Optimum design of overhead travelling crane

K. Jármai, Sz. Nagy
University of Miskolc, Miskolc, Hungary

ABSTRACT: The optimization of overhead traveling cranes is shown in this paper. We have considered welded box main girders. The optimization is made using of firefly algorithm. The objective function is cost the crane girder including the material, the welding preparation, the real welding and the additional welding costs. The design constraints are static stress, local buckling, fatigue and deflection. The un-knowns are the four sizes of the box beam. Parametric inspections have been made changing the span length, load size, number of load cycles and steel grade. Results show using of higher strength steel the cost of the main girder approximately linearly proportional to the material cost. Generally, there is no advantage of using higher strength steel, due to the fatigue and deflection constraints. Changing spam length and number of load cycles the total cost of main girder is changing exponentially.

1 INTRODUCTION

Metaheuristic and nature inspired evolutionary algorithms are efficiently used for solving non-linear engineering problems, such as many dimensional optimization problems. Xin-She Yang proposed the firefly algorithm (Yang, 2010). It is inspired by the flashing behaviour of fireflies. Firefly algorithm like most evolutionary algorithm is developed for solving continuous, unconstrained optimization problems. In real word most engineering problems are constrained.

$$\begin{aligned} &\min f(\overline{x}) \quad && \overline{x} = \{x_1, x_2, \dots, x_n\} \in \mathbb{R}^n \\ &g_i(\overline{x}) \le 0 \quad && i = 1, \dots, q \\ &h_j(\overline{x}) = 0 \quad && j = q+1, \dots m \end{aligned} \tag{1}$$

where $\overline{x} = \{x_1, x_2, \dots, x_n\}$ is vector of solution, design variables. There are q inequality and m-q equality constraints, $f(\overline{x})$ is the objective function.

There are several approaches proposed to handle constrained problems (Yeniay, 2005). One of a group of these approaches is penalty function. In this paper death penalty function is used.

$$min\, f(\overline{x}) + \sum_{i=1}^{q} P_i(\overline{x}) \quad P_i(\overline{x}) = \begin{cases} 0 & g_i(\overline{x}) \le 0 \\ \infty & else \end{cases} \tag{2}$$

This paper presents the optimization of the main girder of overhead travelling crane with the previously presented method.

2 THE CRANE DESIGN

In this paper main girder of overhead travelling crane is designed as a double box beam. The rail placed over the inner web of the box beam.

Dynamic factor $\Psi_d = 1.3$ of workshop crane is selected from BS 2573-1 (1983). The coefficient of the spectrum is according to EN 13001-3-1 (2010) $s_3 = 2$. The safety factor for fatigue is $k_x = k_y = k_\tau = 1$.

Default span length is $L = 16{,}5m$, load $P = 250kN$, distance of wheels $k = 1{,}9m$, height of rail $h_s = 70mm$, specific mass of the service-walkway and rail $p = 1900\, N/m$, steel density $\rho = 7{,}85 \cdot 10^{-6}\, kg/mm^3$ or $\rho_0 = 7{,}85 \cdot 10^{-5}\, N/mm^3$, distance of transverse diaphragms $a = L/10$. The box beams are doubly symmetric.

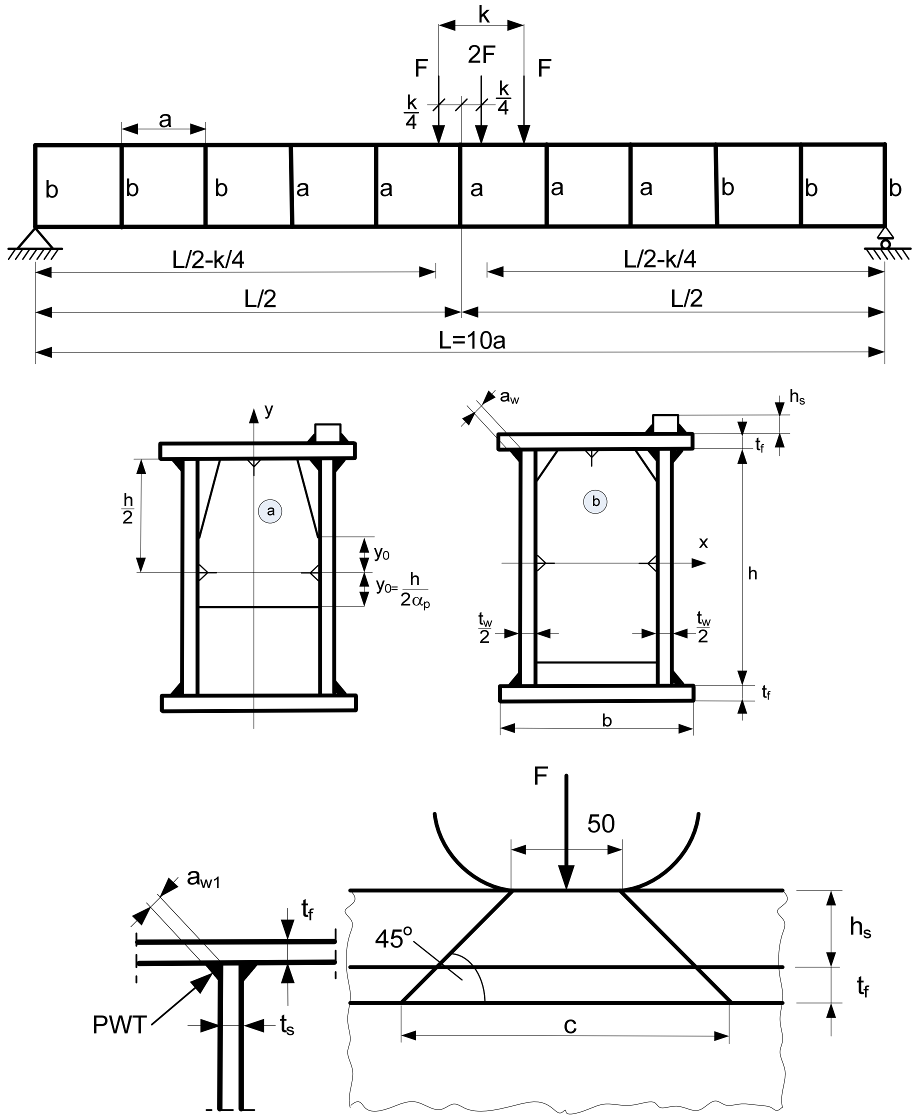

Figure 1. Data and cross-section of the crane beams. Diaphragms are used in the middle of beams for high bending stresses. Diaphragms are used near the beam ends. PWT is used for the welds joining the diaphragms. Load distribution in the beam web from the crane wheel.

3 ACTIVE CONSTRAINTS

The symbols and equations are based on BS 2573-1 (1983), EN 13001-3-1 (2010) and Eurocode 3-1-9 (2005).

Stress from vertical and horizontal bending around x and y axis:

$$g_1 = \sigma_z - k_x f_y = \frac{M_x}{W_x} + \frac{M_y}{W_y} - k_x f_y \tag{3}$$

Compression from wheel:

$$g_2 = \sigma_y - k_y f_y = \frac{2F}{[50 + 2(h_s + t_f)]t_w} - k_y f_y \tag{4}$$

Torsional and shear stress:

$$g_3 = \tau - \frac{k_\tau f_y}{\sqrt{3}} = \tau_V + \tau_t - \frac{k_\tau f_y}{\sqrt{3}} \tag{5}$$

Complex static stress limit:

$$g_4 = \sqrt{\sigma_z^2 + \sigma_y^2 - \sigma_z \sigma_y + 3\tau^2} - f_y \tag{6}$$

Local buckling limits for web plate and flange:

$$g_5 = \frac{2h}{t_w} - 0.67 \cdot 28.42\varepsilon\sqrt{k_{\sigma x}};\ \varepsilon = \sqrt{\frac{235}{f_y}} \tag{7}$$

$$g_6 = \frac{2h}{t_w} - 31\varepsilon\sqrt{k_\tau};\ k_\tau = 5.34 + \frac{4}{\alpha^2};\ \alpha = \frac{L}{10h} \tag{8}$$

$$g_7 = \frac{2h}{t_w} - 60.67 \tag{9}$$

$$g_8 = \frac{b}{t_f} - 0.67 \cdot 28.42\varepsilon\sqrt{k_{\sigma y}} \tag{10}$$

$$g_9 = \frac{b}{t_f} - 31\varepsilon\sqrt{k_{\tau b}};\ k_{\tau b} = 5.34 + \frac{4}{\alpha_b^2};\ \alpha_b = \frac{L}{10b} \tag{11}$$

Fatigue constraints for the weld under the rail:

$$g_{10} = \left(\frac{\sigma_z}{\Delta\sigma_{Rd}}\right)^3 + \left(\frac{\sigma_y}{\Delta\sigma_{Rd}}\right)^3 + \left(\frac{\tau}{\Delta\tau_{Rd}}\right)^5 - 1 \tag{12}$$

4 THE COST FUNCTION

The cost function is consistingof more components.

$$f(\bar{x}) = K_m + \sum_i K_{wi} + K_p \tag{13}$$

where K_m is material cost, K_p is post welding cost and K_{wi} is cost of i-th welding according to (Farkas & Jármai 2015)

$$K_{wi} = k_w\left(\Theta_i\sqrt{\kappa_i \rho V_i} + 1{,}3 C_i a_{wi}^n L_{wi}\right) \tag{14}$$

5 CONCLUSION

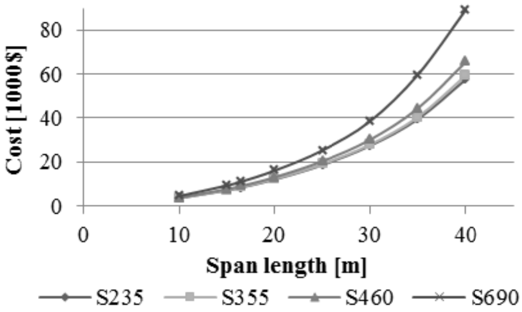

Figure 2. Optimized cost with different length

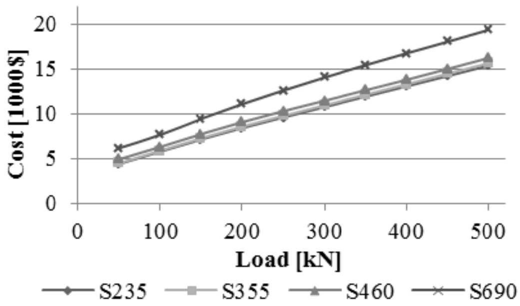

Figure 3. Optimized cost with different load

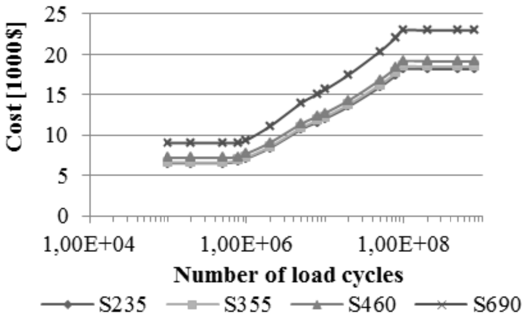

Figure 4. Optimized cost with different number of load cycles

Results of optimisation are shown in (Figs 2-3) after 1000 iteration steps. The biggest change in cost is caused by an increase in span length. It is roughly growing exponentially. The change in the load varies linearly the cost. In the last case if the number of load cycles increases the cost will follow the changing of fatigue limit.

The governing constraints are local buckling(7-11) and limits fatigue (12). These are not depending from the yield stress of steel. It is still harmful for buckling limits. Eurocode 3-1-9 (2010) is not defining higher fatigue limit for high strength steel.

The result of optimization with firefly algorithm and previous reasons are shown there is no any advantage to use more expensive high strength steel in these applications.

REFERENCES

BS 2573-1:1983 Rules for the design of cranes. Part 1: Specification for classification, stress calculations and design for structures.

EN 13001-3-1:2010 Cranes – General design – Part 3-1: Limit states and proof competence of steel structure.

Eurocode 3-1-9:2005 Design of steel structures. Fatigue strength of steel structures.

Farkas, J. & Jármai K. 2015 *Fémszerkezetek innovative tervezése.* Miskolc: Gazdász-ElasztikKiadóésNyomda. (Innovative design of metal structures). (In Hungarian), 625p

Yang, X.S. 2010 Firefly algorithms for multimodal optimization *Lecture Notes in Computer Sciences* 5792: 169-178

Yeniay, Ö 2005 Penalty function methods for constrained optimization with genetic algorithms *Mathematical and Computational Applications* 10: 45-56