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BEHAVIOUR EVALUATION OF "SLEEVED" CONNECTORS IN COMPOSITE TIMBER-CONCRETE FLOORS

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Abstract. The paper presents the structural solution to the joisted floor when the timber joist of composite cross-section and the concrete slab are interconnected via a special semi-rigid connection and form a timber-concrete joisted floor composite element. Tensioned bottom flange is formed of a solid timber joist, the web is of oriented strand boards (OSB) and the compressive top flange is of a concrete slab into which a part of the web is let in. Studies were carried out on the "sleeved" connector in this part of the web between OSB and concrete slabs that should increase the stiffness of this connection. Theoretical and experimental researches on inter-behaviour of connection of the sub-components of composite timber I beam-concrete were carried out, the obtained results are presented and evaluated.

Keywords: timber–concrete, composite I-beam, semi-rigid connection, slip modulus, shear connector, push-out tests.

1. Introduction

Recently composite structures [1] (steel-concrete beams, concrete-filled steel columns, timber-glass blocks etc, including timber-concrete composite, TCC, joisted floors) have been more and more widely used in building. In comparison with reinforced concrete floors, the TCC floors are lighter and more economical. In comparison with timber floors, they are characterised by greater strength and stiffness, increased heat resistance, better sound insulation and decreased vibration effect. Timber joist elements of TCC floors are under tensile stresses, while the upper concrete slab is compressed. Thus, the highest structural properties of these materials are rationally used. When the span length of the composite floor is up to 6 m, joist elements are made of integral rectangular timber (Fig 1*a*). When the span of the timber-concrete composite floor is between 6 and 10 m, joist elements are usually made of glulam timber (Fig 1*b*). Composite cross-section of thin-webbed beams (I-joists) from oriented strand boards (OSB) can also be perfectly used for timber floor beams instead of glued rectangular beams. Structural solutions used for connecting a composite timber I-joist with concrete slab by shear connectors of a certain type (Fig 2*a*) are presented in [2–4]. Nevertheless, the structural properties of the upper compressive flange of I-joist are not efficiently used in a cross-section of such composition. In this paper the structural solution of TCC floor when I-joists are without timber board upper flanges is presented.

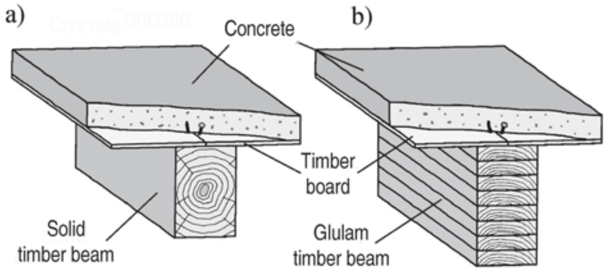


Fig 1. Structural solutions of TCC joisted floor with solid (*a*) and glulam (*b*) timber beams

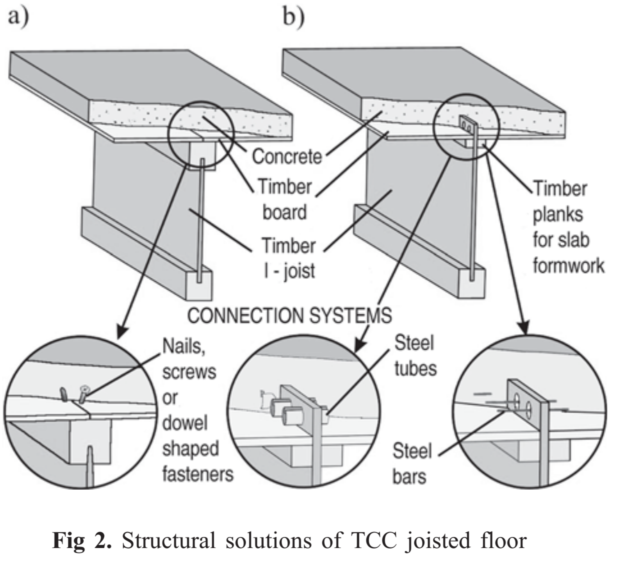


Fig 2. Structural solutions of TCC joisted floor

Embedding in concrete a part of web connects the web and the concrete slab.

In order to achieve better stiffness of the concrete slab and the web joint, the holes are drilled in the embedded part of the web for setting in the connectors of a certain type (Fig 2*b*). After casting these places by concrete mix, concrete dowels of certain stiffness are formed.

2. Peculiarities of TCC floor behaviour

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 sub-components N_i depend on the mechanical index of the interlayer connection – slip unit stiffness *k*. Stiffness of connection determines the distribution of stresses in the cross-sections of the separate sub-components of TCC joist floor (Fig 3). We assumed that the connection of the timber flange boards and the web of I-joist are absolutely rigid, ie there is no slip between these sub-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 sub-components will be only on action of bending moment $M_{i.max}$ (Fig 3*a*), ie mainly two independent flexural members will operate.

The semi-rigid connection does not ensure absolute interaction between the cross-section sub-components and its stiffness depends on the value of the slip between the connecting sub-components (Fig 3*b*).

The rigid connection ensures absolute composite interaction between sub-components, ie when there is no slip between timbers and concrete, the sub-components are under action of the maximal axial force N_{max} and minimal bending moment $M_{i.min}$ (Fig 3*c*).

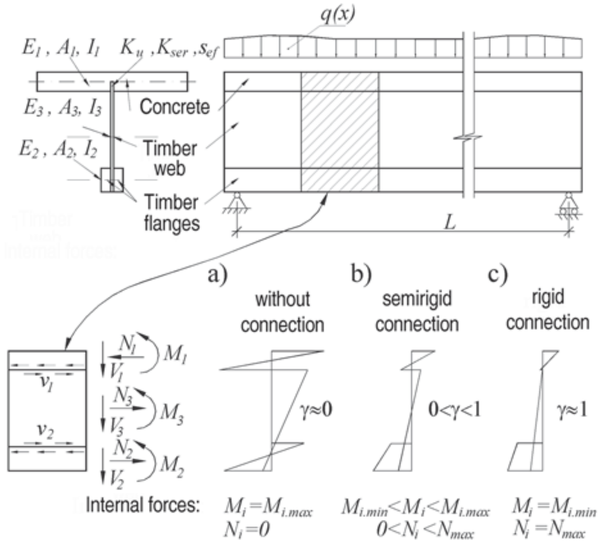


Fig 3. Distribution of stresses in TCC joist cross-section depending on connection stiffness

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. Therefore it is important to know a mechanical factor defined by factor γ of the efficiency of the interlayer connection. Its value settles the distribution of stresses in TCC cross-sectional sub-components.

This factor γ is calculated as [5]:

$$\gamma = 1 \Big/ \left(1 + \frac{\pi^2 \cdot A_1 \cdot E_1}{k \cdot L^2} \right). \qquad (1)$$

Here A_1 – area of the cross-section of concrete layer; E_1 – concrete elasticity modulus; *k* – slip unit-stiffness of the interlayer connection; *L* – floor span.

When the connection is very rigid, the factor γ approaches unit; when there is no connection, the factor γ approaches zero.

One of the main values settling the value of factor γ in formula (1) is the slip unit-stiffness *k,* which is calculated as:

$$k = \frac{K}{s}. \qquad (2)$$

Here *K* – slip modulus of the connection; *s* – distance between shear connectors.

Basing on Eurocode 5 [5], the slip modulus in calculations of cross-sectional sub-components connected by mechanical fasteners shall be determined by a push-out test according to EN 26891 [6], or by empiric formulae presented in Eurocode 5. Nevertheless, they are applied for cross-sections with splicing connections between the sub-components whereas in this paper a connection of a disparate behaviour embedded TCC joisted floor is analysed. Moreover, the mentioned technique does not cover all types of connectors used in connections. Therefore push-out tests were used in this research for establishing the behaviour and slip modulus of TCC joisted floor connection between the web and the concrete slab.

3. TCC joisted floor connection

As it was mentioned above, the behaviour of TCC structures is strongly affected by the stiffness and resistance of the connection between the joist web and the concrete slab. The connection purpose is to resist the longitudinal shear forces acting in the interlayer.

In the testing programme, the timber web is connected to the concrete slab by embedding a part of it into the concrete slab. Moreover, 25 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. The steel connector type was studied in [7].

4. Specimens and equipment

The goal of the research was to establish by tests the load-slip relationships and mechanical indices of the concrete dowel connectors.

The specimens are presented in Fig 4.

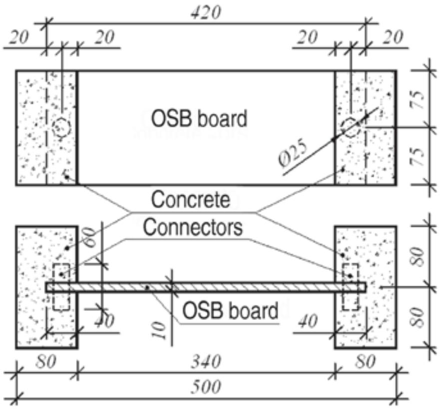


Fig 4. General schematic view of specimens

The timber part of specimens was made from 10 thick OSB, of class III. Their mechanical indices were established by tests and presented in [8].

The fine-grained concrete mix of mobility class S4 was made in UAB "Palmusta". The concrete compressive strength conformed to the class C30/37 [9] (after 28 days being 39,68 N/mm^2). During the concrete hardening period the specimens were kept at indoor temperature and humidity under polythene mantles.

In specimens the "sleeved" metal connector (Fig 5) was used. It was 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 (which external diameter is 25 mm with small longitudinal gap).

Fig 5. "Sleeved" connector

Fig 6. View of the test equipment and the set-in specimen

Composite timber-concrete specimens for this test were made at the laboratory of the Dept of Steel and Timber Structures of the Vilnius Gediminas Technical University (VGTU). The test equipment (Fig 6) was designed in this laboratory as well.

5. Test progress

Short-term push-out tests of connections between the OSB web and concrete part were performed according to the requirements of EN 26891 [6, 10] applying the load-time curve recommended by this standard (Fig 7).

The first specimens were tested after 28 days of concrete hardening.

Push-out tests of TCC specimens were performed at the above-mentioned laboratory by the testing equipment ZIM P10 with 5 tonne capacity load cell, and with Digicon 2000 control console.

The slip between the OSB web and concrete part was measured using four linear voltage displacement transducers (Fig 6).

The information provided by the linear voltage displacement transducer was processed by software ALMEMO AMR5.

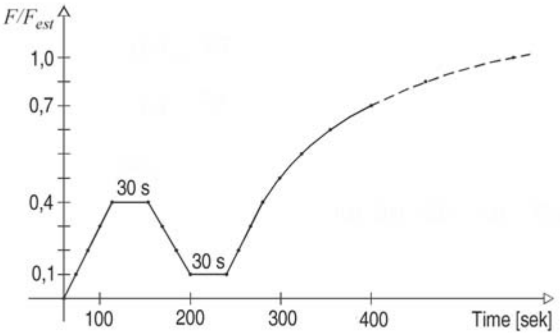


Fig 7. Load-time curve of push-out test of the connection. F – load applied to the specimen, F_{est} – estimated maximum load

6. Test results and failure mechanics

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 ie the ratio between of the force $0{,}4 \cdot F_{max}$ and force indicating the connection slip.

Table 1. Test results

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 8).

Fig 8. View of failure in specimen connection

Load-slip curves of the most of specimens complied with the plastic behaviour, ie any sudden failure of connections was observed (Fig 9).

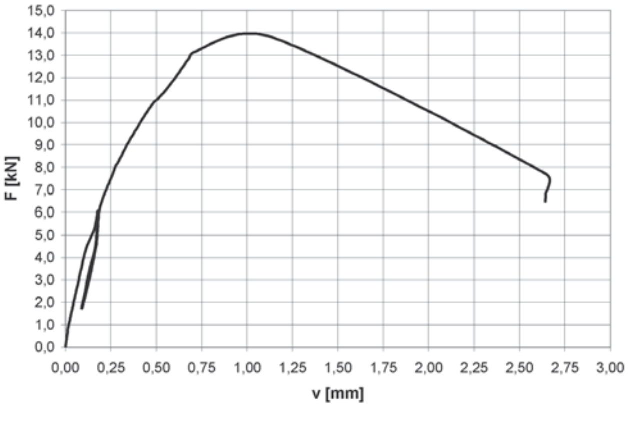


Fig 9. Load-slip curve for specimens

The values of slip modulus of connection that where established in short-term loading tests have quite different coefficients of variation for separate series of tests. In the authors' opinion, different results were obtained because of the influence of a higher coefficient of variation of mechanical properties of the OSB itself [8]. Coefficients of variations of mechanical properties of concrete, OSB and connectors are presented in Table 2.

Table 2. Coefficients of variation of mechanical properties

Material	Mechanical properties	
	Modulus of elasticity	Strength
Concrete	–	7 %
OSB board	6–30 %	6–30 %
Connector	5–35 %	5–24 %

7. Theoretical stress analysis of TCC joisted floor

A floor of a dwelling house with the span L=7,0 m, and timber joists located every 0,5 m was selected for the theoretical analysis of TCC joisted floor. The applied load on the floor is 4,06 kPa. I-joist web is of 10 mm thick OSB 3, bottom flange of the joist is made of C24 class timber girder (45×90 mm). Concrete slab of the floor is 80 mm thick, concrete class C30/37. Mechanical properties of materials were chosen from [5, 9, 11]. The joist concrete slab and OSB web are connected by 25 mm diameter concrete "dowels" located every 75 mm. The computational scheme and cross-sectional dimensions of the analysed TCC joisted floor are presented in Fig 10.

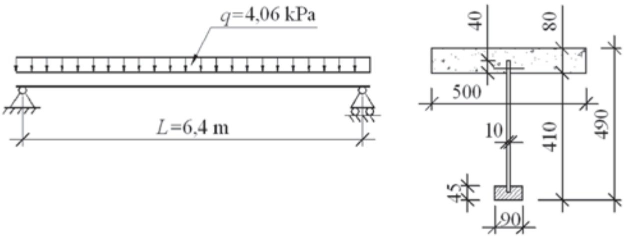


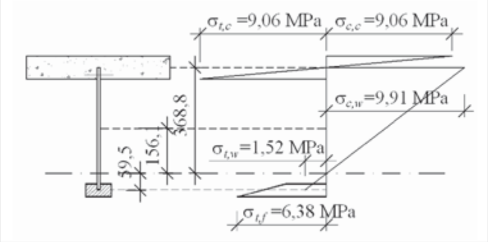
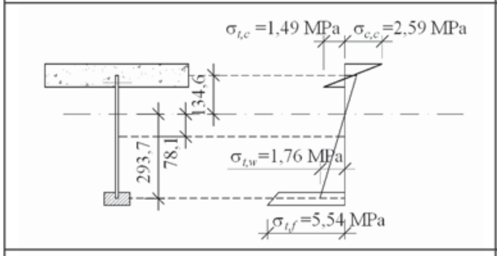
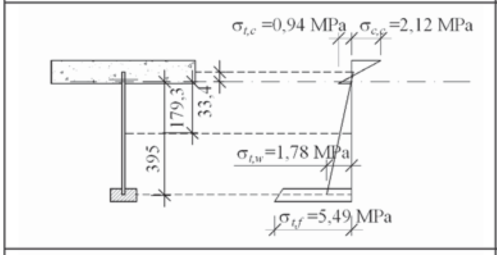
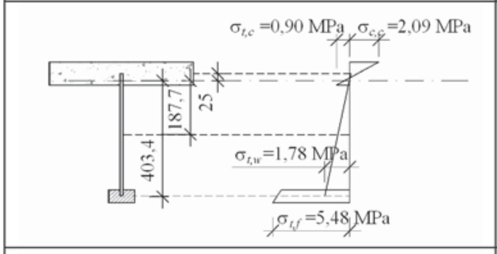
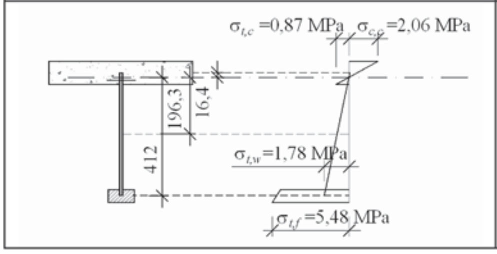
Fig 10. Computational scheme and cross-section of TCC joist

The following constant parameters and indices were assumed in the analysis: pitch of timber joists, distance between connectors, concrete and timber classes, and thickness of OSB web.

Theoretical analysis was made by the method of composite cross-section reduction (called also as γ-method) presented in [5, 12] and technique of glulam thin-webbed beam design in [5, 13]. Usually the reduction method for composite structures is applied, when load-slip relationship is close to the linear elastic behaviour. When the load-slip relationship of connection is non-linear, the elasto-plastic model is applied for its evaluation without consideration of slip modulus of connection [14].

Stresses and their distribution in the joist concrete slab, in web, in timber board flange and the different positions of the neutral axis (NC) of the cross-sections due to changing values of connection slip modulus K_{ser} were established by the above-mentioned theoretical analysis. The values of slip modulus K_{ser} are selected so as to comply with the set of experimental values set received during the test (Table 1). Theoretically, analysis of the TCC joint was performed: the concrete compressive $\sigma_{sc,c}$ and tensile $\sigma_{st,c}$ stresses; stresses of the bottom timber board flange $\sigma_{st,f}$ web tensile $\sigma_{st,w}$ and tensile s*sc,w* stresses. According to the received values, theoretical diagrams are presented in Table 3.

Table 3. Distribution of stresses at the height of the cross-section depending on slip modulus K_{ser} of connection

Stress diagrams of TCC cross-section	K_{ser} [kN/m]
	$K_{ser}\to 0$ $\gamma=0$
	3000 $\gamma=0,08$
	29788 $\gamma=0,46$
	60000 $\gamma=0,64$
	$K_{ser}\to\infty$ $\gamma=1,0$

The results of theoretical analysis presented in Table 3 indicate that on the TCC joisted floors a great influence has the slip modulus of the connection K_{ser}. With the decrease of the slip modulus of some sub-components of composite cross-section, their stresses increase.

When for analysis of theoretical distribution of stresses in TCC cross-section the obtained experimental value of slip modulus of connectors $K_s = 29788$ kN/m was used, factor γ of the efficiency of the interlayer connection was received equal to 0,46 (it is between zero and unit); it means that the "sleeved" connector is suitable for application in a semi-rigid connection system.

8. Conclusions

An innovative concept of a TCC joisted floor, in which the concrete slab for the top flange is applied, and the timber joist is a compound overturned T-joist structure consisting of OSB web with bottom flange of glued to web timber joist, is presented.

Short-time push-out tests on the TCC joisted cross-section connection between the part of concrete slab and OSB web were performed. Load-slip parameters in connections were established.

It was found that the slip modulus values of joints in TCC specimens have a big dispersion which is also characteristic of the tests of timber elements joints.

For reasoning the theoretical distribution of stresses in TCC joisted floor sub-components inter-connected with the shear "sleeved" connectors, it is necessary to fulfill additional investigations and test the fragments of TCC joisted floor of natural dimension.

References

1. Fournely, E. et al. Structural behaviour in mixed buildings. In: Improvement of buildings' structural quality by new technologies. COST C12, Lisbon, Portugal, 2003, p. 3–19.
2. Taylor, S. B.; Hua, G. Dynamic performance of wood framed floor systems with poured toppings. In: 6th World Conference on Timber Engineering (WCTE), paper 4.6.3, Whistler, British Columbia, Canada, 2000.
3. Benitez, M. Tests and analytical evaluation of a composite flooring system. In: 8th WCTE, Lahti, Finland, 2004, p. 549–554.
4. Sigrist, Ch.; Gerber, Ch. Evaluation of floor systems for multi-storey buildings. In: 6th WCTE, paper 4.6.2, Whistler, British Columbia, Canada, 2000.
5. European Standard, prENV 1995-1-1 (Eurocode 5): Design of timber structures. Part 1-1 General rules and rules for buildings, Final draft 2001. 121 p.
6. LST EN 26891 Timber structures – Joints made with mechanical fasteners – General principles for the determination of strength and deformation characteristics (ISO 6891:1983). Vilnius: LSD, 2000. 6 p.
7. Gurkšnys, K.; Kvedaras, A.; Valiūnas, B. Composition of thin-webbed timber beams with concrete slab in floor struc-

tures. In: Proceedings of the International Symposium on Advanced Timber and Timber-Composite Elements for Buildings. COST-E29, Florence, Italy, 2004, p. 77–82.

8. Suško, A. Theoretical and experimental analysis of thick OSB – timber connection (Storos OSB plokštės su medienos jungties vinimi teorinis ir eksperimentinis tyrimas). Vilnius Gediminas Technical University, Master degree work, 2003. 85 p. (in Lithuanian).
9. European Standard, prEN 1992-1 (Eurocode 2): Design of concrete structures - Part 1: General rules and rules for buildings, Final draft 2001. 230 p.
10. Čechavičius, R. Slip of "Bulldog"-type toothed-plate connectors in steel-timber joints of open-web girders. *Journal of Civil Engineering and Management,* Vol X, Suppl 1. Vilnius: Technika, 2004, p. 23–29.
11. LST EN 12369-1 Wood-based panels – Characteristic values for structural design – Part 1: OSB, particle boards and fibre boards (Medienos skydai. Charakteristinės vertės, taikomos statybiniam projektavimui. 1 dalis. OSB, smulkinių ir plaušų plokštės). Vilnius: LSD, 2002. 16 p. (in Lithuanian).
12. Kuhlmann, U.; Schanzlin, J. Calculation of timber-concrete composite floors (Berechnung von Holz-Beton-Verbunddecken). In: Proceedings of seminar for timber-concrete composite systems (Fachtagung Holz-Beton-Verbundbau). Stuttgart University, 2003, p. 25–60 (in German).
13. Solli, K. H. Glued thin-webbed beams, In: Timber Engineering – STEP 1. Eds.: Blass H. J., Aune P., Choo B. S. et al. Almere: Centrum Hout, 1995, p. B9/1–B9/8.
14. Frangi, A.; Fontana, M. Elasto-Plastic Model for Timber-Concrete Composite Beams with Ductile Connection. *Structural Engineering International* (IABSE), Vol 13, No 1, 2003, p. 47–57.

KOMPOZITINIŲ MEDINIŲ-BETONINIŲ PERDANGŲ „ĮVORINIŲ“ JUNGIŲ LAIKYSENOS TYRIMAS

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Santrauka

Aptariamas sijinės perdangos konstrukcinis sprendimas, kai sudėtinio skerspjūvio medinė sija ir betono plokštė tarpusavyje sujungiamos per specialią iš dalies standžią jungtį ir sudaro kompozitinį medinės-betoninės sijinės perdangos elementą. Šio elemento tempiamoji apatinė juosta padaryta iš vientisos medienos lentų, sienelė – iš orientuotųjų skiedrų plokštės (OSB), gniuždomoji viršutinė juosta – iš betono plokštės, į kurią įleista sienelės dalis. Tirta šioje sienelės dalyje tarp OSB ir betono plokščių esanti „įvorinė“ jungtis, skirta šios jungties standumui padidinti. Atlikti kompozitinės medinės-betoninės sijinės perdangos sudėtinių dalių tarpusavio jungčių laikysenos teoriniai ir eksperimentiniai tyrimai, pateikti ir įvertinti gauti rezultatai.

Raktažodžiai: kompozitinė medinė-betoninė konstrukcija, medinė plonasienė sija, slinktis, iš dalies standi jungtis, slankumo modulis, šlyties jungė, išstumiamasis bandymas.

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