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The evaluation with ANSYS of stresses in hazelnut silos using Eurocode 1

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Abstract. In this study, the optimum silo dimensions for the barrel-type steel-concentrated silo with a conical outlet port usable in the hazelnut storage were investigated. Three different types of silo models as Model 1 (1635 tons), Model 2 (620 tons) and Model 3 (1124 tons) were used in the study. Varying wall thicknesses were used for Model 1 (10, 11, 12, 13, 14, 15 and 20 mm), Model 2 (10, 15 and 20 mm) and Model 3 (10, 15 and 20 mm) silos. For Model 1 silo has the most storage capacity here, to determine its optimum wall thickness, the wall thicknesses of 11, 12, 13 and 14 mm were used as different from the other models. Thus the stresses occurring in different lines with ANSYS finite element software were examined. In the study it was determined that the 10, 11 and 12 mm wall thicknesses of the Model 1 silo are not safe in terms of the stresses caused by the vertical pressure loads in the filling conditions. From the view of the filling and discharge conditions, other wall thicknesses and model silos were diagnosed to be secure. The optimum silo dimensions which won't cause any structural problems have been found out as the Model 1 silo with a 13 mm wall thickness when the filling capacity and the maximum von Mises stresses are taken into account. This barrel-type silo with conical outlet port sets forth the most convenient properties in hazelnut storing in terms of engineering.

Keywords: hazelnut; silo; Eurocode 1; ANSYS finite element software

1. Introduction

Circular steel silos are complex thin branched shells of revolution subject to complicated loading and support conditions. Despite the complex behaviour of both forms of structure, traditional design techniques for metal silos often use very simplified methods and rely heavily on the designer's experience. Such design techniques have become increasingly inadequate as the size of modern metal silos has risen. The many failure modes in silo structures all depend on the stress state being induced in the local part of the shell, and these stresses depend on the pressures exerted by the stored solid.

The European Union is now trying to adopt since the 1980 a common system of standards for its member countries with respect to structures and construction. This involves the long process of

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proposing and approving Eurocodes. In Eurocode 1, regarding the calculation of actions in buildings and structures, a specific section (section 4) has been introduced for silos and tanks. Also taken into account are thermal loads, hopper design, concentric emptying and explosions. It is, therefore, the benchmark system for the rest of the world (Ayuga *et al.* 2005). Silo design is dominated by discharge loading conditions, which remain significantly unpredictable even in the early 21st century. The most comprehensive design standard for these loads is the new Eurocode 1 (2007a, b) which defines different classes of silo by size, aspect ratio, wall roughness and construction material, as well as requiring a range of properties to be considered for the stored solids and requiring several different loading conditions to be examined in design calculations (Rotter 2009).

The tools used in silo research include experimental, analytical and numerical techniques. Experimental analyses are complex, and their main drawbacks are high costs and difficulty to generalise results. The application of analytical methods is very complex due to the nature of the problem being solved. Therefore, numerical methods have become usual in research of actions on silos (Vidal *et al.* 2005).

In this study, these methods are now widely used for the design of the silo is made according to Eurocode standard. ANSYS finite element program was used to perform of stress analysis. Aim of this study, to determine the optimum wall thickness depending on the stresses (von Mises stress) caused by pressure loads in filling and discharging conditions of different silo models and wall thickness were investigated.

2. Material and method

2.1 Material properties

In this study was used Tombul hazelnut variety (*Corylus colurna* L.). The reason for the use of this variety, intensive farming in the region as one of the varieties of high quality hazelnuts, and is the emergence of the storage need during the processing and export. Table 1 shows that the enginnering properties concerning Tombul hazelnut variety. The bulk density and static coefficient of friction for hazelnut were determined under the laboratory conditions. The weight of a bulk density container of 1000 ml volume was used to determine bulk density. The bulk density container was filled to 5 cm above the top. The hazelnuts were then allowed to settle into the container and the excess removed before bulk density determination. Galvanized steel surface was used as friction surface for static coefficient of friction (Kibar and Öztürk, 2009). The model silo has a cylindrical bin and a conical hopper (Fig. 1).

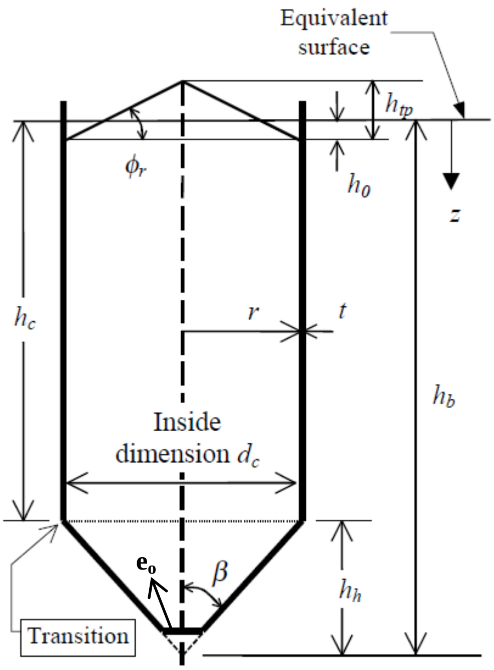
Foreseen in the design for silos, the performances from aspects of engineering depending on stored product were evaluated. Dimensions and materials properties for the developed models are shown in Table 2. The wall of the silo was assumed to be made of flat steel. The steel wall was considered to be isotropic, with the mechanical properties. The wall thickness was assumed constant along the height of the silo.

2.2 Simulation details

The study was designed for three different silo models. The data in Tables 1 and 2 are used in determining of the storage capacity of the silo. Model 1 silo has a storage capacity of 1635 tons

Table 1 The physical and mechanical properties concerning Tombul hazelnut variety

Physical and mechanical properties	Unit	Value
Bulk density, γ_m	$kN.m^{-3}$	4.518
Angle of internal friction, φ_m	degrees	29.8°
Static coefficient of friction, μ_m		0.204
Lateral pressure ratio, K_m		0.55



d_c : characteristic dimension of inside of silo cross-section, (m)
e_o : eccentricity of the centre of the outlet, (m)
h_c : height of vertical-walled segment of silo from the transition to the equivalent surface, (m)
h_b : overall height of silo from the hopper apex to the equivalent surface, (m)
h_h : height of hopper from the apex to the transition, (m)
h_o : depth below the equivalent surface of the base of the top pile, (m)
r : equivalent radius of silo ($r = 0.5\ d_c$), m
t : silo wall thickness, (mm)
z : depth below the equivalent surface of the solid in the full condition, (m)
α : mean angle of inclination of hopper wall measured from the horizontal, (degrees)
β : angle of inclination of hopper wall measured from the vertical (=90°-α), (degrees)
φ_r : angle of repose of a particulate solid, (degrees)

Fig. 1 Bin-hopper geometry for the model silos

and 10, 11, 12, 13, 14, 15 and 20 mm wall thicknesses; in Model 2 silo has a storage capacity of 620 tons and 10, 15 and 20 mm wall thicknesses; in Model 3 silo has a storage capacity of 1124 tons of 10, 15 and 20 mm wall thicknesses were taken into consideration. Some thicknesses were different in Model 1 in order to achieve the optimum ones in the economic sense. This is because, has a maximum storage capacity of the Model 1 silo and is targeting of the achievement of optimum wall thickness with the consideration as economic (Kibar and Öztürk 2011). The automatically filling to hazelnut silo by tremie and it discharge by bunker systems were simulated.

According to Eurocode 1 (2007b), calculation of silo pressure loads for three different silo models were made to the slender silo ($h_c/d_c \geq 2$) and step hopper ($\tan\beta < (1-K_a)/(2x\mu_a)$). Detailed explanations related to this subject are given in Table 2.

In the study, basic properties of the wall material were taken from Eurocode 3 standard (Eurocode 3 2004). The type of steel was the same as used by Vidal *et al.* (2004), Ayuga *et al.* (2006), Vidal *et al.* (2006b) used in S235 steel. The use of commercial software enables easier diversification of results among scientists around the world, and includes the improvements in numerical methods in a faster and more efficient manner. In the study, Shell181 for the silo wall

Table 2 The properties of silo dimensional and construction material

<table>
<tr><th>Models</th><th>Dimensional characteristics of the silo</th><th>The properties of silo construction material</th></tr>
<tr><td>Model 1</td><td>d_c : 12 m
h_c : 30 m
h_b : 36 m
h_h : 6 m
h_s : 2.5 m
h_o : 0.8 m
r : 6 m
t : 10, 11, 12, 13, 14, 15, 20 mm
e_o : 1.5 m
α : 58^{0}
β : 32^{0}
V_s: 1635 ton
- Silo type: slender silo, h_c/d_c = 30/12= 2.5≥2.0
- Action Assessment Classes (AAC): This geometry, the silo is of Eurocode 1 AAC2 (1635 ton<10.000 ton).
- Hopper type: step hopper, tan32<(1-0.5)/(2x0.185).</td><td rowspan="3">- Wall material:
Galvanised carbon steel S235
Elasticity modulus : 2.1×10^{8} kPa
Poisson rate: 0.3
Bulk density: 78.5 $kN.m^{-3}$
Yield strength of steel : 235000 kPa
Designe value of steel yield strength : 188000 kPa
Shear modulus : 81000 kPa</td></tr>
<tr><td>Model 2</td><td>d_c : 8 m
h_c : 26 m
h_b : 30 m
h_h : 4 m
h_s : 1.8 m
h_o : 0.6 m
r : 4 m
t : 10, 15, 20 mm
e_o : 1 m
α : 50^{0}
β : 40^{0}
V_s: 620 ton
- Silo type: slender silo, h_c/d_c = 26/8= 3.25≥2.0
- Action Assessment Classes (AAC): This geometry, the silo is of Eurocode 1 AAC2 (620 ton<10.000).
- Hopper type: step hopper, tan40<(1-0.5)/(2x0.185)</td></tr>
<tr><td>Model 3</td><td>d_c : 10 m
h_c : 30 m
h_b : 35 m
h_h : 5 m
h_s : 2.1 m
h_o : 0.7 m
r : 5 m
t : 10, 15, 20 mm
e_o : 1 m
α : 60^{0}
β : 30^{0}
V_s : 1124 ton
- Silo type: slender silo, h_c/d_c = 30/10= 3 ≥2.0
- Action Assessment Classes (AAC): This geometry, the silo is of Eurocode 1 AAC2 (1124 ton<10.000 ton).
- Hopper type: step hopper, tan30<(1-0.5)/(2x0.185).</td></tr>
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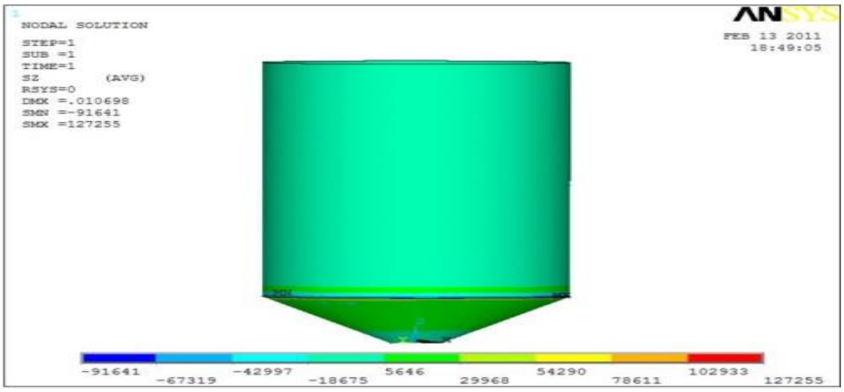

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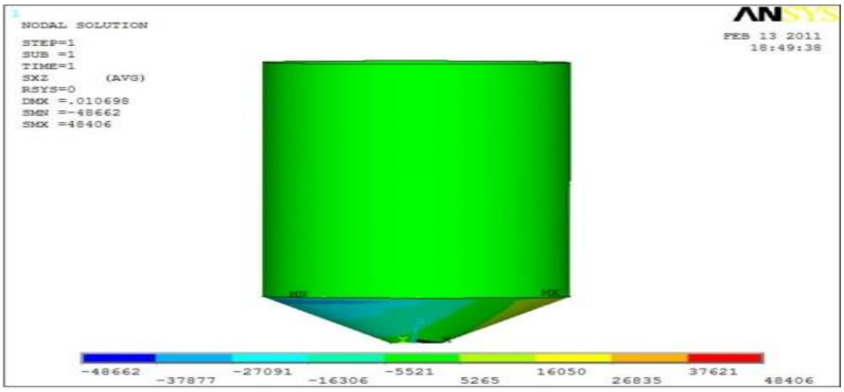

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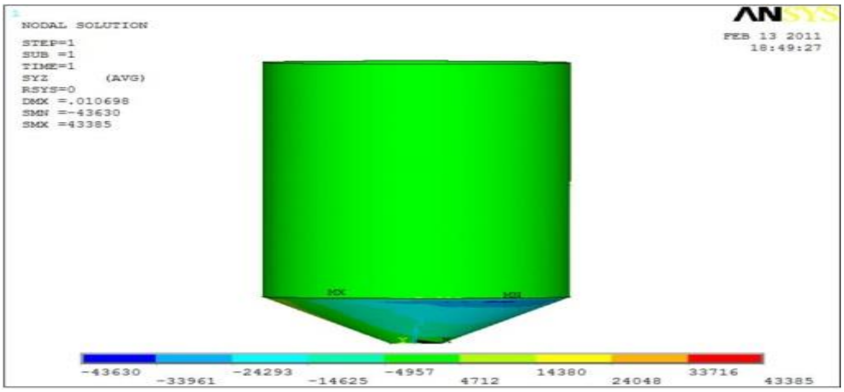
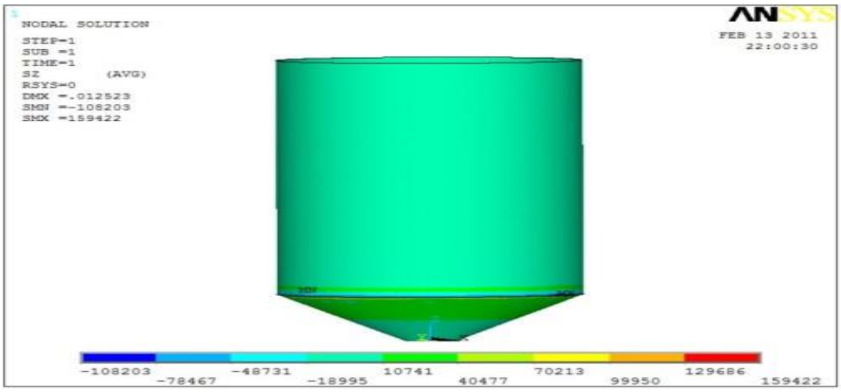


YZ

Fig. 2 The stresses for the optimum silo Model 1, 13 mm in filling conditions for horizontal situation

and Solid181 for the ensiled material are used. The contact element used was an one-dimensional, two-node element, paired with another two-node contact element, with two integration points at the grain-wall contact lines of the elements, as described by Vidal *et al.* (2005). In particular, the contact elements used were Targe169 and Conta171.

The authors used ANSYS 14.0 software package to solve the stress analysis. Three types of simulation models with different storage capacities and the silo wall thicknesses were discussed.



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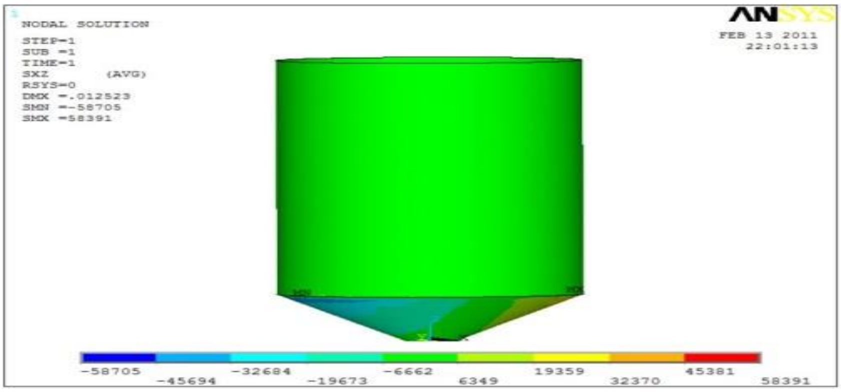

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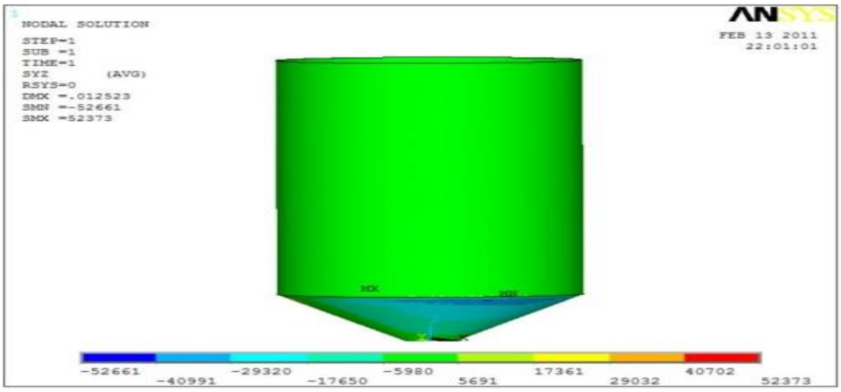
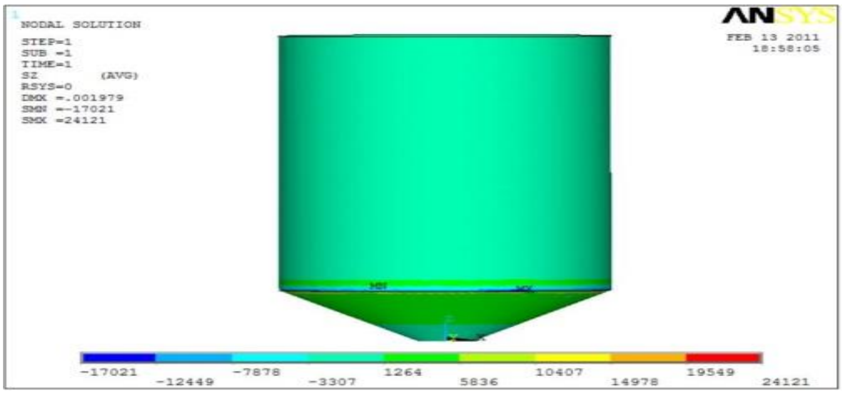


YZ

Fig. 3 The stresses for the optimum silo Model 1, 13 mm in filling conditions for vertical situation

3. Results and discussion

In the filling conditions, Models 1, 2 and 3 were evaluated in terms of the stresses induced by the horizontal pressure, vertical pressure and frictional traction. Maximum the horizontal pressure, vertical pressure and frictional traction caused by the filling loading are 84.16 kPa, 74.78 kPa and 12.55 kPa, respectively. As the silo wall thickness increases from 10 mm to 20 mm, the values of



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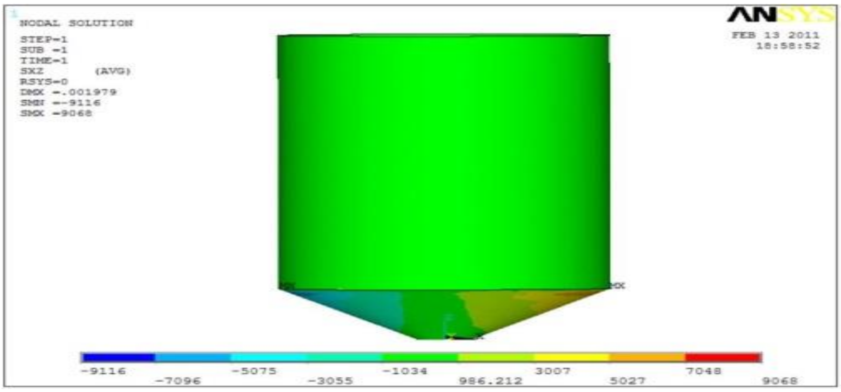

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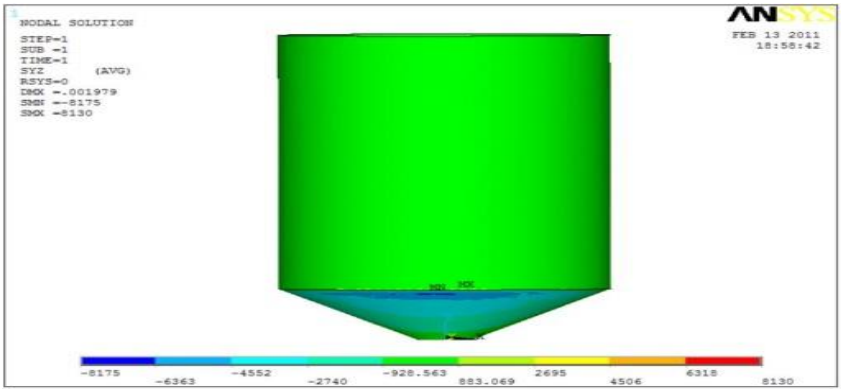


YZ

Fig. 4 The stresses for the optimum silo Model 1, 13 mm in filling conditions for frictional situation

stress occurring whether in the cylinder part of the wall or in its hopper part seem to have dropped. When the stress values of different directions were examined, it was stated that the YZ and XZ shear stresses (Model 1, 13 mm) don't undergo change greatly in the cylinder part of the silo wall but very slightly in the areas close by the transition and the stress towards the Z (Model 1, 13 mm) direction does not show any alternations under some conditions but shows slight changes under some other conditions (Figs. 2-4). High stress values have generally occurred in the high ends or

Table 3 The von Mises stress changes depending on the horizontal pressure

Model Number	Wall thickness, mm	von Mises stress, kPa
1	10	158006
	11	144680
	12	131065
	13	129509
	14	119408
	15	105469
	20	74076
2	10	71516
	15	60163
	20	33729
3	10	112164
	15	81448
	20	58018

the low ends of the transition to the hopper in the models. The main cause of this situation stems from the weight the product filled in the silo causes upon the base. Also, grain moisture depending on storage period at stored hazelnut can be explained. The stress values close to minimum were obtained in around the outlet in that the lower of the pressure exerted by hazelnut, where the product output exists, again in the models.

The maximum stresses occurring in the case of a horizontal pressure under the filling conditions took place in the 10 mm wall thickness in all three models (Figs. 5-6). Accordingly, when the stresses the horizontal pressure load causes upon the wall are examined, the von Mises stresses in the 10 mm wall thickness are: 158006 kPa for Model 1, 71516 kPa for Model 2 and 112164 kPa for Model 3. As such, the von Mises stresses of all three models were determined to be secure, in that they were established as below 188000 kPa which is the calculated yield strength value of the steel (Table 3).

Kovtun and Platonov (1959) stated in the studies they conducted that the horizontal pressure and the stresses are maximized when passing from the cylinder part to hopper. They stated that as the filling process continues in the silo, consolidation will occur with the resilience of the filled product in the silo and because in this consolidation an excessive pressure effect is going to form due to the air pressure, the silo wall materials durable against these pressures should be chosen, otherwise outbursts, breakdowns and deformations will occur. Juan *et al.* (2006) investigated the stresses the horizontal pressure forms upon the hopper walls under the filling conditions in varying wall thicknesses (1, 1.5 and 2 mm). In the study it was determined that the lowest stress value is on the 2 mm wall thickness, and the highest stress value on the 1 mm wall thickness. Similar behaviors are observed in our study. Consequently, the maximum stress in the transition zone, and a lower stress with the increase of the wall thickness values were obtained.

The von Mises stress values caused by the vertical pressure load in the filling conditions are 622075 kPa for 10 mm and for Model 1, 411335 kPa for 11 mm, 340553 kPa for 12 mm and 151764 kPa for 13 mm (Figs. 7-8). The stress value in Model 2 and 10 mm wall thickness is 78952 kPa and it is 124274 kPa in Model 3 and 10 mm wall thickness. The stress values regarding Model 1 and its 10, 11, 12 mm wall thicknesses being over 188000 kPa which is the yield strength value of the steel shows that these silos are not secure. Whereas Models 2 and 3 are in the safe-enough

Table 4 The von Mises stress changes depending on the vertical pressure

Model Number	Wall thickness, mm	von Mises stress, kPa
1	10	622705
	11	411335
	12	340553
	13	151764
	14	139822
	15	128230
	20	90325
2	10	78952
	15	53158
	20	37208
3	10	124274
	15	89646
	20	69006

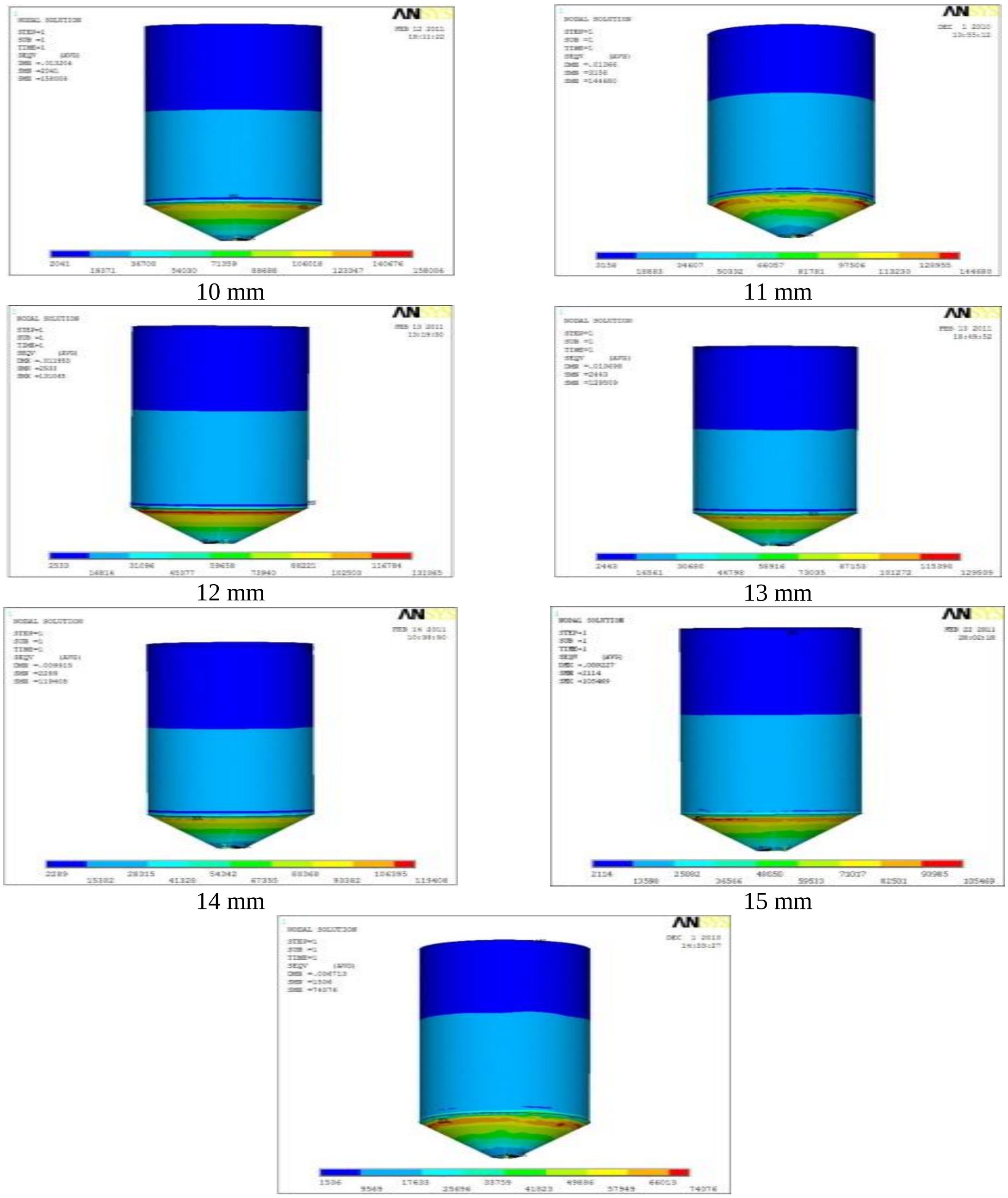
Table 5 The von Mises stress changes depending on the frictional traction

Model Number	Wall thickness, mm	von Mises stress, kPa
1	10	26753
	11	29249
	12	24242
	13	23988
	14	22111
	15	19472
	20	13697
2	10	13249
	15	8866
	20	6238
3	10	20768
	15	15086
	20	10740

boundaries in terms of the stresses caused by the 10 mm wall thicknesses horizontal pressure load (Table 4).

Kovtun and Platonov (1959) observed that as the silo height increases, the vertical pressure increases and it is maximized during transition and also observed the same situation happening on the stresses which occur on the silo surface. Rotter (1986) and Teng and Rotter (1991) stated that on a steel silo, the vertical pressures due to grain load in all the directions may change (X, Y, Z, etc.) and this causes strains in the transition, also the stresses caused by the high local pressure along with these strain induce structural problems in the silo.

The stresses, which are caused by frictional traction load in all three models and in different wall thicknesses under the filling conditions, being relatively low puts forth how safe the silos are in terms of the stresses stemming from this pressure load (Figs. 9-10). The stresses caused by frictional traction were lower than other types of pressure. In this case, the hazelnut parameters in



20 mm

Fig. 5 The stress distribution on the silo wall of horizontal pressure load for Model 1 in filling conditions

Eurocode equation are effective. The maximum von Mises stress in filling conditions due to the pressure applied by hazelnut was obtained as 29249 kPa in Model 1 and 11 mm wall thickness (Table 5). The reason for this is that the thinner wall thickness. Also, the cause of frictional traction differences is caused by the product weight depending on silo height.

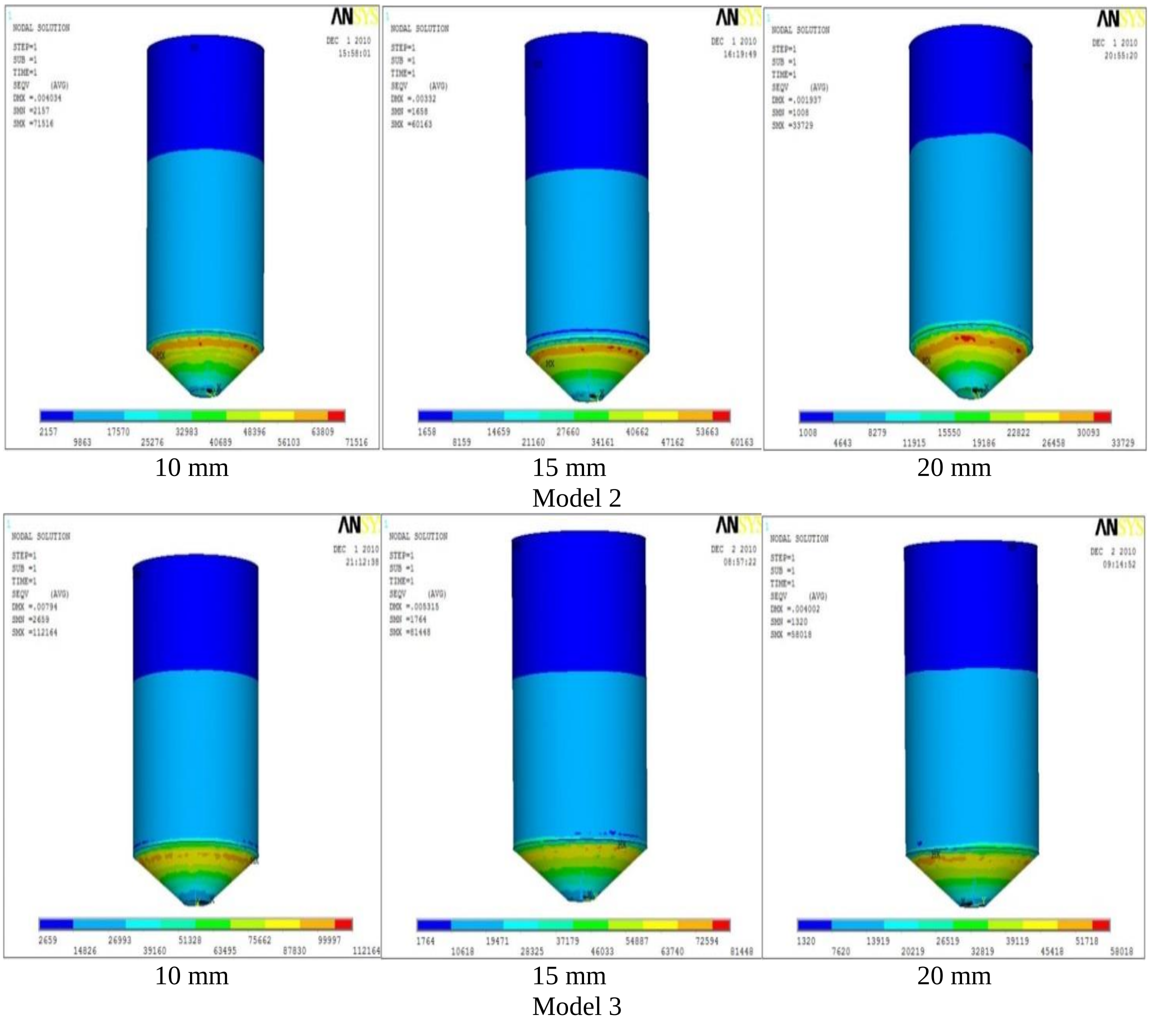


Fig. 6 The stress distribution on the silo wall of horizontal pressure load for Models 2 and 3 in filling conditions

Mark *et al.* (1999) determined that during the filling, the frictional traction increases with the increase of the silo height and the stresses formed by the frictional traction pressure load show alteration not in 1, 1.5 and 2 m but in 0.5 m height. Juan *et al.* (2006) investigated the stresses that the frictional traction causes upon the walls in different wall thicknesses (1, 1.5 and 2 mm) on the hopper walls and conclusively determined that the lowest stress value is on the 2 mm wall thickness.

When the stresses that the pressure loads cause upon the walls are evaluated in terms of the filling conditions by taking the storing capacities in each three models and different wall thicknesses into account, it was determined that as an optimum model, Model 1 and the 13 mm wall thickness come into the prominence.

With the increase of the wall thickness from 10 mm to 20 mm, the stress values of the silo wall occurring whether in its cylinder part or in its hopper part seem to have decreased as it’s assessed

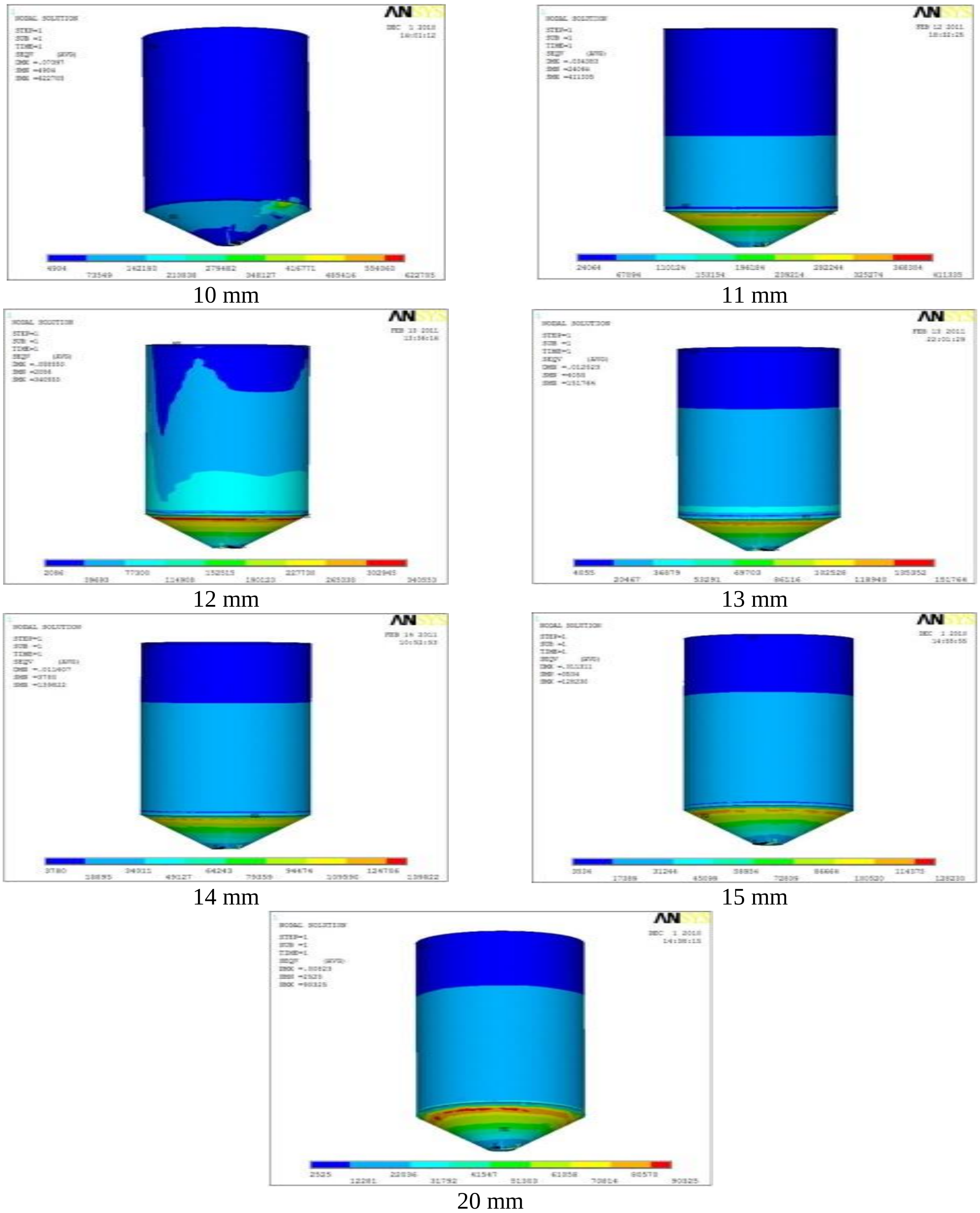
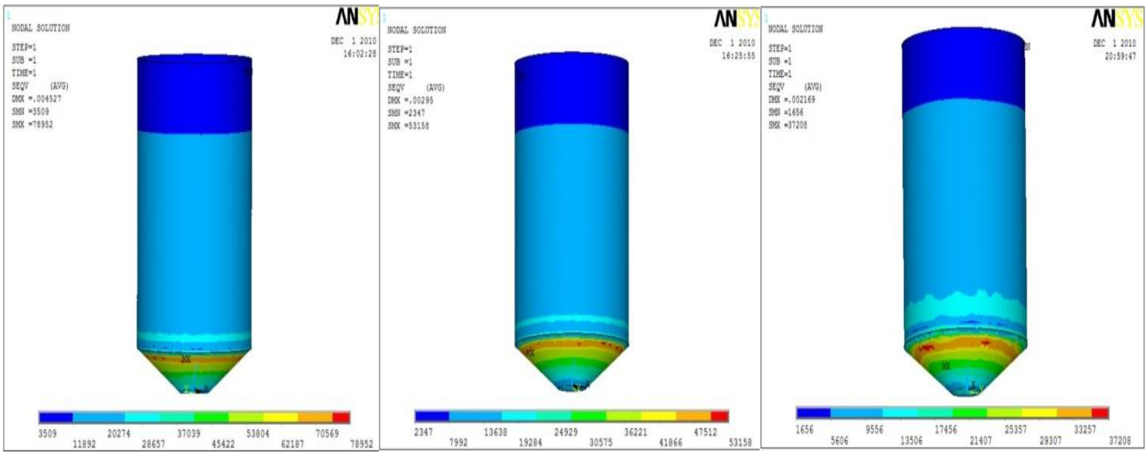


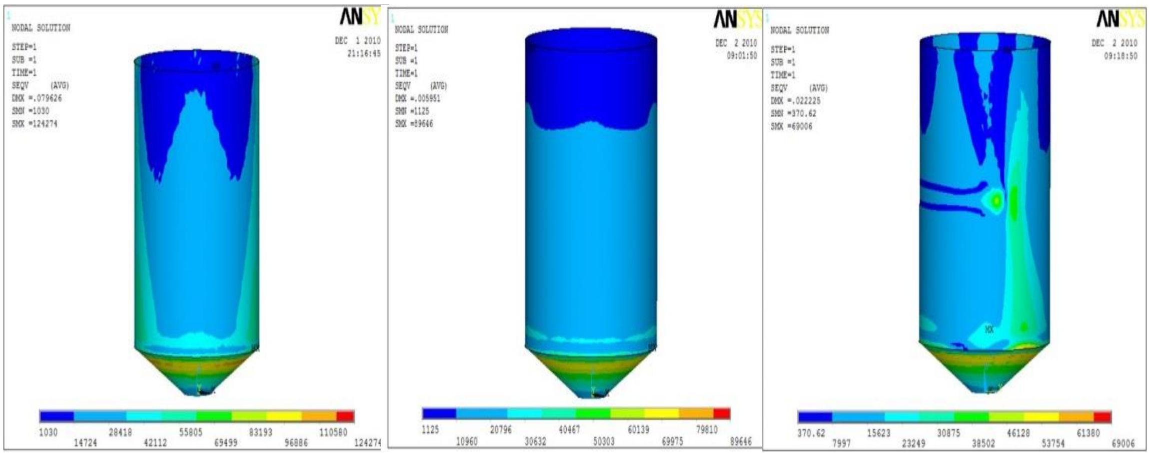
Fig. 7 The stress distribution on the silo wall of vertical pressure load for Model 1 in filling conditions

in terms of the stresses caused by the horizontal pressure and the frictional traction pressure load in all three models under the discharge conditions. This decrease's cause is explainable with the silo becoming more resilient against product pressure with the increase of the wall thickness. The



10 mm 15 mm 20 mm

Model 2



10 mm 15 mm 20 mm

Model 3

Fig. 8 The stress distribution on the silo wall of vertical pressure load for Models 2 and 3 in filling conditions

maximum stress values in the models have generally occurred in the high and low ends of the transition to the hopper. The main cause of this situation can be said to be the loads that the product filled in the silo causes on the base of it. Stress values close to minimum were obtained again in the models around the outlet where the product output exists. But in some conditions, the stress towards the Z-direction has been determined to keep stable from the low end of the transition till the outlet port.

The maximum stresses caused by the horizontal pressure load in all three models have occurred in the 10 mm wall thickness (Figs. 11-12). According to this, we see that the maximum stresses occur in the Y-direction when we evaluate the stresses the horizontal pressure load causes upon the wall. This value is 181095 kPa for the Model 1 silo, 93233 kPa for the Model 2 silo and 153797 kPa for the Model 3 silo. For Y-direction of Model 1 silo and it 10 mm wall thickness being over 188000 kPa which is the yield strength value of the steel shows that these silos are not secure.

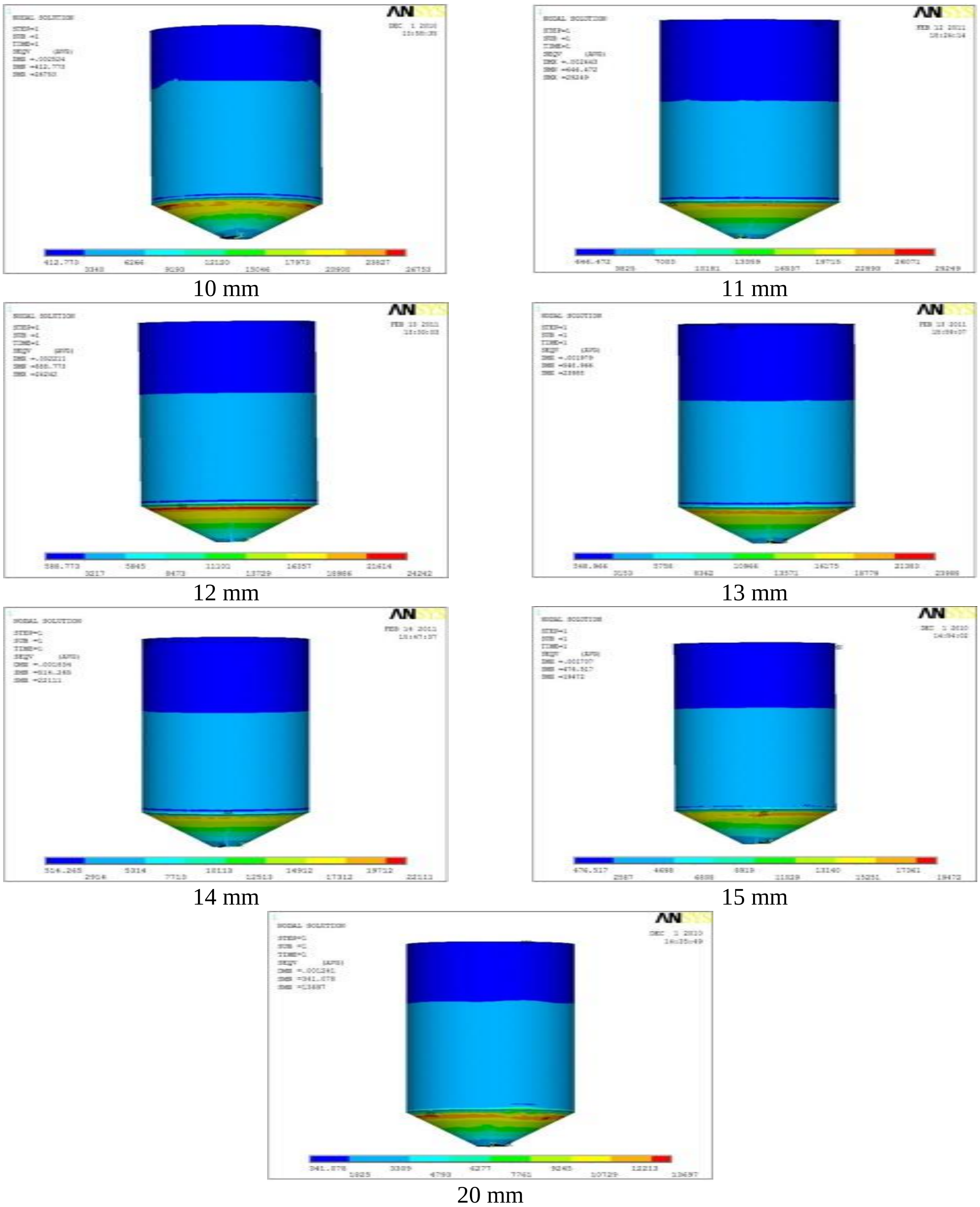
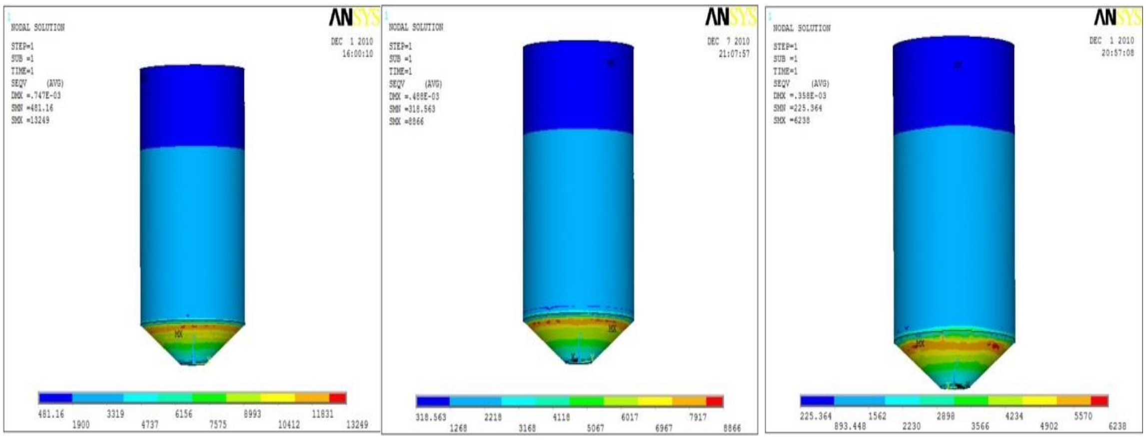


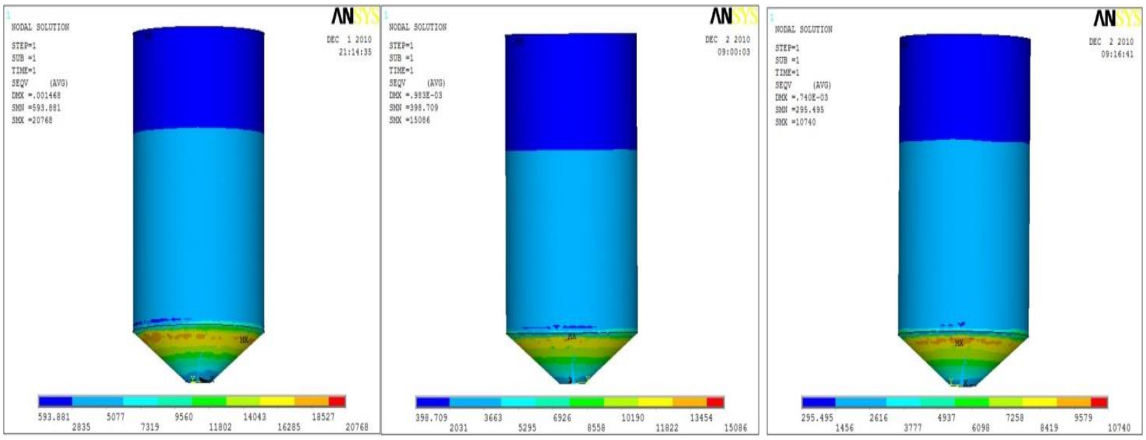
Fig. 9 The stress distribution on the silo wall of frictional traction for Model 1 in filling conditions

Whereas, for the maximum stresses occurring relatedly with the horizontal pressure load under the discharge conditions in all there models are below 188000 kPa, which is the yield strength value of the steel; the silos are secure (Table 6).



10 mm 15 mm 20 mm

Model 2



10 mm 15 mm 20 mm

Model 3

Fig. 10 The stress distribution on the silo wall of frictional traction for Models 2 and 3 in filling conditions

Table 6 The von Mises stress changes depending on the horizontal pressure

Model Number	Wall thickness, mm	von Mises stress, kPa
1	10	167403
	11	162809
	12	151647
	13	149833
	14	138151
	15	122050
	20	85710
2	10	89667
	15	60164
	20	42414
3	10	139142
	15	101052
	20	71979

Table 7 The von Mises stress changes depending on the frictional traction

Model Number	Wall thickness, mm	von Mises stress, kPa
1	10	30963
	11	37159
	12	30691
	13	30455
	14	28089
	15	22558
	20	15854
2	10	16407
	15	10989
	20	7745
3	10	25747
	15	18702
	20	13328

Wojcik *et al.* (2003) evaluated the effect of the stresses that the horizontal pressure forces on the silo under the discharge conditions according to the finite elements and in the concluded that the maximum stresses in the hopper occur in the transition and deformations occur towards the hopper perimeter. Vidal *et al.* (2004) created the simulations of the hopper pressures in the wheat-filled steel silo with the proportions of 2 m diameter, 14.5 m height, 0.6 m outlet diameter and 2.5 mm wall thickness during the discharge process with ANSYS program and determined as a result of the study that the transmitting pressures are maximum during the discharge of the product, that the stresses in the hopper increase as the discharge time continues and that the stresses caused by the pressures in the varying internal frictional angles alter. Chou and Chang (2006) determined that the stresses caused by the horizontal pressure in varying hopper inclinations in a model silo with a height of 2 and a diameter of 0.8 m decrease as the hopper inclinations increase. Vidal *et al.* (2006) investigated the change of the horizontal pressure in a model silo with a height of 15 m, a diameter of 3 m and with an outlet diameter of 0.7 m under the discharge conditions. They stated as a result of the study that the stresses reach their peaks around the transition part of the silo and are at their lowest in the outlet port. The researcher results, our study showed similar results.

The stresses caused by the frictional traction load in all three models and in different wall thicknesses in the discharge conditions being relatively low puts forth how safe the silos are in terms of this pressure load (Figs. 13-14). Again in the discharge conditions, the maximum von Mises stress was stated as 37159 kPa in the 11 mm wall thickness for the Model 1 silo (Table 7).

Tejchman (2002) determined in his study that the stresses, which occur in the different directions of the silo, of the frictional traction pressure load causes shear deformation on the wall. In this study, specifically the deformations in transition and below the hopper zone were observed. Brown (2008) stated that the hopper design is more complex than other silo elements' design in the silo during discharge, the design should be carried out by putting emphasis on two main pressures (wall normal pressures and frictional traction) when designing the hopper. Also determined that the unit weight and the hopper geometry of the product stored upon the horizontal pressures, stress and the frictional traction occuring during the transmittance to the hopper part are of paramount importance. Similar trends were obtained in this study.

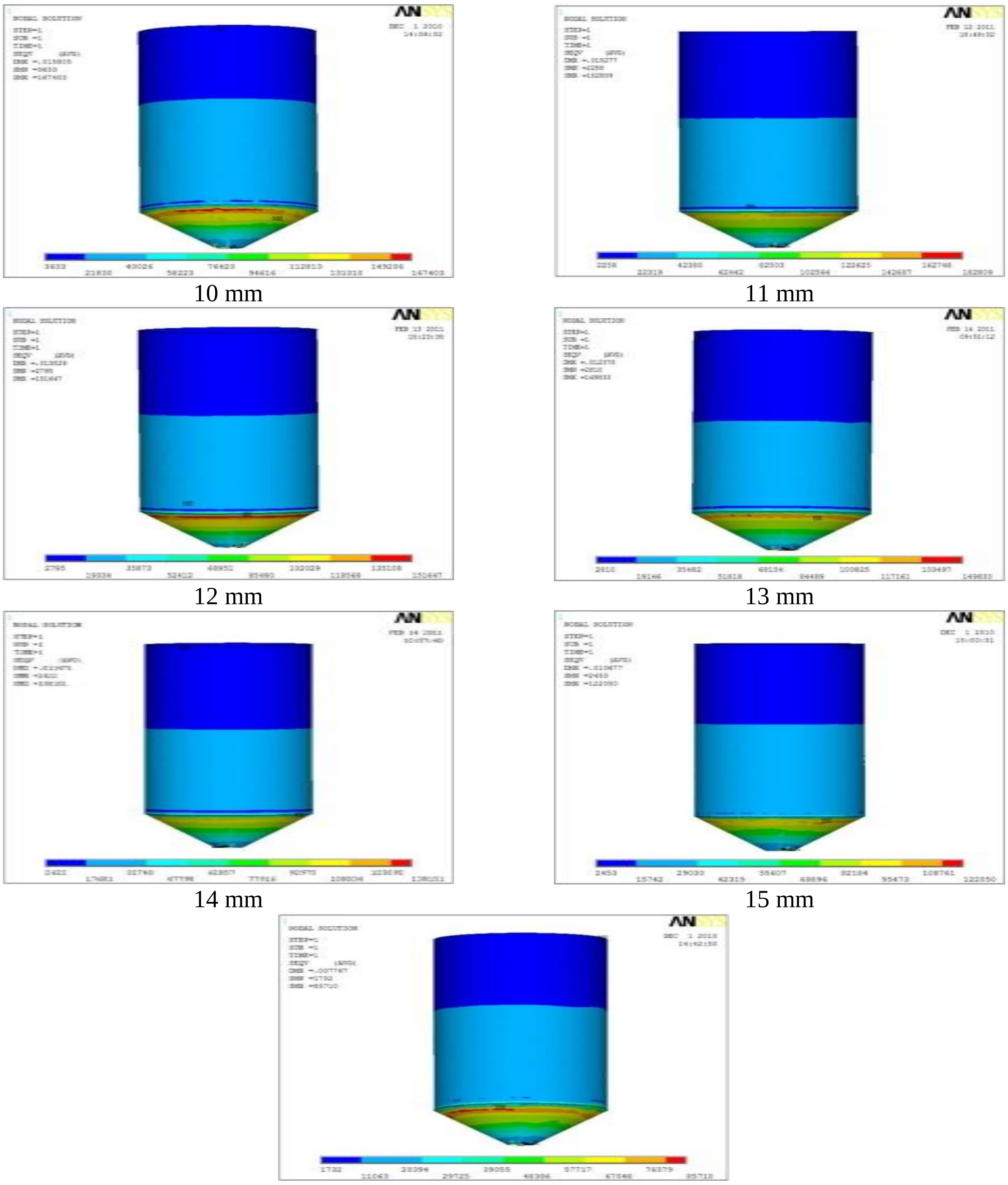
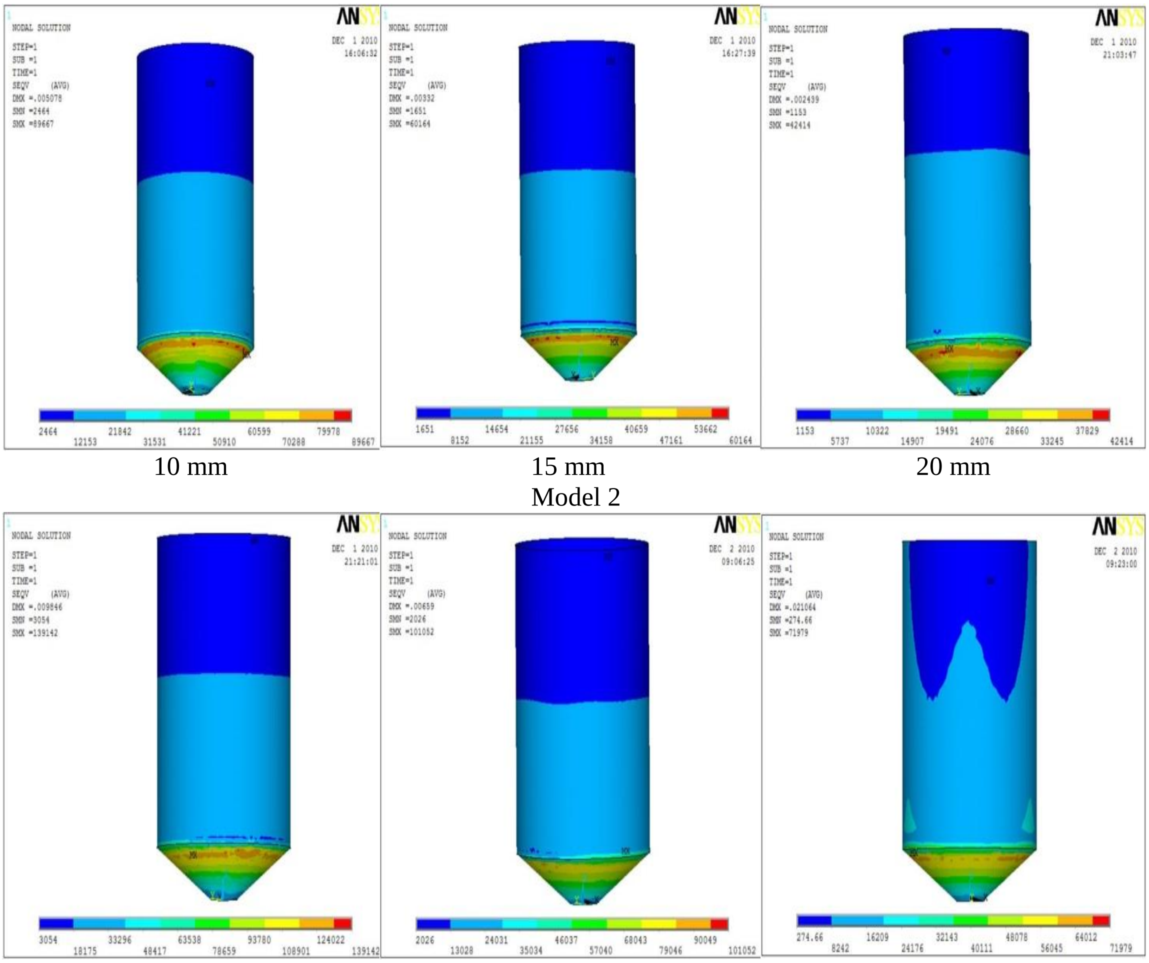


Fig. 11 The stress distribution on the silo wall of horizontal pressure load for Model 1 in discharge condition

In the silo models discussed in the study, when the stresses the pressure loads cause upon the walls from the view of the discharge conditions are evaluated in terms of the model, wall thickness and storage capacities, the Model 1 silo puts forth an advantageous situation for the 13 mm wall thickness in terms of engineering.



10 mm 15 mm 20 mm

Model 2

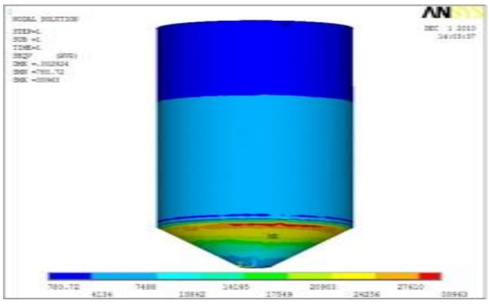
10 mm 15 mm 20 mm

Model 3

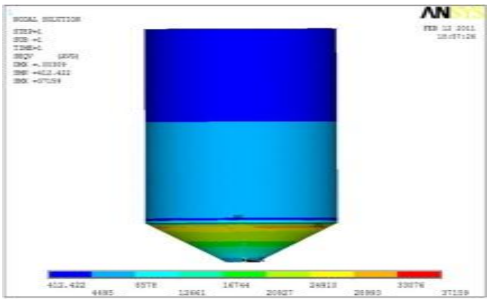
Fig. 12 The stress distribution on the silo wall of horizontal pressure load for Models 2 and 3 in discharge conditions

Examining the stress alterations with wind was conducted pursuant to the condition the silo would be empty. The stress distributions caused by the wind pressure load on the silo wall are given in Fig. 15. When the graphics given in Fig. 15 are examined, the stresses caused by the wind upon the silo wall were noted as secure for Model 1 and 13 mm, whose optimum wall thickness had been determined. As we assess the stresses occurring in different directions (X, Y, XY), we can establish that the stresses upon the cylinder and hopper surface are on the different locations and how there are no or very little changes in some directions (Z, YZ and XZ) for the cylinder surface. In some stress conditions, both the compressive and tensile stresses have occurred on the silo wall. The stresses occurring upon the wall with the wall thickness increases were decreases. The cause of stress decrease is able to be more resistant wall and absorb high pressures with an increase in wall thickness.

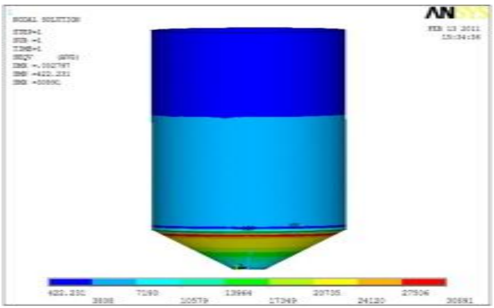
Briassoulis and Pecknold (1986) stated the necessity of doing the wind analysis in the silos



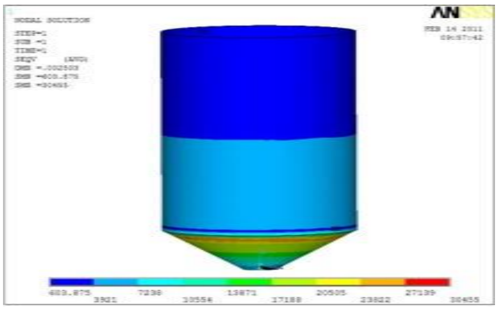
10 mm



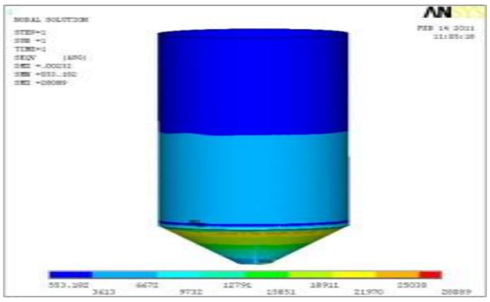
11 mm



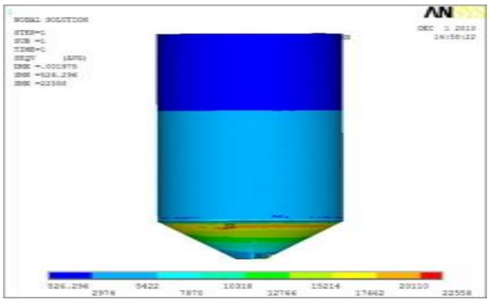
12 mm



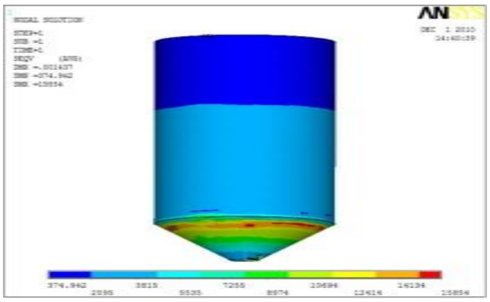
13 mm



14 mm



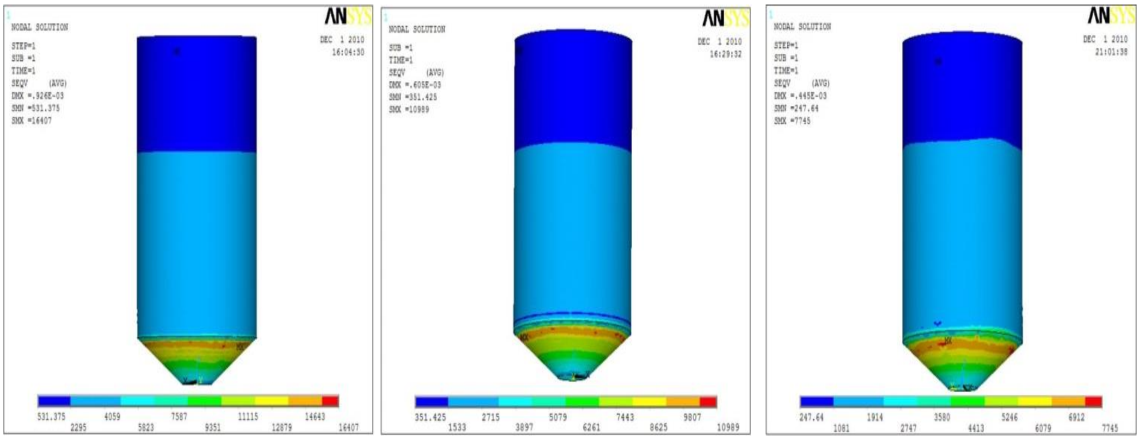
15 mm



20 mm

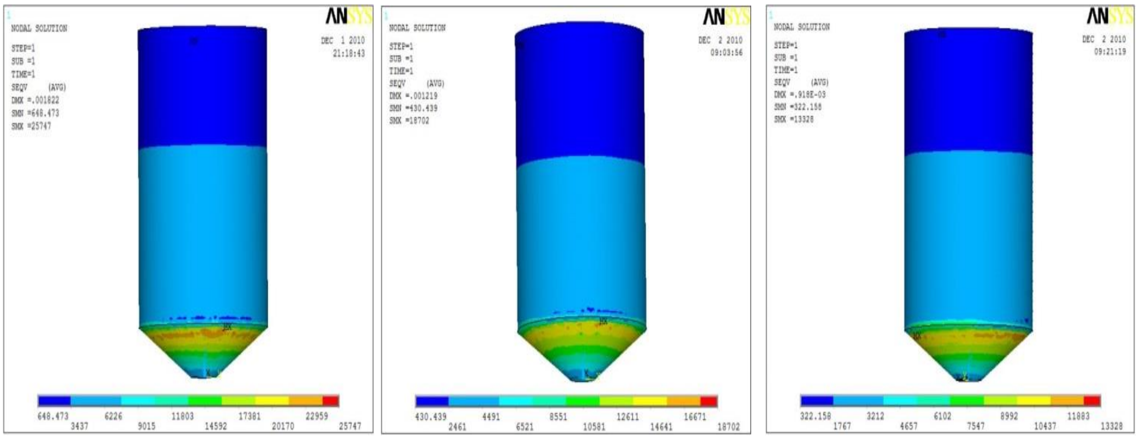
Fig. 13 The stress distribution on the silo wall of frictional traction for Model 1 in discharge condition

when it's empty or in different silo parts. They explained the reason so as the deformations and twists happen towards the top side of the silo especially when it's empty. In our study, a similar situation has been determined. The deformations towards the top of the silo were determined. Mac Donald *et al.* (1990) expressed that the wind pressure load on the cylindrical silo causes both the



10 mm 15 mm 20 mm

Model 2

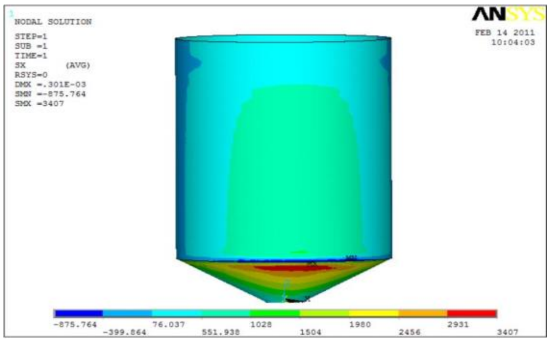


10 mm 15 mm 20 mm

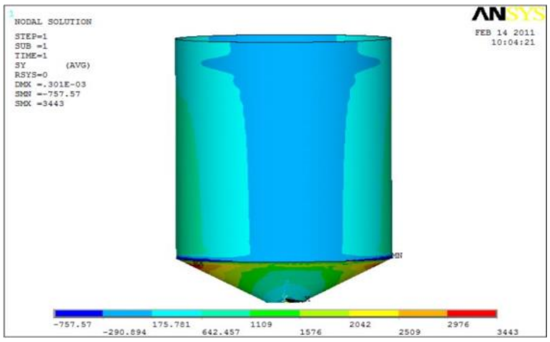
Model 3

Fig. 14 The stress distribution on the silo wall of frictional traction for Models 2 and 3 in discharge conditions

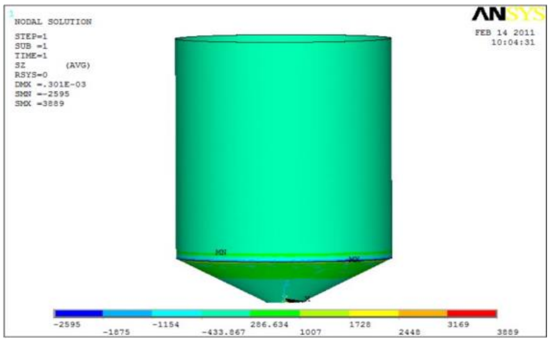
tensile and the compressive stresses also in some locations of the silo, some small-degree deformations occur. In this study, different parts of the silo were occured compressive stresses. Bansal *et al.* (2009b) stated in their studies that as the silo height/diameter ratio increases from 1.25 to 3 under windy conditions, we obtain the maximum bending increase. Jafari and Hassanian (2010) investigated the change of the wind analysis on a slender clyindrical silo with ANSYS software. As a result of the research, they determined that the stresses show an uniform distribution on the wall and that the maximum stress value is 1550 kPa. Depending on the wind load, similar stress values were obtained from this study. In an analysis of wind effects, defined silos for Model 1and 13 mm were used. In this study the wind pressure load was determined to cause low stress values on the silo wall and the stress value as 3634 kPa for the optimum silo conditions (Model 1, 13 mm). When the values regarding the deformations caused by wind on the model silos discussed within the context of this study are examined, the results were found quite low. Results parallel with this one’s (2.34E-02 mm) were put forth by Bansal *et al.* (2009a).



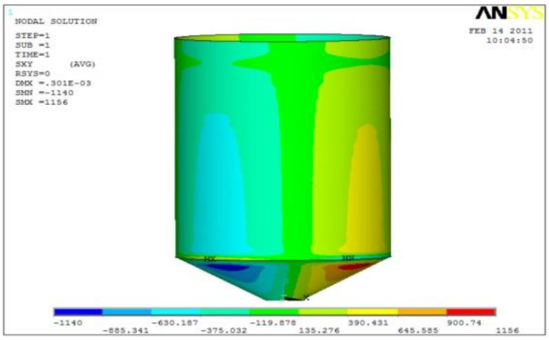
(a) X-direction stress



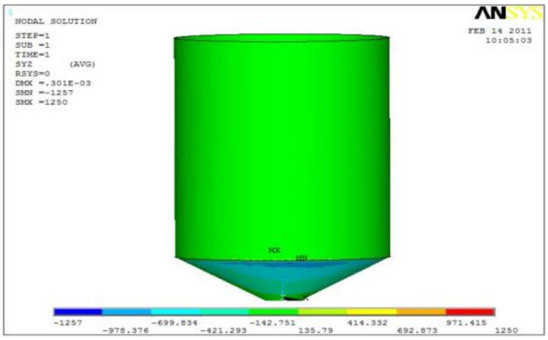
(b) Y-direction stress



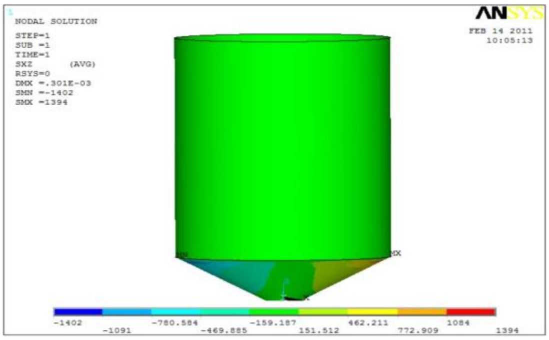
(c) Z-direction stress



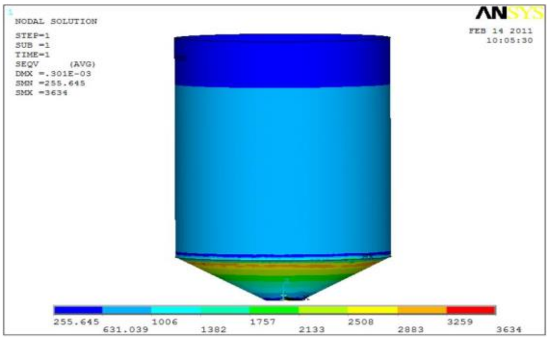
(d) XY shear stress



(e) YZ shear stress



(f) XZ shear stress



(g) von Mises stress

Fig. 15 The stress distribution on the silo wall of wind pressure load

4. Conclusions

Our nation generally uses traditional stores in storage of hazelnuts. Modern storage structures are scarce enough to be called even non-existent. What comes first in the modern storage systems is the cylindrical storage systems (silos). In our nation, the silos are generally used in the agricultural field for storage of cereals and industry plants. In this study, as a pilot study, the conversion of the specie Tombul hazelnut was approached in a barrel-type, steel- construction silo with a conical outlet port.

As a result of the varying conducted simulations, while the highest von Mises stress value in the Models 1 and 2 silos is obtained under the filling conditions in the vertical pressure position, it's obtained in the Model 3 silos under the discharge conditions in the horizontal pressure position. The cause of the highest vertical pressure of von Mises stress is related to changes of the parameters in Eurocode equations. In all three different models, the maximum values of the von Mises stress and the shear stresses exist in the hopper part. This situation is caused by the pressure formed in the hopper area being maximum and results in storage items forcing this area more. Here, maximum stress in filling and discharging conditions is caused horizontal and vertical pressure. When the pressure effect the material to be ensiled (Tombul hazelnut) is going to cause is taken into account, the model, which will cause no permanent deformations, is the Model 1 silo 13 mm wall thickness. For 13mm wall thickness of Model 1 silo, due to more economical to construction costs is recommended. The Model 1 silo puts forth a beneficial situation for the 13 mm wall thickness in terms of engineering. The stresses in barrels and hoppers are not yet fully covered by the researchers, so experiments carried out in test silo installations such as the present one area of special interest. In future studies, Designers of silos with filling and discharge shall be aware of possible in mass and flow regimes associated to large changes of pressure cases. Also before starting structuring the silo, conducting simulations with ANSYS or with any similar software is vital in terms of averting the deficiencies regarding the construction.

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