Minimum cost design of a double box beam structure for an overhead travelling crane

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ABSTRACT: An overhead travelling crane structure of two doubly symmetric welded box beams is designed for minimum cost. The rails are placed over the inner webs of box beams. The following design constraints are considered: local buckling of web and flange plates, fatigue of the butt K weld under rail and fatigue of fillet welds joining the transverse diaphragms to the box beams. To increase the fatigue strength of the last mentioned welds, an efficient post welding treatment (PWT) is considered. For the formulation of constraints the relatively new standard for cranes EN 13001-3-1 (2010) is used. The cost function consists of cost of material, assembly, welding and PWT. PWT is economic, since it is used only for diaphragms near the span centre of box beams, where the bending stresses are high. The optimization is performed by systematic search using a MathCAD program.

1 INTRODUCTION

The main girder of overhead travelling cranes can be designed as a single or double box beam. The rail can be placed in the middle of the upper flange or over the inner web of the box beams. In our case we designed a double box beam with rails over the inner webs (Fig. 1).

The research of post-welding treatments (PWT) does not give any data for these welds. PWT can cause a significant increase of fatigue strength for welds joining the transverse diaphragms to the upper flange, so we use these data.

Our research shows that PWT can result in significant cost savings using them in welds joining the transverse diaphragms to the box or I-beams (Jármai et al. 2014).

2 DATA OF THE TREATED CRANE

The British Standard for cranes BS 2573-1 (1983) is valid at present also. This BS gives characteristic parameters for crane groups. We select a workshop crane with a dynamic factor of ψ_d = 1.3, the governing number of cycles is $N = 4x10^6$, the coefficient of spectrum is according to EN 13001-3-1 (2010) $s_3 = 2$. The safety factor for fatigue is $\gamma_f = 1.25$.

Yield stress f_y = 355 MPa, according to EN 13001-3-1 the maximum design stress for plate thicknesses t < 16 mm is 323 MPa, for 16<t<40 mm 314 MPa. We do not treat hybrid beams constructed with steels of two different yield stresses.

Span length is L = 16.5 m, hook load P = 200 kN, mass of the trolley G_k = 42.25 kN, distance of wheels k = 1.9 m, height of rail h_s = 70 mm, specific mass of the service-walkway and rail p = 1900 N/m, steel density $\rho = 7.85x10^{-6}$ kg/mm^3 or $\rho_0 = 7.85x10^{-5}$ N/mm^3 , distance of transverse diaphragms $a = L/10$ = 1650 mm. The box beams are doubly symmetric.

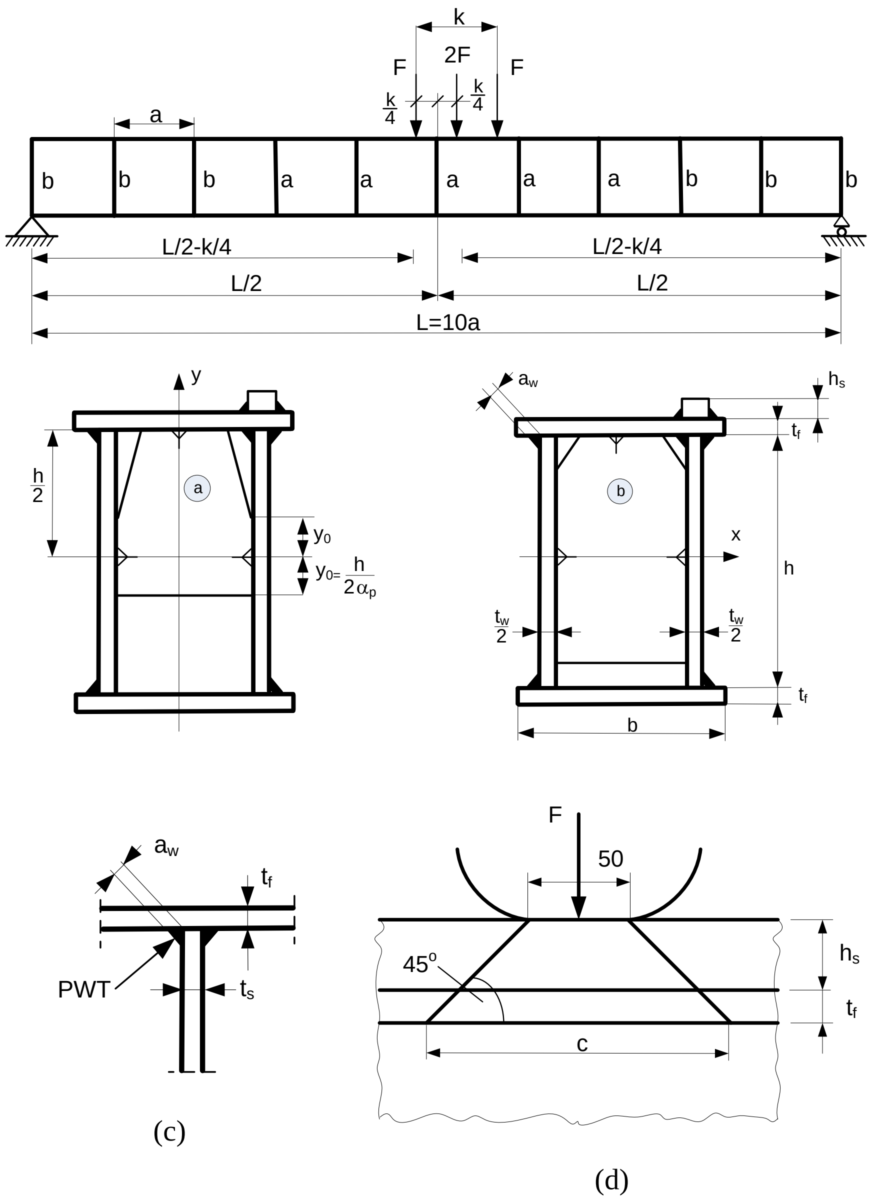

Figure 1. Data and cross-sections of the crane beams. Diaphragms *(a)* are used in the middle of beams for high bending stresses, PWT is used for the welds joining the diaphragms, diaphragms *(b)* are used near the beam ends, *(c)* shows the welds with PWT, *(d)* shows the load distribution in the beam web from the crane wheel.

3 ACTIVE CONSTRAINTS

Stress from the vertical bending

$$\sigma_x = \frac{M_h}{W_x} \qquad (1)$$

3.1 *Compression from a wheel*

According to Figure 1d

$$\sigma_{y1} = \frac{2F}{ct_{w0}}, \; c = 50 + 2\left(h_s + t_{f0}\right) = 50 + 2x100 = 250 \text{ mm} \qquad (2)$$

If $\sigma_{y1} \le k_y f_y, k_y = 1$ (3)

$$\lambda_y = \sqrt{\frac{f_y}{k_{\sigma y}\sigma_e \frac{a}{c}}} \le 0.831 \quad (4)$$

From the diagram of EN13001-3-1 c/a = 250/1650 = 0.15 and α = a/h = 1650/620 = 2.7 $k_{\sigma y} = 1$

$$t_{w.req} = \frac{2h}{60.97\varepsilon} \quad \varepsilon = \sqrt{\frac{235}{f_y}} \quad (5)$$

3.2 *Fatigue constraint for the weld under the rai*l

According to the EN 3001-3-1 (2010) the fatigue strength of a K butt weld for the number of cycles N = 4x10[6] is $\Delta\sigma_C = 112$ MPa, the allowed stress for the spectrum factor s_3 = 2

$$\Delta\sigma_{Rd} = \frac{\Delta\sigma_C}{\gamma_f \sqrt[3]{s_3}} = 71.1 \text{ MPa} \quad (6)$$

and for shear

$$\Delta\tau_{Rd} = \frac{\Delta\tau_C}{\gamma_f \sqrt[3]{s_3}} = 50.8 \text{ MPa} \quad (7)$$

The complex constraint on fatigue is expressed as

$$\eta = \left(\frac{\sigma_x + \sigma_y}{\Delta\sigma_{Rd}}\right)^3 + \left(\frac{\sigma_{y1}}{\Delta\sigma_{Rd}}\right)^3 + \left(\frac{\tau_V + \tau_t}{\Delta\tau_{Rd}}\right)^5 \le 1 \quad (8)$$

3.3 *Fatigue constraint for fillet welds joining the transverse diaphragms*

The fatigue strength

$$\Delta\sigma_C = \alpha_P 63 \text{ MPa} \quad (9)$$

α_P is the coefficient of the effect of PWT, for ultrasonic treatment 1.3, for HiFIT high frequency impact treatment 1.6.

The allowed stress with $\alpha_P = 1.6$

$$\Delta\sigma_{f.adm2} = \frac{\Delta\sigma_C}{\gamma_f \sqrt[3]{2}} = 64.0 \quad (10)$$

The constraint is given by

$$\sigma_x \le \Delta\sigma_{f.adm2} \quad (11)$$

4 THE COST FUNCTION

The cost function is formulated according to the fabrication sequence (Farkas & Jármai 2003, 2008, 2013, 2015).

5 RESULTS OF OPTIMIZATION

The results are given in Table 1.

Table 1. Dimensions in mm, stresses in MPa, volume in mm^3, costs in $. Minima are marked by bold letters.

h	710	660	620	600
b	340	380	420	440
t_{w0}	30	28	26	26
t_{f0}	40	40	40	40
σ_x	61.95	62.6	62.7	62.8
Equation (5)	26.9	25.0	23.5	22.7
Equation (8)	0.978	0.995	0.992	0.983
Volumex10^{-8}	**8.153**	8.222	8.367	8.547
K_t	11.2	12.5	13.9	14.5
K	14230	13890	**13690**	13930

6 CONCLUSIONS

The optimization has been performed by using a MathCAD program. Since the welding cost depends on the web thickness, the cost can be decreased by decrease of web thickness or web height. This decrease is stopped by the increase of cost caused by the increase of flange width. The web thickness is determined by the constraint on the maximal stress from the wheel load. In the systematic search we select a b and for this value h is searched, which fulfils the constraints.

The web thickness is determined by the quality of the weld under the rail. Therefore, it is necessary to use high quality butt K weld.

The governing constraints are the constraint on the compressive stress under rail and those on the fatigue. η should be smaller than 1 and σ_x should be smaller than $\Delta\sigma_{f.adm2} = 64.0$.

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