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Thin-Walled Structures 45 (2007) 883–887
THIN-WALLED STRUCTURES
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Experimental tests of stability and load carrying capacity of compressed thin-walled multi-cell columns of triangular cross-section

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Available online 22 October 2007

Abstract

In the work the results of experimental tests of stability and ultimate load of compressed thin-walled columns of triangular cross-sections are presented. The tests have been conducted in order to prove that by substituting a single-cell cross-section by multi-cell one (at constant value of area) it is possible to exploit the material strength properties more efficiently. The experiments allow for verification of calculation methods proposed earlier and for the analysis of the inevitable imperfections' influence on the behaviour and load carrying capacity of the tested models.

Keywords: Multi-cell thin-walled columns; Stability; Load carrying capacity; Experiments

1. Introduction

Thin-walled columns of closed cross-sections (box-girders) have been applied in various structures for many years. In case of compressed thin-walled columns the local buckling occurs at stress value much lower than the value of material yield limit. Therefore the material strength properties are exploited to a small extent, even when the post buckling range is taken into account. The purpose of the investigation is to prove experimentally that substituting a single-cell column by a multi-cell one, with the assumption of constant cross-section area, it is possible to enlarge its carrying capacity.

In previous works [1,2] dealing with isotropic and orthotropic columns of a cross-section in form of regular polygon (square, hexagon) the authors showed analytically that the low values of local buckling stress of a single-cell thin-walled column subjected to compression can be increased several times due to application of multi-cell cross-section of the same area. In the meantime the values of global buckling stress decrease to a small extent and the values of ultimate stress increase slightly.

2. Problem formulation

Let's consider a thin-walled column of a cross-section in form of an equilateral triangle (Fig. 1a). The following notation is introduced where $t_0 = t_1$—wall thickness, $b_0 = 3b_1$—wall width (measured between intersections of lines halving walls thickness). Let us assume that the column height H equals the length of the half-wave of wall local buckling mode (or its multiple) caused by uniform axial compression.

The local buckling stress can be found from the formula:

$$\sigma_{cr0}^{loc} = k_0 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t_0}{b_0}\right)^2, \quad (1)$$

where k_0—stability coefficient, E—Young's modulus, ν—Poisson's ratio.

Regarding further considerations we assume that column walls are thin and subject to local buckling at very low stress values.

From nine longitudinal strips of a width b_1 a column of a three cell cross-section is built. The outline of the cross-section forms a regular hexagon (Fig. 1b). Each external wall of this column contacts with only one cell of rhomboidal form. As a parameter of cell number n, the number of cells contacting with one external column wall is assumed. Therefore in case of the cross-section shown in

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doi:10.1016/j.tws.2007.08.041

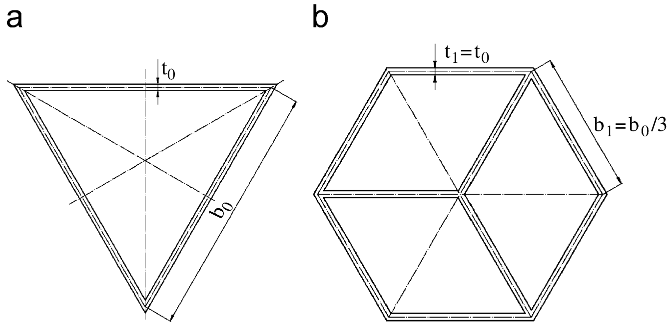

Fig. 1. Cross-sections of considered columns: (a) triangular-single cell, (b) three cells in form of regular hexagon.

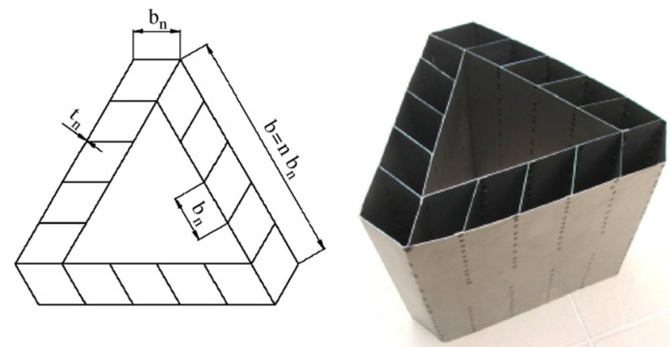

Fig. 2. Multi-cell triangular cross-section and model picture.

Fig. 1b $n = 1$.

$$\sigma^{\mathrm{loc}}_{\mathrm{cr1}} = k_1 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t_1}{b_1}\right)^2 = 9 \frac{k_1}{k_o} \sigma^{\mathrm{loc}}_{\mathrm{cro}}. \tag{2}$$

The buckling stress for uniformly compressed column of the cross-section shown in Fig. 1b can be calculated from the relation (2).

For long uniformly compressed columns k_0 and k_1 can be assumed as [2]: $k_0 = 4.53$ and $k_1 = 4.00$. Then the value of local buckling stress for a three-cell column of hexagonal outline is eight times bigger than for a column of triangular cross-section shown in Fig. 1a. It should be noticed that in both cases the cross-section area is the same $A_0 = A_1 = 3b_0t_0 = 9b_1t_1$.

Such advantageous, regarding local stability, change of thin-walled column of triangular cross-section to the three-cell column of hexagonal cross-section is disadvantageous with respect to the global (Euler) buckling.

For columns of equal areas of cross-sections, equal buckling length and made of the same material, the value of global buckling stress for a column of hexagonal cross-section is 2.25 times smaller than for a column of triangular cross-section.

The values of local and global buckling stress can be increased without changing the cross-section area, substituting the three-cell column of hexagonal cross-section by multi-cell column of a cross-section shown in Fig. 2.

The outline of the cross-section shown in Fig. 2 is the equilateral triangle of trimmed vertices and further on will be called "triangular". The parameter n denotes the number of cells contacting with the wider external wall. The cells have rhomboidal form of a side b_n and the cell length is equal to the column height H.

The cross-section shown in Fig. 1b is a particular case of the cross-section shown in Fig. 2 for $n = 1$.

According to the assumption that the considered columns have equal cross-section areas and external perimeters we obtain the following relations for dimensions b_n and t_n ($t_n = \mathrm{const.}$ for all column walls): $b_n = (2b_1/n+1), t_n = ((n+1)t_1/2n)$, for $n = 1,2,3,\ldots$, where b_1 and t_1—dimensions of the cross-section shown in Fig. 1b, for $n = 1$.

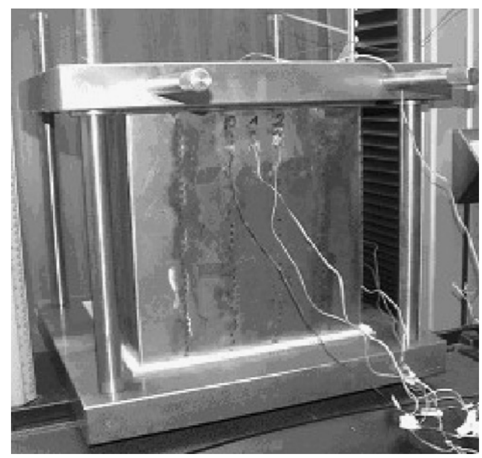

Fig. 3. Test set-up.

For columns of the cross-sections shown in Fig. 3 subjected to uniform compression all walls buckle simultaneously (any imperfections are lacking), then the walls can be treated as long plate strips of the stability coefficient $k = 4$.

Local buckling stress for a column of cell number parameter n can be found from:

$$\sigma^{\mathrm{loc}}_{\mathrm{cr\,n}} = \frac{\pi^2 E}{3(1-\nu^2)} \left(\frac{t_n}{b_n}\right)^2 = \alpha_n \frac{\pi^2 E}{3(1-\nu^2)} \left(\frac{t_1}{b_1}\right)^2,$$

$$\text{where} \quad \alpha_n \frac{(n+1)^4}{16n^2}, \tag{3}$$

It can be easily calculated that for the column of 15 cells ($n = 5$) the local buckling stress is 3.24 times bigger than for the three cell column ($n = 1$, Fig. 1b) and almost 26 times bigger than the local buckling stress for a single-cell column of dimensions $b_0 = 9b_5$ and $t_0 = 5/3t_5$ (Fig. 1a). The cross-section areas of columns are the same.

3. Experimental tests and numerical calculations

The experimental tests have been conducted on two steel models of thin-walled columns of triangular cross-section: one of a single cell and the second of rhomboidal cells ($n = 5$). The purpose of investigations was the analysis of