Evaluation of possibility of using crane-beams with increased load capacity in the existing industrial building

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Abstract. In the face of rapid changes in technological progress and market demands, industrial facilities require technical re-equipping to meet their objectives more and more frequently. In the article, work was carried out to investigate the possibility of equipping the existing production building, which is a two-span steel frame made of solid-wall welded I-beams of constant section, crane-beams with lifting capacity of 10 tons instead of the existing 5 tons, with possible options of reinforcement of structures in case of lack of their bearing capacity.

1. Introduction

We are living in a time of continuous technological growth, where enterprises, that make a product, should provide not only a high quality of product for ourselves, but also should analyze technological process making of product.

However, learning from recent brings the manufacturer to this point, when the production capacity of the enterprise becomes insufficient to cover all requests, as demand outstrips supply and to take necessary decisions: create new production from scratch, which will fulfill the requirements of the Commission at a given point in time or to carry out technological update of existing production for adaptation.

This article will not describe the advantages and disadvantages of each method, as each one will be more rational than the other for a particular production at a certain time.

Therefore, we will consider the second way and assess the possibility of using the increased load beam crane. Inspection of the load capacity of existing steel framework structures in the form of columns, beams and joists of industrial building have always been of interest to manufacturers, who have an interest in increasing the effectiveness of technology process. Generally, in case of technical re-equipment of crane beams associated with increased loading capacity, most often sub-beams are replaced. Thus, the behavior of pre-stressed concrete elements has been investigated after failure of bridge anchorage. Beyond the elasticity limit, the concrete solution begins to break down and the bearing capacity of the beam is gradually reduced.

A stable composite structural design with a steel beam is attached to a precast concrete slab using detachable bolted connections are considered by the authors in the works [3-8].

The experimental and numerical results of determining the tensile strength of a restored concrete beam reinforced with beams of thin interconnected carbon-epoxy rods are given in the article [9].
effective solution to the problem of connecting the reinforced concrete column with the steel beam is proposed in the work [10]. Later, scientists studied the experimental results on the contributions of various resistance mechanisms to the total resistance of two-section beams, which includes bending resistance and their contact stability. Thus, in [11] it was shown that concrete slabs contributed to an increase in the compressive strength of prefabricated beams and columns, and in articles [12, 13], the authors proposed new analytical models that take into account the slip effect and ultimate bending during lateral torsion to calculate the ultimate multilayer resistance steel-concrete-steel beams. The analytical model described in [14] is based on the influence of the longitudinal crack width of a concrete coating depending on the depth of this coating, the diameter of the rod, and the mechanical properties of concrete.

The authors of [15] analyzed the load-bearing capacity of an I-beam, which was tested for bending at three points, taking into account the effect of polyurethane foam with the addition of fiberglass.

2. Materials and Methods
The aim of the project was to check the bearing capacity of load-bearing structures of the steel frame (column, beams and crane beams) of the production building of the plant when replacing the supporting crane-beam with a lifting capacity of 5tf with a supporting crane-beam with carrying capacity of 10tf. The verifications of the bearing capacity of the foundations along the extreme and middle axes in this paper is not considered.

According to the manufacturer’s assignment, in a two-span building made of steel welded frames with a span of 2x18m, support cranes with a lifting capacity of 10 tons are designed for lifting and mowing cargo. The crane beams are operated one at a time, in each span, in a heated room 90cm long. To get answers to the question put at the forefront, we will conduct a visual inspection of the building.
1. We will conduct a full-scale study of the object to determine the types of load-bearing structures, take their sizes, assess the technical condition of beams and columns.
2. We will check the bearing capacity of existing crane beams (on the first and second groups of the limiting state of structures)
3. We will check the load capacity of the frame elements.
4. We will check the bearing capacity of a joint assembly of elements.

3. Results
The field survey revealed the following:
1. The examined building of the production building is a two-span steel frame made of continuous-welded bids of constant cross-section of the column and crossbar.
2. The columns of the block are closed on all sides with plasterboard sheets, which makes it impossible to determine the degree of their corrosion and protection against corrosion by paint coating.
3. The height of the frame in the ridge, to the bottom of the crossbar - 9.75 m, in the zone of the interface between the crossbar and the columns - 9.00 m.
4. The side beams are supported by columns through the sub-bar consoles (№24 GOST 8240-72)
5. The elevation of crane rail head is 7.00 m
6. The crane beams are made from three rolling profiles: the I-beam № 36 and two equal-angle corners № 75x5, butt-welded with feathers to the upper belt of an ordinary rolling I-beam. The walls of the rolling I-beams are reinforced with transverse stiffening ribs with a step of 600 m.
7. At the ends of the building, the vertical connections between the columns are established in the axes 17-18 and 31-32. The frame pitch is 6m.

The technical characteristics of bridge electric cranes with carrying capacity of 10 ton, for calculation we will take according to GOST 22045-89.
4. Check the load capacity of existing crane beams

The crane beams of the machine tool building are made of rolling I-beams № 36 (GOST 8239), reinforced from both sides with equal-angle corners in the top roof area № 75x5 (GOST 8509-72), currently these GOSTs are replaced with GOST 8239-89 and GOST 8509-86 respectively.

![Figure 1. Cross section of crane beams.](image)

Geometrical characteristics:

Cross-sectional area

\[ A = A_{dc} + 2A_{con} = 61.9 + 2 \times 7.39 = 76.68 \text{ cm}^2. \]

Center of gravity position

\[ Y_1 = \frac{61.9 \times 18 + 2 \times 7.39 \times 33.98}{61.9 + 2 \times 7.39} = \frac{1114.2 + 502.2}{76.68} = 21 \text{ cm}. \]

Moment of inertia relative to horizontal axis

\[ J_x = 13380 + 61.9 \times 3^2 + 2 \times 39.5 + 7.39 \times 2 \times 12.98^2 = 16506 \text{ cm}^4 \]

\[ W_{x_{min}} = \frac{J_x}{Y_1} = \frac{16506}{21} = 786 \text{ cm}^3 \]

Vertical moment of inertia for yaw

\[ J_y = 516 + 2 \times 7.39 \times 10.96^2 = 2291.86 \text{ cm}^4; \]

\[ W_y = \frac{2291.86}{15} = 152.79 \text{ cm}^3. \]

The greatest moment in the beam under consideration from a given system of forces occurs when the resultant of all forces located on the beam and the force closest to it are equidistant from the middle of the beam span. In this case, the greatest bending moment will be under the force closest to the middle of the beam span (Winkler rule), see Fig. 2.

The line of influence at the most unfavorable arrangement of the cranes: when the resultant force from the wheels No. 1-2 is located with reference to the left support - 3750 mm, while the maximum torque is under the wheel No. 1 with reference from the left support of 2250 mm.

Estimated bending moment in a under crane beam that occurs when one crane is operating, with a lifting capacity of 10 t:
\[ M_x = \alpha \gamma_f \gamma_t \gamma_d \sum F_k y_i \]

where \(\alpha\) – coefficient taking into account the influence of the dead weight of crane structures, \(\alpha = 1.05\);
\(\gamma_f\) – load safety factor for crane load, (p. 9.8 SP 20.13330.2016 \(\gamma_f = 1.2\))
\(\gamma_t\) – factor taking into account dependence on crane operation mode;
\(\gamma_d\) – factor taking into account local and dynamic actions of a concentrated vertical load from one crane wheel (p. 9.9 SP 20.13330.2016 \(\gamma_d = 1.2\))
\(\sum y_i\) – sum of ordinates of crane reference pressure influence line on crane beam, (see fig. 2);
\(F_k\) – standard maximum vertical pressure of a wheel of the crane upon a way;

Therefore, the design bending moment in the crane beam will be:
\[ M_x = \alpha \gamma_f \gamma_t \gamma_d \sum F_k y_i = 1.05 \times 1.2 \times 1 \times 1.2 \times 6.54 \times 1.625 = 16.07 \, t \times m \]

Horizontal force \(T^n_k\) or cranes with flexible suspension of cargo
\[ T^n_k = 0,05 \times \frac{(9,8Q + G)}{n_0} \]

where \(Q = 10\) t – crane rating
\(M = 700\) kg, \(G = 7\) kN – crane waist weight
\(n_0\) – Number of wheels on one side of valve.

Standard value:
\[ T^n_k = 0,05 \times \frac{(9,8 \times 10 + 7)}{2} = 263 \, kg = 2,625 \, kN. \]

Calculated value:
\[ T^p_k = \alpha \gamma_f \gamma_t \gamma_d T^n_k \]

Therefore:
\[ T^p_k = 1.05 \times 1.2 \times 1 \times 1.2 \times 263 = 398 \, kg. \]

**Figure 2.** Pressure from crane trolley to crane beam.

Design moment from horizontal load
\[ M_y = \sum T_k y_i = 398 \times 1.625 = 646.8 \, kg \times m \]
5. Check the strength of the under crane beams on the joint action of normal stresses in the upper most loaded section:

\[ \sigma = \frac{M_x}{W_x} + \frac{M_y}{W_y} = \frac{1607000}{786} + \frac{64680}{152.79} = 2467.85 \frac{kg}{cm^2} \]

Since the steel grade is not indicated in the project, we take into account the lowest-strength steel that is used in crane beams (VST3PS6 steel according to GOST 380-71 with measurement) has an estimated resistance that equal:

\[ R = 2300 \frac{kg}{cm^2}. \]

Since operating stresses \( \sigma = 2467.85 \frac{kg}{cm^2} > [\sigma] = 2300 \times 0.95 = 2185 \frac{kg}{cm^2} \) more tolerable stresses - strength of existing crane beams is not provided.

6. Check the rigidity of the crane beams

\[ f = \frac{M_x l^2}{10E I_x} = \frac{1607000 \times 600^2}{10 \times 2100000 \times 16506} = 1.66 \text{ cm} \]

\[ 1.66 \text{cm} \leq \frac{1}{400} \times l = \frac{600}{400} = 1.5 \text{cm} \]

Since the design deflection is more than permissible, therefore the rigidity of crane beams is not provided.

7. Check the bearing capacity of the frame elements (columns, girders, consoles)

Results of static frame calculation taking into account loads from two crane-beams located in different spans are performed in LIRA software complex.

7.1. Column joint zone

Maximum bending moment and normal force

\[ M_{max} = -51.3 \ t \times m, \ N_{max} = -5.025 \ t \]

![Figure 3. Cross-section of girder in the zone of conjugation with column.](image-url)
Geometrical characteristics of the section:

\[ A = 211.2 \, \text{cm}^2 ; \, y_1 = 36.3 \, \text{cm}; \, J_x = 357041 \, \text{cm}^4; \, W_x = 7813 \, \text{cm}^3. \]

Let's check crossbar durability

\[ \sigma = \frac{M}{W_x} \pm \frac{N}{A} = \frac{5130000}{7813} + \frac{5025}{211.2} = 681 \, \frac{kg}{cm^2}. \]

The strength of the crossbar in the zone of its connection with the column is provided with a large reserve.

7.2. Crossbar area at the end of amplification (distance of 1.5 m from the column)

Maximum bending moment and normal force

\[ M_{\text{max}} = -25,7 \, t \times m, \, N_{\text{max}} = -4,8 \, t \]

\[ \text{Figure 4. Cross-section of girder at a distance of 1.5m from the column.} \]

Geometrical characteristics of the section:

\[ A = 135.2 \, \text{cm}^2 ; \, y_1 = 25 \, \text{cm}; \, J_x = 55893,6 \, \text{cm}^4; \, W_x = 2236 \, \text{cm}^3. \]

We will check the strength of the crossbar in the area of reinforcement termination

\[ \sigma = \frac{2570000}{2236} + \frac{4800}{1352} = 1185 \, \frac{kg}{cm^2}. \]

Strength of the crossbar in the zone of reinforcement termination is provided with a large reserve.

7.3. Strength test of high-strength crossbars in the ridge assembly

Forces over 4 bolts located in the area of the stretched lower girder belt

\[ M_{\text{max}} = 24,8 \, t \times m, \, N_{\text{max}} = \frac{24,8}{0,5} = 49,6 \, t. \]

Bearing capacity of one high-strength bolt 40X “Select” M24

\[ N^b_{\text{p}} = R^b_{\text{p}} A^b_{\text{Ht}} = 0,7 \times 11000 \times 3,52 = 27104 \, kg \]

where \( R^b_{\text{p}} = 0,7 R^u_{\text{p}} \) – Minimum temporary resistance of bolt to break.

\( A^b_{\text{Ht}} \) – Area of bolt section by thread

\[ \text{Carrying capacity of 4 bolts} \]
More force per bolt, \( N = 49.6 \, t \), i.e. the strength of skate joint is ensured.

7.4. Check the bearing capacity of the connection of the crossbar with the column

The rigidity of the unit is created due to overlap of the upper belt of the crossbar on the end of the column. Upper belt is attached to column support sheet by means of high-strength bolts M30 "Selekt" 40X. Frictional connection.

The tensile force acting on the upper belt is determined from the expression:

\[
N_n = \frac{M_{\text{max}}}{h} = \frac{54.5}{0.8} = 68.2 \, t
\]

The load capacity of one shear bolt

\[
Q^{vb} = \frac{P_v}{A_{vb}} \gamma_b (\mu/\gamma_n)k = 0.7 * 11000 * 5.6 * 1 * \left( \frac{0.35}{1.06} \right) * 1 = 14238 \, kg.
\]

A force that can be received by 6 shear bolts:

\[
N_{\text{force}} = Q^{vb} * n = 14238 * 6 = 85426 \, kg > N_p = 60000 \, kg
\]

Strength of strut connection with a crossbar is provided.

7.5. Checking the bearing capacity of the column rod in the area of the crane console

On the bottom of console \( M_{\text{max}} = 3,035 \, t \cdot m \), \( N_{\text{max}} = -46,2 \, t \).
On the top of console \( M_{\text{max}} = 8,868 \, t \cdot m \), \( N_{\text{max}} = -32,614 \, t \).

The column is pinched in the crossbar and hinged to a foundation. Taking into account the holding influence of columns of extreme rows and adjacent building, the calculated length of columns in the plane of frames is determined from the expression:

\[
l_x = \mu_x * l = 1 * 925 = 925 \, cm
\]

![Cross-section of columns of extreme and middle rows.](image)

Geometrical characteristics of the section:

\[
A = 135.2 \, cm^2 ; y_1 = 25 \, cm ; J_x = 55893,6 \, cm^4 ; W_x = 2236 \, cm^3 ; t_x = 22,3cm
\]

7.6. Top site of columns

Conditional flexibility
\[ \bar{\lambda} = \frac{l_x}{l_x} \sqrt{\frac{R}{E}} = \frac{925}{20.33} \sqrt{\frac{23}{2.06 \times 10^4}} = 1.52 \]

eccentricity ratio

\[ m_x = \frac{MA}{NW} = \frac{886800 \times 135.2}{32614 \times 2236} = 1.64 \]

Section shape effect factor

\[ \eta = (1.75 - 0.1 \times 1.64) - 0.02 \times (5 - 1.64) \times 1.52 = 1.483 \]

the specified eccentricity

\[ m_{efx} = \eta \times m_x = 1.483 \times 1.64 = 2.43; \]

\[ \varphi_{bh} = 0.4. \]

Check the stability of the column top part

\[ \sigma = \frac{N}{\varphi_{bh}A} = \frac{32614}{0.4 \times 135.2} \times 603 \frac{kg}{cm^2} < R_Y = 2300 \times 0.95 = 2185 \frac{kg}{cm^2}. \]

As the grade of steel is not specified in the existing project, we accept steel of Vst3kp2 brand (C235) which was most often used at the design of columns.

7.7. Lower site of columns

Conditional flexibility

\[ \bar{\lambda} = 1.52, \text{ because the column section is constant in height relative eccentricity} \]

\[ m_x = \frac{MA}{NW} = \frac{303500 \times 135.2}{46200 \times 2236} = 0.4. \]

Section shape factor

\[ \eta = (1.75 - 0.1 \times 0.4) - 0.02 \times (5 - 0.4) \times 1.52 = 1.57 \]

the specified eccentricity

\[ m_{efx} = \eta \times m_x = 1.57 \times 0.4 = 0.63. \]

\[ \varphi_{bh} = 0.6 \]

Check stability of column top part

\[ \sigma = \frac{N}{\varphi_{bh}A} = \frac{46200}{0.6 \times 135.2} \times 580 \frac{kg}{cm^2} < R_Y = 2300 \times 0.95 = 2185 \frac{kg}{cm^2}. \]

Therefore, the carrying capacity of the existing columns is ensured.

7.8. Check of bearing capacity of crane consoles

Crane cantilevers are made of two channels welded with walls to column flanges. Section of channels № 24, GOST 8240-72.
Support load on crane beam arm $N = 14.75$ t - at an unfavourable position of crane trolley. At the same time, this load will be received by almost one support cantilever (channel No. 24), in the termination of which the moment value will be $M = 7.34$ t*m.

The maximum normal voltage in the section of the console will be:

$$\sigma = \frac{M}{W} = \frac{734000}{242} = 3033 \text{ kg/cm}^2 > R_y * \gamma_c = 2185 \text{ kg/cm}^2.$$\n
The strength of the cantilever is not ensured.

7.9. Check the strength of the weld that attaches the cantilever to the column

Weld takes support forces on cantilever - transverse force $Q = 14.7$ t acting along seam and moment $M = 7.34$ t*m acting in plane perpendicular to seam plane. The weld roll according to the survey data is 5 mm.

Calculation of welded joints with angular seams at the action of moment in the plane perpendicular to the plane of seams location by formula 178 SP 16,13330.2017:

on seam metal

$$\frac{M}{(W_f R_w \gamma_c)} \leq 1;$$

on seam metal

$$W_f = 0.5*242/6 = 48 \text{ cm}^3,$$

$$734000/48*1800*0.9 = 9.4 >> 1,$$

That is, weld strength b is provided even without considering the action Q.

Based on the above, it is necessary to strengthen the cantilever support of the crane beam.

8. Conclusion

As a result of the visual (full-scale) inspection and calculations, the following was established:

1. Replacing a crane with a lifting capacity of 5 tons with a crane with a lifting capacity of 10 tons is possible, but it is necessary to take measures to strengthen the supporting structures of an existing building, in particular: under crane beams and column consoles.
2. Simultaneous operation of cranes with a lifting capacity of 10 tons in different spans is allowed.
3. Simultaneous operation of cranes with a lifting capacity of 5 tons and 10 tons in one span is possible if the distance between the working cranes is more than 10 m.
4. A crane with a lifting capacity of 10 tons must satisfy the basic technical characteristics of a bridge support crane in accordance with GOST 22045-89.

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