AWST-10/07

Minimum Cost Design of a Square Box Column with Walls Constructed from Cellular Plates with RHS Stiffeners

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Abstract

Rectangular hollow sections (RHS) can advantageously applied in cellular plates as an orthogonal grid of stiffeners. Formulae are given for the overall buckling strength of a uniaxially compressed rectangular simply supported cellular plate. This strength is much more larger than that of a plate stiffened on one side by open section ribs because of the large torsional stiffness of the cellular plate. The four walls of a square box column are constructed from cellular plates with tubular stiffeners. The cantilever column is loaded by compression and bending. In the optimization process the optimal sizes and number of RHS stiffeners in both directions as well as the deck plate thickness and the width of the box column section are sought, which minimize the cost function and fulfil the design constraints. Constraint on maximum stress and limitation of the horizontal displacement of the column top are considered. The cost function contains the cost of material, assembly, welding and painting.

Keywords: *Welded tubular structures, Cellular plates, Square box column, Cost calculation, Structural optimization*

1. Introduction

The aim of the present study is to show that the rectangular hollow section (RHS) stiffeners can be applied in welded cellular plates from which steel structures of advantageous characteristics can be constructed.

Cellular plates consist from two base plates between which a grid of stiffeners is welded. In the case of RHS stiffeners the base plate elements are welded using square butt CJPG (complete joint penetration groove) SAW (submerged arc welding) welds.

Cellular plates have the following advantages over plates stiffened on one side: (a) their torsional stiffness contribute to the overall buckling strength significantly, therefore, their height and thicknesses can be smaller and the welding cost lower, (b) their symmetry eliminates the large residual welding distortions, which can occur due to the shrinkage of eccentric welds, (c) their plane surfaces can be better protected against corrosion.

Box columns of large load-carrying capacity are widely used in bridges, buildings, highway piers, pilons, towers etc. Since the thickness required for an unstiffened column can be too large, stiffened plate sides should be used.

Modern welded structures should be safe, fit for production and economic. In the structural optimization process the safety and producibility is guaranteed by fulfilling the design and fabrication constraints, economy is achieved by minimization of a cost function.

We have developed a cost calculation method and applied it mainly for welded structures. The cost function contents the cost of material, assembly, welding and painting and is formulated according to the fabrication sequence. In the material cost the cost factors for plates and RHS stiffeners are different.

Furthermore we have adapted effective mathematical methods for constrained function minimization, which are applied in the present problem with several variables and highly nonlinear functions.

In the present numerical problem the following data are given: the cantilever column height, the vertical compressive force, the horizontal force acting on column top, the steel yield strength, the factors for cost calculation. The following variables are optimized: width of the square box column section, base plate thickness, number and dimensions of the RHS stiffeners in both directions. Constraints on maximum stress and allowable horizontal displacement on the column top are considered.

In previous studies [1, 2] it has been shown that cellular plates can be calculated as isotropic ones, bending moments and deflections can be determined by using classic results of isotropic plates for various load and support types.

In the book [3] some problems can be found about cellular plates. Welded cellular plates for ships investigated in [4, 5] consist of two face sheets and some longitudinal ribs of square hollow section welded between them using arc-spot welding technology.

2. Characteristics of cellular plates

The Huber's equation for orthotropic plates in the case of a uniform compressive load

$$B_x w'''' + 2Hw''^{\cdot\cdot} + B_y w^{\cdot\cdot\cdot\cdot} + N_x w'' = 0 \qquad (1)$$

where the prime (') and dot (˙) superscripts denote partial derivatives with respect to x and y respectively,

$$H = B_{xy} + B_{yx} + \frac{\nu}{2}\left(B_x + B_y\right) \qquad (2)$$

is the torsional stiffness of an orthotropic plate.

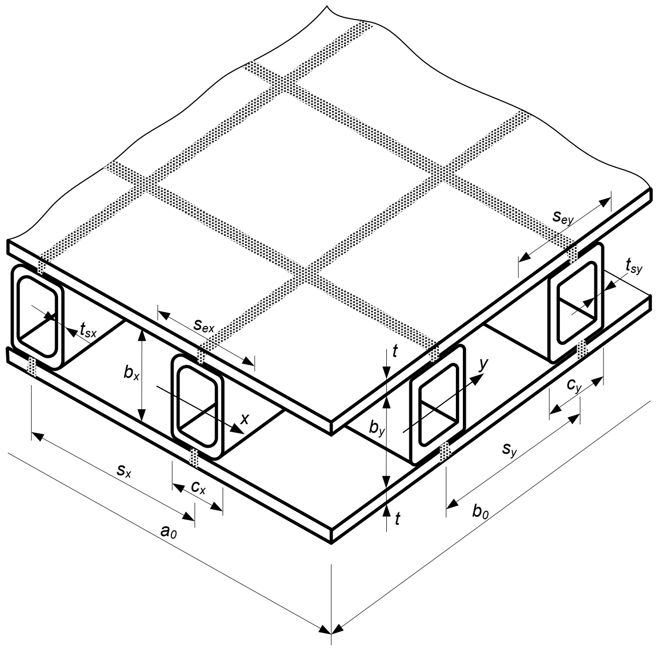

Figure 1. Cellular plate with RHS stiffeners

The corresponding bending and torsional stiffnesses are defined as

$$B_x = \frac{E_1 I_y}{a_y}; B_y = \frac{E_1 I_x}{a_x}; E_1 = \frac{E}{1-\nu^2} \qquad (3)$$

for cellular plates

$$B_{xy} = \frac{GI_y}{a_y}; B_{yx} = \frac{GI_x}{a_x}; G = \frac{E}{2(1+\nu)} \qquad (4)$$

$$H = B_{xy} + B_{yx} + \frac{\nu}{2}\left(B_x + B_y\right) = \frac{E_1}{2}\left(\frac{I_y}{a_y} + \frac{I_x}{a_x}\right) \qquad (5)$$

The solution of Eq.(5) yields the classic overall buckling formula for critical force of a simply supported rectangular plate

$$N_E = \frac{\pi^2}{b_0^2}\left(B_x \frac{b_0^2}{a_0^2} + 2H + B_y \frac{a_0^2}{b_0^2}\right) \qquad (6)$$

Effective plate widths

$$s_{ey} = C_y s_y, s_{ex} = C_x s_x \qquad (7)$$

where

$$s_y = b_0 / n_y, s_x = a_0 / n_x \qquad (8)$$

$$C_y = 1 \qquad \text{if } \lambda_y = \frac{s_y}{56.84 t\varepsilon} < 0.673 \qquad (9)$$

$$C_y = \frac{\lambda_y - 0.22}{\lambda_y^2} \qquad \text{if } \lambda_y \geq 0.673 \qquad (10)$$

$$C_x = 1 \qquad \text{if } \lambda_x = \frac{s_x}{56.84 t\varepsilon} < 0.673 \qquad (11)$$

$$C_x = \frac{\lambda_x - 0.22}{\lambda_x^2} \qquad \text{if } \lambda_x \geq 0.673 \qquad (12)$$

Effective cross-sectional areas

$$A_{ey} = A_{RHSy} + 2s_{ey}t, A_{ex} = A_{RHSx} + 2s_{ex}t \qquad (13)$$

Moments of inertia

$$I_y = I_{RHSy} + 2s_{ey}t\left(\frac{b_y + t}{2}\right)^2, I_x = I_{RHSx} + 2s_{ex}t\left(\frac{b_x + t}{2}\right)^2 \qquad (14)$$

3. Minimum cost design of the square box column

In the optimum design the following variables should be optimized: the column width b_0, the outer and inner base plate thickness t, dimensions and numbers of stiffeners

The buckling constraints are formulated according to the Det Norske Veritas rules [6].

3.1. Constraints

Constraint on overall buckling of a cellular plate wall (Fig. 1)

A cantilever column is loaded by a compression force and a horizontal load, thus, it is subject to compression and bending. From this loading a compression force is calculated for two opposite plate elements, while the remaining plate elements are subject to compression and bending. Since this loading is not so dangerous for the buckling of remaining side plate elements, it is sufficient to design only the two main plate elements.

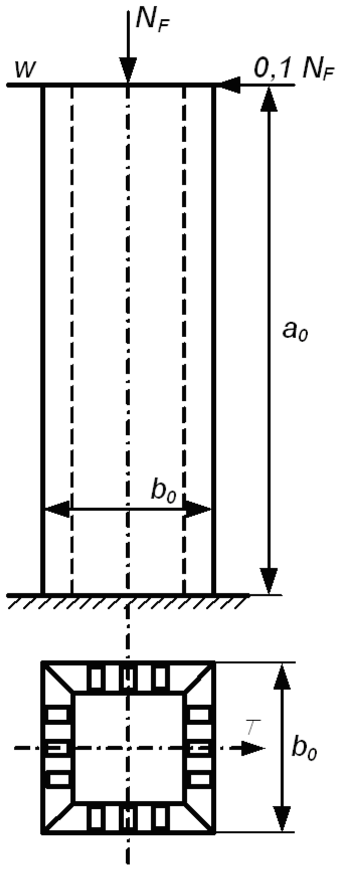

Figure 2. A cantilever column of square box cross section. The walls are constructed from cellular plates with RHS stiffeners

$$\sigma = \frac{N_F}{4A_{ey}(n_y - 1)} + \frac{0.1 N_F a_0}{W_\xi} \le \sigma_{cr} = \frac{f_{y1}}{\sqrt{1+\lambda^4}} \quad (15)$$

where

$$\sigma_E = \frac{N_E s_y}{A_{ey}} \quad (16)$$

$$\lambda = \sqrt{\frac{f_{y1}}{\sigma_E}} \quad (17)$$

$$W_\xi = \frac{2I_\xi}{b_0} \quad (18)$$

$$I_\xi = 2I_y(n_y - 1) + 2(n_y - 1)A_{ey}\left(\frac{b_0}{2}\right)^2 + 2I_{\xi S} \quad (19)$$

where the moment of inertia of RHS stiffeners is given by

$$I_{\xi S} = I_{RHSx}(n_y - 1) + 2A_{ey} s_y^2 n_y \frac{n_y^2 - 1}{24} \quad (20)$$

Constraint on horizontal displacement of the column top

$$w_{max} = \frac{H_F}{\gamma_M}\frac{L^3}{3EI_\xi} \le \frac{L}{\phi}, \gamma_M = 1.5, \phi = 300 - 1000 \quad (21)$$

3.2. Numerical data (Fig. 1)

a_0 = 15000, N_x = 3x10^7 [N], steel yield stress f_y = 355 MPa, elastic modulus E = 2.1x10^5 MPa, shear modulus G = 0.81x10^5, density ρ = 7.85x10^{-6} kg/mm^3, Poisson ratio ν = 0.3.

3.3. Cost function

The general formula for the welding cost is as follows [3, 5, 7]:

$$K_w = k_w\left(C_1\Theta\sqrt{\kappa\rho V} + 1.3\sum_i C_{wi} a_{wi}^n C_p L_{wi}\right) \quad (22)$$

where k_w [\$/min] is the welding cost factor, C_1 is the factor for the assembly usually taken as C_1 = 1 min/kg$^{0.5}$, Θ is the factor expressing the complexity of assembly, the first member calculates the time of the assembly, κ is the number of structural parts to be assembled, ρV is the mass of the assembled structure, the second member estimates the time of welding, C_w and n are the constants given for the specified welding technology and weld type.

C_{pi} is the factor for the welding position (downhand 1, vertical 2, overhead 3), L_w is the weld length, the multiplier 1.3 takes into account the additional welding times (deslagging, chipping, changing the electrode).

In our problem the fabrication has two phases:

(1) fabrication of four cellular plates: (a) welding the grid of RHS stiffeners, (b) welding of the deck plate elements to the grid, (c) welding of the base plate elements to the grid, except the two outermost plate strips to make it possible to weld the transverse stiffeners to the corner diagonal plates.

(2) Fabrication of the whole square box column from four cellular plates: (a) welding of the deck plates and the transverse stiffeners to the four corner diagonal plates, (b) welding the 8 outermost base plate strips to the corner plates.

The cost functions are formulated according to these fabrication phases. For each phase the number of assembled elements, the volume of the assembled structure, the characteristics of used welds (size, type, welding method and weld length) should be determined as shown in Eq (22).

1a: Welding of the grid of RHS stiffeners.

Continuous (n_y-1) stiffeners in x-direction of sizes b_y, c_y, t_{sy} (cross-section area A_{RHSy}), intermittent (n_x-1) ones in y-direction of sizes b_x, c_x, t_{sx} (A_{RHSx})
Number of assembled elements $\kappa_1 = n_y - 1 + (n_x - 1)n_y = n_x n_y - 1$.
SMAW (shielded metal arc welding) fillet welds of size $a_w = 0.5t_{sx}$.

Volume:

$$V_1 = a_0(n_y - 1)A_{RHSy} + (n_x - 1)A_{RHSx}\left[b_0 - (n_y - 1)c_y\right] \quad (23)$$

Weld length: $$L_{w1} = 2(b_x + c_x)2(n_x - 1)(n_y - 1) \quad (24)$$

Welding cost:

$$K_{w1} = k_w\left(\Theta\sqrt{\kappa_1 \rho V_1} + 1.3x0.7889x10^{-3}a_w^2 L_{w1}\right), \quad (25)$$

$\Theta = 2, \rho = 7.85x10^{-6}$ kg/mm^3, k_w = 1.0$/min.

1b: Welding of deck plate elements to the grid of stiffeners from above.

Special square butt CJPG (complete joint penetration groove) SAW (submerged arc welding) welds. Since their gap is of size t (plate thickness), the C_w constant relating to an I-butt weld is multiplied by 1.5.

$$\kappa_2 = n_x n_y + 1 \quad (26)$$

$$V_2 = V_1 + a_0 t\left[b_0 + \sqrt{2}\left(\frac{b_y}{2} + 1\right)\right] \quad (27)$$

$$L_{w2} = a_0(n_y - 1) + b_0(n_x - 1) \quad (28)$$

$$K_{w2} = k_w\left[\Theta\sqrt{\kappa_2 \rho V_2} + 1.3x1.5\left(0.01066t^2 + 1.698\right)10^{-3}L_{w2}\right] \quad (29)$$

1c: Welding of the base plate elements to the grid from outside.

The difference from 1b is that the two outermost plate strips are not welded to make it possible to weld the transverse stiffeners to the corner plates. The other difference is that one side of the plate strips second from outside are welded using SAW fillet welds of size $a_{w1} = 0.7t$ instead of square butt welds.

$$\kappa_3 = n_x(n_y - 2) + 1 \quad (30)$$

$$V_3 = V_2 + a_0(n_y - 2)s_y t, s_y = b_0 / n_y \quad (31)$$

Length of square butt welds:

$$L_{w3} = a_0(n_y - 3) + s_y(n_x - 1)(n_y - 2) \quad (32)$$

Length of fillet welds: $L_{w3a} = 2a_0$ (33)

$$K_{w3} = k_w\left[\begin{array}{l}\Theta\sqrt{\kappa_3 \rho V_3} + 1.3x1.5\left(0.01066t^2 + 1.698\right)10^{-3}L_{w3} + \\ +1.3x0.2349x10^{-3}a_{w1}^2 L_{w3a}\end{array}\right] \quad (34)$$

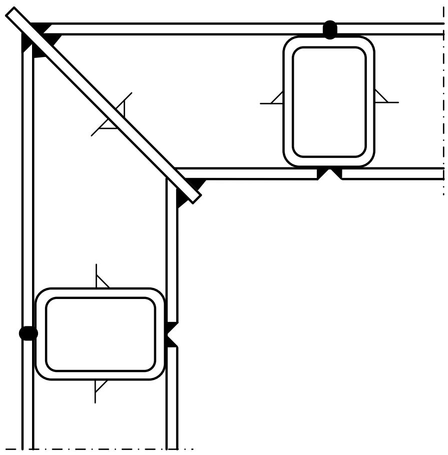

Figure 3. The corner of the square box column

2a: Welding of the whole square box column from four cellular plates using four corner diagonal plates of sizes a_0, t_c and $(\sqrt{2}b_y + 8t_c)$.

Welding of 4x2 SAW fillet welds of size a_{w1} and length of $L_{w4} = 8a_0$ connecting the corner plates to the deck plates as well as welding of $8(n_x$-1) transverse stiffeners to the corner plates with SMAW fillet welds of size a_w and length of

$$L_{w4a} = 8(n_x - 1)\left(2\sqrt{2}b_x + 2c_x\right). \quad (35)$$

$$V_4 = 4V_3 + 4a_0 t_c\left(\sqrt{2}b_y + 8t_c\right) \quad (36)$$

$$K_{w4} = k_w\begin{pmatrix}\Theta_1\sqrt{8\rho V_4} + 1.3x0.2349x10^{-3}a_{w1}^2 L_{w4} + \\ +1.3x0.7889x10^{-3}a_w^2 L_{w4a}\end{pmatrix} \quad (37)$$

2b: Welding of the $8n_x$ closing base plate elements to each other using square butt welds of length

$$L_{w5a} = 8(n_x - 1)\left[s_y - \sqrt{2}\left(\frac{b_y}{2} + t\right)\right] \quad (38)$$

to the base plates and to the corner plates using SAW fillet welds of size a_{w1} and length $L_{w5} = 16a_0$

$$V_5 = V_4 + 8a_0 t\left[s_y - \sqrt{2}\left(\frac{b_y}{2} + t\right)\right] \quad (39)$$

$$K_{w5} = k_w\begin{bmatrix}\Theta_1\sqrt{(8n_x + 1)\rho V_5} + 1.3x0.2349x10^{-3}a_{w1}^2 L_{w5} + \\ +1.3x1.5\left(0.01066t^2 + 1.698\right)10^{-3} L_{w5a}\end{bmatrix} \quad (40)$$

$\Theta_1 = 3$.

Cost of painting of the surface S_p

$$K_p = k_p\Theta_p S_p, k_p = 14.4x10^{-6}\ \$/\mathrm{mm}^2,\ \Theta_p = 2,\ S_p = 4a_0 b_0 \quad (41)$$

Material cost

$$K_m = k_{mplates}\rho\left[8a_0 b_0 t + 4a_0 t_c\left(\sqrt{2}b_y + 8t_c\right)\right] + 4K_{mRHS} \quad (42)$$

$$K_{mRHS} = k_{RHSy}a_0 A_{RHSy}\left(n_y - 1\right)\rho + k_{RHSx}A_{RHSx}\left[b_y - \left(n_y - 1\right)c_y\right]\left(n_x - 1\right)\rho \quad (43)$$

$k_{mplates} = 1.0$ \$/kg, $k_{mRHS} = 1.24$ \$/kg.

Total cost

$$K = K_m + 4\left(K_{w1} + K_{w2} + K_{w3}\right) + K_{w4} + K_{w5} + K_p \quad (44)$$

4. Optimization techniques

In the structural optimization process for an engineer it is important to know the behaviour of the structure well, the stresses, deformations, stability, eigenfrequency, damping, etc. It is as important to have a reliable optimization technique to find the optimum.

In our practice on structural optimization we have used several techniques in the last decades. We have published them in our books and gave several examples as engineering applications [3, 5, 7]. Most of the techniques were modified to be a good engineering tool in this work.

The general formulation of a single-criterion non-linear programming problem is the following

minimize $f(x) \quad x_1, x_2, ..., x_N$, (45)

subject to $g_j(x) \le 0, \quad j = 1,2,...,P$, (46)

$h_i(x) = 0 \quad i = P+1,...,P+M$, (47)

f(x) is a multivariable non-linear function, $g_j(x)$ and $h_i(x)$ are non-linear inequality and equality constraints, respectively.
In the last two decades some new techniques appeared e.g. the evolutionary techniques, like Genetic Algorithm, *GA* by Goldberg [8], the Differential Evolution, *DE* method of Storn & Price [9], the Ant Colony Technique [10], the Particle Swarm Optimization, *PSO* by Kennedy & Eberhart [11], Millonas [12] and the Artificial Immune System, *AIS* [13, 14, 15]. Some other high performance techniques such as Leap-frog with the analogue of potential energy minimum from Snyman [16, 17], Snyman-Fatti method and the Harmony Search technique have also been developed.

4.1. The Particle Swarm Optimization algorithm

Several methods have been developed to escape from being caught in local optima. The Particle Swarm Method of global optimization is one of such methods. A swarm of birds searches for food, protection, etc. in a very typical manner. If one of the members of the swarm sees a desirable path to go, the rest of the swarm will follow quickly. Every member of the swarm searches for the best in its locality - learns from its own experience.

Additionally, each member learns from the others, typically from the best performer among them. Even human beings show a tendency to learn from their own experience, their immediate neighbours and the ideal performers. The Particle Swarm method of optimization mimics this behaviour. Every individual of the swarm is considered as a particle in a multidimensional space that has a position and a velocity. These particles fly through hyperspace and remember the best position that they have seen. Members of a swarm communicate good positions to each other and adjust their own position and velocity based on these good positions. The Particle Swarm method of optimization testifies the success of bounded rationality and decentralized decisionmaking in reaching at the global optima. It has been used successfully to optimize extremely difficult multimodal functions.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbours of the particle. This location is called *lbest*. when a particle takes all the population as its topological neighbours, the best value is a global best and is called *gbest*.

The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of *PSO*). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

Another reason that *PSO* is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications.
The method is derivative free, and by its very nature the method is able to locate the global optimum of an objective function. Constrained problems can simply be accommodated using penalty methods.

Lately, the *PSO* was successfully applied to the optimum shape and size design of structures by Fourie and Groenwold [18]. An operator, namely craziness, was re-introduced, together with the use of dynamic varying maximum velocities and inertia.

PSO was applied at several structural optimization problems cost minimization of an orthogonally stiffened welded steel plate, ring-stiffened conical shell, optimization of a wind turbine tower structure, optimization of a stiffened shell Farkas & Jármai [3, 5, 7].

4.2. The IOSO program

IOSO is an advanced semi-stochastic algorithm for constrained multi-objective optimization (Egorov 1998) incorporating certain aspects of a selective search on a continuously updated multi-dimensional response surface. Both weighted linear combination of several objectives and true multi-objective formulation options creating Pareto fronts are incorporated in the algorithm. The main benefits of this algorithm are its outstanding reliability in avoiding local minima and its computational speed. Samples are compared to more traditional semi-stochastic optimizers like genetic algorithms. Furthermore, the self-adapting response surface formulation used in this research allows for incorporation of realistic non-smooth variations of experimentally obtained data and allows for accurate interpolation of such data. This optimization algorithm also allows for a finite number of equality and inequality constraints.

4.2.1 Multi-objective optimization concepts

There is a growing need for the multi-disciplinary and multi-objective approach to design with a large number of design variables, resulted in an increased interest in the use of various versions of hybrid [19], semi-stochastic [20] and especially stochastic [21] constrained optimization algorithms. It should be pointed out that including more objectives in the optimization process often has similar effects on the overall optimization effort required as including more constraints especially if these constraints are incorporated as penalty functions. The multi-objective optimization problem maximizes a vector of *n* objective functions

$$\max \mathbf{F}_i(\mathbf{x}) \text{ for } i = 1, \ldots n \tag{48}$$

subject to a vector of inequality constraints

$$g_j(\mathbf{x}) \leq 0 \text{ for } j = 1, \ldots m \tag{49}$$

and a vector of equality constraints

$$h_q(\mathbf{x}) = 0 \text{ for } q = 1, \ldots \mathrm{k} \tag{50}$$

In general, the solution of this problem is not unique. With the introduction of the Pareto dominance concept the possible solutions are divided into two subgroups: the dominated and the non-dominated. The solutions belonging to the second group are the "efficient" solutions, that is, the ones for which it is not possible to improve any individual objective without deteriorating the values of at least some of the remaining objectives.

IOSO approach is based on the widespread application of response surface methodology, based upon the original approximation concept, within the frameworks of which it adaptively uses global and middle-range multi-point approximations. One of the advantages of this approach is the possibility of ensuring good approximating capabilities using a minimum amount of available information. This possibility is based on self-organization and evolutionary modelling concepts [22]. During the approximation, the approximation function structure is being evolutionarily changed, so that allows us to approximate successfully the optimized functions and constraints having sufficiently complicated topology. The obtained approximation functions can be used by multi-level procedures [19] with the adaptive change of simulation level within both a single and multiple disciplines of object analysis, and also for the solution of their interaction problems.

Multi-objective optimization problem solution [19] is based on the use of approximation functions for individual objectives and constraints. The current search area of adaptive changing makes it possible to search numerically the Pareto-optimal set without the use of any versions of composite objective functions (convolution approach). To reduce the computing time significantly, we have developed a multi-level multi-objective constrained optimization methodology that is a modified version of a method of Indirect Optimization based upon Self-Organization (IOSO) [22] and evolutionary simulation principles. Each iteration of IOSO algorithm consists of two steps. The first step is the creation of an analytical approximation of the objective function(s). Each iteration in this step represents a decomposition of the initial approximation function into a set of simple analytical approximation functions so that the final response function is a multi-level graph. The second step is the optimization of this approximation function. This approach allows for corrective updates of the structure and the parameters of the response surface approximation. The distinctive feature of this approach is an extremely low number of trial points to initialize the algorithm (typically 30 to 50 values of the objective function for the optimization problems with nearly 100 design variables). During the IOSO operation, the information concerning the behaviour of the objective function in the vicinity of the extremum is stored, and the response function is made more accurate only for this search area.

While proceeding from one iteration to the next, the following steps are carried out: modification of the experiment plan; adaptive selection of current extremum search area; choice of the response function type (global or middle-range); transformation of the response function; modification of both parameters and structure of the optimization algorithms; and, if necessary, selection of new promising points within the researched area. Thus, during each iteration, a series of approximation functions for a particular objective of optimization is constructed. These functions differ from each other according to both structure and definition range. The subsequent optimization of these approximation functions allows us to determine a set of vectors of optimized variables.
It should be pointed out that the IOSO approach is different than the artificial neural network approach that performs fast interpolation of the existing experimental data sets. Our approach combines a multi-level graph theory, a special version of radial basis function formulations, and neural networks into a self-adaptive response surface optimization algorithm capable of exploring and optimizing data that is outside of the original data set.

3.5. Results

Box columns of large load-carrying capacity are widely used in bridges, buildings, highway piers, pilons, towers etc. Since the thickness required for an unstiffened column can be too large, stiffened plate walls should be used.

The unknows were the dimensions of the column, width, thicknesses, number of stiffeners. The total number of unknowns is 9 (b_0 column width, t_h plate thickness, b_x, b_y are stiffener heights in x - and y directions, c_x, c_y stiffener widths in x - and y directions, t_b stiffener thickness, n_x and n_y x - and y directions) (Fig.1) and the number constraints is 11. The constraints include the upper and lower size limits of the unknowns (for example minimum and maximum thickness).

Table 1. Results of the stiffened box column

b_0	t_h	b_x	c_x	c_y	t_{bx}	t_{by}	n_x	n_y	Cost
3250	9	90	50	40	7	7	12	2	55399
2843	12	67	29	37	11	8	8	2	56515

Result show, that both techniques have found an optimum. The first row belongs to Particle swarm optimization, the second row belongs to IOSO.

4. Conclusion

Design, fabrication and economy are the three parts of an optimum design. If we consider the analytical aspects of the design, the effect of different welding and other technologies on the cost of the structure, than we can reach a minimum cost solution using efficient optimization techniques. Particle swarm and IOSO are two of them. A stiffened column with cellular structure is shown. The two techniques give nearly the same result. The difference comes from finding the discrete values. When we compared unstiffened thick-walled column, stiffened cellular column with flat stiffeners and half I-beams and the hollow type stiffeners at the cellular column, we found that the best construction is the hollow section type stiffener. Further considerations will relate to earthquake and/or fire resistant design of this kind of structure.

Acknowledgements

The authors gratefully acknowledge the support of the Hungarian Scientific Research Fund under the OTKA 75678 project number. The project was also supported by the TÁMOP 4.2.3-08/1 entitled *Acknowledgement and dissemination of scientific results*.

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