GÉPTERVEZŐK IX. ORSZÁGOS SZEMINÁRIUMA

1. kötet

GTE Borsod megyei szervezetének
Géptervező szakosztálya

Miskolci Egyetem Gépelemek Tanszéke

MTA Miskolci Akadémiai Bizottsága

1993. szeptember 30 — október 1.

OPTIMUM DESIGN OF BELT-CONVEYOR BRIDGES

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We've dealt with the optimum design of belt-conveyor bridges for a long time. We've collected the state of the art computational technics for the analysis of these kind of structures. In the education, the subjects Steel structures and Welded structures contain practical work for students to design a belt-conveyor bridge [1].

There are two main problems raised here, **1.,** is to determine the forces and deformations at every members and nodes, **2.,** is to make a size or a topology optimization.

THE FINITE ELEMENT PROGRAM PART

To compute the forces and displacements of a plane or a space truss, the most convenient way to use finite elements. We've built a finite element subprogram based on the matrix displacement method. The present method is usable only for pin-jointed trusses, loaded at their joints. The element of these trusses are called rods and they possess only axial stiffness. The structures can be statically determined or statically indeterminate and they can composed of members with different cross-section and elastic moduli. The Choleski's method is used for the decomposition, which was found to be favourable for solution by computer.

Data containing the coordinates of the nodes, bar-ends numbering, cross sectional areas, forces at nodes (it is possible to give uniformly or linearly distributed loads), suppressed displacements as usual at every FEM code. The Young module can be different for every bar. Data are saved in a file. So the FEM part is general in the sense, that any plane or space truss problem can be solved running it.

THE OPTIMIZATION PROCEDURE

There are several optimization techniques available for nonlinear optimization. We've used two different direct search techniques, the Complex method of Box and the Hillclimb method of Rosenbrock. Both techniques solve the following single objective optimization problem

the objective function	$y = f(x_1, x_2, \ldots, x_n)$ to be minimized	(1)
the unknown variables	$x_1, x_2, \ldots, x_n$	
the nonlinear constraints	$x^L_i \le x_i \le x^U_i$ $\quad i = 1,2,\ldots,m$	

where x^L_i and x^U_i are the lower and upper limits for the constraints.

The Complex method starts generating a so called Complex from the upper and lower limits.

$x_{ij} = x^L_i + r_{ij} (x^U_i - x^L_i)$, where random numbers are $0 \le r_{ij} \le 1$ (2)

The geometrical movements at the sets of points resulted by transferring the worst point (where the function value is the largest) to a new one through the centroid of the sets. No derivatives are required. These movements are reflection and halving to the centroid. In details the procedure can be found in [2] with some extension such as finding discrete results. The procedure is stopped by a convergence criterion, where difference between the largest and smallest function values in the sets of points should be less than a given value.

The Hillclimb procedure the method of rotating coordinates can be considered as a further development of Hooke and Jeeves method. At this procedure the coordinate system is rotated in each stage of minimization in such a manner that the first axis is oriented 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. A screen for runing the method can be seen in Fig.2. Boundary zones are established to brake the quick procedure near the boundaries by modifying the objective function

$$f^{new} = f^{old} - (f^{old} - f^*) (3\lambda - 4\lambda^2 + \lambda^3), \qquad (3)$$

where λ = distance into boundary zone / width of boundary zone

If there is a function improvement in a direction, than the program increases the step length, otherwise decreases that one. The convergence criteria, which stops the procedure contains the difference of two objective function values in two succession steps, which should be less than a given value. In details the procedure can be found in [3].

Both optimization techniques are general in the sence that they can solve the problems formed in (1).

ANALYSIS OF BELT-CONVEYOR BRIDGE STRUCTURE

This kind of bridge can be compute as a plane or a space truss structure (Fig.1.).

The plane structure contains three different members, the chord, the diagonal and the column. These are rectangular thin-walled members. The uniformly distributed loads are reduced to the nodes as concentrated forces. The constraints are as follows

1., - 6., size constraints

1.,	$x[1] = b_0$	width of the chord
2.,	$x[2] = t_0$	thickness of the chord
3.,	$x[3] = b_1$	width of the diagonal
4.,	$x[4] = t_1$	thickness of the diagonal
5.,	$x[5] = b_2$	width of the column
6.,	$x[6] = t_2$	thickness of the column

7., - 15., geometric constraints

	limits
ratio of width of different members	
7., $x[7] = b_1/b_0$	$0.5. \le x[7] \le 1.0$
8., $x[8] = b_2/b_0$	$0.5 \le x[8] \le 1.0$
9., $x[9] = b_1/b_2$	$1.0 \le x[9] \le 2.0$
limit slendernesses at different members	
10., $x[10] = b_0/t_0$	$15 \le x[10] \le 40$
11., $x[11] = b_1/t_1$	$15.. \le x[11] \le 35$
12., $x[12] = b_2/t_2$	$15 \le x[12] \le 32$
angle between column and diagonal	
13., $x[13] = \sin \Theta$	$0 \le x[13] \le 1.0$
overlapping	
14., $x[14] = \frac{p}{q} = 0.5 - \frac{2e + b_0}{2 * b_1} \cos\Theta + \frac{b_2 * \sin\Theta}{2 * b_1}$	$0.5 \le x[14] \le 0.8$
eccentricity	
15., $x[15] = 0.45*b_0$	$-0.55*b_0 \le x[15] \le 0.25*b_0$

16., - 18., stress constraints

16., $x[16] = A_0 = 3.72*b_0*t_0$ $\qquad A_0 \ge \frac{F_c}{\sigma_{adm}}, \ \sigma_{adm} = 160$ [MPa]

17., and 18., contain A_1 and A_2 instead of A_0

19., - 20., global buckling of members

$N \leq \kappa * N_{pl}$

where N is the compression force,

κ is the reduction factor,

$N_{pl} = A * R_y$ is the plastic force,

R_y is the yield stress.

$$\kappa = \frac{N_{cr}}{N_{pl}} = \frac{1}{2\lambda^2}(\psi - \sqrt{\psi^2 - 4\lambda^2}), \qquad \psi = 1 + \alpha(\lambda - 0.2) + \lambda^2$$

$\alpha = 0.206$ according to Eurocode 3.

for the compression force at the chord

19., x[19] = N $\qquad$ x[19] $\geq 1.5\ F_{chord}$

for the compression force at the column

20., x[20] = N $\qquad$ x[20] $\geq 1.5\ F_{column}$

<u>*21., - 22.,constraints on fatigue of weldments*</u>

fatigue of weldment at column - chord connection

21., x[21] = $F_{column}/(4*a_{w2}*b_2)$ $\qquad$ x[21] $\geq$ -160 [MPa]

where effective weldment size is $a_{w2} = t_2$.

fatigue of weldment at diagonal - chord connection

22., x[22] = $\sqrt{\sigma^2 + 2(\tau_p{}^2 + \tau_o{}^2)}$ $\qquad$ x[22] $\leq$ 180 [MPa]

where $\tau_p = \dfrac{F_{diag}\cos\theta\sin\theta}{2a_{w1}b_1}$, $\qquad a_{w1} = t_1$

$$\sigma_o = \tau_o = \frac{F_{diag}\sin^2\theta}{2\sqrt{2}a_{w1}b_1(1+\sin\theta)}$$

punching shear of diagonals, the critical force at the chords N_{cr}

23., x[23] = $N_{cr} = R_y * t_1(2h_1 - 4t_1 + b_e + b_{eu})$ $\qquad$ x[23] $\geq 1.5\ F_{diag}$

where $b_e = \dfrac{10}{\frac{b_0}{t_0}}\dfrac{t_0}{t_1}b_1$ $\qquad b_{eu} = \dfrac{10}{\frac{b_1}{t_1}}\dfrac{t_1}{t_2}b_1$

OPTIMIZATION

We've made a size optimization, where the number of unknowns are 6. The 23 nonlinear constraints are described in the previous chapter.

The objective function is the volume of the structures.

$$V = \sum_i A_i * L_i$$

where A_i and L_i are the cross section areas and length of the members

The optimization is made by connected the finite element program to the optimization one. Both the Complex and the Hillclimb methods were used. The discrete member sizes came from DIN standard [5].

The programs are written in *Borland C language* and run on 486 PC.

The span length is 25 m, the truss height is 2.2 m, the nodal loads are 12.5 KN. The results can be seen in Fig. 3. by the Complex method. Fig. 4.,5. show the survey of fulfilling the constraints. Fig. 6. shows a node after optimization.

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ACKNOWLEDGEMENT

The present work was supported by the Hungarian Fund for Scientific Research Grants OTKA No. T-4407.

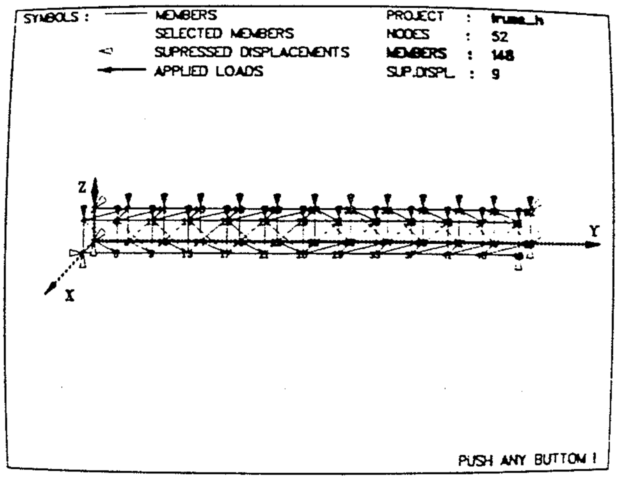


Fig. 1.

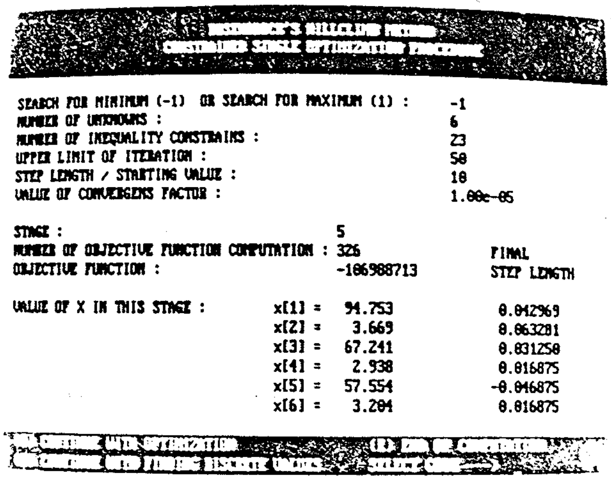


Fig. 2.

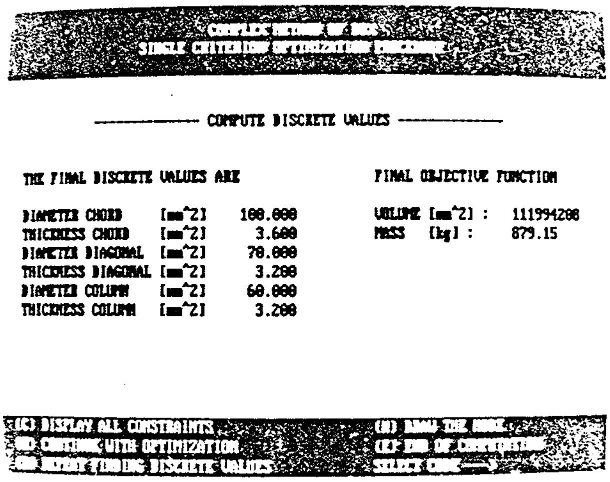
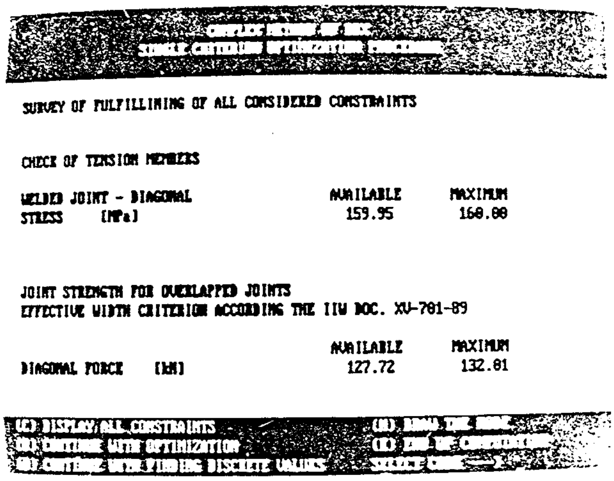


Fig. 3.



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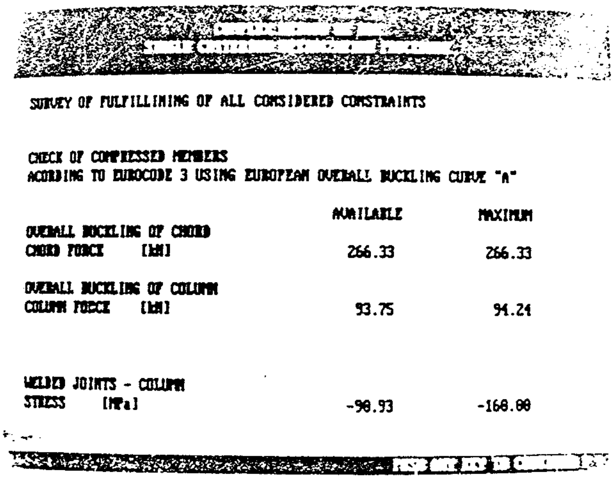

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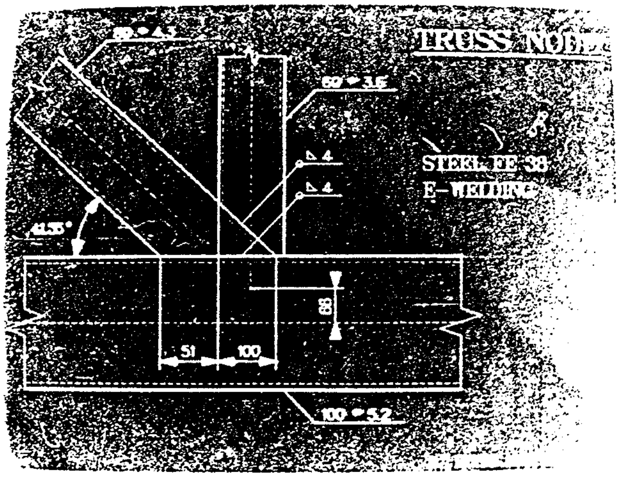

Fig. 6.