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RIGID JOINTS ON GLUED-IN RODS OF BENDING AND COMPRESSION-BENDING ELEMENTS OF LARGE-SPAN LAMINATED TIMBER STRUCTURES

Alexander Pogoreltsev[1], **Stanislav Turkovsky**[2], **Vladimir Stoyanov**[3]

ABSTRACT: Elements of large-span laminated wood structures can have a long length, which causes difficulties for manufacturing and transportation. This is especially true for bent laminated elements of arches, frames, meridional ribs of domes and other structures. There is a need to break down long structures into technological elements with implementation of consolidation rigid joints. Russia has developed a system of node joints of wooden structures on inclined glued-in rods - the "TSNIISK System". The basic principle of rigid joints is to fasten the embedded part to the wooden element by means of obliquely glued rods. Two types of rigid joints are proposed: with unidirectional inclined glued-in rods and with glued-in rods forming V-shaped anchors. A methodology for calculating knots and joints on glued rods has been developed. During the design and construction of long-span buildings and structures with glued wooden frames, control tests are conducted. Examples of control tests of the mineral fertilizer warehouses structures are presented. The results of the control tests confirm the correctness of the calculation methodology. Hundreds of buildings and structures with glued wood frames with glued-in rods used in the nodes have been built in Russia.

KEYWORDS: Bending, compression-bending, glued-in rebar, glued-in rod, large-span**,** rigid joint, test, V-shaped

1 INTRODUCTION

Elements of large-span glue laminated timber structures can have a long length, which causes difficulties for manufacturing and transportation. This is especially true for bent laminated elements of arches, frames, meridional ribs of domes and other structures. There is a need to devide long structures into technological elements with the arrangement of rigid joints performed on the assembly.

The traditional solution is the dowel joints. The assemblies with steel plates in wood kerfs and steel pads on dowels are widely used.

A modern type of joints are steel rods with metric threads or reinforcing bars glued into the wood.

In Russia, a new type of consolidation joints on obliquely glued rods has become widespread. In the laboratory of wooden structures of the Central Research Institute of Building Structures named after V.A. Kucherenko (CNIISK). The institute has developed a system of node joints of wooden structures on glued-in rebars - "TSNIISK System". The founder of the system is S.B. Turkovsky, who is conducting research since 1974 [1].

Based on the results of studies of knotted joints on inclined glued-in rods, the design principles and calculation methods for such joints have been developed.

2 KNOT CONNECTIONS ON GLUED-IN RODS

The basic elements of the CNIISK System are rod elements glued into the wood at an angle to the fibers [2]. The 0° and 90° angles are special cases. In Europe, mainly glued-in rods with metric threads are used [3]. In Russia, mostly periodic profile bars A400 or A500 are used, but bars from other materials - different grades of steel, aluminum alloys, composite reinforcement (carbon fiber, fiberglass, basalt-plastic), etc. can also be used. The main requirement is that the rods have irregularities on the surface: periodic profile (steel or composite reinforcement), threads (e.g. metric), special rifling, etc. The bars are glued with epoxy adhesives.

The first satisfactory results were obtained by S. Turkovsky in 1975 when testing a girder joint on a new type of joints - obliquely bonded reinforcing bars (Fig. 1). Despite the fact that the joint was located in the area of maximum bending moment, the failure occurred outside the joint.

The use of inclined glued-in rods makes it possible to obtain rigid joints equivalent in bearing capacity to a solid section. The use of inclined glued-in rods is widespread in joints stressed by bending or compression with bending.

Compression-curved assemblies include support assemblies of columns rigidly connected with the foundation. The first objects with such assemblies on threaded adhesive screwed rods are the 24 m span warehouse (1979) and the panel production shop (1983) built at the Volokolamsk Experimental Building Structures Plant. Scheme of the support assembly of 6 m high columns is shown in Fig. 2a. The bearing structures of the roof were lenticular glued timber trusses, in which the junction of the upper and lower chords was also

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made on glued-in screwed rods for the first time for such trusses.

A tennis court was built in 1983 in the Moscow region. Its main load-bearing structures were a double-hinged frame of 18 m span with glued wooden uprights of variable height (6 - 8) m and a bent-roofed girder.

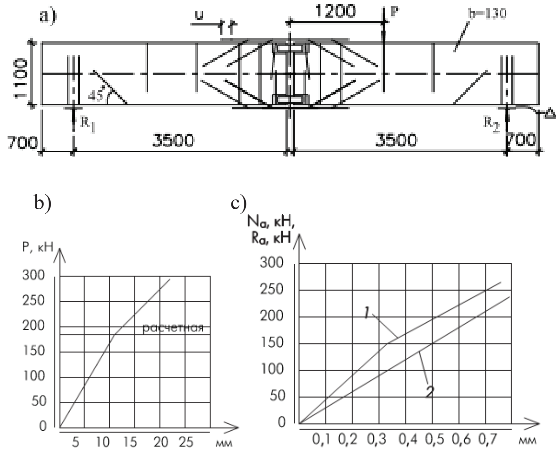


Figure 1: Bending tests of a beam with a rigid joint: a - test pattern; b - deflections in the middle of the span; c - shear deformations in the joint

The design of the stiffening of the struts differed from the first two in that the glued-in rebars were used (Fig. 2 b)

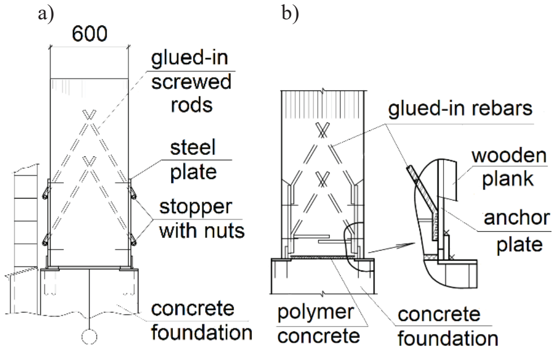
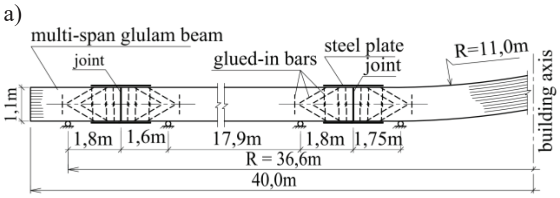


Figure 2: Stiff pinch-post assemblies in the foundation: a - bonded-rod warehouse assembly (1979); b - bonded-rod tennis court assembly (1983)

Bendable joints in large-span structures were first used in the construction of the community center of the pioneer camp (now holiday home) "Lipki" in the Moscow region, built in 1985 (Fig. 3).

a)



b)

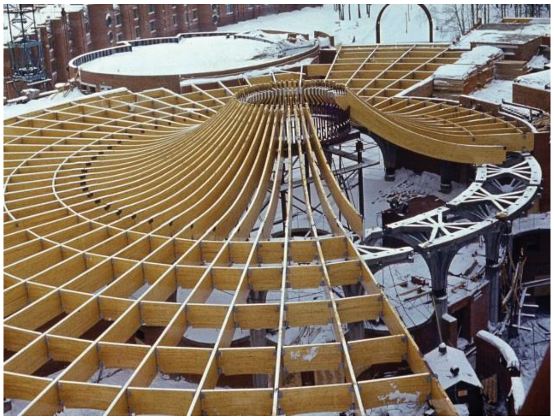
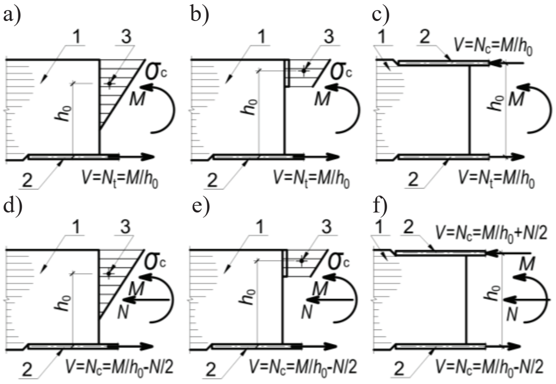


Figure 3: Radially arranged multi-span beams of the Lipki boarding house roof with rigid joints on inclined glued-in bars (1985): a -structural scheme of the girder; b - installation of roof beams

3 DESIGN AND CALCULATION OF RIGID JOINTS

3.1 CALCULATION SCHEMES

The basic principle of a rigid joint is to fasten the embedded plate to the wood member by means of obliquely bonded rods. The bending moment and the longitudinal force cause tension and compression in the joint. The tensile force Nt is taken up by the embedding plate, and the compression force Nc is taken up by the stop at the ends of the wooden elements, either by the stop through the centering gasket or by the embedding plate (Fig. 4). The magnitudes of the forces depend on the shoulder of the internal force pair h_0.



1 - glulam element; 2 - embedded detail; 3 - center of gravity of the compressive stress diagram

Figure 4: Joint force diagrams: a, b and c - bending members; d, e and f - compression-bending members

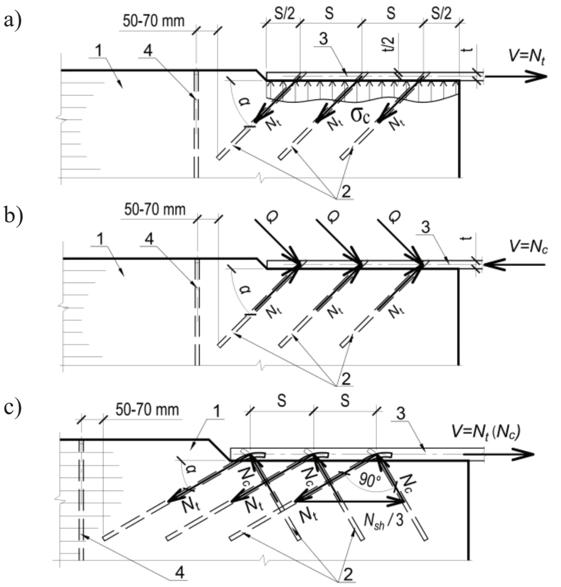
The axial forces in the embedded parts cause shear forces V between the part and the wood, which are taken up by the glued-in rods. In the tensile zone, the embedded parts are always installed, while in the compressed zone, the structural solutions for the transmission of the compressive forces can be different:

- By the butt-end of wooden elements (Fig.4a and Fig.4d), in this case, if there are no technical possibilities to ensure a tight adjacency, a gap of 30 ± 10 mm is made which is filled with polymer concrete during assembly;
- through the centering gasket (Fig.4b and Fig.4e), which is made of steel or polymer concrete;
- through the embedded part (Fig.4c and Fig.4f).

3.2 JOINTS DESIGN SCHEMES AND THEIR CALCULATION

Two types of structural solutions for rigid joints have been developed (Fig. 5): with unidirectional inclined glued-in rods and with glued-in rods forming V-shaped anchors.

Two types of joint designs have been developed: with unidirectional inclined glued-in rebars and with glued-in rebars forming V-shaped anchors.



1 - glued wooden elements; 2 - inclined glued-in rods; 3 - embedded detail; 4 - transversely glued-in rods

Figure 5: *Types of structural solutions for rigid joints: a - unidirectional inclined glued-in rods in the tensile zone; b - unidirectional inclined glued-in rods in the compressed zone; c - V-shaped anchors*

3.2.1 Joints with unidirectional inclined glued-in rods in the tensile zone

In the tensile zone of a joint with unidirectionally inclined riveted rods, the bending work of the rods is not considered, assuming the formation of a plastic joint at the point where the rod is attached to the embedded plate, which is usually done by welding.

The displacement force in the embedded plate V is decomposed into the tensile force in the rods N_t and the compressive force on the contact between the embedded plate and the wood σ_c (Fig.5a):

$$N_t = V / (n \cdot k_n \cdot \cos\alpha), \qquad (1)$$

where:

N_t - pulling force in the inclined glued-in rod;
V - shear force in the embedded part of the joint;
n - number of inclined glued-in rods;
k_n - non-uniformity factor that takes into account the number of glued-in rods;
α - angle of inclination of a glued-in rod to the direction of force in the embedded plate.

$$\sigma_c = N_t \cdot \sin\alpha / (b_{e.d} \cdot S \cdot k_{n.\sigma}), \qquad (2)$$

where:

σ_c - the normal buckling stress under the embedded part;
$b_{e.d}$ - width of the embedded plate;
S - step of inclined glued-in rods;
$k_{n.\sigma}$ - nonuniformity coefficient, taking into account the pitch and angle of glued-in rods and the stiffness of the embedded plate.

Based on the results of many years of research, a methodology for calculating the rigid joints of wooden structures on glued-in rods has been developed. It is based on determining the bearing capacity of glued-in rods during pulling out and punching. The main provisions of the calculation procedure are outlined in the Russian Construction Norms and Rules [4,5].

The calculated value of bearing capacity $R_{ax.\alpha.d}$ for pulling out or punching out of a rod glued-in at an angle to the wood fibers should be determined by the formula:

$$R_{ax,\alpha,\mathrm{d}} = f_{v,\alpha,d} \cdot \pi \cdot d_1 \cdot l_{ad} \cdot k_v \cdot k_d \leq f_{a.d} \cdot A_a, \qquad (3)$$

where:

$f_{v.\alpha,d} = f^A_{v.d} \cdot m_{dl} \cdot \Pi m_i$ – design resistance of wood to pulling or punching of the rod glued-in at an angle to the fibers;
$f^A_{v.d}$ – design resistance of wood to pulling out or pressing the core glued-in at the angle of 90° to the fibers, for the loading mode A by SP 64.13330 [4], characterized by linearly increasing load at standard machine tests;
m_{dl} – coefficient of prolonged strength, corresponding to the combination of loading;
Πm_i – product of the coefficients of working conditions mi, considering the angle of slope of the rod to the direction of wood fibers, temperature and humidity conditions of operation;
d_1 – hole diameter;
l_{ad} – calculated length of the rod;
d – diameter of the glued-in rod;
k_v – coefficient taking into account uneven distribution of shear stresses depending on the calculated length of the rod;
k_d – coefficient taking into account the dependence of design resistance on the rod diameter;
A_a – sectional area of the rod;
$f_{a.d}$ – design resistance of the rod material.

It should be noted that the length of the glued-in rods is not only determined by the required load-bearing capacity. In the wood at the end of a tensile bonded rod, normal tensile stresses occur across the fibers. The shallower the gluing depth in relation to the section height and the greater the angle of the rod to the direction of shear of the embedded detail, the higher the magnitude of the maximum stresses. Thus, if the inclination angle of the glued-in rod is 45°, the gluing depth should be set on the condition that the vertical projection of the rod is not less than 0.4h - cross-sectional height. If the gluing depth is less, to reduce the tensile stresses across the fibers, the rod should be glued-in across the fibers at a distance (50-70) mm along the fibers from the end of the stretched inclined glued-un rod.

3.2.2 Joints with unidirectional inclined glued-in rods in the tensile zone

If the compression forces in the joint are taken by the embedded plate, the shear force in it V acting on one rod is decomposed into the compressive force in the rod N_c and the shear force Q (Fig.3b):

$$V / (n \cdot k_n) = N_c \cdot \cos\alpha + Q \cdot \sin\alpha, \tag{4}$$

Hence:

$$N_c = V \cdot \cos\alpha / (n \cdot k_n), \tag{5}$$

$$Q = V \cdot \sin\alpha / (n \cdot k_n). \tag{6}$$

The bearing capacity of a rod glued-in at an angle to the wood fibers, working for pulling with bending or punching with bending, should be checked by the formula:

$$(N_c / R_{a.d})^2 + Q / F_{v.R.d} \leq 1, \tag{7}$$

where:

$R_{a.d} = f_{a.d} \cdot A_a$ – design bearing capacity of one rod under the condition of tensile strength of the rod material;

$F_{v.R.d}$ – design bearing capacity of the rod in terms of its operation as a dowel in bending at rigid (welded) connection of the glued-in rod with a steel embedded part, MH, it is taken:

$$F_{v.R.d} = 65d^2 \cdot \sqrt{m_{дл}} \cdot \Pi m_i \text{ – for rebars A300;} \tag{8}$$

$$F_{v.R.d} = 85d^2 \cdot \sqrt{m_{дл}} \cdot \Pi m_i \text{ – for rebars A400;} \tag{9}$$

where d is the nominal diameter of the reinforcing bar.

As far as in the rigid joints of bending and compression-bending structures the bearing capacity of unidirectional inclined glued-in bars in the stretched zone is considerably higher than in the compressed zone, the bars are located in the stretched zone, and compression is taken by the frontal stop or through the centering gasket. In structures with a variable arrangement of the compressed and stretched zones, such as arches, the glued-in rods are placed on both sides.

3.2.3 Joints with V-shaped anchors

One of the glued-in rods of the V-shaped anchor, glued-in at an angle α to the direction of the shear force V, works for pulling out (tensioned rod), the second one, glued-in at an angle β, works for pushing through (compressed rod) (Fig. 5c). The forces in the rods are determined from the expression:

$$V / (n \cdot k_u) = N_t \cdot \cos\alpha + N_c \cdot \cos\beta, \tag{10}$$

where N_t and N_c are the pulling and punching forces in obliquely glued-in rods.

Hence:

$$N_t = V / (n \cdot k_n \cdot \cos\alpha \cdot (1 + \mathrm{tg}\alpha / \sin\beta)), \tag{11}$$

$$N_c = V / (n \cdot k_n \cdot \sin\beta \cdot (1/\mathrm{tg}\alpha + 1/\sin\beta)). \tag{12}$$

When α = β, the forces in the tensile and compressed rods are equal:

$$N_t = N_c = V / (n \cdot k_n \cdot (1 + \cos\alpha)), \tag{13}$$

In practice for V-shaped anchors the angle between the glued-in rods is usually taken to be 90°. Then, with the angle of the rod to be pulled out α:

$$N_t = V \cdot \cos\alpha / (n \cdot k_n), \tag{14}$$

$$N_c = V \cdot \sin\alpha / (n \cdot k_n). \tag{15}$$

The design value of the bearing capacity $R_{ax.\alpha.d}$ for the pulling out or punching through of the rod glued-in at an angle to the wood fibers shall be determined according to the formula (3).

V-shaped anchors can be installed in both tensile and compressed zones. However, it is most effective to install them in the tensile zone, especially for compression-curved elements.

4 JOINT CONTROL TESTS

4.1 PURPOSES OF CONTROL TESTS

For large-span structures, control tests of the main assemblies are often required. The rationale for the need to test the knots of laminated timber structures is that:
- structures of unique structures;
- constructions of structures of the 1st responsibility class according to GOST 27751-2014 [6];
- pilot experimental constructions;
- long-span structures with manufacturing defects;
- large-span structures with assembly defects;
- units of critical structures during the mastering of production.

The purposes of control tests of large span laminated timber structures joints are:
- evaluation of the correctness of the adopted design solutions and calculation assumptions;

- determination of the bearing capacity in the absence of the standard calculation methods;
- verification of manufacturability.
- quality control of manufacturing;
- verification of assemblability and quality control on assembly;
- expert evaluation of the causes of structural failures.

An example of testing to determine the bearing capacity of bendable assemblies of critical experimental structures during production development is the above-mentioned test of the rigid girder joint of the boarding house "Lipki" (Fig. 3).

4.2 TESTS OF JOINTS OF LARGE SPAN STRUCTURES

High chemical resistance to various salts aggressive to steel and concrete makes wood competitive in the construction of structures for the storage of such materials. An example of control tests are tests of rigid joints on glued-in rods of the main elements of glued wood frameworks of mineral fertilizer storage facilities and other similar structures.

4.2.1 Warehouse of anti-icing chemicals in Moscow

During the reconstruction of the Moscow Ring Road in 1999, a de-icing agent warehouse was built in Moscow, the frame of which was made in the form of three-jointed bent-beam frames with a span of 60 m - the first long-span structure with compression-curved rigid joints on glued-in rebars (Fig. 6a) [7].

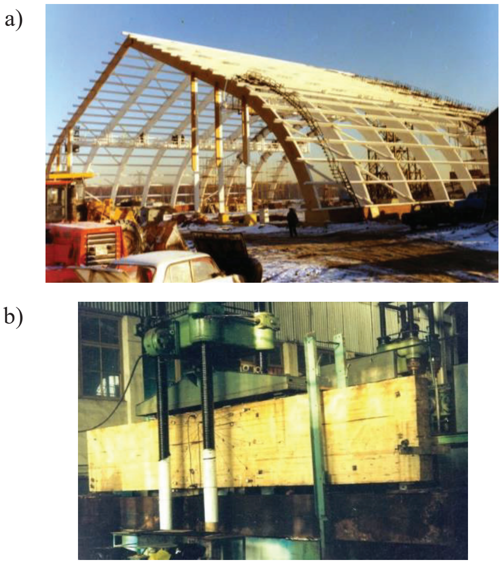


Figure 6: *De-icing agent storage with a span of 60 m: a - installation; b - rigid joint testing*

In order to assess the correctness of the adopted design solutions and design assumptions, control tests were carried out on a fragment of the structure with a rigid joint in the middle of the length (Fig. 6b). The joint was made symmetrical with a frontal stop through epoxy-based polymer concrete. Since the bearing capacity of the joint is determined by the tensile zone, bending tests were performed, with the tensile forces in the joint corresponding to the forces in the tensile zone of the compression-bending joint of the bent frame.

To assess the stress-strain state of the wood in the joint area, electrical strain gauges were glued and mechanical strain and displacement sensors were installed. During the tests, the opening of the joint in the tensile zone, the shear deformations of the embedded plate relative to the wooden element, and the relative deformations along the fibers in the compressed zone were determined.

The tests confirmed the correctness of the adopted design solutions and design assumptions. The failure was caused by wood rupture in the tensile zone outside the joint.

During the tests, an additional task was set to check the effectiveness of the method developed in CNIISK to strengthen glued wooden elements in which shrinkage cracks and delamination of glue joints can appear in the process of tests [8]. In the supporting zone of one of the joined fragment elements in the middle of the section height, an artificial through crack was created with the length of about half the element length. There was performed an inclined reinforcement by reinforcing bars with diameter of 20 mm of class A400 with length of 1000 mm glued-in at an angle of 45° to the fibers. Along the artificial crack, shear gauges were installed.

At the initial stage of tests, approximately up to the normative load, shear was minimal, the structure did not work as a composite element on compliant bonds, but as a monolithic one. The test results confirmed the effectiveness of inclined reinforcement of zones with high levels of tangential stresses and tensile stresses across fibers for strengthening and restoration of wooden structures, primarily the supporting zones of beams.

4.2.2 Potassium salt deposits in Volgograd Region

In the Volgograd region at the mining and beneficiation plant for the extraction and processing of potassium salts two warehouses with frames of glued wooden structures were built (Fig.7).

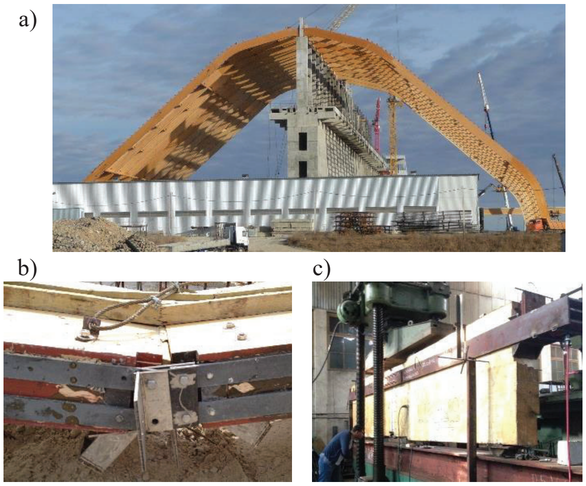


Figure 7: *87.2 m span warehouse arches: a - frame assembly; b - joint of collapsed arch; c - joint testing*

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Structural scheme represents three hinged glued wooden arches with 87.2 m span and 36.7 m height at the ridge. Each half-arch consists of three elements, which at their ends are fitted with embedded parts fixed on inclined glued-in rebars. During installation, the elements are joined into a semi-arch by rigid joints by connecting the embedded parts with M20 bolts made of A4-80 stainless steel.

In 2014, at the beginning of installation of the frame of the first warehouse, two bent wooden girders collapsed as a result of a hurricane. The bolts in the lower rigid joints had sheared off after the half-arcs collapsed. To determine the cause of the collapse, a decision was made to repair one of the rigid joints and conduct a test to confirm sufficient load-bearing capacity. An 8-metre long section with a rigid joint in the middle was cut out of one of the collapsed arches. Restoration of the joint consisted of installing new bolts.

In the first phase, tests were performed for compressive force and bending moment (Fig. 7c). The H and M ratios corresponded to the forces in the arch for the design load combination. During the tests, the shear deformations of the embedded parts relative to the wood, the joint opening width in the tensile zone, and the compression deformations along the fibers in the compressed zone were determined. When the required level of loading was reached, no fracture occurred, the instrumentation showed that the joint was working in the elastic stage.

Since the load-carrying capacity of the joint is determined by the work of the glued-in rods in the tensile zone, it was decided to conduct further tests only in the bending zone, comparing the forces in the glued-in rod located in the tensile zone with the forces in the compression-bending element joint. The bolts were replaced with stronger bolts of class 10.9. The bolts sheared off under a load much greater than the design load.

In the third phase, the bolts were replaced by welding. The failure of the joint occurred from the rupture of the glued-in rebars.

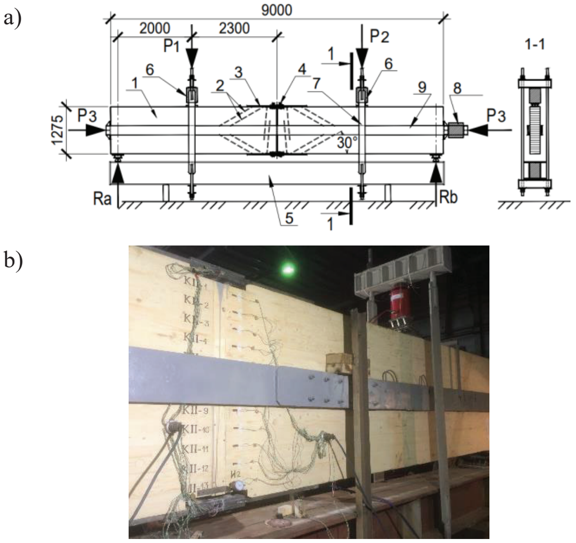
Tests showed sufficient load-bearing capacity and confirmed that the rigid bonds on the bonded bars were not the cause of the collapse.

4.2.3 Potash warehouses in Perm Territory

The main load-bearing structures of the potash production complex warehouses in Perm Krai, built in 2016-2020, are glued wooden triangular arches with a span of 60 m and a height at the ridge of 38.5 m. The 49.3 m long half arches, based on technological and transport limitations, consist of 2 elements along the length with a rigid joint between them on unidirectional obliquely glued-in rebars. Due to the fact that the warehouses of chemical enterprises belong to the constructions of the 1st responsibility class and two companies selected for the manufacture of glued wooden structures of warehouse frameworks had no experience in the manufacture of critical structures with the nodes on the glued-in rebars, the control tests of the rigid joint were required.

A full-scale fragment with a rigid butt-joint in the middle of the span was tested in compression and bending (Fig. 8). The two elements forming the fragment were manufactured at two QDC manufacturing plants. The tensile forces in the joint are taken up through the embedded detail by unidirectional obliquely glued-in rebars. The compression is transmitted by the frontal stop via polymer concrete alignment pads.

In the area of the joint, the test fragment is equipped with electric strain gauges and mechanical strain and displacement sensors to record the stress-strain state of the wood and steel embedded parts, shear strains of the embedded parts, opening of the joint in the tensile zone, deflections of the sample, etc. (Fig. 8b).



1 – laminated wood test sample; 2 - rebars 22 mm diameter, 1000 mm long, glued-in at an angle of 30° to the grains; 3 - anchor plate; 4 – bolts; 5 - power traverse; 6 - hydraulic jack with capacity 1000 kN; 7 - vertical tie bar; 8 - hydraulic jack with capacity 1500 kN; 9 - horizontal tie bar

Figure 8: *Control tests of a compression-bending rigid joint of an arch with a span of 60 m*

Maximum bending moment in the rigid butt-joint M = 667 kN-m with a longitudinal force N = -532 kN and a shear force Q = 64 kN. The adopted testing scheme allowed to have ratios of internal forces in the butt at any stage of tests, which were proportional to the previously given design values. Loads were applied on the specimen by means of hydraulic jacks in a special stand (Fig.8a). Compressive force N was created by resting it in the end face of a 1500 kN hydraulic jack. The bending moment M was created by two hydraulic jacks of 1000 kN capacity each, with different loads on jacks, resulting in a transverse force Q at the junction.

The tests were conducted in two stages. The first stage of tests was conducted with metal overlays removed in the compressed zone of the joint, which allowed for the exclusion of embedded parts with glued-in rebars in the compressed zone. The second stage was performed with the overlays in place to allow the wood and metal embedded parts with the glued-in rebars to work together in compression.

Each stage consisted of several stages. The first two stages of the tests in both stages were characterized by the work of the specimen in the elastic strain zone. In the first stage, only vertical loads were applied to the specimen, allowing only pure bending to be simulated in the element junction zone. The second stage simulated compression with bending, adding horizontal compressive loads to the vertical loads.

The third stage was conducted only for the second stage of tests and was a continuation of the second stage. At this stage, the specimen was brought to failure.

The maximum loads exceeded the design loads by 1.8 times and the required maximum test loads by 1.18 times. The test results showed that the technical solutions adopted in the design are technological, provide the required load-carrying capacity and confirm the quality of rigid joints in the manufacture of structures.

4.2.4 Mineral fertilizer warehouse of Gomel Chemical Plant

In 2021, a mineral fertilizer warehouse was built at the Gomel chemical plant. The main load-bearing structures were three-armed non-symmetrical triangular arches (Fig. 9a). One half-arch has a slope to the horizon of 45°, the second - 30°. The second half-arch, 33.2 m long, has a rigid joint on inclined glued-in rebars.

The building code of Belarus regulates the compulsory control tests of critical structures. In 2020, in Brest (Belarus), tests were carried out on a fragment of a half-arch with a rigid joint on glued-in rebars (Fig. 9b). The tests were conducted under the scientific supervision of A. Naychuk according to the method developed by A. Pogoreltsev [9]. The tests were conducted in two stages: in compression with bending and in bending. The sample was equipped with measuring instruments (Fig. 9c).

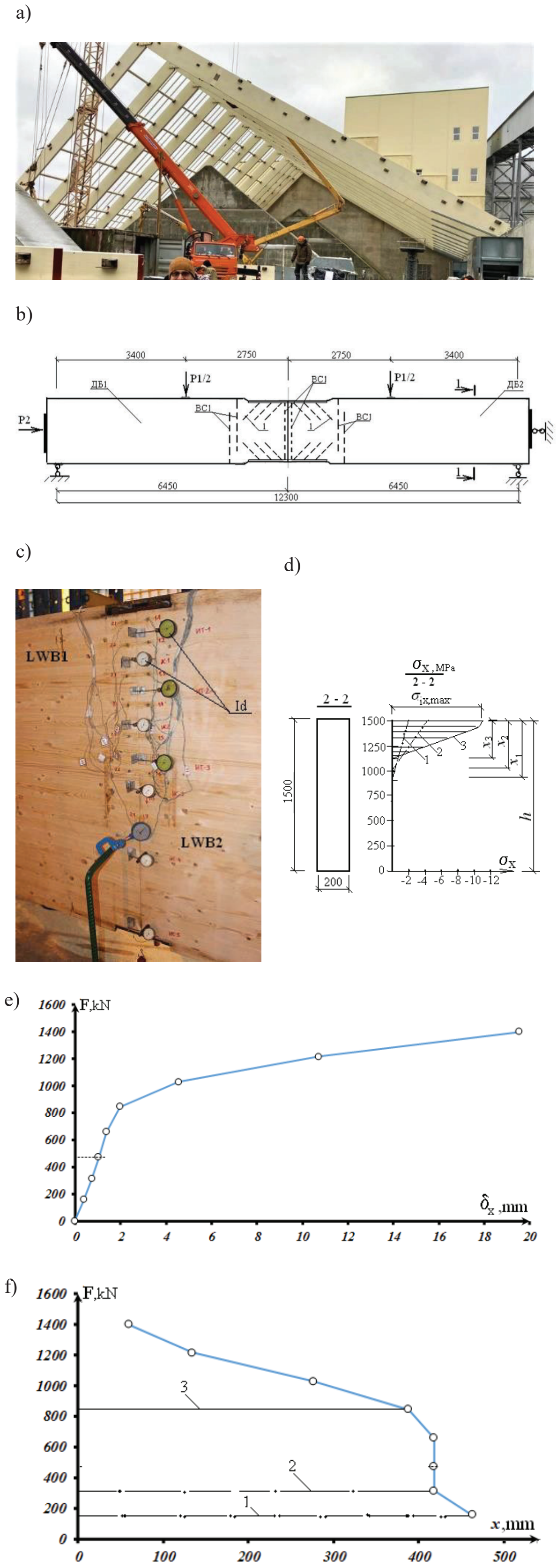
While carrying out the tests, there were determined the regularities of change in the stress-strain state of wood in the area of location of the inclined glued-in rebars, compliance of connection elements, height of the compressed zone (Fig. 9e and 9e), the width of joint opening in the stretched area between the ends of the connected elements (Fig. 9f), depending on the magnitude of applied loads.

It follows from the test results that the height of compression zone of the joint is not a constant value and depends on the suppleness of the embedded parts and the level of tension in the connecting plates. The height of the compressed zone decreases with increasing load.

When testing the specimen under the loading scheme of the compression-bending element the carrying capacity of the joint in vertical direction is Rsup,c,90 = 131.5 kN and in horizontal direction - Rsup,c,0 = 124.9 kN, which is more than values of the required carrying capacity.

When testing the prototype according to the bending element loading scheme, the value of actual bearing capacity Rsup,v = 364.9 kN, which is significantly higher than the value of the required bearing capacity.

At the same time, numerical studies of the joint operation were performed (Fig. 9g). The obtained data were compared with the test results.



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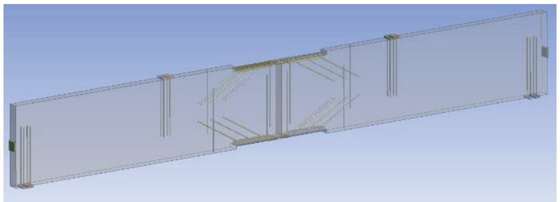

1 - F = 157 kN; 2 - F = 315,3 kN; 3 - F = 843,8 kN

Figure 9: *Fertilizer warehouse: a - installation of arches with a span of 45 m; b - test scheme of a fragment with a rigid joint; c - indicators and strain gauges in the joint zone; e - diagram of normal compressive stresses in section 2-2; f) - dependence of height of compressed zone x on the load value; f) - dependence of width δx of joint opening on the load value; g) - numerical model*

The discrepancy between the data obtained as a result of numerical calculations and tests was most typical for the value of compression zone height, which was 22%. Such a difference is caused by the fact that during the prototype production, a partial adhesive bond between the surfaces of the embedded parts and the wood in the process of gluing of the inclined reinforcing bars took place. This circumstance led to a decrease in the suppleness of the embedded parts and an increase in the height of the compressed zone. In the KE model, the friction coefficient between the surfaces of the embedded parts and the wood was assumed to be zero.

5 CONCLUSIONS

During all the control tests, additional research tasks were solved as part of the glued-in rebar joints research program.

The results of control tests confirm the correctness of the design assumptions laid down in the Russian construction norms and rules [4, 5].

Over the past 25 years in Russia, dozens of buildings with large-span laminated wooden structures using rigid joints on the glued-in rebars have been built: water parks at the Abzakovo ski resort (beams of span 29.8 m), in Ulyanovsk (lenticular trusses of span 32.3 m), in Mytishchi ((lenticular trusses of span 44 m), Rostov-on-Don (lenticular trusses of span 35 m), Saint Petersburg (90 m diameter dome), Novosibirsk (95 m diameter dome); swimming pools in St. Petersburg (lenticular trusses with spans of 45 m and 56 m), Saransk (frames with spans of 40 m and 30 m), Kazan (frames with spans of 54.6 m); sports palaces in Moscow (lenticular trusses with 48 m span and frames with 42 m span), Nefteyugansk (metal and wood lenticular trusses with 42 m span); ice palaces in Moscow (metal and wood lenticular trusses with 50,5 m span), Krasnoyarsk, Irkutsk and Novokuznetsk (sickle-shaped arches with 99,9 m span and many others).

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