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INTERSECTION DIMENSIONS SELECTION OF AN I-PROFILE SHAPE IN ORDER TO SECURE A MINIMAL MASS FOR A OVERHEAD CRANE GIRDER

Mirsad Colic, Elmedin Mesic, Ahmet Cekic
Faculty of Mechanical Engineering
Vilsonovo setaliste 9, Sarajevo
B&H

Mirza Colic
RLE Engineering & Services GmbH
Frankfurter Ring 117, Munich
Germany

ABSTRACT
A quality constructive solution can be considered one that ensures the proper functioning and reliability of the product with the least possible cost. Therefore, it is the main goal of every designer to obtain the required girder capacity with minimal material expense in the cross section design of a full plate girder. This ensures an optimal material participation in the overall price of the finished structure already in the initial stage of design. This paper presents the I-profile shape cross-section optimization at the overhead crane main girder, where the metal sheets stability calculation to buckling is made according to BAS/JUS U.E7.121/1986. The mathematical model is solved using the nonlinear programming method SUMT (sequential unconstrained minimization technique) where from the goal function with constraints, with introduction of the penalty function, a new function without constraints is formed and the function minimum is sought.
Keywords: optimization, girder, overhead crane

1. INTRODUCTION
Full plate girder with an I-profile cross section consists of a vertical element, called web, and horizontal elements, known as flanges. The connecting between web and flanges is performed by welding. The web height varies in a very wide range. Often is the web very high, in relation to the thickness of the plate from which it is made, thus it is necessary to provide for the transverse stiffeners. Stiffening increases resistance to buckling. While designing these carriers, section dimensions are usually given through empirical formulas that are based on years of experience. There are different guidelines for specific dimensions selection from both foreign and domestic practices. Of course the simpler ones give less accurate results. This represents only the first step, because the proper selection of section dimensions needs to be confirmed by the load control and the girder stability. Experience has shown that these solutions are acceptable, but not always optimal, because they do not provide for lowest material cost. Savings on weight construction often also means its lower price. This paper shows the determination of cross section dimensions for an overhead crane girder example, in order to provide the minimum weight. Plate stability on buckling was done according to BAS/JUS U.E7.121/1986.

2. INTERSECTION DIMENSIONING IN THE MIDDLE OF THE GIRDER
Optimal cross section dimensioning for plate girders of an I-profile is a good example of using nonlinear programming with constraints.

5.1. The mathematical model

For the cost function a girders weight is selected, which has the following form:

$$F(t,h_T,t_1,b)=l\,\rho\,g\left[t\,h_T+2\,b\,t_1+(b-t)t\frac{h_T}{l_T}+a\,c\right] \qquad \text{... (1)}$$

where: t, h_T, t_1, b, a, c and l - are shown on Figure 1, l_T - the distance between the rigid verticals, ρ - specific mass of steel, g - speed of gravity.

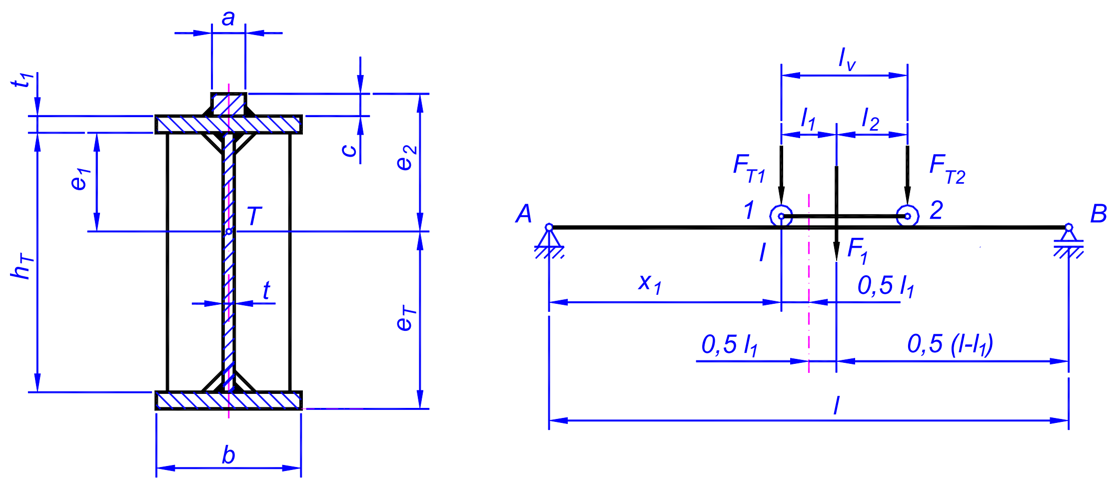

Figure 1. Calculation draft

Requirements that construction should meet:
- flanges:

$$\left.\begin{aligned}
&\sigma_v-\nu\,\sigma_{u,p1}\geq 0\\
&\sigma_v-\nu\,\sigma_{u,p2}\geq 0\\
&k_{p,\max}\,t_1-b\geq 0\\
&b-k_{p,\min}\,t_1\geq 0\\
&t_1-1{,}2\,t\geq 0\\
&2t-t_1\geq 0
\end{aligned}\right\} \qquad \text{... (2)}$$

- the web:

$$\left.\begin{aligned}
&\sigma_v-\nu\,\sigma_{u,r}\geq 0\\
&\sigma_{ux}-\nu\,\sigma_{s,r}\geq 0\\
&\sigma_v-\sigma_{ux}\geq 0\\
&t-5\geq 0
\end{aligned}\right\} \qquad \text{... (3)}$$

- deflection:

$$w_d-w\geq 0 \qquad \text{... (4)}$$

where: σ_v - the tension on the extension limit, $\sigma_{u,p1}$ - maximal tension in the upper flange, $\sigma_{u,p2}$ - maximal tension in the lower flange, $\sigma_{u,r}$ - maximal tension in the girders web, $\sigma_{s,r}$ - flexion tension in the girders web, σ_{ux} - border tension on buckling, ν - level of security.

5.2. The solution method

For resolving the cost function minimization problem (1) with constraints (2), (3) and (4) which have a form of inequality $c_j(t, h_T, t_1, b) \geq 0,\ j = 1,2,...,m$, a penalty function method SUMT (sequential unconstrained minimization technique) is used. With the introduction of penalty function here, a new cost function is formed, without limitations (5), and then the function minimum is determined:

$$\phi(t, h_T, t_1, b, r) = F(t, h_T, t_1, b) + r\sum_{j=1}^{m}\frac{1}{c_j(t, h_T, t_1, b)} \qquad \text{... (5)}$$

To solve the problem, a previously made computer program in FORTRAN was adjusted [8].

3. THE CALCULATION RESULT AND CONCLUSION

Elaborated examples of girder optimization, cross sections according to Figure 1, with standard crane capacities 50 kN, 100 kN, 160 kN, 200 kN, 250 kN and 320 kN, for spans of 8 m, 12 m, 16 m, 20 m and 25 m and different allowed deflections from l/500 to l/1000 were made. Some of these results are shown in Table 1. Calculation results that show the girder weight dependence from allowable deflection for different spans of the bridge and crane with capacity 200 kN are shown in Figure 2.

Table 1. Optimal dimensions for girders cross-section with 16m span and the capacity of 200kN

Load capacity [kN]	Allowed girder deflection	Calculated cross section dimensions [mm]				Tensions [MPa]		Deflection [mm]	Girder weight [N]
		t	h_T	t_1	b	$\sigma_{u,p1}$	$\sigma_{u,p2}$		
200	l/500	6,47	889,79	12,10	211,11	136,148	159,501	29,730	17162,2
	l/600	6,83	930,01	10,96	240,10	126,821	146,166	26,395	18342,5
	l/700	7,40	1000,00	11,93	210,09	118,054	133,956	22,685	19228,7
	l/800	7,80	1049,99	12,91	200,04	108,999	121,573	19,774	20399,8
	l/900	8,22	1099,99	13,03	200,06	101,892	111,950	17,533	21577,9
	l/1000	8,20	1100,00	14,86	211,19	93,212	101,033	15,899	22952,0

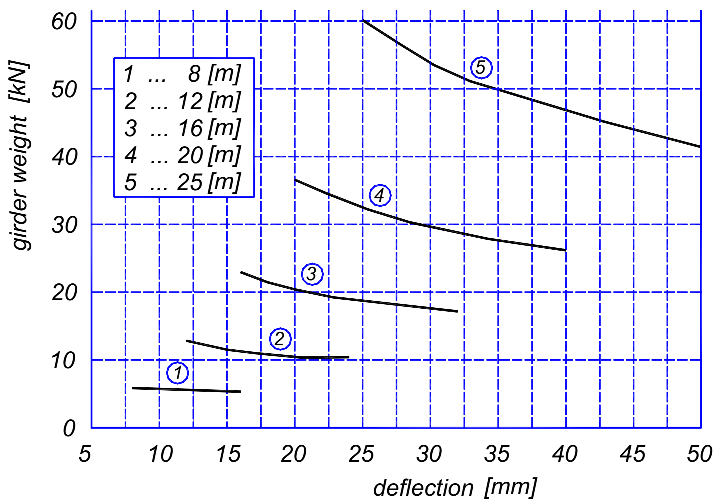

Figure 2. The girder weight dependence from allowable deflection and bridge span

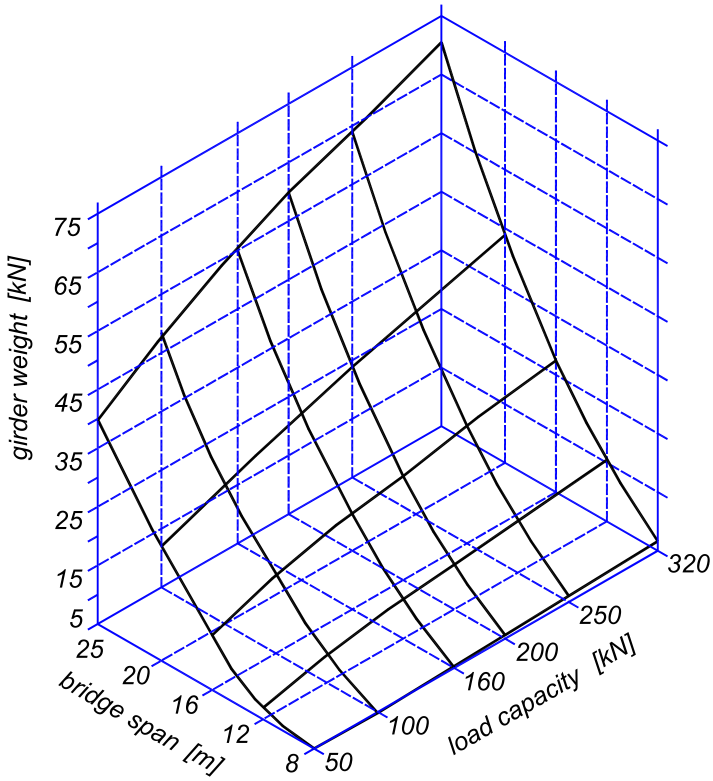

Figure 3. Girder weights with allowed deflection of l/1000

Figure 3 shows the girders weight change, depending on the span of the overhead crane and the load with the allowable deflection of l/1000. For all calculations a rail of 50x40mm was used. The girder is made of steel S235. As stated in the introduction, this paper shows cross section dimensions determination in order to provide the minimum weight. Plate stability to buckling is according to BAS/JUS U.E7.121/1986. The presented process can be applied to the design of box-section beams.

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