SCIENTIFIC SOCIETY
OF MECHANICAL ENGINEERS

INTERNATIONAL FEDERATION
OF INFORMATION PROCESSING
WORKING GROUP 5.7

APMS - COMPCONTROL 85

Session 2

Preprint
Volume III

Budapest, August 27 — August 30, 1985

OMIKK TECHNOINFORM
Budapest 1985

COMPUTERIZED OPTIMUM DESIGN OF ECONOMIC SERIES OF WELDED PROFILES FOR LOAD-CARRYING STRUCTURES

Prof.Dr.techn.József FARKAS,DrSc.[x], Dr.techn.Károly JÁRMAI[x]
Dr.techn.László SZABÓ[xx] and Ferenc SZABÓ, Mech.Eng.[x]

[x]Technical University for Heavy Industry, Miskolc

[xx]Steel Manufacture Co-operative, Miskolc

ABSTRACT

The main aims and phases of economic design of welded profiles are summarized. The economy of optimal sections is illustrated by a numerical example.
The main optimum design characteristics of following structures are given: centrally and eccentrically compressed steel members of square hollow section, welded I-sections subjected to bending and compression, welded box sections subjected to bending and shear, longitudinally stiffened box sections subjected to various loadings.

Economic welded profiles may result in significant savings in mass, cost and energy. Series of economic welded profiles can be computed by using optimum design techniques. In the optimum design procedure an optimum solution should be searched which minimizes the objective /cost or mass/ function and satisfies the design constraints.

The optimum design procedure /structural synthesis/ consists of the following three main phases: /1/ Preparation: selection of materials, profiles, type of structure, production technology; /2/ Mathematical minimization of the objective function with fulfilment of the design constraints; /3/ Evaluation: design aids, series of optimal profiles, comparative studies, rules of economic design.

The main types of structures are as follows: centrally compressed struts, eccentrically compressed beam-columns, planar and spatial trusses, statically determinate beams subjected to bending and shear, statically indeterminate continuous girders and frames, stiffened, cellular or sandwich plates and shells, prestressed, pneumatic and cable structures.

The following types of profiles may be used: rolled, cold-formed, welded open and closed thin-walled sections, circular or rectangular hollow sections, large welded I- and box sections stiffened with longitudinal and vertical ribs and diaphragms, extruded aluminium profiles.

Selection of materials: weldable structural steels of higher tensile strength, aluminium-alloys, composites /fibre reinforced plastics/ can be used in modern structures.

Metal structures play an important role in different industries. Some important applications are as follows: cranes, ships, vehicles, storage tanks and rocks, silos, pressure vessels, pipelines, belt conveyor bridges, machine tool structures /e.g. press frames, manipulators, mounting desks/, industrial buildings, towers, etc.

There are many mathematical function-minimization methods. At the Department of Materials Handling Equipments of the Techn. Univ. Miskolc we have elaborated computer programs for some mathematical programming methods, e.g. the combinatorial discrete backtrack method, the Box- and Rosenbrock-method, the dynamic programming method. Most of optimal series were computed by using backtrack method on a CDC 3300 computer in Fortran. Since 1983 we have used also personal computers Commodore VC 64 in Basic.

Discrete methods are important for the optimum design of plated steel structures, because designers should apply the fabricated series of profiles or plate thicknesses.

The main aims of economic design are as follows:

/1/ to compute optimal series of profiles which may serve as design aids for complex structures;

/2/ to reduce the mass and cost by using higher strength steels instead of steel Fe 360 of yield stress 235 MPa;

/3/ to use more detailed and realistic cost functions as objective functions.

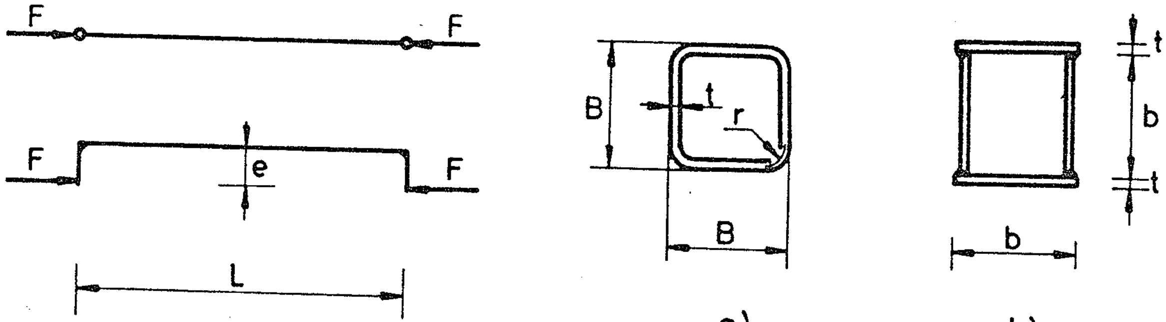
In order to illustrate the mass savings which may be achieved by optimal series, consider a simple welded I-beam subjected predominantly to bending. The required section modulus is $W = 4,5.10^6$ mm^3. According to the Hungarian Standard MSZ 323-79 for welded I-beams the suitable section has the following dimensions in mm: web 800.10, flanges 240.20; cross-sectional area $A = 17200$ mm^2, section modulus $W = 4,566.10^6$ mm^3. By using formulae of optimum design [3, 4] , with a limiting slenderness ratio for web $1/\beta = 145$ and flange $1/\delta = 30$, the optimum height of web is $h_{opt} = \sqrt[3]{1,5W/\beta} = 993$, rounded 1000 mm. The web thickness is $t_w = \beta h = 7$ mm, and the dimensions of flanges are 280.12 mm. The cross-sectional area is $A_{min} = 13720$ mm^2. Thus, by using the optimum section, 25% mass savings may be achieved. The optimal section has two more advantages: /1/ the web thickness is smaller, so smaller longitudinal fillet welds are needed, /2/ the moment of inertia is 20% greater, so the deformations from bending will be smaller.

The use of higher strength steels may result in significant mass and cost savings. In some cases, when displacement or fatigue constraints are active, the application of higher strength steels is uneconomical. Thus, detailed research should be performed for each case to predict the attainable savings in mass or cost.

The main parts of costs are the material and production costs. The minimum mass design does not take into account the production costs. The difference between the structures designed for minimum mass or cost, respectively, may be significant. In the case of welded structures, welding costs may affect the total cost /e.g. stiffened plates/. Thus, the welding costs should be considered in economic design. This is more difficult than the minimum mass design, because the welding costs have many components, vary in time and depend on many factors.

In the following the main cases studied by our research group are described by charts containing the most important data.

1. Optimal series of square hollow sections for centrally compressed struts and eccentrically compressed beam-columns



a) b)

Types of sections: /a/ cold-finished, according to ISO/DIS 4019.2 /1979/, r = 2t
/b/ welded

Data: force F, length L, eccentricity e
e = 0,25b, 0,50b, 0,75b, b
material: structural steel of various yield stress /235, 355, 450, 690 MPa/

Unknown dimensions to be optimized: /a/ B, t; /b/ b, t

Objective function: cross-sectional area

Design constraints: global and local buckling

Design method: developed at Univ. of Liège

Mathematical minimization method: backtrack

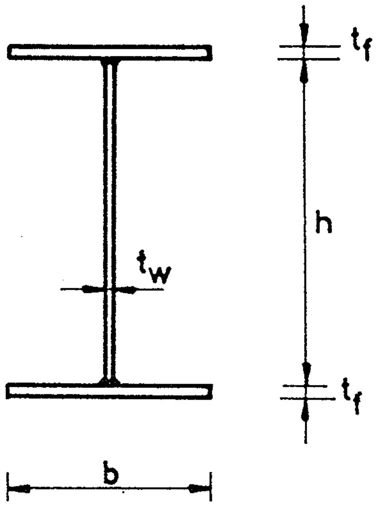
Computer: CDC 3300

Language: Fortran

Application: minimum mass design of trusses in the case of stress constraints

References: [1], [2], [3], [4], [5], [6]

2. Optimal series of welded I-sections subjected to bending and compression



Data: bending moment M

compressive force N

$$m = \frac{100\ M}{R_u\ h_o^3}$$

$$n = \frac{N\ h}{2\ M}$$

limiting stress

R_u = 200 MPa

h_o = 1000 mm

Material: steel of yield stress 235 MPa

Unknown dimensions to be optimized: h, t_w, b, t_f

Objective function: cross-sectional area

Design constraints: /1/ stress $\sigma_N + \sigma_M \leq R_u$

/2/ web buckling

$$\frac{h}{t_w} \leq 145 \sqrt[4]{\frac{(1 + \sigma_N/\sigma_M)^2}{1 + 173\,(\sigma_N/\sigma_M)^2}}$$

/3/ flange buckling $b/t_f \leq 30$

$$\sigma_N = N/A; \quad \sigma_M = M/W_x; \quad A = ht_w + 2bt_f; \quad A_f = bt_f\ ;$$

$$A_w = ht_w; \quad W_x = h(A_f + A_w/6)$$

Mathematical method: backtrack

Computer: CDC 3300

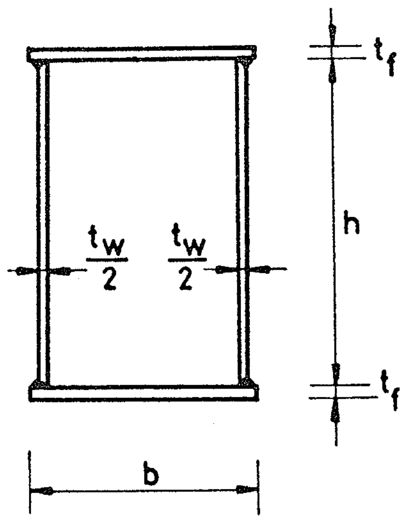
Language: Fortran

Results: tables of optimal dimensions for some given values of m and n

Application: minimum mass design of frames with stress constraints

References: [1], [3], [4]

3. Optimal series of welded box sections subjected to bending and shear



Data: bending moment M

shear force Q

$$m = \frac{100\ M}{R_u\ h_o^3}$$

$$q = \frac{Q\ h_o}{2M}$$

Limiting stress

R_u = 200 MPa

h_o = 1000 mm

Material: steel of yield stress 235 MPa

Unknown dimensions to be optimized: h, $t_w/2$, b, t_f

Objective function: cross-sectional area

Design constraints: /1/ stress $\sqrt{\sigma_M^2 + 3\tau^2} \leq R_u$

/2/ web buckling

$$\frac{2h}{t_w} \leq 145 \sqrt[4]{\frac{1 + 3(\tau/\sigma_M)^2}{1 + 20(\tau/\sigma_M)^2}}$$

/3/ flange buckling $b/t_f \leq 30$

/4/ web thickness limitation $t_w/2 \geq 3$ mm

/5/ welding technology $t_f \geq 0{,}7 t_w/2$

$$\sigma_M = \frac{M}{W_x} ; \quad \tau = \frac{Q}{h t_w} ; \quad W_x = \left[\frac{h^3 t_w}{12} + \frac{b t_f}{2}(h + t_f)^2 \right] \frac{1}{\frac{h}{2} + t_f}$$

Mathematical method: backtrack

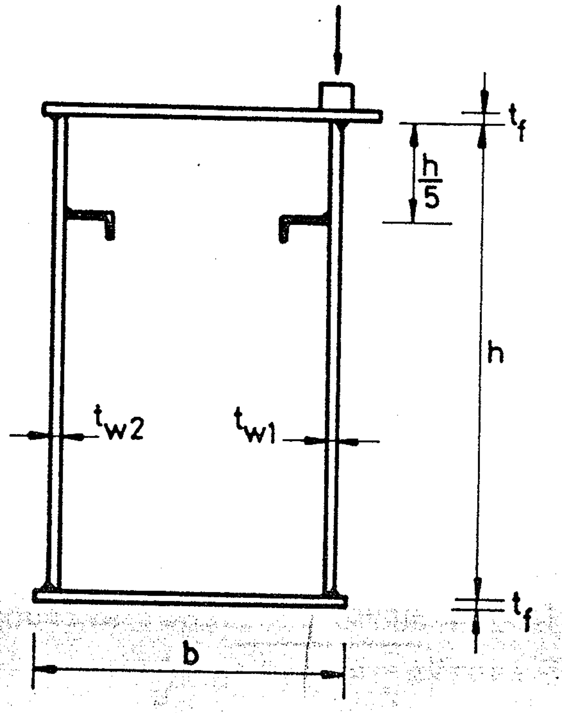
Computer: CDC 3300, language: Fortran

Results: tables of optimal dimensions for some given values of m and q

Application: minimum mass design of statically determinate and indeterminate continuous girders

References: [1], [3], [4]

4. Optimal series of welded, longitudinally stiffened box sections subjected to biaxial bending and transverse wheel load



Data: bending moments M_x and M_y transverse wheel load

References: [1], [7]

Material: steels of yield stress R_y = 235 and 355 MPa
hybrid structure: webs of R_y = 235, flanges of R_y = 355 MPa

Unknown dimensions to be optimized: h, t_{w1}, t_{w2}, b, t_f

Objective function: cross-sectional area, neglecting the stiffeners and the rail

Design constraints: /1/ static stress
/2/ fatigue
/3/ local buckling of webs
/4/ local buckling of flange

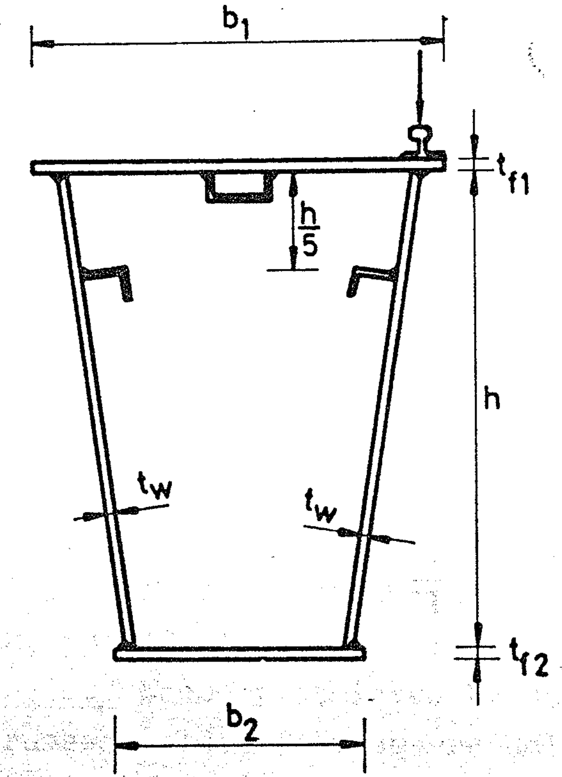
Design method: according to BS 2573 /1983/ and BS 5400: Part 3: 1982

Mathematical method: backtrack

Computer: CDC 3300, language: Fortran

Application: minimum mass design of overhead travelling cranes with two main girders of box section

5. Optimal series of welded, longitudinally stiffened trapezoidal box sections subjected to biaxial bending and transverse wheel load



Data: bending moments M_x and M_y transverse wheel load

References: [9], [10]

Material: steel of yield stress 235 and 355 MPa

Unknown dimensions to be optimized: h, t_w, b_1, b_2, t_{f1}, t_{f2}

Objective function: cross-sectional area neglecting the stiffeners and the rail

Design constraints: /1/ static stress
/2/ fatigue
/3/ local buckling of webs
/4/ local buckling of flange

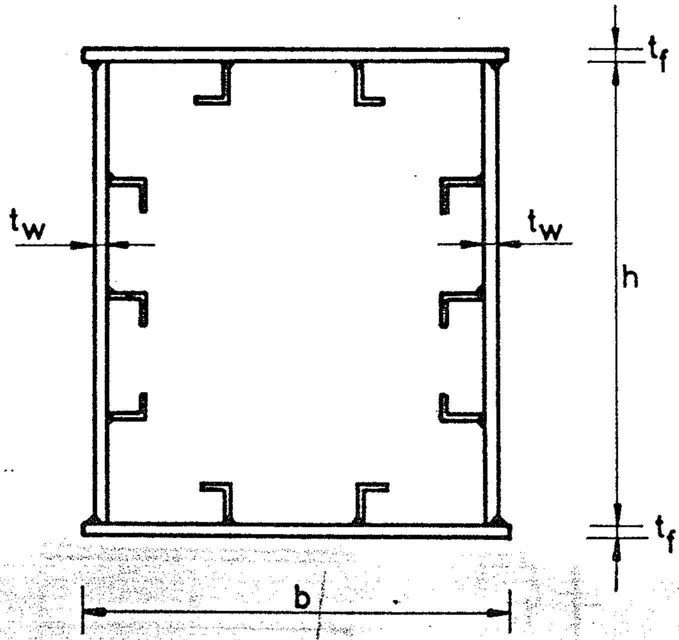
Design method: according to BS 2573 /1983/ and BS 5400: Part 3 /1982/

Mathematical method: Rosenbrock /constrained/

Computer: Commodore VC 64, language: Basic

Application: minimum mass design of overhead travelling cranes with one main girder of box section

6. Optimum design of welded, longitudinally stiffened box sections subjected to biaxial bending, compression, shear and torsion



Data: bending moments
compressive force
shear force
torque

Material: steel of yield stress 235 MPa

Unknown dimensions to be optimized: h, t_w, b, t_f and stiffener dimensions

Objective function: cross-sectional area including stiffeners

Design constraints: /1/ stress
/2/ local buckling of plates
/3/ buckling of stiffeners
/4/ upper and lower size limits

Design method: according to DIN 4114 and DASt Richtlinie 012

Mathematical method: Rosenbrock /constrained/

Computer: Commodore VC 64, language: Basic

Application: optimum design of main girders of crane jibs for floating and portal cranes

Reference: [10]

REFERENCES

1. Farkas,J., Szabó,L.: Optimum design of welded I-beams by means of backtrack programming /in Hungarian/. COMPCONTROL '79. Sopron, 1979. Budapest, OMKDK-Technoinform, 1979. pp.475-480.
2. Farkas,J.: Economy of the application of higher strength steels in compression members of welded square box cross-section and in hybrid I-beams /in Hungarian/. Gép 35/1983/ pp.453-459.
3. Farkas,J.: Metal structures /textbook in Hungarian/, 2nd. ed. Budapest, Tankönyvkiadó, 1983.
4. Farkas,J.: Optimum design of metal structures. Budapest, Akadémiai Kiadó - Chichester, Ellis Horwood, Ltd. 1984.
5. Farkas,J.: Optimum square hollow sections for centrally and eccentrically compressed steel members. Proc. 2nd Coll. on Stability of Metal Structures, Paris, 1983. Final Report, CTICM, pp. 121-125.
6. Farkas,J.: Economy achieved by using higher strength steels in trusses welded from square hollow sections. Welding of Tubular Structures. Proc. 2nd Int. Conf. Boston, USA, 1984. Oxford, etc. Pergamon Press, 1984. pp.137-144.
7. Farkas,J.: Application of higher strength steels in overhead travelling cranes with two main girders of box cross-section /in Hungarian/. Kolloquium über konstruktionelle Entwicklung von Materialtransport und Baumaschinen, Budapest, 1984. GTE, pp.265-276.
8. Jármai,K.: Optimal design of welded frames by Complex programming method. Publ.Techn.Univ.Heavy Ind. Miskolc Ser.C. Machinery 37/1982/ pp.79-95.
9. Jármai,K.: Optimum design of overhead travelling cranes with one main girder of box cross-section by a personal computer /in Hungarian/. Kolloquium über konstruktionelle Entwicklung von Materialtransport und Baumaschinen, Budapest, 1984. GTE, pp.253-264.
10. Kuester,J.L., Mize,J.H.: Optimization techniques with Fortran. New York, McGraw Hill, 1973.