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CAD of Welded Plane Frames

by

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1. Introduction

The total design process of a structure is a multi-stage procedure, which ranges from consideration of over-all system requirements to the detailed design of individual components. All levels of the design process have some greater or lesser degree of interaction with each other.

The objective of the work presented herein was to develop a practical end efficient computer program for the elastic design of welded steel frames. The work is computer oriented, because the elastic optimal design of such structures by hand is not possible, and because the enormous amount of data, which should be processed [1,2]. The method obtains minimum mass designs of plane frame structures using design variables that specify both geometry and member sizes.

The computer program containts two main parts: (1) a finite element program for the determination of bar forces and displacements of modes in a given plane frame, (2) the optimization procedure "Hillclimb", improved by Rosenbrock [3], has been modified for the personal computer, to be a "memory saver" and faster one.

2. The Hill algorithm

The procedure is based on the "automatic" method propored by Rosenbrock [3]. At the Hill algorithm, the coordinate system is rotated in each stage of minimization in such a manner that the first axis is orinted towards the locally estimated direction of the valley and all the other axes are made mutually orthogonal and normal to the first one. No derivatives are required.

The optimization problem may be expressed as follows:

Minimize or Maximize $y = f(x_1, x_2, \ldots, x_N)$ (1)

Subject to constraints $x_i^L \leq x_i \leq x_i^U \quad i = 1,2,\ldots, M$ (2)

$x_i \geq 0$ (3)

The function to be optimize is multivariable and nonlinear with nonlinear inequality constraints. The explicit variables in this problem, x_i, $i = 1, \ldots, N$, usually represent physical parameters of the structure to designed such as dimensions, spacings etc. The objective function $f(x_i)$ which is to be extremized, expresses the minimum structural mass, minimum cost, maximum factor of safety, etc. The implicit variables, $x_{N+1}, \ldots, x_M$ are functions of explicit variables, for example mechanical stresses, displacements, local and global stability of structures, etc. [4].

The search procedure of the optimization program to find the continuous values of the variables is terminated when the convergence criteria are satisfied.

The procedure was modified by a secondary search to find the discrete values of the variables. It was described in details in [2].

3. Analysis of plane rigid frames

The displacement or stiffness method of linear-elastic analysis has been explained and developed in the context of simply connected trussed frames. The method is based upon the satisfaction of conditions of equilibrium, linear elasticity, and deformation compatibility [5].

For a plane, rigidly connected framework not only the two displacement components per joint but also the joint rotation should be found.

The program can calculate the nodal displacements and bending moments in rigid-jointed plane frames. The elements of the frame can have different sectional properties, and the loading may be a combination of concentrated, distributed and hydrostatic loads.

4. The method of solution

The objective function which is to be minimized expressed the total volume of the frame:

$$V = (a\, A_1 + A_2\, L/2\, \cos\alpha) \cdot 2 = 15{,}2\, A_1 + 26{,}1\, A_2\ (m^3)$$

see Fig. 1.

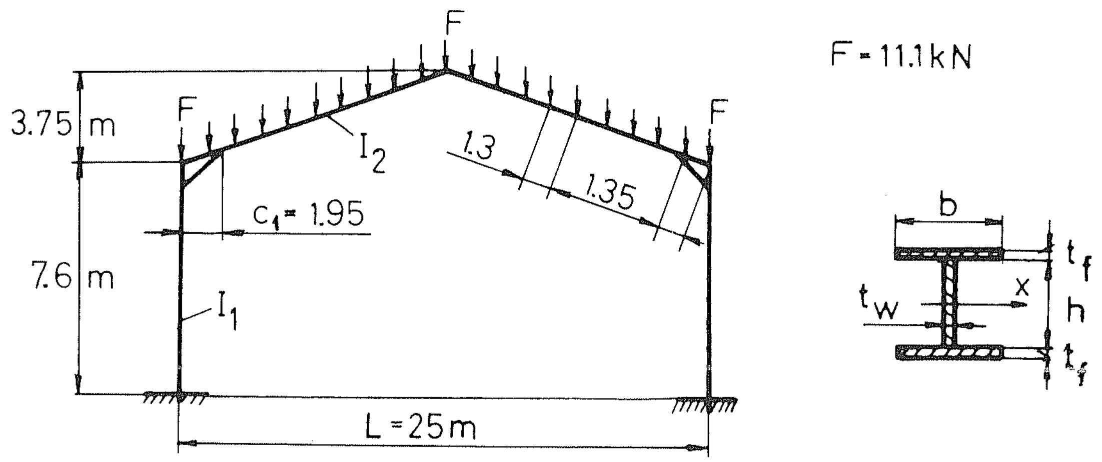

FIG.1.

Loading conditions.
The load applied to the frame is also shown in Fig. 1.
Material: steel Fe 360 is used.

Design constraints

Stress constraints.

Maximum elastic stresses in the columns and rafters due to bending M_i and compression N_i, which are determined by the finite element program:

$$\sigma_{Mi} + \sigma_{Ni} = \frac{M_i}{W_i} + \frac{N_i}{A_i} \leqq R_u \qquad i = 1,2$$

Considering the I-section sizes as shown in Fig. 1., the cross section areas are:

$$A_i = h_i \; t_{wi} + 2 \; b_i \; t_{fi}$$

the section moduli are:

$$W_{xi} = h_i(b_i \; t_{fi} + h_i \; t_{wi}/6)$$

the moments of inertia are:

$$I_{xi} = W_{xi} \frac{h_i}{2} \qquad i = 1,2$$

The limiting stress for steel Fe 360 can be taken

as $R_u = 200$ MPa

Local web buckling constraints

In the case of bending and compression the following approximate interactive formula may be used

$$\frac{h_i}{t_{wi}} \leqq 145 \sqrt[4]{\frac{(1 + \sigma_{Ni}/\sigma_{Mi})^2}{(1 + 173(\sigma_{Ni}/\sigma_{Mi})^2}} \; ; \qquad i = 1,2$$

Local flange buckling constraints

In the case of a compressed flange the buckling constraint can be written as

$$\frac{t_{fi}}{b_i} \leqq 30$$

The buckling constraints are valid only for steel Fe 360, for steel Fe 520 the ultimate thickness ratios should be decreased by the following factor:

$$\sqrt{\frac{R_{u360}}{R_{u520}}} = \sqrt{\frac{200}{280}} = 0,84515$$

5. Results of computations

The program was developed in BASIC language on Commodore 64 type microcomputer. The memory of the computer was sufficient for smaller problems. For larger problems we want to adapt the program to TPA 1148 type computer to decrease the computing time.

Final dimensions of the frame:

	h	tw	b	t_f (mm)
column	760	6	220	9
rafter	480	5	180	8
volume	$2,67312 \cdot 10^8$ (mm^3)			

The fulfilment of the constraints:

	stress (MPa)	web buckling	flange
column/limit	199,87/200	126,67/127,39	24,4/30
rafter/limit	198,25/200	96 /111,53	22,5/30

The iteration number was 104.

6. Conclusions

The advantage of the procedure is that any reasonable frame dimensions, loading, constraints and cost or mass model, which reflects the user's practive, may be utilized. The optimization algorithm does not require the computation of derivatives. The method is especially adaptable to dealing with a discrete member spectrum. The method has been demonstrated on a structural engineering problem.

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