ISSN 2522-4182

DOI: 10.32347/2522-4182.15.2024.156-173
УДК 624.011

STRUCTURAL BEHAVIOUR ANALYSIS OF A CLT CONNECTION WITH BONDED-IN RODS UNDER SHEAR LOADING

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Abstract. The test results presented in this paper show the load-carrying capacity, deformability and failure modes in shear in-plane and out-of-plane of CLT panels with the newly developed solution of a universal connector for CLT timber structures, which offers the possibility of quick and easy installation and assembly, as well as easy disassembly and reuse. This solution shall contribute to the necessary reconstruction of the damages in Ukraine and facilitate the quick restoration of housing as well as providing a long-lasting sustainable and circular connection solutions. The developed connector is a unit in the form of a steel plate on glued-in rods, that are embedded in the CLT panels and developed in the frame of research project "ReConnect - Efficient connections for modular prefabricated timber buildings to help reconstruction in Ukraine". This allows to connect CLT panels in various arrangements together or to other building parts such as foundations or concrete cores. Connections with glued-in rods are widely used in Eastern European countries, especially in long-span timber structures for buildings of various types. ReConnect is funded by Swedish Institutet, the partners from O.M. Beketov National University of Urban Economy in Kharkiv (Ukraine), Chalmers University of Technology,

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Keywords: glued-in rods (GiR), bonded-in rods, combined loading, group effects, universal joint, CLT panels, connector.

INTRODUCTION BACKGROUND

Building with timber and the shift of the construction sector towards a circular economy are key elements to success in order to achieve a more sustainable built environment and a more sustainable society. Very often the experience, skills, and workmanship regarding timber on the construction site are limited. Besides training also the development of simple connection and detailing solutions need to be developed, that can be easily and safely applied by unskilled personnel. Prefabricated connections with bonded-in rods or bolted connections are examples of such solutions.In their development it as to be put emphasis on long-lasting sustainable and circular solutions instead of unsustainable single use solutions of buildings. Adaptable buildings that can be extended over time are suitable to provide quick shelter for many and allows the further extension when recourses are available. Modular prefabrication of elements allows the fast production, construction, and even reaction to local demands.

There are different examples of connections that can be seen as first steps towards the direction of a universal timber connection systems that allow for high performance, prefabrication, easy application, dis-assembly and reuse. Examples are: Bolts, dowels, screws, or bonded-in steel rods. Especially bonded-in rods allow for a direct transfer of tension forces along the grain direction of the timber. By placing rods at different inclination into the timber, brittle failure in the timber in tension perpendicular to the grain can be prevented and the connection can resist a variety of loading directions. By combining the rods with adequate connection elements into one system, it becomes possible to prefabricate, assemble and disassemble timber components. The rods remain in the timber but the connector element can be easily adapted and re-connected. Such a connection system has to be developed towards predictability of behaviour, universality in application, reusability and efficiency.

THE PROJECT RECONNECT AND APPLICATION AREA OF CONNECTOR

The project has the objective to develop a novel connection system for timber members that makes it possible to adopt the concepts of reusability, adaptability and circularity of members in timber structures. By optimizing the connection layout, we intend to enhance the performance towards low damage and to avoid brittle failure modes in the timber. The project will reduce the complexity of high-performance connections for timber buildings and lower the entrance barrier towards the use of timber in structures. Often the experience, skills, and workmanship regarding timber on the construction site are limited. Besides training also the development of simple connection and detailing solutions need to be developed, that can be easily and safely applied by unskilled personnel. Prefabricated connections with bonded-in rods or bolted connections are examples of such solutions.

The conducted primary tests of the connector made it possible to evaluate the parameters of strength and deformability relative to the data obtained during calculations using existing methods of glued-in rods as dowels when loading them perpendicularly relative to the axis of the glued-in rod. A statistical analysis of the obtained experimental data was conducted, the characteristic values of the connector strength and the magnitude of the slip module were determined as the main necessary parameters for using this joint in CLT building.

The prefabrication of the proposed connection in the factory and its uniform spacing along the edges of CLT panels makes it possible to produce entire series of unified building components of different sizes and layout solutions, see. The regular spacing allows that the CLT panels can be prefabricated mostly independent of its later application, and they can be combined in different arrangements in a structure depending on the specific demand.

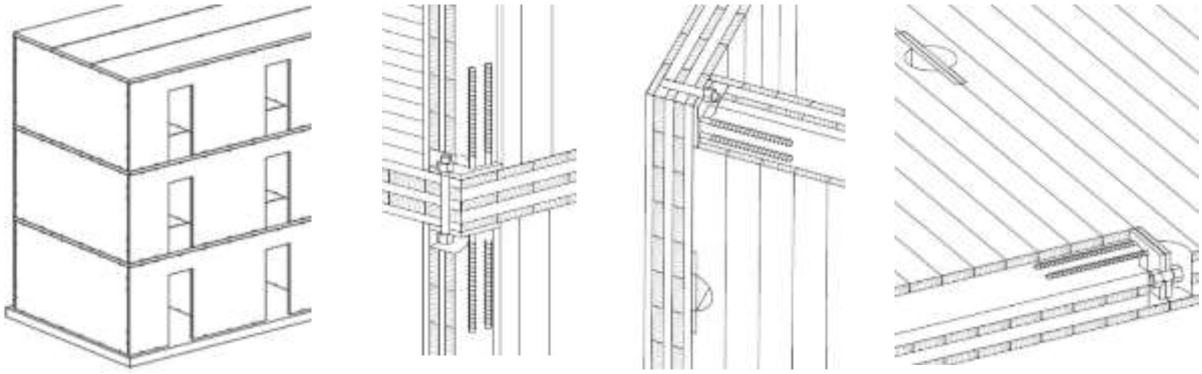


Fig. 1 Options for using a unit in a building made of CLT panels.
Рис.1.Приклад застосування конектору у каркасі будівлі з ПКД панелей

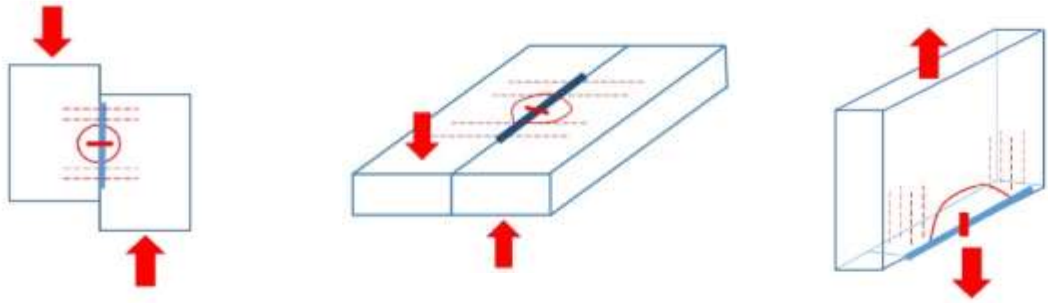
The connector is installed in the side face of CLT panels in a pre-milled recess for the plate and can be completely hidden in the interior or invisible, which is also good in fire conditions

For the first time, this type of connection for CLT panels was proposed [13] in the frame of the EECTC conference in Kharkiv (Ukraine) in 2018. In the conference proceedings tests of glued-in rods in CLT samples were reported (Bidakov et al. 2018), where pull-pull configuration with different variants for their location in the panel cross section were studied. To date, many laboratory tests have already been carried out on glued-in rods in CLT, both single (Andersen &Høier 2016[9], Azinovic et al. 2018[11], Azinovic et al. 2019[12], Jockwer et al. 2023 [15], Stepinac et al. 2013 [17]) and groups of glued-in steel rods (Ayansola et al. 2022) [10], and others [18- 25]. However, this new connection type requires further laboratory testing on the full connection, since the metal plate can redistribute the actions to the different rods. Depending on the loading condition of the CLT panel and subsequently the connector the rods experience various loading conditions, including complex stress states with simultaneous axial loading with pull-out of the rod and lateral loading with the rod acting as a dowel and stressing the timber perpendicular to the grain. Another possible complex combination of stresses is pullout and torsion.

For an initial assessment of the load-bearing capacity of the connection with the steel plate and glued-in rods in a CLT panel and for the evaluation of the prospects for its serial use, analytical calculations and modelling of a 3-story building were carried out.

The current draft version of Eurocode-5 (prEN1995-1-1: 2023,[16]) (prEN 2023) contains recommendations regarding design of bonded-in rods (BiR) and, hence, opens the possibility of a more wide implementation of BiR solutions in practice. The design standard works together with the testing standard for the bondline strength in EN 17334(EN 2021) [14], which assures the high-performance and high quality of the BiRsolutions.To consider the variety of loading states acting on the connector, different tests have to be performed. An overview of the possible tests carried out in this project are shown in this project are shown in.

The geometric configuration is provided for connecting CLT panels with a thickness of 100-120 mm since the width of the metal plate is 80 mm and must be hidden. For CLT panels 120-140 mm, it is proposed to use a connector with a plate width of 100 mm, in order to increase the load-bearing capacity of the connection. From a static point of view it is important to reduce the distance from the edge of the panel to the axis of the glued-in rods, which should,however, not be less than 2.5 d according to EOTA TR 070 (EOTA 2019) [5] or prEN1995-1-1:2023 (prEN 2023)[16]in order to avoid splitting. Increasing the distance from the edge of the CLT panel to the axis of the rods improves furthermore its fire resistance. Hence, the position of the rods in the panel must be carefully chosen to achieve high efficiency and still keep the rods in the longitudinal layers of the panel.



a *b* *c*

Fig . 2 Test configurations for the connector: shear in-plane *a*- shear out-of-plane *b*, pull-pull *c*
Рис.2.Схеми випробувань конектору: зсув у площині панелей (а), зсув з площини панелей (б), розтяг або висмикування (в).

The option of attaching the plate to the CLT panel with full-threaded screws is also possible as one of the variations of this type of connector. Particularly efficient and low compliance of the connection can be ensured by inclined screws in different directions. Inclined screws have low slip deformations and can be quickly installed in production without quality control of the connection, unlike glued-in steel rods. A connection with screws can be a second equivalent version of the developed system for connecting building frame panels, which is based on the same pitch of standardized connections along the edges of the CLT panel, DLT panels or GLT elements.

MATERIALS AND METHODS
CONNECTOR GEOMETRY

The proposed type of connection consists of a 12 mm thick steel plate (steel grade S355) to which steel bars RiBa A500C diameter 10 mm are welded. The length of the reinforcing bars is 150 mm. The bars are glued into pre-drilled holes using a two-component epoxy adhesive system, see. To distribute the high shearing or pulling forces across the thickness of the CLT panel with its orthotropic and heterogeneous boards, it was decided to use 8 glued-in rods for the connection.The steel plate has 8 holes for the rods and a centric hole of 23 mm diameter in the middle of the plate for connecting it with a bolt M20 to the other unit in another CLT panel . The connection between the steel plate and the CLT panel is rigid due to the lack of slip deformation in the timber element, and deformations might only occur in bending of the steel plate. This connector can also be attached to reinforced concrete members or foundations. It is also possible to attach such a connector to steel components and structures or even weld them to them with a discontinuous seam. The connector has a semi-circular milled hole in the CLT panel around at 2/3 of its thickness to allow installation of a bolt or nut

This connector unit makes it possible to assemble and connect CLT panels in 6 main cases: a) two floor panels parallel to the span, b) two wall panels in a planar manner, c) two wall panels at the corner of a building (L shape), d) a longitudinal wall panel and a transverse wall or partition wall (T-shape), e) wall panel to the foundation, f) floor to wall joint. It is also possible to attach beams and columns to CLT panels using the proposed unit in combination with glulam beams.

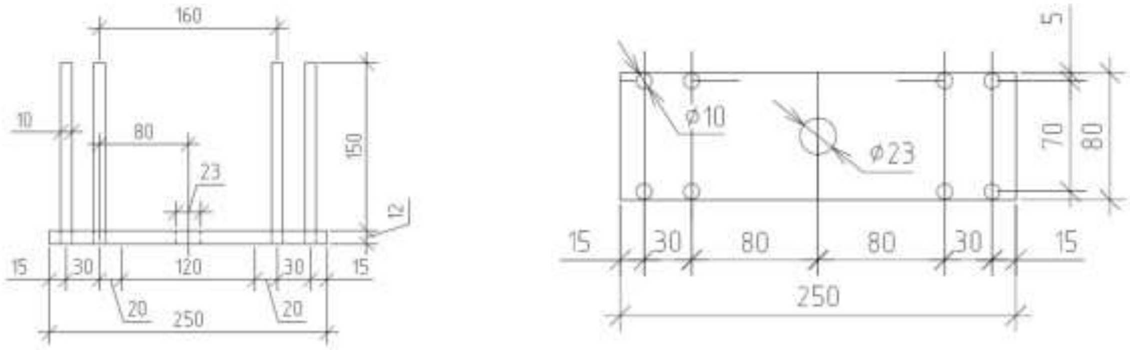


Fig. 3. Geometric parameters of the connector
Рис.3. Геометричні параметри конектора

a *b* *c*

Fig. 4. General view of the installation of the connection (a) and assembly of two units (b) and of the unit directly to CLT panel (c) Photo by Andrii Bidakov

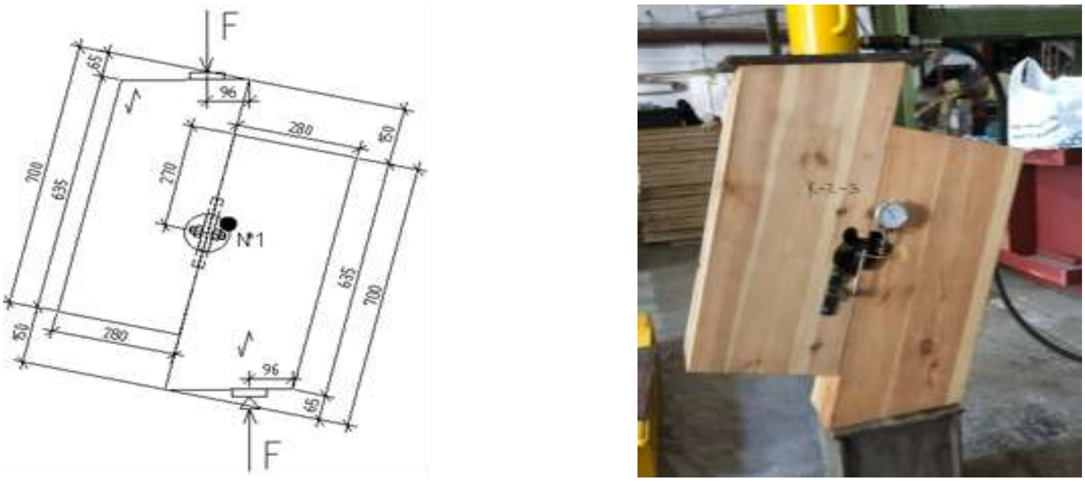
Рис.4.Загальний вид контактора (а) та стикування двох пластин (b) і стикування пластини конектора напряму з іншим елементом із ПКД панелі (с). Автор фото Андрій Бідаков

SHEAR IN-PLANE. SIZE OF SPECIMENS AND TESTS SETUP

The tested connection was between two CLT panel parts with dimensions280×700mm and a thickness of the panel of 140mm with board layers 40/20/20/20/40mm, see Fig.5. The specimens had undercuts on the supports to ensure an inclination of the connection of about 14˚ and the application of a load along the vertical axis passing through the centre of the tested connection. Measurement devices were attached on the sides of the connection near the joint line for relative displacement measurements on the front of the test specimens.

The test specimens were loaded with a universal 500 kN jack. During the test, both thejack force and the relative displacement between the two members of the connection were measured. The test procedure and the evaluation were based on EN26891 [6]. Both the ultimate load $F_{V,test}$and the stiffness k_s per connector were determined. The stiffness was determined in the range between 10% and 40% of the ultimate load in the linear-elastic range. Five test specimens were tested for serie K-2.

The connection components of the studied samples had strict geometry and the connection of the parts of the connection was performed with one M20 bolt with firm tightening by hand. The level of tension of the bolt was not controlled. The small diameter of the hole in the CLT panels (Fig. 6) for tightening the bolt during testing was increased to make it possible to install bolts with a diameter of M22 and M24, since the M20 bolts were destroyed before the destruction of the wood around the glued-in steel rods began, which needed to be investigated.



a *b*

Fig . 5 Geometry of tested connection (a) and scheme of loading (b). Photo by Andrii Bidakov

Рис. 5. Геометричні розміри випробуваних зразків(a) та схема прикладання навантаження (b). Автор фото Андрій Бідаков

a *b*

Fig. 6 General view of the specimen before test. Photo by Andrii Bidakov

Рис. 6. Загальний вид зразків перед випробуваннями. Автор фото Андрій Бідаков

SHEAR OUT-OF-PLANE

The tested connection in CLT panels loaded out-of-plane had dimensions 750×2000mm with thickness of the panel of 100mm with boards layers 20/20/20/20/20mm, see Fig.7.

a *b*

Fig. 7 Panels with connectors before tests out-of-plane. Photo by Andrii Bidakov

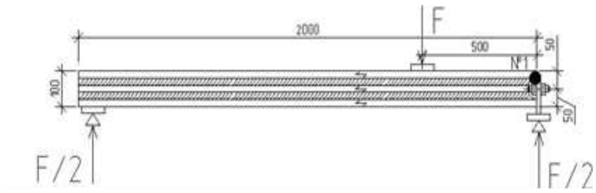
Рис. 7. Панель з конектором перед випробуваннями на зсув із площини. Автор фото Андрій Бідаков

The specimen was positioned horizontally and located on two supports in such a way that one support point was in the form of a metal plate fixed to the connector with a bolt. The support of this end of the panel with the connector was through the edge of the fixed plate, which had a width greater by 40 mm, which made it possible to develop deformation of the connector when loading the panel along a line at a distance of 500 mm from the connector (Fig.8). The panel support is hinged. Measurement devices were attached near the connectionon the top of the CLT panelfor relative displacement measurement of the test specimens. The total number of tested specimen s of series P-1 was 5 pcs.The test specimens were loaded with a universal500 kN jack. During the test, both thejack force and the relative displacement between support and outer layers of CLT panel were measured. The ultimate load $F_{V,test}$and the stiffness k_s per connector were determined. The stiffness was determined in the range between 10% and 40% of the ultimate load in the linear-elastic range.

Each sample was loaded until failure during testing. At all stages of loading, a visual absence of connection curvature was noted as a result of uneven distribution of the load between the glued-in rods.

STRENGTH AND DEFORMATIONS
SHEAR IN-PLANE

Load-displacement plots for series K-2 or shear in-plane are shown on Figure 9



a

b

Fig. 8.Geometry of tested specimens (a) and scheme of loading (b) Photo by Andrii Bidakov

Рис. 8. Розміри випробуваних зразків та схема навантаження. Автор фото Андрій Бідаков

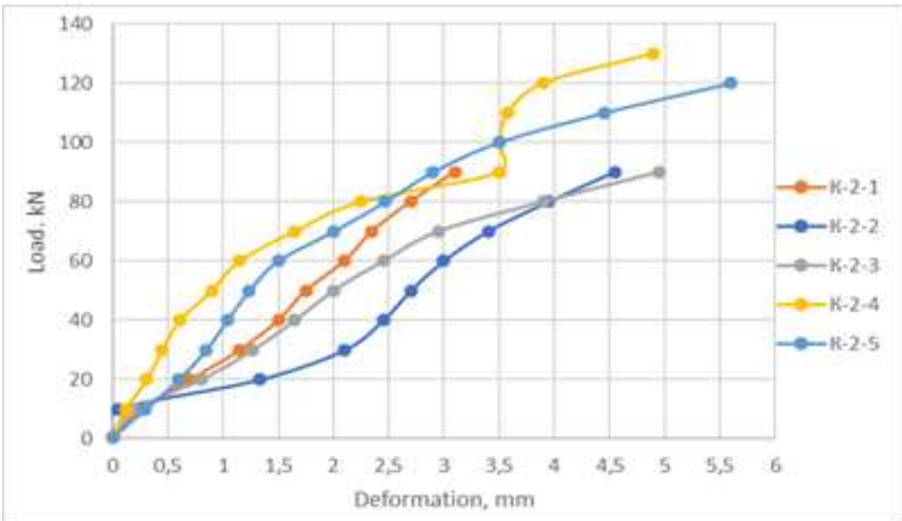


Fig. 9 Force-displacement plots for tests of series K-2

Рис. 9 Графік навантаження-переміщення для зразків серії К-2

The deformation of steel rods welded to a metal plate after testing the connections has a characteristic classic bending shape as in single shear dowel type steel-timber connections with thick steel plates, see fig. 10-b) from (Jockwer and Jorissen, 2018) [3]. According to EOTA

TR070:2019-10[5] the glued-in steel rods by loads acted perpendicular to rods axis needs consider as dowels. The bending intensity of one group of rods (4 rods) is greater than that of the other group (fig. 10-a) by the testing connections in the plane of the CLT panel's, which is explained by the existing heterogeneity of the panel structure and the uneven distribution of forces in the metal plate itself.

For dowels where d>8mm in timber-to-timber and woodbased panel-to-timber connections according to EN1995-1-1[8]:

$$K_{ser} = \frac{\rho_k^{1,5} \cdot d}{23} = \frac{350^{1,5} \cdot 10}{23} = 2{,}847 kN/mm \qquad (1)$$

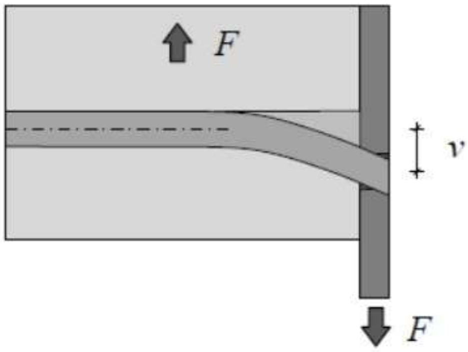
for 8 dowels: K_{ser}=2,84*8=22,72kN/mm

The test procedure and the evaluation were based on DIN EN26891 [6]. Both the ultimate load $F_{V,test}$ and the stiffness k_s per connector were determined. The stiffness was determined in the range between 10% and 40% of the ultimate load in the linear-elastic range.

$$k_s = K_{ser} = \frac{0{,}4 \cdot F\max - 0{,}1 \cdot F\max}{\upsilon_{04} - \upsilon_{01}} \qquad (2)$$

The mean value of the slip modulus in the shear tests of the connector in the CLT plane of the panel is Ks=31.28 kN/mm.

a



b

Fig. 10 Deformations of steel rods after test (a) and scheme of the work steel-timber dowel type connectors (b) from [3]

Рис.10. Деформації сталевих стержнів після випробувань (а) та схема роботи штифтових з'єднань сталева пластина-деревина (b) згідно до [3]

Table1. Slip module $k_{s,connector}$ for joint with dowel-type fasteners per shear plane by tests in-plane of the specimen serie K-1

Табл.1. Модуль ковзання $k_{s,connector}$ для штифтових з'єднань на один шов зсуву при випробуваннях у площині панелі для серії зразків К-1

	υ_{01},mm	υ_{04},mm	F_{01}, kN	F_{04}, kN	k_s, kN/mm
K-2-1	0,538	1,4748	9,82	39,28	31,45
K-2-2	1,202	2,443	9,95	39,8	24,05
K-2-3	0,692	1,636	9,91	39,64	39,64
K-2-4	0,193	1,037	13,87	55,48	49,31
K-2-5	0,362	1,204	12,05	48,2	42,91

The method according to EN 14358 [7] can be used taking 5 individual test results into account for the determination of the characteritic value of load-carrying capacity of the considered connector by assumption of logarithmic normal distribution (3) – (8).

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n}\ln m_i \qquad (3)$$

$$s_y = \max\left\{\begin{array}{l}\sqrt{\dfrac{1}{n-1}\sum_{i=1}^{n}(\ln m_i - \overline{y})^2}\\ 0{,}05\end{array}\right. \qquad (4)$$

$$m_k = \exp(\overline{y} - k_s(n)s_y) \qquad (5)$$

$$k_s(n) = \frac{6{,}5n+6}{3{,}7n-3} \qquad (6)$$

n=5 and corresponding ks=2,48

$$m_k = \frac{F_{V,calcul,i}}{F_{V,Test,i}} = \frac{Calculated}{Tested} \qquad (7)$$

$$F_{V,Test,k}=74954{,}7N=74{,}96kN$$

for one connector with 8rods (d10 mm and length 150 mm)

$$F_{V,calcul,k}= F_{V,k}*8rods \qquad (8)$$

$$F_{V,calcul,k}= F_{V,k}*8rods=7715{,}8N*8=61726{,}4N=61{,}7kN$$

$$m_k = \frac{F_{V,calcul,i}}{F_{V,Test,i}} = \frac{Calculated}{Tested} = \frac{61{,}7}{74{,}96} = 0{,}823$$

The load-carrying capacity of the connection is higher than the calculated value, which confirms the possibility of using the existing methodology for calculating glued-in rods as dowels by shear of the considered connector in-plane of CLT panel.

The characteristic value of the load-carrying capacity of the connector by shear in plane of the CLT panel is 74,96kN according to test results and 61,7kN according to the calculation.

SHEAR OUT-OF-PLANE

Load-displacement plots for series P-1 or shear out-of-plane are shown on Figure 11.

Statistic parameters of slip module $k_{s,connector}$ by tests out-of-plane:

Mean value 32,54kN/mm

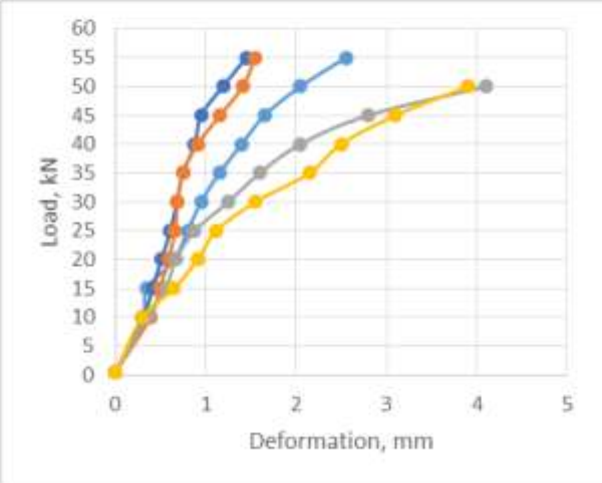


Fig. 11 Force-displacement plots for tests of series P-1

Рис.11. Графік навантаження-переміщення для зразків серії К-2

Table. 2. Slip module $k_{s,connector}$ for joint with dowel-type fasteners per shear plane by tests out-of-plane of the specimen serie P-1

Табл.2. Модуль ковзання $k_{s,connector}$ для штифтових з’єднань на один шов зсуву при випробуваннях із площині панелі для серії зразків P-1

	υ_{01},mm	υ_{04},mm	F_{01}, kN	F_{04}, kN	k_s, kN/mm
P-1-1	0,203	0,821	6,42	25,68	31,18
P-1-2	0,212	0,623	6,48	25,92	47,25
P-1-3	0,262	0,663	6,39	25,56	47, 8
P-1-4	0,224	0,825	5,92	23,68	25,59
P-1-5	0,188	1,07	5,96	23,84	20,25

Using the above methodology for calculating the characteristic value of the load-carrying capacity of the connection as group of dowels by shear tests in-plane and out-of-plane in CLT panel equal:

$$F_{V,calcul,k}= F_{V,k}*8rods=7715{,}8N*8=61726{,}4N=61{,}7kN$$

Characteristic value of the connectors carrying capacity based on test results and determined acc. to algorithms of the standard EN14358:

$F_{V,Test,k}=55017,3N=55,2kN$ for one connector with 8rods (d=10mm and length 150mm).

$$m_k = \frac{F_{V,calcul,i}}{F_{V,Test,i}} = \frac{Calculated}{Tested} = \frac{61,7}{55,2} = 1{,}118$$

RESULTS AND DISCUSSION
STATISTIC PARAMETERS OF TESTED SPECIMENS

Statistical parameters of laboratory static test results are the basis for qualitative assessment of strength and deformability of the joint. Based on statistical parameters, it is possible to determine characteristic values necessary for performing engineering calculations and comparing the obtained valueswith the values obtained by existing calculation methods for the joint in question.

Regression model statistics by shear tests in-plane: coefficient of correlation 0,4987; covariance of two samples 6,68 and standard error 0,931. Regression model statistics by shear tests out-of-plane: coefficient of correlation –0,9438; covariance of two samples −2,566 and standard error 0,479..

The equation of the linear regression function:

- in-plane

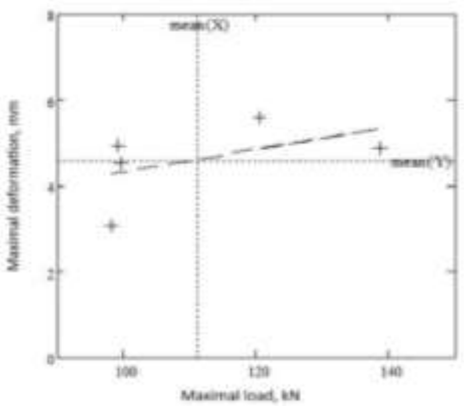
$$r(x) = b_0 + b_1 \cdot x; \; r(x) = 1{,}752 + 0{,}026 \cdot x; \qquad (9)$$

- out-of-plane

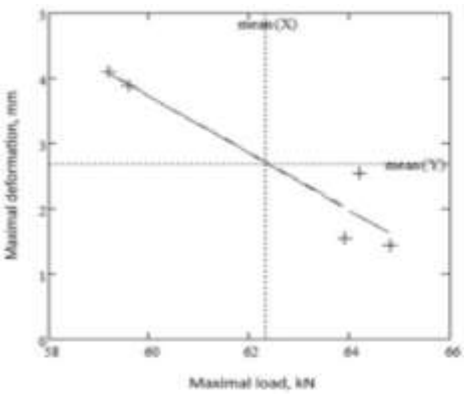
$$r(x) = b_0 + b_1 \cdot x; \; r(x) = 30{,}001 - 0{,}438 \cdot x; \qquad (10)$$

where $r(x)$–maximal deformation (mm) and x–maximal load (kN).

Analysis of the graph of the linear regression function of the statistical sample of maximum deformations on the statistical sample of destructive loads (see Fig. 12) shows that the experimentally obtained points do not go beyond the upper and lower limits of the confidence interval.



a



b

Fig. 12 Graph of the linear regression function of the statistical sample of maximum deformations on the statistical sample of destructive loads
a - in-plane; *b* - out-of-plane

Рис.12. Графік функції лінійної регресії статистичної вибірки максимальних деформацій на статистичну вибірку руйнуючих навантажень
a – у площині панелі; *b* – із площини панелі.

ISSN 2522-4182

The coefficient of variation of slip modulus in the shear tests in-plane of the connector in the equal COV=37.66% and coefficient of variation of the strength for this series of assemblies is quite high (16.13%) that shows a relatively large spread of connector strength results across samples. By shear tests of the connector out-of-plane in the CLT panel COV=38.7% and coefficient of variation of the strength is quite low (4.34%) and shows a relatively small spread in the strength results of the samples.

The value of the correlation coefficient of two samples is r = 0.4987, below the threshold value of the correlation coefficient (*table. 9.2, p. 162*[1]) r (P = 0.95; f = 5-2 = 3) = 0.88, where *P* – the limits of the confidence interval, *f* – the number of degrees of freedom.

This indicates the significance of the determined correlation coefficient.

Table 3. Data of statistical indicators of linear regression of destructive loads and maximum deformations of connections by shear test in-plane and out-of-plane

Табл. 3. Дані статистичних показників лінійної регресії руйнуючих навантажень і максимальних деформацій вузлів з конектором при випробуваннях у площині та із площини панелі

	Average value	Median	Standard deviation	Dispersion
	shear in-plane			
Maximal load, kN	111,2	99,5	17,933	323,76
Maximal deformation, mm	4,62	4,9	0,93	0,866
	shear out-of-plane			
Maximal load, kN	62,34	63,9	2,707	7,328
Maximal deformation, mm	2,71	2,55	1,256	1,577

Limits of 95% confidence intervals for linear regression equations (in our case n = 5) with satisfactory accuracy are recommended to be estimated using the expressions (11 – 12) [2], given on p. 408:

- in-plane

$$D = \sqrt{\frac{\sum(Y - mean(Y))^2 - \frac{(\sum(X - mean(X)) \cdot (Y - mean(Y)))^2}{\sum(X - mean(X))^2}}{n-2}} = 1{,}074, \quad (11)$$

$$= b_0 \pm t_{n-2;\,0.05} \cdot D + b_1 \cdot X = 1{,}752 \pm 3{,}182 \cdot 1{,}074 + 0{,}026 \cdot X, \quad (12)$$

- out-of-plane

$$D = \sqrt{\frac{\sum(Y - mean(Y))^2 - \frac{(\sum(X - mean(X)) \cdot (Y - mean(Y)))^2}{\sum(X - mean(X))^2}}{n-2}} = 1{,}45, \quad (13)$$

$$\Delta_{\text{в, н}} = b_0 \pm t_{n-2;\,0.05} \cdot D + b_1 \cdot X = 30{,}001 \pm 3{,}182 \cdot 1{,}45 – 0{,}438 \cdot X, \quad (14)$$

Where $\Delta_{\text{в, н}}$ – the upper and lower limits of the 95% confidence intervals for the linear regression equation;

b_0, b_1 – coefficients of the linear regression equation (see [2], tabl. 8.8);

$t_{n-2;\,0.05}$ – parameter of the Student distribution for the two-sided test (α=0.025), significant at the 5% level, given on page 131 [2], (see[2],table. 27), $t_{n-2;\,0.05}$= 3,182;

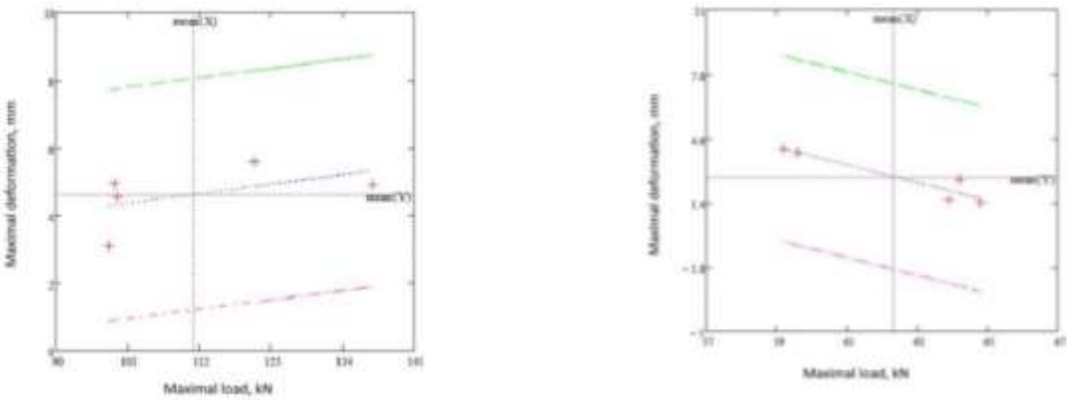
$mean(X)$, $mean(Y)$ – mean values of statistical series *X* and *Y*.

On the Fig.13 shows the limits of the confidence interval for the regression line of the statistical sample of maximum deformations on the statistical sample of destructive loads with the limits of the confidence interval constructed according to the data in the table. 4.

Table 4. Parameters for estimating confidence intervals of linear regression equations

Табл.4.Параметри для оцінки довірчих інтервалів рівнянь лінійної регресії

№	Statistical series	b_0	$\pm t_{n-2;\ 0.05} \cdot D$	$b_1 \cdot X$
	shear in-plane			
1	X and Y	1,752	±3,419	0.026×X
	shear out-of-plane			
2	X and Y	–30,001	±4,614	-0.438×X



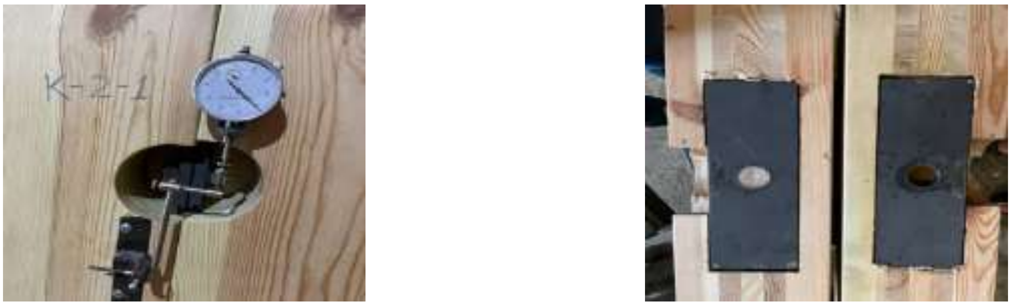
a *b*

Fig. 13 Graph of the linear regression function of the statistical sample of maximum deformations on the statistical sample of maximum loads:
1 – graph of the linear regression function; 2 – the lower limit of the confidence interval; 3 – the upper limit of the confidence interval; *a* - in-plane; *b* - out-of-plane

Рис.13.Графік функції лінійної регресії статистичної вибірки максимальних деформацій на статистичну вибірку руйнуючих навантажень:
1 – графік функції лінійної регресії; 2 – нижня межа довірчого інтервалу; 3 – верхня межа довірчого інтервалу; *а* – у площині панелі; *b* – із площини панелі.

DISCUSSION

The typical failure mode of the tested specimens of the serie K-2shown in fig. 14-a) occurred due to displacement of the connected parts of the connection along the joint line from the front side. When disassembling the unit, the shift of the plates in the milled recesses was about 5 mm and, respectively, the timber was compressed on the other side of the plate (fig.14-b).



a *b*

Fig. 14 Failure mode of the tested specimens in serie K-2. Photo by Andrii Bidakov

Рис.14. Характер руйнування випробуваних зразків серії К-2. Автор фото Андрій Бідаков hole in the middle of the plate was taken to be 23 mm for installing the M20 bolt, and was increased to a diameter of 26-28 mm for installing the M24 bolts, since the failure of the connection occurred as a result of the shearing of the M20 bolt (fig. 15). When increasing the diameter of the bolt, it became necessary to enlarge the hole milled in the timber to allow the installation of new bolts.

Fig. 15 Failure of bolt M20 and enlarged hole milled in the timber for bolts M24. Photo by Andrii Bidakov

Рис.15. Руйнування болтів М20 та фрезерування отвору у деревині для встановлення болтів М24. Автор фото Андрій Бідаков

The typical failure mode of the tested specimens of the series P-1 shown in fig. 16-a) occurred due to displacement of the connected parts of the connection along the joint line from the front side. When disassembling the unit, the shift of the plates in the milled recesses was about 5 mm and, respectively, the timber was compressed on the other side of the plate (fig.16-b).

a

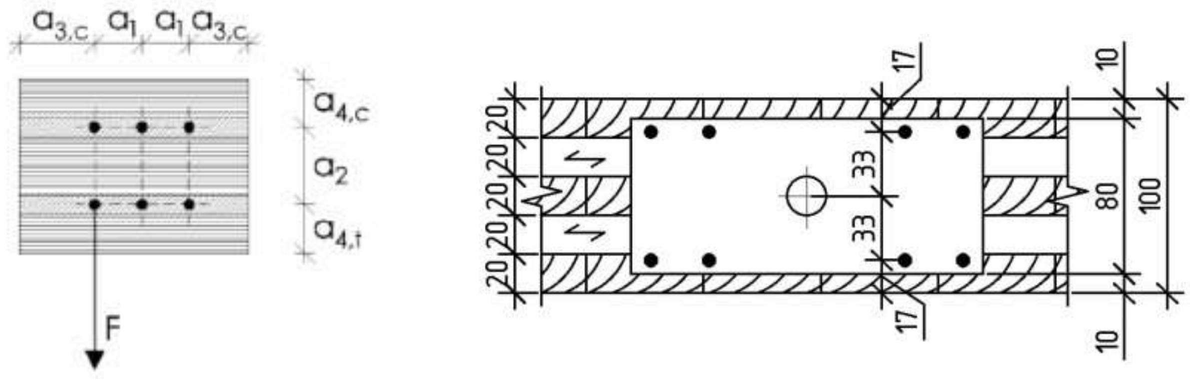
b

c

Fig. 16. Failure mode of tested specimens in seriesP-1: Photo by Andrii Bidakov
a- specimen P-1-1;
b - specimen P-1-2;
c - specimenP-1-4

Рис.16. Характер руйнування зразків серії Р-1. Автор фото Андрій Бідаков

The calculated value of the carrying capacity of the connection is higher than the results obtained during testing since the distance from the axis of the glued-in rod to the side edge of the panel is 17 mm or 1,7 d (see fig. 17-b), while the calculated strength corresponds to the condition under which the distance should not be less than $a_{4,t}$=6d=6*10=60mm according to ETA 21/0914[4] where minimal distance for laterally loaded dowel-type fasteners in the narrow side of cross laminated timber (fig. 17-a).



a *b*

Fig. 17 Minimum spacings, edge and end distances for laterally loaded dowel-type fasteners in the narrow side of cross laminated timber acc. to ETA 21/0914 [4] (a) and in tested specimens (b).

Рис.17. Мінімальні відстані до граней ПКД панелі при навантаженні штифтів у поперечному напрямі відносно їх вісі при встановленні у бічну грань панелі згідно до ЕТА 21/0914 [4] (а) та відстані у випробуваному зразку при навантаженнях із площини панелі (b).

Comparatively analysis diagram of slip module of connector in CLT panel edge by shear test in-plane and out-of-plane shown on fig. 18, where marked min/max values and mean value.

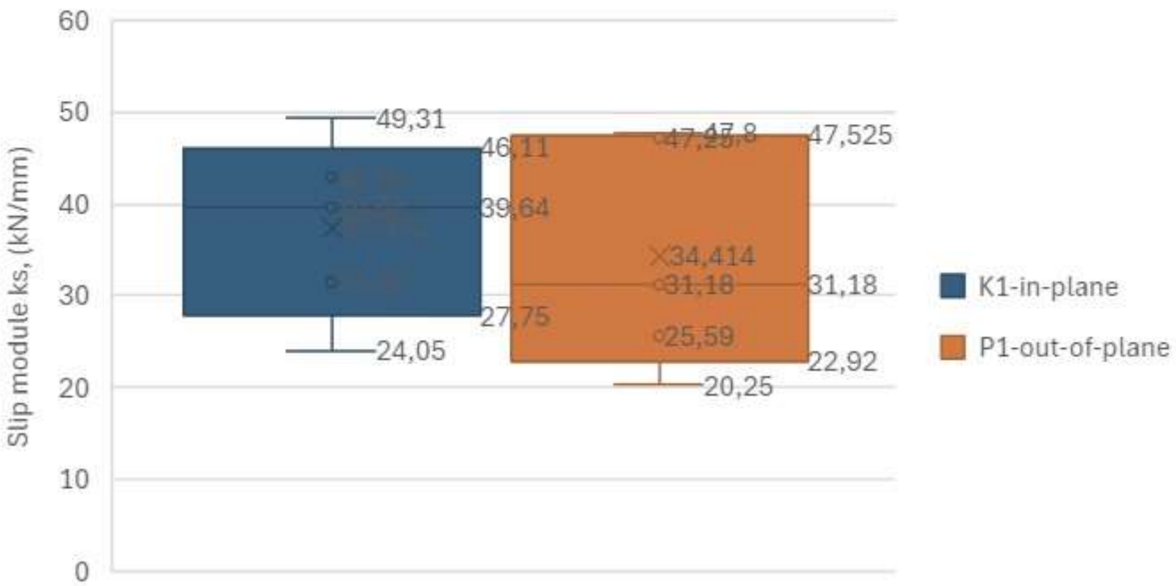


Fig. 18 Slip module values analysis of tested specimens with connector by shear test.

Рис.18. Аналіз величин модуля ковзання випробуваних зразків з конектором при випробуваннях на зсув

CONCLUSIONS

In this paper, the strength and slip moduli of connectors with glued-in steel rods located in edge side of CLT panels subjected to shear loading in-plane and out-of-plane of the CLT panel were investigated. 10static tests were conducted till failure of each specimen. The results were compared with data obtained by calculation of existing methods as for dowels type fasteners.

Connections with glued-in rods in CLT panels have already been studied by several researchers. Most of the research has been done on uniaxially loaded rods. However, the application of rods in practical applications requires also the evaluation of rods under complex loading situations with interaction of axial and lateral loads. In this project, a new type of connection system with a steel plate and glued-in rods for CLT panels is investigated both analytically and experimentally. The proposed new type of connection system is universal, easy to implement in production and can be used (with minor modifications) in buildings of 5 floors and above. The glued-in rods can be replaced with screws if necessary. However, it should be considered that the costs of connections with glued-in rods is much cheaper in Ukraine than connections using fully threaded self-tapping screws.

Tests of connection in CLT panels with a connector loaded by shear in-plane and out-of-plane of the panel revealed a fairly reliable character of their failure in the area of placement of a metal embedded part with steel glued-in rods that work as dowels. The character of the failure is ductile by shear in-plane and is accompanied by crushing of the wood around the glued-in rods in the places of their attachment to the metal plate. By tests out-of-plane occurred brittle failure mode due to the cracking of the boards at the final stage of loading the sample.

Non-linear dependence of loads to deformations was observed on the all stages of connection loading. Characteristic value of the carrying capacity of connector by shear in-plane of the CLT panel equal 74,96kN according to test results and out-of-plane 55,2kN. The calculated strength higher that test results by shear out-of-plane because the distance should not be less than 6d but in testing specimens this value was 1,7d which explains the low level of carrying capacity. The average value of the slip modulus in the shear tests of the connector in the CLT in-plane of the panel is Ks=31.28kN/mm and out-of-plane Ks=32.54 kN/mm.

The proposed geometry is suitable without modification for the case-study building with 3-5 floors, where the forces do not exceed the analytical and experimental resistances. For tall buildings in platform construction, when the load between the walls exceeds the crushing strength of the timber perpendicular to the grain of the floor panels, it is necessary to insert steel tubes between the connector plates that transfer the loads through the floor panel. This solution has been used already in many cases for the transfer of loads through floors between columns.

ACKNOWLEDGEMENTS

The work presented in the paper has been conducted in the project “Efficient connections for modular prefabricated timber buildings to help reconstruction in Ukraine” within the programme for Academic Collaboration in the Baltic Sea Region, which is funded by The Swedish Institute (SI). We would like to thank SI for their financial support for this research project!

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АНАЛІЗ ПОВЕДІНКИ З'ЄДНАННЯ ПКД ПАНЕЛЕЙ НА ВКЛЕЄНИХ СТЕРЖНЯХ ПІД ДІЄЮ НАВАНТАЖЕНЬ ЗСУВУ

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Анатація. Результати випробувань, представлені в цій публікації, показують несучу здатність, деформації та моделі руйнування при зсуві в площині та із площини ПКД панелей за результатами нещодавно розробленого рішення універсального з'єднувача для дерев'яних конструкцій ПКД панелей, який дає можливість швидкого та легкого встановлення та складання, а також легкого розбирання і повторного використання. Це рішення сприятиме необхідній реконструкції пошкоджень в Україні та сприятиме швидкому відновленню житла, а також забезпечуватиме довгострокові стійкі та циркулярні рішення з'єднань. Розроблений з'єднувач являє собою вузол у вигляді сталевої пластини на вклеєних стрижнях, які вклеюютьсяуПКД панелі і розроблені в рамках дослідницького проекту «ReConnect – Ефективні з'єднання для модульних збірних дерев'яних будівель для допомоги реконструкції в Україні». Це дозволяє з'єднувати ПКД панелі у різних схемах разом або з іншими частинами будівлі, такими як фундаменти чи бетонні стіни. З'єднання на вклеєних стрижнях широко використовуються в країнах Східної Європи, особливо в багатопролітних дерев'яних конструкціях будівель різного типу. ReConnect фінансується SwedishInstitutet, а партнерами є Харківський національний університет міського господарства імені О.М. Бекетова (Україна), Технологічний університет Чалмерса, Гетеборг (Швеція), Талліннський технологічний університет (Естонія) та Рівненський національний університет водного господарства та природокористування (Україна).

Ключові слова: вклеєні стрижні (GiR), комбіноване навантаження, групові ефекти, універсальне з'єднання, ПКД панелі, CLT, з'єднувач, конектор

Стаття надійшла до редакції 01.11.2024