INNOVATIVE DESIGN OF STIFFENED PLATES AND COLUMNS, AN OVERVIEW

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Abstract: *Welded stiffened plates and shells are widely used in various structures, e.g. bridges, ships, bunkers, tank roofs, vehicles, etc. They are subject to various loadings: compression, shear, bending or combined load. The shape of the plates can be square, rectangular, circular, trapezoidal, etc. Plates and shells can be stiffened in one or in two directions with stiffeners of many different shapes. This study contains the minimum cost and weight design of different longitudinally stiffened plates. The deflections due to lateral pressure and compression stress are considered in the stress calculation and constraint. Furthermore, the local buckling constraint of the base plate strips is also formulated. The cost function as the objective function includes two kinds of steel and three kinds of welding technologies. The unknowns are the thickness of the base plate (*t_f*) and the dimensions and the number of stiffeners (n).*

Keywords: *structural optimization, stiffened plates, shells*

1. INTRODUCTION

The main requirements of modern welded metal structures are load-carrying capacity (safety), fitness for production, and economy. This goal can be achieved by the combination of design-fabrication and economy. The primary objective of attaching longitudinal stiffeners is to improve the buckling strength of relatively thin compression panels.

This paper gives comparisons for stiffened plates with different loadings, different shape of stiffeners (flat, L-shape, trapezoidal), different steel grades, and different welding technologies (SMAW, GMAW, SAW) to show the necessity of a combination of design, fabrication and economic aspects. Safety and fitness for production are guaranteed by fulfilling the design and fabrication constraints.

The economy is achieved by minimizing the cost function. It is shown, that the optimum sizes depend on the welding technology, the material yield stress, the profile of the stiffeners, the load cycles and the place of the production. In the calculations the objective function was the cost, or the mass. The unknowns are the sizes of the stiffened plate the constraints are the stress, the overall and local buckling of the cover plate and the stiffeners [1-5].

2. LONGITUDINALLY STIFFENED PLATE LOADED BY A UNIAXIAL COMPRESSION

The geometric characteristics and the uniformly distributed compression force loading of stiffened plate are shown in Figure 1. The stiffened plate is simply supported on all four edges. Geometrical parameters of the stiffened plate with flat ribs, L-shaped ribs and trapezoidal ribs can be seen in Figure 2.

The global buckling calculation of stiffened plates according to the method of Mikami and Niwa [6], the effect of residual welding and initial imperfections stresses is considered by defining the buckling curves for a reduced slenderness. The other constraints are the single panel buckling and the local and torsional buckling calculation of stiffeners. This constraint eliminates local buckling of the base plate between the ribs. From the classical buckling formula, it is calculated for simply supported ends and compressed in one direction.

The given data are: base plate width B = 6000 [mm], base plate length L = 3000 [mm], static compression force N = 1.974x10^7 [N], material density ρ = 7.85x10-6 [kg/mm^3], Young's modulus E = 2.1x10^5 [MPa], and yield stress f_y = 355 [MPa], the Poisson coefficient is 0.3. The calculations were made for different shape of stiffeners and it was found that the trapezoidal stiffener is the best one. There were no great differences in the application of the Mikami rules, or the API [7] standard. The results were different using different welding technologies. The cheapest was the submerged arc welding technique if we do not consider the equipment cost [8-10].

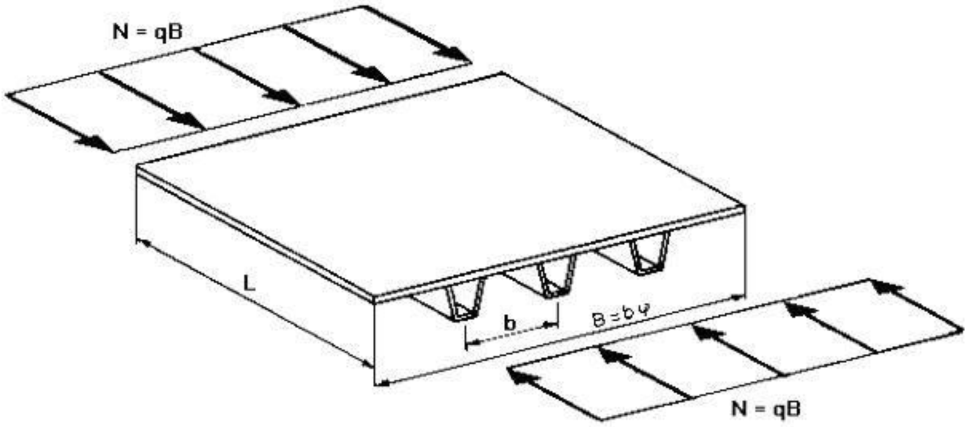

Figure 1: Stiffened plate loaded by uniaxial compression

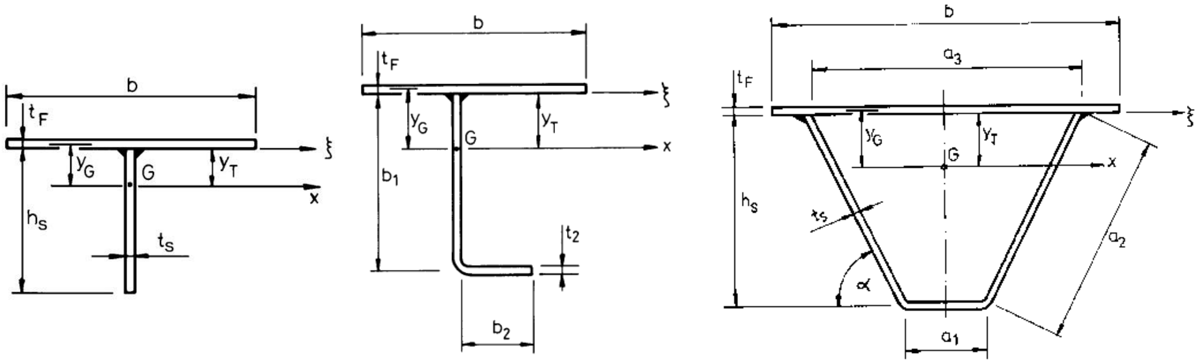

Figure 2: Dimensions of the flat rib, L rib and trapezoidal ribs

Table 1: Optimum dimensions with *L*-shaped stiffener (SAW)

	k_F/k_m	t_o [mm]	t_s [mm]	φ	K/k_m [kg]
Mikami	0	18	7	9	2936
	1	18	7	9	3658
	2	19	7	8	4373
API	0	17	7	10	2844
	1	17	7	10	3614
	2	19	7	8	4373

3. LONGITUDINALLY STIFFENED PLATE LOADED BY UNIAXIAL COMPRESSION AND LATERAL PRESSURE

The geometric characteristics and the uniformly distributed compression and bending force loadings of stiffened plate are shown in Figure 3. The stiffened plate is simply supported on all four edges. Geometrical parameters of the stiffened plate with flat ribs, L-shaped ribs and trapezoidal ribs can be seen in Figure 2. In the following calculation, stiffened plates with L and trapezoidal ribs are compared. The given data are: base plate width B = 4000 [mm], base plate length L = 6000 [mm], static compression force N = $1.974\text{x}10^7$ [N]. The Young's modulus is E = 2.1 x 10^5 [MPa], material density is ρ = $7.85\text{x}10^{-6}$ [kg/mm^3]. In the calculation, there are values of lateral pressures p_0 = 0.005, 0.01, 0.02 [MPa] and yield stresses f_y = 255, 355 [MPa]. The applied welding technology is GMAW. The unknowns, the thicknesses of base plate and stiffener and the number of ribs, are limited in a range. The results are shown in Table 2. Increasing the lateral pressure, the plate becomes more expensive. Two steel grades have been compared. The optima in both cases are close to each other. In this case the trapezoidal stiffener is the best again [10].

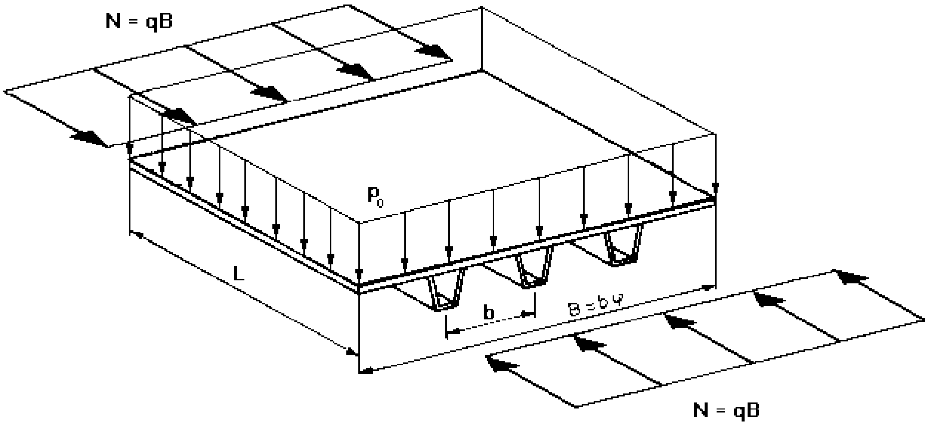

Figure 3: Stiffened plate loaded by uniaxial compression and lateral pressure

Table 2: Optimum dimensions with ***L*-shaped** stiffener for k_F/k_m=1.5, the cost minima

f_{ly} **[MPa]**	p_0 **[MPa]**	t_f **[mm]**	t_s **[mm]**	φ	K/k_m **[kg]**	
					k_F/k_m=0	k_F/k_m**=1.5**
235	0.02	26	11	5	5867	7560
235	0.01	29	9	4	5950	7107
235	0.005	26	8	5	5411	6639
355	0.02	27	11	4	6246	7616
355	0.01	26	10	4	5926	7158
355	0.005	24	8	5	5432	6627

4. STIFFENED COLUMNS

A special column is applied. The objective function is the cost of the structure, including material, welding and painting costs (Figure 4).

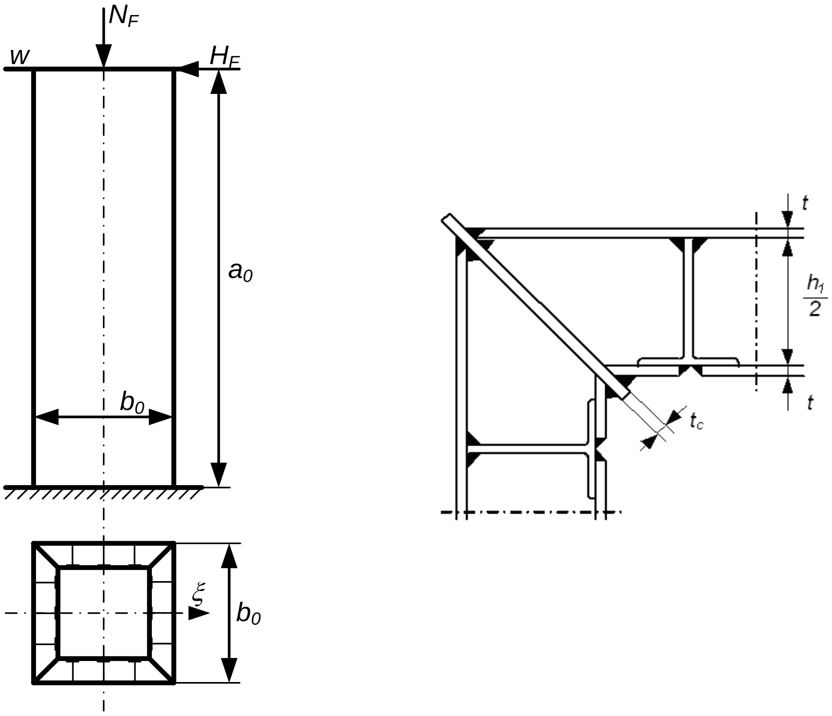

Figure 4: A cantilever square box column with cellular plated walls and the welded corner

The constraints are as follows:

- the buckling force,
- constraint on horizontal displacement of the column top,
- constraint on local buckling of face plates connecting the transverse stiffeners,
- limitation of the column width.

The unknowns are the main sizes and plate thicknesses shown on Figure 4 and 5.

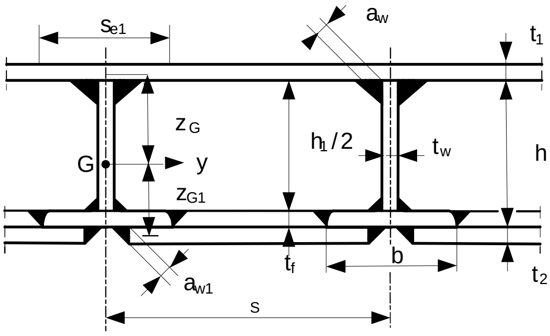

Figure 5: A part of the cross-section of the cellular plated wall with welded T-stiffeners

Table 3: Results of the optimization. Dimensions in mm, volume in mm^3, cost in €. The displacement w is near w_{adm}= 15 mm. The optima are marked by bold letters. h_{min} = 300, t_{wmin} =4. The case of n = 6 cannot be used, since n_{max} = 5.

n	t	h	t_w	V_7x10^{-9}	Kx10^{-5}
3	29	300	4	11.080	3.641
4	22	230	14	9.077	2.646
5	**21**	**240**	**4**	**8.910**	**2.578**
6	*20*	*230*	*4*	*8.880*	*2.572*

Another type of the stiffened column is shown on Figure 6. It is formed by circular element and the result is a cellular shell. Optimum results are shown on Table 4.

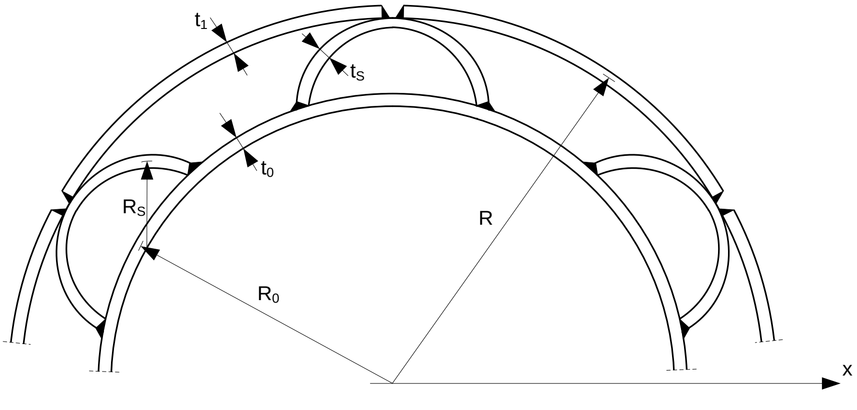

Figure 6: Dimensions of a cellular shell

Table 4: Details of the optimization. The maximal displacement in each case is near the allowable value of 15 mm. Dimensions in mm, volume V in mm^3, cost in €. The optimum is marked by bold letters.

D_s	t_s	**n$_s$**	t_0	t_1	V_4**x10^{-9}**	K**x10^{-5}**
193.7	16	34	30	30	10.40	1.648
219.1	20	26	30	30	10.53	1.599
244.5	**20**	**24**	**30**	**30**	**10.59**	**1.577**
273.0	*12.5*	*34*	*30*	*30*	*10.61*	*1.634*

Both versions have been optimized for minimum cost to satisfy the constraint on column top displacement, stress, local stability and the column width limitation. The results show that the cellular shell version costs 157700 € and the cellular plate version costs 276900 €. Thus, the cellular shell version is more economic to solve this design problem than that of the cellular plated one. It means that the cellular shell can advantageously be applied for such design problems.

Many applications have been given is [11-16]. They demonstrate the benefits of using stiffened plates and shell, even if the welding is relatively expensive, but the improvement of the rigidity is even larger.

4. CONCLUSIONS

As we stated at the beginning, the main requirements of modern welded metal structures are load-carrying capacity (safety), fitness for production, and economy. These requirements can be met by structural optimization: economy is achieved by minimizing the cost function. The safety and fitness for production are guaranteed by fulfilling the design and fabrication constraints. The cost function includes the material and the welding costs, using different steel grades and different welding technologies.

The results show the high influence of the form of the stiffeners on the optimal sizes of the stiffened plates. Material cost optimization results in a higher number of ribs. In total cost optimization the dimensions increase first, then the number of ribs. Comparisons show that it is worth considering both the technology and the costs of the structure and optimizing them in the design phase.

Comparisons of stiffened plates show that the application of optimization is beneficial, since it is possible to reduce the cost of the structure by 15-25%. If we compare non-optimized versions, in that case the cost saving can be even higher.

At the cellular box and shell column it is visible, that large strength can be achieved using them. These relatively new kinds of structures give more opportunities to improve the strength using less materials.

The main conclusion is, that the optimum sizes depend on the welding technology, the material yield stress, the profile of the stiffeners and the place of the production (labour cost). It has the greatest effect on the structure cost.

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