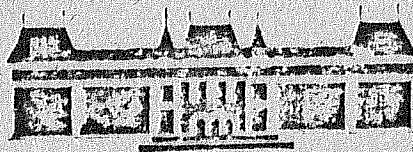


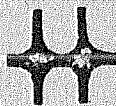
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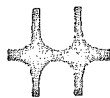
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BULLETINS FOR APPLIED MATHEMATICS

Dr. Károly JÁRMAI department engineer (TUHI)

OPTIMAL DESIGN OF METAL STRUCTURES



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OPTIMAL DESIGN OF METAL STRUCTURES

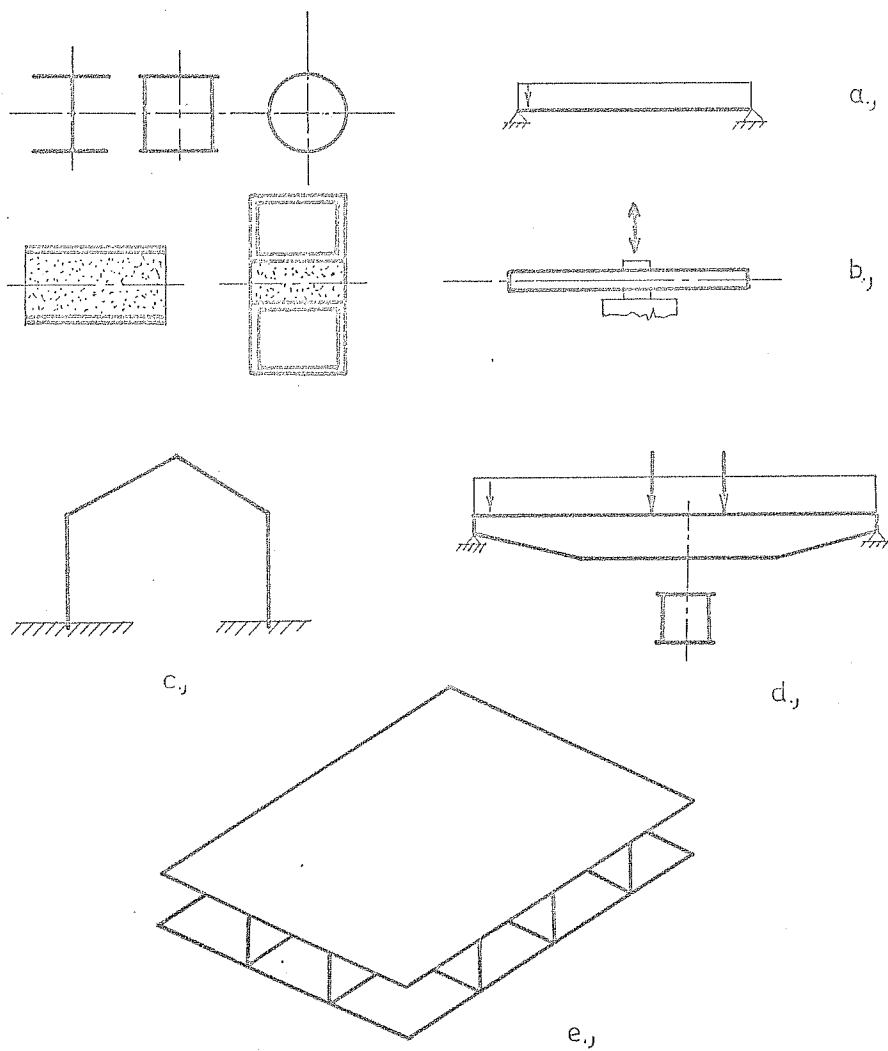
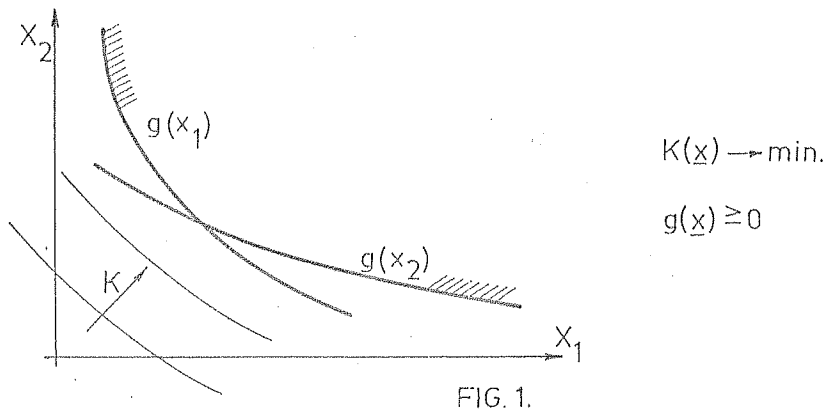
Károly J á r m a i

Optimization means finding those values of design variables, subject to relevant constraints, that minimize the cost or weight function. The design of a structure is characterized by a set of parameters, specifying the configuration of the structure and the properties of the structural members. Analytical optimization methods generally are applicable only to simple structures. See the grapho-numerical method for a two variables problem Fig. 1. For the optimization of complicated structural assemblies programming methods should be employed. Programming methods are also necessary if the design variables are discrete in nature, or if the objective function is not available in analytical form.

The main research theme of the group "Metal structures" in our department is the optimal design of metal structures. In our research work several mathematical programming methods were adopted and applied to various optimal design problems. For example we elaborated the optimal design of the following structures /Fig.2./:

/a/ I- and box cross-sectional and tubular girders [1, 2, 3] simply supported, /b/ sandwich beams with thin metal faces [4] and with box cross-sectional faces [5, 6], /c/ welded portal frames with various columns and rafters [1, 7, 8], /d/ main girders of welded box cross-section of overhead travelling cranes [9], /e/ cellular plates.

The aim of the present contribution is to give a short description of the complex method of Box [10] and



its application to the optimal design of a welded portal frame.

1. The Complex Algorithm

The algorithm minimizes the nonlinear objective function

$$y = f /x_1, x_2, \dots, x_n/$$

subjected to inequality explicit constraints and nonlinear inequality implicit constraints of the \underline{n} independent and $\underline{m} - \underline{n}$ dependent variables

$$x_i^U \leq x_i \leq x_i^L ; \quad i = 1, \dots, n; \quad i = n + 1, \dots, m.$$

In the first iteration cycle an original "complex" is generated. The complex contains $k \geq n + 1$ feasible points or vertices in an \underline{n} - dimensional design space. It is assumed that an initial feasible point exists.

$$x_{ij} = x_i^L + r_{ij} /x_i^U - x_i^L / , \quad i = 1, \dots, n ; j = 2, \dots, k$$

where x_{ij} the i th coordinate of the j th point, r_{ij} random numbers between 0 \div 1.

Each point is examined to see whether it satisfies the explicit and the implicit constraints. If not the trial point is moved halfway towards the centroid of the remaining points as follows.

$$x_{ij}^{\text{New}} = \frac{x_{ic}^{\text{Old}} + x_{ij}}{2} ;$$

$$x_{ic} = \frac{1}{k-1} \sum_{j=1}^k /x_{ij} - x_{ij}^W / \quad i = 1, \dots, n$$

Once x_{ij}^{New} is obtained it must then be examined for feasibility. The function values are evaluated at each of points. The points with the worst and the best function values are determined. The convergence criterion checked:

$$|f_{max} - f_{min}| < \beta$$

If it is not fulfilled the worst point x_{ij}^W for which $f / x_{ij}^W = f_{max}$, is rejected and replaced with a new one

$$x_{ij}^{New} = \alpha / x_{ic} - x_{ij}^W + x_{ic} \quad i = 1, \dots, n$$

where α is the reflexion coefficient.

This procedure - reflexion and contraction - is repeated, until the convergence criterion is fulfilled or the iteration number reaches its ultimate value.

Some modifications were implemented at the complex algorithm [8] related to the expansion and halving steps, to the variability of complex 's size /k/, convergence and reflexion coefficients / β , α /. The main modification was the adoption of discrete member sizes, which made the search more practicable.

2. Minimum Weight Design of Welded Plane Frames

We illustrate the application of the above described method by the numerical example of a plane frame, made of welded I-section bars as shown in Fig. 3. We consider the dimension of columns and rafters to be different. So the number of variables is eight.

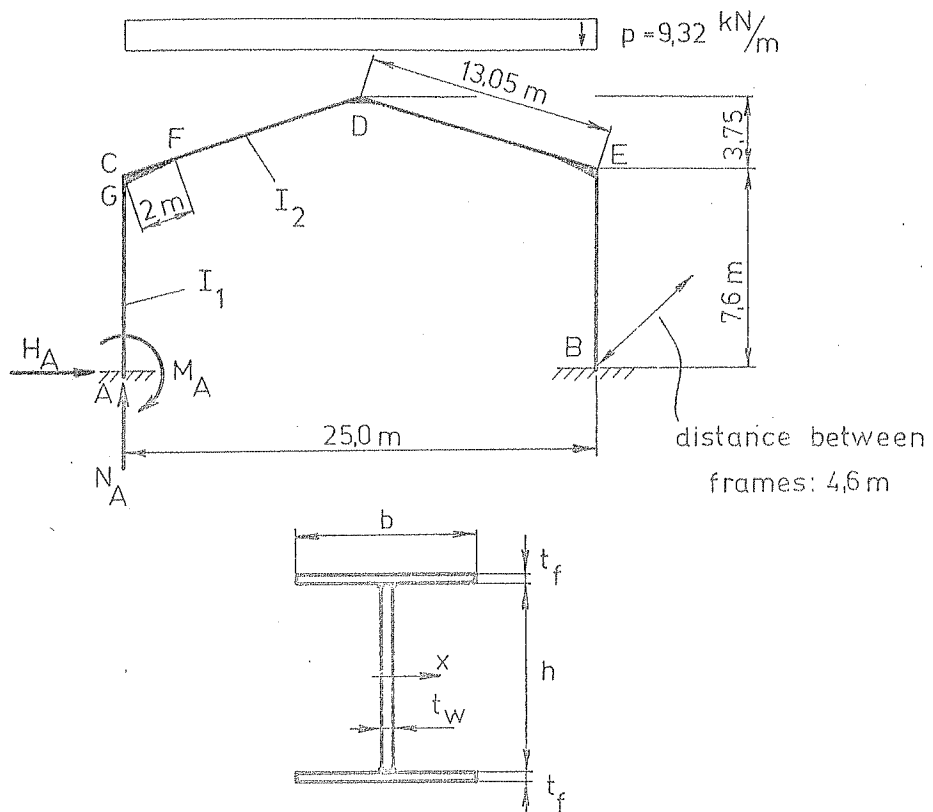


FIG. 3.

The volume of the frame made of welded I-sections subjected to bending and compression should be minimized. The objective function is

$$V = 2 \sum_i A_i \ell_i \quad i = 1, 2$$

where $A_i = h_i t_{wi} + 2 b_i t_{fi}$, and ℓ_i are the area and length of the i the member, respectively. The constraints of maximum stresses in the columns and rafters are

$$\sigma_{Mi} + \sigma_{Ni} \leq R_u$$

where $\sigma_{Mi} = M_i / W_{xi}$; the section modulus $W_{xi} = h_i / b_i t_{fi} + h_i t_{wi} / 6$

and

$$\sigma_{Ni} = N_i/A_i \quad i = 1,2$$

M_i and N_i the bending moment and compressive force, respectively, R_u the limit stress.

The constraints of web and flange buckling for steels of tensile strength 370 MPa may be expressed as [3]

$$\frac{h_i}{t_{wi}} \leq 145 \sqrt[4]{\frac{1 + \frac{\sigma_{Ni}}{\sigma_{Mi}^2}}{1 + 173 \left(\frac{\sigma_{Ni}}{\sigma_{Mi}} \right)^2}}}; \quad \frac{b_i}{t_{fi}} = 30 \quad i=1,2$$

The computer program was written in Fortran IV and run on computer CDC 3300 and ODRA 1304, respectively. Concerning the effectiveness of the computation it was found, that the best values of k are around $2n/16$, the best values of α are from 1,3 to 1,7 and the best values of β are around 600 /0,5 %/. Parameters and final values are shown in Table 1. for three runs.

k	α	β	k_1	t_{w1}	b_1	t_{f1}	h_2	t_{w2}	b_2	t_{f2}	$V \cdot 10^{-3}$	CPU time
14	1,3	600	540	4,5	280	10	620	6	110	9	2,7082	111,6
16	1,3	1200	600	5	200	13	560	5,5	170	8	2,7602	106,3
18	1,3	600	620	5,5	200	13	580	5,5	170	7	2,7625	114,6

Table 1. Dimensions in mm and sec.

3: Comparison of Computational Results Obtained by the Backtrack Programming Method

For the characterization of the complex method it

is useful to compare it with other methods. We have solved several optimum design problems with the backtrack programming method. This method was found to be effective and easily manageable [5, 7]. Using discrete variables the complex programming method may be compared to the backtrack one. The eight variables frame problem was solved by the backtrack method too. The complex method is faster than the backtrack one. The CPU time of complex is fifth - tenth part of the backtrack's one, depending on the parameters k, α, β . The advantages of backtrack method become visible at the final values of the merit functions. The final values obtained by the complex programming method are 3-4 % larger than those obtained by the backtrack one.

4. Conclusions

The complex method has been treated whereby low cost or weight designs may be generated for realistic computer expense by an approach which does not require the computation of derivatives. The advantage of the procedure is that any reasonable cost or weight model, which reflects the user's practice, may be utilized. The method is especially adaptable to dealing with a discrete member spectrum.

The method has been demonstrated to be of practical worth on a common structural engineering problem. The results obtained from application of the algorithm was compared with those obtained by the backtrack programming method.

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Address:

Dr. Károly Jármai

department engineer

Technical University for Heavy Industry
Department of Materials Handling Equipments

H-3515. Miskolc-Egyetemváros