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INFLUENCE OF INTERMEDIATE RINGS AND HEIGHT OF SKIRT ON EFFECTIVE WIDTH OF COMPRESSION ZONE IN JUNCTION COLUMN - CYLINDRICAL SHELL OF STEEL SILO

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Key words: *steel silo, intermediate rings, compression zone, effective width*

ABSTRACT

Steel silos are interesting, complicated facilities. When they are raised above the ground, they combine shell and frame elements. In places of join of the 2 types of elements, stresses arise with very high values. It may leads to local loss of stability of thin-walled shells. One discussion point is how to determine the effective width l_{eff} of distribution of compressive stresses of supports by height of shell. Unfortunately, reference standards БДС EN 1993-1-6: 2007 and БДС EN 1993-4-1: 2007 do not give an answer to this question. Obviously there are a lot of influencing factors and is very difficult to be covered in an analytical expression and / or table.

In his research the author has analysed the impact of:

- the presence of the intermediate stiffening rings on the cylindrical shell;
- position of discharge hopper by height.

1. Introduction

In analytical (manual) solution of the steel silos, cylindrical body should be checked for local loss of stability due to meridional (axial) compression according to the methodology shown in standards БДС EN 1993-1-6:2007 [2] and БДС EN 1993-4-1:2007 [3]. Taking into consideration discrete supports, in the cylindrical body will appear concentrated axial forces. They will spread at some angle α to the vertical axis, see fig. 1 and will smoothly decrease on height. The value of the angle depends on directly by effective width l_{eff}. Obviously as this angle is bigger the effective width l_{eff} in the shell will be larger, respectively the meridional stresses $\sigma_{x,Ed}$ will be smaller.

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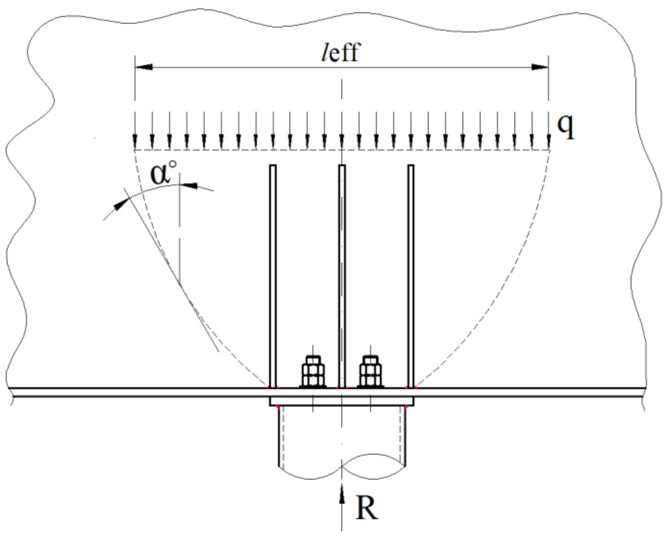


Fig. 1. Angle α of spreading of compressive stresses in the cylindrical shell and effective width l_{eff}

Unfortunately the above quoted standards [2] and [3] do not give information nor for the value of the angle α, neither for l_{eff}. Only in the standard БДС EN 1993-1-5:2005 [1] there is written formula for calculating of the l_{eff} in case of local pressure but it is valid for steel plates only. It is not recommendable to use this formula for cylindrical shells [5].

In his research in 2016 the author tried to determine the influence of following parameters on the distribution of the meridional normal stresses by height, respectively on the effective width l_{eff}:

- presence of the vertical stiffeners;
- presence of the conical discharge hopper;
- influence of the internal pressure on the shell.

Unfortunately in his research from 2016 the author did not have the possibility to analyse the influence of:

- presence of intermediate stiffening rings on the cylindrical body;
- the position of the discharging hopper by height (height of the skirt).

The purpose of this article is to fill the gap.

2. Numerical research

In order to find answer of the above mentioned questions, the author did several spatial research models of steel silo using software ANSYS [6]. The silo has dimensions as follow:

a) volume V = 110 m^3
b) stored product – lime;
c) internal diameter D = 3 485 mm;
d) height of the cylindrical body h_c = 10 950 mm;
e) number of the courses on the height - 5 pcs.;
f) thickness of the 1st course $t_{s,1}$ = 7 mm, and the others - $t_{s,2}$ = 6 mm, $t_{s,3}$ = $t_{s,4}$ = $t_{s,5}$ = 4 mm;
g) number of columns under the silo - 8 pcs. ;
h) used material - steel S235, according to standard БДС EN 10025-2 [4].

During the modelling of facility, the following conditions are accepted:

- all the elements are introduced as shells (shell181) with their real thickness;
- maximum size of the finite elements is 50 mm;
- the frame structure under the silos is simulated only with its columns, which are 8 pcs. and are fixed to the foundation;
- with one exception, the discharging hopper in research models of silos is jointed to the cylindrical body at some distance above lower edge, see fig. 2. This solution allows the girders or

columns supporting structure to be put precisely under the cylindrical body, i.e. additional bending moments will be omitted.

- vertical load is evenly distributed and it is applied to upper edge of the cylindrical body;
- the study was carried out taking into account the influence of the displacements caused by the load, i. e. taking into account the effects of second order;
- the option "symmetry" is used to facilitate the calculations. This option permits to research only parts of the structures which have axis of symmetry and a symmetrical load.

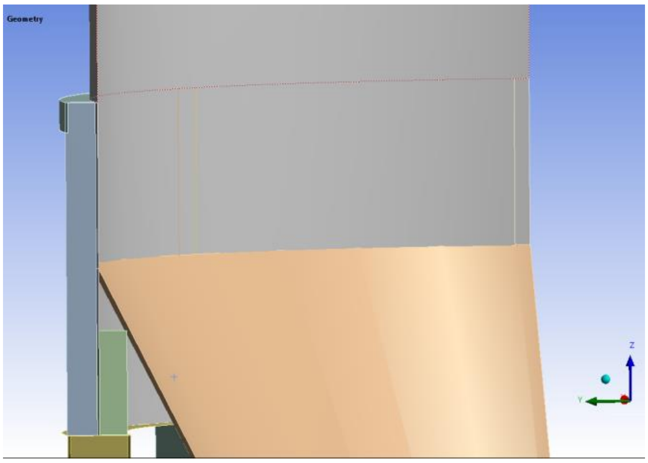


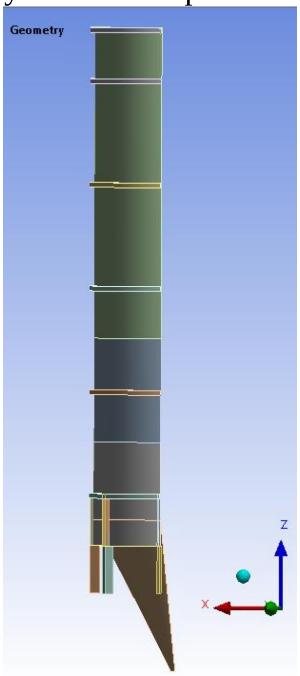
Fig. 2. Joint of the discharging hopper to the cylindrical body

Vertical stiffeners are placed inside and outside of the cylindrical body, above the 8 columns.

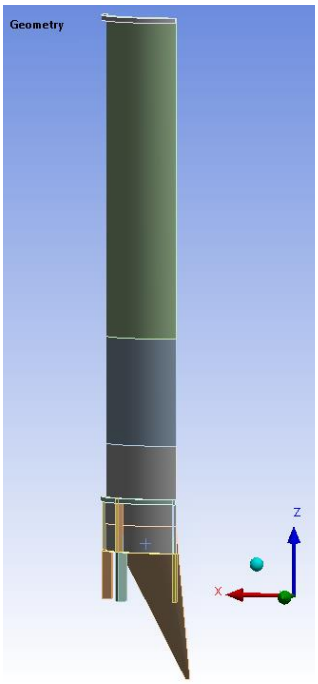
In order to take into account the effect of the intermediate rings, the study was conducted with the following constructive solutions:

a) a number of rings, both intermediate and at the top of the facility, are placed on the cylindrical shell of the silo, see fig. 3 - a);

b) there are not intermediate rings on the cylindrical body of the silo. Such a type of stiffening elements are placed only on shell's top and on a some distance above the columns, see fig. 3 - b)



a) cylindrical body with a many intermediate rings



б) cylindrical body without intermediate rings

Fig. 3. Stiffening rings on the cylindrical body.

Normal meridional stresses $\sigma_{x,Ed}$, caused by the vertical load F_x, are accounted in the joints above supports, by height of the cylindrical body. Knowing the thickness t of the shell and the value of the base reaction R, effective width l_{eff} can be calculated according to the formula:

$$l_{eff} = \frac{R}{\sigma_{x,Ed}.t}, \quad (1)$$

where:

R is a vertical reaction in the support, see fig. 1, caused by the vertical load F_x;

$\sigma_{x,Ed}$ – axial normal membrane stresses on the height of the cylindrical body;

t – thickness of the cylindrical steel shell.

Angle α of distribution of the pressure force in the shell, see fig. 1, due to the base reactions R, is determined according to the equation:

$$\alpha = \text{arctg}\left(0{,}5.\frac{l_{eff} - s_s}{z}\right), \quad (2)$$

in which:

s_s is the width of the support;

z – vertical distance between the application point of the base reaction R and joint, where meridian normal stresses $\sigma_{x,Ed}$ are accounted.

Six silos are modelled and researched to account the effect of intermediate stiffening rings on the cylindrical body. These silos have different heights of joint of hopper to the cylindrical shell. In half of them are put intermediate rings. Particular characteristics of the researched silos are indicated below:

Silo № 1

a) conical hopper is placed at height h = 1100 mm above the supports;

b) at height h = 1100 mm, outside of joint shell - hopper, there is a ring, reached out by vertical stiffening plates. They are placed outside and inside of the cylindrical body;

c) no intermediate stiffening rings on the cylindrical shell.

Silo № 2

Almost the same as the **Silo № 1**, but on the cylindrical body are placed 4 intermediate stiffening rings. They have angular section L100x10, welded on rib.

Silo № 3

a) conical hopper is placed at height h = 550 mm above the supports;

b) at height h = 1100 mm, outside of joint shell - hopper, there is a ring, reached out by vertical stiffening plates. They are placed outside and inside of the cylindrical body;

c) no intermediate stiffening rings on the cylindrical shell.

Silo № 4

Almost the same as the **Silo № 3**, but on the cylindrical body are placed 4 intermediate stiffening rings. They have angular section L100x10, welded on rib.

Silo № 5

a) conical hopper is placed at height h = 0 mm above the supports;

b) at height h = 1100 mm, outside of joint shell - hopper, there is a ring, reached out by vertical stiffening plates. They are placed outside and inside of the cylindrical body;

c) no intermediate stiffening rings on the cylindrical shell.

Silo № 6

Almost the same as the **Silo № 5**, but on the cylindrical body are placed 4 intermediate stiffening rings. They have angular section L100x10, welded on rib.

In order to account the effect of height of the ring girder, conical hopper and stiffening ring made from angular section L100x10 are placed on 3 different heights above the supports - h = 1100 mm, h = 800 mm и h = 500 mm. Vertical stiffeners reach to the stiffening ring, i.e. to the upper course of the ring beam.

Taking into consideration that stiffening rings do not have practical effect in the researched silo with the volume V = 110 m^3 and 8 supports, rings are not used.

Silo № 7

a) conical hopper is placed at height h = 800 mm above the supports;

b) in front of it is placed ring at the same height. The ring is reached out by vertical stiffeners. They are placed outside and inside of the cylindrical body, above the columns.

Silo № 8

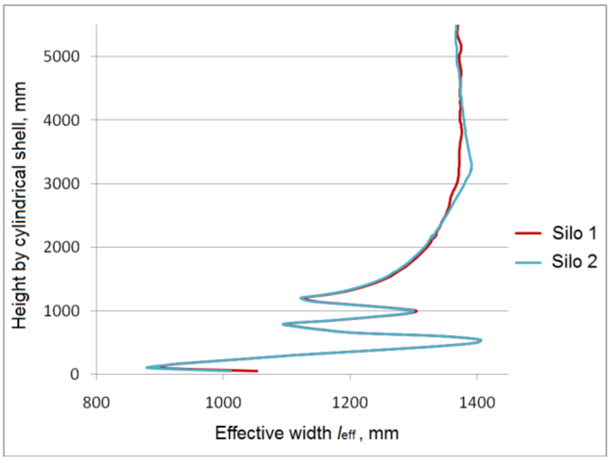
a) conical hopper is placed at height h = 500 mm above the supports;

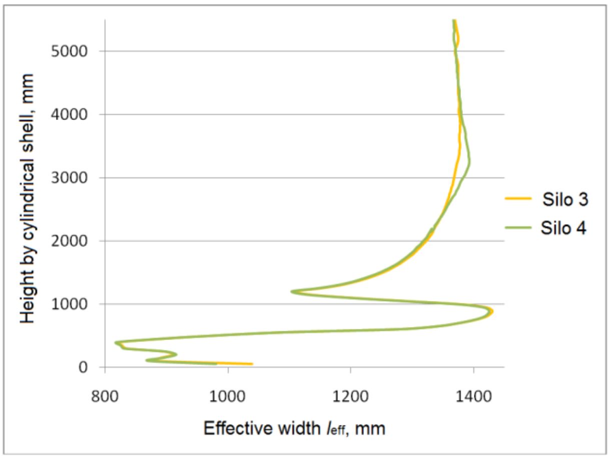
b) in front of it is placed ring at the same height. The ring is reached by vertical stiffeners. They are placed outside and inside of the cylindrical body, above the columns.

3. Results

3.1. Effect of the presence of the intermediate rings on the cylindrical body

The graphics of fig. 4 show that in the silo with 8 columns (supports) the intermediate rings, placed by height, have a little influence on the membrane normal stresses $\sigma_{x,Ed}$, respectively on effective width l_{eff} .





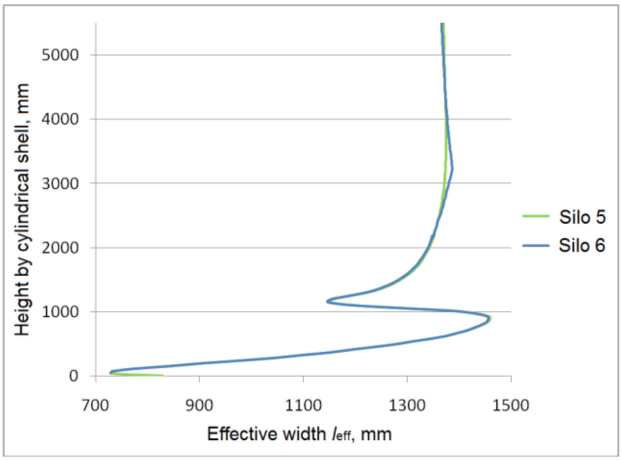


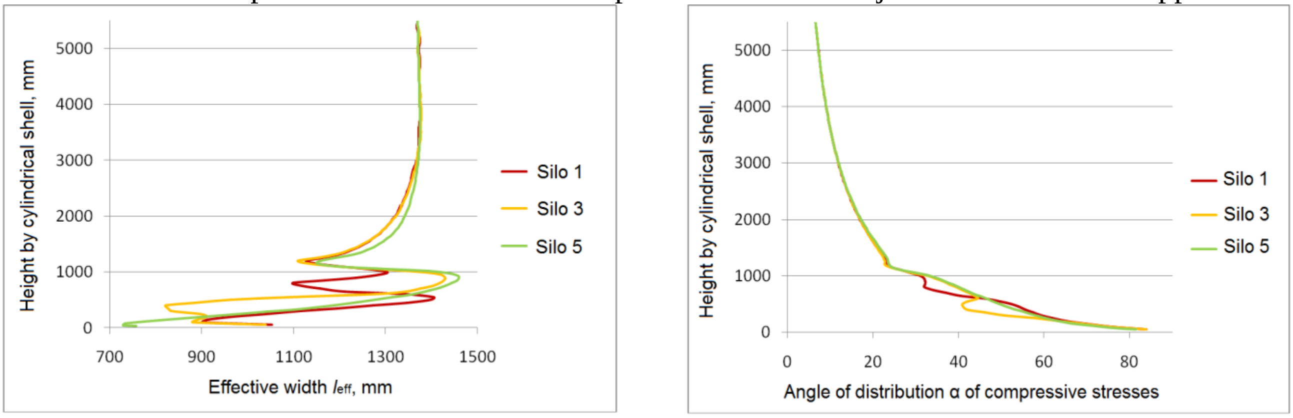
Fig . 4. Change of effective width l_{eff}, depending on presence of intermediate stiffening rings

In the silos 2, 4 and 6, at the height $h = 2500 \div 4000$ mm, are calculated effective width l_{eff} bigger than the maximum possible value $l_{eff,max} = 1368.6$ mm. Similar phenomenon is reported in the research of the *Knoedel* and *Ummenhofer* [7]. Most probably this discrepancy with the reality is due to the fact that on the enough height values of the stresses $\sigma_{x,Ed}$ between the supports become bigger those above them, see fig. 7. Hence the effective width l_{eff}, calculated to the formulae (1) becomes unrealistically large.

3.2. Effect of different height of joint cylinder - conical hopper

The graphics on the fig. 5 show that the joint of the conical hopper to the cylindrical body in its inferior edge (Silos № 5) leads to faster equalizing of the normal meridional stresses $\sigma_{x,Ed}$ above the stiffening ring at the height $h = 1100$ mm. When the hopper is jointed at the levels $h = 1100$ mm or $h = 550$ mm, there is almost no difference in the normal stresses $\sigma_{x,Ed}$, respectively in the effective width l_{eff}.

In the cylindrical shell above the lower stiffening ring, reached by vertical stiffeners, the angle of distribution α of compressive stresses does not depend on the level of joint of the conical hopper.



a) modification of the effective width l_{eff} b) modification of the angle of distribution α

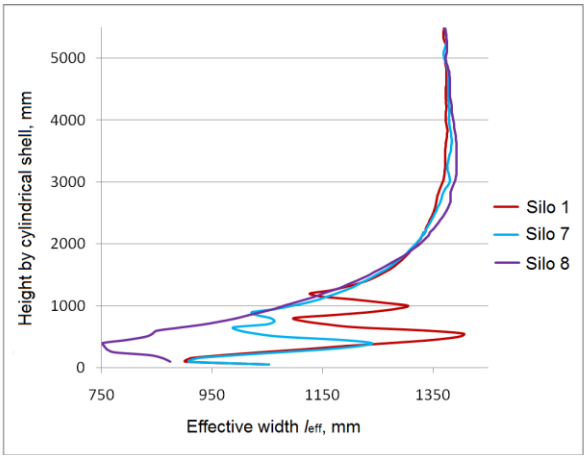
Fig. 5. Change of effective width l_{eff} and angle of distribution α in dependence of the level of joint of the conical hopper.

3.3. Effect of different height in the ring beam

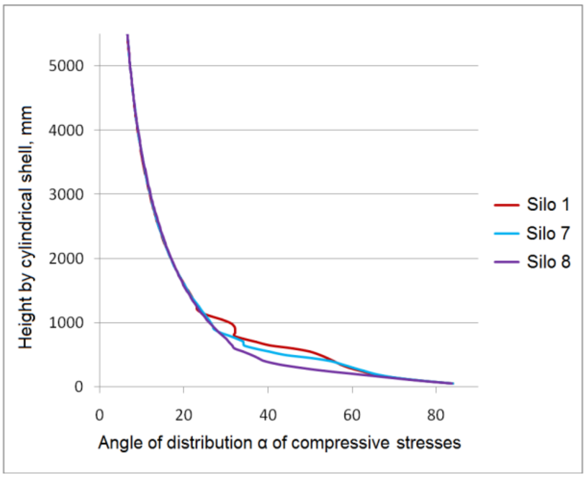
Obviously as lower is placed stiffening ring reached out by vertical stiffeners as smaller is the value of l_{eff} above the ring, see fig. 6. In addition, in lower "skirt" are calculated effective widths l_{eff} bigger than the maximum possible value $l_{eff,max}$

In the zone above the most highly placed stiffening ring, i.e. $h > 1100$ mm, differences of values of l_{eff} and α are small.

In the zone below the most highly placed support ring, i.e. $h < 1100$ mm, the angle of distribution α of compressive stresses is bigger when the height of ring beam ("skirt") is lower.



a) modification of the effective width l_{eff}



б) modification of the angle of dissipation α

Fig. 6. Modification of the effective width l_{eff} and of angle of distribution α depending on the level of the supporting ring

It can be seen that the value of the angle decrease by height. Fortunately the effective width l_{eff} increase, see fig. 4 and fig. 6. The practical consequence is that if the value l_{eff} would be determined for a point situated at distance l_R above the stiffening ring reached out by vertical stiffeners, and they would be used later for analytical research, these values will be conservative concerning the safety.

The distance l_R is calculated through the expression [2]:

$$l_R = 0{,}1.L \leq 0{,}16 r.\sqrt{\frac{r}{t}} \quad , \tag{3}$$

where:

L is the distance between the rings, stiffening the cylindrical body of the silo;
r – the radius of the cylindrical body;
t – the thickness of the cylinder.

An interesting effect is observed in the current research – when the distance from the supports is bigger, it is supposed that the values of the meridional normal stresses $\sigma_{x,Ed}$ in one horizontal section would be equalized, but it does not happen. Something more, at enough height the values of the stresses between the supports become bigger than these above them fig. 7.

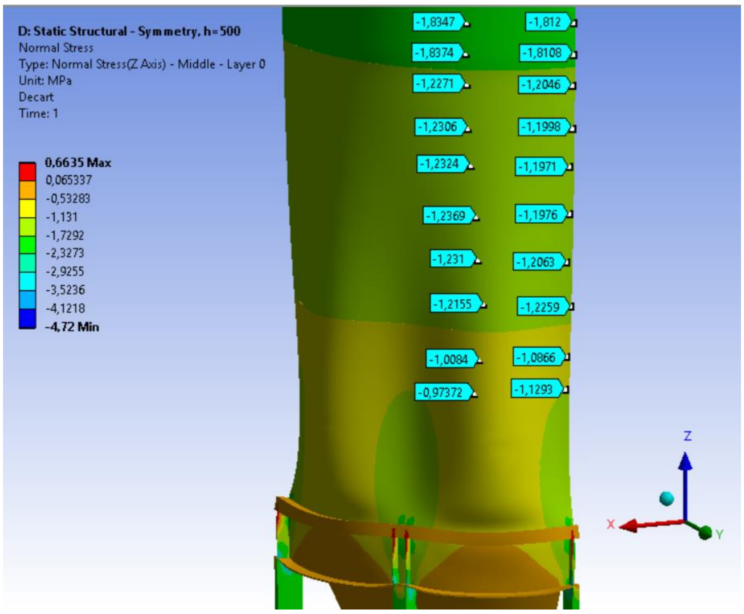


Fig. 7. Change of the meridional normal tensions $\sigma_{x,Ed}$ at height

4. Conclusions

From the current study, done with one relatively small steel silo, but in 8 different variants could be taken conclusions as follow:

- when position of the stiffening ring to which vertical stiffeners reach is not changed, the change of the place of joint of the hopper to the cylinder has a small influence;

- for small - diameter silos with 8 columns, the intermediate stiffening rings have too small influence on the distribution of the meridional (axial) compressive stresses;

- the angle of distribution α, determined for the stresses $\sigma_{x,Ed}$, accounted immediately above the stiffening ring reached out by the vertical stiffeners, is within the borders $\alpha = 25^0 \div 40^0$. In other words the use of the results of *Whitmore* [8], showing that the angle $\alpha = 30^0$ is good enough for the initial (manual) calculation of the steel silo. After their conduction a spatial design model should be created. It will determine the real value of the stresses within supports area;

- the angle of distribution α decrease by height z, but the effective width l_{eff} increases continuously to its maximum value;

- no complete equalization of the values of the meridian normal stresses $\sigma_{x,Ed}$ in one horizontal section.

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