



DESIGN, FABRICATION AND ECONOMY OF WELDED STRUCTURES

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Károly Jármái • József Farkas

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Edited by

Dr. Károly Jármai

Professor of Mechanical Engineering
University of Miskolc, Hungary

Dr. József Farkas

Professor Emeritus of Metal Structures
University of Miskolc, Hungary



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1.2 Our Research Relating to the Minimum Cost Design of Welded Structures

Károly Jármái, József Farkas

University of Miskolc, H-3515 Miskolc, Hungary, altjar@uni-miskolc.hu

Abstract

The main components of our structural optimization system for economic design of welded structures are the design and fabrication constraints, the cost function as well as the efficient mathematical methods for constrained function minimization. This structural optimization system has been applied for stiffened plates and shells as well as for tubular structures. The aim is to give designers useful aspects for cost savings, since welding is an expensive joining technology. Using realistic numerical models, cost comparisons have been worked out for optimized plates stiffened in one or two directions, for cellular plates as well as for circular and conical shells stiffened by rings, stringers or orthogonally. The economic design has been worked out for tubular structures as follows: a triangular truss beam, a strengthened pipeline, tubular frames and a wind turbine tower of circular shell or truss structure.

Keywords: stiffened plates, stiffened cylindrical shells, tubular structures, minimum cost design, structural optimization

1 Introduction

Optimization means a search for better solutions, which better fulfil the requirements. For load-carrying engineering structures the main requirements are the safety, fitness for fabrication and economy. In our optimization system the safety and producibility are guaranteed by design and fabrication constraints and economy is achieved by minimization of a cost function. For the constrained function minimization efficient mathematical methods should be used.

It can be concluded that this structural synthesis has four main components as follows: design constraints, fabrication constraints, cost function and mathematical methods.

Design constraints relate to the maximum stresses, stability, fatigue, displacements and can be formulated according to rules of Eurocode 3 for steel structures (Eurocode 3 2002) and Eurocode 9 for aluminium ones (Eurocode 9 2002). In some cases, e.g. for stiffened shells Eurocode 3 does not give suitable rules, thus the Det Norske Veritas (DNV 2002) formulae are used.

In the calculation of structural stability the effect of initial imperfections and residual welding distortions should be taken into account. We have shown that, in the case of overall flexural buckling of a compressed strut the use of Euler formula can cause an unsafe design of about 30% error. It has been shown that in the flexural buckling of compressed struts the cross-sectional type has also an important effect, e.g. a circular hollow section is much more economic than an open angular profile (Farkas & Jármái 1997).

Fabrication constraints relate to the size limitations as well as to the residual welding deformations. The available profile selection should also be taken into account. We have worked out a suitable relative simple calculation method for the residual welding stresses and distortions on the basis of Okerblom's method (Farkas & Jármai 1998) and formulae are developed for the calculation of deformations caused by shrinkage of circumferential welds in circular cylindrical shells (Farkas 2002).

For the calculation of welding times for different weld types and welding technologies formulae have been worked out on the basis of the Pahl-Beelich method as well as using a COSTCOMP software (Farkas & Jármai 2003). The cost function is formulated according to the fabrication sequence. Some efficient mathematical methods have been adapted, developed and used such as SUMT, backtrack, Rosenbrock hillclimb and particle swarm optimization (PSO) algorithm. (Farkas & Jármai 1997, Farkas & Jármai 2003).

Our aim is to give designers useful aspects for cost savings, since the welding is an expensive joining technology. The most suitable structural versions are selected by cost comparisons of optimized solutions. Since only optimized versions can be compared realistically, the structural optimization is the best basis for cost savings. In the following this structural synthesis is systematically applied for three main structural types i.e. for stiffened plates, stiffened shells and tubular structures. In the case of stiffened structures the main question is: a thicker unstiffened or a thinner stiffened version is more economic? To answer this question a systematic research is necessary, since the economy depends on loads and type of stiffening.

2 Stiffened plates

In the case of stiffened plates an unstiffened plate has a very small bending stiffness, thus, the stiffened version is in all cases more economic than the unstiffened one. For stiffened plates some useful comparisons have been worked out. Figure 1 illustrates these cases.

A plate stiffened on one side and a cellular one are compared to each other in the case of longitudinal stiffeners and uniaxial compressive force and it is concluded that the cellular plate is more economic because of its larger torsional stiffness Figs. 1a and 1b) (Farkas & Jármai 2006).

It is also found that, in the case of uniaxial compression an orthogonally stiffened plate is more economic than a longitudinally stiffened one (Fig. 1c) (Farkas & Jármai 2007). A calculation method is worked out for the optimum design of an orthogonally stiffened plate loaded by bending (Fig. 1d) (Jármai et al 2006).

Special gridwork design has been applied to find the optimum solution of a stiffened plate supported at four corners (Fig. 1e) (Farkas et al. 2007).

For comparison the same problem has been solved for a cellular plate supported also at four corners (Fig. 1f). It has been found that the cellular plate is more economic than the stiffened one (Farkas & Jármai – to be published)..

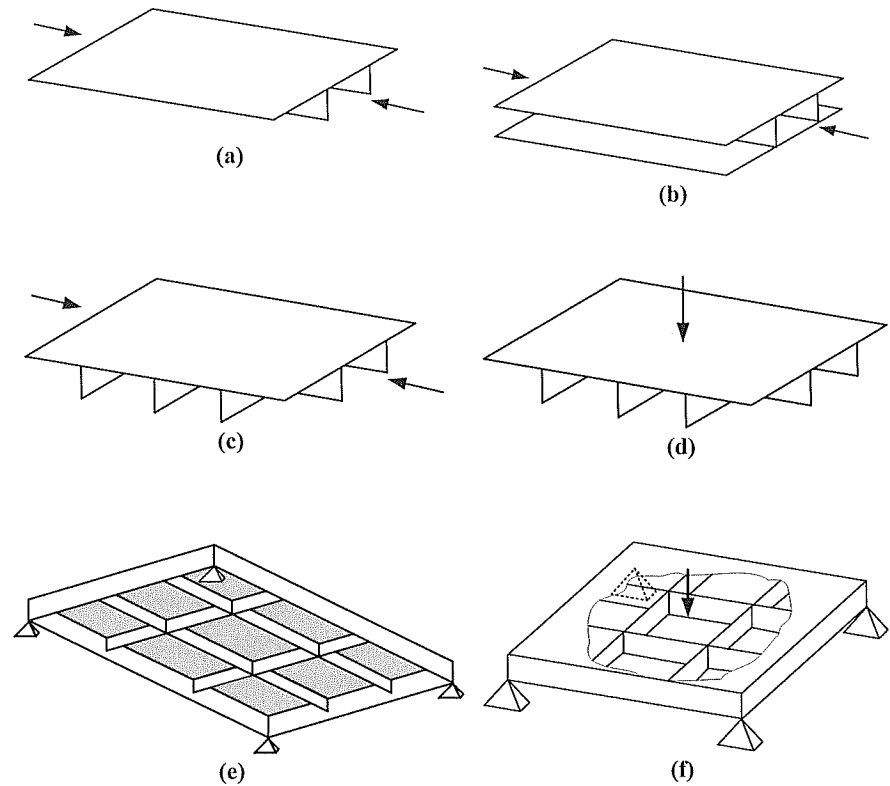


Figure 1. a) Longitudinally stiffened plate, b) longitudinally stiffened cellular plate, c) orthogonally stiffened plate, d) stiffened plate loaded by bending, e) stiffened plate supported at four corners, f) cellular plate supported at four corners

3 Stiffened circular cylindrical and conical shells

A ring-stiffened circular cylindrical shell is more economic than an unstiffened one in the case of external pressure, since these shells are very sensitive against buckling for this load (Fig.2a) (Farkas et al. 2002).

On the other hand, a cylindrical shell is very stiff against buckling for compressive load or bending, thus, the ring-stiffening cannot be economic (Fig.2b) (Farkas et al. 2004).

A stringer stiffening is economic only in that case, when a deflection constraint for the whole structure is active (Figs 2c and 2d) (Farkas & Jármai 2005a). For stiffening halved rolled I-section stringers should be used welded outside of the shell.

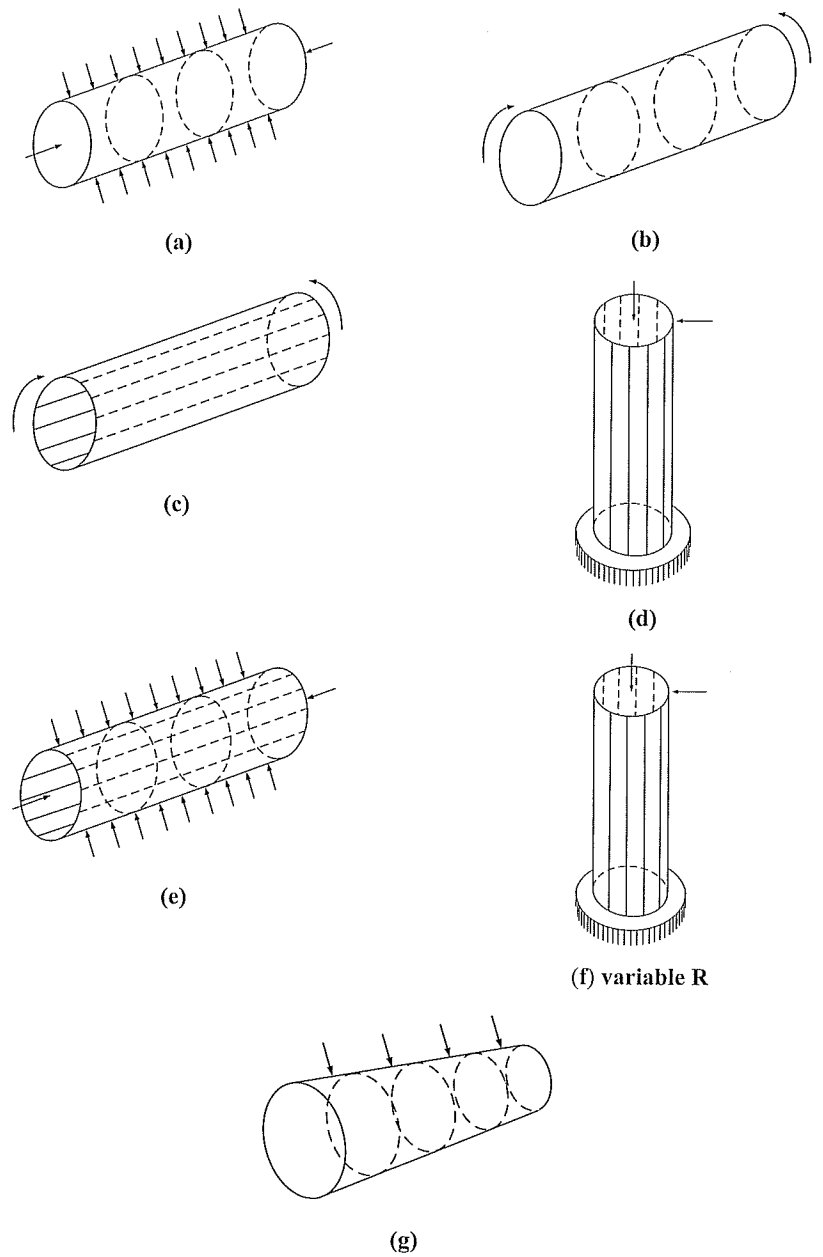


Figure 2. a) ring-stiffeners, external pressure, b) ring-stiffeners, bending, c) stringer stiffeners, bending, d) stringer stiffeners, bending, displacement constraint, e) orthogonal stiffening, external pressure and axial compression, f) radius also optimized, g) slightly conical shell, external pressure, ring-stiffeners

In the case of a column loaded by compression and bending, the stringer stiffening can be economic only when a displacement of the column top is restricted and the shell radius is kept constant (Fig.2d) (Farkas & Jármai 2005b). When the radius is also optimized, the stiffening cannot be economic (Fig.2f) (Farkas et al.2007).

In order to generalize the problem of stiffened shells the case of orthogonally stiffened shell is worked out for axial compression and external pressure (Fig.2e) (Jármai et al. 2006).

Similarly to a cylindrical shell, a slightly conical one can be economic with ring-stiffeners for external pressure (Fig.2g) (Farkas et al.2007).

4 Tubular structures

The height of a triangular tubular truss beam can be optimized, since, increasing it the chord forces decrease but the length of braces increases (Fig.3a) (Farkas & Jármai 2001).

Optimum dimensions of a welded tubular truss are determined, which strengthen a column-supported oil pipeline for a larger span length. The cost comparison shows that the cost of the strengthened pipe is much lower than that of the larger pipe without strengthening (Fig.3b) (Farkas & Jármai 2004).

A simple tubular frame supporting a pressure vessel is optimized for seismic loads (Fig.3c) (Farkas & Jármai 2006).

An earthquake-resistant design is worked out for a multi-storey frame with tubular columns, rolled I-beams and seismic resistant beam-to-column connections (Fig.3d) (Jármai et al. 2006).

A wind turbine tower is designed as a ring-stiffened cylindrical shell as well as a tubular truss structure (Figs 3e and 3f). The cost comparison of the two structural optimized versions show that the tubular truss version is much more cheap, than the shell structure (Farkas & Jármai 2006).

5 Conclusions

Our research is focused to the economy of welded structures. This problem needs a systematic research, since the economy depends on structural characteristics as follows: loads, type of structure, design and fabrication constraints, type of profiles, costs.

Our method is to work out numerical problems using realistic structural models and compare the costs of candidate versions. Since only optimized versions can be realistically compared to each other, the structural optimization system should be used. For this system we have developed calculation methods for residual welding distortions and for fabrication costs as well as adapted some efficient mathematical methods.

The investigated problems of stiffened plates and shells as well as tubular structures are briefly overviewed.

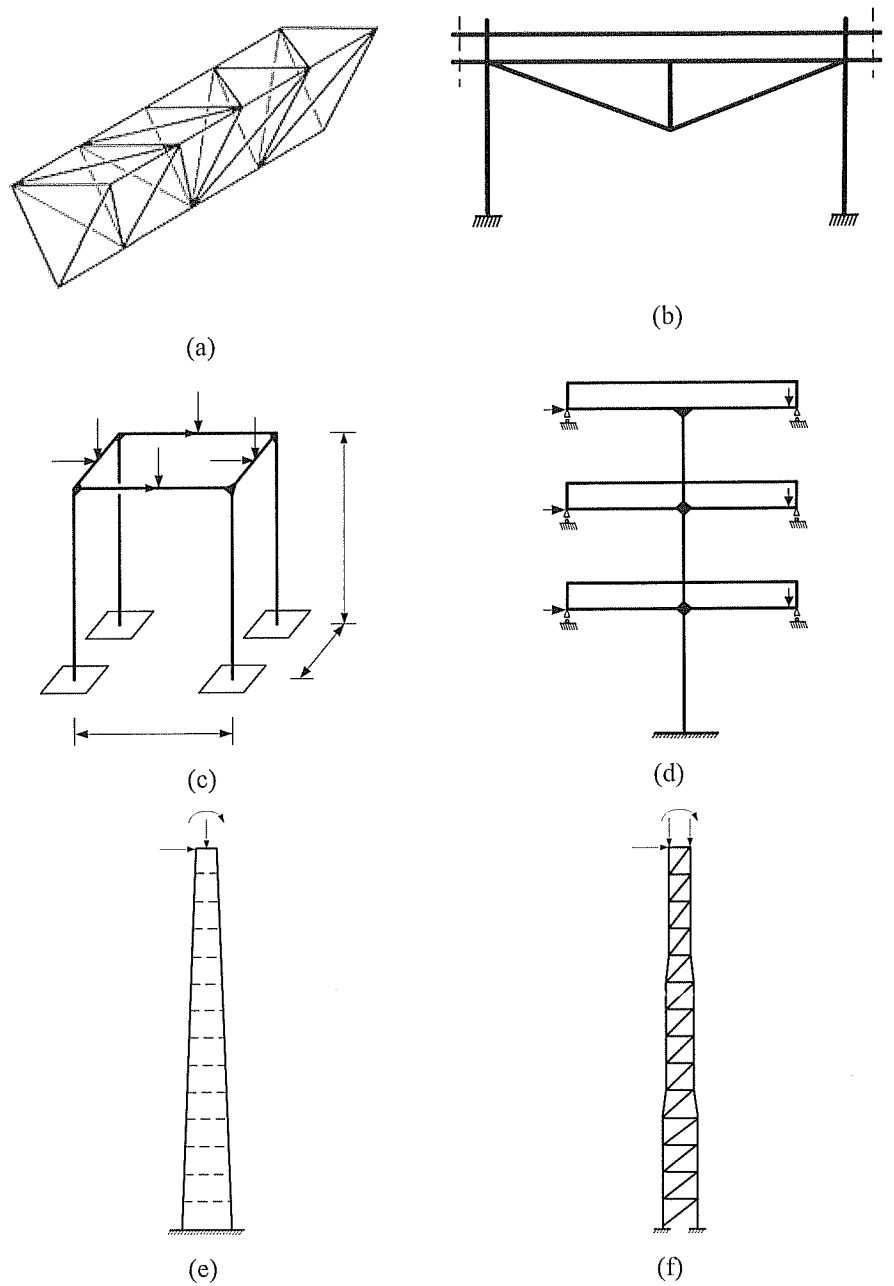


Figure 3. a) A tubular truss beam, b) a column-supported pipeline strengthened by a tubular truss, c) a simple tubular frame supporting a pressure vessel and loaded also by seismic forces, d) a multistory steel frame with a tubular column and rolled-I-section beams, e) a wind turbine tower of ring-stiffened shell structure, f) a wind turbine tower of tubular truss structure

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