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Optimization of welded square cellular plates with two different kinds of stiffeners

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ABSTRACT

Cellular plates are constructed from two face plates and a stiffener grid welded between them. It is shown that the square cellular plates can be calculated as isotropic ones. Therefore, the classic formulae for maximum bending moment and deflection, valid for isotropic plates, can be used. The stiffeners can be made from halved rolled I-profiles, or from welded T-sections. These two kinds of cellular plates are optimized, and their minimum volumes and costs are compared to each other. The comparison shows that the cellular plate with welded T-stiffeners is more economic.

1. Introduction

Stiffened plate is one of the most frequently used structural components in welded structures. They are used as load-carrying elements of ships, bridges, offshore platforms, roofs, etc. In stability problems of welded structures the effect of initial imperfections and residual welding stresses should be taken into account. Many papers have been dealt with the stability and calculation of this kind of structures [1–4].

Two types of stiffened plates can be constructed: plate stiffened on one side (in the following briefly *stiffened plate*) and cellular plate. Cellular plates consist of two face plates and a grid of stiffeners welded between them. The cells produce a large torsional stiffness; thus, the cellular plates can be calculated as isotropic ones. Cellular plates have some advantages over stiffened ones as follows: (a) their torsional stiffness contributes to the overall buckling strength significantly, therefore, their dimensions (height and thickness) can be smaller, (b) their symmetry eliminates the large residual welding distortions, which can occur in stiffened plates due to shrinkage of eccentric welds. Therefore cellular plates can be cheaper than stiffened ones, as it will be shown in the next section.

In their previous studies, the authors have designed cellular plates with halved rolled I-stiffeners [5–7]. In the present study, these rolled stiffeners are replaced by welded T-stiffeners. The comparison of the cellular plates with the two different kinds of stiffeners shows that using welded T-stiffeners significant savings in mass and cost can be achieved.

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The formulae for the two kinds of stiffeners are nearly the same; thus, the formulae for halved rolled I-stiffeners are described and then the differences for welded T-stiffeners are given.

2. Bending and torsional stiffness of a cellular plate

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

$$B_x w'''' + 2Hw''^{\cdot\cdot} + B_y w^{\cdot\cdot\cdot\cdot} = p \tag{1}$$

where the torsional stiffness of an orthotropic plate is

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

ν is the Poisson ratio, and w is the deflection.

The corresponding bending and torsional stiffnesses are defined as

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

for cellular plates

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

where E is the Young modulus, G is the shear modulus, I_x and I_y are the second moment of inertias in two directions, and a_x and a_y are the distances between stiffeners in two directions.

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

for plates of quadratic symmetry

$$H = B_x = B_y. \tag{6}$$

Thus, the torsional stiffness of a cellular plate of quadratic symmetry equals to its bending stiffness.

3. Bending moments and deflections

Lee et al. [8] have solved the differential equation for rectangular orthotropic plates (Eq. (1)) supported at four corners by using a polynomial function.

They gave formulae for bending moments and deflections as a function of bending and torsional stiffnesses. In the case of a square cellular plate, the bending stiffnesses are equal to the torsional stiffness ($B_x = B_y = H$) and the maximum bending moment is

$$M_{\max} = 0.15pL^2 \tag{7}$$

and the maximum deflection is expressed by

$$w_{\max} = 0.025p_0L^4/B_x \tag{8}$$

where L is the plate edge length, p_0 is the factored intensity of the uniformly distributed normal load and p is the load intensity including the self mass of the plate.

Results for square isotropic plates according to Timoshenko & Woinowsky-Krieger [9] for $\nu = 0.3$ (they used a simple approximate energy model)

$$M_{\max} = 0.1404pL^2 \tag{9}$$

and

$$w_{\max} = 0.0249p_0L^4/B_x. \tag{10}$$

It can be seen that the constants are nearly the same.

4. Cellular plate with halved rolled I-section stiffeners

4.1. Geometric characteristics (Fig. 2)

The upper face plate parts can locally buckle from the compression stresses caused by bending. This local buckling is considered by using effective plate widths according to Eurocode 3 [10]

$$s_e = \rho s, s = \frac{a}{n} \tag{11}$$

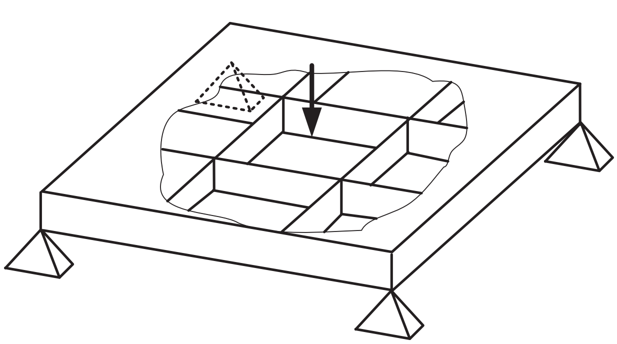

Fig. 1. A cellular plate supported at four corners.

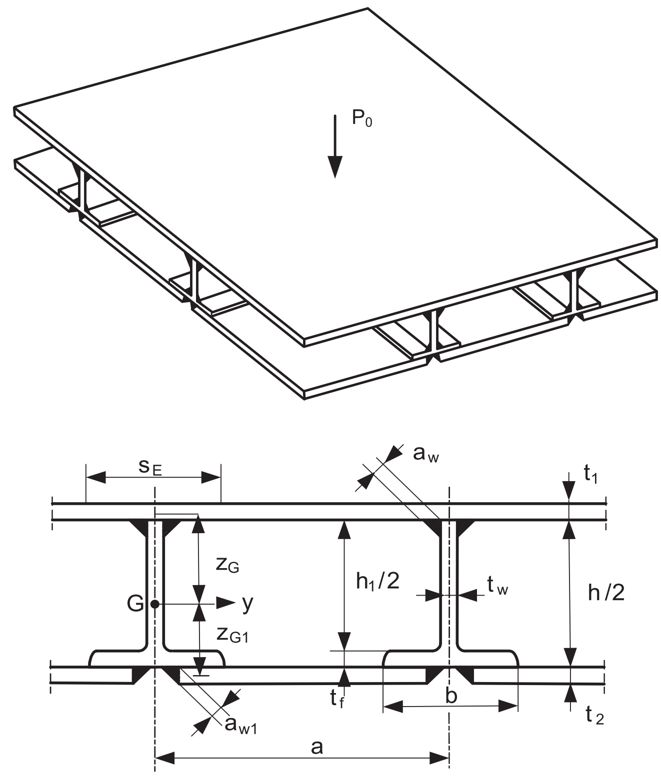

Fig. 2. Cellular plate and dimensions of halved rolled I-section stiffener.

$$\rho = \frac{\lambda_p - 0.22}{\lambda_p^2}, \lambda_p = \frac{s}{56.8\varepsilon t_1}, \varepsilon = \sqrt{\frac{235}{f_y}} \tag{12}$$

n is the number of spacing, and f_y is the yield stress. (See Fig. 1.)

Cross-sectional area of a halved rolled I-section stiffener

$$A_S = \frac{h_1 t_w}{2} + bt_f, \quad h_1 = h–2t_f. \tag{13}$$

Cross-sectional area of a stiffener with upper and bottom base plate parts

$$A = s_e t_1 + at_2 + A_S, \quad a = \frac{L}{n+1}. \tag{14}$$

Distances of the center of gravity

$$z_G = \frac{1}{A}\left[at_2\left(\frac{h}{2} + \frac{t_1}{2} + \frac{t_2}{2}\right) + bt_f\left(\frac{h_1 + t_1 + t_f}{2}\right) + \frac{h_1 t_w}{2}\left(\frac{h_1}{4} + \frac{t_1}{2}\right)\right] \tag{15}$$

$$z_{G1} = \frac{h + t_1 + t_2}{2} - z_G. \tag{16}$$

Moment of inertia

$$I_y = s_E t_1 z_G^2 + at_2 z_{G1}^2 + bt_f\left(\frac{h_1 + t_1 + t_f}{2} - z_G\right)^2 + I_{y1} \tag{17}$$

$$I_{y1} = \frac{h_1^3 t_w}{96} + \frac{h_1 t_w}{2}\left(\frac{h_1}{4} + \frac{t_1}{2} - z_G\right)^2. \tag{18}$$