; 3 – simply supports with distribution cross-arms; 4 – subsidiary steel beam; 5 – hydraulic jack; 6 – anchor bolts of supports; 7 – ground



Fig 8. View on specimen and test equipment

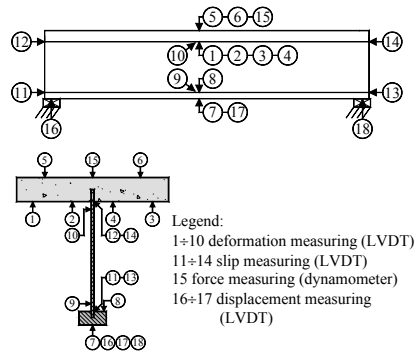


Fig 9. Review of measuring points

Short-term bending tests of TCC beams were performed according to the requirements of LST EN 380 and LST EN 595 and applying the load-time

curve recommended by these standards (Fig 10). According these standards a loading rate was used 0.25 Q per minute (0.903 kN/min).

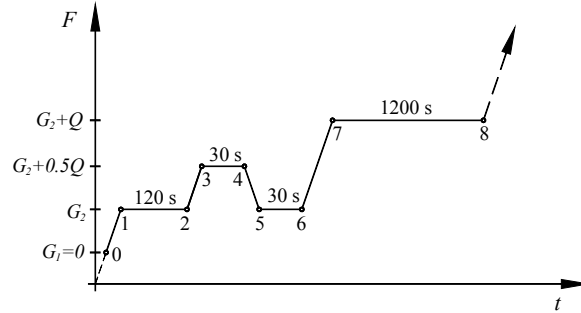


Fig 10. Load-time curve of bending test of the TCC beams: F – load applied to the specimen; G_1 – self weight of beams ($G_1=9.62$ kN); G_2 – permanent load of beams ($G_2=1.35$ kN); Q – live load for category A according STR 2.05.04:2003 ($Q=3.61$ kN)

The failure of tested beams corresponded to brittle behaviour. Failure of specimens KMBS 01; 02; 03; 04 occurred at finger joint of timber flange. It shall be noted that finger joints of specimens did not satisfy the requirements according standard LST EN 385. In the above-mentioned standard the minimum length of a finger for bearing structures is 10 mm, whereas the length of fingers in TCC beams was 7 mm. Failure of sample KMBS 05 occurred due to insufficient gluing after tearing out OSB web from timber chord at the beam support.

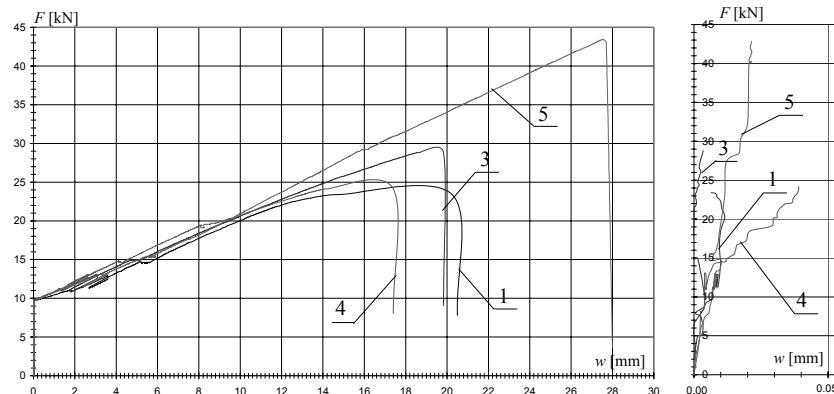


Fig 11. Measured load-deflection (left) and load-slip diagram (right):
1 – KMBS 01; 3 – KMBS 03; 4 – KMBS 04; 5 – KMBS 05

Fig 11 (left) shows measured in the middle of the span load-deflection diagrams of the bending tests, while the slip of interconnection between OSB web and concrete slab shown in Fig 11 (right).

Values of experimental resistance of TCC beams are presented in Table 2. The value of experimental resistance of sample KMBS 05 was 1.5–1.83 times greater than of other samples. At the author's opinion so happened because the timber chord of sample KMBS 05 was without finger joints, which were in other samples. The values of interconnection slip between OSB web and concrete slab are minimal (see Fig 11).

Table 2. Failure load of TCC beams measured in the bending tests

Failure load	KMBS 01	KMBS 02	KMBS 03	KMBS 04	KMBS 05
F_{max} [kN]	24.00	27.23	29.41	24.74	43.44

The values of main physical and mechanical values of the materials (concrete, timber, OSB) used in investigated structures were established by additional tests.

5. Comparison between test and theoretical results. The influence of variation coefficients of mechanical characteristics of materials and connectors and stress-strain distribution changes in time on the elastic structural behaviour of TCC structure in chapter is analysed. There is also presented comparison of experimental and theoretical results.

Calculated values according design method presented in chapter 2 depend on the geometrical and mechanical properties (modulus of elasticity and slip) of the different components of the composite structure (timber, OSB, concrete and connectors). These mechanical properties of materials and connectors were obtained from short-term standard tests which exhibit different coefficients of

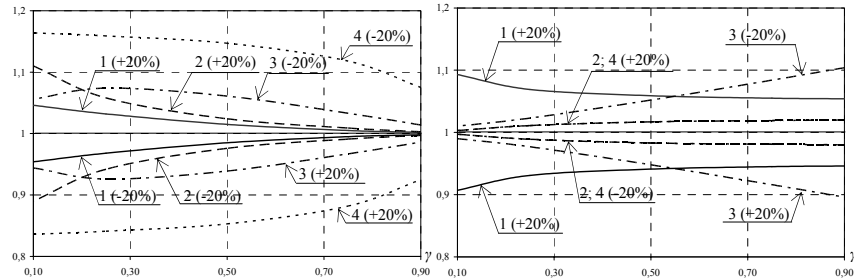


Fig 12. Influences of variation coefficients ($\pm 20\%$) of connector's slip modulus (left) and modulus of elasticity of timber (right) subjected to coefficient of efficiency of the interlayer connection: 1 – normal stresses of timber; 2 – shear flow in connections; 3 – deflection of beam in the middle of span; 4 – slip of connection

variation. A parametric study executed in this chapter shows that the high values of variation coefficients for modulus of elasticity of timber and slip modulus of the connectors have great influence on the elastic structural behaviour of TCC (Fig 12).

For all component materials of a TCC beam (timber, OSB, concrete and connectors) a creep phenomenon is characteristic. Creep includes three distinct types of behaviour: time-dependent (viscoelastic) creep, mechano-sorptive (moisture change) creep and recovery that is ascribed to differential swelling and shrinkage.

The stresses at the time moment $t = \infty$ and deformations can be found calculating them from expressions (5), (6) and (7), with changing the stiffness properties E_i into $E_{i,fin}$:

$$E_{i,fin} = \frac{E_i}{1 + \psi_2 \cdot k_{def}} \quad , \quad (19)$$

here: E_i – is the mean value of the material elasticity modulus; ψ_2 – is a factor for the quasi-permanent value of a variable action; k_{def} – is a deformation factor taking into account the effect of the load and the moisture content in the structure on the stiffness parameters.

Using such method of calculation of TCC structures the stresses and deformations can be obtained only at the time moments $t = 0$ and $t = \infty$. However, the theoretical analysis performed in this chapter shows that the critical creep deformations of TCC beam cross-section may be discovered in different time: from $t = 3$ to 7 years. That necessitates additionally investigations of long-term behaviour for proposed TCC beams.

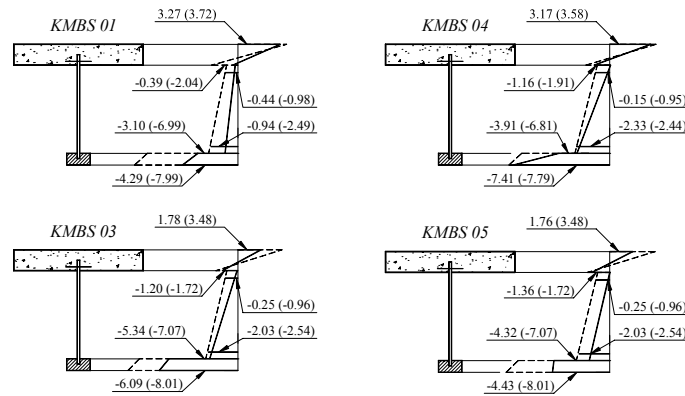


Fig 13. Distribution of the values of experimentally obtained (solid lines) and theoretically defined (dashed lines and numbers in braces) normal stresses (in MPa) at the middle of the span

Comparison of values of experimental and theoretical stresses of cross-section of TCC beams defined under the service load is presented in Fig 13. Experimental results correspond to 8 point in load-time curve received from bending tests of the TCC beams (Fig 10). The values of experimental stresses of cross-section of TCC beams were calculated with presumption of Hooke's law. Theoretical calculations were made according to design method given in Chapter 2.

The comparison shows quite good agreement between experimental and theoretical results.

Results and Conclusions

1. The structural concept of the new type of TCC joisted floor in which for the top flange of the composite beam is concrete slab is used and through suggested new type of the interlayer connectors is connected with the timber beam itself which is of composite I shape comprised from OSB web and bottom flange of timber board glued into the web is presented, and the behaviour of this structure and its practical suitability and the developed design method are evaluated.
2. The types and properties of the most often used TCC section connections between the concrete slab and timber beam have been analysed. Two types of connectors that are suitable for concrete slab and OSB web interlayer connection because they more effectively increase the stiffness and strength of the embedded connection of the proposed timber-concrete composite beams have been chosen and analysed.
3. Short-time push-out tests of the TCC connection between the part of concrete slab and OSB web have been performed. Load-slip parameters in connections with different types of connectors in which the thickness of OSB web and the distance between the connectors were changing have been established. From the tests it is determined that the slip modulus of connections with "sleeved" connectors is 10–40% higher than of connections with rebar connectors. It was established that the thickness of OSB web has almost no influence on connection stiffness. Nevertheless, the connection resistance of specimens with 12 mm thick OSB was 40–80% greater in comparison with the specimens where 10 mm thick board was used. Author due to carried out analysis has offered the "sleeved" connectors to use for practice in interlayer connections between concrete slab and OSB web.
4. A series of four-point short-term bending tests on full-scale TCC beams were performed. The deflections in the middle of the span and the slip in interlayer between the concrete slab and OSB web were established very

small values under service loads. This confirmed the high slip stiffness of embedded connection with proposed “sleeved” connectors. The failure of structures was brittle and this happened usually in timber flange which was usually located close to finger joints.

5. Basing on the known design methods of mechanically jointed beams and timber thin-webbed beams, a rational design method for the proposed new flexural TCC beams was developed.
6. Having analysed the test results and the behaviour and mode of failure of the new structure it was established that the values of experimental stresses of the components are only slightly different from the values of theoretically calculated stress by the proposed engineering method.
7. For application in practice of the new type of TCC structures it is necessary to arrange an additional protection of the groove part of the beam web set into concrete to avoid swelling of OSB during concrete casting and hardening. The author proposed to use a polyurethane varnish for such protection.
8. The long-term structural behaviour can be predicted with standard calculation models as presented. Although the additional long-time investigation of the proposed new TCC beams and “sleeved” connectors need to be examined.
9. Basing on the results of the performed theoretical and experimental studies, it is proposed to use the developed new TCC beam with “sleeved” connectors for floor systems and similar structural applications especially in dwelling houses with up to 10 m span floors.

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KOMPOZITINIŲ MEDIENOS-BETONO SIJŲ IR JUNGIŲ KŪRIMAS IR BANDYMAI

Bendroji darbo charakteristika

Tyrimų sritis ir aktualumas. Pastaruoju metu Lietuvoje ir kitose Europos bei pasaulio šalyse vis daugiau statoma lengvųjų konstrukcijų pastatų. Tačiau tokių pastatų perdangoms dar nėra plačiau naudojami gaminiai iš medienos. Tradicinės lengvo medinio karkaso perdangos pasižymi vibracijomis, garso pralaidumu ir mažu atsparumu kaitrai. Išvardytos problemos racionaliai sprendžiamos naudojant kompozitines medienos-betono (toliau – KMB) perdangas. Tokio tipo perdangos, palyginti su medinėmis, yra ne tik stipresnės ir standesnės, bet ir labiau atsparios kaitrai, geresnė jų garso izoliacija. Palyginti su iš neatsinaujinančių išteklių pagamintomis gelžbetoninėmis perdangomis, KMB perdangos yra lengvesnės ir ekonomiškesnės. Šios savybės skatina naudoti KMB perdangas naujai statomuose pastatuose. Statybinėse konstrukcijose naudodami medieną vietoj betono ar plieno, galime iš esmės sumažinti energijos poreikį ir išsiskiriančio anglies dvideginio kiekį gamybos metu.

Kai KMB perdangos tarpatramis yra iki 6 m, sijiniai mediniai komponentai paprastai daromi iš vientisinės stačiakampio skerspjūvio medienos. Kai kompozitiniai medienos-betono perdangos tarpatramiai yra nuo 6 iki 10 m, sijiniai mediniai komponentai daromi iš kljuotinės stačiakampio skerspjūvio medienos. Medinėms perdangos sijoms pagaminti vietoj kljuotinio stačiakampio skerspjūvio sijų sėkmingai gali būti panaudotos ir sudėtinio dvitėjo skerspjūvio sijos (plonasienės medinės sijos) su plona sienele iš orientuotųjų skiedrų plokščių (toliau – OSB). Šios plonasienės medinės sijos su betono plokšte jungiamos tam tikro tipo jungėmis. Tačiau taip sukomponuotame skerspjūvyje neveiksmingai išnaudojamos medinės plonasienės sijos viršutinės gniuždomosios juostos konstrukcinės savybės. Autorius šiame darbe pateikia naują KMB sijinės perdangos konstrukcinį sprendimą, kai plonasienės medinės sijos neturi viršutinės medinių lentų juostos. Sienelė su betono plokšte jungiama per į plokštę įleidžiamą viršutinę sienelės dalį. Šis sprendimas leidžia sutaupyti konstrukcijos medžiagų, gamybos išlaidų. Tačiau tiek pasiūlytosios KMB sijos, tiek įlaidinės (įleistinės) jungties tarp betono ir sijos sienelės elgsena yra mažai ištirtos. Todėl išlieka aktualūs ir teoriniai, ir eksperimentiniai tyrimai, skirti naujo tipo KMB sijos elgsenai analizuoti ir projektavimo metodikai parengti.

Tyrimų objektas – KMB sija, sudaryta iš betono plokštės, medinės plonasienės sijos ir jungės, tinkamos šių sijų jungčiai tarp betono ir OSB

plokščių. Šių jungių ir sijų pagrindinėms mechaninėms charakteristikoms ir jų statistiniams parametrams nustatyti buvo atlikti natūralaus didumo jungčių ir sijų trumpalaikiai bandymai. Pasiūlytas KMB sijos skaičiavimo algoritmas pagrįstas žinomais gama ir skerspjūvio redukavimo metodais.

Pagrindinis darbo tikslas. Siekiant padidinti kompozitinės medienos-betono perdangos veiksmingumą, jos elementams pritaikyti medinės plonasienės sijas bei sukurti tarpsluoksnio jungties junges, išanalizuoti jų elgseną, praktinio taikymo galimybes ir parengti projektavimo metodiką.

Darbo uždaviniai:

- Apžvelgti labiausiai paplitusių KMB perdangų tarpsluoksnio jungčių tipus ir įvertinti jų ypatumus.
- Sukurti įlaidinę jungtį (analizuojant skirtingų tipų betono kaištines junges) tarp betono plokštės ir OSB sienelės.
- Bandymais nustatyti skirtingų tipų betono kaištinių jungių mechanines charakteristikas, esant skirtingiems OSB sienelių storiams ir atstumams tarp jungių.
- Išanalizuoti KMB perdangų ypatumus, skaičiavimo metodus ir jų ypatybes.
- Sukurti naują KMB perdangos konstrukciją.
- Parengti ir atlikti šios naujos kompozitinės sijos eksperimentinius tyrimus.
- Įvertinus teorinių ir eksperimentinių tyrimų rezultatus, parengti tolygiai išskirstytos simetrinės apkrovos veikiamos sukurtosios kompozitinės sijos projektavimo metodiką.

Mokslinis naujumas:

- Pritaikius efektyvias medinės plonasienės sijas, sukurta naujo tipo KMB konstrukcija.
- Sukurta naujo tipo betono plokštės ir sijos sienelės įlaidinė jungtis su tam panaudota „įvorine“ plieno jūge.
- Eksperimentiniais tyrimais nustatyti betono plokštės ir sijos sienelės įlaidinės jungties racionalūs matmenys ir jungės atspario bei slankumo modulio vertės.
- Gauti ir išanalizuoti simetrinių apkrovų veikiamos kompozitinės medienos-betono sijos elgsenos nauji eksperimentinių tyrimų rezultatai.
- Parengta tolygiai išskirstyta simetrinė apkrova veikiamos sukurtosios kompozitinės medienos-betono sijos projektavimo metodika.

Darbo aprobavimas ir publikacijos. Pagrindiniai disertacinio darbo tyrimo rezultatai aptarti penkiose mokslinėse techninėse konferencijose. Disertacijos tema publikuota 9 mokslo darbai, iš jų du – recenzuojamuose

periodiniuose mokslo leidiniuose, du – tarptautinių ir trys – respublikinių konferencijų pranešimų leidiniuose, du – mokslo populiarinimo leidiniuose (žr. 21–22 psl.).

Disertacijos apimtis. Darbą sudaro bendra darbo charakteristika, žymenų sąrašas, įvadas, penki skyriai, bendrosios išvados, literatūros sąrašas ir priedai. Darbe yra 70 paveikslų ir 15 lentelių. Viso 157 puslapiai.

Disertacijos struktūra

Pirmąjį skyrių sudaro įžanginė dalis, kurioje trumpai apžvelgti KMB perdangų privalumai, konstrukciniai tipai bei šių konstrukcijų gamybos technologijų ir tyrimų istorija. Pateiktas naujo tipo KMB sijinės perdangos konstrukcinis sprendimas, kuriame šios perdangos viršutinė juosta yra betoninė plokštė, o medinė sija yra sudėtinio tėjinio skerspjuvio, sudaryto iš OSB sienelės ir prie jos priklijuotų arba į ją įklijuotų medinių lentų apatinės juostos.

Antrajame skyriuje atlikta lenkiamųjų kompozitinių sijų su iš dalies standžiomis jungtimis skaičiavimo metodų apžvalga. Aptarti šių metodų privalumai ir trūkumai. Pateiktas γ metodas, įteisintas Europos šalių projektavimo normose EC 5 ir skirtas projektuoti lenkiamus mechanškai sujungtus skerspjuvius.

Trečiajame skyriuje atlikta dažniausiai naudojamų KMB skerspjuvio jungčių tarp betoninės plokštės ir medinės sijos tipų ir jų savybių analizė. Išnagrinėtos dviejų tipų jungtys, tinkamos naudoti betono plokštės ir medinės sijos sienelės jungtims: I tipo jungė – 3 mm skersmens ir 100 mm ilgio armatūros strypas, II tipo – „įvorinė“ plieno jungė, pagaminta iš 0,5 mm storio ir 60 mm pločio bei 72 mm ilgio skardos juostelių.

Ketvirtajame skyriuje aptartos KMB jungių ir dviatramių sijų bandymo metodikos bei eksperimentų rezultatai. Nustatyti konstrukcijoje naudotų medžiagų (betono, medienos, OSB) pagrindiniai fizikiniai ir mechaniniai rodikliai.

Penktame skyriuje lyginami eksperimentiniai ir teoriniai rezultatai. Taip pat atlikta medžiagų savybių sklaidos ir ilgalaikių deformacijų įtakos KMB sijos elgsenai teorinė analizė.

Pagrindiniai darbo rezultatai ir išvados

1. Pasiūlytas iš esmės naujo tipo KMB sijinės perdangos konstrukcinis sprendimas, kuriame šios perdangos viršutinė juosta yra betoninė plokštė, o medinė sija yra sudėtinio tėjinio skerspjuvio, sudaryto iš OSB sienelės ir į ją įklijuotų medinių lentų apatinės juostos. Išanalizuota šios konstrukcijos elgsena ir praktinio taikymo galimybės taip pat parengta jų projektavimo metodika.

2. Darbe atlikta dažniausiai naudojamų KMB skerspjūvio tarp sluoksnių jungčių tipų ir jų savybių analizė. Pasiūlytosios KMB sijų įlaidinės jungties standumui ir stiprumui padidinti išnagrinėtos dviejų tipų jungtys tinkamos naudoti betono plokštės ir medinės sijos sienelės jungtims.
3. Bandymais nustatyti jungčių su skirtingo tipo jungėmis apkrovos ir slinkties priklausomybės nuo OSB sienelės storio ir atstumo tarp sijų parametrai. Nustatyta, kad jungčių su naujo tipo „įvorinėmis“ jungėmis slankumo moduliai yra 10–40 % didesni nei jungčių su armatūrinėmis jungėmis. Nustatyta, kad OSB sienelės storis beveik neturi įtakos jungties standumui. Tačiau bandinių su 12 mm storio OSB plokšte jungties atsparis 40–80 % didesnis nei bandinių su 10 mm storio plokšte. Autorius, remdamasis atlikta analize, pasiūlė praktikoje jungčiai tarp OSB sienelės ir betono plokštės naudoti „įvorines“ junges.
4. Atlikta serija KMB sijų trumpalaikių gryo lenkimo bandymų. Nustatytos KMB sijų tarpatriamio vidurio įlinkių ir slinkčių tarp OSB sienelės ir betono plokštės labai mažos reikšmės, apkrovus jas nuolatine ir naudinga apkrovomis. Tuo patvirtinamas „įvorinių“ sijų efektyvumas esant įlaidinei jungčiai. Konstrukcijos irties pobūdis pasirodė esąs trapus, ir tai įvyko beveik visais atvejais, trūkus medinių lentų dantytų dygių jungtims.
5. Remiantis lenkiamų mechanškai sujungtų skerspjūvio komponentų ir medinių plonasienių sijų projektavimo metodikomis, parengtas racionalus lenkiamų nagrinėjamų naujo tipo KMB sijų projektavimo metodas.
6. Apdorojus bandymo rezultatus ir išanalizavus naujosios konstrukcijos elgseną bei irties pobūdį, nustatyta, kad eksperimentiniai komponentų įtempiai nedaug skiriasi nuo pasiūlytu inžineriniu metodu apskaičiuotų teorinių reikšmių.
7. Taikant naujo tipo KMB konstrukcijas praktikoje, būtina papildomai apsaugoti sijos OSB sienelės įlaidinę dalį į betoną, apsaugant ją nuo brinkimo betonavimo ir betono kietėjimo metu. Autorius pasiūlė apsaugai naudoti poliuretalinį laką.
8. Pateiktas standartinis skaičiavimo modelis, kuriuo atsižvelgiama į ilgalaikių deformacijų įtaką konstrukcijų elgsenai. Modelio patikimumui įvertinti reikia atlikti nagrinėjamų KMB sijų ir „įvorinių“ sijų papildomus tyrimus, veikiant ilgalaikėms apkrovoms.
9. Remiantis atliktų teorinių ir eksperimentinių tyrimų rezultatais, siūloma naudoti sukurtą naujo tipo KMB siją su „įvorinėmis“ jungėmis ir jų analizės bei projektavimo metodiką pastatų iki 10 m tarpatriamio perdangų projektavimo ir statybos praktikoje.

Briefly about the author

Kęstutis Gurkšnys was born in Vilnius on March 9, 1977.

BSc and MSc degrees in Civil Engineering, Faculty of Civil Engineering, Vilnius Gediminas Technical University in 1999 and 2001, respectively. PhD studies at Vilnius Gediminas Technical University in 2001–2005. Erasmus visit (3 months) to Bauhaus-Universität Weimar (Germany) in 1999. Assistant at the Department of Steel and Timber Structures, Vilnius Gediminas Technical University since 2002.

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Vedęs. Žmona Daiva, sūnus Tauras (g. 2005 m.).

Kęstutis Gurkšnys

**DEVELOPMENT AND TESTING OF COMPOSITE
TIMBER-CONCRETE BEAMS AND CONNECTIONS**

Summary of doctoral dissertation
Technological Sciences, Civil Engineering (02T)

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**KOMPOZITINIŲ MEDIENOS-BETONO
SIJŲ IR JUNGIŲ KŪRIMAS IR BANDYMAI**

Daktaro disertacijos santrauka
Technologijos mokslai, statybos inžinerija (02T)

SL 136. 2006 01 17. 1,75 apsk. leid. 1. Tiražas 100 egz.
Leido Vilniaus Gedimino technikos universiteto
leidykla „Technika“, Saulėtekio al. 11, LT-10223 Vilnius-40
Spausdino UAB „Biznio mašinų kompanija“, Gedimino pr. 60,
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