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# THE EXPERIMENTAL VERIFICATION OF THE LATERALLY LOADED CYLINDRICAL SHELL WITHOUT INITIAL IMPERFECTIONS

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**Abstract:** The main purpose of the research is to determine the influence of initial imperfections on the loss of stability of the laterally loaded cylindrical shell. However, in this phase of research, there are not any initial imperfections added on purpose to the examined structure. This article focuses on the verification of the process of loss of stability itself. Attention is devoted to the match of the loading curves and limit load of occurred loss of stability. The results of the fully nonlinear numerical analysis and experiment on the hydraulic press are compared.

**KEYWORDS:** cylindrical shell, saddle support, stability, FEM, experiment

## 1 Introduction

Further discussed topic belongs to the area of thin-walled shell structures. The purpose of ongoing research is to determine the influence of initial imperfections on the loss of stability of the laterally loaded cylindrical shell [1]. However, this article focuses on one of the basic parts of this problematics - verification of the deformation process itself. In this phase of research, there are not any initial imperfections added on purpose to the examined structure. The considered structure is part of a road tank (for example [2]), which was simplified to the form of a cylindrical shell located on one saddle support [3]. Two models are closely described: the ideal numerical model and the experimental model. The results of the fully nonlinear numerical analysis and experiment on the hydraulic press are compared. Attention is devoted to the match of the loading curves. Limit load of occurred loss of stability is monitored too. The main goal is verifying a match of the behaviour of the experimental and numerical model of given geometric parameters. The most important geometric parameters are the embracing angle of the saddle support and the wall thickness of the shell. If sufficient match is achieved, the verification on models with an intently added initial shape imperfection will follow in the next phase of the research.

## 2 Parameters of laterally loaded cylindrical shell

The **basic geometric parameters** of the model of the laterally loaded cylindrical shell are shown in Fig. 1. For the description of the chosen variant, the most important are the shell length L = 300 mm, the radius R = 75 mm and the shell wall thickness t = 0.53 mm. The selected variant corresponds to dimensionless parameter R/t = 141.5. At both ends is the shell ended by flat circular covers of thickness $t_1$ = 16 mm. This thickness ensures sufficient rigidity of the covers and prevent their excessive deformation. Thereby, help to avoid of negative influence on analysed results. In the middle of the cylindrical shell is firmly connected a rigid saddle with a width b = 20 mm and embracing angle 2θ = 120°. These dimensions have been chosen with regard to the possibilities of model production and supporting in the hydraulic press.

The **numerical model parameters** of the ideal laterally loaded cylindrical shell are in accordance with the parameters of Fig. 1. A combination of simple support in two edge nodes of finite element mesh (points A, B see Fig. 1) and prevention of the saddle support from lateral displacements and tilting was chosen as boundary condition. The shell may thus lose stability in both the symmetrical and the non-symmetrical shape according to the vertical plane passing through the axis of the cylindrical shell. Vertical force F is introduced into the numerical model through the saddle. The undeformed numerical model is shown in Fig. 2 [1].

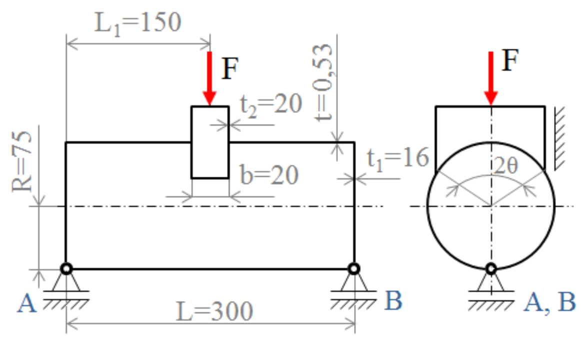

Fig. 1 Geometric parameters of the experimental and numerical model.

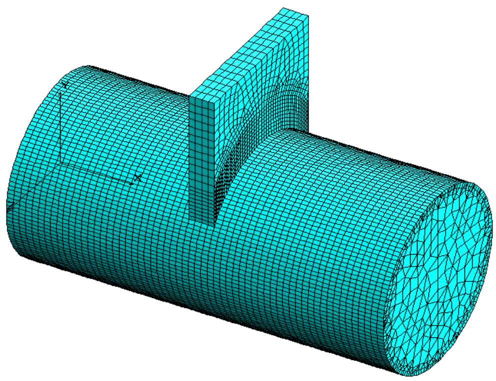
Fig. 2 Example of undeformed model (2θ = 120°).

For the best approximation, it is necessary to compare the behaviour of the real experimental shell with the results of fully nonlinear numerical analysis. Geometric nonlinearity (large displacements) and material nonlinearity (plasticity) are therefore taken into the consideration. The von Mises bilinear model of elastic-plastic behaviour of the material with yield strength $R_{p0.2}$ = 189 MPa is used. Where for the elastic region is considered a Young's modulus of elasticity E = 1.9 · $10^5$ MPa and for the plastic region a slight reinforcement by using a tangential module $E_T$ = 19 MPa. The Poisson number μ = 0.3 is considered. For the strategy of controlling the iteration process was selected the method of arc-length increment of the loading curve. A mesh consisting of four-node shell elements SHELL4T is constructed for numerical analysis. The numerical model of this ideal shell does not consider any deliberately added initial imperfections. The numerical analysis was carried out by means of a computer program COSMOS/M [4] based on the finite element method (FEM).

The **parameters of the real experimental** model of the laterally loaded cylindrical shell without deliberately inserted initial imperfections are shown in Fig. 1. An example of undeformed experimental model is shown in Fig. 3. The same figure shows that it is a compact model where both the saddle and the covers are welded to the shell. For conformity with the numerical model, it was important to achieve same boundary conditions - simply supported. Which would allow the shell to incline slightly to the side if needed. Only steel supports are used in this case. On both sides, the experimental model is placed on a pair of sheet metal stripes (see Fig. 3) in a hydraulic press. The bottom plate with thickness of 16 mm provides sufficient rigidity and stability for the support while the narrow upper plate with thickness of 5 mm allows the model to be placed only in a small area under the lid. There were always two short cylindrical rods of 12 mm diameter between the bottom plate and the hydraulic press base plate. On both sides of the model, the supporting is realized in the same way. The arrangement in this form makes possible the very slight rotation of the shell during loading (in the z-axis direction).

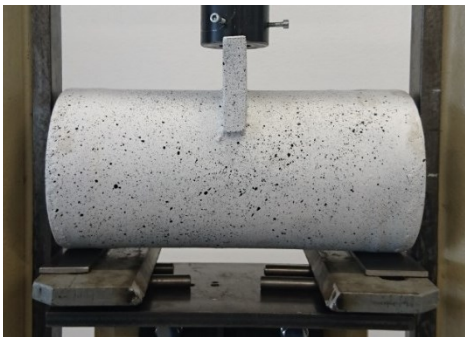

Fig. 3 Supported experimental model in the hydraulic press.

Fig. 4 Deformed experimental model at the end of the loading.

## 3 Evaluation of the results

The following lines evaluate the results of the numerical analysis of the ideal model and the experimental model of the laterally loaded cylindrical shell.

**The loading curve of the numerical model** of the ideal laterally loaded cylindrical shell is shown in Fig. 5. It shows the dependence of the limit load acting on the shell through the saddle and vertical displacement of the saddle $u_y$. During loading, there is one loss of stability in the form of a non-linear collapse (i.e., an axially symmetrical shape of loss of stability). This is an illustrative example where the carrying capacity of the structure suddenly and significantly decreases soon after reaching the peak of the loading curve. The described loss of stability occurs in computational step 251 with a vertical displacement value of $u_y$ = 0.59 mm and after reaching the limit load $F_{NUM}$ = 7225 N. The course of the loading curve ends at a vertical displacement value $u_y$ = 10.32 mm in the computational step 580. Termination of the calculation procedure is probably due to second loss of stability.

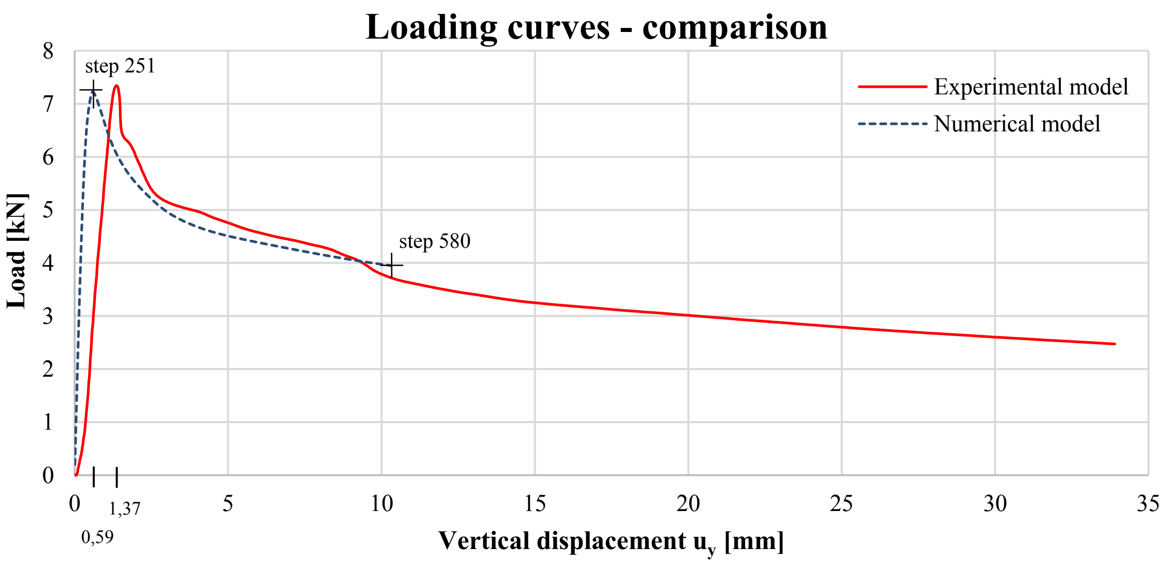


Fig. 5 Loading curves – comparison of the experimental and numerical model.

The result from loading of the experimental model in the hydraulic press is a set of values of the load applied to the saddle and the corresponding vertical displacements of the moving part of the hydraulic press. The loading curve was directly obtained by the plotting of these values into the graph. For better comparison, both loading curves are shown together (Fig. 5).

**The loading curve of the experimental model** is shown in Fig. 5. One significant loss of stability (in the form of a nonlinear collapse) occurred during the loading of the experimental model. The loss of stability occurred at a vertical displacement value of $u_y$≈1.37 mm, which corresponded to the limit load $F_{EXP}$ = 7342 N. The following signs of the second and third loss of stability already seem to be less significant. After the first loss of stability the second and third (second at $u_y$≈1.58 mm, third at $u_y$≈9.2 mm) follows. However, compared to the first loss of stability they seem to be almost insignificant. The deformed shape of the model at the end of the loading is shown in Fig. 4.

Tab. 1 The comparison of the limit loads of experiment and numerical analysis.

| | **Experiment** | **Numerical ideal shell** |
|---|---|---|
| **Limit load F [N]** | 7 342 | 7 225 |

## CONCLUSION

Paper examines the comparison of loading curves of the numerical model of the ideal laterally loaded cylindrical shell and the experimental model (shown in Fig. 5). There can be seen that both loading curves are quite similar. Area of first loss of stability does not differ too much. The value of the experimental model limit load is just slightly higher than the value resulting from numerical analysis (see Tab. 1). This suggests that the results of the numerical analysis correspond very well with the results of the experiment.

Of course, few differences can still be found. The loss of stability of the ideal shell occurs earlier according to numerical analysis than in the real experiment. The explanation could be the initial setting of the clearances in the supports of the experimental model. Which corresponds to a less steep slope of the linear part of the loading curve.

The second noticeable difference is that after the loss of stability, the load curves differ slightly in partial details. Although they remain approximately equidistant. While the experimental loading curve reaches up to third loss of stability (at least small indication). On the contrary, the loading curve resulting from the numerical analysis does not contain any indication even of a second loss of stability. Moreover, where the third loss of the stability of the experimental loading curve is indicated, the numerical analysis terminate the calculation procedure, probably due to the second loss of stability. The cause of differences could be found in the use of a simplified model of the material behaviour in the elastic-plastic area of the numerical analysis.

Despite minor differences, the results seem accurate enough to follow the next phase of research - experimental verification with intently added initial shape imperfection.

## ACKNOWLEDGEMENTS

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