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INFLUENCE OF INITIAL IMPERFECTIONS ON THE LATERALLY LOADED CYLINDRICAL SHELL

VLIV POČÁTEČNÍCH IMPERFEKCÍ NA PŘÍČNĚ ZATĚŽOVANOU VÁLCOVOU SKOŘEPINU

Abstract

The article deals with the assessment of influence of initial imperfection on the loss of stability of laterally loaded cylindrical shell. The studied structure is a simplified case of the horizontal cylindrical shell (road tank [1, 2]) located on saddle supports. The initial geometrical imperfection is situated in the vicinity of the saddle and it is considered as the state of preload of the saddle from the own weight of shell and its content's weight. Change of reduction factor α in response to the change of geometrical parameters of numerical model (embracing angle 2ϑ, thickness of the shell t) is monitored in the article. In the context of changing reduction factor α process of deformation of shell is also observed in this article. Numerical analyses were performed by finite element method computer program COSMOS/M [3].

Abstrakt

Článek se zabývá posouzením vlivu počáteční imperfekce na stabilitní únosnost příčně zatěžované válcové skořepiny. Zkoumaná konstrukce je zjednodušenou variantou případu válcové skořepiny (cisterny [1, 2]) uložené na sedlových podporách. Počáteční tvarová imperfekce se nachází v blízkém okolí sedla a je uvažovaná jako stav předzatížení sedla od vlastní tíhy skořepiny a tíhy jejího obsahu. Sleduje se změna hodnoty tzv. redukčního faktoru α v závislosti na změně geometrických parametrů numerického modelu (úhel opásání 2ϑ, tloušťka stěny pláště skořepiny t). V souvislosti s měnícím se redukčním faktorem je v tomto článku sledován také průběh deformace pláště skořepiny. Numerické analýzy jsou provedeny v počítačovém programu COSMOS/M [3], který je založen na metodě konečných prvků.

Keywords

cylindrical shell, finite element method, initial imperfections, loss of stability, saddle support

1 INTRODUCTION

The area of interest is the research of loss of stability of thin-walled shell structures. Specifically cylindrical car tank, which is stored on two saddle supports. A simplified version in the form of cylindrical shell loaded through a rigidly bonded saddle (laterally loaded cylindrical shell) is used as explored structure. In the first phase of the research the loss of stability is solved only in the elastic range. It needs to be said, that influence of initial imperfections on carrying capacity of saddle supported cylindrical shells were not yet examined. So, motivation of this work is to explore and try

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to assess the influence of initial imperfections, specifically on laterally loaded cylindrical shells (saddle supports). First step of research consists of comparisons between values from performed numerical analyses and values from European Recommendation ECCS [4]. In ECCS [4] are established relations for taking the initial imperfection into consideration only for cylindrical shells under few type of loading (axial compression, bending moment, torque moment, pressure etc.). Not for case of laterally loaded cylindrical shell. For the first approach it was the only available comparison. Influence of initial imperfection is in ECCS [4] expressed by so-called reduction factor α. It was established as a lower bound of the ratio of the experimental buckling load to the theoretical critical load of the perfect cylinder. Assuming the buckling occurs in elastic range. In later graphs are for comparison used two curves of reduction factor according to ECCS [4], curves α_0 and α_b. Where α_0 is reduction factor for axially compressed cylindrical shell and α_b is reduction factor for cylindrical shell subject to bending moment.

Following the article [5], numerical analyses were performed on a model with embracing angle of *60°* for range of thickness parameter *R/t <70; 250>*. The *R/t* is ratio of radius of shell *R* to the thickness of the shell *t*. Change of reduction factor α in response to the change of thickness *t* of the shell is studied. Aim of this article is the evaluation of results of all commonly used variants of embracing angle (*60°, 90°* and *120°*). Attention is also given to the character of the deformation of shell during its loading. An additional bending state is introduced into the shell with the initial shape imperfection [6] which usually causes decrease of carrying capacity [7, 8]. However, sometimes this effect is completely opposite and the carrying capacity of the imperfect shell is increased. The initial geometrical imperfection is considered as the state of preload of the saddle from the own weight of shell and its content's weight. Imperfection has been made by auxiliary linear analysis, when the saddle is pressed into the shell by precisely defined value (in this case *2 mm*). This deformed model is then used as the default model for the following nonlinear analysis.

2 NUMERICAL MODEL

The numerical model is a thin-walled shell of length *L=300 mm* and diameter *D=150 mm* [5, 9]. The thickness of the shell *t* varies in range of *0.3÷1.1 mm* with scaling by increments *0.1 mm*. The shell is ended by covers of thickness t_1*=30 mm*. This thickness ensures sufficient rigidity of covers, which prevents them from excessive deformation and thus the results of computational analyses are not influenced. The saddle of width *b=20 mm* and embracing angles *2ϑ (60°, 90°* or *120°)* is rigidly bonded to the middle of the shell. The wall thickness of the saddle t_2*=20 mm* is again considered thick enough so that the results of computational analyses are not influenced.

Boundary conditions were chosen as combination of simple support in two edge nodes of finite element mesh (points A, B see Fig. 1) and prevention of deflection of the saddle from the vertical direction. Numerical model is loaded by static vertical force which is introduced to shell through the saddle. Dynamics of loading should be solved in later phases. The material used on all parts of the model (shell, covers and saddle) is of the same mechanical values, specifically Young´s elastic modulus $E=1.9E+5\ N.mm^{-2}$, Poisson's ratio $\mu=0.3$.

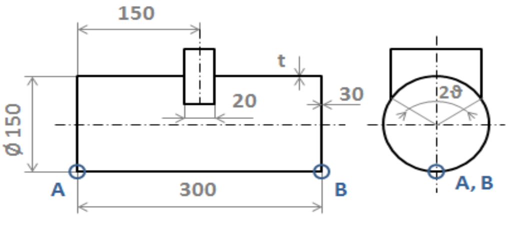

Fig. 1 Geometrical parameters of numerical model

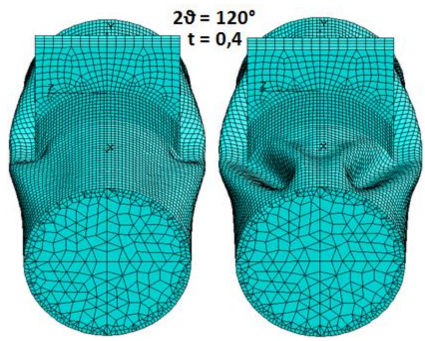

Fig. 2 Deformed imperfect model at the beginning (left) and at the end of loading (right)

3 EVALUATION OF RESULTS OF NUMERICAL ANALYSES

From the results of numerical analyses can be deduced that the first eigenshape is side-deflection of cylindrical shell. Shell has an inclination to stand on the edge of the saddle on side of deflection. Symmetrical pressing of the saddle into the shell is then the second eigenshape.

Certain combination of both eigenshapes has been observed at the most of performed analyses. At the beginning of the loading the symmetrical pressing of the saddle into the shell occurred, which corresponds with linear part of loading curve. Than the side deflection of the cylindrical shell started to demonstrate, followed by the loss of stability. That corresponds to the non-linear part of the loading curve. The process of deformation is characterised by the redistribution of originally symmetrically arranged waves into a shape, in which a significant wave occurs together with a significant dimple in the area of the saddle's horn at the side of deflection. The rest of deformations smoothes almost completely (e. g. Fig. 8, Fig. 9). This text concerned the shells without initial imperfections.

Considering an imperfect shell, the process of deformation is affected by the initial imperfection. The general character of the deformation is almost identical with the perfect shell. However, local deformations of various depths and shapes can occur in the vicinity of the saddle. In case of higher thickness of the shell these deformations often disappear with increasing load. Sometimes local dimples of approximately circular shape can appear mostly in the vicinity of the saddle.

Note: Scale of deformation of all following deformed numerical models is exaggerated for better visualisation of deformation process.

3.1 Embracing angle $2\vartheta = 120°$

From the graph in Fig. 3 it is obvious, that with increasing thickness parameter *R/t* the value of the reduction factor α decreases. That means that with decreasing thickness of shell the carrying capacity of the shell decreases. This trend has been expected and curve $\alpha_{120°}$ is approximately similar to the curves of the reduction factors α_0, α_b as taken from the ECCS [4].

The last two points of curve $\alpha_{120°}$ that are appropriate to the thickness of shell *0.3* and *0.4 mm* (*R/t=250*, resp. *187.5*) show a small scale deviations. Slight stiffening of the construction and an increase of the curve can be explained by the closeness of first and second eigenshape. Therefore, the introduced initial imperfection makes the shell lose the stability by the higher second eigenshape (symmetrically, see Fig. 2). The rest of numerical models lose the stability in the first eigenshape.

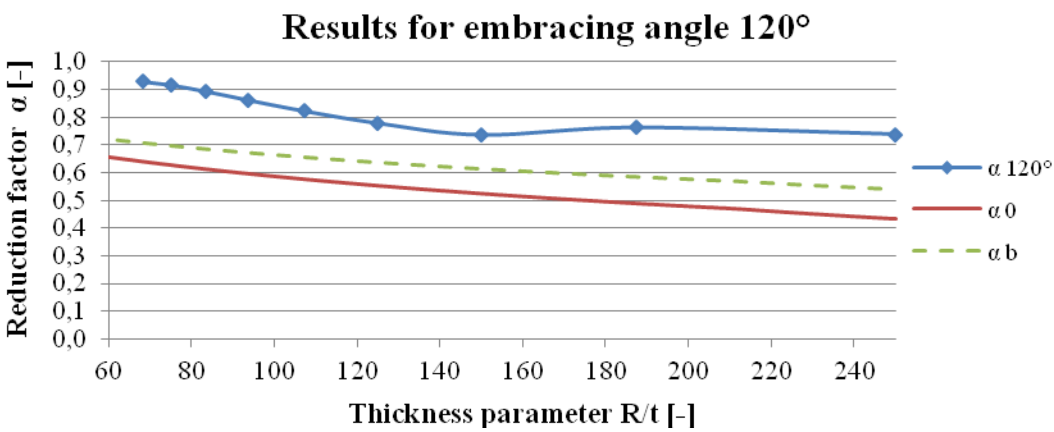

Fig. 3 Dependence of the reduction factor α vs. thickness parameter *R/t* for embracing angle *120°*

3.2 Embracing angle *2ϑ=90°*

Compared to the previous variation (*2ϑ=120°*) the imperfect models with the embracing angle *90°* vary from the expected character of the curve in three cases (see Fig. 4). The reason is probably the initial imperfection, which causes the appearance of additional local waves and dimples, which causes stiffening of the shell. The eigenshape of the deformation stays the same (side-deflection). However, the process of the deformation of perfect and imperfect models is clearly different. But final deformed shape is very similar in both models.

A possible explanation could be that at the beginning of loading additional dimples and waves are formed in the vicinity of the saddle of the imperfection shell. The dimples and waves have stiffening effect. Therefore the limit force will increase until a loss of stability is reached and than a sudden decrease of loading force occurs and the waves are redistributed into new shape. The final deformed shape of perfect and imperfect construction is however very similar (see Fig. 5, Fig. 6).

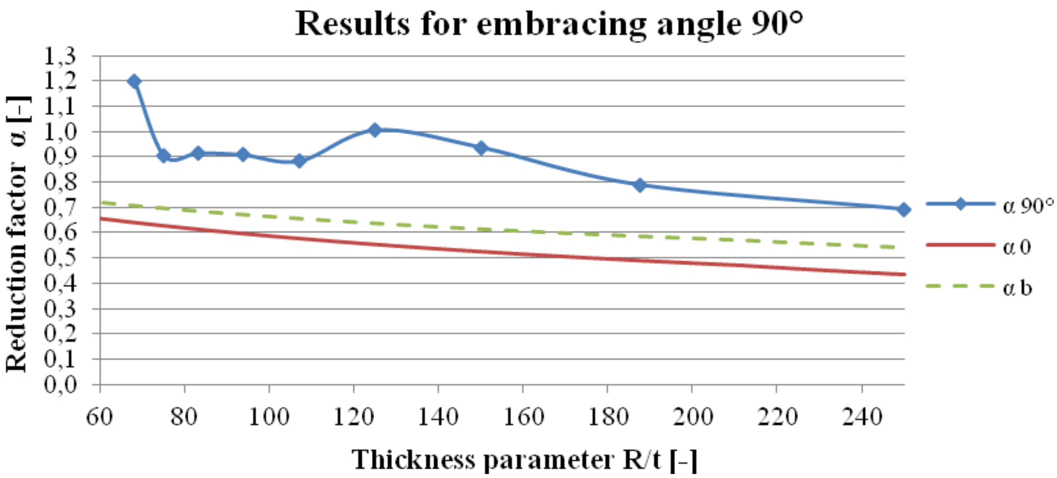

Fig. 4 Dependence of the reduction factor *α* vs. thickness parameter *R/t* for embracing angle *90°*

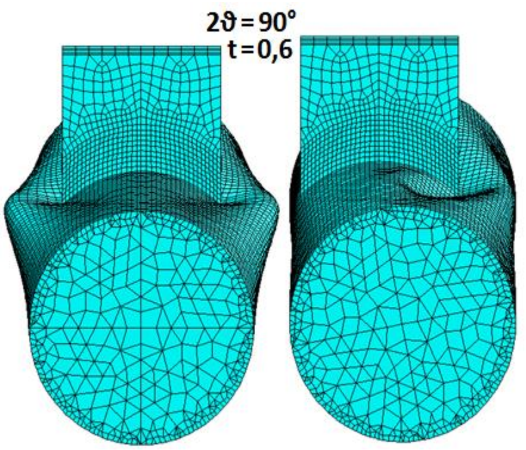

Fig. 5 Deformed perfect model at the beginning (left) and at the end of loading (right)

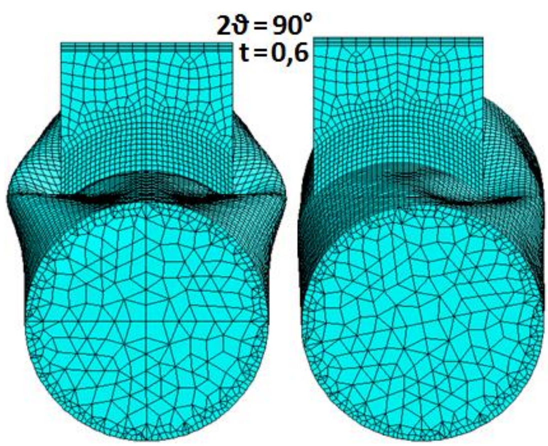

Fig. 6 Deformed imperfect model at the beginning (left) and at the end of loading (right)

3.3 Embracing angle $2\vartheta = 60°$

The typical for this embracing angle is a combination of symmetrical and non-symmetrical character of deformation. The initial symmetrical pressing of saddle into the shell is followed by the side-deflection. Lowered carrying capacity (in terms of limit force) is possibly caused by the small embracing angle of saddle. The saddle is narrow and therefore susceptible to early side-deflection and pressing to the shell.

The narrow saddle combined with the initial imperfection is probably the cause of considerable stiffening of the shell in the almost whole range of the thickness parameter *R/t* (see Fig. 7). The values of the reduction factor are noticeably higher to those expected from the curves for embracing angles *90°* and *120°*. For the angle of *60°* can be considered that the introduced initial imperfection causes additional imperfections in the beginning phase of loading. These small waves in the vicinity of the saddle cause that the limit force necessary for their surpassing increases. The final shape of the deformation of perfect and imperfect construction is again quite similar (see Fig. 8, Fig. 9).

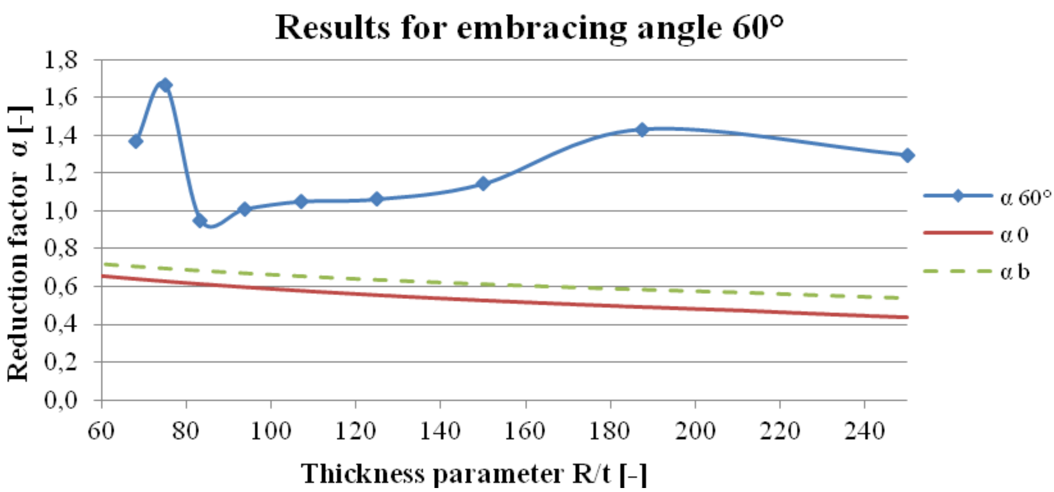

Fig. 7 Dependence of the reduction factor *α* vs. thickness parameter *R/t* for embracing angle *60°*

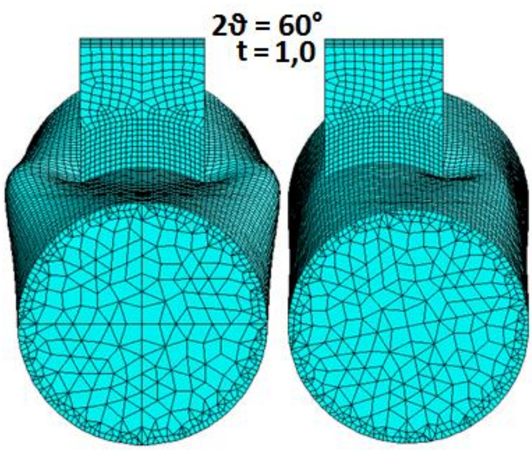

Fig. 8 Deformed perfect model at the beginning (left) and at the end of loading (right)

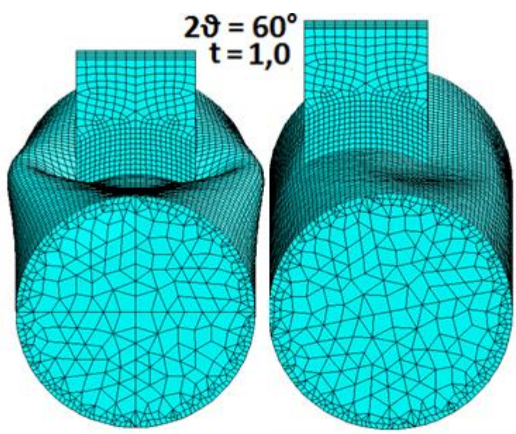

Fig. 9 Deformed imperfect model at the beginning (left) and at the end of loading (right)

4 CONCLUSION

The article describes the theoretical observations of carrying capacity of horizontal cylindrical shell on saddle supports affected by initial shape imperfections. The numerical models with embracing angles 60°, 90° and 120° were examined. Based on evaluation of the first series of numerical analyses can be said that the influence of initial imperfections on carrying capacity of laterally loaded cylindrical shell varies with embracing angle 2ϑ.

Results for one specifically defined and induced initial imperfection (*2 mm*) shows following findings. The initial imperfection of the models with embracing angle $2\vartheta=120°$ mostly weakened the construction and caused decreasing of carrying capacity. For imperfect models with embracing angle $2\vartheta=90°$ was the situation similar (decrease of carrying capacity) but in three cases the slight stiffening of the shell occurred. And lastly, for imperfect models with embracing angle $2\vartheta=60°$ the stiffening of the shell occurred in almost all cases.

The results also show that the most of the observed variants lose stability in the first eigenshape. It means that the cylindrical part of model deflects on the side and shell has a tendency to lay on one edge of the saddle. This is valid regardless of the embracing angle and at the same time it is very important finding for prepared experimental verification.

Finally, it can be said that the value of the reduction factor did not fall under value $\alpha=0.65$. This conclusion is valid for all embracing angles. Thus, obtained values of reduction factor α are always higher then values taken from ECCS [4] (see Fig. 3, Fig. 4 and Fig. 7).

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