Hartmut PASTERNAK[1]
Steffen KOMANN[2]

ABOUT THE ROLE OF LONGITUDINAL STIFFENERS IN SILOS

Summary

This paper will present the influence of longitudinal stiffeners in case of large concentrated loads applied to thin-walled shells. The arrangement of longitudinal stiffeners has a favourably effect on the load carrying capacity of a column-supported silo.
The tests which are carried out on cylindrical silo models, the measurement of the initial imperfections and the numerical analysis of the shells are presented. In these series of tests and numerical investigations only longitudinal stiffeners without a ringstiffener on the upper end were investigated.

1. Introduction

Silos with axial load and supported locally at several points on the circumference are used very often in practice. On the supported points of the shell the longitudinal compressive stresses are much higher than in case of a continuously supported silo. Several codes (e. g. DIN 18800, part 4 [1]) give rules for calculating the buckling resistance of a continuously supported silo, but the codes do not consider the effect of higher compressive stresses on the columns.

In the last few years some research papers about buckling resistance of single-supported shells [3, 5, 6] have been published. Based on these methods, it is possible to consider the high local axial load in the buckling resistance check.

/1 Prof. Dr.-Ing. habil., Brandenburg Technical University of Cottbus, Germany
Dept. of Steel Structures, www.bauwesen.tu-cottbus.de/Stahlbau
/2 Dipl.-Ing.
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Therefore several methods for decreasing the high stresses in the silo shell may be derived:

- vertical stiffeners on the support
- vertical stiffeners on the support and a ring beam at the upper end
- reinforced wall thickness.

The best way of these possibilities is the second one, because the upper ring stiffener at the end of the longitudinal stiffeners avoid a high local bending in the shell.

The application of longitudinal stiffeners without a upper ring beam is saving cost during the production process.

2. Tests

The tests were carried out at 20 models with 700 mm in diameter and 700 mm height. The sheet thickness was 1 mm (Fig. 1), and the used material was S 255. The difference between these models were the length of the longitudinal stiffener on the support and the cross-section of these stiffeners. The several stiffeners length were increased from 10 per cent up to 50 per cent of the height of the cylinder.

They are two cross-sections of the longitudinal stiffeners:

- 1 mm thickness and 20 mm width (series 1)
- 2 mm thickness and 30 mm width (series 2)

The cylinders were terminated by a flat-bar ring at the lower edge with a thickness of 1 mm and a width of 30 mm supported on 3 support plates with 100 mm width. Three supports were chose to guarantee a statically determinated support.

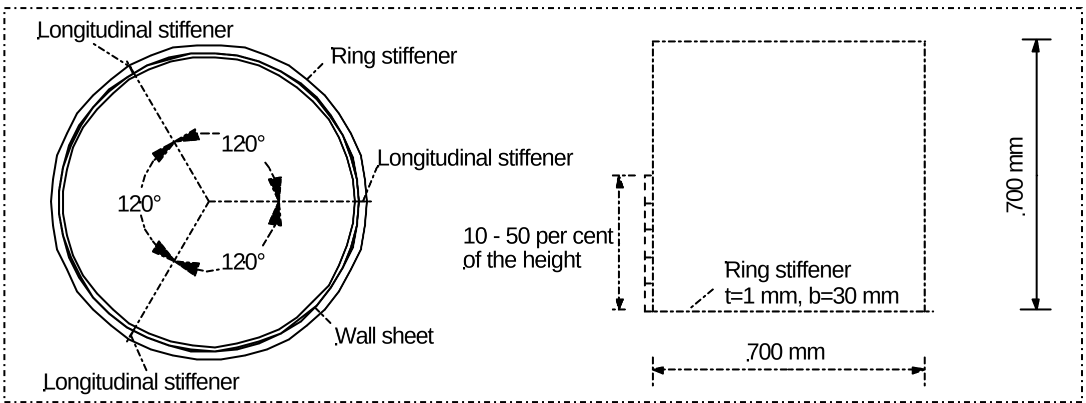


Fig. 1 Geometry of the test cylinders

2.1 Measurement of geometrical imperfections

At first, the geometrical imperfections of the cylindrical shell were measured. Therefore it was created a device (Fig. 2) for recording the geometrical shape of the model. The measurements were done at the surface from outside in meridional direction and with a distance of 50 mm in the circumferential direction.

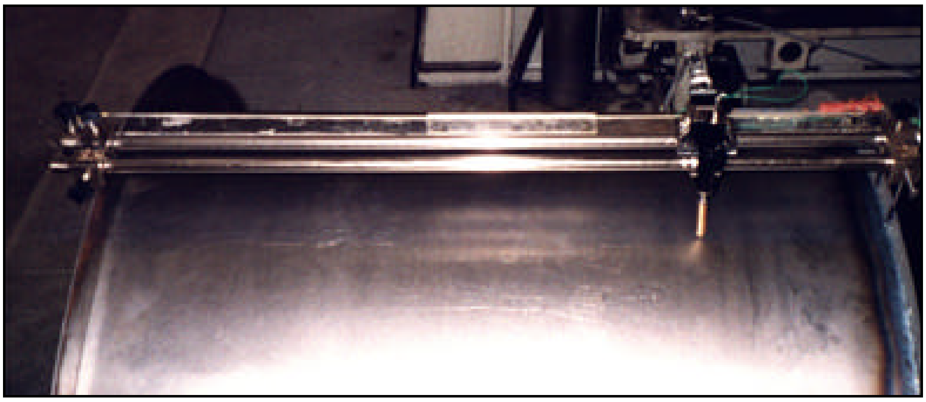


Fig. 2 Device for geometrical imperfections measurement

A recorded shape for one model is presented in Fig. 3.

The real measured values of imperfections are very important for the further numerical calculations by means of Finite-Element-Method. At first, the perfect shell was modelled, next the imperfections were considered, so that the analysis were carried out at a non-perfect geometrical model.

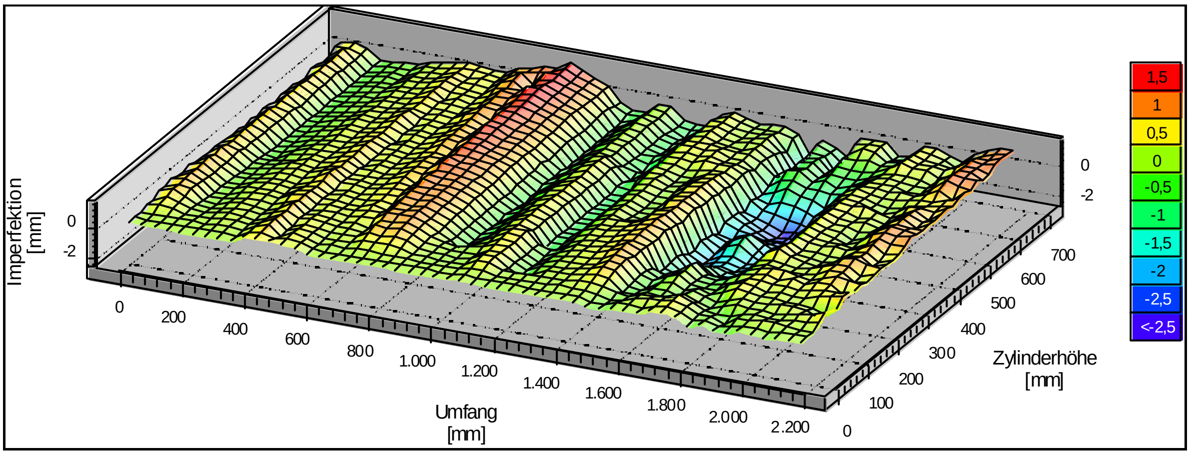


Fig. 3 Recorded shape of one model

2.2 Test setup

The silo models were supported on three points on support plates with 100 mm width (Fig. 4). Thus it was a free-rotating, non-moveable support.

The dynamometers for record the reactions at the supports were installed along the circumference under the support plates at angels 0°, 120° and 240° respectively. At the upper rim of the silo model a ring stiffener were puted from outside and from inside of the shell a timber plate (with diameter of the silo, to avoid buckling) is located.

Fig. 4 Test setup

The test model were situated on the support plates and positioned carefully in order to limit the eccentricity of the vertical cylinder axis with respect to the vertical centreline of the hydraulic jack.

The axial force were applied by means of a hydraulic jack and a steel plate. An aluminium plate were interposed between the upper edge of the shell and the top steel plate in order to compensate small irregularities between the contact surfaces.

During the tests the reactions on the three dynamometers were measured. These reactions were not the same at these three supports due to small imperfections on the silo and in the test setup.

The tests were carried out deformation controlled with a rate of 5 mm per hour. The advantage of that procedure is that it can be observed not only buckling, but also the post-buckling behaviour of the shell.

2.3 Test results

The failure occured mostly due to shell buckling. Only in one case the longitudinal stiffener failed. The reason for this behaviour was obviously a large geometrical imperfection of this stiffener.

In the other cases any influence of the stiffeners cross-section couldn‘t be observed. The failure mode was the same and the load level was almost the same, too (Fig. 5)
Obviously, the stiffness of the vertical stiffeners were larger than a required minimum.

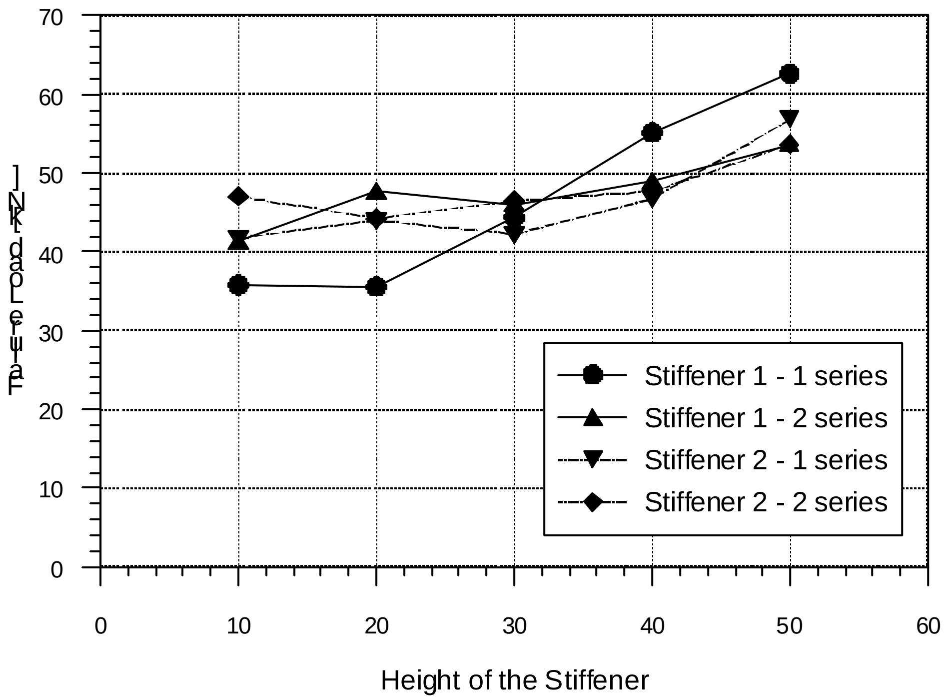
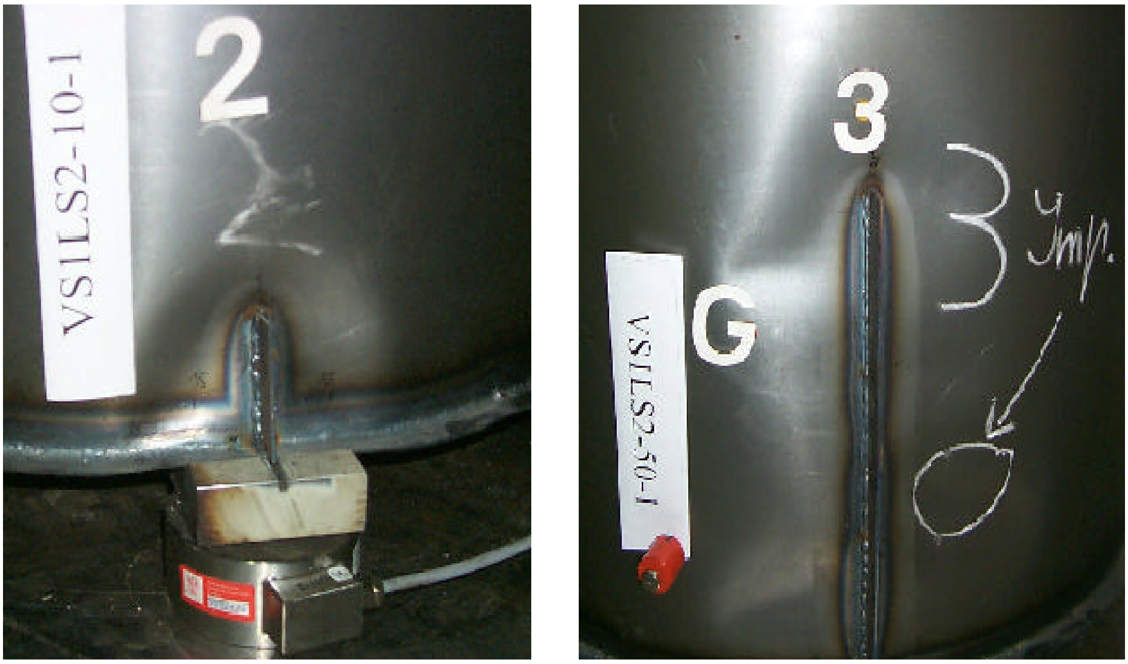


Fig. 5 Failure load dependig on the height of stiffeners
(in per cent of the cylinder heights)

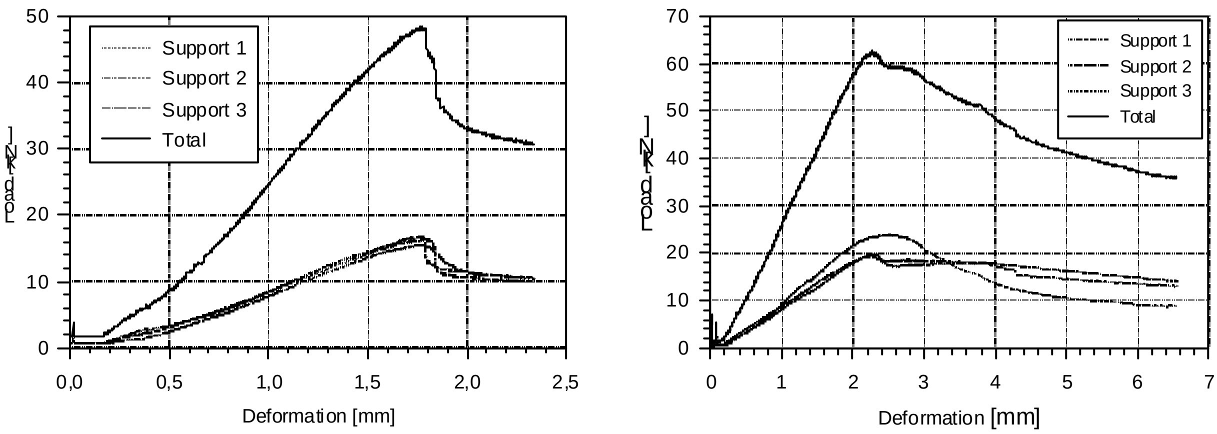
As expected, the failure load for shorter vertical stiffeners is smaller than for longer ones. In Fig. 6 are presented the failure modes for models with a stiffeners length of 10 per cent and of 50 per cent of the cylinder height.



a b

Fig. 6 Failure modes

In Fig. 6a it can be observed, that the buckle occurs in the whole region around the short stiffener. Using the longer stiffener, the shell collapsed at the end of the vertical stiffener.



A – stiffener height 10 per cent B – stiffener height 50 per cent

Fig. 7 Load – deformation diagrams

The load-deformation curves show, that in case of a shorter stiffener the failure occur suddenly (typical behaviour of shells). When the stiffeners are longer, the shell is characterised by a „horizontal branch" of the load-deformation curve.

3. Finite Element Analysis

The finite element analysis were done by using the software „ABAQUS“ and using shell elements S4R. The geometrical and physically non-linear calculations were carried out on a third of a silo. Thus it was possible to minimize the calculation time. The real measured imperfections of the silo wall are included in the model.

In Fig. 8, a finite element model with the distribution of von Mises stresses for the case of a stiffeners length of 10 per cent and 50 per cent of cylinder height is presented.

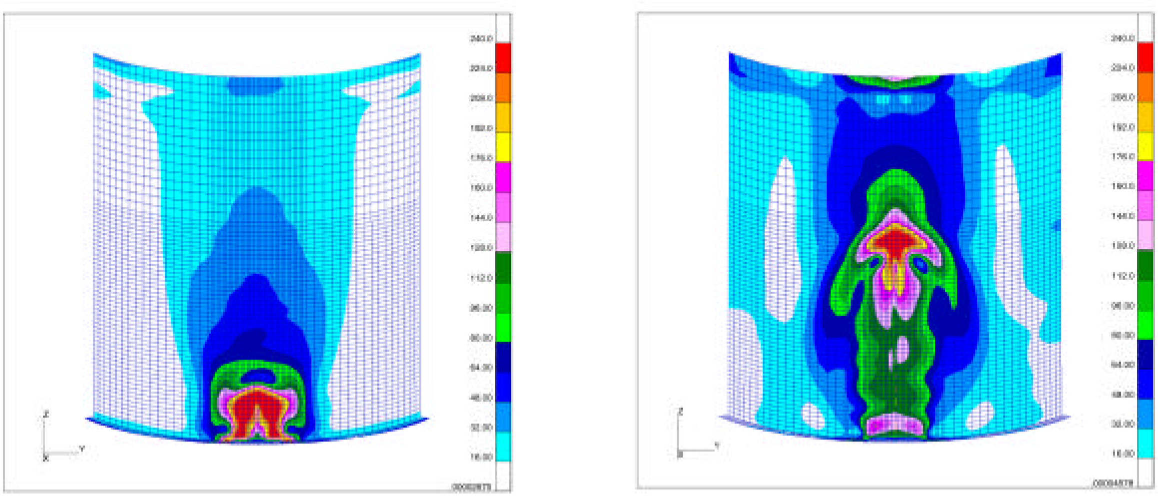


Fig. 8 Von Mises stress distribution (N/mm^2)

In Fig. 9, the influence of the load application region is presented. The tests were carried out with the assumption that the whole load will be apply on the upper edge of the cylinder. In practice, one part of the load is introduced by wall pressure (friction) and the other by tension due to the stored material in the hopper.

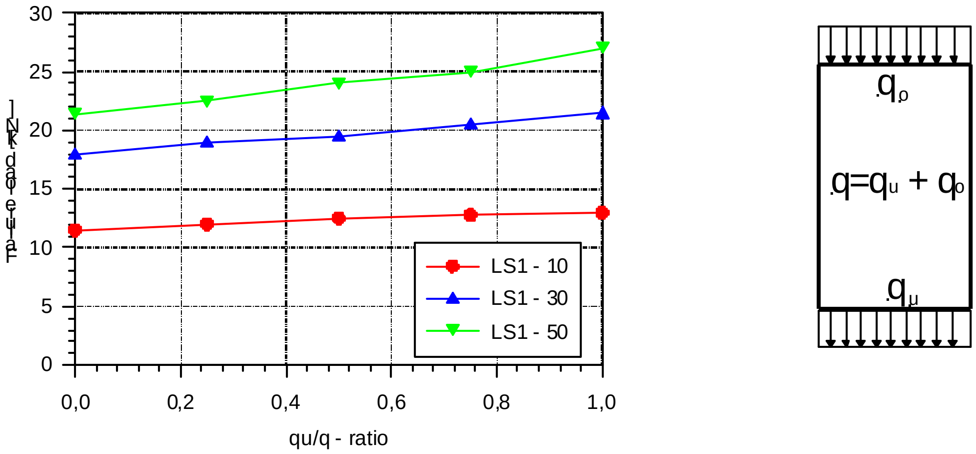


Fig. 9 Failure load depending on the load introduction

Generally, it may be observed that in case of the load introduction is on the bottom rim of the cylinder the failure load increased. The influence is more important for longer longitudinal stiffeners.

4. Conclusions

The buckling resistance can be calculated according to DIN 18 800, part 4 for unstiffened shells with continuous support.

Supplementary recommendations for considering local supported shells without any stiffeners are given in [3, 5, 6].

The aim of this ongoing research project is to get a statement about the optimal dimensions of the longitudinal stiffeners, e. g. the stiffness (which is sufficient to satisfy the minimum stiffness) and the length.

References

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