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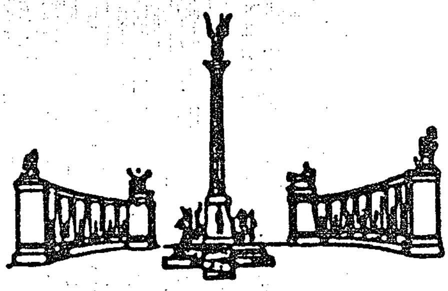

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DECISION SUPPORT SYSTEM FOR DESIGN OF STEEL STRUCTURES ON PERSONAL COMPUTER

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SUMMARY

An interactive multicriterion optimization programsystem is presented for the economic design of steel structures. The efficiency of the program is shown on the design of the double-box girders of overhead travelling cranes. The objective functions were the mass, the welding-, surface preparation costs and the total cost of the crane.

INHALTSANGABE

Der Verfasser behandelt ein interaktives Programmsystem mit mehreren Zielfunktionen zur Optimalbemessung von Stahlkonstruktionen. Die Wirksamkeit des Programmes ist am Beispiel der Optimalbemessung der Kastenträger von Zweiträger-Laufkranen gezeigt. Als Zielfunktionen sind die Masse, die Schweisskosten, die Kosten der Oberflächenvorbereitung und die Gesamtkosten gewählt.

1. Introduction

In the most general terms, optimization theory is a means of mathematical results and numerical methods for finding and identifying the best candidate from a collection of alternatives without having to explicitly enumerate and evaluate all possibble alternatives. The process of optimization lies at the root of engineering, since the classical function of the engineer is to design new, better, more efficient and less expensive sytems as well as to devise plans and procedures for the improved operation of existing system.

Because of the scope of most engineering applications and the tedium of the numerical calculations involved in optimization algorithms, the techniques of optimization are intended primarily for computer implementation [1].

2. The formulation of the interactive decision support system

Engineering designers are continually making decisions. If the formulation of the optimization problem is a multicriterion one, it has the possibility to compare the effect of the objective functions on the final dimensions of the structure [2].

We have used five various single criterion optimization methods, such as the Complex method of Box [4], the Hillclimb method of Rosenbrock [5], the Flexible tolerance method of Himmelblau, Direct-random search method (DRS) of Weisman and the Direct search-feasible direction method (DSFD) of Pappas.

The multivariable optimization algorithms are the min-max method, two types of global criterion methods, the weighting min-max and the weighting global criterion methods, the pure weighting and the normalized weighting methods.

The programsystem consists of four blocks as can be seen in Figure 1.

The min-max optimum compares relative deviations from the separately attainable minima. The relative deviations are as follows:

$$z_i'(\bar{x}) = \frac{\left|f_i(\bar{x})-f_i^o\right|}{\left|f_i^o\right|} \; ; \quad z_i''(\bar{x}) = \frac{\left|f_i(\bar{x})-f_i^o\right|}{\left|f_i(\bar{x})\right|}$$

where f_i^o the ideal solution. Knowing the extremes of the objective functions, the program chooses the minimum as an optimum point.

$$z_i(\bar{x}) = \min_{x \ni X} \; \max_{i \ni I} \left\{ z_i'(\bar{x});\; z_i''(\bar{x}) \right\}$$

The weighting min-max method using coefficients to give the relative importance of the criteria:

$$z_i(\bar{x}) = \min_{x \ni X} \; \max_{i \ni I} \left\{ w_i z_i'(\bar{x});\; w_i z_i''(\bar{x}) \right\}$$

where $\sum_i w_i = 1$.

The global criterion methods describe how close the decision maker to the ideal solution f_i^o.

Type 1 is $f(\bar{x}) = \sum_i \left(\frac{f_i^o - f_i(\bar{x})}{f_i^o}\right)^p$; $\quad p = 1,2,3 \ldots$

Type 2 is $L(f) = \left[\sum_i \left|\frac{f^o - f(\bar{x})}{f_i^o}\right|^p\right]^{1/p}$; $\quad 1 \leq p \leq \infty$

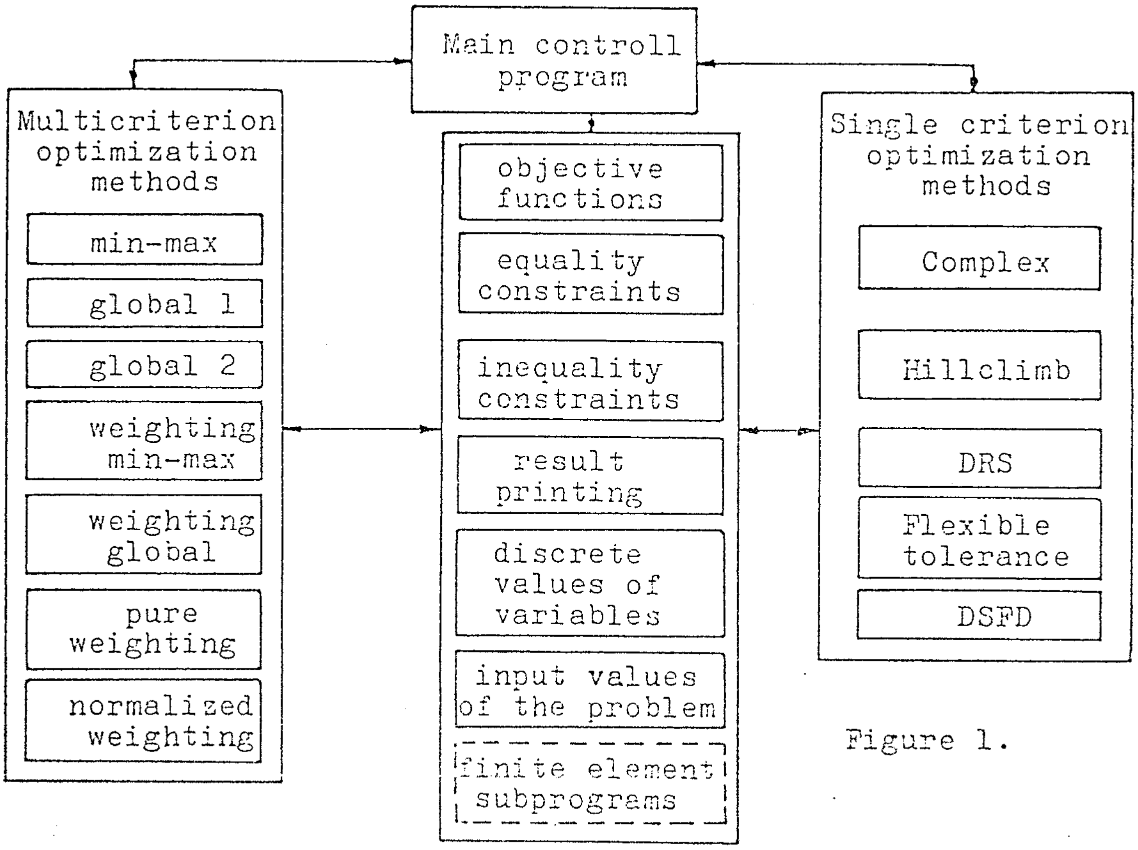

Figure 1.

The weighting global criterion method uses weighting coefficients as $\sum_i w_i = 1$.

$$L_2(f) = \left[\sum_i w_i \left| \frac{f_i^o - f_i(\bar{x})}{f_i^o} \right|^2 \right]^{1/2} ; \qquad p = 2$$

is means the weighting distance from the ideal solution.

The pure weighting method is a well known way for the scalarization of the function. It changes the multicriterion optimization problem to a scalar one as follows,

$$f(\bar{x}) = \sum_i w_i \; f_i(\bar{x}); \qquad w_i \geq 0$$

In this case there is a great effect of the values f_i on the optimum.

Normalizing the functions we get best results according to the weighting coefficients.

$$f(x) = \sum_i w_i \frac{f_i(\bar{x})}{f_i^o} \qquad ; \qquad \sum_i w_i = 1$$

3. Optimum design of the main girders of overhead travelling cranes

The double girder of the crane is made of welded box section, stiffened at the webs, which have different thicknesses. See Figure 2.

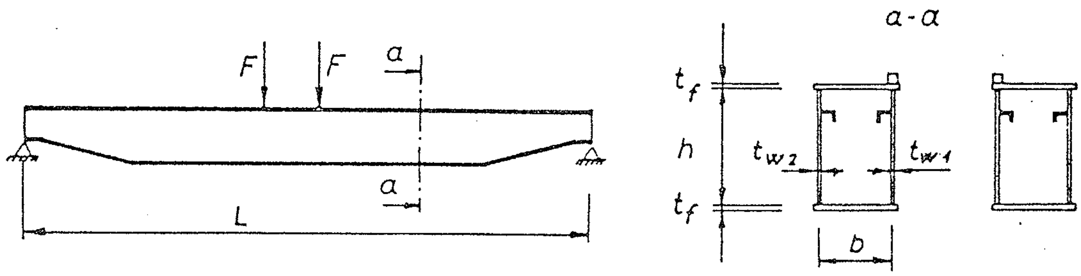

Figure 2.

The five unknown indepentent variables are the dimensions of the asymmetric box section;
height of webs: $h = x(1)$; thicknesses of webs: $t_{w1} = x(2)$ $t_{w2} = x(3)$; width of flanges: $b = x(4)$; thickness of flanges: $t_f = x(5)$.

The objective functions are as follows: $f_i(\bar{x})$

1) mass of the main girder

$$F_1(\bar{x}) = (A \cdot L + h_s \cdot 0.05 \cdot L + t_{w2} \cdot h \cdot b \cdot n_{df} + p_j \cdot L + A_{br} \cdot L)$$

where the density is $\varrho = 7,85$ kg/dm^3
h_s the height of rail
p_j the mass of foot-path per meter
n_{df} number of diaphragms
A_{br} cross section of web stiffener,

2) welding cost

$$F_2(\bar{x}) = k_h \sum_i A_i \cdot L_i \cdot \varrho_i$$

where k_h the cost of welding joints per weight
A_i and L_i the cross sections and lenght of the ith welding joint,

3) surface preparation cost

$$F_3(\bar{x}) = k_f(2 \cdot L \cdot h + 2 \cdot b \cdot L)$$

where k_f is specific cost of surface preparation,

4) total cost, including material-, welding-, and surface preparation cost

$$F_4(\bar{x}) = k_a\ F_1(\bar{x}) + F_2 + F_3 \qquad \text{(Ft)}$$

where k_a is the cost factor of the material.

The inequality constraints are as follows: $G_j(\bar{x}) - 0$

1) maximum stress under main loading,
2) local buckling of flanges under main loading, taking account bending, shear and torsion,
3) local buckling of flanges under main loading, when only bending, such as compression for the flange is taking account,
4) local buckling of main web, under the rail, taking accoung the compression of the weel,
5) local buckling of the secondary web,
6) maximum stress under total loading,
7) local buckling of flange under total loading,
8) local buckling of the main web,
9) local buckling of the secondary web,
10) fatigue of weldments under shear and local compression,
11) fatigue of weldments under tension and compression,
12) deflection of the girder

and ten constraints on the upper and lower limits of independent variables,

$$x_i^L \leq x_i \leq x_i^U \quad (i=1,2,\ldots,5)$$

So the number of constraints is 22.

The constraints are according to the Hungarian standars MSZ 9749, MSZ 15024 and to taking account the local compression of the weel we used TGL 13503/2. We made these kind of optimization according to the DIN 15018, DASt 012 and DIN 4114 and compared the result using various standards in [3].

In the computer program there is a subprogram to give geometric, material and loading data of the structure.

In our example the main data are as follows:

span of crane 25 (m);
lifting capacity 240 (kN);
weight of crane carriage 30 (kN);
axle base of carriage 2 (m);

type of welding: K; number of load cycles $<6\cdot10^5$, web stiffeners are 120x80x8 (mm) angle profile. Material Fe 360 is used with the yield stress R_y = 240 MPa.

The cost factors are: material cost 17 Ft/kg; welding cost 54 Ft/kg; surface preparation cost 108 Ft/m^2.
Results can be seen in Table 1. for one girder.

	x(1)	x(2)	x(3) (mm)	x(4)	x(5)	mass $\times 10^3$kg	costs welding $\times 10^3$Ft	costs surf. $\times 10^3$Ft	total $\times 10^5$Ft
1 st. obj.	1360	7	6	550	20	7.78	5.97	7.37	1.79
2 nd obj.	1380	6	5	770	15	7.51	4.24	7.47	1.74
3 rd obj.	1100	18	5	760	19	10.63	20.6	5.96	2.4
4 th obj.	1300	6	5	670	18	7.54	4.23	7.04	1.73
min-max	1280	12	8	600	19	9.51	14.6	6.95	2.19
global 1	1240	6	5	700	19	7.89	4.22	6.72	1.78
global 2	1320	6	5	760	16	7.62	4.23	7.15	1.75
weighting min-max $w_i = 0.25$	1200	7	5	710	19	8.11	5.09	6.5	1.83
normalized weighting $w_i = 0.25$	1260	6	5	630	20	7.66	4.22	6.83	1.74

Table 1.

The active constraints in most cases were the fatigue, local buckling of webs and the size constraints of thicknesses. The deflection limit in this case was span/600.

The designer has the possibility to give discrete values for the independent variables. In our example the distance between discrete values for the five variables were 20; 1; 1; 10; 1 mm. In Figure 3. the effect of the importance of various objective function can be seen on the mass of the structure.

There is no significant effect of welding and total cost on the mass, but the surface preperation cost's effect is great.

Using higher strenght steel (Fe 520), the mass of the structure can be reduced, but the reduction of cost depends on the material cost.

The computer program made on IBM PC/AT, with 1 Mbyte memory, 20 Mbyte Wincherster disc and 1.2 Mbyte floppy disc,

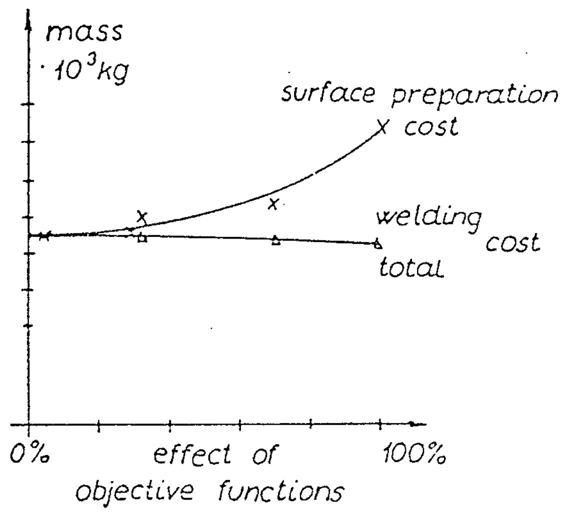

Figure 3.

and with math coprocessor 80287, with Microsoft FORTRAN 4.0 Optimizing compiler and overlay linker.

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