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Specificity of strength calculation for glued-in steel rods in LVL with unidirectional veneer

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Design of LVL elements with glued-in steel rods and metal connectors joints is considered as semi-rigid connection and requires considering the compliance. The beams with a metal connector and glued-in steel rods and solid beams test results comparative analysis has been made in the paper. Design method of glued-in rods in LVL is proposed and failure mode is considered. It enables reducing the distance between the rods axes and the distance from the rod axis to the edges in the beam cross section and increasing the joint strength.

Keywords: glued-in steel rods, semi-rigid connection, laminated veneer lumber Ultralam – R), axes and edge distance, model of rupture, two-side fixing.

Особливості розрахунку міцності вклеєних стержнів у ЛВЛ брусі з однонаправленим шпоном

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При проектуванні вузлових з’єднань ЛВЛ брусу на вклеєних стержнях з металевими вставками є напівжорсткими та потребують врахування податливості. У статті виконано порівняльний аналіз результатів випробувань балок з металевим вузлом на вклеєних стержнях та цільних балок. Розроблена методика розрахунку міцності вклеєних стержнів на висмикування з урахуванням характеру руйнування зразків, яка дозволяє знизити відстані між осями стержнів та від осі стержня до граней у поперечному перерізі балки та збільшити міцність з’єднання. Овалізація деревини навколо вклеєного стержня при руйнуванні з’єднання обумовлена різницею міцності ЛВЛ брусу при сколюванні вздовж волокон по пласті та по грані, що насамперед є результатом шпонової структури цього брусу та враховується при розрахунках руйнівного зусилля згідно до запропонованої методики. Проведений аналіз рекомендованих відстаней між вклеєними стержнями, які регламентовані стандартами різних країн, дозволив сформулювати рекомендації щодо конструктивних вимог при проектуванні з’єднань на вклеєних стержнях у ЛВЛ брусі. Результати розрахунків балок з металевою вставкою, отриманих у аналітичному програмному комплексі ANSYS, показали незначну розбіжність відносно результатів, отриманих при експериментальних натурних випробуваннях балок, яка складала біля 13%. Руйнування усіх балок відбувалось через висмикування вклеєних стержнів у нижній розтягнутій зоні балок. Для збільшення несучої здатності з’єднання, зменшення розтріскування деревини та забезпечення в’язкого руйнування рекомендується встановлення гвинтів у напрямі поперечному до напряму вклеєних стержнів. Також для зменшення деформативності напівжорстких з’єднань з металевою вставкою можливо встановлювати гайки з двох сторін для включення стержнів у роботу на продавлювання у стиснутій зоні. Досліджений вузол с металевою вставкою на вклеєних стержнях може використовуватись при створенні сітчастих оболонок складної просторової геометричної форми.

Ключові слова: вклеєні стержні, напівжорстке з’єднання, шпоновий брус ЛВЛ (Ultralam – R), відстань між стержнями, модель руйнування, двостороння фіксація вузла.

Introduction. The problem of strength and deformability of node joints on glued-in rods and a metal connector using an LVL beam is extremely relevant and has been considered when designing complex geometric shape atrium project (Fig. 1), where a nodal solution has been proposed that requires testing. Its results are presented in this publication. The lack of recommendations regarding the calculation and design of the joints on the glued-in rods in the structural elements of LVL beam increased the relevance and interest in this type of connections. The geometry of the atrium computational model has been created in the Tekla Structures program, and then exported to the SCAD Soft program to make the calculation.

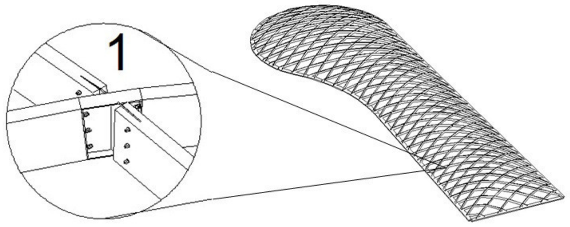


Figure 1 – General view of the atrium and nodal joint

Review of the latest research sources and publications. The peculiarities of the LVL beam with the help of glued-in rods also arouse great research interest of colleagues from different countries, including M. Stepinac [13], R. Steiger, E. Gehri, A. Buchanan, E. Serrano, N. Meyer, and others. In the CIS countries, glued-in rods as a rigid joint of timber structures are an joints integral engineering solution when designing frameworks for large-span buildings. In practice of the CIS countries, the glued-in rods use is cheaper than screw joints, which are popular in the European countries and are an alternative to glued-in rods. However, the elements of the well-known construction “Metropol Parasol” in Seville (Spain), which is a landmark of this city, are made with the help of LVL beams on glued-in rods. Glued-in rods in timber structures joints are used in two versions, forming rigid and semi-rigid joints: joining timber-to-timber or with welding glued-in rods to the metal element (Fig. 2-a) and joining timber to the metal connector on the bolts (Fig. 2-b).

The first variant of the joint is usually prefabricated, which is not demountable. The second variant of the joints or semi-rigid joints is increasingly used in combined frames or complex systems of structures, where metal-free solutions are impossible.

a) b)

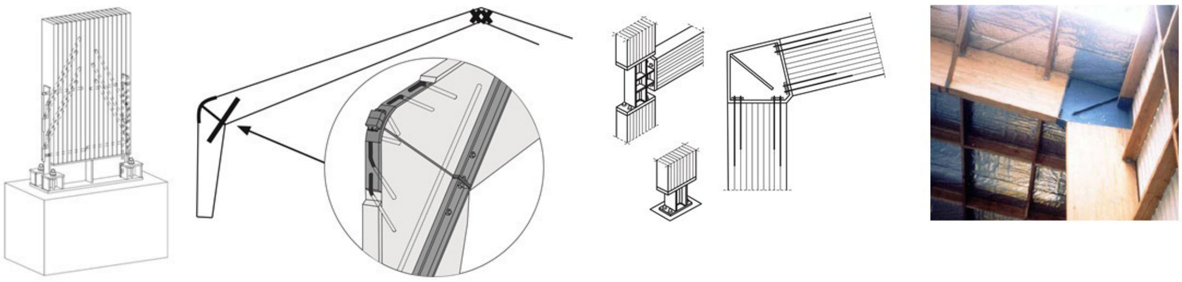


Figure 2 – Rigid and semi-rigid joints with glued-in steel rods:
a – rigid heel joint in a foundation column and a moment joint in a three-hinged frame;
b – semi-rigid moment joint and heel joints

Definition of unsolved aspects of the problem. The bolted joints compliance of timber structures on glued-in rods semi-rigid joints is not only joints deformations, but also glued-in rods ductility, which is correspondingly less than the first one. For inclined glued-in rods according to the norms [1], the compliance is 0.001 mm/kN. There are known the methods for compliance accounting of dowel joints in timber structures such as trusses, due to the large number of the perforating structure elements nodal joints, which have a significant effect on the magnitude of the total structural deformation or deflection. The deflection determination for trusses with lower height is especially important. The manual of SNiP on the calculation of timber structures [10] proposed to determine the movement of truss nodes, considering the joints compliance according to the rules of structural mechanics with the introduction of the reduced modulus of elasticity (Section 6.29). In the tutorial of professor Serov E.N. [8] it is indicated that if there are specific normative values for the joints compliance and an arbitrary level of their bearing capacity use, the deflection caused by the joints compliance definition, considering the forces acting in them, should be determined by the formula:

$$f_c = f_{tj} + f_{aj} = \sum_1^{mk} \Delta_{Hi} \frac{N_{ci}}{N_{H.ci}} + \sum_1^{m} \Delta_{Hi} \frac{\sigma_{смi}}{R^{\alpha}_{смi}} \qquad (1)$$

where: f_{tj} – deformation of compliance in tension dowel joints;

f_{aj} – deformation of compliance in the angle joints and buffer stops;

k – number of dowel joints;

m – number of joints on the angle joints and buffer stops;

Δ_{Hi} – the normative value of compliance of the i-th joint at its full load-carrying capacity;

N_{ci} – force in the i-th joint;

$N_{H.ci}$ – load-carrying capacity of the i-th dowel joint;

$\sigma_{смi}$ – crumple stress in the i-th joint;

$R^{\alpha}_{смi}$ – design resistance to crumble in the i-th joint.

Problem statement. High strength and cost, slightly exceeding the laminated timber cost, ensured high popularity in the market of timber construction for veneer lumber or LVL based on softwood produced by Ultralam and Kerto. The veneered structure of the LVL beam requires additional tests of timber structure joints classical types, which are often used for laminated timber elements. The behavior of LVL and its destruction during tests of joints structural elements differ from laminated timber and require the additional recommendations regarding the rules for the nodal joints design and their calculation.

Basic material and results. Under the guidance of professor Fursov V.V. in 2016, a nodal joint on glued-in rods with a metal connector installed in the middle of an LVL beam with a unidirectional arrangement of Ultralam veneer was tested (type R). Fig. 3 shows the beams loading with static load and the installation location of measuring devices for determining deformations. Tests of the nodal connection were the key and the LVL beam research final logical stage [7, 9], since for the node complete analysis, tests of strength and elastic characteristics under compression from different angles, specimens for chipping and specimens for pulling single glued-in rods were previously performed.

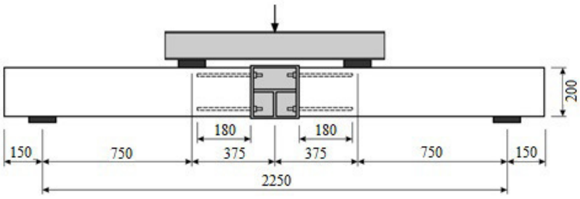


Figure 3 – The loading condition of beams with a metal connector

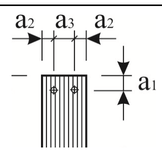
The first type of the beams were tested with a cross section of 75x200 mm, a span of 2.25 m with a node located in the middle of the beam, where M16 studs were installed in upper and lower parts. The second type of the beams differed from the first one that in the upper part of the cross section M10 studs were glued-in, and in the lower part M16 studs were glued-in. Solid beams without a nodal connection were also tested. Strength grade of steel studs is 5.8. Adhesive compound is based on resin ED-20. The insertion depth was 180 mm and the diameter of all holes was made 2 mm larger than the diameter of the glued-in rod. The distances between the axes of the rods in all sections were taken to be the same (Fig. 4). The tests of the beams were carried out by static loading them with a 25-ton jack through a traverse, distributing the load to 2 points in the thirds of the span. The model was detached from the plane on the supports and in the places of load application.

Before the test, each beam was loaded for 1 ton and was completely unloaded; then all the nuts in the joint were tightened. Load step was 1 t on the traverse, an exposure load at each step was 2 min. All beams were brought to destruction. The displacements were measured on supports and in the span using measurement devices with a scale value of 0.001 mm.

Figure 4 – The location of rods and the joint after destruction

Results and discussions. The pattern of specimen destruction has a typical brittle character in the form of pulling out rods covered with timber layer or wedge-shaped chipping of timber around rods. When drilling holes, the center distance and the distance to the edges were taken to be less than recommended by the standards of various European countries and European technical conclusions [1-5], as shown in Table 1, where d is the diameter of the glued-in rod. Considering the tests results of single glued-in rods under axial loading in specimens of LVL beam with unidirectional veneer, it was noted that the fracture pattern has a characteristic splitting and a small area of get out timber, as detailed in [7]. In addition to single glued-in rods, specimens with two glued-in rods with a center distance of less than recommended were also tested. For example, according to the norms of Russia on the design of timber structures SP 64.13330.2017 [1] the minimum distance from the package sides to the rod axis is taken to be at least 2d and the distance between the axes of the rods should be at least 3d.

Table 1 – Distances between the glued-in steel rods, according to the standards of different countries

			
	a_1	a_2	a_3
СП 64.13330.2017 (Russia) [1]	2d	2d	3d
DIN 1052 DIN EN 1995-1-1 (Germany) [4]	2.5d	2.5d	5d
ÖN B 1995-1-1 (Austria) [5]	2.5d	2.5d	5d
New Zealand [11]	2.5d	2.5d	5d
R. Steiger (Switzerland) [12]	2.3d	2.3d	4d
Z-9.1-791 [2]	1.75d	1.75d	3.5d
Z-9.1-778 [3]	1.875d	1.875d	3.75d
Tests	1.16d (18.5 mm	1.16d (18.5 mm	2.37d (38 mm)

The reduced axial spacing of the glued-in rods and the distances to the edges did not violate the proposed pattern of destruction, since the area of the get out timber did not reach the edges or outer edges, as shown in fig. 5. An analysis of the rods destruction behavior enables to note that the area of the sheared timber is ovalized around the glued-in rod, see fig. 6. The largest part of the timber is cleaved along the layers of veneer in the cross section of an LVL beam, where the area of the timber does not exceed 4 layers of veneer with a total width of 13-15mm.

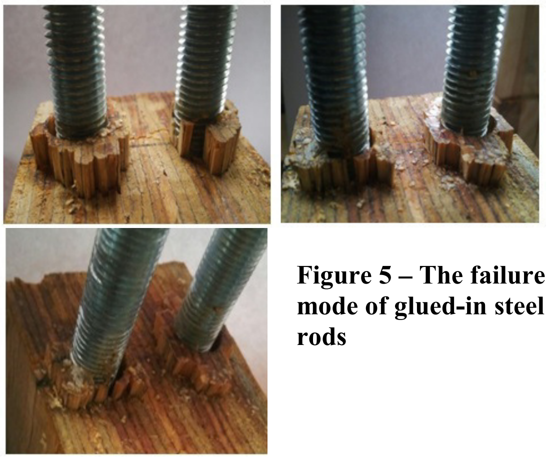


Figure 5 – The failure mode of glued-in steel rods

Beams were also tested with a modification of the joint, by installing studs with a smaller diameter in the upper cross-sectional area, which as a result had little effect on the breaking load and the beam deformability in the middle of the span, see fig. 7. The upper rods were not included in the extrusion, but only fixed a metal connector, which crushed the upper part of the beam cross-section. Also, the deformation in the beam upper zone was increased by crumpling the rods thread in the upper zone. The level of the tightened nuts was not monitored.

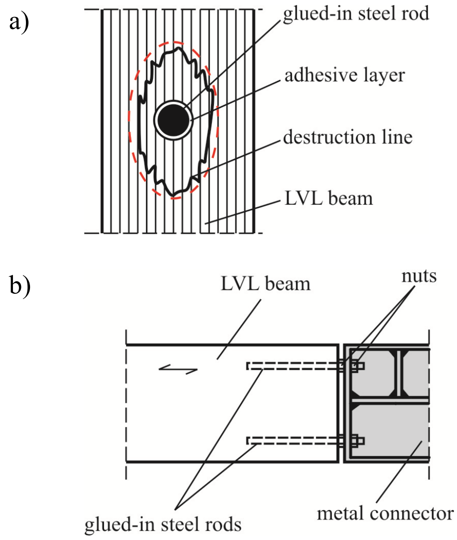
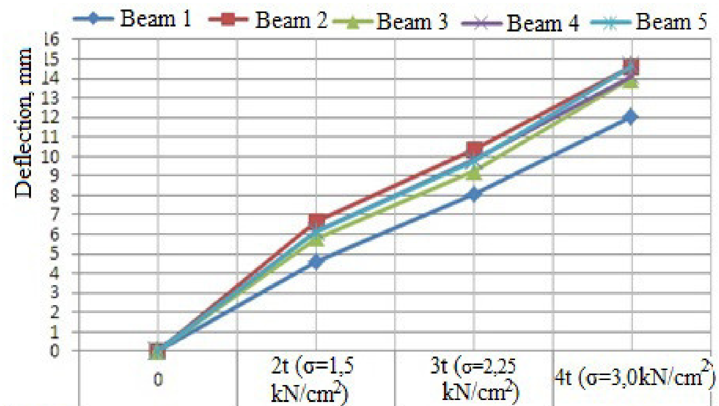


Figure 5 – The failure mode of the glued-in steel rods which were placed parallel to the grain in a LVL beam:
a – ovalization of the timber shear area;
b – two-side fixing

When testing 5 beams with a metal connector, the values of the beams deflections at three points were analyzed separately: in the middle of the span and in the thirds of the beam span, where concentrated forces were applied. The results of beam mid-span deformations at various loading levels are shown in Fig.7, where a strong coincidence of the beams deformation curves can be observed 2-5. Breaking load for beams was observed in the range from 48 kN to 55 kN. A slight divergence of the beams curves deformations in the middle of the span increased with an increase of the load close to destructive.



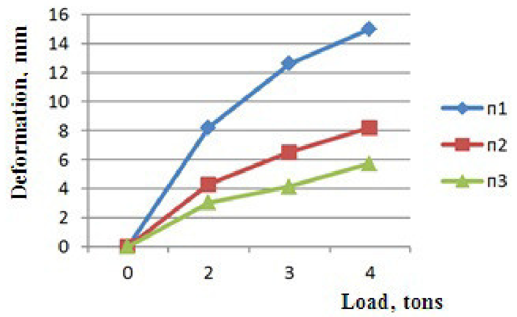
	0	2t (σ=1,5 kN/cm²)	3t (σ=2,25 kN/cm²)	4t (σ=3,0kN/cm²)
Beam 1	0	4,586	8,102	12,046
Beam 2	0	6,668	10,384	14,604
Beam 3	0	5,8	9,26	14,024
Beam 4	0	6,13	9,85	14,13
Beam 5	0	6,126	9,782	14,648

Figure 7 – Beam deflection in the middle of the span with a metal connector

For a comparative assessment of the beam deformability with a connector, tests of solid beams without a node were performed. Curve n1 in fig. 8 shows the deformations in the beam mid-span, and the curves n2 and n3 show the beam deformation in thirds of the span. Fig. 8-a) shows the deformations of the solid beam with a characteristic significant excess of the deformation or deflection in the middle of the span. The beam with the connector at the initial stages of loading had a deformation in the span slightly higher than in the thirds of the span, since the beam stiffness in the node is higher due to the metallic elements of the connection and the lack of the glued-in rods pliability.

It should be considered that the beam geometric model in the calculation is idealized and free of a number of inaccuracies associated with the connection on the glued-in rods implementation, the contact surfaces quality, etc., which constitute loose deformations that are not considered in the design software packages.

a)



b)

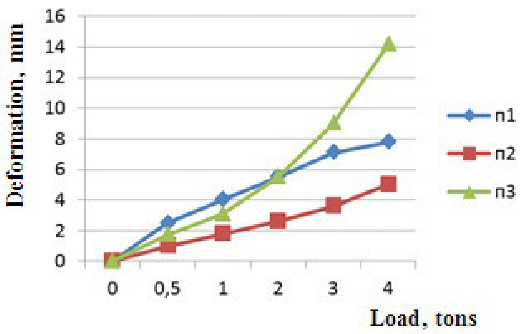


Figure 8 – Deflection curves of a solid beam (a) and a beam with a connector (b)

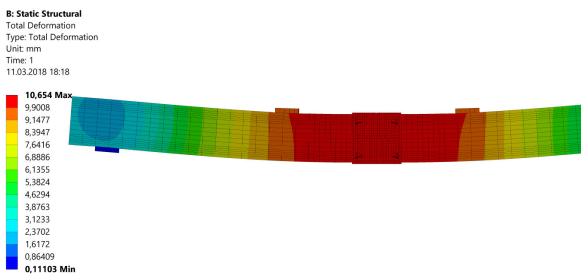


Figure 9 – Beam deformation according to calculation

The proposed method for calculating the strength of glued-in rods includes a number of prerequisites in the form of parameters borrowed from various formulas for calculating glued-in rods in solid or glued timber. The need to develop a modified method of calculation is primarily due to the large difference between the experimental strength values and the various analytical data on the joint strength. Also, the developed formula (2) for the calculation of rods in an LVL beam includes not only the main design parameters (see Fig. 10), but also the features observed during testing, such as the ovalization of sheared timber around the rod, and therefore the strength value when splitting LVL timber along the grain on the edge and on the face.

$$R_{ax,k} = \pi \cdot d_h \cdot l \cdot (f_{v,k,ed} \cdot f_{v,k,fl})^{0,5} \cdot k_c \qquad (2)$$

where: $R_{ax,k}$ – the characteristic pull-out capacity of GIR in LVL with unidirectional veneers, in N;

$f_{v,k,ed}$, $f_{v,k,fl}$ – the characteristic shear strength flatwise and edgewise for LVL with unidirectional veneers (Ultralam type R) in N/mm^2;

l – anchorage length;

d_h – drilled hole diameter;

k_c – coefficient that considers the uneven shear stress distribution depending on the rod anchorage length:

$$k_c = 1{,}2\text{-}0{,}02 \cdot l/d \qquad (3)$$

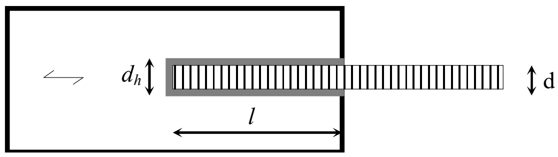


Figure 10 – The main parameters of the design model

To ensure the joint design strength on the glued-in rods, it is necessary to follow the rules of the glued-in rods placement along the grain in the beam cross-section, namely the minimum distances, as shown in Fig.11. It should be noted that the distance between the rods along the veneer layers is greater than in the perpendicular direction relative to the veneer due to the ovalization of the sheared timber around the rod formed by the difference in shear strength along the LVL grain on the face and on the edge.

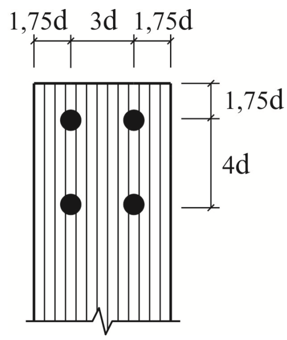


Figure 11 – Recommended distances between the glued-in rods and to the edges

The specified minimum distances between the rods and to the LVL element cross section edges can be used if the rods are accurately glued in (without distortions of the holes and the rods when gluing). To reduce the beam with a metal connector on the glued-in rods deformability, it is possible to use double-sided installation of nuts on the rods located in the upper part of the beam cross section, or in a compressed zone. It is also possible to perform a controlled tightening of the nuts not exceeding 70% of the timber compressive strength calculated value along the grain. Created prestress in the node reduces loose initial deformations by 32-40%. The complexity of tightening the nuts to a predetermined value should be considered.

The proposed calculation method and design rules are of advisory nature and require further studies to clarify some data. Fig. 12 shows the glued-in rods strength diagram obtained during the tests ("tests" curve) and the expected values, according to various norms, as well as according to the proposed method (2), the "proposing" line. Symbols of straight lines plotted on the diagram are as follows: "tests" - test results, "din" – the value expected by the German standards, "ru" – according to the Russian standards, "ru-vr" – according to the Russian standards using the temporal resistance value when splitting LVL beam, "en" – the value expected by the pan-European methodology.

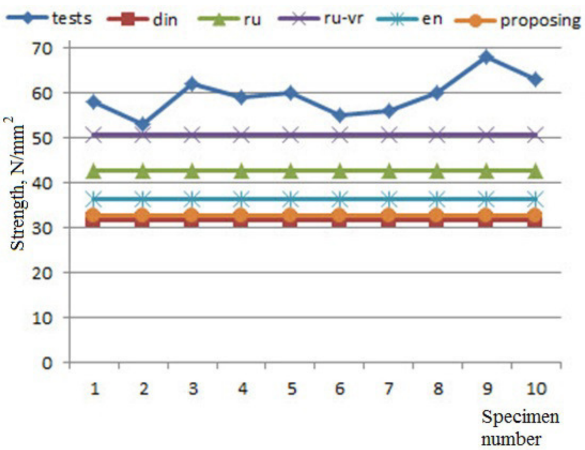


Figure 12 – The strength of the glued-in rods obtained during testing and the expected values, according to various standards, as well as according to the proposed method of calculation

Conclusions. The tests of the nodal joint on the glued-in rods with a metal connector and the analysis of the experimental data confirm the possibility of reducing the center distance between the glued-in rods to 2.4d and the distance to the faces 1.2d, while not allowing the block scheme of destruction of a group of glued-in rods. To calculate the strength of glued-in rods in a LVL beam with an unidirectional veneer installed along the grain, it is possible to use the calculation formula (2), which takes into account the deviation of the shear strength along the grain in the LVL beam. The fragile nature of the fracture with cracking along and across the veneer requires the installation of screws or the use of an LVL beam with cross veneer layers. A comparative analysis of the deformability of the beams on glued-in rods with a metal node confirms the need to take into account the compliance of this semi-rigid connection.

Also, an obvious and necessary addition to the considered type of connection with a metal connector should be performed with two-sided installation of nuts relative to the metal connector, that ensures that the glued-in rods located in the compressed zone of bending element are included to the work, potentially with a smaller diameter than the rods installed in the lower zone.

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