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KOMITET KONSTRUKCJI METALOWYCH PRZY ZARZĄDZIE GŁÓWNYM POLSKIEGO ZWIĄZKU INŻYNIERÓW I TECHNIKÓW BUDOWNICTWA

POLITECHNIKA GDAŃSKA

ZRZESZENIE „MOSTOSTAL"

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ECONOMIC DESIGN OF FRAMES OF STEEL GANTRY STRUCTURES ON IBM PC

1. Introduction

There has been a revolutionary change in the analysis and design of engineering systems in the last decade. With the advent of fast digital computers and introduction of finite element method the "cut and try" design philosophy has been changed into "model and analyze". Scarcity of resources and need for efficiency in today's competitive world, have forced engineers to evince greater interest in economical and better designs.

The structural design process is essentially an iterative process in which the designer alternates between analysis and design until the most efficient solution is obtained. The vector optimization procedures offer the designer a large number of so called Pareto optima, using various methods and weighting parameters. The connection between the single-criterion and multicriteria optimization is an efficient tool of decision support system.

2. Decision support system

The program code was developed in FORTRAN language on IBM PC/AT type computer. It contains seven multicriteria and six single-criterion optimization methods as can be seen in Fig.1.

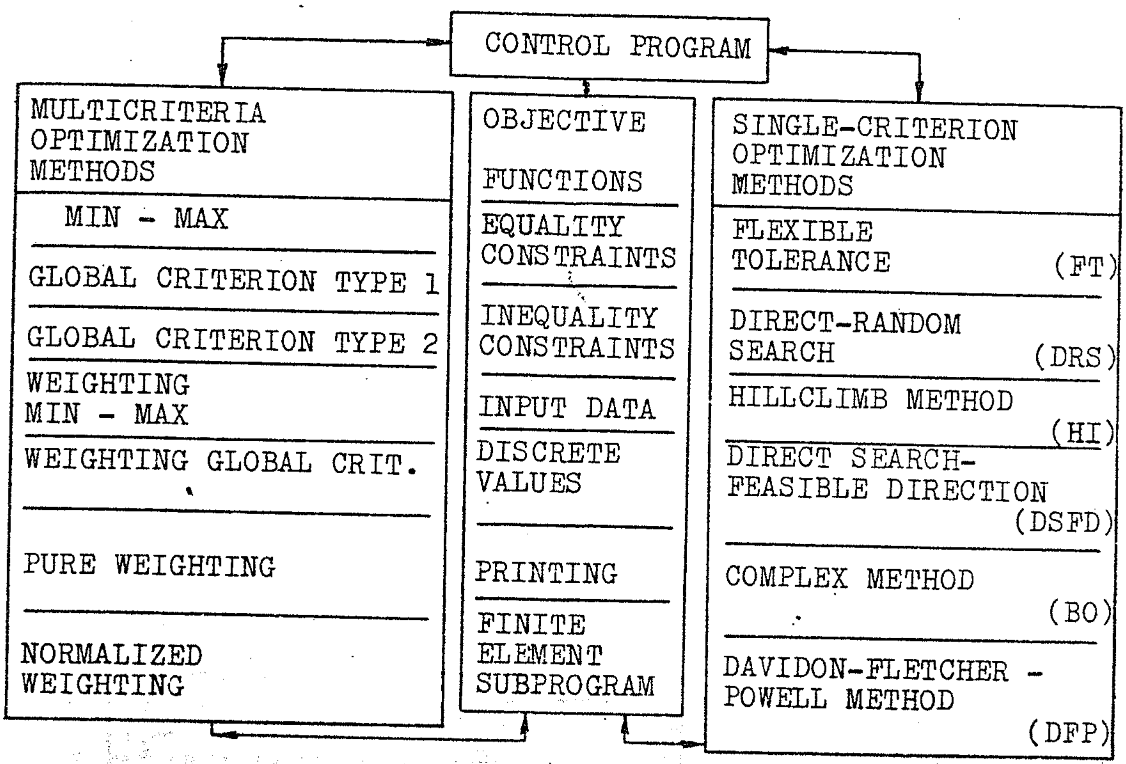

Figure 1.

These methods use the same objective functions, constraints and input data [1]. Each technique has its own advantages and disadvantages, none algorithm is suitable for all purposes. The choice of a particular algorithm for any situation depends on the problem formulation and the user. These nonlinear constrained methods use continuous variables complemented by a secondary search to find the optimal discrete variable values [2].

Optimization methods are good tools for design of economic structures, for finding the best structural sizes using various cost factors and weighting coefficients.

3. Economic design of frames of steel gantry structures

The plane frame made of welded I-members, the heights of webs in columns and rafters increase linearly. The frame has pinned bases. There is a crane runway at columns, see Fig.2.

Number of independent variables is ten, these are the heights and thichnesses of webs, width and thichnesses of flanges both at columns and rafters. The tenth variable is the span length of the frame.

Number of objective functions is three:

- mass of the frame
- mass/floor space of the frame
- cost of the frame including material-, welding-, surface preparation and painting costs.

The cost factors are 17 Ft/kg; 54 Ft/kg and 108 Ft/m^2 respectively.

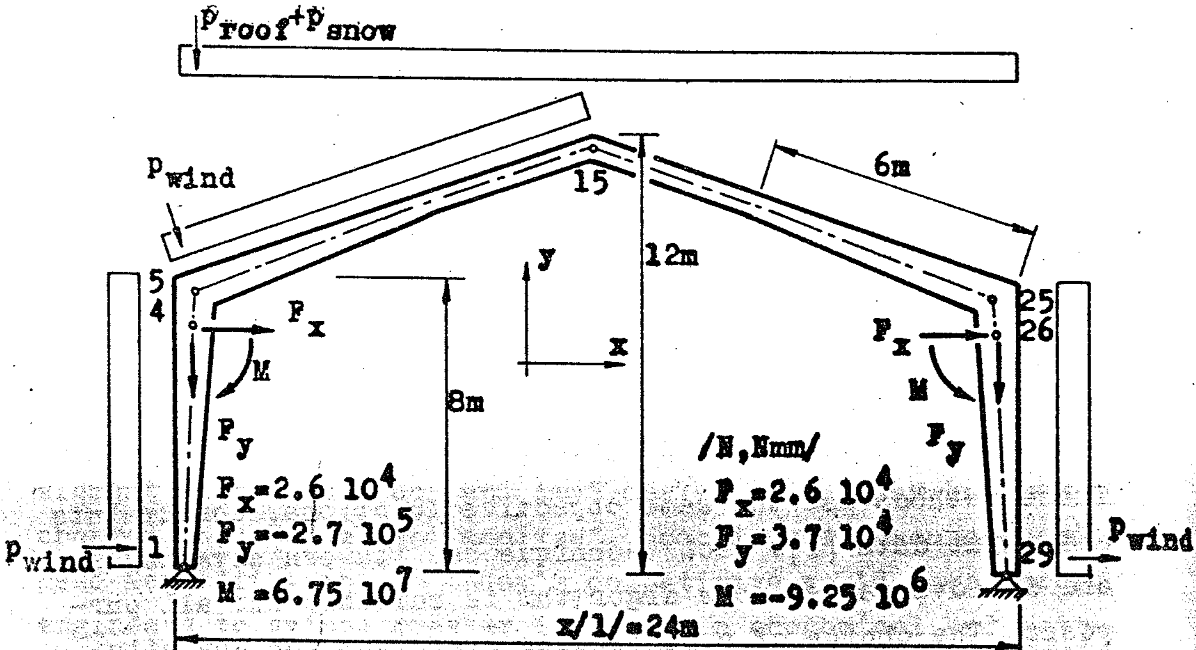

Figure 2.

The inequality constraints are formulated according to the standards MSZ 15021, MSZ 15024 and BS 5950. They are as follows:

1- 4. Statical stress constraints at various nodes considering bending, compression and shear.

5- 6. Local flange buckling constraints for columns and rafters

$$\sigma_A \leq \varphi_b' R_u$$

where σ_A is the superposition of normal stresses due to bending and compression,

R_u is the ultimate stress

φ_b' is the decreasing factor which depends on the slenderness, yield stress and distance of diaphragms.

7-10. Local web buckling constraints for columns and rafters

$$\sigma_r \leqq 1{,}1 \ \varphi_b \ R_u$$

where σ_r is the reduced stress, φ_b decreasing factor depends on the slenderness, yield stress, stress state of web and distance of diaphragms.

11-12. Lateral buckling constraints at the eaves point.

The heights of webs increase linearly, so we can use the recommendations of BS 5950.

$$\frac{F}{A} + \frac{M_B}{W_{xp}} \leqq p_b$$

where ultimate stress for lateral buckling is p_b. F and M_B are the axial force and the bending moment at a given member, respectively.

W_{xp} is the plastic section modulus.

The maximum bending moment is:

$$M_B = \frac{M_E \ M_p}{\phi_B + (\phi_B^2 - M_E M_p)^{1/2}} = p_b \cdot W_{xp}$$

where $M_p = Ry \ W_{xp}$ is the maximum plastic moment, the yield stress $Ry = 235$ MPa

the elastic bending moment $M_E = \dfrac{M_p \ \pi^2 E}{\lambda_{LB}^2 \ Ry}$

$$\phi_B = \frac{M_p + (\eta_{LT} + 1) M_E}{2}$$

for welded profiles the so-called Perry coefficient is

$$\eta_{LT} = 2\alpha_b \lambda_{LO} \ ; \ \eta_{LT} \leqq 2\alpha_b(\lambda_{LB} - \lambda_{LO})$$

$$\eta_{LT} > \alpha_b(\lambda_{LB} - \lambda_{LO})$$

$$\alpha_b = 0.007 \ ; \quad \lambda_{LO} = 0.4 \ \left(\frac{\pi^2 E}{Ry}\right)^{1/2}$$

$\lambda_{LB} = n_t \ U_L \ v_t \ c \ \lambda$ the minor axis slenderness ratio.

n_t is determined from consideration of the loading and restraint conditions of the member.

For columns $n_t = 1$.

For rafters $n_t = (1.5 - 0.5 \ R_f) \geqq 1$;

where R_f is the ratio of the flange area at the point of minimum moment to that at the point of maximum moment. In our case it is the same, so $R_f = 1$. U_L, the buckling parameter for tapered members should be taken as 1.0.

$$v_t = \left[\frac{\frac{4a_e}{h}}{1+(\frac{2a_e}{h})^2 + \frac{1}{20}(\frac{\lambda}{x_e})^2} \right]^{1/2}$$

where a_e is distance between reference axis and restraint axis

x_e is the torsional index

$$x_e = 0.566\ h\ (\frac{A}{J})^{1/2} \ ; \quad J = \frac{1}{3} \sum_i t_i^3 b_i \ .$$

t_i and b_i are the thicknesses and widths of plate members.

$$c = 1 + \frac{3}{x_e - 9}(R-1)^{2/3} q^{1/2}$$

where $q = \frac{L_T}{L}$; L_T the length of the tapered pont.

$R = \frac{h_{max}}{h_{min}}$; h_{max}, h_{min} are the greather and lower web heights, respectively.

13. Elastic lateral buckling of the compressed flange at rafter

$$\frac{M_{max}}{\bar{W}_c} \leq 1.2\ \varphi\ R_u$$

where $\bar{W}_c$ is the section modulus, the decreasing factor φ depends on the slenderness of flange and yield stress.

14-15. Vertical and horizontal displacement constraints for the apex and eaves points of the frame.

The displacement, forces and bending moments are calculated by a finite element subprogram, which use 29 modes and 28 elements.

16-35. Size constraints, upper and lower limits of variables.

4. Numerical example

Main design data of the frame are as follows: Height of eaves points: 8 m; height of apex: 12 m; distance between frames: 6 m; lenght of the haunch from the eaves point: 6 m; distance of purlins: 2 m; the uniformly distributed vertical load: 0.4 kN/m^2; concentrated loads and bending moments from the crane runway (see Fig.2.).

The effect of the objective functions to each other can be seen in Fig.3-4. There is no significant effect between the mass and cost of the frame. The second objective function decrease the mass/floor space ratio of the frame. Using various weighting parameters the designer can find a great number of optima and he can choose his best optimum using various aspects such as manufacturing, aesthetic, etc.

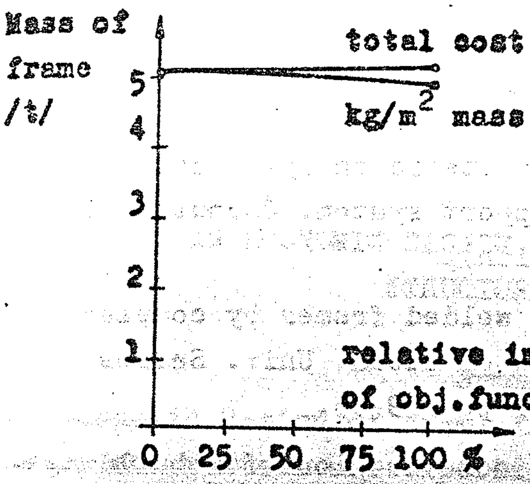

Fig.3.

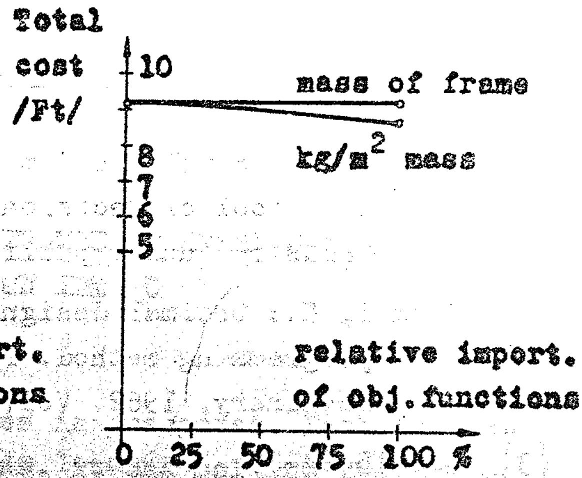

Fig.4.

Increasing the yield stress from 230 to 355 MPa may result in mass savings. Introducing a material cost ratio ξ as

$$\xi = \frac{C_{1kgFe370}}{C_{1kgFe520}}$$

$\xi = 1$ represents the mass savings directly, which are about 22 %. Fig.5. shows the relative material cost savings, depending on the cost factor.

If the height of webs does not increase linearly, but is constant, the mass of the frame is approximately 18 % greater. The reason of it is that using pinned base points the lower part of collumns is oversized.

With these computer program the changing of input data, constraints and objective functions can be done easier and quicker.

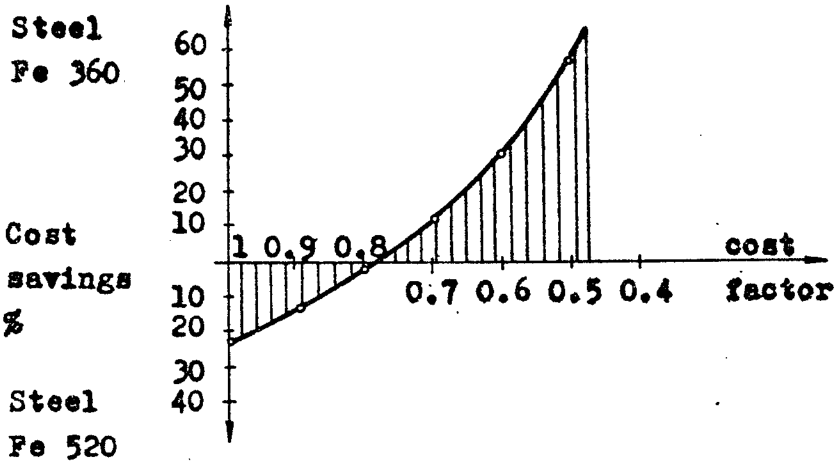

Figure 5.

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[4] MSZ 15021-86: Design of load bearing structures of buildings. Design loads for biuldings. Hungarian National Standard. 1986.

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EKONOMICZNE PROJEKTOWANIE RAM STALOWYCH Z BELKAMI PODSUWNICOWYMI PRZY POMOCY KOMPUTERA OSOBISTEGO

Streszczenie

W referacie przedstawiono ekonomiczne projektowanie stalowych ram z belkami podsuwnicowymi z wykorzystaniem komputera osobistego. Słupy i belki ram wykonano z spawanych elementów dwuteowych z liniowo zmieniającą się wzdłuż wysokości ścianką.
Program wspomagający opracowano wykorzystując sześć różnych optymalizacyjnych metod z funkcją jednocelową i siedem metod z funkcją wielocelową. W oparciu o normę węgierską zastosowano 10 zmiennych, trzy funkcje celu oraz trzydzieści pięć warunków nierówności.

AN ECONOMIC DESIGN OF FRAMES OF STEEL GANTRY STRUCTURES ON IBM PC

Summary

An economic design of steel frames is presented. Both the columns and rafters are tapered ones. At the columns there are crane runway girders. The computer program connects six single criterion and sewen multicriteria optimization methods.
Ten variables including the span length. 35 inequality constraints and three objective functions are used at economic design regarding the design rules of the Hungarian standard.