University of Pardubice
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ANALYSIS OF THE STABILITY OF THREE-AXLE CISTERN WALL WITH REGARD TO THE INITIAL IMPERFECTIONS

DISSERTATION THESIS PRECIS

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Content

1 Introduction

The dissertation deals with the problem of loss of stability of thin-walled shell structures. This type of structure is used in e. g. transport technology, construction and the chemical or food industry. Shells can be described as thin-walled structures where the wall thickness has significantly lower to negligible value in relation to other parameters.

The biggest advantage of the shells is their high load-carrying capacity at relatively low weight. In today's era of ever-increasing demands for increasing material quality while reducing the weight of structures, their importance is certainly up to date. In general, the membrane stiffness of the shell is many times higher than the bending stiffness. When a compressed shell is overloaded, one of the limit states – that is loss of stability – can occur. The loss of stability is often significantly affected by initial imperfections.

The area of interest of the dissertation is a part of a cylindrical road tank mounted on saddle supports. The particular construction case investigated in the dissertation is limited to the area of the cylindrical shell in the vicinity of one saddle support. The shell is loaded via rigid saddle support which is firmly attached to the middle of the shell length. In this dissertation, the geometric initial imperfection due to overloading of the cylindrical road tank shell at the saddle support is considered. Thus, the main focus is on determining the effect of the geometric initial imperfection on the loss of stability of the laterally loaded cylindrical shell.

2 Current state of the studied problematic

2.1 Publications of important authors

This chapter presents an overview of the major authors who have conducted research on cylindrical shells located on saddle supports, including a brief description of their research.

L. P. Zick [1] is the author of one of the first approaches to solving the problem of cylindrical shells located on a pair of saddle supports, from which many later standards (mainly Anglo-American) are based. The author himself indicates that the purpose of the article is to determine the approximate stresses occurring in this type of structure. For a long time, this was the only solution aimed at practical design, but it should be noted that it is an approximate solution. In terms of determining the reactions, it compares a cylindrical shell supported on two saddle supports to a beam on two supports with overhanging ends that is loaded by a continuous load. This solution corresponds to the time of the article – 1951.

V. Křupka [2], [3], [4] has extensively researched shell structures not only on the basis of analytical approaches but also experimentally. His research of saddle supports included bending conditions of shells, i. e. deformation of the shell cross-section. In contrast to *Zick's* original analogy of shell-to-beam behaviour, this approach takes into account the redistribution of reactions in saddle supports due to the deformation of the shell cross-section.

Experiments were performed on a simplified cylindrical model, which was supported at the ends and loaded in the middle through rigid saddle support. Both free and welded saddle support were investigated. The model considered in this thesis is based on these models.

He also introduced the methodology for the design of free saddle supports in the European Design Recommendation for Steel Structures ECCS [5]. Where it converts the case of a laterally loaded cylindrical shell (on saddle supports) to the case of an axially compressed cylindrical shell using semi-membrane theory. However, current powerful computers and computer programs were not available to solve the initial imperfections problem. Therefore, the available conservative approach of considering the effect of initial imperfections for an axially compressed cylindrical shell was adopted.

A. S. Tooth with colleagues **G. C. M. Chan** and **J. Spence** [6] performed experiments similar to those of *V. Křupka* in [2], [3]. The tests were performed on models with different R/t ratios (R – shell radius, t – shell wall thickness) and with saddle supports, both welded and free. They found that two main types of structural collapse occur here. For relatively thick-walled shells (low R/t ratio), gradual plastic collapse occurred, while for shells with higher R/t ratios, elastic-plastic buckling occurred. The limiting value of the ratio was approximately $R/t=200$. The above structures were investigated in a range of simple experimental tests on similar models used by *V. Křupka* and on which this dissertation is based.

2.2 Initial imperfections

Initial imperfections are defined as imperfections in the geometry, imperfections in the supporting and loading of the shell, as well as residual stresses and imperfections in the distribution of material properties. Initial imperfections introduce certain amount of bending stress into shell structures at the very beginning of loading. The initial imperfections thus affect the load-carrying capacity of the real shell. In engineering practice, the most significant initial imperfections in thin-walled shell structures are considered to be geometric imperfections (imperfections of shape), which may already arise during the manufacture or manipulation of the structure.

Three types of geometric deviations are listed in the standard ČSN EN 1993-1-6 [7]:

- out-of-roundness (circularity deviation),
- eccentricity (deviation of the continuity of the centreline surface in the direction perpendicular to the shell along the sheet metal joints),
- local dimples (local deviations in the direction perpendicular to the shell from the nominal centreline surface).

For cylindrical shells, the most significant of these geometric imperfections is considered to be a dimple. It is not only the depth of the imperfection that affects the shell, but also the position within the structure.

In this dissertation, the geometric initial imperfection due to overloading of the cylindrical road tank shell at the saddle support is considered. The assumption is that this type of imperfection is more similar to the shape of the deformation during the loss of stability of a laterally loaded cylindrical shell and therefore more significant.

2.3 Brief summary of initial imperfection solutions according to standards and recommendations

The problem of firmly attached saddle supports is solved e. g. in the Czech standard ČSN 690010 [8], in the Czech version of the European standard ČSN EN 13445-3 [9], or in the European standard AD-Merkblatter [10]. All solutions are based on similar principle. The calculation is performed using relations where the initial imperfections are not solved separately but are included in the safety coefficients.

In contrast, in the European ECCS Recommendation [5], the influence of initial imperfections is included in the solution by a separate reduction factor. Therefore, the methodology according to this recommendation is furthermore given the main attention. The ECCS [5] includes a chapter dealing with cylindrical shells loosely supported on saddle supports. Since the consideration of the effect of initial imperfections on a laterally loaded cylindrical shell is not available, the available approach established for the axially compressed cylindrical shell has been adopted. This approach is with high probability conservative. Thus, a procedure is offered to specify the effect of initial imperfections in a laterally loaded cylindrical shell.

2.4 Axial elastic imperfection reduction factor

The consideration of the influence of initial imperfections on the carrying capacity of axially compressed cylindrical shell is realized in ECCS [5] by the so-called *axial elastic imperfection reduction factor* α_x, according to relation (1):

$$\alpha_x = \frac{0{,}62}{1 + 1{,}91 \cdot (\Delta w_k/t)^{1{,}44}} \tag{1}$$

Where Δw_k is the *characteristic imperfection amplitude*, which expresses the depth of the maximum allowed imperfection. The relation (2) for its determination combines the requirement for the shell manufacturing quality and the main geometrical parameters of the axially compressed cylindrical shell (R – shell radius, t – shell wall thickness).

$$\Delta w_k = \frac{1}{Q} \cdot \sqrt{\frac{R}{t}} \cdot t \tag{2}$$

Where Q is the fabrication quality parameter, indicating three fabrication tolerance quality classes A, B, C (see *Tab. 1*).

Tab. 1: Values of fabrication quality parameter.

Fabrication tolerance quality class	**Description**	**Q**
A	Excellent	40
B	High	25
C	Normal	16

The dependence of the axial elastic imperfection reduction factor α_x on the thinness parameter R/t is shown in *Fig. 1* for all considered fabrication tolerance quality classes (A, B, C).

It can be seen in *Fig. 1* that the value of α_x decreases significantly with the increasing value of the thinness parameter *R/t*. This demonstrates the relatively high sensitivity of the axially compressed cylindrical shell to initial imperfections.

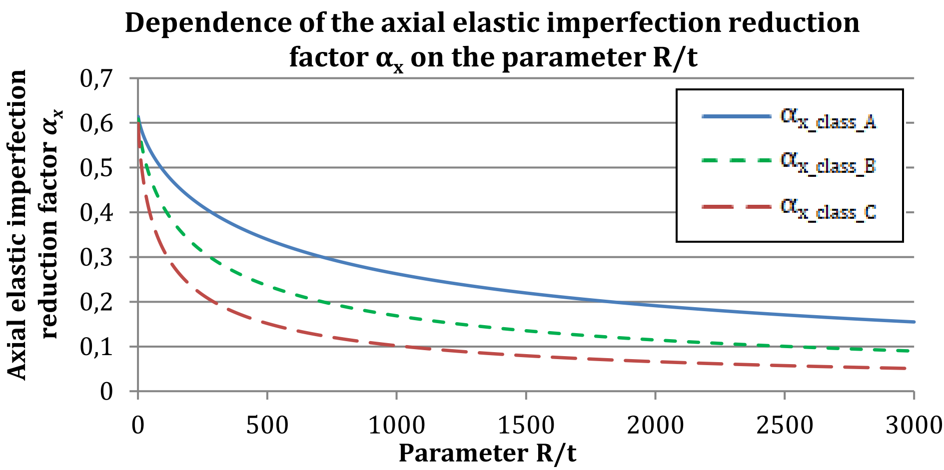

Fig. 1: The illustration of the axial elastic imperfection reduction factor α_x for three fabrication tolerance quality classes.

The influence of initial imperfections on the decrease of the carrying capacity of the axially compressed and laterally loaded cylindrical shell is diametrically different and will be explained in more detail in Chapter 3. On this basis, it can be assumed that the axial elastic imperfection reduction factor α_x (determined for the axially compressed cylindrical shell) is too conservative for use in the laterally loaded cylindrical shell. Therefore, the aim of this dissertation is to directly improve the elastic imperfection reduction factor of laterally loaded cylindrical shell.

2.5 Numerical approach to determine the elastic imperfection reduction factor

There also is second approach to determine the reduction factor – numerical approach. Non-linear numerical analyses performed in computer programs exclusively based on the finite element method are used to express the influence of the initial imperfection nowadays. Numerical models of real structure with actually modelled initial imperfection are important part of this thesis.

The application here does not depend on whether the design is of a standard structural node (e. g. an axially compressed cylindrical shell) or a non-standard structural node (e. g. a laterally loaded cylindrical shell). Determination of the influence of the initial imperfections can be obtained using the results of geometrically non-linear analysis model with geometric imperfection (GNIA) and the results of geometrically non-linear analysis of ideal model (GNA).

The numerical elastic imperfection reduction factor can also be determined as the ratio of *the limit load of real shell with initial imperfection* $\boldsymbol{F_{GNIA}}$ to *the limit load of ideal shell without initial imperfection* $\boldsymbol{F_{GNA}}$, according to the relation:

$$\alpha = \frac{F_{GNIA}}{F_{GNA}} \tag{3}$$

For the purpose of differentiation, the elastic imperfection reduction factor obtained by the numerical approach is referred to as "reduction factor" in this thesis. The approach using relation (3) is used to solve the practical problem in the dissertation thesis.

3 Aims of the dissertation thesis

The dissertation thesis follows the research of *V. Křupka*, whose method for the solution of cylindrical shells placed on saddle supports is presented in ECCS [5]; the aspiration of this dissertation is to enhance the existing research with the influence of initial imperfections.

For shell structures, two types of stresses are important – membrane and bending. A shell with purely membrane stresses has high load-carrying capacity but is all the more sensitive to initial imperfections (e. g. axially compressed cylindrical shells), whereas a shell with significant proportion of bending stresses has lower load-carrying capacity from the very beginning of loading. The additional bending state introduced e. g. by an initial imperfection, does not cause such significant drop in load-carrying capacity when this type of shell loses stability (e. g. laterally loaded cylindrical shell).

Cylindrical shells supported on saddle supports are solved in the European ECCS Recommendation [5], but information on the influence of initial imperfections on the loss of stability of laterally loaded cylindrical shells is not available. Based on analysis of the current state of the problem and as mentioned earlier it is clear that the effect of initial imperfections on this type of structure has not been directly studied. Therefore, to account for initial imperfections, the *elastic imperfection reduction factor* α_x was used in the ECCS procedure [5]. Where this coefficient was determined for an axially compressed cylindrical shell, to which the case of a laterally loaded cylindrical shell is converted in the solution. However, due to the different nature of these two structures, in terms of the initial level of bending stress, this approach is likely to be conservative. It is a solution on the safe side but may lead to unnecessary over-dimensioning of the structure.

The aim of the dissertation is to determine a new *elastic imperfection reduction factor* α_{LLCS}, which will be determined specifically for a laterally loaded cylindrical shell (LLCS) with initial geometric imperfection. The result of this work is to find the dependence of the reduction factor α on several geometrical parameters of the cylindrical shell, namely:

- the embracing angle of the saddle support 2θ,
- the thinness parameter R/t,
- the imperfection amplitude parameter $\Delta w/t$,
- the saddle support width parameter b/R,
- the parameter of the saddle support distance from the edge of the shell L_1/R.

The reduction factor determined in the dissertation can be subsequently used in the methodology presented in ECCS [5] for the design of saddle-supported cylindrical shells.

4 Processing methods and way of solution

4.1 Methodology in ECCS

The ECCS [5] solution for saddle supported cylindrical shells is based on the semi-membrane theory, by means of which a laterally loaded cylindrical shell is converted to the equivalent axially compressed cylindrical shell. This is followed by the determination of *the plastic limit state resistance of the shell*. Furthermore, *the characteristic and design buckling stresses* are important for determining the limit state of loss of stability, for which *the relative slenderness* and *the plastic limit relative slenderness* must be determined; and from these, *the buckling resistance reduction factor for elastic-plastic effects*. Since the effect of initial imperfections and their own consideration for laterally loaded cylindrical shell is not yet available, the known procedure for solving initial imperfections for axially compressed cylindrical shell is used. An important part here is the relationship for *the characteristic buckling stress*. This relation contains a rather complex *buckling resistance reduction factor for elastic-plastic effects* χ_x. It is through this coefficient that *the influence of initial imperfections*, the *elastic-plastic behaviour of the material,* and the *relative slenderness of the structure* can be taken into account in the calculation. Specifically, the observed influence of initial imperfections is expressed here by *the axial elastic imperfection reduction factor* α_x.

The reduction factor α_{LLCS} determined by this dissertation thesis should replace *the axial elastic imperfection reduction factor* α_x in the design of laterally loaded cylindrical shells, according to the methodology described above.

4.2 Numerical analyses

The basis for the solution of the considered problem is the knowledge and results of nonlinear numerical analyses of GNA and GNIA types. In most of the cases in the dissertation, the stability loss is solved only in the elastic region of the material behaviour, because according to the described ECCS methodology [5] the influence of material nonlinearity can be additionally supplemented by the so-called buckling resistance reduction factor for elastic-plastic effects. In the calculations, a material with the same mechanical values is considered for all parts of the model (shell, covers, saddle support), namely Young's modulus of elasticity in tension $E=1.9 \cdot 10^5$ *MPa* and Poisson's number $\mu=0.3$.

In nonlinear numerical analyses performed for the purpose of comparison with the experimental results, material nonlinearity is of course also considered and GMNA, GMNIA analyses are used. In this case, the von Mises bilinear model of elastic-plastic material behaviour with yield stress *Rp0.2=189 MPa* is used. The elastic modulus $E=1.9 \cdot 10^5$ *MPa* is considered for the elastic region and for the plastic region slight stiffening via tangential modulus $E_T=19$ *MPa* is considered. The Poisson number of $\mu=0.3$ is also considered for these calculations. In this dissertation, the numerical analyses are performed in the COSMOS/M [11] program based on the finite element method.

The observation of the influence of initial imperfections on the laterally loaded cylindrical shell is carried out on a numerical model, which is constructed from SHELL4T shell elements (*Fig. 2*) in three initial variants according to the value of the saddle support embracing angle. The schematic of the geometrical parameters of the considered laterally loaded cylindrical shell including the boundary conditions is shown in *Fig. 3*.

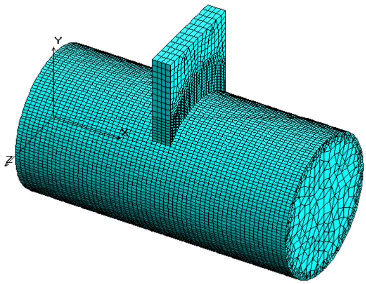

Fig. 2: The undeformed numerical model (2θ=90°).

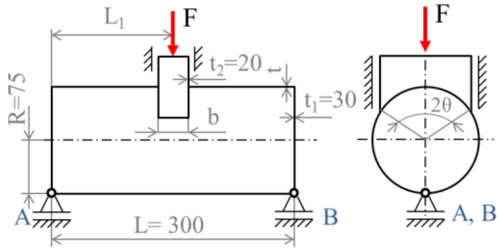

Fig. 3: The schematic of geometric parameters of a laterally loaded cylindrical shell.

In the dissertation, the geometric initial imperfection due to overloading of the cylindrical road tank shell at the saddle support is considered. In the numerical analyses, the initial imperfection is created by the auxiliary linear analysis where the saddle support is pushed into the shell by precisely defined value *Δw*. The deformed model is then used as the initial model for the nonlinear numerical analysis.

The individual series of numerical analyses are devoted to assessing the influence of the depth of the initial imperfection, the width of the saddle support, and the distance of the saddle support from the rigid edge. Within these three sub-problems, dimensionless parameters have been introduced in the dissertation and the influence of the following variables is investigated:

- *The embracing angle of the saddle support 2θ* – the values are considered as the three most common variants used in practice (60°, 90°, and 120°).
- *The dimensionless thinness parameter R/t* is the ratio of the shell radius *R* to the shell wall thickness *t*. Numerical analyses are performed on models with the same geometrical parameters. Except for the wall thickness *t*, by changing it, the change of the parameter *R/t* was obtained. The thinness parameter is investigated in the range of values *(68; 250)*, according to the thickness *t* gradation (see *Tab. 2*). This range has been chosen with respect

to the commonly used shell structures for transport means. Higher thicknesses are generally not used.

Tab. 2: The range of the thinness parameter R/t for R=75 mm.

t [mm]	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
R/t [-]	250	187.5	150	125	107.14	93.75	83.33	75	68.18

- *The dimensionless parameter of the imperfection amplitude $\Delta w/t$*, which is the ratio of the imperfection amplitude Δw to the shell wall thickness t. It is investigated in this work on the interval $\Delta w/t$ *(0.1, 0.5, 0.75, 1.0, 1.5, 2.0)*.
- *The dimensionless saddle support width parameter b/R*, which is the ratio of the saddle support width b to the shell radius R. The saddle support width is chosen in six different values (see *Tab. 3*).

Tab. 3: The introduction of the parameter b/R.

b [mm]	5	10	20	30	40	50
b/R [-]	0.07	0.13	0.27	0.40	0.53	0.67

- *The dimensionless parameter of the distance of the saddle support from the shell edge L_1/R*, which is the ratio of the distance of the centre of the saddle support from the shell edge L_1 to the shell radius R. Three different positions of the saddle support relative to the rigid edge are considered (see *Tab. 4*).

Tab. 4: The introduction of the parameter L_1/R.

L_1 [mm]	37.5	75	150
L_1/R [-]	0.5	1.0	2.0

4.3 Experimental approach

As an example of non-standard structural node, the laterally loaded cylindrical shell is difficult nonlinear problem. Solving the loss of stability of the structure by numerical analyses in finite element method-based programs can be very efficient, relatively fast, and accurate. However, the results of numerical analyses still need to be verified by experiments.

The real test specimens of the laterally loaded cylindrical shell are made by welding. Rigid covers are welded at both ends to the cylindrical shell of sheet metal. A part representing the intended saddle support is then welded in the middle of the shell length. Both the covers and the saddle support are several times thicker than the shell so that only the deformation of the cylindrical part of the shell can occur. The boundary conditions are implemented in agreement with the numerical models in the form of simple supporting of the shell on two supports with the possibility of small sliding motion in the direction of the z-axis.

The intended initial imperfection has been created in real specimens by pushing the saddle support (in the vertical direction) into the circular shell so that, after unloading, the permanent deformation corresponds to the required value of the initial imperfection. After unloading the test machine, the resulting deformed experimental model could be set back to the initial position for the actual experiment.

5 Achieved results

5.1 The reduction factor

In this dissertation, three series of nonlinear numerical analyses (GNA, GNIA) of the stability loss of laterally loaded cylindrical shell model are presented. The input values of the chosen parameters were the embracing angle *2θ (60°, 90°,* and *120°),* and the thinness parameter *R/t (68÷250)*. The subsequent analyses determine the values of the reduction factor with respect to:

- *the effect of the depth of initial imperfection ($\alpha_{\Delta w/t}$),*
- *the effect of the width of the saddle support ($\alpha_{b/R}$),*
- *the effect of the saddle support distance from the shell rigid edge ($\alpha_{L1/R}$).*

The partial reduction factor ($\alpha_{\Delta w/t}$, $\alpha_{b/R}$, $\alpha_{L1/R}$) was determined on the basis of the results obtained for each series of analyses. It can be noted that in all cases the values of the reduction factor were in the range of $\alpha = 0.82 - 1$. The minimum value of the reduction factor for each of the three variants was then plotted on the graph. The envelope line of the minimum values of the respective reduction factor was drawn through this minimum (see *Fig. 4*, *Tab. 5*). No value of the given variant fell below the envelope value thus determined. A comparison of all the resulting envelope lines for the considered parameters is shown in *Fig. 4*.

For the comparison in *Fig. 4*, the numerically determined reduction factors were supplemented by the corresponding currently available ECCS [5] reduction factor. Hereby, α_{ECCS} corresponds to the axial elastic imperfection reduction factor α_x depending on the value of the characteristic imperfection amplitude Δw_k. The fabrication tolerance quality classes (A, B, C) according to ECCS [5] are indicated by vertical dashed lines in *Fig. 4*.

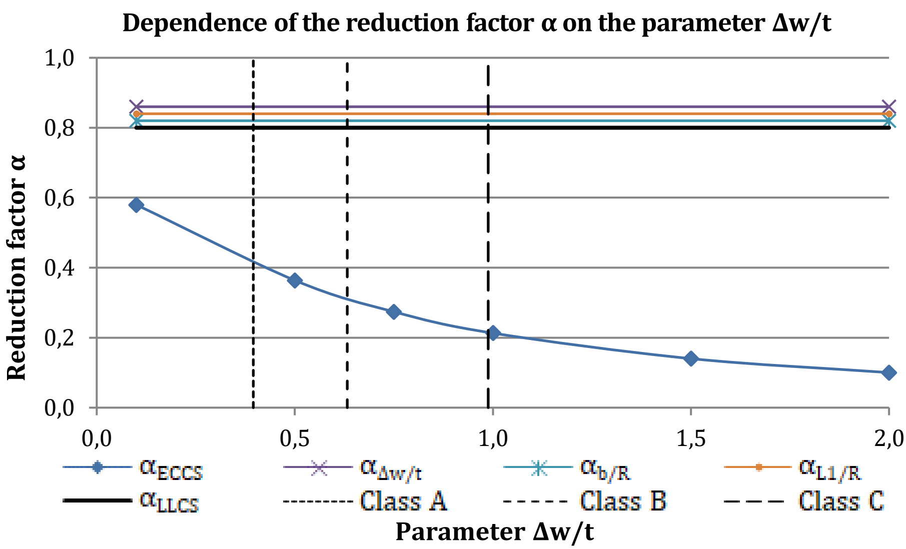

Fig. 4: The overview of the resulting values of the reduction factors.

Considering the lowest value of the reduction factor, among all numerically determined variants, ***the new reduction factor α_{LLCS} was determined***

directly for the laterally loaded cylindrical shell (see *Fig. 4*, *Tab. 5*). The resulting value of the α_{LLCS} reduction factor was determined to be slightly conservative and therefore on the safe side. The comparison of the determined value of the reduction factor α_{LLCS} with the course of the reduction factor α_{ECCS} clearly shows new possibilities of using the presented variant of problem solution.

Tab. 5: The summary of reduction factor values.

Variant	α_{ECCS}	$\alpha_{\Delta w/t}$	$\alpha_{b/R}$	$\alpha_{L1/R}$	α_{LLCS}
Reduction factor value	0,58 - 0,1	0,86	0,82	0,84	**0,8**

5.2 Experimental verification

The results obtained from the FEM analyses were then verified by experiments as planned. This part of the presented work focuses on the experimental verification of the outcomes of the nonlinear numerical analyses with experiments. For this task, a total of 10 experiments (7 models without initial imperfections and 3 models with intentionally created initial imperfections) were carried out. The main compared parameter was the limit load value of the first loss of stability. To a lesser extent, attention was also paid to the progress of the load curves and the corresponding shapes of the deformation.

The comparison of the achieved results showed relatively good agreement, both the values of the limit load at the loss of stability and the load curves. With one exception, where the specimen was probably affected already from manufacture, the relative error for the limit load values ranged from *1.59* to *11.2 %*. This range is valid across all variants evaluated, regardless of the embracing angle or the presence of intentional initial imperfection.

At the end of this chapter, the example of matching results is given. The selected variant is described by the following parameters: saddle support embracing angle $2\theta=120°$, shell wall thickness $t=0.53\ mm$, cover thickness

t_1=16 mm, and saddle support width b=20 mm. In the context of the dimensionless parameters introduced in this work, the selected variant corresponds to the following values: R/t=141.5, $\Delta w/t$=0, b/R=0.27, and L_1/R=2.0.

Fig. 5 shows a comparison of the load curves of the ideal shell numerical model and the experimental model, i. e. without intentionally created initial imperfections. In terms of the progression, the load curves are largely similar, including the region of the first loss of stability, which does not differ much. The value of the limit load of the experimental model is only slightly higher than the value obtained from the numerical analysis (F_{EXP_0}=7342 N and F_{GMNA_0}=7225 N, respectively). The relative error of the obtained limit loads is *1,59 %*. This indicates that the results of the numerical analysis agree reasonably well with the experimental results.

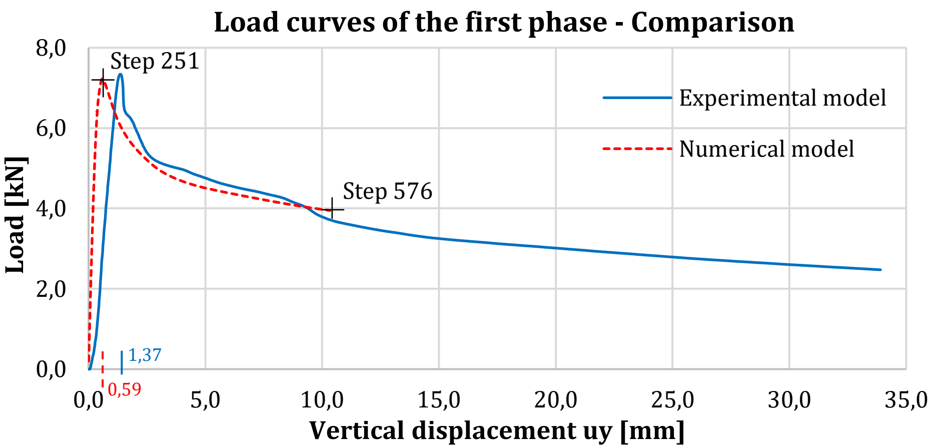

Fig. 5: Load curves – the comparison of experimental and numerical model – first phase of verification.

Next, the comparison of the deformed numerical model at the end of loading (u_y=10.33 mm) with the corresponding deformed experimental model, at a similar value of vertical displacement (u_y~10.3 mm), is made. The comparison of the shapes of the deformation in *Fig. 6* and *Fig. 7* shows fairly good agreement in the distribution and number of the main waves for both models.

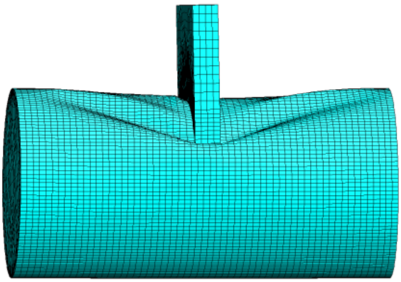

Fig. 6: Deformed numerical model of the ideal shell at the end of loading (at u_y=10.33 mm, computational step 576, 1:1).

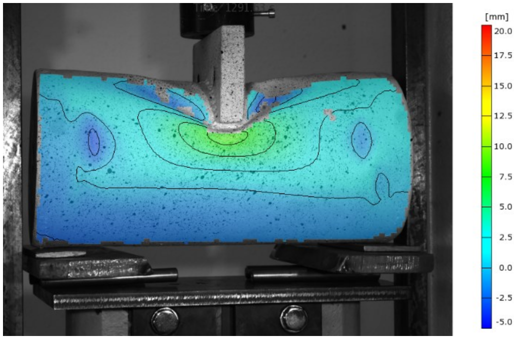

Fig. 7: Deformed experimental model (at u_y~10.3 mm) - ARAMIS system.

6 Contributions of the dissertation

The analysis of the current state shows that the consideration of the effect of initial imperfections directly for laterally loaded cylindrical shells has not yet been sufficiently solved. The European ECCS Recommendation [5] includes a chapter dealing with saddle supported cylindrical shells (as a variant of the laterally loaded cylindrical shell). *However, this chapter does not include a solution to the influence of initial imperfections on this type of structure.* To consider the influence of initial imperfections, ECCS [5] refers to the use of the reduction factor determined for the axially compressed cylindrical shell, to which the case of the laterally loaded cylindrical shell is converted. However, as discussed earlier, the sensitivity of these two variants of the cylindrical shell is diametrically opposed. The axially loaded cylindrical shell is significantly more sensitive to the influence of the initial imperfection. Thus, the approach of applying the available reduction factor (determined for the axially compressed cylindrical shell) to take into account the influence of initial imperfections in the laterally loaded cylindrical shell is likely to be very conservative.

The contribution of the dissertation is extending the level of knowledge in the field of cylindrical shells located on the saddle supports. In response to the above-described situation, the results obtained thus show the validity of the assumption of relatively high conservatism of the current approach. **In this dissertation, new reduction factor α_{LLCS}** (*Fig. 4*, *Tab. 5*) **was determined, which specifically takes into account the influence of the considered initial geometric imperfection on the loss of stability of laterally loaded cylindrical shell.**

Generally, cylindrical shells on saddle supports are used in e. g. transport technology, chemical, construction, and food industries. The possibility of using reduction factor designed specifically for laterally loaded cylindrical shells could result in reduction of the shell wall thickness. On this basis, it would be possible to design modern lightweight road tank structures, or laterally loaded cylindrical shells in general, without unnecessary conservatism.

The results obtained in the presented work in the current state establish the basis for possible future effort to include reduction factor designed directly for laterally loaded cylindrical shell in the ECCS [5]. It is also necessary to consider the proposed reduction factor as the first step for its use in engineering practice in the design of laterally loaded cylindrical shells.

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Abstract/Souhrn

This thesis deals with the influence of the initial imperfections on the loss of stability of saddle supported cylindrical shell. The researched structure is laterally loaded cylindrical shell with a geometric initial imperfection. The region of one saddle support is considered. Numerical analyses are performed by the finite element method computer program COSMOS/M [11].

Disertační práce se zabývá vlivem počátečních imperfekcí na ztrátu stability válcové skořepiny uložené na sedlových podporách. Zkoumaným případem je příčně zatěžovaná válcová skořepina s geometrickou počáteční imperfekcí. V práci je uvažována oblast okolo jedné sedlové podpory. Numerické analýzy jsou provedeny v počítačovém programu COSMOS/M [11], který je založen na metodě konečných prvků.