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Analysis of different types of bolted joints for i-beams and their comparative laboratory research

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Abstract. The article considers the results of laboratory tests for different types of bolted joints for the I-beams. The tests were subjected to a steel I-beam cross section with splice joint by friction, flange and combination of the splice joint by friction and flange joints under a bending. A brief review and analysis of existing solutions for bolted joints for girders are given, the main difficulties with the use of welded joints and bolted joints are indicated. The results of laboratory tests of different types of bolted joints for I-beams, using high-strength bolt connections, are presented. The pictures of stress distribution in the elements of joints are investigated, and the deflections of beams using different types of joints are determined. It is shown that the deflections of beams with splice joints are significantly influenced by the ductility of the entire connection. According to the test results, the conclusions about the obtained pliability values are made and the graphs of joint deformation at various stages of loading are given. The obtained pliability values may be used in further virtual experiments.

1. Introduction

Bolted joints are used in cases when the weight or size of a structural element is so big that it can’t be produced and delivered to the building site in the whole form. At the installation site, separate pre-fabricated elements get connected with bolted joints, structural solutions of which determine labor intensity of production and installation of beams, as well as the ultimate cost of the structure during exploitation. Paper [1] provides a detailed analysis of structural solutions of bolted joints for gantry beams with riveted joints or welded flange splices. It is shown that the type of gantry beams’ flange splice determines structural solution of bolted joints as well.

In the course of designing a bolted joint of gantry beams, it is necessary to structurally coordinate the elements of the upper flange’s joint with the elements of the gantry rail – both the rail and the elements of its attachment to the flange. In riveted gantry beams, vertical flange rivets with a flat head were put on the upper flange in order to form a leveled surface for the gantry rails’ support. The bolted joint of road bridge superstructures made of welded beams has a composite structure; the joint is friction-welded, its flanges are connected using automatic welding, and the web is attached using covers with high-strength bolts [2].

For welded gantry beams, bolted joints can be either welded or attached using high-strength bolts [3]. The type of joint is conditioned by the operational mode of crane bridges. Installation of a welded bolted joint is a labor-consuming operation which requires a welder to be highly qualified, because improper welding for long-span gantry beams at heavy thickness of flanges and the web can lead to their rapid fatigue rupture. Therefore, bolted joints of welded gantry beams, especially in case of cranes for heavy-duty operation, are recommended to be constructed using high-strength bolts, as they possess higher fatigue endurance [4]. At that, bolt heads on the upper flange hamper convenient position of the gantry rail's foot, which requires a structural extension of the flange plate.

In some cases, bolted joint of beams can be constructed with the use of end plates. However, this joint as a joint performed on site had not become frequently applicable in long-span beams, and is mainly used as a bearing joint of a beam with columns when it is adjacent form one side [5,6]. End-plate splice is characterized by a minimal number of assembly components and bolts. Analysis of publications showed that of an end-plate splice in beam span under moving load is barely studied.

Considering the abovementioned circumstances for single-span gantry beams, a variant of construction of a combined half-end-plate and splice bolted joint is developed (figure 1). In such joint, compressive stress is taken by the end plates, and the stretching stress is taken by caps on high-strength bolts. This allows for simplifying the structural alignment of elements of the crane runway and the joint on the upper flange, and ensures the necessary reliability of the stretched part of the joint. A utility model patent has been obtained for the mentioned structure [7]. The combined half-end-plate and splice joint has been calculated using ANSYS software suite [8]. In the result of calculation, areas of stress concentration in the joint have been determined. Optimization of structural solution of the joint allowed reducing the influence of concentrators on its stressed state.

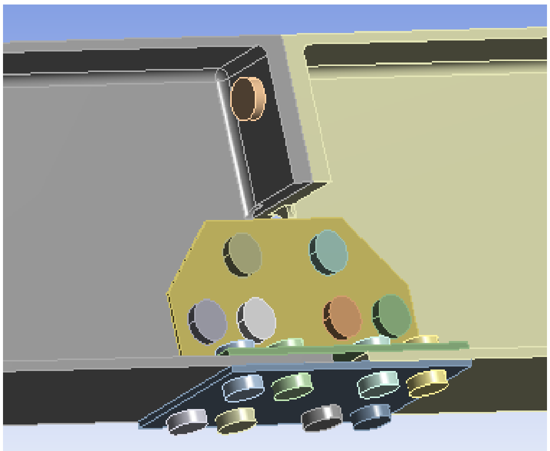

Figure 1. Finite element model of combined half-end-plate and friction splice connection.

2. Results of experiments on beam models with various types of joints

In order to get more detailed information about stress-strain state of the combined half-end-plate and splice joint and compare its operation with friction splice joints and end-plate splice joints, laboratory tests have been carried out. Tests were put over three-meter models of 40Б1 rolled beam made of C245 steel according to STO ACHSM 20-93 standard on simple bending and cross-bending. Joints were placed in the middle of the beam span, the area of simple bending was 500 mm.

Friction splice and end-plate splice joints were calculated and constructed in accordance with requirements provided in [9,10] for the effect of the ultimate bending moment. Construction of the combined half-end-plate and splice joint is assembled similar to the end-plate splice joint and friction splice joint, i.e. end-plate connection is used in the upper zone till the zero axis, whereas friction connection is used below the zero axis. High-strength bolts M16 made of steel 40X Selekt were used in the joints. Treatment of contact surfaces was carried out with the use of steel brushes without preservation. Bearing capacity of the friction splice joint amounted 346 kN. Tension of bolts for the rated force of 12 tons was performed by NT-1-800 torque wrench.

Models of beams were exposed to loading in a test bed (figure 2 and figure 5) till the load of 250 kN by steps 50 kN each. At the load of 250 kN the joint was operating in elastic stage.

Figure 2. Experimental model of a beam with friction splice joint in the test bed.

Deformations in flanges and the web of beams' joints were measured by resistance strain gauges with the base of 10 mm. Registration of signals was carried out by SIIT-3 strain-gauge system. Figure 3, 4 and 6 present layouts of resistance strain gauges' position in each type of joints.

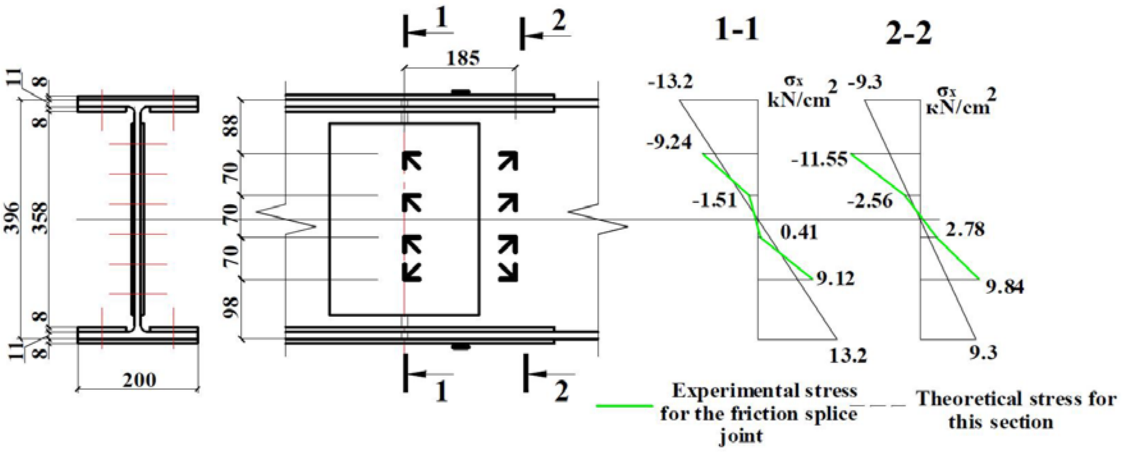

Figure 3. Layout of sensors' location and curves of normal stresses for the friction splice joint of the beam under simple bending.

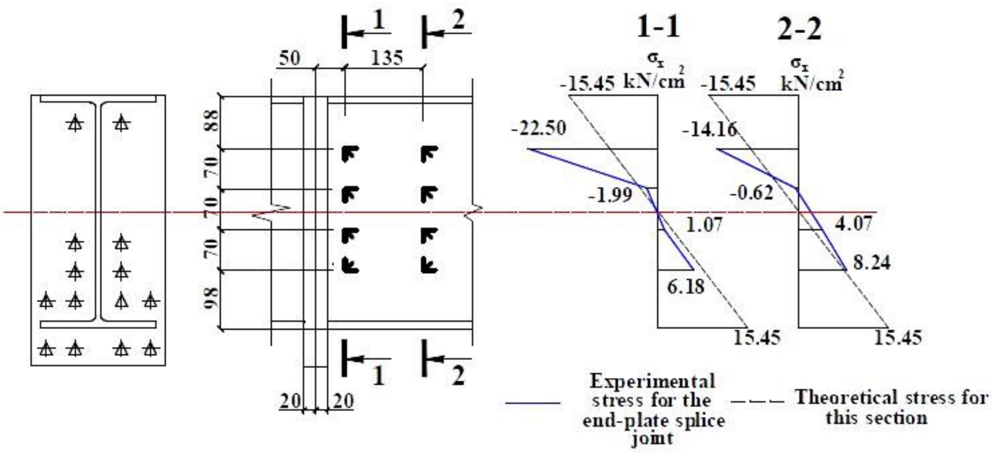

Figure 4. Layout of sensors' location and curves of normal stresses for the end-plate splice joint of the beam under simple bending.

Beam deflection and mutual shearing of coupling elements were controlled by Mercer gauges with a division value of 0,01 mm.

Measurement of stress state of the models was carried out in two beam sections. The first one is located directly along the beam's joint, and another one is positioned 185 mm away from the axis of the beam joint.

Structural characteristics of the joints and their geo-metric characteristics in the place of resistance strain gauges' location are given in Table 1.

Table 1. Characteristics of the studied bolted joints of beams.

No.	Type of joint	The number of elements	The number of bolts	Geometric characteristics			
				I_x, cm^4	W_x, cm^3	I_x, cm^4	W_x, cm^3
				axis of the joint (section 1-1)		*outside the joint (section 2-2)*	
0	A beam without a joint	–	–	–	–	20020,0	1011,0
1	Friction splice joint	8	56	24313,0	1180,0	34475,0	1674,0
2	End-plate splice joint	2	14	20020,0	1011,0	20020,0	1011,0
3	Combined half-end-plate and splice joint	7	26	28238,0	Upper flange 1116,0 Lower flange 1870,0	25968,0	Upper flange 1026,0 Lower flange 1260,0

The pattern of stress state of the friction splice joint at simple bending under load of 250 kN is presented in Fig.3, from which it can be concluded that experimental values are well-coordinated with the theoretic ones in both the joint area (in section 1-1) and outside the joint (in section 2-2). Under cross-bending for the friction splice joint, concordance of experimental and theoretical stresses is satisfactory.

Stress state of the beam in the area of end-plate splice joint (figure 4.) characterizes influence of the end plate on the size and the nature of distribution of normal stresses. Attention is drawn to considerable value of stress σx in constricted area 50 mm away from the axis of the joint, which exceeds the theoretical value almost 2 times. 185 mm away from the axis of the joint, theoretical and experimental stresses caused by common bending almost coincide.

Figure 5. Model of a beam with combined half-end-plate and splice joint in the test bed.

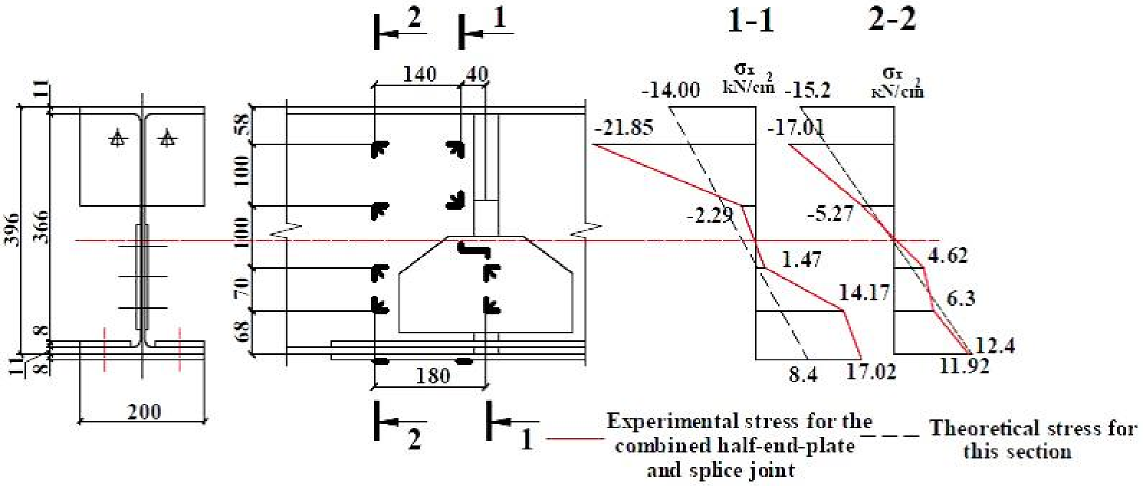

Figure 6. Layout of sensors' location and curves of normal stresses for the combined half-end-plate and splice joint of the beam.

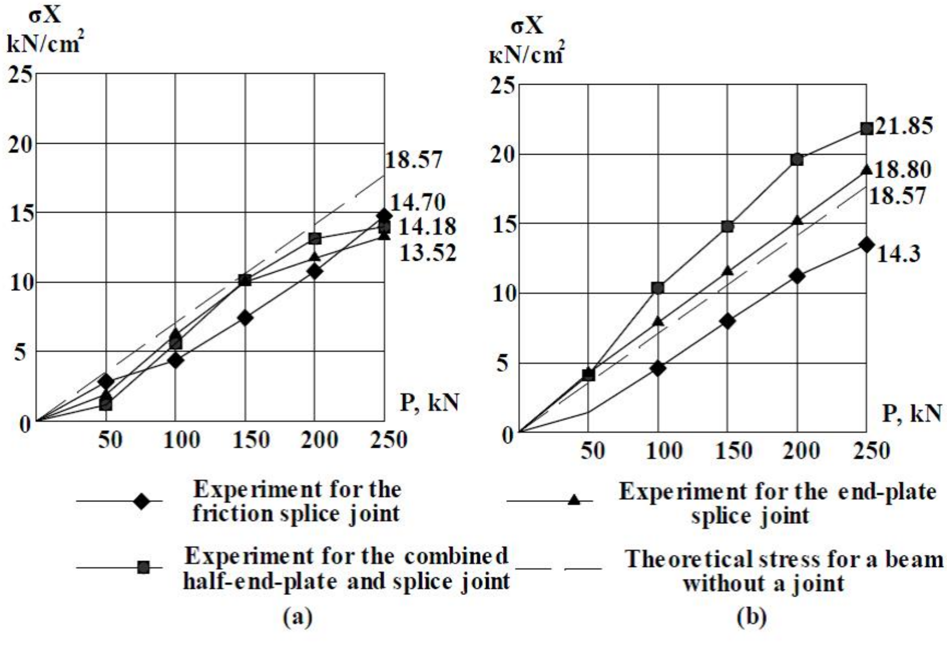

Figure 7. Changes of stresses under simple bending in stretched (a) and compressed (b) areas of beam joints.

3. Analysis of results obtained on deformability of beam models

Deflections of beams were also analyzed at various loading patterns. Results are given in fig.8. Comparing the results of deflections of beams with various types of joints, we can conclude that all joints possess enhanced deformability compared to a beam without a joint, except for beams with the end-plate splice joint.

This can be explained by the influence of ductility of joints with friction splice joints.

Comparing the graphs in figure 8, it can be concluded that the more continuous is the effect of the ultimate bending moment (the area of simple bending) the higher is ductility of the friction slice joint and thus the bigger is deflection. Experimental beams with friction splice joints and combined half-end-plate and splice joints under loading up to 100 kN possess elastic deformation; then in the range of loads from 100 to 150 kN, mocroshears occur in the joints; this leads to an increase in deflection of beams. Deflection of a beam with an end-plate splice joint is practically similar to theoretical deflection of a beam without a joint.

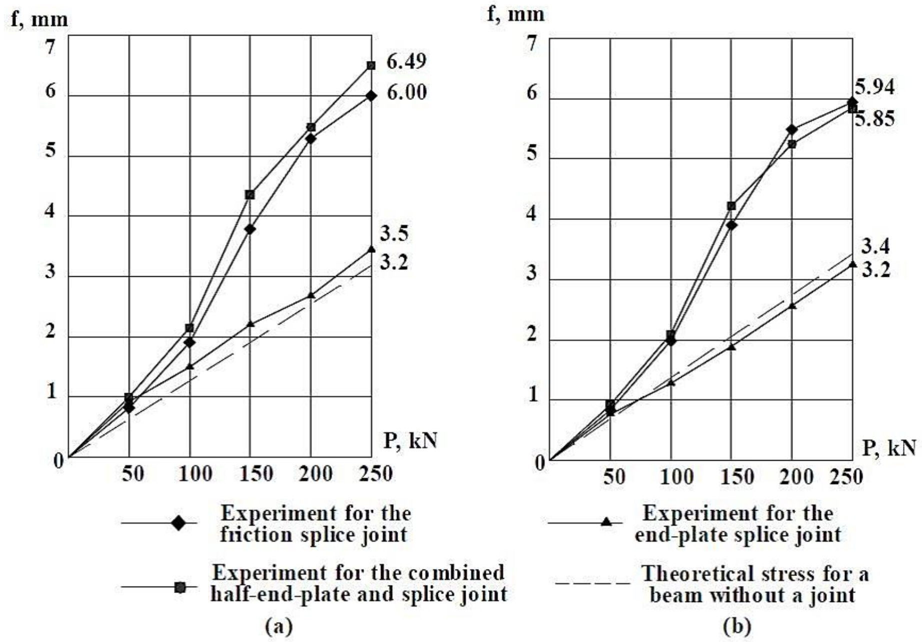

Figure 8. Dependencies of deflections of experimental beams with various types of joints under simple bending (a) and cross-bending (b).

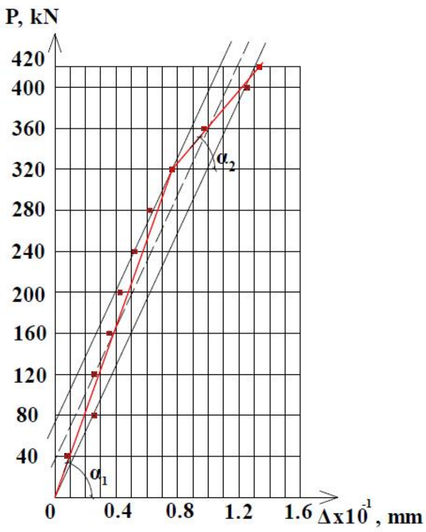

Figure 9. Ductility of the friction splice connection under axial tension.

In order to prove this hypothesis, a test on axial tension of a friction splice connection with three high-strength bolts was carried out. Results of the test are presented in figure 9. The figure shows that when imposing an external load, the bolted joint experiences deformations, i.e. in reality friction splice joints have a zone of preliminary shearing which is characterized by an interaction of coarseness of the contacting surfaces. Modulus of shearing at the first segment of the diagram (α_1) is G1 =67,0 kN/cm2;

at the second segment (α_2) of the diagram G2 = 46,0 kN/cm2. Deformability of the connection has increased almost 1,5 times.

The obtained results prove the results of publication [11], authors of which note that when calculating friction splice bolted connections, the critical stage of operation of the joint after the macroshear should be considered, when a shearing in the connection occurs, having run out of friction stress. Macroshear wasn't registered in friction splice connections under load of 250 kN, which is proved by figure 8.

4. Conclusion

Thus, experimental research on stress and strain state showed that beam models with friction splice bolted joints possess ductility which should be taken into account when evaluating their deformation state. Operation of combined half-end-plate and splice joint beams under load is greatly influenced by ductility of the friction part of the joint. In order to reduce this influence, additional research should be carried out.

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