JÓZSEF FARKAS (1)
KÁROLY JÁRMAI (2)
FERENC J.SZABÓ (3)

OPTIMUM DESIGN OF LONGITUDINALLY STIFFENED ARBITRARILY LOADED BOX SECTIONS

STABILITY OF STEEL STRUCTURES
TIHANY, HUNGARY
1986
VI. PLATE AND BOX GIRDERS
CONTRIBUTION

Summary: In the optimum design of box sections stiffened by welded longitudinal open or/and closed ribs the following design constraints are considered: constraint on static stress, constraints on local buckling of plate elements between the stiffeners, prescription of the minimal moment of inertia of the stiffeners and size constraints for the four main unknown dimensions. The optimal dimensions, which minimize the whole cross-sectional area and fulfil the design constraints, are computed by using the Rosenbrock direct search mathematical programming method. The developed computer program in BASIC enables the calculation of more structural versions and the significant decrease of the cross-sectional area.

INTRODUCTION

In the design of jibs of floating cranes special requirements should be fulfilled. The jib is subjected to biaxial bending and shear, torsion and axial compression. The mass of jibs should be minimized, therefore longitudinal stiffeners have to be applied. For practical fabrication reasons the number of stiffener profiles should be restricted. Open angle and closed trapezoidal stiffeners may be used /Fig.1/.

(1) Professor of Metal Structures, DSC.
(2) Department Engineer, Dr.Eng.
(3) Postgraduate research scholar
Technical University for Heavy Industry, Department of Material Handling Equipments, Miskolc, Hungary

There are also some geometrical restrictions: in the cross-section of maximal bending moment the height h, width b and plate thicknesses t_f and $t_w/2$ /Fig.2/ may be optimized. The height and width should be varied along the jib length considering the constructional aspects, thus, in some sections the height, in others the height and the width should be kept constant. The layout of stiffeners is also determined by constructional aspects, thus, in arbitrary case the distances between the stiffeners may be different.

A computer program has been developed at our Department considering the above-mentioned design aspects. The aim of the present paper is to give a brief description of this program.

In the optimum design procedure the optimal dimensions are searched by which the cross-sectional area is minimized and the design constraints are fulfilled (Farkas 1984). The objective function is the cross-sectional area including the stiffeners.

The design constraints express the restrictions relating to the maximal reduced stress, local buckling of plate elements between the stiffeners and buckling of stiffeners.

The optimization problem is solved by using the Rosenbrock method (Rosenbrock 1960, Kuester and Mize 1973). This iterative direct search method results in optimal dimensions which are subsequently discretized considering a series of discrete values of unknown dimensions determined by fabrication aspects (Jármai 1984).

The optimization program, developed for personal computer Commodore 64 in BASIC makes it possible to investigate more design versions, to make useful comparisons and to achieve mass savings of 10-30%.

Unfortunately, the new DIN 18800 standards for stability of steel structures, containing the newest research results, are not available yet, therefore the checks for buckling of plate elements and stiffeners are performed according to the following design rules:
FEM /Fédération Européenne de la Manutention/ Rules for the design of hoisting appliances, Paris, 1970;
DASt /Deutscher Ausschuss für Stahlbau/ Richtlinie 012, Beulsicherheitsnachweise für Platten, Köln, 1978.

OBJECTIVE FUNCTION AND DESIGN CONSTRAINTS

In the objective function the whole cross-sectional area is considered /Fig.2/:

$$A = ht_w + 2bt_f + 4ut_f + \sum_i A_{si}$$

where the last term expresses the cross-sectional area of stiffeners. Fig.1 shows the two types of stiffeners, the characteristics of the stiffeners are given in Table 1.

The unknown dimensions to be optimized are h, $t_w/2$, b and t_f.

The value of u as well as the type, number, sizes and positions of the stiffeners should be taken by the designer.

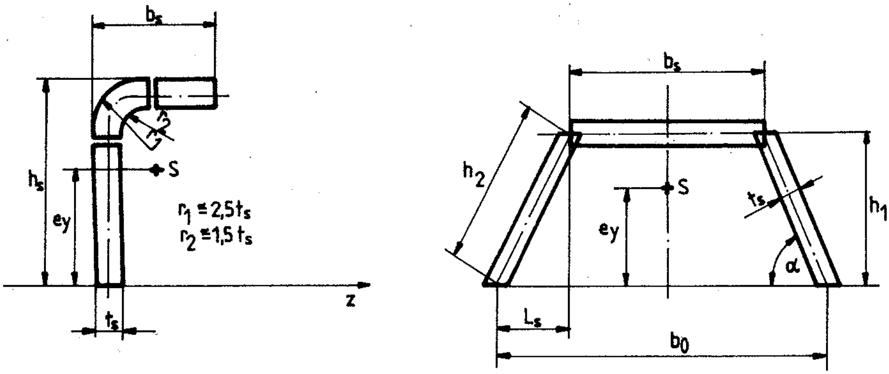

Fig.1. Angle and trapezoidal stiffeners

Table 1. Characteristics of the stiffeners considered in the calculations /Fig.1/

Type of stiffener	Dimensions [mm]	A_s [mm^2]	e_y [mm]	$10^{-6} I_x$ [mm^4]	$10^{-6} I_y$ [mm^4]
	$b_s x h_s x t_s$				
Angle	120x80x5	954	89.4	1.6760	0.5338
	120x80x6	1133	90.8	2.0625	0.6278
	$h_1 x b_o x b_s x t_s$				
Trapezoidal	180x350x150x5	2809	114.0	9.7726	35.2993
	180x350x150x6	3371	114.0	11.6715	42.3609

The constraint on static stress may be expressed as

$$\sqrt{\sigma^2 + 3\tau^2} \leq \sigma_{adm}$$

where σ is the maximal normal stress due to biaxial bending and compression, τ is the shear stress due to torque and shear forces, σ_{adm} is the admissible stress depending on the yield stress of steel and the safety factor. It should be noted that, for floating cranes, it is not necessary to check the structure for fatigue. For other types of cranes, e.g. portal jib cranes, the fatigue stress constraint should also be considered.

<u>The constraint on local buckling</u> of the web and flange plate elements between the stiffeners. Check for the i-th plate element of width b_i and thickness t_i:

$$\sqrt{\sigma_{max}^2 + 3\tau^2} \le \sigma'_{cr}/\gamma$$

$$\sigma'_{cr} = \sigma_{cr} \qquad \text{when} \qquad \sigma_{cr} \le 0.6\sigma_y$$

$$\sigma'_{cr} = \sigma_y\left(1.474-0.677\sqrt{\sigma_y/\sigma_{cr}}\right) \qquad \text{when} \qquad 0.6\sigma_y < \sigma_{cr} < 2.04\sigma_y$$

$$\sigma'_{cr} = \sigma_y \qquad \text{when} \qquad \sigma_{cr} \ge 2.04\sigma_y$$

σ_y is the yield stress, γ is the safety factor, σ_{max} and τ are the maximal normal and shear stresses in the i-th element, respectively.

$$\sigma_{cr} = \frac{\sqrt{\sigma_{max}^2 + 3\tau^2}}{\frac{1+\psi}{4}\frac{\sigma_{max}}{\sigma_{kr}} + \sqrt{\left(\frac{3-\psi}{4}\frac{\sigma_{max}}{\sigma_{kr}}\right)^2 + \left(\frac{\tau}{\tau_{kr}}\right)^2}}$$

$$\sigma_{kr} = k_\sigma \sigma_E, \qquad \tau_{kr} = k_\tau \sigma_E,$$

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_i}{b_i}\right)^2 = 1.8980\text{x}10^5 \left(\frac{t_i}{b_i}\right)^2 \quad [\text{MPa}]$$

$E = 2.1\text{x}10^5$ MPa is the modulus of elasticity, $\nu = 0.3$ is the Poisson's ratio. Formulae for the buckling coefficients k_σ and k_τ are given, for example, in TGL 13503/02 /1982/ Table 17. These coefficients depend on $\alpha_i = b_i/L$ and $\psi = \sigma_{min}/\sigma_{max}$, where L is the distance between the transverse diaphragms.

<u>The constraint on buckling of stiffeners.</u> This check is performed according to the DASt Richtlinie 012 in the form

$$I \geq I^{*} = \gamma^{*} \frac{b\, t^{3}}{12\,(1-\nu^{2})} = 0.092\, \gamma^{*} b t^{3}$$

Some formulae for the coefficient γ^{*} are given, for example, in TGL 13503/02 /1982/ Table 21. γ^{*} depends on $\alpha = b/L$ and $\delta = A_s/(bt)$, where A_s is the cross-sectional area of a stiffener without the effective plate part. <u>b</u> is the width of the whole stiffened plate field. <u>I</u> is the moment of inertia of the effective cross-section of a stiffener relating to the centroidal axis parallel to the plate. To obtain the effective cross-section, effective widths of the plate parts at the stiffener should be calculated according to the DASt Richtlinie 012, Section 5.2.

It should be noted that, for more than two stiffeners and for linearly varying normal stress, formulae of γ^{*} cannot be found in the literature. In these cases the formulae for two stiffeners and constant compressive normal stress may be used, but this is a rough approximation.

Furthermore, it is worth noting that the FEM Rules do not contain detailed prescriptions for checking the stiffeners as compressed struts and the buckling of the whole stiffened plate. The DASt Richtlinie 012 does not consider the correction of I^{*} relating to the effect of initial imperfections of stiffeners. These aspects are already considered in TGL 13503 /1982/.

In the numerical examples of Scheer, Nölke and Gentz (1980) the buckling coefficients are taken from several other publications. In these publications the buckling coefficients are given only in diagrams which is not suitable for computers. Thus, designers have many difficulties in calculations and, to simplify them, use incorrect rough approximations.

The following <u>size constraints</u> are considered /in mm/:

$$150 \leq h \leq 4000; \qquad 150 \leq b \leq 4000;$$
$$2 \leq t_f \leq 40; \qquad 2 \leq t_w/2 \leq 40.$$

NUMERICAL EXAMPLE

In order to illustrate the computations, two versions of a box section are optimized as shown in Fig.2.

Data: bending moments $M_x = 7614$, $M_y = 2177$ kNm, torque $M_t = 915$ kNm, compressive force $N = 4124$ kN, shear forces

Q_x = 505 kN, Q_y = 0. Stiffeners according to Table 1 with thicknesses of 6 mm. The constant distances between the stiffeners: a = c = d = e = 350, f = 300, g = 400 mm. L = 2500 mm. σ_{adm} = 355MPa, γ = 1.14. Loads are factored with 1.5.
The program begins with calculations only if the starting section fulfils the design constraints. The characteristics of the starting section and the optimal versions are given in Table 2. Results are given also for two other versions when b or b and h should be kept constant.

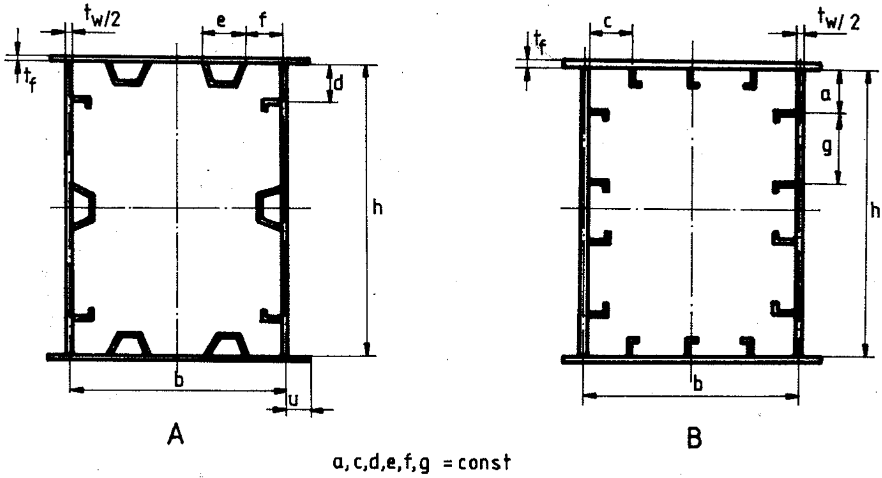

Fig.2. Versions A and B considered in the numerical example.

Table 2. Results of the numerical example /Fig.2/

Section	h	$t_w/2$	b [mm]	t_f	A [mm^2]
Starting	2500	11	1900	12	125 352
Optimal A	2000	8	1450	9	83 578
Optimal B	2050	9	1400	9	78 683
Version A b=1900 constant	2450	10	1900	8	104 798
Version A h=2500 b=1900 constant	2500	10	1900	10	113 558

It can be seen from the comparison of optimal versions A and B that, to decrease the cross-sectional area, the distances between the stiffeners should be decreased, because the constraints on local buckling of plate elements are active. Thus, the cross-sectional area of the version B with more angle stiffeners is less than that of version A.

Furthermore, it can be concluded that, in the cases when b or b and h are constant, the cross-sectional area is greater than for the cases when b and h are free variables.

CONCLUSIONS

Designers need formulae or relatively simple computer programs for all practical cases of checking the buckling of stiffened plates and stiffeners.

The FEM Rules /1970/ and DASt Richtlinie 012 /1978/ do not contain the newest research results relating to the effect of initial imperfections on the buckling of stiffeners.

In order to achieve mass savings the plate thicknesses should be decreased. To avoid local buckling of the web and flange plates longitudinal stiffeners should be used.

The elaborated computer program is suitable for optimization of box sections with more longitudinal ribs and for selection of the optimal structural version.

REFERENCES

Farkas,J. (1984) Optimum design of metal structures.Chichester, Ellis Horwood Ltd., Budapest, Akadémiai Kiadó.

Jármai,K. (1984) Computer-aided optimal design of structures made of higher strength steels. Proc. 7th Int. Conference on Metal Structures, Gdańsk, Politechnika Gdańska, Vol.1. 39-46.

Kuester,J.L. and Mize,J.H. (1973) Optimization techniques with Fortran. New York, McGraw Hill.

Rosenbrock,H.H. (1960) An automatic method for finding the greatest or least value of a function. Computer Journal 3, 175-184.

Scheer,J., Nölke,H. and Gentz,E. (1980) Beulsicherheitsnachweise für Platten. DASt Richtlinie 012. Grundlagen, Erläuterungen, Beispiele. 2.Aufl. Köln, Stahlbau-Verlags-GmbH.