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On the Buckling of Thin Walled Stiffened Cylindrical Shells (TWSCS) under Uniform External Pressure

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Abstract

In this paper is analysed the buckling behaviour under uniform external pressure of cylindrical shells stiffened with stringers. The critical buckling pressure was determined according to the analytical calculation methodology presented in SR EN 1993-4-1:2007 [8] and also using numerical analysis with finite element method (FEM). The results obtained were verified experimentally by using a scale model of stiffened cylindrical shell.

Key words: *buckling, stiffened cylindrical shells, uniform external pressure, FEM*

Introduction

Thin walled cylindrical shells are commonly used in many applications, such as silos for storing bulk solids. Due to the dimensional characteristics, in particular the ratio medium radius – wall thickness that has high values, these structures are vulnerable to the buckling phenomenon [6]. For silo structures, an internal vacuum occurs due to discharge of the stored products, so that atmospheric pressure acts as uniform external pressure.

Theoretical and experimental studies [6], have shown that the buckling strength of these structures can be increased by means of stiffeners.

The critical buckling pressure was calculated according to SR EN 1993-4-1:2007 [8], by minimizing the equation (1) for integral values of j that represents the number of circumferential waves:

$$q_{cr} = \frac{1}{Rj^2}\left(A_1 + \frac{A_2}{A_3}\right) \tag{1}$$

where R is the shell mean radius and the terms A_1, A_2 și A_3 are presented in [8]. Their calculation expressions depend on: number of stringers, cross-sectional area of stiffener, moment of inertia of stiffener about middle surface of shell, torsional constant for stiffener, distance from centroid of stiffener to middle surface of cylindrical shell.

In the numerical calculation with FEM was used linear buckling analysis. In such analysis, the bifurcation point is determined for an ideal elastic structure.

The critical buckling load is calculated as:

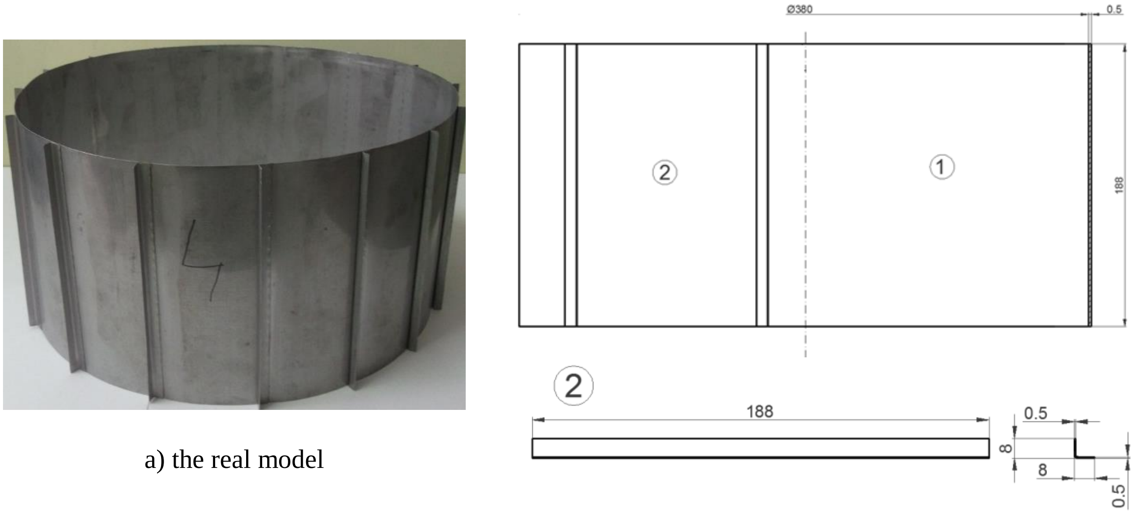
$$P_{cr} = \lambda_{cr} \cdot P \tag{2}$$

where λ_{cr} is the load factor determined with linear buckling analysis and P is the load applied to the structure. If a unit load is applied, the load factor λ_{cr} obtained represents the critical buckling load P_{cr}.

Dimensional Characteristics of the Analyzed Model

Thin walled stiffened cylindrical shell that was analyzed had the following dimensional characteristics: wall thickness $t = 0.5$ mm; mean radius $R_m = 190.25$ mm, length $L = 188$ mm.

The cylindrical shell had 16 stiffeners having the shape *equal leg angle* L 8x8x0,5, as can be seen in Figure 1.



a) the real model

b) model dimensions: 1 – cylinder with 16 stringers; 2 – stringer

Fig. 1. The analyzed model

The geometric dimensions were established based on the dimensions of the skirt at the base of a silo with a storage capacity of 140 m^3 (SPG 140), by using the similitude principles [7].

Numerical Results

Numerical analysis with FEM was made with finite element package ANSYS.

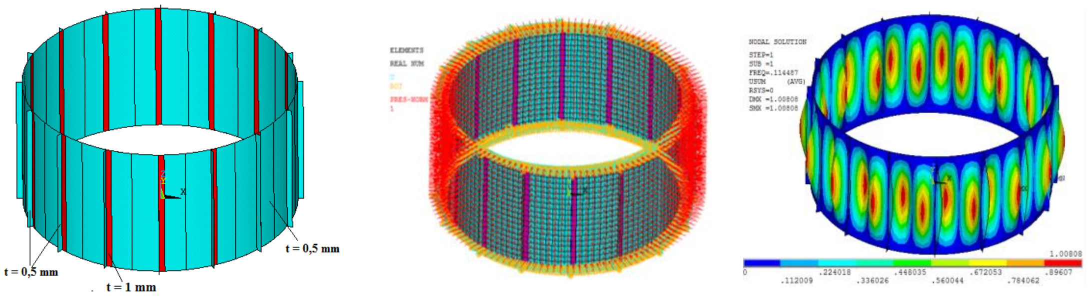
The cylindrical shell and the stringers were modelled as common body. At the joints, the wall thickness was considered to be the sum of the cylinder thickness (0.5 mm) and the stringer thickness (0.5 mm), as can be seen in Figure 2,a.

In order to model the stiffened shell, SHELL93 element type was used both for cylindrical shell and stringers.

In Figure 2,b is presented the finite elements model for the shell stiffened with 16 stringers with the loads (external pressure) and the boundary conditions (at both ends were blocked all degrees of freedom (both translations and rotations) in order to simulate the same conditions as were used in the experimental investigation).

In Figure 2,c is presented the deformed shape corresponding to the critical buckling pressure, obtained with linear buckling analysis.

As can be seen in Figure 2,c, the critical buckling pressure value is $q_{cr}^{num.,l.,p.} = 0.114$ N/mm^2.



a) geometric model b) finite elements model c) critical deformed shape

Fig. 2. Numerical calculation of critical buckling pressure

Experimental Results

In the present experimental work, a vacuum pump was used to apply the loading. The pressure value was measured with a manovacuumeter (fig. 4). The same method of loading was used in [1, 2, 3, 4, 5].

a) local buckling b) overall buckling

Fig. 3. Local and overall buckling shapes for stiffened shell under uniform external pressure

The stiffened shell was loaded until the pressure reached **0.5 bar (0.075 MPa)** and the both the shell and stringers buckled suddenly. The first dimples of the local buckling (fig. 3,a) appeared at external pressure value of **0.65 bar (0.065 MPa)** and preceded **t**he overall buckling.

Formation of the local dents was accompanied with claps. Then, the dents started growing and covered several adjacent stringers, process that was accompanied with a loud noise (fig. 3,b).

Analyzing the buckling deformed shape obtained both numerically (fig. 2,c), and experimentally (fig. 5), it can be seen that overall buckling occurs, covering both the cylindrical shells and the stringers.

As shown in Table 1, there is a good agreement between the value of critical pressure determined analytically and numerically (the difference is only 1.78%).

The stiffened cylindrical shell loaded experimentally buckled at a critical pressure value by about 50% lower than the value established theoretical. This aspect is in accordance with the provisions of SR EN 1993- 4-1:2007 [8] indicating the application of a reduction coefficient of elastic imperfections α_n whose recommended value is $\alpha_n = 0{,}5$, to account for the presence of geometric imperfections.

Table 1. Theoretical and experimental results on the value of the critical buckling pressure

Critical buckling pressure, q_{cr} [N/mm^2]			**Differences [%]**		
Analytical $q_{cr}^{\,an.,p.}$	Numerical $q_{cr}^{\,num.,l.,p.}$	Experimental $q_{cr}^{\,exp}$	Analytical-numerical	Analytical-experimental	Numerical-experimental
0.112	0.114	0.075	1.78	49.33	52.00

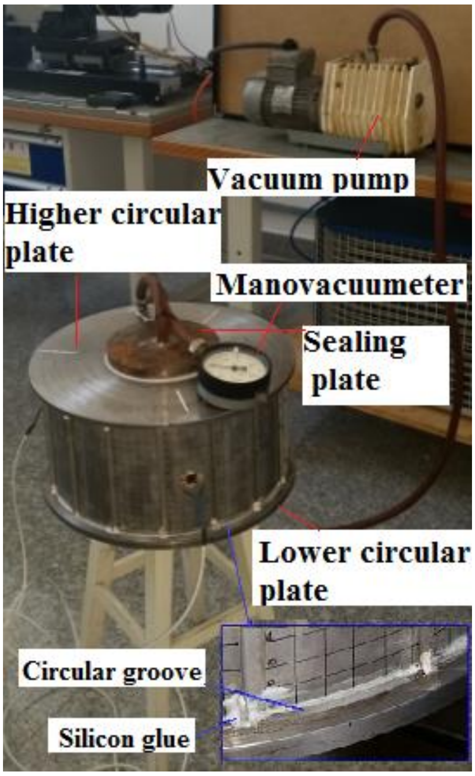


Fig. 4. Experimental test system

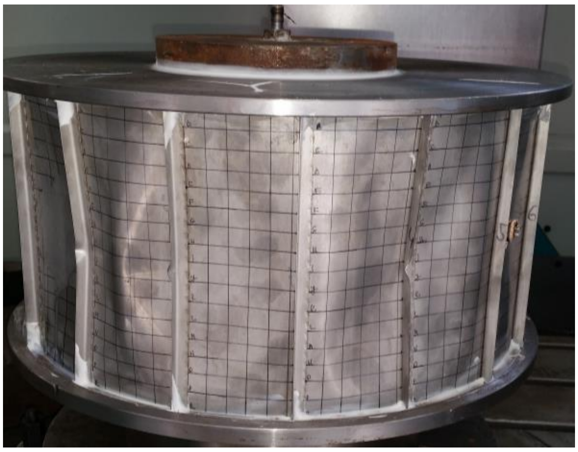


Fig. 5. Deformed shape obtained experimentally

Conclusions

In this paper is presented a comparative analysis on the buckling behavior of stiffened cylindrical shells subjected to uniform external pressure, using analytical, numerical and experimental methods.

The critical buckling pressure values shown in table 1 indicate a good agreement between analytical and numerical results. In the experiment, buckling occurred at a critical pressure value by about 50% lower than the theoretical value. This apect outlines the effect of the initial geometrical imperfections on buckling behavior of thin stiffened cylindrical shells subjected to uniform external pressure, because these imperfections have not been taken into account in the theoretical calculation.

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Studiul stabilității învelișurilor cilindrice subțiri rigidizate (ICSR) supuse la presiune exterioară uniformă

Rezumat

În cadrul acestui articol este analizată comportarea la pierderea stabilității a ICSR cu nervuri verticale, supuse la presiune exterioară uniformă. Valoarea presiunii critice de pierdere a stabilității a fost determinată pe baza metodologiei de calcul analitic prezentată în SR EN 1993-4-1:2007 [8] și pe baza analizei numerice utilizând metoda elementului finit (MEF). Rezultatele astfel obținute au fost verificate pe baza încercărilor experimentale ce au fost efectuate pe un model la scară de înveliș cilindric subțire rigidizat.