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Buckling and post-buckling behaviour of elastic seven-layered cylindrical shells – FEM study

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ABSTRACT

The paper is devoted to buckling and post-buckling problems of an elastic seven-layered cylindrical shell under uniformly distributed pressure. The shell is an untypical sandwich structure composed of main corrugated core and two three-layer faces. Numerical FEM model for the shell has been elaborated. The calculations have been performed with the use of the ANSYS code for elastic shells of different dimensions. The linear and non-linear analyses of the shells have been performed with the use of the finite elements method. Critical pressure and equilibrium paths for the family of seven-layered shells subjected to uniformly distributed external pressure are calculated. The influence of corrugation pitch of main core and the length of the shell on the critical pressure has been determined. The results of these investigations are presented on the graphs.

1. Introduction

The first sandwich structures were designed and made in the mid of 20th century. Libove and Butdorf [1] elaborated the theoretical model for sandwich plates with corrugated cores. Plantema [2] and Allen [3] presented basic monographs for sandwich structures. Objective basic research for sandwich structures were intensively conducted in further decades. Simitses [4], Noor et al. [5], Vinson [6], and Carrera and Brischetto [7] presented a review of computational models and theories for layered plates and shells. Carlsson et al. [8], Cheng et al. [9], Peng et al. [10], Magnucka-Blandzi and Magnucki [11], Isaksson et al. [12], Kazemahvazi and Zenkert [13], Kazemahvazi et al. [14] and Seong et al. [15] presented analytical and numerical-FEM modelling of sandwich structures with corrugated or metal foam cores. Magnucka-Blandzi [16] and Thai and Vo [17] described a sinusoidal shear deformation theory of functionally graded plates.

Stability problems of structures were extensively studied, first of all, for the purpose of the development of the aerospace engineering. The selected important papers and monographs related to these problems in chronological order are as follows: Hutchinson and Koiter [18], Budiansky [19], Grigoluk and Kabanov [20], Yamaki [21], Bushnell [22], Simitses [4], Bažant and Cedolin [23], Teng [24] and van der Heijden [25]. A review of recent studies on stability of liquid-containment shells of revolution is presented by Zingoni [26]. At present the studies of buckling problems concern single layer and multilayer structures. Malinowski and Magnucki [27] described optimal design of a sandwich ribbed flat baffle plate of a circular cylindrical tank. Jasion and Magnucki [28] theoretically investigated the elastic buckling of barrelled shells. Błachut and Magnucki [29] described strength, stability and optimisation of pressure vessels. Jasion [30] presented the stability analysis of shells of revolution. Belica et al. [31] studied dynamic stability of an isotropic metal foam cylindrical shell. Jasion et al. [32] calculated global and local buckling of sandwich plates with metal foam core. Szyniszewski et al. [33] described local buckling of a steel foam sandwich panel. Belica and Magnucki [34] investigated the stability of porous-cellular cylindrical shells under combined loads. Jasion and Magnucki [35] presented the post-critical behaviour of sandwich cylindrical shells with variable thickness. Jasion and Magnucki [36] analytically, FEM-numerically and experimentally studied the global buckling of the sandwich column. Magnucki and Jasion [37] analytically and FEM-numerically investigated the pre-buckling and buckling states of barrelled shells. Magnucki et al. [38] studied the strength and buckling of sandwich beams with corrugated core. Magnucki et al. [39] analytically and FEM-numerically studied the strength and buckling of a sandwich beam with thin binding layers between faces and a metal foam core. Jasion [40] presented the stabilisation of equilibrium paths of sandwich shells.

The subject of the present paper is a seven-layered cylindrical shell composed of a corrugated main core and two three-layered facings with steel foam cores. The seven-layered structure of the shell is a generalisation of the classical sandwich shells. The shell

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is subjected to uniformly distributed external pressure. Buckling and post-buckling behaviour of the shell will be numerically studied with the use of the FEM method in the ANSYS system. Structurally efficient designs were determined for seven-layered shell with the trapezoidal core with different corrugation pitch.

2. The structure of the seven-layered shell

The seven-layer cylindrical shell presented in the paper is a shell of revolution. The wall of the shell of a thickness t is composed of the main core and two three-layered faces. The cross section of the seven-layered shell is shown in Fig. 1. The main core of the shell is made of a thin steel trapezoidal-shape sheet. The main core is attached to two additional three-layered faces: outer and inner. Each of these three-layered faces has a metal foam core. The geometric parameters of the seven-layered shell are as follows: L is the length of the shell, R is the radius of the middle surface of the shell, t_{c1} is the thickness of the main core, t_0 is the thickness of the steel sheet (formed in the trapezoidal-shape), b_1 is the parameter of the main core, b_0 is the corrugation pitch of the main core, t_{c2} is the thickness of the core of the faces, t_{f1} and t_{f2} are the thicknesses of the inner and the outer layer of the faces, respectively. Between all layers of the shell, bonding conditions were imposed. In the research programme it is assumed, that all the steel layers and the steel foam of cores of the three-layer faces are homogenous and isotropic. The mechanical constants of the shell (Young's moduli and Poisson's ratios) are defined as: E_f and ν_f for all the steel layers, E_c and ν_c for the steel foam of cores of the three-layered faces. Similar structure with a sinusoidal corrugated main core was presented by Malinowski et al. [41]. They showed the results of numerical calculations of elastic buckling of shells for different geometrical parameters.

3. FEM model of the seven-layered shell

The FEM model for seven-layered cylindrical shell was built as shell-solid structures. The corrugated main core (t_0), the outer and inner layers of the thicknesses: t_{f2}, t_{f1} were modelled as the shell structures. A mid-surface of all layers has been modelled using the shell elements. The metal foam cores of faces are modelled as solid structures. The numerical model was prepared with the use of the ANSYS finite elements: SHELL181 and SOLID185. For the shell

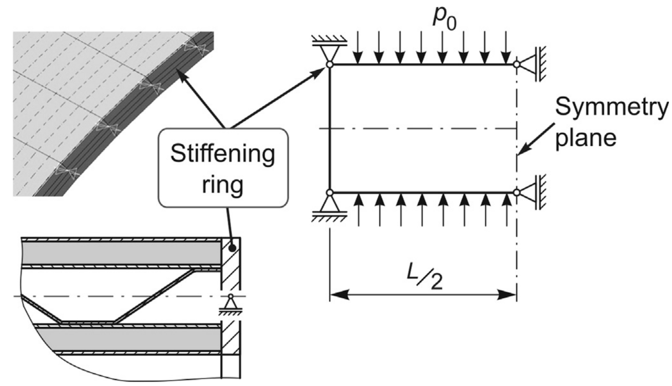

Fig. 2. FEM model and boundary conditions of seven-layered structure.

elements, four nodes and six degrees of freedom at each node have been used. The solid 186 element consists of eight nodes and three degrees of freedom at each node. The seven-layered cylindrical shell is modelled in the cylindrical coordinate system. The edges of the multilayer shell are closed by thin rings connecting the different layers of the seven-layer shell (Fig. 2). The corrugated core is bonded to the inner and outer three-layer faces. Rings placed on the outer edges of the shell are needed for structural reasons. The shell is simply supported on a circular lateral edge with the radius R. At the supported edge the radial and circumferential displacements are blocked. Only the longitudinal displacement and all rotations are allowed. In the symmetry plane of the shell, the longitudinal displacements are blocked (Fig. 2). Such support corresponds to the boundary conditions BC2f described in Eurocode 3 [42]. The uniformly distributed radial external pressure p_0 was added on the outer cylindrical layer of the thickness t_{f2}.

4. Elastic buckling – critical pressure

The critical pressure is calculated for the family of seven-layered cylindrical shells for selected geometric variables. The design variables are as follows: length L of the shell (L=3, 4, 6 and 8 m) and corrugation pitch b_0 of the main core (b_0=0.08, 0.1, 0.125 and 0.15 m). The following constants of geometric data are assumed: the radius of the middle surface of the shell R=2 m; the total thickness of the shell wall t=53.6 mm

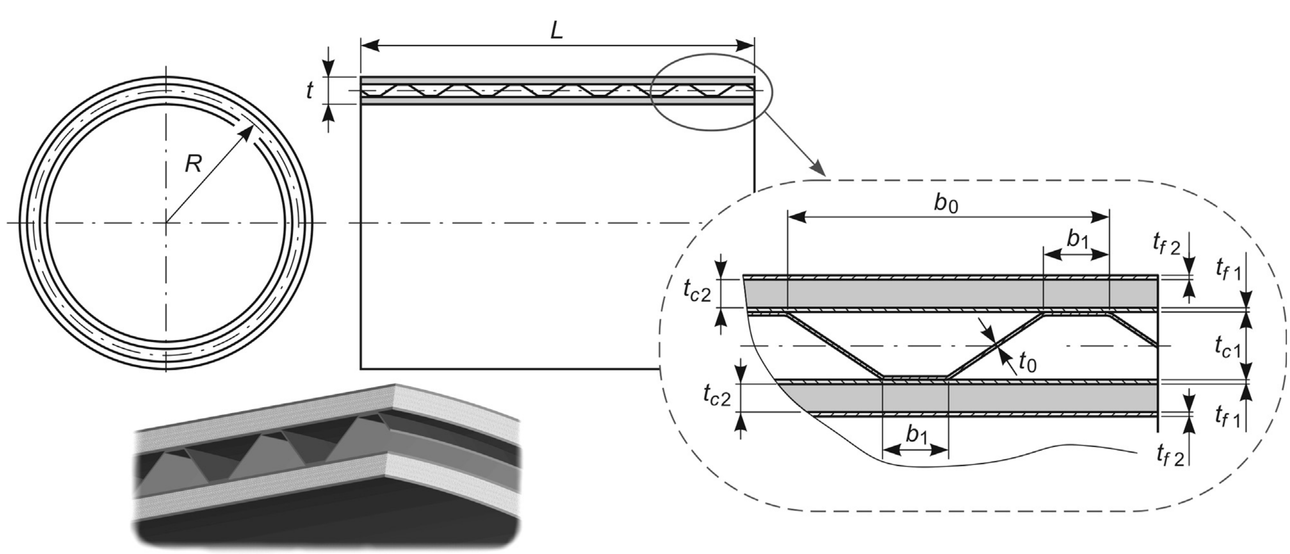

Fig. 1. Geometry of the seven-layered cylindrical shell.