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STABILITY AND SUPERCRITICAL BEHAVIOUR OF THIN-WALLED CYLINDRICAL SHELL WITH DISCRETE AGGREGATE IN BENDING

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Abstract. A 3-D geometrically and physically nonlinear problem of elastoplastic deformation, loss of stability, and supercritical behaviour of a cylindrical shell with discrete aggregate loaded in bending is analyzed. The numerical analysis of the problem is based on the FEM and an explicit cross-type time integration scheme. The results of the analysis are compared with the experimental data.

1. Introduction

In most papers, the stability of thin-walled cylindrical shells is studied without considering initial imperfections. Known solutions of this problem, obtained by analytical methods in the linear approximation, excluding stress moment and nonlinearity subcritical state of cylindrical shells [1], overestimate the critical load values [2-4]. The stability of cylindrical shells filled with granular materials is poorly known. Below the results of numerical studies of geometrically and physically nonlinear formulation of loss of stability under bending of thin-walled cylindrical shell filled with sand are shown. The reliability of the calculation results is confirmed by experimental data.

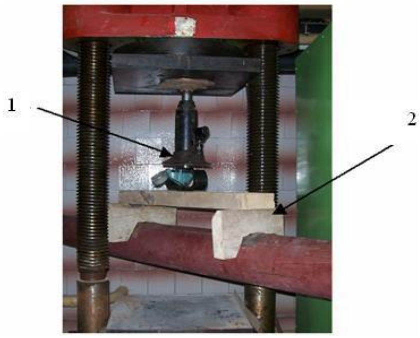


Fig. 1. Experimental assembly: 1 – thrustor, 2 – loading device.

2. The experimental method for studying the stability of thin-walled shell

Experiments were performed on thin-walled steel tube (1), outer diameter R = 8 cm, the wall thickness h = 0,075 cm (h/R = 0,0094), the length L = 250 cm. The tube is filled with sand. It is

section of the shell at different stages of loading (*u* is the vertical displacement of the loading device on the Fig. 3 and below). Figure 5 compares the zone of shell loss of stability in the residual position obtained in the calculation (a) and experiment (b).

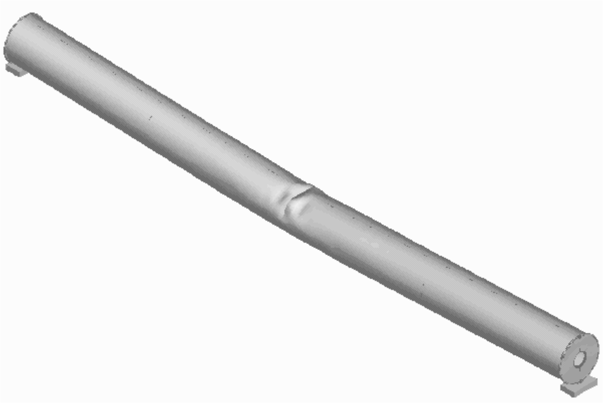


Fig. 3. Final shapes of the deformed shell.

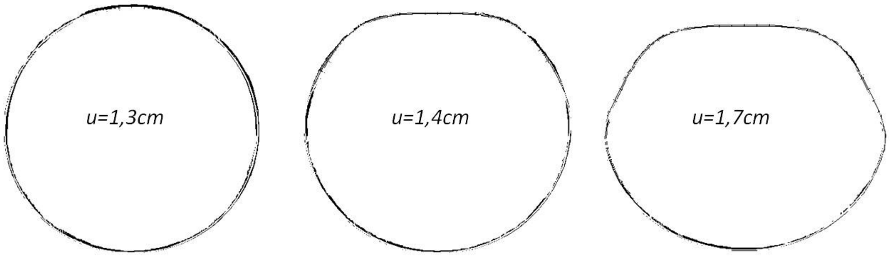
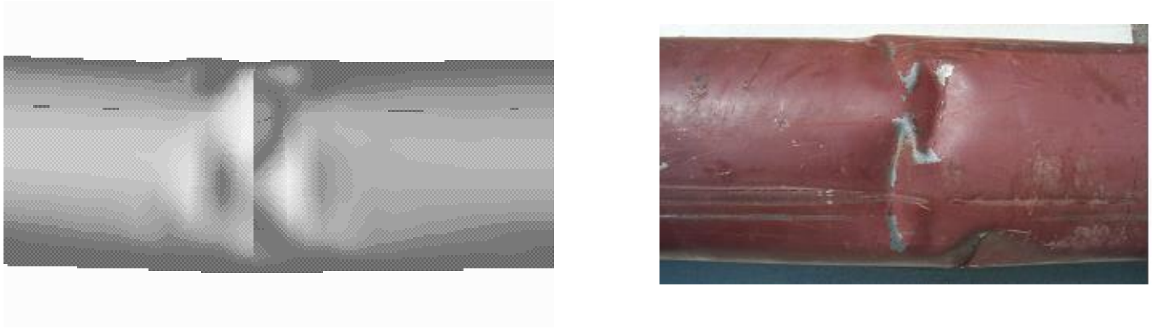


Fig. 4. Central cross section of the shell at different stages of loading.



a) b)

Fig. 5. Zone of shell loss of stability in the residual position in the calculation (a) and experiment (b).

Figures 6, 7 show graphs changes depending on *u* the following functions:

- contact force on the loading device (solid line - experiment, the dotted and dashed lines - calculation of nonlinear and linear (Fig. 2) of deformation curve, respectively);
- parameter of wrinkling *DR* [7]

$$DR = \sum_{i=1}^{N} |y_i - y_s| / y_s , \qquad y_s = \sum_{i=1}^{N} y_i / N , \tag{2}$$

which characterizes the derivation of the vertical coordinate of y nodes of finite element mesh of shell from the average in the area of zone formation of corrugations.

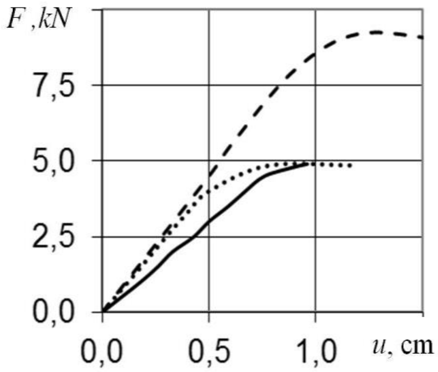


Fig. 6. Contact force *F* on the loading device versus *u*: solid line is the experimental result, the dotted and dashed lines are calculations of nonlinear and linear of deformation curve.

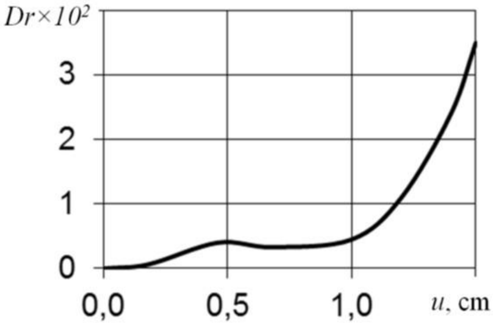


Fig. 7. Parameter of wrinkling *DR* versus *u*.

Analysis of the results of calculations and experiments shows that local crosswise dimple of rhombic type is formed by moving the loading device 1 cm in the middle part of the cylindrical shell. Loss of stability of the shell is marked by a heavy increase in the parameter of wrinkling DR on the graph of its depending on the vertical displacement of the loading device u. With further loading, the length of dimple increases in the circumferential direction until it reaches approximately half the diameter of the shell. Then its development is stopped. Next loading leads to expansion of the zone of loss stability in the circumferential direction of the shell due to the formation of new dimples located chequer-wise relative to the first. Along the length of the shell loss stability in the considered range of loading does not exceed half of its diameter.

In magnitude of the critical load at which the shell loses stability and computational complex "Dynamics-3" when using a non-linear deformation curve (Fig. 2) and the experiment give similar results. Application of the model in the calculation of elastoplastic deformation with linear hardening overstates the critical load of about 2 times. The disarrangement between calculations and experiments on the number of dimple, their location and size is explained by inaccuracy in the experiment (imperfections of the specimens shape, symmetry breaking in the loading conditions) and simplifications in the calculation scheme (taking into account the symmetry of the computational domain as viewed ¼ of the shell).

Analysis of stress-strain state in the zone of loss of stability showed that longitudinal stresses are prevailing here. Longitudinal stresses change sign and increased circumferential tensile stresses on the inner surface of the shell in the area of the first dimple in the moment of loss of stability (compressive stress change into the tensile stress). The magnitude of the longitudinal stress reaches the yield stress, which indicates the occurrence of plastic deformation in this zone. Longitudinal stresses on the outer surface at this point remain compressive and their absolute value also exceeds the yield stress. Thus, the formation of dimple in the shell occurs in the presence of plastic deformation and leads to an increase in the area of the moment of tilts in a complex state of stress.

5. Conclusions

Computational model [5-7] is qualitatively correct and acceptable accuracy describes elastoplastic deformation, loss of stability, and supercritical behavior of thin-walled cylindrical shell with discrete aggregate under bending. Non-linear hardening model must be used in the study of shell loss of stability in elastoplastic field, as the critical load is significantly dependent on the current tangent modulus.

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