# APPLICATION OF WELDED STUDS FOR FASTENING OF RAILWAY BRIDGE DECK

**V.V. KNYSH**[1], **S.A. SOLOVEJ**[1], **A.A. GRISHANOV**[1], **G.O. LINNIK**[2] and **M.G. MALGIN**[3]
[1]E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua
[2]Ukrzaliznytsya
5 Tverskaya Str., 03680, Kiev, Ukraine. E-mail: cpi@lotus.uz.gov.ua
[3]MIDAS Information Technology Co., Seul, Korea. E-mail: malgin@midasit.com

Proposed is a new structure of fastening of slabs of ballast-free bridge deck to T-girders of railway bridges, which provides for change of thread studs to welded ones. Arc-contact welding allows for stud positioning directly over vertical wall of T-girder that does not result to angular deformation of girder upper flange typical in application of thread studs. Aim of present work was evaluation of possibility of application of welded studs for fastening of slabs of ballast-free bridge deck in construction and repair of railway bridges. For that, fatigue tests of welded joints of stud to upper flange of girder from the most wide-spread steels St3sp (killed) and 09G2S were carried out at different ranges of loading, which are realized in stud preliminary tightened with 6 tf force during rolling stock movement. It is determined that cyclic life of such joints exceeds $5\cdot10^6$ cycles of stress alternation at loading range $\Delta P \le 3$ tf. Numerical simulation showed that application of oak board and rubber band as spacing layer between slab of ballast-free bridge deck provides for cyclic life of welded stud not less than $5\cdot10^6$ cycles of stress alternation, since loading range exceeds $\Delta P = 3$ tf. However, application of fast hardening nonshrinking mixtures (cast-in-place concrete) as spacing layer allows reducing range of loading to $\Delta P = 1$ tf, that guarantees welded stud life not less than $5\cdot10^6$ cycles of stress alternation. 13 Ref., 2 Tables, 16 Figures.

**Keywords:** *welded joint, welded stud, slab of balast-free bridge deck, fatigue resistance, fatigue test*

Nucleation and propagation of fatigue cracks in welded assemblies and structure elements of spans of railway bridges can be prevented with the help of technological methods (measures), directed on increase of welded joint fatigue resistance as well as by improvement of existing structural solutions, including structure of bridge deck, which has significant effect on life of railway bridge span [1–4]. Perspective direction for improvement of technical characteristics of spans under operation is progressive replacement of timber-based bridge deck by reinforced concrete slab-based bridge deck. The latter has the following advantages, namely high stability of element positioning and long-term operation; protection from corrosion and contamination of upper flange of girders and connections between them; being economic as for total cost of manufacture, laying and operation during bridge service life.

However, structure of bridge deck based on reinforced concrete slabs (Figure 1) has some disadvantages. Applied structure of fastening of slab to main or longitudinal T-girders of span

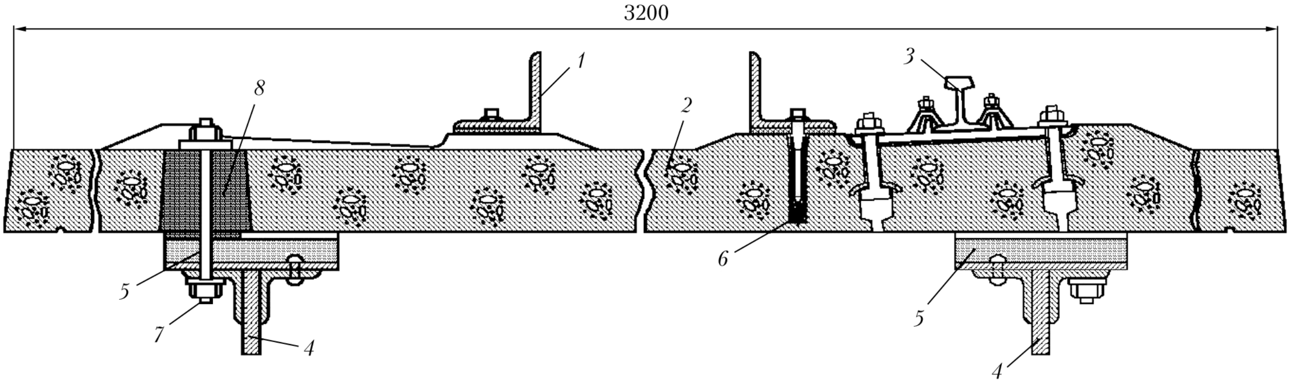


**Figure 1.** Structure of bridge deck based on BFBD slabs: *1* — contrangle; *2* — reinforced concrete slab of bridge deck; *3* — rail; *4* — main or longitudinal beam; *5* — spacing layer; *6* — polymer dowel with screw spike; *7* — high-strength stud; *8* — hole for stud

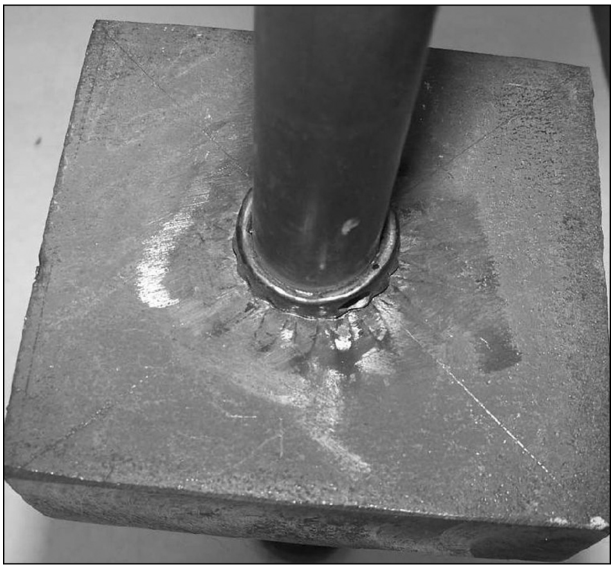

**Figure 2.** Stud to plate welded joint

can be referred to such disadvantages. Existing technology of fastening of slabs of balast-free bridge deck (BFBD) by removable high-strength thread studs provides for their positioning with eccentricity in relation to vertical wall of longitudinal girder that provokes for appearance of additional loading on upper flange of girder in rolling stock movement, that results in preliminary nucleation of fatigue cracks of $T_4$ and $T_9$ types [5].

It is obvious that elimination of indicated eccentricity requires positioning of fastening studs of BFBD slabs in the plane of vertical wall of T-girder. Such structural solution is possible only under condition of application of welding processes. Considering restricted normative limits on organizing of works on replacement of bridge deck as well as possibility of application of standard fasteners, stud welding is relevant to be carried out with the help of arc-contact technology. However, given welded element (welded stud operating under alternating tension) is absent in domestic and foreign reference documents on fatigue calculation [6–9].

Therefore, aim of present work lies in estimation of possibility of application of welded studs for fastening of BFBD slabs in construction and repair of railway bridges.

**Materials and investigation procedure.** Experimental investigations on fatigue resistance of welded joint of stud to upper flange of solid (not composite) T-girder was carried out on mock-up specimens. The latter consist of the following parts: stud, plate simulating solid upper flange of T-girder; and gripping part. Stud from low-alloy steel 09G2S was welded using arc-contact method on center of the plate (Figure 2), and electric-arc welding by stick electrodes UONI-13/55 was used for gripping part. Dimensions of the gripping part are stipulated by gripping devices of test machine ZDM-10pu, which allows for carrying out test of the specimens at alternating stresses of repeated or reversed cycles in ±10 tf loading range. Testing of mock-up specimens was carried out at uniaxial cyclic tension with 5 Hz frequency. Such loading scheme corresponded to scheme of loading of high-strength studs in fastening of BFBD slabs in railway bridge spans. Complete fracture of the specimen or exceeding of testing base of $5 \cdot 10^6$ cycles of stress alternations were taken as criterion of test completion.

The first series of specimens for fatigue tests consisted of four mock-up specimens, where 22 mm diameter stud was welded to 09G2S steel ($\sigma_y$ = 375 MPa, $\sigma_t$ = 510 MPa ) plate of 30 mm thickness: two specimens each with cylindrical and prismatic gripping parts (Figures 3 and 4). The tests were carried out at zero-to-tension cycle with maximum force 6 tf. Such stud loading was determined on full-scale structures (see Figure 1), spacing layer of which consists from 200× 40 mm size oak board and 200 × 8 mm rubber band. It should be noted that today given

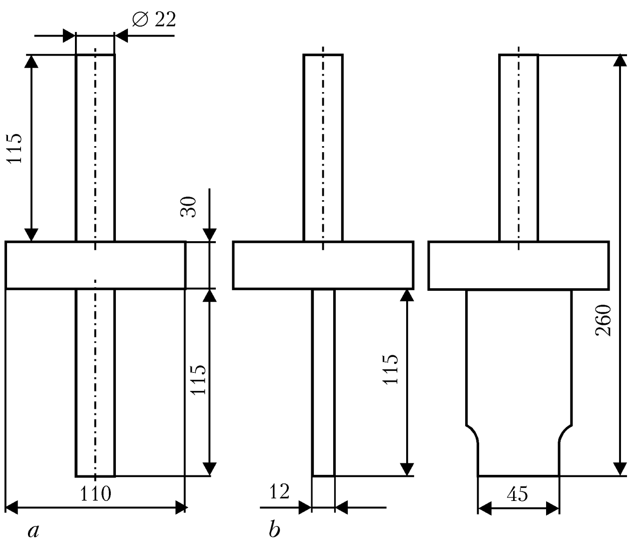


**Figure 3.** Drawing of mock-up welded joint of stud for fastening of BFBD slabs to upper flange of T-girder with cylindrical (*a*) and prismatic (*b*) gripping parts (first series of specimens)

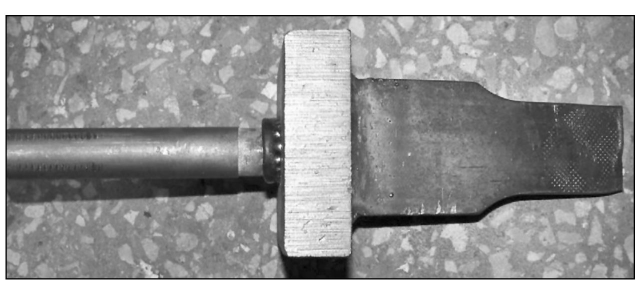

**Figure 4.** View of welded mock-up specimen for fatigue testing with prismatic gripping part

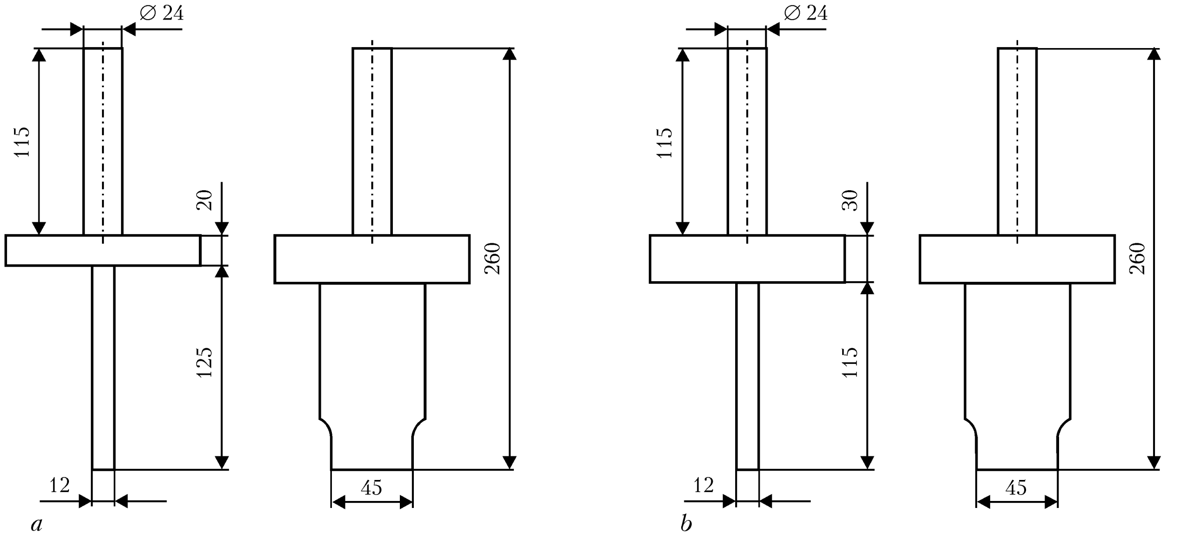


**Figure 5.** Drawing of mock-up specimen of welded joint of fastening stud of BFBD slabs to upper flange of T-girder from St3sp (*a*) and 09G2S (*b*) steels (second and third series of specimens, respectively)

structure of the spacing layer is a basic one in construction and repair of railway bridges in Ukraine.

Test procedure was improved and corrected based on results of testing of first series of specimens. Diameter of welded stud was increased to 24 mm. Taking into account that most of T-girder of railway bridge spans are manufactured from St3sp (killed) low-carbon steel and low-alloy steel 09G2S, therefore, 24 mm diameter stud in mock-up specimens of second series was welded to St3sp steel ($\sigma_y$ = 235 MPa, $\sigma_t$ = 420 MPa) plate of 20 mm thickness, and 24 mm diameter stud in specimens of third series was welded to 09G2S steel ($\sigma_y$ = 375 MPa, $\sigma_t$ = 510 MPa) plate of 30 mm thickness (Figure 5). Each series consisted of eight specimens. The gripping part of specimens was made prismatic.

The tests were carried out on following procedure. Cyclic life of stud welded joints was determined at different loading ranges. Maximum applied loading was not changed and made 6 tf, that corresponded to stud tightening force at mounting of BFBD slab. Initial minimum applied loading made 0 tf, that corresponded to complete unloading of the stud. If set initial loading range of 6 tf promoted preliminary fracture of two specimens at life not less than $5\cdot10^6$ stress alternation cycles, then the range was reduced by 1 tf due to increase of minimum loading. Schematic representation of loading ranges in fatigue testing of the second and third series of specimens is given in Figure 6.

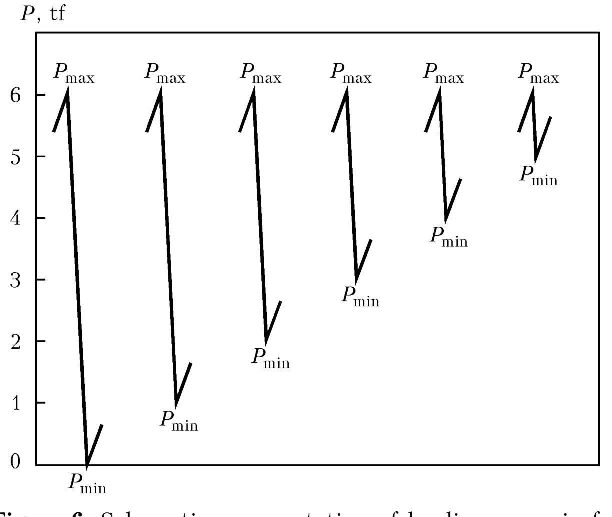


**Figure 6.** Schematic representation of loading range in fatigue testing of mock-up welded specimens of second and third series

**Investigation results.** Failure of all specimens of first series took place on welded joint of stud to plate, simulating solid horizontal flange of T-girder. Specimen life determined in experimental way lies in the range from 53,500 to 105,600 cycles of stress alternation (at that necessary cyclic life of $\leq 5\cdot10^6$ cycles of stress alternation are not provided):

| Number of specimen | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of cycles before failure *N* | 105,600 | 165,800 | 53,500 | 175,900 |

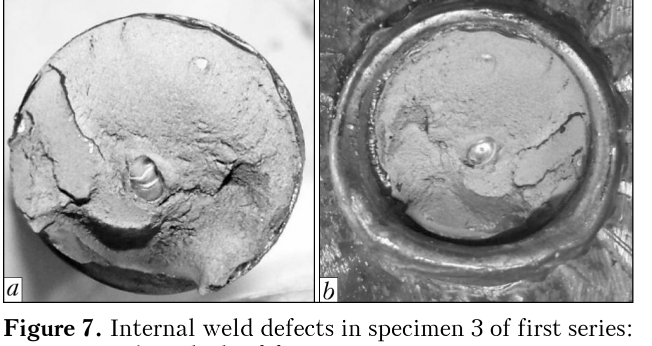


**Figure 7.** Internal weld defects in specimen 3 of first series: *a* — pores; *b* — lack of fusion

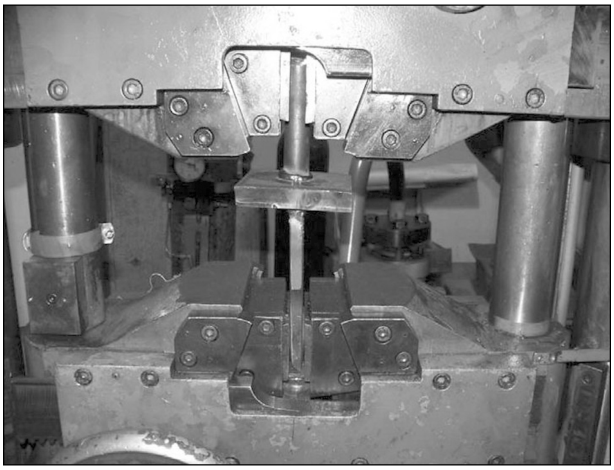

**Figure 8.** Fatigue tests of specimen of welded joint of second series on ZDM-10pu machine

Performed fractographic analysis of failure places determined presence of such internal defects as pores on welded joint center and lack of fusion on edge (Figure 7). Presence of defects indicates possible deviations of technological parameters of welding process, caused by effect of external factors or insufficient adjustment of welding technology. It should be noted that loading of mock-up specimen with zero-to-tension stress of 6 tf promotes for achievement of 160 MPa maximum stresses in throat area of 22 mm diameter welded stud. Limited life of defect-free butt welded joints under such stresses is at the level of $2\cdot10^6$ cycles of stress alternation with 50 % failure possibility [10, 11]. Calculation value of margin of limited durability of butt welded joints on basis of not less than $5\cdot10^6$ cycles of stress alternation at 95 % failure possibility

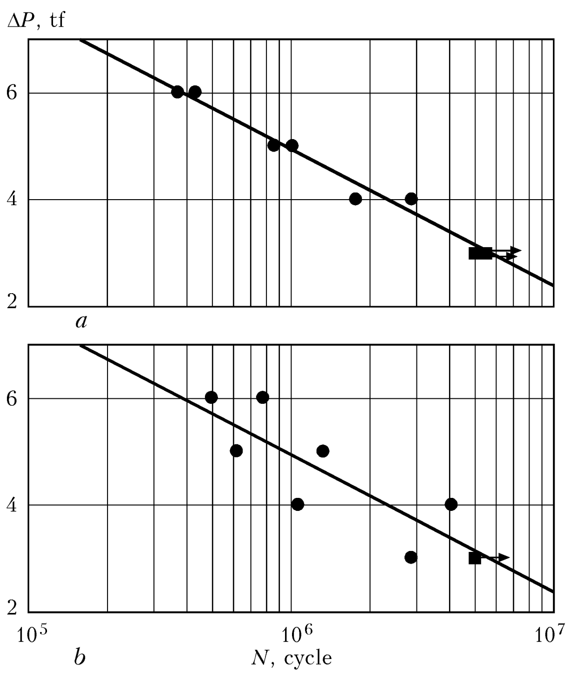


**Figure 9.** Fatigue curve of welded joints of 24 mm diameter stud to plate from St3sp (*a*) and 09G2S (*b*) steels

**Table 1.** Results of fatigue tests of mock-up specimens of second and third series

| Specimen No. | *N*, cycle | |
|---|---|---|
| | Second series | Third series |
| 1 | 433,500 | 782,400 |
| 2 | 371,600 | 499,800 |
| 3 | 1,011,900 | 623,600 |
| 4 | 863,000 | 1,326,100 |
| 5 | 1,757,600 | 4,080,800 |
| 6 | 2,873,300 | 1,062,500 |
| 7 | > 5,000,000 | 2,873,300 |
| 8 | > 5,000,000 | > 5,000,000 |

*Notes*. 1. For all specimens $P_{max}$ = 6 tf. 2. For specimens 1 and 2 $P_{min}$ = 0; 3, 4 — 1; 5, 6 — 2; 7 and 8 — 3 tf.

according to [6] makes 114 MPa. It should be considered that values of stress concentration coefficient for stud to plate joint significantly exceed the values of stress concentration coefficient typical for butt joints ($\alpha_\sigma$ = 1.1–1.3).

Thus, it can be concluded using the results of testing of first series of specimens that application of welded studs in railway bridge spans is possible under condition of reduction of stress effect in the throat area of stud due to increase of stud diameter and decrease of loading ranges in use of new structures for spacing layer between BFBD slab and upper flange of T-girder.

Equipment for arc-contact welding «Nelson Nelweld 6000» provides for welding of 24 mm diameter studs. Increase of stud diameter from

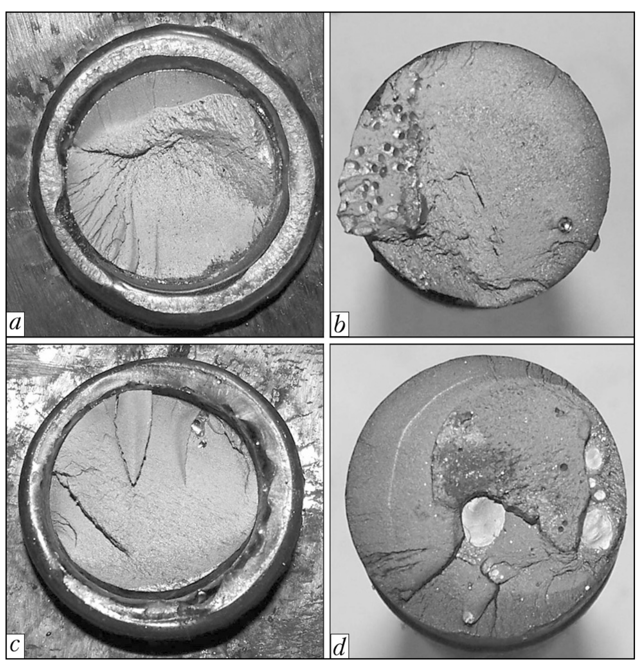


**Figure 10.** Fracrtures of mock-up specimens 3 and 4 of second (*a*, *b*) and 5 and 6 of third (*c*, *d*) series

**Table 2.** Properties of materials of spacing layer between BFBD slab and upper flange of T-girder

| Material | Element of bridge deck | Modulus of elasticity $E$, MPa | | Poisson coefficient ν |
|---|---|---|---|---|
| | | Range | Calculation | |
| Concrete | BFBD slab | $3\cdot10^4$ | | 0.2 |
| Concrete | Spacing layer | $3\cdot10^4$ | | 0.2 |
| Wood across the grain | Same | 500–1000* | 750 | 0.16 |
| Rubber | » | 7–14** | 10 | 0.5 |
| Steel | Stud | $2.1\cdot10^5$ | | 0.3 |

*Data are taken from work [13], ** — from [4, 13].

22 to 24 mm allows for reducing maximum stresses in the throat area from 160 to 130 MPa.

Testing of second and third series of mock-up specimens were also carried out on ZDM-10pu machine at 5 Hz frequency (Figure 8).

Results of fatigue tests of specimens from second series (stud was welded to plate from St3sp steel) and from third one (stud was welded to plate from steel 09G2S) are given in Table 1, and Figure 9 represents corresponding fatigue curves. Failure of specimens of second series took place on welded joint of stud to plate. Cyclic life of tested specimens exceeds the values of $5\cdot10^6$ cycles of stress alternation at loading range $\Delta P \leq 3$ tf. Fractographic analysis was carried out for place of fracture of mock-up specimens. Presence of such internal defects as pores (Figure 10, *b*) reduces cyclic life of the specimens by 20 % (life of specimen 4 with pores makes 863,000 cycles of stress alternations and 1,011,900 cycles for specimen 3 without pores).

Failure of specimens of third series took place in welded joint of stud to plate. Cyclic life of tested specimens also exceeds the values of $5\cdot10^6$ cycles of stress alternation at $\Delta P < 3$ tf loading range. At that, experimental data for specimens of third series have larger spread in comparison with specimens of second series. Presence of pores and lack of fusions (Figure 10, *d*) promotes 4 times reduction of cyclic life of specimens (life of specimen 5 makes 4,080,800 cycles of stress alternation and 1,062,500 cycles for specimen 6 without pores).

Considering data received on mock-up specimens of first series, increase of stud diameter from 22 to 24 mm resulted in 3–6 times increase of life under similar levels of loading range from 0 to 6 tf. At that, peculiarities of fracture of studied specimens of all three series indicate the necessity of adjustment of technology of arc-contact welding for fastening studs of BFBD slabs. Reduction of amount of internal defects allows

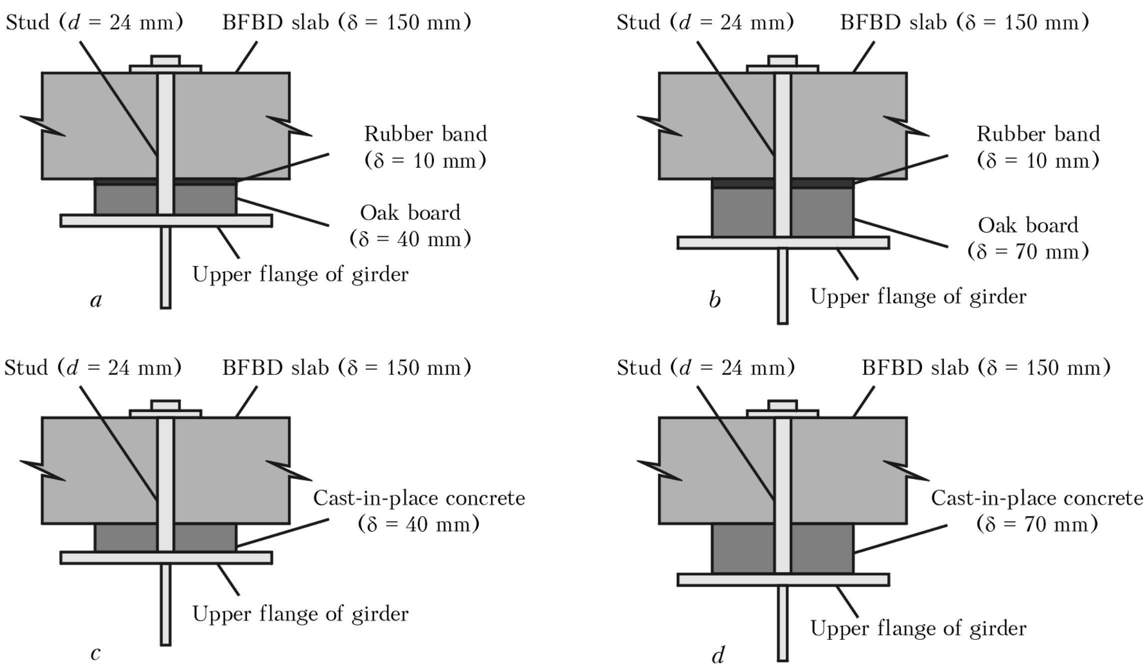


**Figure 11.** Types of spacing layer of bridge deck from oak board, rubber band (*a*, *b*) and cast-in-plate concrete (*c*, *d*) of various thickness

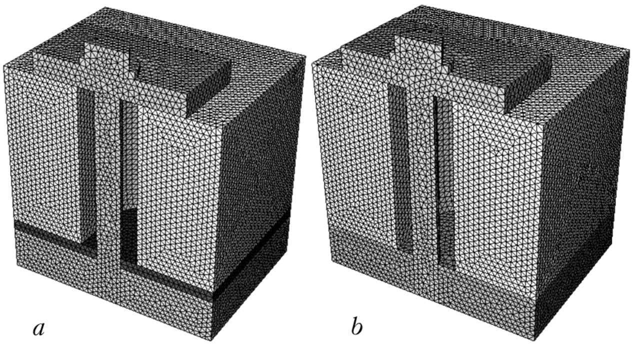


**Figure 12.** Fragment of calculation models for spacing layer from wood and rubber (*a*) and cast-in-place concrete (*b*)

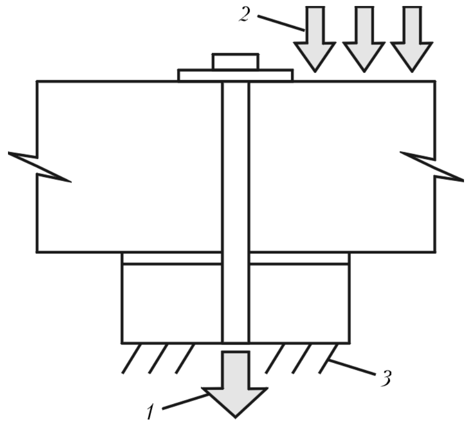


**Figure 13.** Scheme of calculation model: *1* — set movement of stud basis (tightening); *2* — pressure from transport wheel; *3* — rigid attachment

for increasing a possibility of nonfailure of welded joints of 24 mm diameter studs in loading range from 3 to 6 tf.

Data of full-scale investigations showed that loading ranges effecting welded stud exceed 3 tf in use of the spacing layer between BFBD slabs and T-girder (oak board and rubber band). Range of stud operating alternating stresses from 3 to 6 tf can be achieved by means of increase of rigidity of the spacing layer, for example, thanks to application of fast hardening nonshrinking mixtures (concretes).

Numerical calculation was applied to change of initial (6 tf) tightening force of welded stud during passing of rolling stock depending on applied types of the spacing layers since stress-strain state of elements of bridge deck in initial condition and in passing of rolling stock depends on the spacing layer between BFBD slab and T-girder. All numerical calculations were performed in program complex midas Civil using finite-element method.

The following conditions were used in performance of numerical modelling: reinforced concrete slab of BFBD had typical geometry dimen-

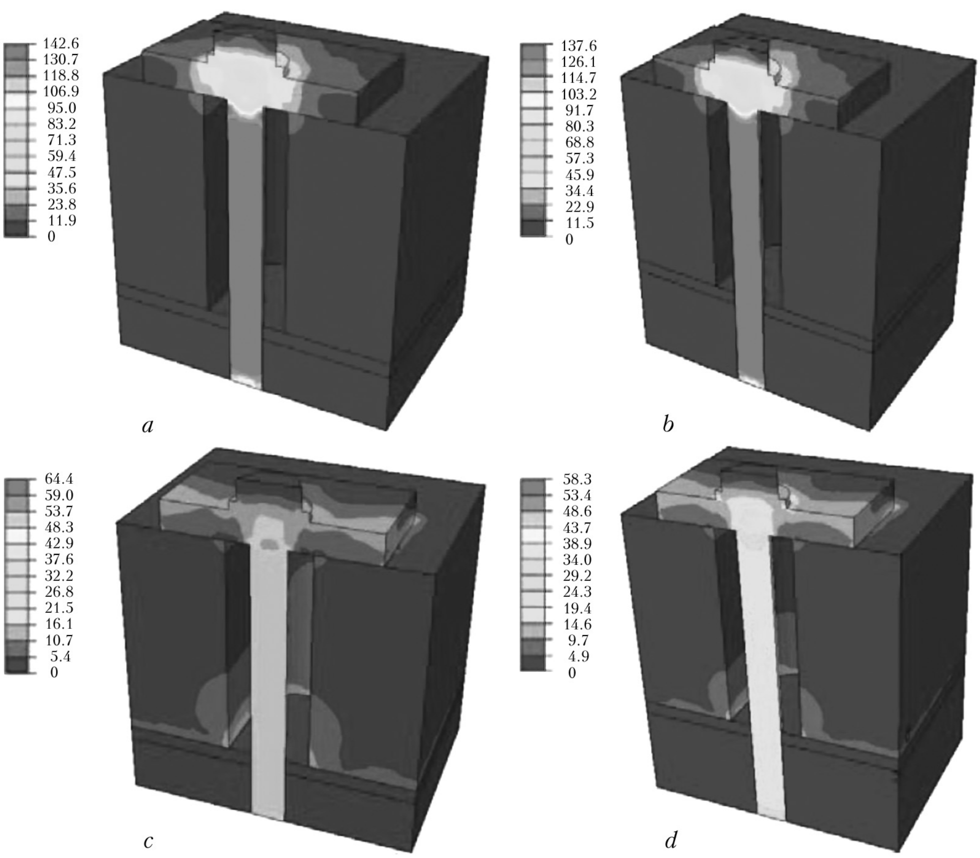


**Figure 14.** Isofields of stresses in welded stud in initial condition (*a*, *b*) and during passing of rolling stock (*c*, *d*): *a*, *c* — spacing layer from oak board of δ = 40 mm and rubber band of δ = 10 mm; *b*, *d* — spacing layer from 70 mm oak board and 10 mm rubber band

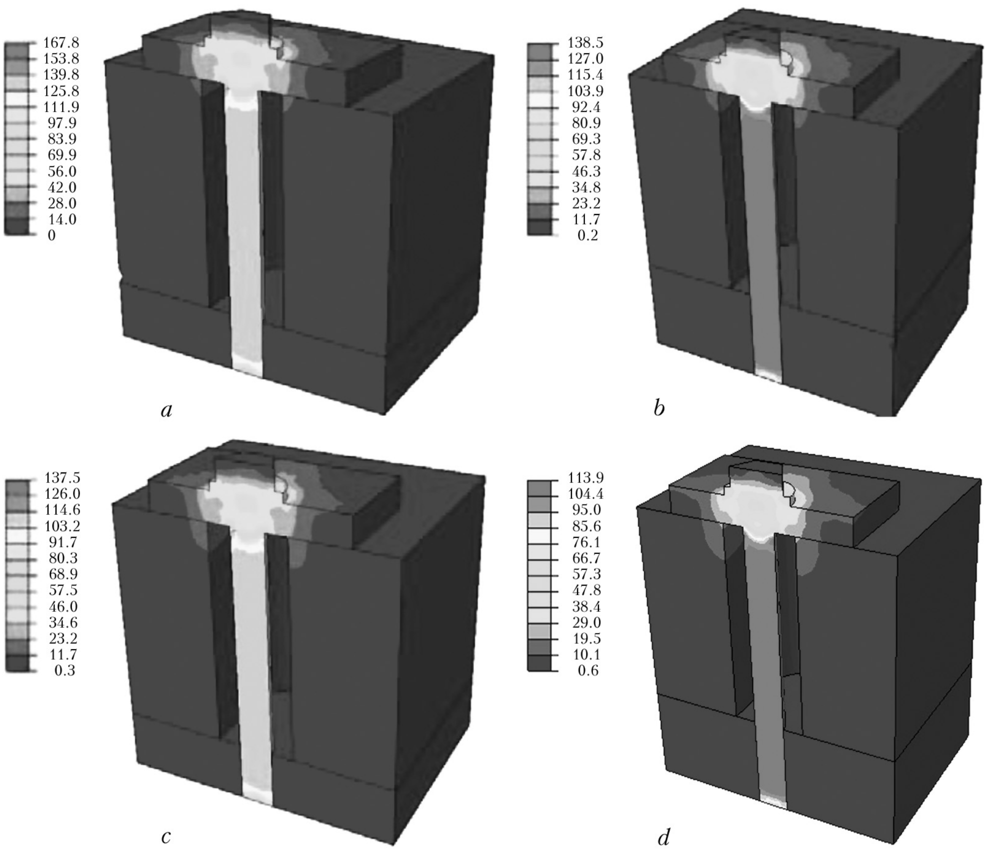


**Figure 15.** Isofields of stresses in welded stud in initial condition (*a*, *b*) and during passing of rolling stock (*c*, *d*): *a*, *c* — spacing layer from cast-in-place concrete of δ = 40 mm; *b*, *d* — the same, but δ = 70 mm

sions [12], diameter of welded stud was 24 mm, initial tightening force made 6 tf and axial loading from railway transport was 30 tf.

Four spacing layers were investigated between BFBD slab and T-girder, namely oak board of δ = 40 mm and rubber band of δ = 10 mm (Figure 11, *a*), δ = 70 mm oak board and δ = = 10 mm rubber band (Figure 11, *b*), cast-in-place concrete of δ = 40 (Figure 11, *c*) and 70 mm (Figure 11, *d*). In all calculation schemes the width of elements for the spacing layer made 200 mm, calculation models were approximated by finite elements in form of tetrahedrons (Figure 12). Table 2 [4, 13] provides for properties of materials of the spacing layer, assumed in numerical calculation.

Initial 6 tf tightening force of the stud was set by movement of its basis for corresponding value that simulated pressing of reinforced concrete slab to spacing layer. At that, reduction of tightening force (stud unloading) was carried out by applying of distributed loading to BFBD slab surface from pressure of wheel of railway transport. Ban for linear and angular displacements of assemblies on lower surface of the spacing layer (Figure 13) was imposed as boundary conditions in the calculation models.

Calculations of stress-strain state of welded stud for four investigated types of spacing layer between BFBD slab and upper flange of T-girder

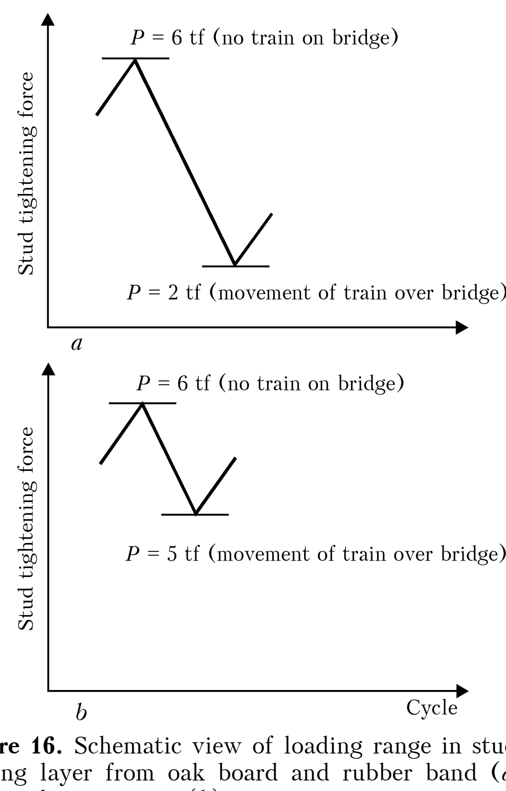


**Figure 16.** Schematic view of loading range in stud with spacing layer from oak board and rubber band (*a*) and cast-in-place concrete (*b*)

were carried out. Isofields of stresses were received for welded stud in initial condition (at 6 tf tightening force) and during passing of rolling stock for spacing layer from wood and rubber (Figure 14) and cast-in-place concrete (Figure 15). Tensile stresses of around 130 MPa (Figures 14, *a*, *b* and 15, *a*, *b*) appear in tightening of the stud with 6 tf independent on spacing layer between BFBD slab and upper flange of T-girder in cross section of the stud.

During passing of rolling stock stresses in the stud reduce to 40 MPa with spacing layer from wood and rubber and to 110 MPa with spacing layer from cast-in-place concrete. Increase of thickness of oak board from 40 to 70 mm promotes 7 % reduction of stresses in the stud (see Figure 14 *c*, *d*) and that decreases by 5 % with rise of thickness of cast-in-place concrete from 40 to 70 mm (see Figure 15, *c*, *d*). Figure 16 shows view of loading ranges in the stud in use of wood and rubber as well as cast-in-place concrete.

**Conclusions**

1. New structure of fastening of reinforced concrete slab of ballast-free railway bridge deck is proposed. It provides for welding of studs over vertical wall of longitudinal T-girders at their fastening that eliminates angular deformation of upper flange.

2. Cyclic life tests of welded joints of stud (steel 09G2S) to upper flange of T-girder (steels St3sp and 09G2S), produced by arc-contact method, were carried out. Cyclic life of such joints at different loading ranges, being realized in preliminary 6 tf tightened stud during passing of rolling stock, was determined. It is shown that life ($5\cdot10^6$ cycles of stress alternation) of stud welded joint is provided in $\Delta P < 3$ tf operating loading range.

3. Numerical simulation of stress-strain state of elements of bridge deck in initial condition and during passing of rolling stock verifies the data of full-scale investigations about the fact that ranges of operating loads in welded stud significantly depends on the spacing layer between BFBD and girder. Cyclic life of welded stud is not less than $5\cdot10^6$ cycles of stress alternation in use of oak board and rubber band as spacing material, since loading range makes $\Delta P \approx$ $\approx 4$ tf. Application of 40 and 70 mm thick cast-in-place concrete as spacing layer between BFBD slab and T-girder allows reducing loading range in welded stud to $\Delta P \approx 1$ tf. This guarantees its cyclic life of not less than $5\cdot10^6$ cycles of stress alternation.


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