OPTIMIZATION AND COMPARISON OF WELDED I- AND BOX BEAMS

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Abstract. The optimization is made for welded I- and box beams. Optimization means mass minimization in this case. The considered cross sections are welded I- and box. The unknowns are the sizes. The constraints are the overall and local stability, stress and size limitations. We have made the stability calculations according to the Eurocode 3. Several steel grades have been considered, from 235 up to 690 MPa yield stress. The beam length, the bending and compression forces are also changed. For the optimization the Excel Solver is used. A great number of comparisons show the best optima in the function of length, bending forces and moments and steel grades.

Introduction

Structural optimization is a design system for searching better solutions, which better fulfil engineering requirements. The main requirements of a modern load-carrying structure are the *safety, fitness for production and economy*. The safety and producibility are guaranteed by design and fabrication constraints, and economy can be achieved by minimization of a cost function.

The main aim of this paper is to give designers and fabricators aspects for selection of the best structural solution at beams. A lot of structural versions fulfil the design and fabrication constraints and designers should select from these possibilities the best ones. A suitable objective function helps this selection, since a modern structure should be not only safe and fit for production but also economic.

The symmetrical plated unstiffened I- and box cross-sections of the beam has four variable dimensions and four longitudinal fillet welds. Since the cross-section is constant for the whole beam, in the minimum volume design it is sufficient to optimize the cross-section area. For the minimum cost design the whole beam should be investigated. The minimum cross-section area design results in relatively simple closed formulae.

In a numerical problem, it is shown that the optimal cross-sectional dimensions are different as I- and box beams for minimum cross-sectional area.

Minimum cross-sectional area design

The symmetrical plated unstiffened I- and box cross-sections of the beam has four variable dimensions (h, t_w or $t_w/2$, b, t_f) and four longitudinal fillet welds (Fig. 1). Since the cross-sections are constant for the whole beam, in the minimum volume design it is sufficient to optimize the cross-section area. For the minimum cost design the whole beam should be investigated [1,2,3,4].

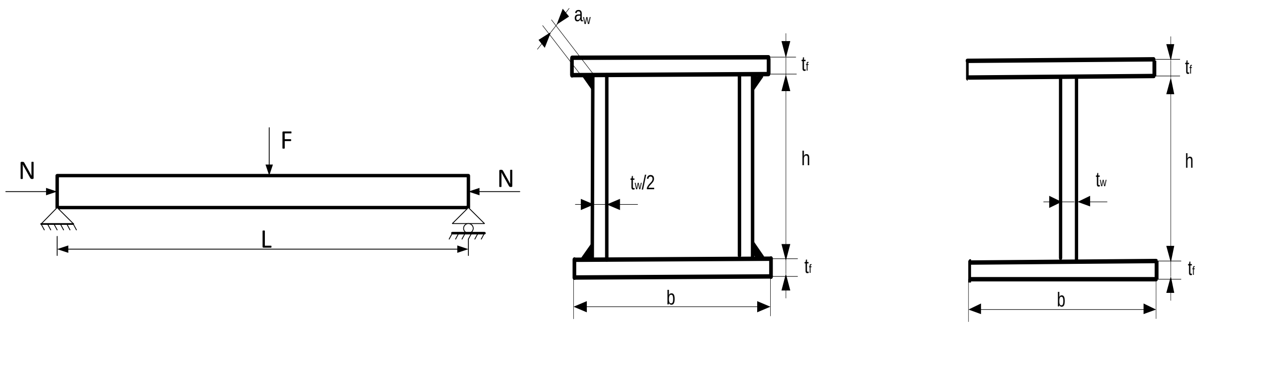


Fig. 1. Simply supported welded I- and box beams

The formulation of the optimum design of an I- and box beam is as follows: find the optimum values of the dimensions h, t_w, $t_w/2$, b, t_f to minimize the whole cross-section area (objective function)

$$A = ht_w + 2bt_f \tag{1}$$

and fulfil the following constraints:

(a) stress constraint $\sigma_{max} = \frac{M}{W_x} \le f_{y1}$ or $W_x \ge \frac{M}{f_{y1}} = W_0$ (2)

The moment of inertia $I_x = \frac{h^3 t_w}{6} + 2bt_f \left(\frac{h}{2}\right)^2; W_x = \frac{I_x}{h/2} = \frac{h^2 t_w}{3} + bt_f h$ (3)

The bending moment is expressed as, $M_x = \frac{FL}{4}$ and $M_y = \gamma M_x$ (4)

where γ is the bending factor, with a value between 0 and 1.

(b) constraint on local buckling of webs (we consider than both bending and shear occur at webs)

$\frac{h}{t_w/2} \le \frac{1}{\beta}$, or $t_w \ge 2\beta h$ where $\frac{1}{\beta} = 69\varepsilon$; $\varepsilon = \sqrt{\frac{235MPa}{f_y}}$ (5)

(c) constraint for local buckling of compressed upper flange of box beam $\frac{b}{t_f} \le \frac{1}{\delta} = 42\varepsilon$, or $t_f \ge \delta b$ (6)

constraint for local buckling of compressed upper flange of I-beam $\frac{b}{t_f} \le \frac{1}{\delta} = 28\varepsilon$, or $t_f \ge \delta b$ (7)

Stress constraint for the columns

According to Eurocode 3 [5] the box section is not susceptible to torsional deformations, thus $\chi_{LT} = 1$, k_{yx} = 0 and the second constraint in EC3 should not be considered.

$$\frac{N}{\chi_{min} A f_{y1}} + \frac{k_x M_x}{W_x f_{y1}} + \frac{k_y M_y}{W_y f_{y1}} \le 1 \quad (8)$$

where *N* is the compressive force [N],

A is the cross section of the beam [m^2],

f_{y1} is the safety factor $f_{y1} = f_y/1.1$, (9)

$\chi_1 = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$; $\phi = 0.5\left(1 + \eta_b + \bar{\lambda}^2\right)$ and $\eta_b = \alpha(\bar{\lambda} - 0.2)$,

α is the imperfection factor),

$\lambda = \frac{KL}{r}$ where $r = \sqrt{\frac{I}{A}}$, (10)

$\bar{\lambda} = \frac{\lambda}{\lambda_E}$ where $\lambda_E = \pi \sqrt{\frac{E}{f_y}}$ (E is the modulus of elasticity [MPa], f_y is yield stress [MPa]).

These values must be calculated in the x and the y axis too. The specific buckling will be the bigger of these two values.

$k_x = 1 - \frac{\mu_x N}{\chi_x A f_y}$, but $k_x \le 1.5$ (11)

$\mu_x = \bar{\lambda}_x\left(2\beta_{M_x} - 4\right)$ but $\mu_x \le 0.90$ (12)

$k_y = 1 - \frac{\mu_y N}{\chi_y A f_y}$, but $k_y \le 1.5$ (13)

$\mu_x = \bar{\lambda}_y\left(2\beta_{M_y} - 4\right)$ but $\mu_y \le 0.90$ (14)

β is a factor which takes into account the change of the bending moment along the beam. In the calculation this is $\beta_{M_x} = \beta_{M_y} = 1.4$.

Optimization

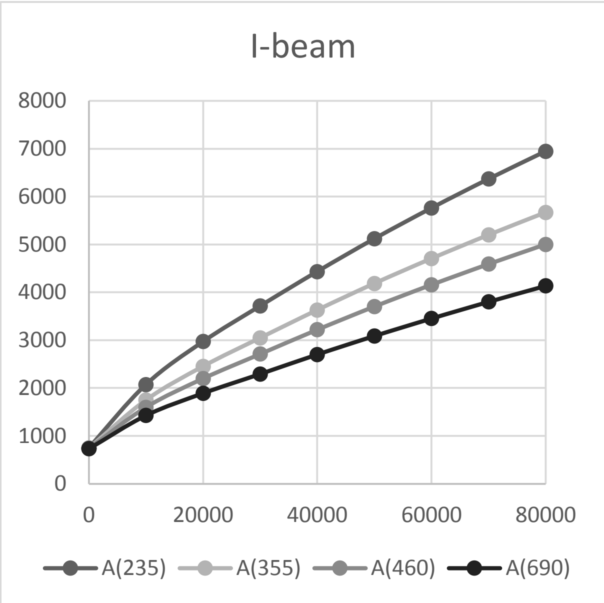
Design Data

Compression force: *N = 0-80 [kN],*
Concentrated force: *F = 0-80 [kN],*

Column length: *L = 1-10 [m],*
Bending factor: *γ = 0-1 [-],*
Yield stress: f_y *= 235, 355, 460, 690 [MPa].*

Optimum results and comparisons

Figure 2 shows the optimum cross section areas in the function of the concentrated force for the welded I- and box-column, where the compression force is 25kN, the length of the columns is 4m and the bending factor is 30%. The relationship between the force and the cross area is nonlinear, and it is clearly seen that the 3 times stronger steel has not belong a three times smaller cross section.



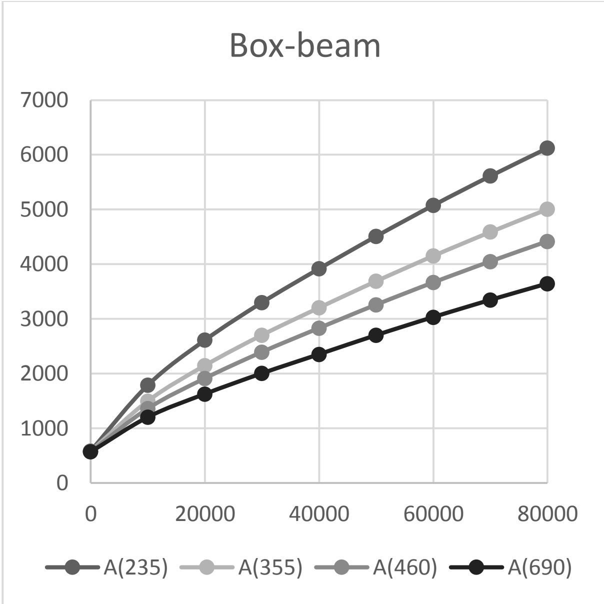
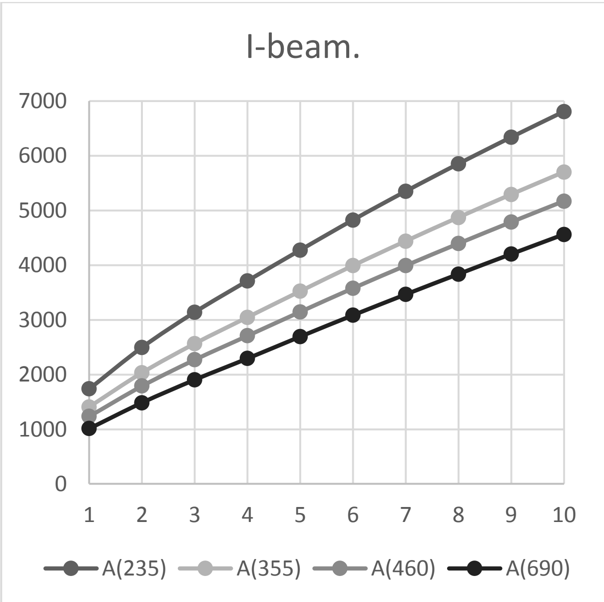


Figure 2.: Optimum cross section areas [mm^2] in the function of the concentrated force for I- and box-columns, (L=4m, N=25kN, γ=0.3)

Figure 3 shows the optimum cross section areas [mm^2] in the function of the span length for I- and box-columns. It is visible, that the box beam is lighter, the mass reduction is about 15 %. The benefit using higher strength steel is similar to the previous comparison.



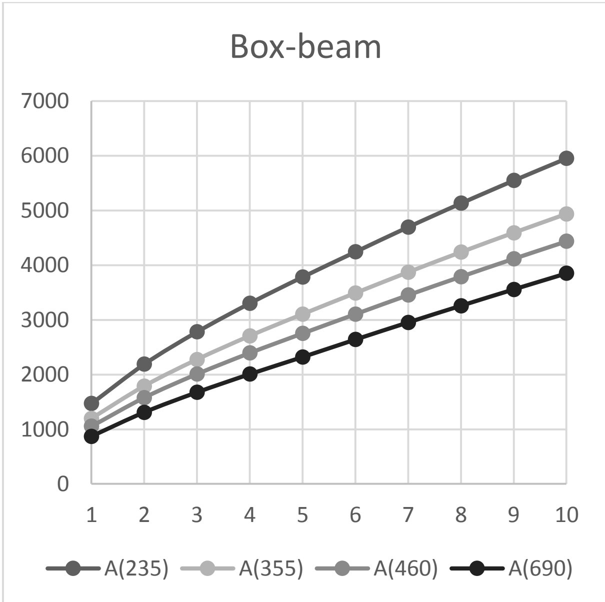


Figure 3.: Optimum cross section areas [mm^2] in the function of the length for I- and box-columns, (F=30kN, N=25kN, γ=0.3)

Conclusion

The paper shows that the optimization of bended and compressed I- and box beams can be made by Excel Solver. The Reduced Gradient Method is useful for this calculation. The cross sections of the beams are optimized. Unknowns are the sizes of the cross sections. At the optimization first unrounded unknown values have been determined, and after that a rounding is done to be manufacture-able. Constraints are the overall and local buckling ones according to Eurocode 3. The relationship between the steel grades and the

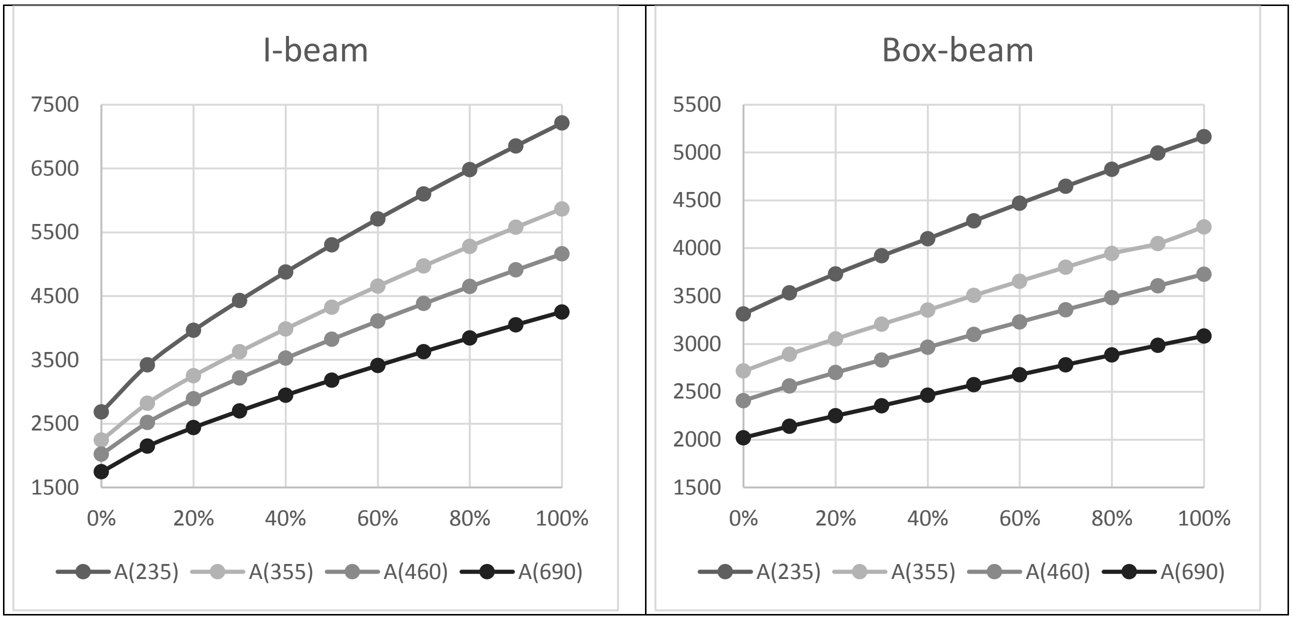


Figure 4.: Optimum cross section areas [mm^2] in the function of the bending factor for I- and box-columns, (F=30kN, N=25kN, L=4m)

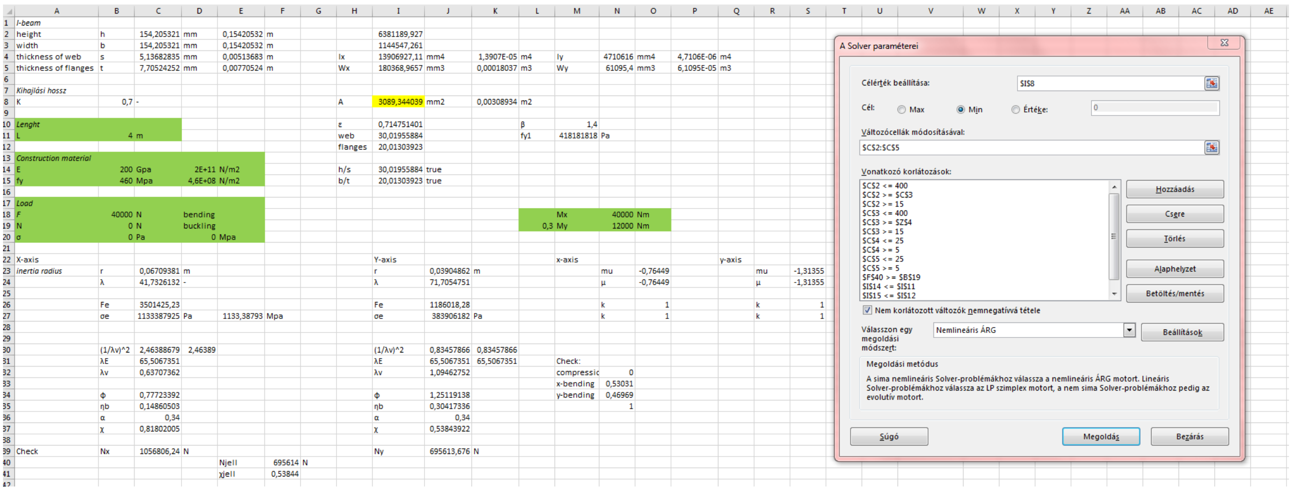


Figure 5: Screenshot of the Excel Solver

mass of the beams is not linear, but smaller. The applicability of the higher strength steel depends on its relative cost to the mild steel. Changing the span length between 1-10 m the mass is not linearly increase, but smaller. In general the welded box beam is more economic, the mass is smaller with about 15 %. Next step will be the cost optimization of these type of structures, considering the welding, the cutting and the painting costs.

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