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MULTICRITERIA OPTIMIZATION OF STIFFENED BOX GIRDERS VIA STABILITY CONSTRAINTS

STABILITY OF STEEL STRUCTURES
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XII. COLD FORMED MEMBERS AND INTERACTIVE BUCKLING
CONTRIBUTION

Summary: A decision support system, contains seven various type multicriteria and six various singlecriterion optimization techniques, is applied to optimize welded, stiffened box girders. Using various slendernesses, the computer program determine a great number of optima. Increasing the limit slendernesses can be seen the effect on the volume and deflection of the girder. The great number of Pareto optima give the possibility of making better decisions at design.

1. Introduction

The increased availability of digital computing devices has been a significant contributing factor in the emergence of structural optimization as a discipline in its own right. The optimality criteria and the nonlinear programming methods have received considerable attention in this period of development.

Usually a scalar-valued objective function is optimized over a feasible design space and the result is then used as a guiding devise in striving for the best practicable structure. However,

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there often exist several structural design problems, which involve several, usually conflicting, objectives to be considered by the designer. A promising approach for solving this type of problem seems to be multiobjective nonlinear programming, where a vectorvalued objective function is examined. The problem is stated as:

Find the vector of design variables $\bar{x}$ which minimizes the vector of criterion or objective functions

$$f(\bar{x}) = \{f_1(\bar{x}), f_2(\bar{x}), \ldots, f_k(\bar{x})\} \qquad (1)$$

subject to $g_j(\bar{x}) \leq 0 \quad j = 1,2, \ldots, M$

and the objective functions $f_j(\bar{x})$ may be noncommensurable.

The multiobjective optimization arose in a natural fashion in mathematical economics; its use in engineering and structural design is relatively recent. A variety of techniques and applications of multiobjective optimization have been developed in the past several years.

A vector $\bar{x}^*$ is called Pareto-optimal for the problem of eqn (1) if there exists no feasible vector $\bar{x}$ which would decrease some objective function without causing a simultaneous increase in at least one objective function. Usually several Pareto optima exist for a vector optimization problem and additional information is needed to order the Pareto-optimal set.

This clearly makes it possible to bring in additional considerations not included in the optimization model, thus making the multiobjective approach a flexible technique for most design problems.

Several numerical methods have been suggested for solving a vector optimization problem. We have used seven of them (Jármai 1988). Each method in general, generates a different Pareto-optimal solution.

We used the

- min-max method,
- weighting min-max method,
- two types of global criterion method,
- weighting global criterion method,
- pure weighting method,
- normalized weighting method

as multiobjective optimization methods, and the
- flexible tolerance method of Himmelblau,
- direct-random search method of Weisman,
- hillclimb method of Rosenbrock,
- direct search-feasible direction of Pappas,
- complex method of Box,
- conjugate gradient method of Davidon-Flecther-Powell,

as singleobjective optimization methods.
The developed decision support system (DSS) contains these algorithms and the designer can change the method, solving the problem (Jármai 1989.a).

2. Limit slendernesses at welded, stiffened box girderds

Frieze (1980) determined the values of limit slendernesses for welded box girders, without longitudinal stiffeners. For steel Fe 360 for pure bending, the limit slendernesses of web and flanges are 145 and 30 respectively.

Longitudinally stiffened webs and flanges allow larger plate slendernesses and reduce the mass of structure. Very slender webs and flanges buckle simultaneously and it is difficult to consider the interaction in the design. Thus we made some experiments to determine limit slendernesses, when the interaction of web and flange buckling may be neclected (Jármai 1989.b).

We found, that up to limit slendernesses 200 and 60, at a stiffened box girder, the interaction may be neclected. The yield stress of the steel was 300 MPa.

According to Klöppel, Scheer (1960) the buckling coefficients due to pure bending and shear are k_B = 110,8, k_τ = 10, respectively.

At speciment 200-60 if the concentrated load is 30 kN the computation according to the Hungarian standard MSZ 15024 (1985) is as follows:

F = 30 kN; σ_B = 132.5 MPa; τ_Q = 26.6 MPa; σ_r = 140.2 MPa
so the reduced buckling coefficient k_r is as follows:

$$k_r = \frac{\sigma_r}{\sqrt{\left(\frac{\sigma_B}{k_B}\right)^2 + \left(\frac{\tau_B}{k_\tau}\right)^2}} = 48.07 \qquad (2)$$

the slenderness ratio λ_o is

$$\lambda_o = \frac{3.3}{\sqrt{k_r}} \left(\frac{h}{t_w}\right) = 118.98 \tag{3}$$

the equivalent slenderness is $\lambda_E = \pi \sqrt{\frac{E}{R_y}} = 82.3$

$$\bar{\lambda}_o = \frac{\lambda_o}{\lambda_E} = 1.45 \tag{4}$$

so the decreasing factor φ_b is

$$\varphi_b = \frac{1}{\bar{\lambda}_o^2} = 0.48 \ . \tag{5}$$

There is no buckling if

$$\sigma_r \le 1.1\ \varphi_b\ R_n\ ;\ 140.2 < 157.8 \text{ MPa} \ . \tag{6}$$

So buckling of web does not occur. If the force is higher than F = 35 kN, buckling may occur, or the safety is too small according to the code.

3. Economic design of welded, stiffened box girders

The investigated structure is shown in Fig.1.

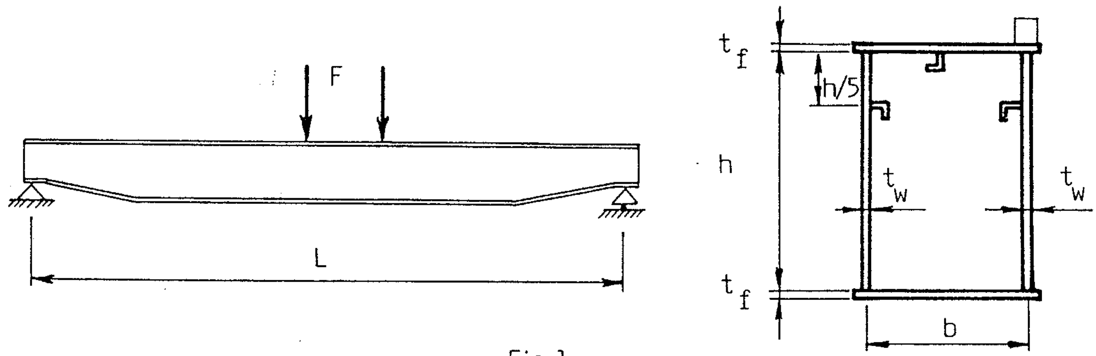

Fig.1.

Independent variables: height of web h = x(1), width of flanges b = x(2). The other dimensions of the beam, using limit slendernesses are as follows:

$$t_w = 0.2\ \frac{h}{30} = \frac{h}{150} = \frac{x(1)}{150} \tag{7}$$

$$t_f = \frac{b}{2} \cdot \frac{1}{30} = \frac{b}{60} = \frac{x(2)}{60} \tag{8}$$

Objective functions:

- volume of the girder

$$V = (2\ ht_w + 2\ bt_f)\ L = (2x(1)\ \frac{x(1)}{150} + 2\ x(2)\ .\ \frac{x(2)}{60}).3000 \tag{9}$$

as the speciment beam length was L = 3000 mm.

$V = F(1) \Rightarrow \min$

- deflection of the girder

$$w_{max} = \frac{FL^3}{48EI_x} \qquad (10)$$

$$I_x = 2\frac{h^3 t_w}{12} + \frac{h^2 b t_f}{2} = \frac{x(1)^3 \frac{x(1)}{150}}{6} + \frac{x(1)^2\, x(2)\,.\,\frac{x(2)}{60}}{2}$$

$$w_{max} = F(2) \Rightarrow \min$$

<u>Contraints</u>:

- stress constraint $\frac{FL}{4W_x} \le R_{adm}$ or $R_{adm} - \frac{FL}{4W_x} \ge 0$ (11)

where $W_x = 2\frac{h^2 t_w}{6} + hb\ t = \frac{x(1)^2 \frac{x(1)}{150}}{3} +$

$+ x(1)\ .\ x(2)\ \frac{x(2)}{60}$; R_{adm} the admissible stress,

- size constraints.

For the independent variables $x_i^{min} \le x_i \le x_i^{max}$ $(i = 1,2)$. Four geometric constraints relating to the span length and the height of web:

$$L_{max} - x(2) \ge 0\ ; \qquad x(2) - L_{min} \ge 0 \qquad (12)$$

$$h_{max} - x(1) \ge 0\ ; \qquad x(1) - h_{min} \ge 0 \qquad (13)$$

3.1 Description of the problem in the coordinate system of variables

The concentrated load at the middle of the beam is 4800 N at span lenght 3 m, the maximum stress at midspan is 54 MPa. (as at the test beam were). So we choose an upper and lower limit both for the height and width of girder. They are 100÷400 mm, 100÷300 mm respectively.

Objective functions are as follows:

$$F(1) = \left(\frac{x(1)^2}{75} + \frac{x(2)^2}{30}\right) .\ 3000 \qquad (14)$$

$$F(2) = \frac{4800}{48.2{,}06.10^5}\ \frac{LL^3}{\frac{x(1)^4}{900} + \frac{x(1)^2 . x(2)^2}{120}} \qquad (15)$$

Inequality constraints are as follows:

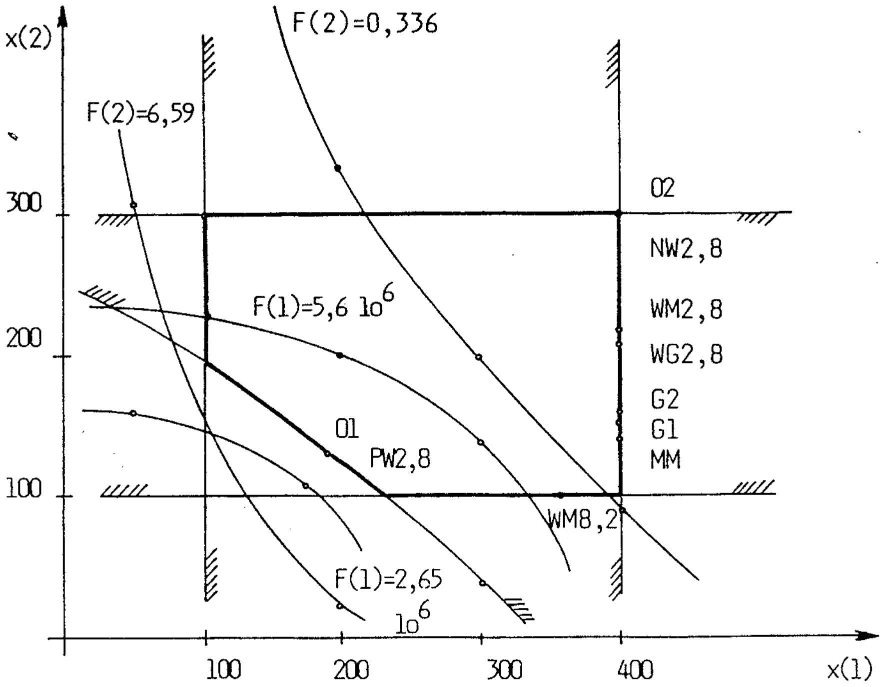
x(2)
F(2)=0,336
F(2)=6,59
300
200
100
O2
NW2,8
WM2,8
WG2,8
G2
G1
MM
F(1)=5,6 lo6
O1
PW2,8
WM8,2
F(1)=2,65
lo6
100
200
300
400
x(1)

Fig.2.

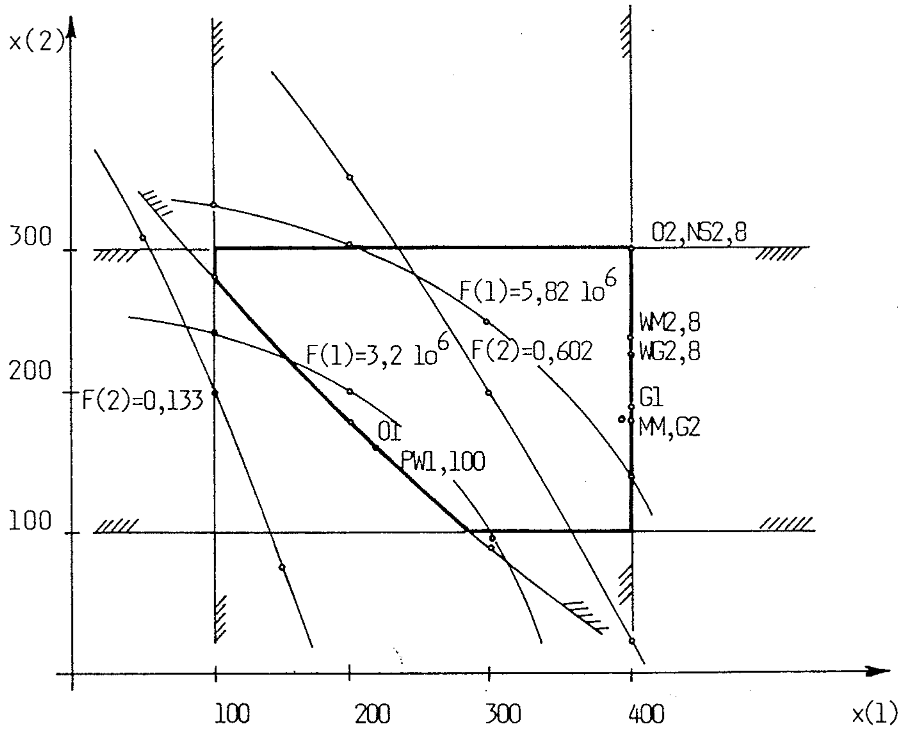
x(2)
300
200
100
O2,NS2,8
F(1)=5,82 lo6
WM2,8
WG2,8
F(1)=3,2 lo6
F(2)=0,602
F(2)=0,133
G1
MM,G2
O1
PW1,100
100
200
300
400
x(1)

Fig. 3.

$$G(1) = 54 - \frac{\frac{4800.3000}{4}}{\frac{x(1)^3}{450} + \frac{x(1).x(2)^2}{60}} \geq 0 \qquad (16)$$

$$G(2) = 400.-x(1) \geq 0 \qquad (17)$$

$$G(3) = x(1)-100. \geq 0 \qquad (18)$$

$$G(4) = 300.-x(2) \geq 0 \qquad (19)$$

$$G(5) = x(2)-100. \geq 0 \qquad (20)$$

Fig.2.3. show the F(i) and G(i) functions. 01 and 02 means the single-criterion optimum, WM is the weighting min-max, WG is the weighting global, PW is the pure weighting and NW is the normalized weighting method. Numbers mean the weighting coefficients, for example WM 2.8 means weighting min-max method where $w_1 = 0.2$, $w_2 = 0.8$, respectively.

Using the decision support system, we can get the various optima in the coordinate systems. The so called Pareto optima take place between the single-criterion optima.

Comparing the optima caused by various slendernesses (Table 1) it can be seen, that larger slendernesses cause decreasing in volume and increasing at deflection.

	x(1)	x(2)	F(1)(mm³)	F(2) (mm)
slendernesses 150/30				
1.obj.	190	130	$0.3134.10^7$	$0.20065.10^1$
2.obj.	400	300	$0.154.10^8$	$0.8829.10^{-1}$
min-max weighting	400	140	$0.836.10^7$	$0.24014.10^0$
min-max $w_1=0.2, w_2=0.8$	400	220	$0.1127.10^8$	$0.1409.10^0$
slendernesses 200/60				
1.obj.	220	170	$0.2897.10^7$	$0.1684.10^1$
2.obj.	400	300	$0.93.10^7$	$0.16611.10^0$
min-max weighting	390	180	$0.6183.10^7$	$0.3292.10^0$
min-max $w_1=0.2, w_2=0.8$	400	240	$0.768.10^7$	$0.2194.10^0$

Table 1.

There is another possibility to reduce the volume of the beam: using higher strength steel.

References

Frieze, P.A. (1980): Behaviour and design of thin-walled rectangular hollow sections. Thin-walled structures. London, Granada, pp. 445-477.

Jármai, K. (1988): Design of economic steel structures. Candidate of Science Dissertation, Miskolc, Hungary,187 p (in Hungarian)

Jármai, K. (1989.a): Single- and multicriteria optimization as a tool of decision support system. Computers in Industry, Elsevier Science Publishers, Vol. 11. No.3. pp. 249-265.

Jármai, K. (1989.b): Design of economic, stiffened box girders, experiments for the local buckling interaction. Publ. of the Techn. Univ. 7 p. (under publication).

Klöppel,K., Scheer, J. (1960): Beulwerte ausgesteifter Rechteckplatten. Verlag von Wilhelm Erns & Sons. Berlin.

MSZ 15024 (1985): Design of steel constructions for buildings. Design requirements. Hungarian National Standard. (in Hungarian).