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Durability of Crane Metal Structures

Nataliia Fidrovska[1, a)], Evgen Slepuzhnikov[2, b)], Roman Ponomarenko[2, c)], Maryna Chyrkina[2, d)] and Igor Perevoznyk[3, e)]

[1]*Kharkiv National Automobile and Road University, Yaroslava Mudrogo street, 25, 61002 Kharkiv, Ukraine*
[2] *National University of Civil Defence of Ukraine, Chernyshevska street, 94, 61023 Kharkiv, Ukraine*
[3]*Kharkiv State Automobile and Road College, Kotelnikivska street, 3, 61051 Kharkiv, Ukraine*

[a)] nfidrovskaya@ukr.net
[b)] Corresponding author: ors2011@ukr.net
[c)] prv1984@ukr.net
[d)] chirkina2505@gmail.com
[e)] igorperevoznyk1970@gmail.com

Abstract. Concentration of loads in structural elements, as well as in machine parts, is created by geometrical concentrators, i.e. local changes in the size and shape of the form from the overturning along the stress line (laps, stiffeners, welded and bolted connections). Concentration of loads is one of the main factors of decrease of support of stiffness of both machine parts and structural elements. The load increase in the concentrator area can be characterized by the theoretical concentration coefficient, but there is no clear methodology for its determination. The operating load of structural elements is always non-stationary, and all normative characteristics are set for stationary loads. That is why one of the problems of forecasting the support of the second frame is the estimation of the shock absorption at the rotor, which occurs at the non-stationary process of the load and its replacement by the stationary equivalent in its shock absorption. In a thin-walled girder, the non-planar chord loses its cylindrical shape when loaded. The areas of the belt between the walls try to straighten the angles and increase the radius of curvature under tension, while under compression, on the contrary, their curvature decreases. This leads to a decrease in the longitudinal stiffness of the belt and redistribution of stresses. The article examines the factors that affect the operation of the crane girders of the overhead crane.

INTRODUCTION

Crane girders are connected by means of direct joining of their elements or by means of tie rods. Changing the height of the girder is designed in the form of a piecewise transition with a broken profile of the belt or steps with galleries. In all cases these units have significant load concentrators. Moreover, unlike machine parts, in thin-walled structures the stress concentration occurs not only in "concave" nodes, but also in "convex" ones.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

In the work [1], the friction resistance reserve is considered, which is compared with the permissible number of cycles.

In the works [2, 3] the method of imitating dynamic operation of overhead cranes on crane girders for cranes of different vantage capacity was established.

The work [4] obtained the results of the element-by-element investigation of the load-deformed state of crane girders in the standard mode of operation.

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Mathematical modeling of mechanical phenomena that take place in the gantry crane girders is considered in the works [5, 6]. An assessment of the effect of changes in the position of the loading force on the loads that occur in the crane girder is given.

The work [7] examines the remaining life of the crane metal structure, the main aspects of the design methodology of the crane resource assessment.

On the basis of the numerical analysis of the stressed-deformed state in the crane metal structure the hazardous zones with the most intensive process of accumulation of damages in the work are identified [8].

PRESENTATION OF THE MAIN MATERIAL

In a thin-walled girder, the flat belt loses its cylindrical shape when tensioned [9]. The belt areas which are located between the walls, when stretched out, try to straighten the curves and increase the radius of rounding, and when clenched, their curvature becomes reduced [10]. This leads to a decrease in the belt's rigidity and overloading. In the area of the belt, which is far from the walls, the loads decrease, and near the walls they increase [11–12]. These circumstances must be taken into account both in the calculations of the strength, as well as on the strength of the resistances [13–15].

Strength calculations of the elements of the pebble knot (Fig. 1) are carried out according to the nominal net tensile strength. When determining these loads for the tie nodes, it is necessary to take into account the nerve load of the curved belt, which occurs as a result of its collapse.

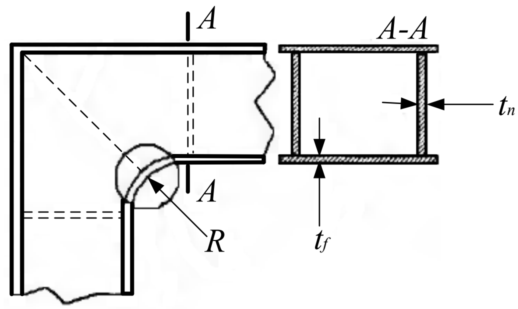

FIGURE 1. Scheme of girder and corner junction nodes.

Equivalent moment of the support is calculated using the area of the girder, which falls within the zone, the boundaries of which lie from each wall on both sides at a distance of b_r=0.5 R. For a box girder:

$$b_{fe} = b_{f1} + b_{f2} . \tag{1}$$

When the zones are redrawn, each section is counted only once.

If the girder coupling node is a part of the structure, which is operated in a sufficiently intensive mode (mode groups A6-A8) and the curved belt lies in the zone of cyclically acting loads, the node must be rechecked for the tensile strength.

In this case the acting loads are calculated by the gross torsion, i.e. by the actual width of the belt, according to the load of the first calculation case.

The value of the structural coefficient for the galvanic joint $k_a=a_\sigma/a_{\sigma B}$, at $a_{\sigma B}$ =1, is equal to the value of the stress concentration coefficient, i.e. $k_a=a_\sigma$.

In fillet connection at $0.5 \le R/h \le 0.5$; $t_n/t_c \le 3$ and t_n=40÷120. It is possible to take $k_a=a_{\sigma b}$=4.5.

When installing a diagonal diaphragm welded to the curvilinear belt, the concentration of loads decreases significantly and at R/h = 0.2–0.8 we get k_a=1.7.

The group of concentrators for determining the interval of viscosity is selected depending on the construction of the node. In most cases this will be the attachment of a transverse diaphragm or stiffener to the belt.

In a welded connection of the wall with a curved girdle, transverse loads act. In case of a flat contraction of the gallic nodes, they can be evaluated in terms of the evenness of the curvilinear belt area:

$$pRd\varphi = 2Sd\varphi / 2 , \tag{2}$$

where loads are linear $p=t_c\sigma_{cz}$,

longitudinal force in the belt $S=\sigma b_{fe} t_f$,
σ – rated normal stresses in the belt,
b_{fe} – equivalent belt width.

Tangential stresses in the same place of the wall are determined by the formula:

$$\tau_z = Q_z / A_n, \tag{3}$$

where A_n is the area of the perking walls,
Q_z – crossing force, this is perceived by the walls.

Calculation of the strength of curved belt joints, made without edge separation should be carried out from the condition:

$$\tau_{esnc} \le \gamma_n \gamma_d \gamma_m R_{nc} \tau, \tag{4}$$

where the effective stresses are determined by the formula $\tau_{es} = \sqrt{\tau_x^2 + \tau_z^2}$,

where $\tau_z = \sigma_{cz} \dfrac{t_c}{j h_c}$.

Were, t_c – is the wall thickness, j – equals 1 or 2 for single-sided and double-sided joints, respectively, and h_c is the calculated height of the joint.

For assemblies that are under intensive cyclic stress conditions, such as supra-girder assemblies with a galling transition. It is better to weld such joints with edge separation, or to make them double-sided with achieving the condition of equal strength.

When calculating the fatigue resistance of the welded girder-wall connection at the curvilinear section, equivalent stresses are determined taking into account the asymmetry coefficient of the stress cycle.

Corner joints are characterized by a variety of designs, which arise in the search for ways to reduce the stress concentration. Calculation of such knots for strength is carried out under the condition:

$$\sigma_{es} \le [\sigma] = \sigma_t / n, \tag{5}$$

or $\sigma_{es} \le \gamma_n \gamma_a \gamma_m \sigma_t$ without considering the stress concentration, but using the rated stresses:

$$\sigma_{es} = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}, \tag{6}$$

which are calculated from the net section taking into account the equivalent width of the belt. The equivalent width is equal to the width of the part of the belt which falls within the zone whose boundaries are at a distance from each wall $b_r = \pm 10 t_f$.

For fatigue resistance calculations, the effective stresses are calculated from the gross section. The design factor is $k_a = a_{\sigma b}$, as it is for galvanic joints. It is recommended to find this value taking into account the design features of this node.

The following recommendations can be used to estimate the stress concentration coefficients $a_{\sigma b}$ in some nodes of the considered class.

The maximum stresses can reach very high and difficult to predict values in the angular connection of girders with a direct chord connection. Therefore, it is not recommended to use such connections for load-bearing structures. In the conditions of the connection of box girders with chords, the maximum stresses are located in the end zone of the chord. As shown by the results of FEM (finite element method) calculations at $t_f/t_w = 0.5 \div 2.5$, $a = (0.3 \div 0.6)h$ and the thickness of the brace is equal to the wall thickness $t_v = t_w$ the concentration factor is $a_\sigma = 1.5 + 1.2 t_f/t_w$.

If the thickness of the girder is equal to the thickness of the chord ($t_v = t_f$), then $a_\sigma = 2.4 + 0.3 t_f/t_w$. Thus, the smaller values of the stress concentration factor will be in the case where the girder has the same thickness as the thicker element of the girder.

If a sloping plate with thickness equal to the thickness of the chord is added to the girders and to the chords, then the stress concentration factor will be $a_\sigma = 1.7 + 0.63 t_n/t_c$.

There are cases where a sufficiently large rod is welded into a corner joint to equalize stress distribution across the width of the chord. This method complicates the design of the node and requires very high quality welding of the girdle-to-bar connection.

When $D=(10\div15)t_n$, the stress concentration coefficient in this node has approximately the same values as in the version of the box girder connection with braces.

In the corner transitions, there is also a significant stress concentration, the level of which strongly depends on the bend angle of the belt. The strength calculation is carried out without considering the stress concentration, but using nominal stresses. Calculated from the net cross-section, taking into account the equivalent width of the belt, which is determined as for angular connections. If a diaphragm is welded in the bend zone of the belt, then $b_{ne}=b_n$.

Since such nodes are often located in the zone of supports, in the zone of significant tangential stresses, we can recommend using the conditions that arise as a result of changing the section of the girder and are accounted for by the design factor, which at $b/t_n 60\div120$ is determined by the formula:

$$k_a = 1 + 0.8\left(a_\sigma - 1\right)\left(1.14 - 0.14\frac{t_n}{t_o}\right)^2, \tag{7}$$

where t_n=20 mm.

If the relative thickness of the belt is reduced, the stress concentration will be 15÷20% less.

The design factor can be derived as $k_a=a_\sigma$ in the finite element size $\Delta_e=(2\div4)t_n$.

Unlike machine parts, in thin-walled structures the stress concentration occurs not only in the “concave” corners (zones 1) but also in the "convex" corners (zones 2, Fig. 2). In a thin-walled girder, the non-planar chord loses its cylindrical shape when loaded. The areas of the belt between the walls tend to straighten the corners and increase the radius of curvature when stretched, while, on the contrary, their curvature increases when compressed.

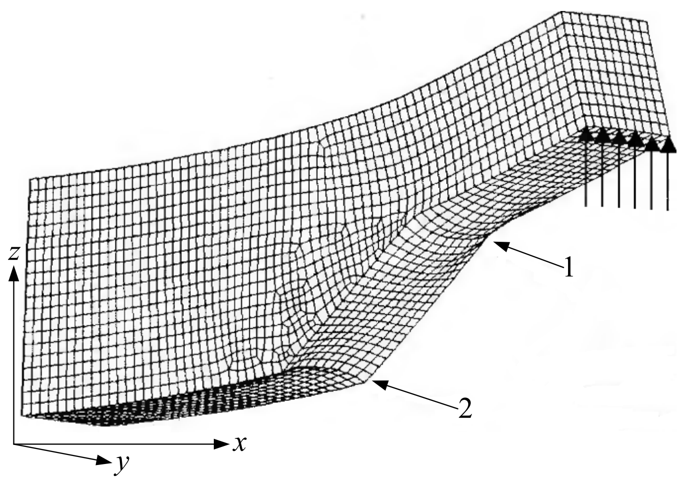

FIGURE 2. Finite element model of a girder with angular transitions in the deformed state: 1 - curved corners, 2 - convex angles.

Installing a diaphragm that is welded to the curvilinear girdle provides an opportunity to reduce stress concentrations in the assembly. If the bend is made by joining sheets by welding, the seam must be double-sided and its quality must be confirmed by defectoscopy. Corner welds, which are located in the transition area, should also be double-sided, if possible. The group of concentrators for determining the endurance limit is selected depending on the design of the assembly.

If we analyze the experimental data on the determination of the fatigue curve index *m* for welded structures, we can say that they have a significant difference, but the general trend shows that this index increases with increasing ratio $\sigma_{-1\kappa}/\sigma_b$ and the value of the cycle asymmetry coefficient *R*.

This coefficient can be calculated according to the formula:

$$m = \frac{\lg\cdot10^6 - 3}{\lg\sigma_B - \lg\sigma_{RK}}\cdot \tag{8}$$

Figure 3 shows the fatigue curves plotted using the above formula (solid lines) and the ITW recommendations at m=3 (dashed lines).

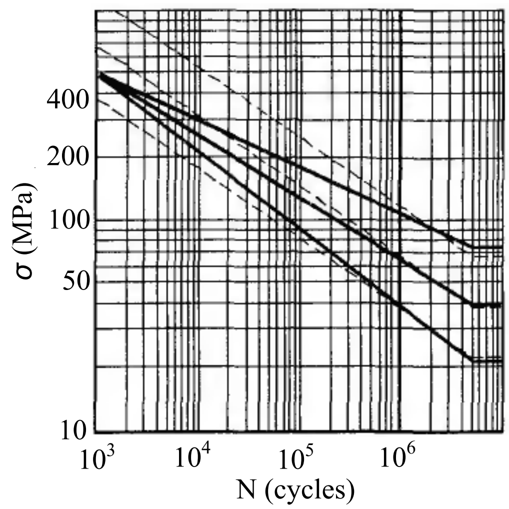

FIGURE 3. Fatigue curves.

In European standards and technical documents, the same slope of fatigue curves with m=3÷3.5 is accepted for all welded joints. In fatigue curves plotted in tangential stresses, take m_τ=4.

The article deals with the determination of fatigue resistance of bridge crane girders and factors affecting the durability of the bridge metalwork.

In engineering analytical calculations the design stresses are found as:

$$\sigma_a = k_a \sigma , \tag{9}$$

where k_a the design factor that takes into account the influence of the local stress state of the lower level.

The calculated welded joints will be in the lower stress field, which depends on the specimen that was used to determine the endurance limit. This may be due to the fact that the calculated area falls within the influence zone of a multiscale concentrator (e.g., a corner weld), or the assembly has size connections that differ from the base specimen, or it is loaded with additional bending that is not in the specimen and is not taken into account in determining the nominal stresses.

In such cases, the stresses for fatigue resistance calculations must be found with the above features in mind. The dimensions of the elements in the area of the weld should be sufficiently large:

$$\Delta_e = \left(2 \div 4\right) t , \tag{10}$$

where t is the thickness of the main sheet.

The design stresses should be determined in the center of these elements.

When analyzing the results of stress calculations by means of FEM, it should be taken into account that normal stresses are used for fatigue resistance calculations. The maximum principal or acting perpendicular to the concentrator (of the weld) as well tangential stresses. In order to determine them, the orientation of the finite element in space must be taken into account.

If we take into account that the stress state of the lower level has gradients that are very small compared to the stress field gradients from the welded joint, we can approximate that:

$$k_a = a_\sigma / a_{\sigma\beta} , \tag{11}$$

where a_σ and $a_{\sigma\beta}$ is the theoretical stress concentration coefficients of the lower level for the structural element and the base sample, respectively.

CONCLUSIONS

The article deals with the determination of fatigue resistance of bridge crane girders and factors affecting the durability of the bridge metalwork.

This makes it possible to improve the engineering methodology for calculating the fatigue resistance of overhead crane girders.

A variety of combinations of factors causing local bending significantly reduces the reliability of theoretical estimates.

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