Particular features of the load-bearing elements of rigging lifting systems

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Abstract. The problems of deformability of a large-capacity metal support beam are considered. The results of experimental studies and numerical analysis of beam deformability are presented. These studies take into account the specific interaction of stresses arising from the impact of loads on the product at operation, and residual welding stresses. Recommendations on stabilization of form deflections of metal construction of beams are given.

1. Introduction
For the installation of heavy products are used special beam elements that make up the lifting rigging system. This system is shown in figure 1 and consists of two blocks: mobile and stationary. The mobile unit is moved relative to the stationary unit by means of a skidding system. Heavy weight items rise by using four hydraulic strand jacks. The jacks are installed on the main beams of the movable portal. The skidding system consists of a pathway fixed to the main beams of the stationary unit, on the way laid rubber-metal sliding plate coated with PTFE (Teflon). Four skidding beams are moved along the plates, on which the supports of the movable portal are installed. The skidding beams are moved by means of hydraulic cylinders (two hydraulic cylinders on each beam). Anchor blocks are attached to the ends of the hydraulic cylinder rods. Due to the presence of a large span under the beam, an additional firm support is installed (figures 1, 2). The beam is made by welding.

Figure 1. Layout of the portal (top view).
Research of such systems are described in many articles [1-7]. Actual is the calculated research and analysis of welding stresses and deformations of beams [4, 8, 9] and research deformation beams at load [4, 10, 11].

The stress-strain state of any welded structures must take into account their deformability at all stages of a product’s life [1, 4]: assembly, welding [8-11], transportation, mounting, operation, and refurbishment. Thus, skidding beams deflection, which is critical for serviceability limit states (developing excessive deformations caused by exposure to loads and resulting in interruption of normal operation), in general is given by

\[ f = f_{des} + f_{ass} + f_{we} + f_{n} + f_{q} + f_{res}, \]

where \( f_{des} \) is design deflection; \( f_{des} = f_{cr} \), \( f_{cr} \) is the crown in vertical plane; \( f_{des} = 0 \) in the horizontal plane; \( f_{ass} \) is beam deflection caused by assembly operations at various stages of longitudinal beam assembly; \( f_{we} \) is beam deflection as a result of making welding joints, which leads to variations in different directions; \( f_{n} \) is beam deflection through exposure to external concentrated and moving loads; \( f_{q} \) is beam deflection under the action of its own weight; \( f_{res} \) is beam deflection caused by interaction of residual welding stresses with the stresses under process (at all manufacturing stages) or accidental strength loads at manufacturing stages, during transportation and mounting, as well as stresses under working loads.

The expression (1) corresponds to the concept of limit states of structures [4, 9, 10]. The significance of the components depends on the span of the beam and the number of loading cycles [1].

The calculations in this article are devoted to one of the factors, namely \( f_{n} \).

![Figure 2. The layout of the rigging system (front view).](image)

2. Preparation of calculation schemes
To determine the characteristics of the load-bearing elements of the lifting rigging system, was calculated the movements of the elements of the system, as well as strength calculation. Two beams with a total length of 46 meters. The beam bends under the weight of 300 tons of mobile portal system (figure 2).
3. Material characteristic

Material of structural elements—steel 09G2S GOST 19281-2014, used at low temperature. The characteristics of this steel to determine the bearing capacity given in table 2.

| Elastic modulus      | $E = 2.06 \times 10^5$ MPa |
|----------------------|---------------------------|
| Yield strength       | $\sigma_y = 315$ MPa     |
| Ultimate strength    | $\sigma_u = 420$ MPa     |
| Elongation           | $\delta = 21\%$       |
| Design resistance    | $R = 305$ MPa           |
| Factor of working conditions of elements | $\gamma_c = 0.85$ |

4. Bearing capacity and deformability of structures

Paper [4] provides a design schematic for determination of beam residual deformations under bending as a result of the interaction between external load stresses and residual welding stresses from longitudinal welds. The result of calculating the residual welding stresses in the cross section of the beam is shown in figure 4.

Residual welding stresses in the joining zone reach the yield strength $\sigma_y$ for steel structures. Their interaction with the external load stresses produces elastoplastic deformations and, as a result, residual movements in the structure (deflection, angle of rotation, etc.).

Because beam structures contain a large amount of welding joints located along the beam longitudinal axis (longitudinal corner welds, including girth welds) and along the transverse axis (transverse welds for welding up the diaphragms), and each of them contributes to the product’s strain-stress state, it is the most feasible to use the experimental method of study.

Therefore, multiple tests were carried out on beam models made of 09G2S steel. The beams were subjected to transverse bending under one-time static and periodic loading in the span midpoint, as well as under moving load. Beam measurements for recording residual deflections were made using a measuring rod with dial gauge indicators with the scale interval of 0.01 mm fixed on it.

Figure 3. A design scheme for beam.

The load from the portal with the load evenly distributed on the four pillars the top of the portal. The composite beam has two section options. The cross-section values of the two beam sections are set in table 1.

| Area (A) (cm²) | Moment of inertia in torsion (J) (cm⁴) | Moment of inertia (Iₓ) (cm⁴) |
|---------------|---------------------------------------|-----------------------------|
| 796           | 320818                                | 1236900                     |
| 672           | 318540                                | 679424                      |

Table 1. Characteristics of cross sections of beam.
Experimental results of loading welded box-section beams are shown in figure 5. Tests were carried out on a beam with the span of 1000 mm at the loading frequency of 300 cycles per minute. Beam tests under conditions of the stress type being studied were carried out up to the stress level of 190 MPa and 250 MPa, respectively. Deformation characteristics stabilization (residual deflection increment is zero) occurs after 10000 cycles for box-section. If the experiment is continued up to 100000 loading cycles, incrementation of residual deflection is not observed. Welded beams are characterized by a high rate of residual deflection stabilization.

Residual deflection of beams in equivalent loading conditions depends on the level and distribution area of the maximum residual strain stresses. Maximum residual deflection is observed in the beam structure that includes a combination of longitudinal and transverse welds. The influence of transverse (relative to beam centerline) welding joints on the development of residual deflections is so critical that it must be taken into account when evaluating structures functionality in terms of serviceability limit states.
Repeated loading of welded beam assemblies is defined by accumulation of plastic deformations resulting in the increase of residual deflection. Residual deflection increment decreases, as the number of loading cycles is increased, when external load stresses are less than the material yield strength. Experimental data analysis reveals that residual deflection of welded beams under the action of periodically varying load applied in span midsection, or under a moving load, is from 0.2 to 1 multiplied by L/1000, where L is the beam span. The value of L/1000 equals the beam crown that is defined in the beam's design and manufacturing process.

Occurrence of secondary residual deformations is typical for any welded metallic structure of machines, including lifting and transportation, construction and road-building, and other types of machines [10-11].

5. Skidding beam research
Experimental measurements of deflection during operation were performed on the skidding beam. The calculated results of the greatest deflection of the beams coincided with the experiment.

For example, when a moving load is between the supports A and B, the beam deflection is 18.7 mm. Graphs of reactions in the supports of beams, depending on the position of the mobile load are shown in figures 6.

In the process of moving the top portal on the beams is observed, the separation of beam 1 from supports: C, D and F (figure 6).

6. Conclusion
As a result of the calculation of the stress-strain state of the beams of the lifting rigging system of large load capacity, the displacements of these beams from the payload are determined taking into account the stiffness parameters of the beams and various kinematic conditions of their support, which is important from the point of view of the limit state of the system for tilting.

![Figure 6. Dependence of the value of the support reaction forces on the position of the load.](image)

Deformability of long welded beams, including the value of crown, in the operating stage are, to a certain degree, determined by the laws of interaction between stresses produced by external load and residual stresses produced by welding of the beam metallic structure. Residual stresses development
can be stabilized by means of its preliminary periodic loading in the range of 300 to 500 cycles using a moving load that corresponds to the maximum design value appropriate for the beam operating conditions.

References
[1] Vershinsky A, Shubin A and Masyagin A 2018 MATEC Web of Conf. 251 03035 IPICSE-2018
[2] Nikitin K 2013 The fundamental principles of industrial safety (Guidebook. Krasnoyarsk: Siberian Federal University) 104
[3] RD 10-112-96 1996 Guidelines for inspection of lifting machines with expired lifetime. Part 1. General information 301
[4] Vershinsky A 1984 Maintainability and load-carrying capacity of crane metallic structures (Moscow: Mashinostroyenie) 258
[5] Sokolov S 2005 Metallic structures of lifting and transportation machines (Guidebook. Saint-Petersburg: Politekhnika) 312
[6] Braude B, Gokhberg M and Zvyagin I 1988 Crane reference book (Vol. 1 Leningrad, Mashinostroyenie) 520
[7] Kontsevoy E and Rosenstein B 1979 Refurbishment of crane metallic structures (Moscow, Mashinostroyenie) 270
[8] Leoveanu I S, Taus D and Ungureanu V V 2010 J. of Civil Engineering 5(3)
[9] EN 25817 1992 Arc-welded joints in steel (Guidance on quality levels for imperfection ISO 5817) 125
[10] Kotelnikov V, Yeremin Y, Zaretsky A and Korotky A 2000 The concept of evaluating residual lifetime of lifting crane metallic structures that are past their nominal service lifetime (Industrial labor safety)
[11] Kapyrin P and Sevryugina N 2018 IOP Conf. Ser.: Mater. Science and Engin.