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REINFORCEMENT OF STEEL CYLINDRICAL SILO DUE TO REPURPOSE OF CONSTRUCTION

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Abstract: *During the exploitation of the steel cylindrical silo there was a repurpose of construction that required the need for creating a revision on the lower part of the silo. In addition, due to the change in the type of material stored in the silo, the load was increased. An analysis of all relevant impacts has begun to determine the actual stress and strain state on the structure. The construction is modeled in the Abaqus software package. Based on static influence, the necessary reinforcements are foreseen and the construction is dimensioned according to European regulations - Eurocodes.*

Key words: *steel cylindrical silo, reinforcement, modeling of FEM.*

1. Introduction

Silos are used for the storage of various granular materials such as gravel, cement, grain agricultural products. They are widely used in civil engineering and agriculture, processing industry, with full utilization of all the advantages that they provide. They are built individually as well as in battery groups, in the open or indoors, and represent a typical expression of modern welded structures. They can be in a cross-section of a circular, square or rectangular shape. [1].

In this paper reinforcement of steel cylindrical silo due to repurpose of construction was presented. Dimensioning was carried out based on the Europian standards and previosly published paper [2]. In these cases of increasing loads on construction there is a probability that welded joints can break down, therefore they can be checked by modern methods [3].

2. Load Analysis

During the exploitation of the steel cylindrical silo, after the repurpose occurred, there was a need for the creating a revision on the lower part of the silo. Due to the change in the type of material stored in the silo, the load was increased. All relevant impacts were analyzed to determine the actual stress and strain on the structure. In addition to the usual effects of constant and occasional load (own weight of the construction, storage material), the influence of horizontal wind force was taken into account when calculating the

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cylinder silo. An empty silo is exposed to winding due to the wind effect [4] due to its geometric characteristics.

The European standard EN1993-1-6 [5] contains the theoretical background and provides a superior methodology for the explicit evaluation of the resistance to buckling of silo mantle. The regulations include analytical expressions for calculating buckling due to strain and also proposes several numerical methods, such as linear bifurcation analysis, to obtain a critical load of elastic buckling, as well as analyzes involving geometric and material nonlinearities and imperfections. An analytical procedure was also designed to estimate the resistance of mantle to the buckling, depending on the thickness of the sheet. Most of the approaches recommended by the European standrad require the use of computer methods, such as finite element methods for the buckling analysis of the mantle.

The wind load according to EN 1991-1-4 [6, 7] was simulated as a distributed pressure on the circumference of the mantle. This pressure varies along the height and volume of the mantle. However, the variation along the height of the silo is not significant, therefore it is assumed that it is constant along the entire height.

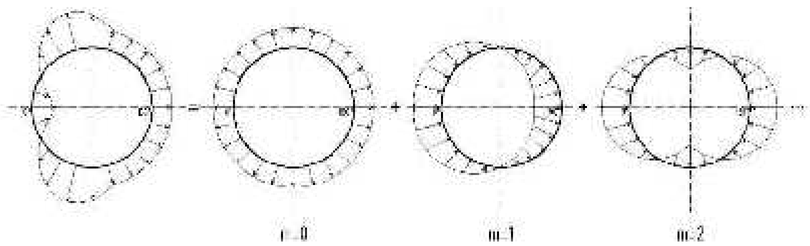


Fig. 1. *Distribution of wind load, on cylindrical mantle [8]*

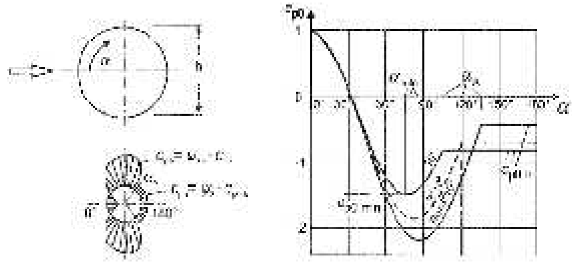


Fig. 2. *Distribution of wind pressure, on a cylindrical mantle with different Reynolds numbers [9]*

3. Silo Geometry

The paper presents the calculation of the steel cylinder silo before and after remedation. The volume of the silo is V = 60 m³, the diameter of the cylindrical part is D = 2.87 m, the height of the cylindrical part is Hc = 8.4 m, the roof height is Hk = 0.54 m and the height of the leaf is Hl = 1.7 m. Silo pillars are 8.0m high. The mantle of the silo is made of 6 layers of different thickness of the sheet. To accept the horizontal component of the load on each joint of the sheet, a horizontal U80 encircling and vertical bends L60 / 60 are installed in order to further enclose the silo. At the bottom of the cylindrical section there is a reinforcement with the ribs of 10mm are positioned in order to further strengthen the places on which the silo lies on the pillars. Roof is made of 3mm thick sheet. The sheets are mutually welded together. The roof is conical with a hole at the top of R = 0.68 m on which there is a stiffness made up from U100. The silo's leaf is made of 4 segments of 4mm thick sheet, with horizontal and vertical stiffnesses, at the bottom of the leaf there is an opening of 0.68 m.

It was necessary to carry out the remedation of the silo, in order to enable the repurpose of the structure, which was demanded by the revision opening at the bottom of the cylindrical part and additional reinforcement of this opening and bottom of the cylindrical part. Because of this, another reinforcement with the ribs above the existing one were added to receive this additional load.

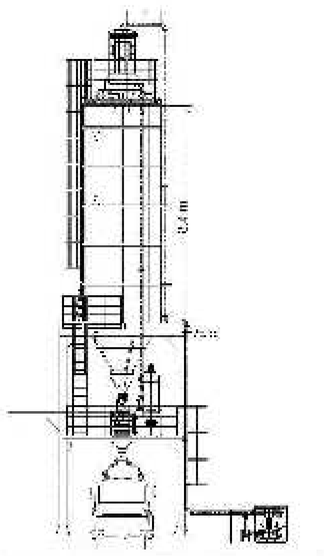


Fig. 3. *Silo before remedation*

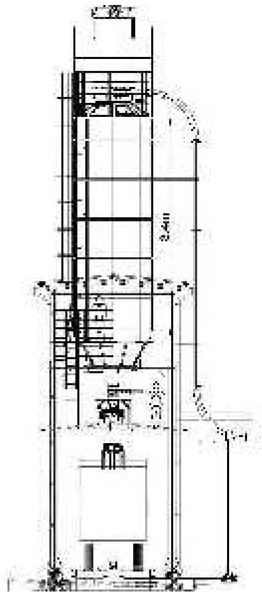


Fig. 4. *Silo after remedation*

4. Calculation of silo in the software package „Abaqus''

4.1. Model of silo construction

The software package ABAQUS [10, 11] was used to simulate a silo with geometric and material properties similar to the existing construction and to perform the required analysis.

ABAQUS 6.7 is a software package based on FEM (Finite Element Methods), which consists of a number of engineering programs. It is developed by Hibbitt, Karlsson & Sorensen Inc. ABAQUS is one of the comprehensive programs designed to solve a wide range of problems, both related to mechanics, and to other fields of science.

The silos model is made up of thin shells (*3D shell deformable part*), where all the parts, the mantle as well as all the stiffnesses are modeled as thin plates surface-rigidly bound.

On the lower part of the silo, the supports are placed, which simulates the silos on the steel beams. Since all parts are modeled as thin plates, S4R element is used for all parts of the silo. It is a rectangular-shaped, double-curved, infinite shell with reduced integration and 4 knots. Each node has 5 degrees of freedom: moves in the direction of each coordinate axis and two rotations in the coordinate plane. Such characteristics meet the requirements of modeling EN 1993-1-6 [5]. The material is modeled as elastic and isotropic for all structural elements, with the Yang modulus of elasticity 210 GPa, and Poason's coefficient ν = 0.3.

4.2. Influences on the Silo Caused by Constant Loading

Horizontal pressure on the mantle of the cylindrical part, as well as pressure on the mantle leaf, is presented in the form of a horizontal distributed load. While the vertical load due to friction is presented as a vertically distributed load applied by horizontal stiffening, with an appropriate intensity. Table 1 and 2 show the load values that are variable in height.

Constant load: filter up: Q=1.75 kN/m'
transition part: Q=0.49 kN/m'
vibro bottom: Q=3.04 kN/

Distributed constant load acting on the mantle in [kN/m²] Table 1 and Table 2

z	Vertical load due to friction	Horizontal pressure on the mantle
0	81.23	0
0.9	67.14	5.25
2.4	269.10	9.1
3.9	531.97	13.86
5.4	794.18	16.65
6.9	1151.89	20.02
8.4	1486.62	21.9

z	Pressure on the leaf
8.2	29.98
8.7	30.87
9.2	27.81
9.7	23.08
10.2	16.44
10.6	9.99

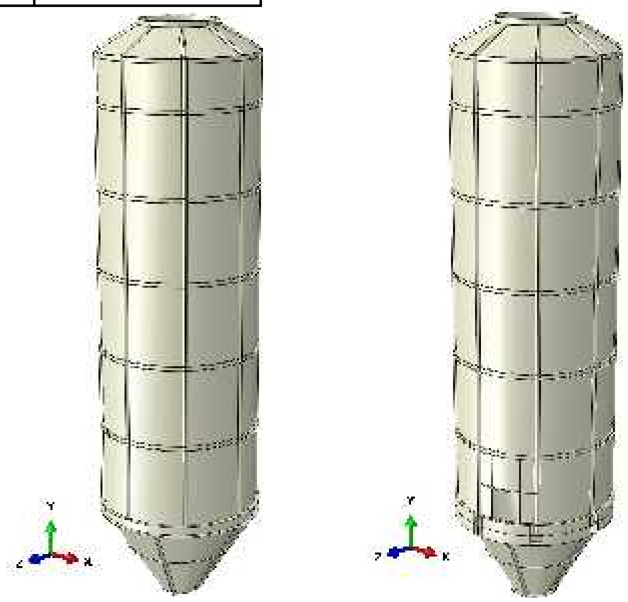


Fig. 5. *3D models of silo (left –model before remedation, right –after remedation*

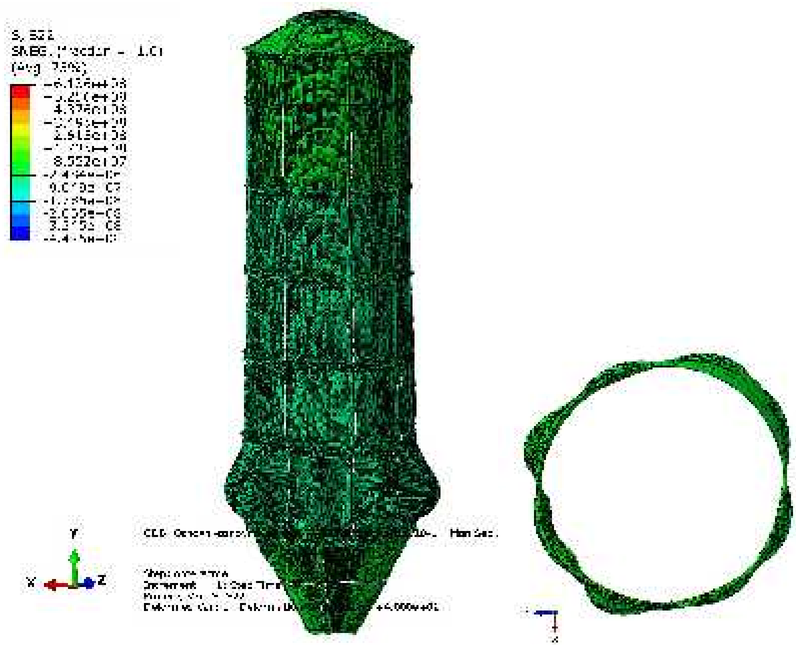


Fig. 6. *Deformations and stresses due to their own load, for model before remedation*

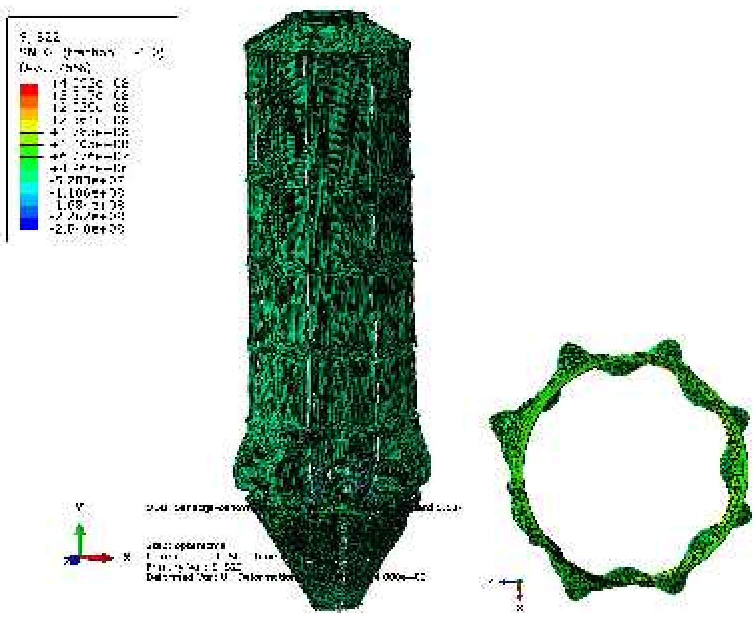


Fig. 7. *Deformations and stresses due to their own load, for model after remedation*

Influences on the silo caused by constant loading are given in Fig. 6 and 7.

4.3. Influences on the Silo Due to The Wind Effect

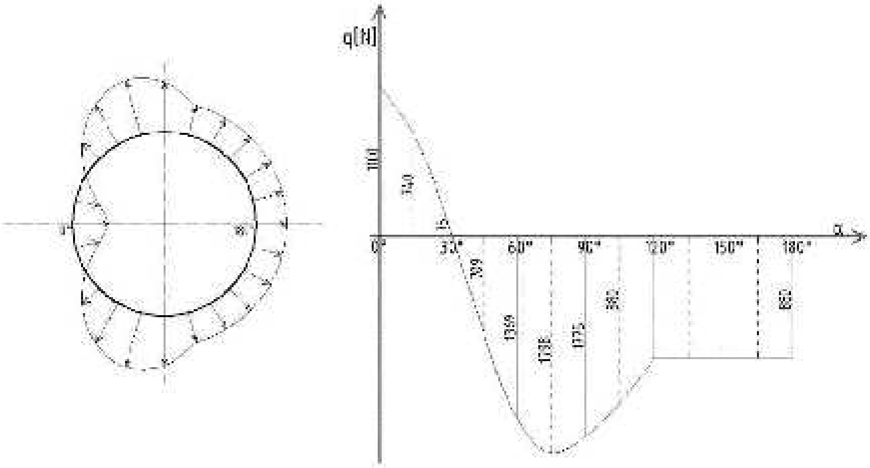


Fig. 8. *Distribution and wind load values*

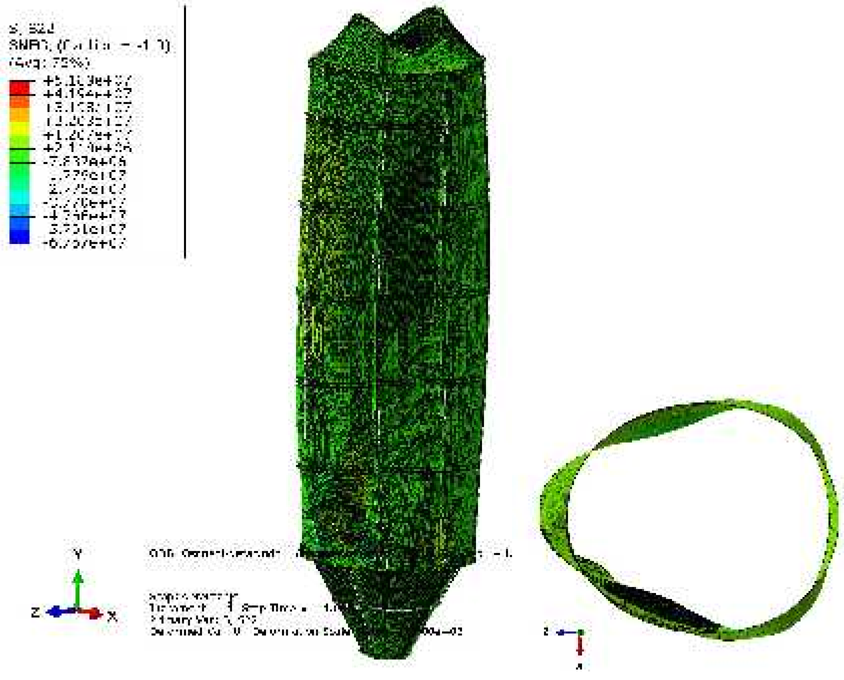


Fig. 9. *Deformations and stressess due to the effect of wind on the silo, for the model before remedation*

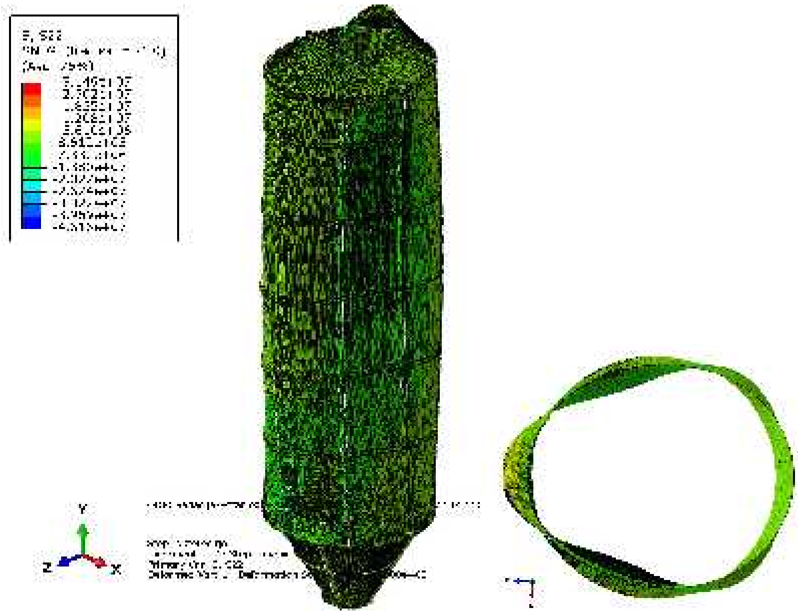
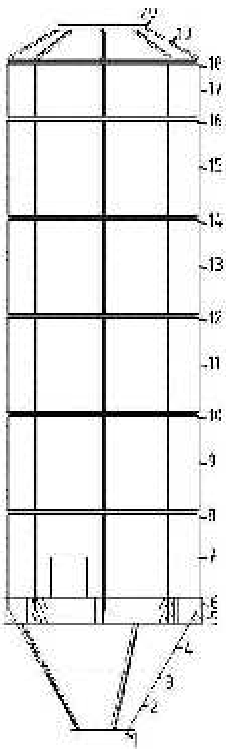


Fig. 10. *Deformations and stressess due to the effect of wind on the silo, for the model after remedation*

4.4. Analysis of the Influences

Normal stresses given in MPa in the direction of the vertical axis Table 3



point	Models			
	Before remedatio, basic load	Before remedatio, wind load	After remedatio, basic load	After remedatio, wind load
1	2.01	-2.15	1.09	0.34
2	2.24	-0.29	2.11	0.17
3	3.85	-0.41	5.15	0.48
4	6.93	0.23	5.52	0.35
5	-30.53	0.28	-24.51	1.16
6	0.00	0.00	-7.88	-0.13
7	-32.54	-1.10	-29.50	0.24
8	13.31	-1.38	13.30	-0.42
9	-24.85	-4.95	-24.01	-3.23
10	12.28	-1.91	23.53	-2.49
11	-13.72	-5.07	-12.78	-4.52
12	8.47	-1.96	8.29	-0.92
13	-5.58	-5.10	-5.81	-4.92
14	4.62	-1.79	4.43	-0.92
15	-1.92	-3.95	-2.24	-3.88
16	1.00	-1.12	0.90	-0.59
17	-1.25	-1.83	-1.50	-1.77
18	2.89	-0.40	1.65	0.02
19	0.37	1.14	-0.19	1.05
20	-2.72	-18.51	-3.18	-17.21

5. Conslusions

In the calculations on the model before remedation, very high values of stresses are obtained in the part where the silo lies on the beams. For this reason, another reinforcement was added above the existing one, which additionally and sufficiently reinforced the silo. After calculating the model after the remedation, it can be seen that the reinforcements that were added around the revision hole prevented buckling of the mantle due to their own load and obtained satisfactory stresses. From all of the above, it can be concluded that the stiffening is necessary, however silo failure would not occur.

Acknowledgement

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