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THE MOST IMPORTANT RESEARCH RESULTS AND NEW RESEARCH PROJECTS IN THE FIELD OF METAL STRUCTURES

Károly JÁRMAI and József FARKAS

Summary

Teaching of metal structures and related topics have a long term history at the University of Miskolc. Hundreds of students could get familiar of this topic. The teaching material was continuously developed, installing new research results from the literature or of our own. Eight books and book chapters were published, most in English, several students aids, papers in international journals, papers in conference proceedings. The area has a strong past, an active present and a promising future.

1. Teaching activity

Teaching of subject Metal Structures started in 1954 at the Technical University for Heavy Industry. Prof. Farkas started his carrier at the university in 1950. First he worked at Department of Mechanics at the Faculty of Mechanical Engineering, than in 1959 he moved to the Department of Materials Handling Equipment.

Courses on Metal Structures have been thought between 1955-66 during 2 semesters at the Mechanical Engineering Faculty and at the Mining Faculty on the Mining Mechanics speciality. From 1966 one-semester courses have been held for the specialities of Chemical Engineering, Applied Mechanics, Machine Tool Design, Welding Technology, Technical Translator, Material Handling Equipment. The courses of Metal Structures and Welded Structures have been continuously developed. Copybooks, books of professional welding engineer courses and university textbook of Metal Structures (in 1974 and 1983) have been published [1]. In the modular education system the block of courses "Design of Engineering Structures" started in 1994. The courses are as follows: Design of connections, Analysis of Engineering Structures,

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Optimization of Engineering Structures.

From 1961, in the frame of Professional Welding Engineer teaching program the course of Welded Structures is going on. Nowadays another course "CAD in Welding" was added to the Professional European Welding Engineer teaching program.

Teaching is going for foreign students in English. The English language education was supported by the book of Prof. Farkas entitled: Optimum design of metal structures, published by Ellis Horwood in the UK in 1984 [2]. In 1997, Profs. Farkas and Jármai published a new book entitled Analysis and design of metal structures by Balkema Publishers in The Netherlands [5].

A number of diploma works was made in this topic in the last decades. During the last three years there were 24 diploma works and 4 scientific student works. PhD training started at the faculty in 1992. There were 9 full time PhD and 3 part time PhD students on these subjects.

Many scientific dissertations for titles of university doctor, candidate of science and two theses for doctor of science have been defended in this group.

2. Scientific activity

Main research fields are as follows: calculation of welding residual stresses and distortions, local and overall stability, design of stiffened plates, sandwich structures, vibration damping, tubular structures, frame structures, press frames, structural optimization algorithms, single and multiobjective optimization, cost calculations, expert systems, neural networks. The published books and conference proceedings are

Prof. Farkas' book entitled "*Optimum design of metal structures*", published in 1984 got the honour of the Hungarian Academy of Science. The newest results were published in the book "*Analysis and optimum design of metal structures*" written with Prof. Jármai and published by Balkema Publisher in 1997.

3. International relations

Profs. Farkas and Jármai are Hungarian delegates of the International Institute of Welding (IIW), they take part in the activity of commissions XV and XIII respectively. They are active members of subcommissions XV-E (tubular structures), XV-F (interaction of design and fabrication), joint working groups X-XV "Residual stresses and distortion prevention" and "Brittle fracture of welded moment connections in seismically affected steel structures". They are founding members of the International Society of Structural and Multidisciplinary Optimization (ISSMO). In the journals of IIW and ISSMO (Welding in the World and Structural Optimization) they publish regularly. The International Symposia on Tubular Structures were held in the following cities: 1984 Boston, 1989 Lappeenranta, 1991 Delft, 1993 Nottingham, 1994 Melbourne, 1996 Miskolc (this symposium was organized by the University of Miskolc and the proceedings were published by Balkema Publisher in The Netherlands) [4], 1998 Singapore.

The ISSMO World Congresses were held in the following cities: 1993 Rio de Janeiro, 1995 Goslar, Germany, 1997 Zakopane, 1999 Buffalo, USA. Miskolc would like to organize the next congress.

Papers, which were presented on these conferences have the main topic on structural optimization, the way to design safe and economic structures. Comparison of different solutions is possible for optimized versions. The group has developed a cost function, which contains not only the material costs, but also welding, cutting, surface cleaning, painting, additional costs, etc. The constraints are also developed, taking into account the residual distortions, to increase the quality of fabrication. In Udine at the International Center for Mechanical Sciences (CISM) we have organized a course in 1998 entitled "*Mechanics and design of tubular structures*". These lectures were published in a volume by Springer Verlag in 1999 [7].

International co-operation is going on with the University of Kosice, Departments of Materials Handling, Steel and timber structures and Technical mechanics.

European projects, like Tempus JEP 0438 made it possible to have a joint curriculum development on Design of engineering structures under the leadership of Prof. Guerlement, from Mons, Belgium, in 1991-1992. In the frame of Tempus we have written a number of student aids in English.

There is a running project with the Osaka University on Design of welded structures between 1998-2000.

We have published a number of technical papers with professors of other universities, like Prof. Horikawa, Osaka, Prof. Ohkubo, Matsuyama, Prof. Petershagen, Hamburg, Prof. Choo, Singapore, Prof. Haagensen, Trondheim.

We are applying for the cooperation with the University of Pretoria in South Africa and University of Coimbra in Portugal.

4. Running research projects

OTKA 4497, 1992-95, OTKA 19003, 1996-99, project leader is Prof. Farkas. Topic is optimization of steel and composite structures.

OTKA 4407, 1992-96, OTKA 22846, 1997-2000, project leader is Prof. Jármai. Topic is the optimization and application of expert systems in the design of engineering structures.

OTKA F 29231,1999-2002, project leader is György Kovács PhD student. Topic is the application of ALGOR finite element program in structural analysis.

Prof. Farkas is the program leader for the university PhD program on Design of Engineering Structures.

Prof. Jármai is the program leader for the OMFB joint research co-operation with the Osaka University between 1998-2000.

Profs. Farkas and Jármai took part in the evaluation of applications at the Hungarian Academy of Science, at the Ministry of Education, National Science Foundation and were opponents at PhD and doctoral theses. They are members of several committees of the Academic Committee of Miskolc.

5. Industrial consultations activity

Design of welded underground fluid storage tanks (ÁTI, ÉLITI), evaluation of fabrication of storage tanks (BVG), design of a welded casting ladle (OKÜ), evaluation of design of aluminium-corrugated plate bin silos and frame structure (MEZŐGÉP), design of lightweight industrial frames (Fémmunkás), evaluation of the construction of pressure vessels support system (BVK), evaluation of crane designs (Ganz Darugyár), design of punch presses for the shoe industry (Könnyűipari Gépgyár, KAEV).

6. Some new research results from the last years

6.1 Optimum cost design of welded box beams with longitudinal stiffeners using advanced backtrack method

The use of longitudinal stiffeners in box girders loaded in bending, results in savings in weight and cost. To study these savings, the optimized box beams without and with stiffeners are compared to each other. The minimum cross-sectional area design can be solved analytically. A cost function is defined containing material and fabrication (welding) costs. This function is nonlinear in the structural dimensions to be optimized, therefore an advanced backtrack method is worked out and applied [8].

The original version of backtrack was modified by rebuilding the algorithm so, that it is independent from the number of variables, since in the original algorithm all variable value is calculated by the halving procedure, except the last one. Another development is, that the Van Wijngaarden-Dekker-Brent method was built into the algorithm to calculate the last variable value from the cost function. In case of mass minimization this calculation is relatively easy, because of the linearity, but introducing a nonlinear cost function the analytical solution is in most cases impossible. This method

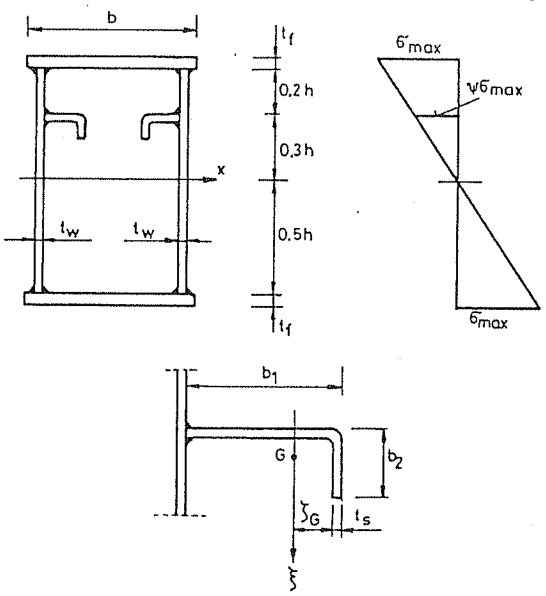


Figure 1. Cross section of stiffened box girder

combines root bracketing, bisection and inverse quadratic interpolation to converge from the neighbourhood of a zero crossing. While the false position and secant methods assume approximately linear behaviour between two prior root estimates, inverse quadratic interpolation uses three prior points to fit an inverse quadratic function. This method combines the sureness of bisection with the speed of a high-order method when appropriate. This calculation is built into the computer code with subroutine.

Comparisons of the optimized cross-sectional areas and costs of box beams without and with longitudinal stiffeners placed in a distance of 1/5 web height show that the use of stiffeners results in considerable savings. The minimum cross-sectional area design is solved analytically deriving closed formulae for the optimum beam dimensions. The cost function contains material and welding costs, considering also the welds necessary for transverse diaphragms. Since this cost function is nonlinear, a new version of backtrack discrete programming method is developed and used. This version contains a subroutine for the computation of the roots of a nonlinear function with one variable

6.2 Optimum design of welded stiffened plates loaded by hydrostatic normal pressure

The optimal positions of horizontal stiffeners are computed considering the condition that the base plate parts, having equal thicknesses and loaded by factored bending moments, should be stressed to yield strength. The trapezoidal stiffeners are designed for bending using the stress and local buckling constraints. The optimal number of stiffeners is determined on the basis of material and fabrication cost calculations. It is shown by a numerical example that the non-equidistant stiffener arrangement gives 18% weight and 12-14% cost savings compared to the equidistant one [9].

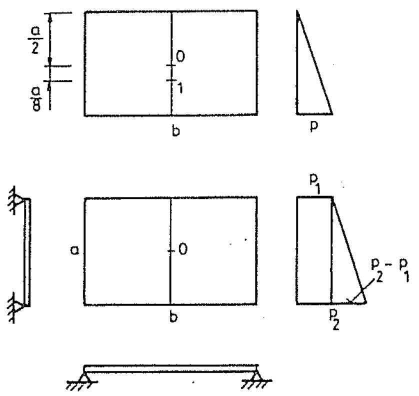


Figure 2. Points where the maximum bending moment arises

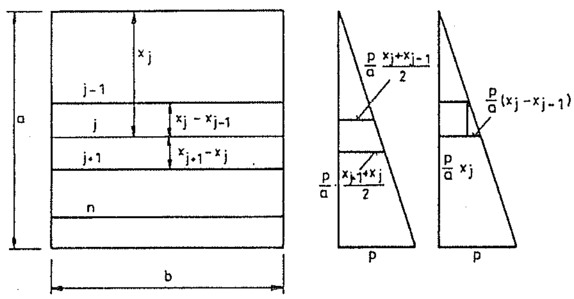
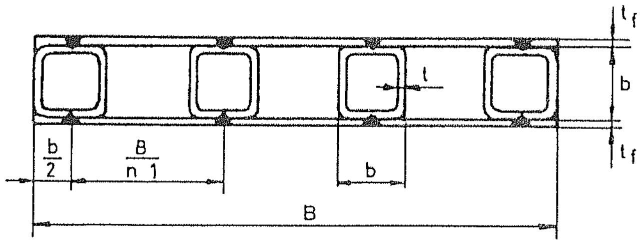


Figure 3. The distances of stiffeners and the pressures for the calculation of bending moments acting on stiffeners

The optimum horizontal stiffener positions can be calculated on the basis of the condition that each base plate part, having the same thickness and loaded by bending, should be stressed to yield strength. This non-equidistant stiffener distribution is more economic than the equidistant one. This economy can be verified by cost calculations. In the illustrative numerical example it is shown that the optimum number of stiffeners is 7 or 8 and the non-equidistant stiffener arrangement is 18% lighter and 12-14% cheaper than the equidistant one.

6.3 Optimum design of welded cellular plates for ship deck panels

The investigated cellular plates consist of two face sheets and some longitudinal ribs of square hollow section (SHS) welded between them using arc-spot welding technology. The cellular deck panels are subject to axial compression and a transverse load causing bending. In the optimization procedure the dimensions and number of longitudinal SHS ribs as well as the thickness of face sheets are sought which minimize the cost function and fulfil the design constraints. The width and length of the three-span panel are known. The cost function contains the material and fabrication cost. The



design constraints relate to the stress due to compression and bending and to the eigenfrequency of the structure [10].

Figure 4. Shipdeck panel with tubular stiffeners, connections are made made by arc-spotwelds

A computer program of Rosenbrock's Hillclimb mathematical programming method is used for optimization.

The optimum number of ribs is larger for minimum weight design (k_f/k_m = 0) i.e. n=8 for f_y = 235 and n = 6 for f_y = 355 MPa, than for minimum cost design (k_f/k_m = 1 or 2) i.e. n = 7 for f_y = 235 and n = 6 or 5 for f_y = 355 MPa. The optimum number of ribs depends on f_y. Cost savings of 14-18% can be achieved using steel of yield stress 355 instead of 235 MPa.

The cost difference between the best and worst solution for f_y = 235 MPa and k_f/k_m = 2 is 100(2747-1683)/1683 = 63%, which emphasizes the importance of structural optimization. Calculations show that the stability and stress constraints are in most cases active and the eigenfrequency constraint is passive.

6.4 Optimum design and comparison of hollow flange beams

A hollow flange beam (HFB) consists of a straight web and two hollow flanges. The shape of flanges can be triangular (TFB), circular (CFB) or square (SFB) one. To compare these structural versions with welded I-beams an optimization procedure is developed. The optimum cross-sectional dimensions are determined which minimize the cross-sectional area and fulfil the design constraints on stress due to bending and on local buckling of web and compression flange. The comparison shows that a HFB has smaller cross-sectional area (weight), larger moment of inertia (smaller deflection) and larger critical bending moment of lateral-torsional buckling [11].

The minimum cross-sectional area design of four welded beam types considering the maximum stress due to bending and the limiting local buckling slendernesses gives a basis of comparison relating to the beam weight, deflection and lateral-torsional buckling strength.

The cross-sectional area (weight) of HFB-s is smaller than that of I-beams. The moment of inertia about the major axis of HFB-s is larger, therefore the beam deflection is smaller than that of I-beams.

The lateral-torsional buckling factor in function of $\varphi = L/10h$ is larger for HFB-s than that for I-beams. These realistic comparisons give designers a basis for selection of suitable structural versions.

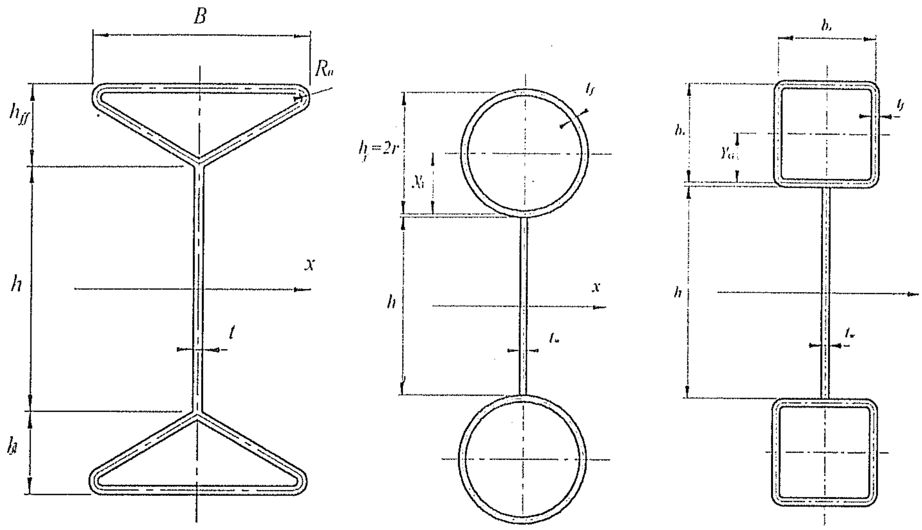


Figure 5. Dimensions of TFB, CFB and SFB

6.5 Optimum design of a statically indeterminate tubular truss

The minimum weight design of a two-span truss is treated. The truss is welded from square hollow section rods and the height at the middle support is linearly increased. The cross-sectional areas of all chords are the same and two different cross-sectional areas are considered for bracing, since the bracing forces near the middle support are higher than those in other parts. Thus, in the optimization procedure three cross-sectional areas and two factors for high are sought, which minimize the structural volume and fulfil the stress and buckling constraints. For the calculation of the overall buckling strength of compression members closed formulae are applied, which can be derived from the buckling curves of the Japanese Road Association. First the cross-sectional areas are calculated using an iterative process for constant height factors, then these factors are varied. Finally the strength of overlapped nodes are checked according to CIDECT design formulae. The illustrative numerical example shows that the optimum truss geometry depends on the number of different cross-sectional areas [12].

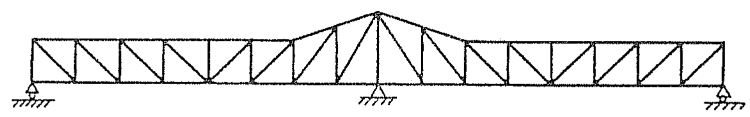


Figure 6. A two-span truss with increased height at the middle support

The evaluation of the results of the numerical example gives the following conclusions.

(a) designing the truss with three different cross-sectional areas, i.e. all chords with the same profile and bracing divided into two profile groups, the structure of increased height at the middle support gives the minimum structural weight, numerically $\Omega = 1.6$ and $\omega = 1.3$;

(b) designing the truss with three different profiles, for the optimum version of parallel chords is the solution of $\Omega = \omega = 1.2$;

(c) designing the truss with only two different profiles, i.e. one profile for all chords and other for all bracing rods, the solution of truss with parallel chords gives the minimum weight;

(d) from the above conclusions it follows that the optimum geometry of such trusses depends on the number of different profiles considered in the design of rods.

6.6 Expert systems and artificial neural networks in structural optimization

Artificial Intelligence (AI) techniques are the best utilized in identifying and evaluating design alternatives and relevant constraints while leaving the important design decisions to the human. Expert systems and artificial neural networks are used in structural optimization. We show the benefits of these systems in the optimum design of main girders of overhead travelling cranes and stiffened plates. At the example the double crane girders are welded and stiffened box ones, with one trolley on them. We have used the British Standard for the structural analysis [13].

The cost function contains the material and the fabrication costs (Fig. 7).

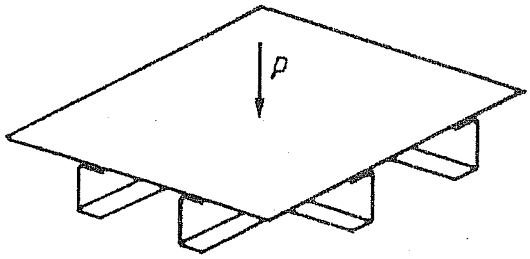


Figure 7. Stiffened plate with simply supported ends

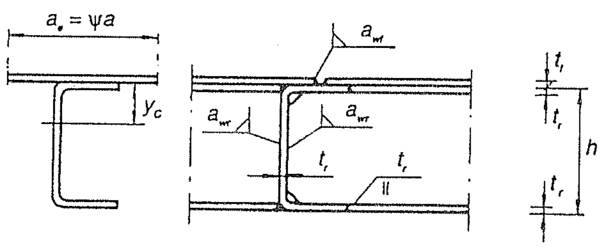


Figure 8. Stiffener of the plate

Application shows, that neural networks are useful in engineering calculations.

Using NeuNet, we can optimize, but we can be quite sure that neural networks will not replace conventional computers. Basic reasons preclude neurocomputers replacing conventional ones for most tasks. Conventional computers are now very inexpensive. They are extremely fast and accurate for executing mathematical subroutines, text processing, computer-aided design, data processing and transfer, and many other tasks. The best hope for the widespread use of artificial neural systems, or neurocomputing, is in computationally intensive areas that are not successfully attacked by conventional computers. It seems that the areas requiring human-like inference and perception of speech and vision are the most likely candidates for applications. If these succeed, there will be more applications in real-time control of complex systems and other applications that we cannot yet anticipate.

Neural networks are also expected to be widely applied in expert systems and in a variety of signal processors. At present, such systems are available as aids for medical diagnosis, financial services, stock price prediction, solar flare forecasting, radar pulse identification, and other applications. As most researchers agree, future artificial neural systems are not going to replace computational and artificial intelligence simulations on conventional computers either. Rather, they will offer a complementary technology. The ultimate goal may be to exploit both technologies under the same roof, while presenting a single, flexible interface to the user.

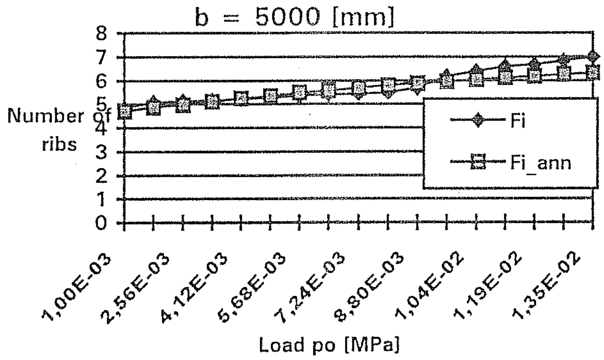


Figure 9. Number of ribs in the function of the load with optimization (Fi) and with the neural network (Fi_ann)

In the long term, we could expect that artificial neural systems will be used in applications involving vision, speech, decision-making, and reasoning. Also, neural networks may offer solutions for cases in which a processing algorithm or analytical solutions are hard to find, hidden, or nonexistent.

7. Other researches

In the last decade there were several projects, where we made joint researches with other colleagues at other departments or faculty, or with foreign professors. These topics are: to build fracture mechanics into optimization [14], energy optimization of sugar drying equipment [15], optimization of furnace wall structures [16], optimum design of bridge deck panels [17] and padeyes [18].

8. Further research plans

We would like to continue research on the following fields:

- tubular structures, especially considering fatigue and costs of nodes,
- stiffened plates, taking into account simultaneous bending and compression, or biaxial compression,

- wall structures of bunkers,
- optimization for post weld treatments,
- optimization of prestressed steel structures,
- frame structures, taking into account semirigid connections,
- optimum design of grillages,
- development of optimization techniques,
- application of expert systems in structural optimization,
- application of neural networks in structural optimization.

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