SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
14 (2008)

POSTBUCKLING BEHAVIOR OF SADDLE LOADED SHELL

Doubravka STŘEDOVÁ, Petr TOMEK

Department of Mechanics, Materials and Machine Parts

1.Introduction

The thin-walled shells are generally considerably sensitive to a loss of stability. Sometimes this leads to a collapse of the whole structure. The limit load is often influenced by initial imperfections of the real shells in comparison to the limit load of the ideal shells. The imperfections may be entered into the design already during production as the imperfections of the shape, distribution of material characteristics, real load, real boundary conditions, etc. Various imperfections may be introduced into the design also deliberately because of the requirement for a gradual, controlled crash of the structure. Especially in the automotive industry, the controlled deformations of the deformation zones assembled of thin-walled structural parts are often used. Of course, the price of the structure plays important role too.

This article is devoted to the post-buckling behavior of cylindrical shells loaded in radial direction by a solid punch. For example, it can be represented by a thrust of the solid saddle into a horizontal cylindrical shell of tank cars. Firstly, the computer analysis of the stability of the preliminary model is performed. On the basis of it, the real experimental model is made. The experiment, which reveals some differences and the actual behavior of the numerical model, follows. The main contribution of this article is to tune the numerical model so that the differences between calculation and experiment are minimal.

2. Preliminary numerical analysis

In order to examine post-buckling behavior of shells, it is necessary to adjust the model and numerical procedure so that a sudden loss of stability and divergence of calculation is avoided. The computational model with supported edges is chosen for a preliminary numerical analysis. The choice of the boundary conditions is based on comparison between both the numerical and analytical results supplemented with experiments [1]. Dimensions (see ***Fig. 1***), material parameters and calculation are listed below.

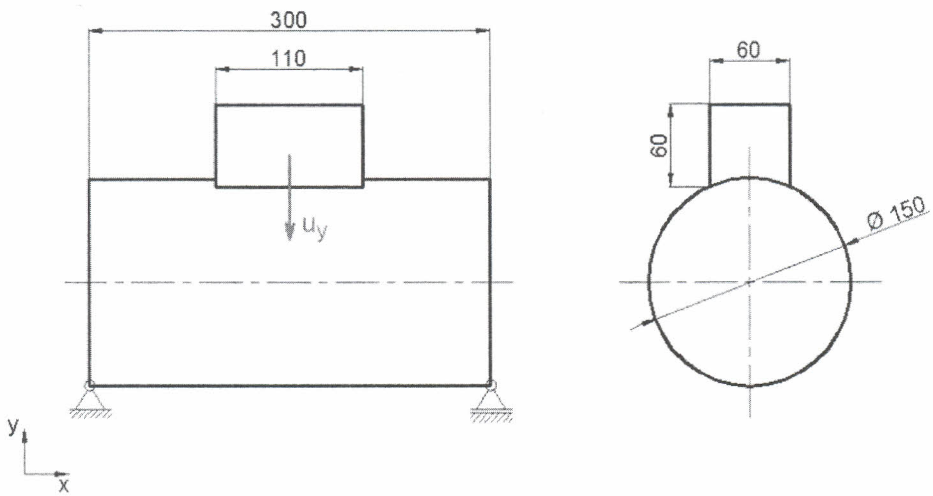

Fig. 1 *Dimensions of the numerical and experimental models*

The thickness of the cylindrical part of the model is δ_1 = 0,6 mm, circular peripheral covers δ_2 = 8 mm. The saddle is in comparison to the cylindrical shell stiff, therefore a theoretical wall thickness of the saddle is chosen δ_3 = 30 mm. For non-linear elastic-plastic analysis, von Mises's bilinear model of material with Young's modulus of elasticity $E_1 = 2{,}1.10^5$ MPa, Poisson's number μ = 0,3, tangent modulus E_{tang} = 20 MPa, and yield strength R_y = 218 MPa is chosen. The whole model is meshed by element SHELL 4 node 181. The *displacement control strategy* is used in the analysis.

The results of numerical analysis of examined shell (see ***Fig. 2***) show that the model repeatedly loses its stability (non-linear buckling). The first loss of stability occurs when the vertical displacement of the saddle is $u_y \approx 1$ mm. The instability is accompanied by visible deformations of the computational model. A new equilibrium state is achieved. The deformed shell performs material hardening due to increasing load. The second loss of stability occurs when $u_y \approx 30$ mm. This loss of stability is accompanied again by redistribution of deformation to another shape. The analysis, however, ceases to converge and collapses. It is caused by a sudden change of the loading curve due to the loss of stability. A redistribution of the deformation into apparent strong wave in the middle of the model is visible (see ***Fig. 3***).

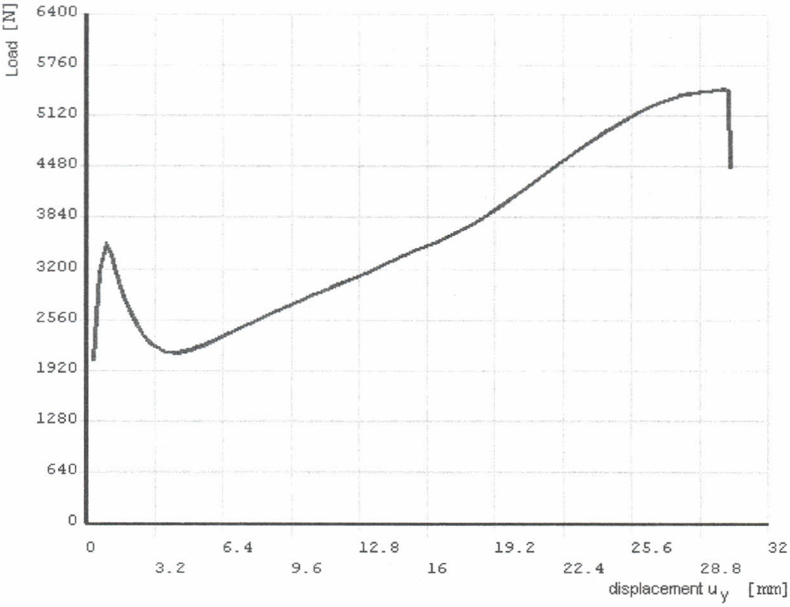

Fig. 2 *Loading curve of preliminary numerical analysis*

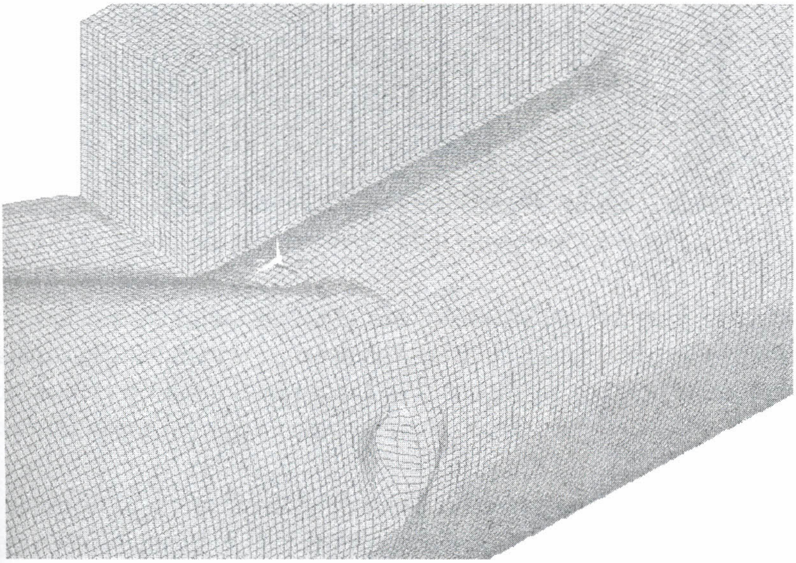

Fig. 3 *Deformed shape, u_y = 30 mm*

3. Experiment

Based on preliminary numerical analysis, the experimental model with same dimensions as the numerical model in Figure 1 is made. The actual thickness of the cylindrical shell is δ_1 = 0,56 mm and of the cover is δ_2 = 8 mm. The saddle is made of square tube 60x60x3-110 mm. For the sake of achieving a sufficient stiffness of the saddle, the square tube is inside longitudinally reinforced and further equipped with thick covers. The saddle together with the covers are welded to the cylindrical shell, see ***Fig. 4***.

The loading force acting on the saddle was recorded throughout the course of the experiment. The output is a diagram of load vs. displacement shown in ***Fig. 6***. The experiment was terminated when the vertical displacement of the saddle is u_y = 65 mm. The deformed model is shown in ***Fig. 5***. Comparing the results of preliminary analysis with the experiment (see ***Fig. 2*** and ***Fig. 6***), a significant difference in loading forces is apparent. The reason probably is a lower thickness of the real cylindrical shell and further, lower carrying capacity due to its initial imperfections.

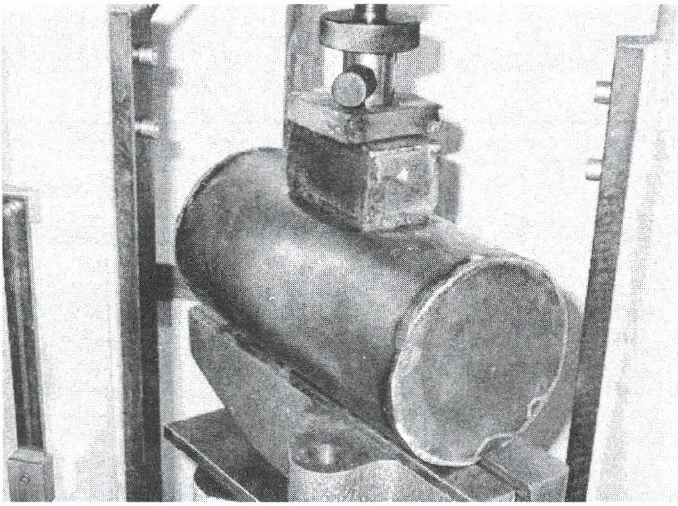

Fig. 4 *Experimental model mounting in the press*

Furthermore, real material characteristics of the real shell were different from initial values specified in the preliminary numerical analysis. The material characteristics of the cylindrical shell were reached by means of a tensile test. Based on these facts, a new numerical model with real geometrical characteristics and real material characteristics was created.

The influence of initial imperfections in carrying capacity of the analyzed cylindrical shells is not taken into consideration. It is a subject of a future research.

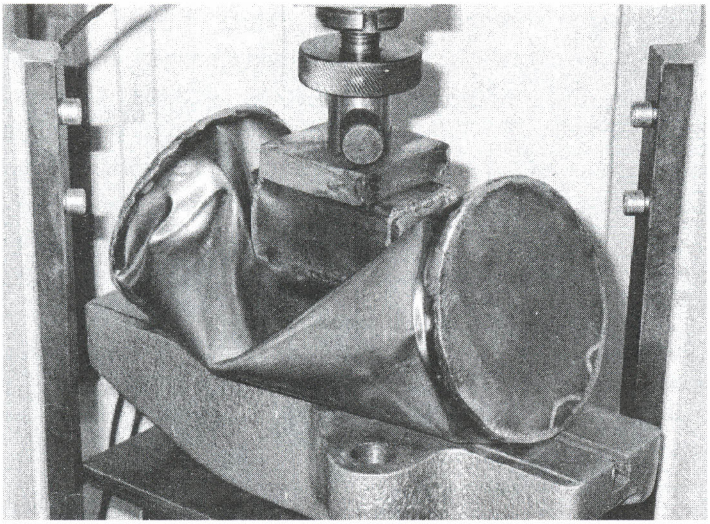

Fig. 5 *Finish of the experiment, maximal displacement*

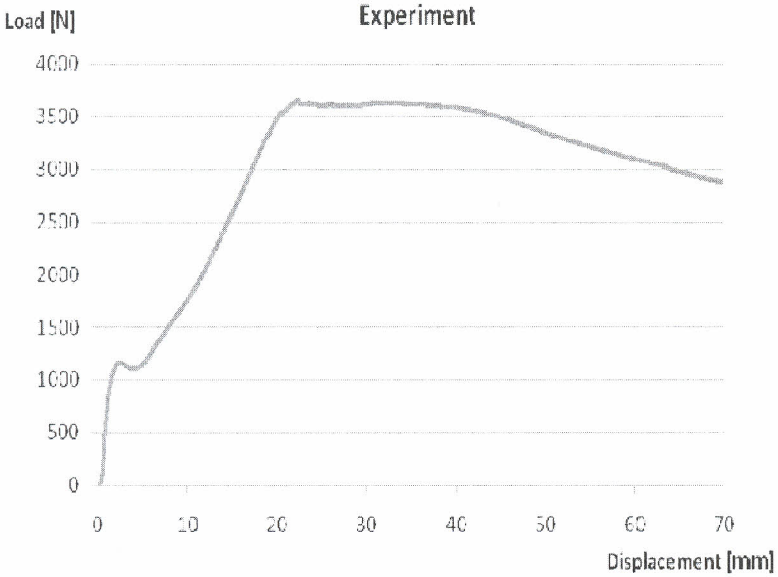

Fig. 6 *Loading curve of the experiment*

4.Numerical analysis

Overall dimensions of the new numerical model are identical to ones in ***Fig. 1***, i.e. thickness of the shell is $\delta_1 = 0{,}56$ mm and of covers $\delta_2 = 8$ mm. The thickness of the saddle is due to a sufficient stiffness $\delta_3 = 30$ mm. Von Mises's bilinear material model with Young's modulus of elasticity $E_1 = 2{,}1.10^5$ MPa, Poisson's number $\mu = 0.3$, modified yield strength $R_y = 170$ MPa and tangential modulus $E_{tang} = 20$ MPa is considered. The shell and saddle are again meshed by element SHELL 4 node 181. When using more complex element (SHELL 8 node 281) no significant changes in results are noticeable. The *displacement control strategy* is used in the analysis. Changing the material characteristics and geometry, the nonlinear analysis is performed. Both the elastic-plastic material and large displacements are used. The equilibrium curve is shown in ***Fig. 7***. ***Fig. 8*** represents a deformed shape for a maximum vertical displacement of the saddle u_y = 66 mm. Two following cases of loss of stability happen due to an increasing load. The first one occurs for vertical displacement $u_y \approx 1$ mm and the second one for $u_y \approx 26$ mm. In case of the preliminary calculation described in paragraph 2, the collapse of computational procedure occurred after the second loss of the stability. Now, the situation is different. The analysis continues which may be explained by a softer structure due to lower material characteristics. The sharp changes in the equilibrium curve are not expected.

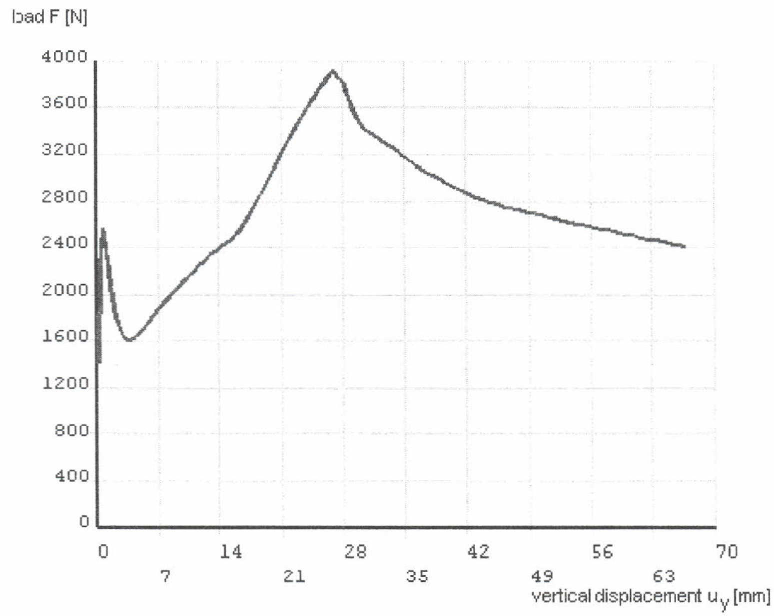

Fig. 7 *Loading curve of the numerical analysis*

Fig. 8 *Deformed shape, u_y = 66 mm*

5.Conclusion

The deformed shapes of experimental and numerical models are almost identical. The deformations in vicinity of the covers are in a good accord (see ***Fig. 9***). Mainly, the number and location of the waves is worthwhile noting. ***Fig. 10*** shows uneven deformation of the experimental model regard to the longitudinal plane ZY. The reason could of it be an influence of initial imperfections which are not prescribed to the computational model.

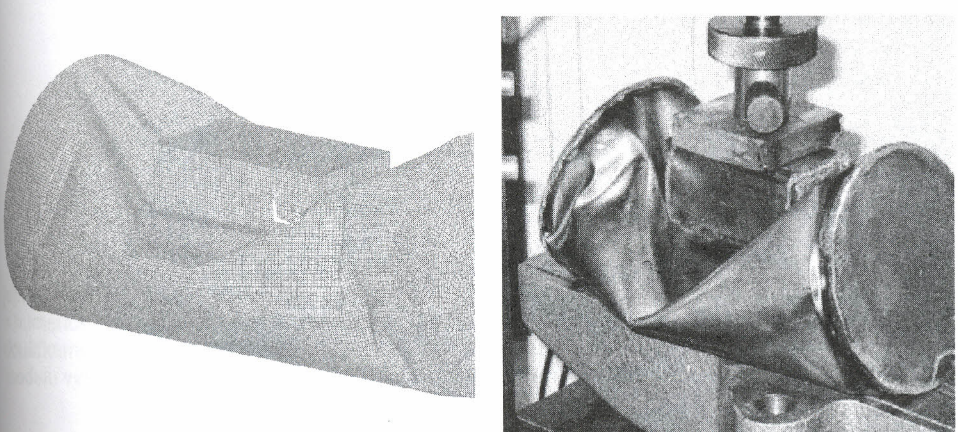

Fig. 9 *Comparison of deformed shapes*

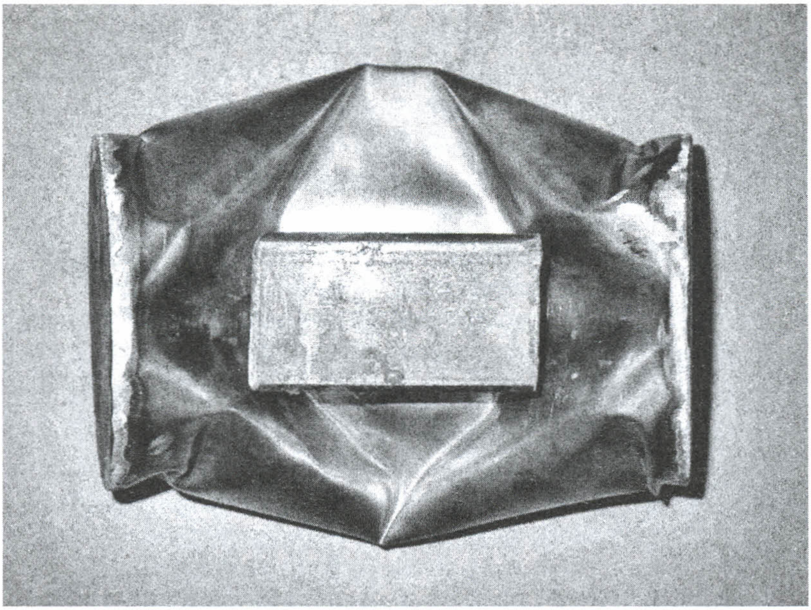

Fig. 10 *Deformation of the experimental model*

The considerable difference between both the experimental and computational loading curves, namely at the first loss of stability, may be explained by influence of the initial imperfections of the experimental model. The experimental value of the limit force F_{LIM} is 50% lower than the computational one. The first loss of stability occurred in the real shell slightly later because of the adjustment of clearances between the shell and basement. The difference in the post-buckling area may be influenced by a simplified von Miseses bilinear model of material without hardening of the real material. It is neglected in the first phase of this research. Despite of all these differences, a relatively good consistency in the behavior of numerical and physical model is achieved.

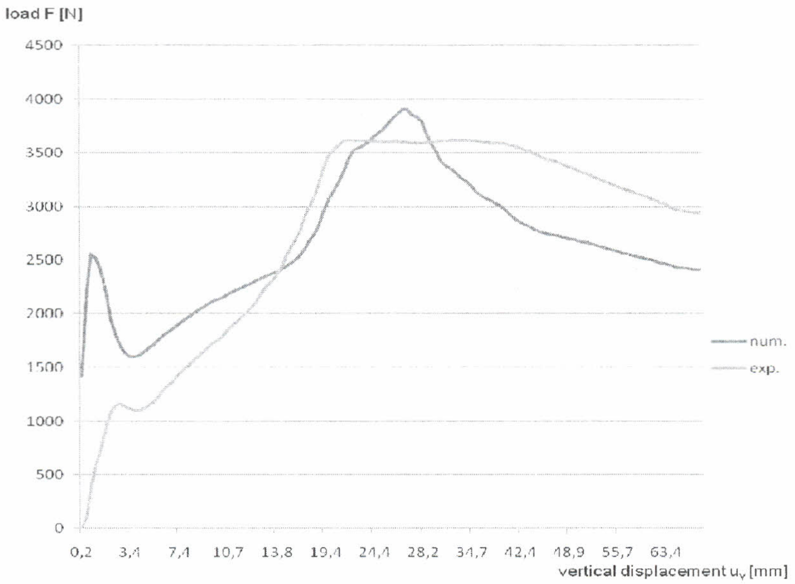

***Fig. 11** Comparison of loading curves*

Submited: 21.05.2009

References

1. KŘUPKA, V. *Buckling and limit carrying capacity of saddle loaded shells*; ECCS Colloquium on Stability of Plate and Shell Structures, Ghent University, 6 – 8 April (1987), pp. 617 – 622
2. KŘUPKA, V., SCHNEIDER, P. *Stavba chemických zařízení I, Skořepiny tlakových nádob a nádrží;* 3. vydání; PC-DIR spol. s.r.o. – Nakladatelství Brno; December (1994), 272 s.; ISBN 80-214-0570-8

Resumé

POKRITICKÉ CHOVÁNÍ RADIÁLNĚ ZATÍŽENÉ VÁLCOVÉ SKOŘEPINY

Doubravka STŘEDOVÁ, Petr TOMEK

Tento článek pojednává o ztrátě stability válcové skořepiny při vtlačování tuhého razníku do jejího pláště. Dále obsahuje porovnání pokritického chování reálné válcové skořepiny s numerickým modelem. V numerickém modelu tvořil razník a skořepina jedno těleso s různými tloušťkami stěn. Dosažené výsledky (deformace a průběh zatěžující síly) upraveného numerického modelu vykazovaly přijatelné odchylky od reálné skořepiny.

Summary

POSTBUCKLING BEHAVIOR OF SADDLE LOADED SHELL

Doubravka STŘEDOVÁ, Petr TOMEK

This article deals with the loss of stability of the cylindrical shell subjected to a punch of the stiff body – supporting saddle. It also compares post-buckling behavior of the real experimental cylindrical shell with the numerical model. The numerical model together with the saddle is created as one body. The resulting loading curves of both the real model and the computational model are in a relatively good accord. The differences will be studied within a future research where the emphases will be put on the initial imperfections.

Zusammenfassung

NACHKRITISCHES VERHALTUNG DIE ZYLINDRISCHE SCHALE

Doubravka STŘEDOVÁ, Petr TOMEK

Dieser Artikel behandelt einen Stabilitätsverlust der Zylinderschale bei Einpressung von einem festen Pressstempel in ehre Mantelfläche. Der Artikel umfasst eine Vergleichung des Nachkritischen Verhalten von der wirklichen Zylinderschale und von einem numerischen Modell. In dem numerischen Modell bilden der Stempel und die Zylinderschale einen Körper mit unterschiedlicher Wändestärke. Erzielte Ergebnisse (Deformation und Belastungskräfteverlauf) des eingeordneten numerischen Modell haben annehmbare Abweichungen von der wirklichen Zylinderschale angezeigt.