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Analytical Study On The Pressures Exerted By Various Storage Materials On The Cylindrical Silo And Design Of The Shell Wall For The Storage Of Cement

R Sabari Bhawani[*1], Dr. I YaminiSreevalli[*2]
*[*1] Vellore Institute of Technology, Chennai, 600127,*
[*]2Professor, M Tech Structural Engineering, VIT Chennai-600127, India

Abstract: *A Silo is a structure used for storing Bulk materials (powdery/granular). The density and other material properties like angle of internal friction, lateral pressure ratio etc. affects the pressure on the silo wall. In the current work, the effect of variation of pressure on the shell wall due to different storage materials with same and different densities are studied. Eurocode 4 (EN 1991-4) gives the detailed information regarding the various pressures in a Silo during filling and discharge. Firstly, the Silo is modelled and analyzed using Staad pro for cement and the same is designed. This shell wall is kept constant for storing the other materials, here we have taken six other materials including Cement. The variation in the pressure difference, storage height, wall deflection etc. is found using FE Analysis. The shell wall is only designed for the ensile material cement, and the other materials like fly ash, sand, Clinker, aggregates and Raw meal are filled in the same shell wall and analysed. The effect of these ensile materials on the shell wall is studied in detail.*
Keywords: *Bulk density, ensile materials, shell wall design, wall pressure*

I. Introduction

The silos are storage structures used to store different storage materials like powdery and granular materials (cement, sand, clinker, aggregate, etc). There are different types of Silos like Concrete and Steel Silos.

Concrete is most frequently used for Silo construction. Storing of Bulk materials is very essential in agricultural, chemical, mining and other industries. A silo can be either used for long-term or short-term storage. Storage in silo involves many transportation process like arrival of material in truck, discharge into vessel for shipping.

A Silo is also known as a Bin, Bunker, etc. The physical properties of stored material influences the flowability of the material and also affects the pressure acting on the silo walls and bottom. These physical properties vary with age of the stored material and also it differs from one material to the other.

Shape: Circular, Rectangular Silos
Method of loading and unloading: This depends on the type of material stored and economic factors.
Loading: Pneumatic (pumping, air slides)
Mechanical (Conveyors, bucket elevators)
Gravity (Dump cars, trucks)
Discharging: Gravity (direct without devices)
Mechanical (Vibrating feeder, vibrator)
Pneumatic (aeration, air slides, air jets)

II. Literature Review

According to Eurocode the flow patterns are of two major types namely- funnel type and mass flow type. The test station consists of a Silo for storing the material to be tested and one experimental Silo. The testing material was transferred between these two Silos with the help of two screw electric conveyors. Horizontal pressure is calculated at different heights and the hopper transition effects were also considered. Couto, Ruiz and Aguado [1] found that the pressure is not constant in the static state because the grain underwent resettling. Variations in flow speed caused changes in pressure distribution inside the silo. Increased thrust was obtained in the silo-hopper transition and reduced thrust in the Silo walls.

DeshBandhu Mukherjee, PrasantaPatra, Amiya Samanta [2] studied the effect of ovalization on RC circular walled Silo during the action of wind load. The Silo was modelled and analysed using ABAQUS 10.0. It was found that Silo with H/D<1, do not have severe ovulation phenomena effect. But in Silo with H/D>1 this effect is significant, plays a significant role in the design of Silo walls. This bending phenomenon is different from beam bending. It was found that the values of hoop stress are critical in windward side and the same occur at mid half height of the Silo wall.

A 3D Numerical analysis on the effect of bulk solid on strength and stability of metal cylindrical silos with corrugated walls without stiffeners during filling was studied [3]. Hypoplastic constitutive model of dry sand and wheat Silo were made. Finite Element analysis was done and the results were compared with EUROCODE. The strengthening effect of solid, wall thickness, solid granular hardness, initial void ratio and wall friction angle on buckling strength was investigated. It is found that the Bulk solids increased the buckling strength of the Silo during filling. Buckling strength is increased with increasing granular hardness and initial void ratio of the solid.

EutiquioGallego, Angel Ruiz, Pedro Aguado [4] used wheat as a storage material to generate action on the Silo. 3D modelling is performed using ANSYS. Fine mesh was used in the transition zone. Element size of 0.1 m was maintained throughout the silo except for the transition between silo hopper and bin, element size of 0.025m was used in this area. Thickness of the Silo wall was kept as 0.03m. Grains were given 8Node isoparametric element(SOLID185) and the Silo wall was given SHELL281 element with 8Nodes and 6 DOF at each node. The only load considered was full weight of the bulk material. For filling simulations, the nodes at silo bottom were restrained and for discharge simulations the restrains were removed for a free flow. The silo was loaded and discharged after a gap of 5minutes. They found that the experimental normal pressure is greater than those predicted by FE model. Whereas, normal pressure calculated from Eurocode is slightly greater than the experimental values.

ZaouiDjelloul, Djermane Mohammed [5] studied the behaviour of Silo walls due to earthquake loads. Silo walls experience additional stresses because of unsymmetrical pressure distribution in the Silo. This leads to ovalization of Silo walls. For analysis purpose, Silo was considered as a Cantilever Beam with multiple point loads one above the other. Finite Element Analysis was done using ANSYS. Filling process in FEA was carried out by Multi step analysis strategy. The values obtained from Eurocode 1 part 4 is higher than the values in FEA, this is probably due to the negligence of wall flexibility effect.

A slight deviation was introduced in a perfect cylindrical unstressed Silo, to study the effects of imperfection. Imperfection was applied in the inward radial direction. The authors [6] made an assumption that the bulk solids are homogeneous and linear elastic. A ground supported Steel Silo with radius 5m was analysed in Abaqus finite element software. Load was given in vertical direction to simulate the gravity loading. The presence of geometric imperfection has been shown to cause significant local variation in wall pressure. It is seen that the height of imperfection affects the local pressure variation.

2.2. Design loads

Silo loads:

Dead Load: Self weight of the Silo (walls, roof, ring beam, hopper + weight of items supported by Silos)

Live Load: Pressure due to the stored material. Only 80% of material loads are considered during design (As per EN:1991part4)

Wind Load: Silos must be designed to resist the overturning effects caused by Wind or Earthquake Load. Wind and Earthquake Load must not act simultaneously, which ever effect is greater must be designed

Equipment Load: Loads caused due to vibrating equipments alter the effect of other loads

Seismic Load: Walls/Columns supporting Silos are vulnerable to Earthquake Loads. Foundations may be affected due to this load

2.2.1Material load:

According to Eurocode 80% of the material load is considered for the Design and Analysis

2.2.2 Seismic Load data:

Zone III

Zone factor = 0.15

Response factor = 2

Importance factor = 1.5

2.2.3 Temperature data:

	A	B	C	D	E	F	G	H
1	**Calculation of BM due to Material temperature**							
2								
3	Thickness of wall, t				=	0.3	m	
4	Max temp of material inside, Ti				=	120	deg	
5	Min outside ambient temp, To				=	13	deg	
6	Grade of Concrete, fck				=	37.5	N/mm^2	
7	Ec				=	3.07E+07	N/m^2	
8	Ixx				=	1885.74	m^4	
9	Ixx				=	1.89E+15	mm^4	
10	Coef of thermal expansion, εt				=	1.10E-05	per degree	
11	Ca				=	15		
12	Cc				=	1.75		
13	Cs				=	2		
14	ht (1/3rd)	top	0.8*To		=	96	deg	
15	ht (2/3rd)	top	0.5*To		=	60	deg	
16								
17	**ht (1/3rd) top**							
18	1/k = (1/Ca+t/Cc+1/Cs)				=	0.7381		
19	ΔT = (t/Cc)*((Ti-To)/(1/k))				=	19.2774	deg	
20	ΔM = Ec*I*εt* ΔT/t				=	4.09E+01	kNm/m	
21								
22	**ht (2/3rd) top**							
23	1/k = (1/Ca+t/Cc+1/Cs)				=	0.7381		
24	ΔT = (t/Cc)*((Ti-To)/(1/k))				=	10.9161	deg	
25	ΔM = Ec*I*εt* ΔT/t				=	2.32E+01	kNm/m	
26								
27	**Mt1**							
28	Moment of Inertia, I				=	0.00113	m^4	
29	Mt1 = Ec*Lc*ΔT1*I/(d*(1-µ))				=	30.52	kNm/m	

Moment Calculation due to temperature effect

2.3 Design dimensions

Inner dia, dc = 14m
Outer dia, d = 14.6m
Height of Silo above ground level, H = 42.8m
Height from transition to equivalent surface, Hc = 30.3m
Eccentricity during discharge, eo = 5.08m
Eccentricity during filling, ef = 0
Silo capacity = 3572x1.4T = 5000T
Silo plan area, A = Πx 142/4 = 153.9m2
Perimeter, U = Πx14 = 43.98m
Density of Concrete, γc = 25 N/mm2
Seismic Zone = Zone 3
Site Location- Savannah Cements, Kenya

2.4 Pressure calculations:

According to Eurocode 1 there are different pressures acting on a Silo due to the stored material, they are listed below
Symmetrical Filling Pressure
Symmetrical Discharge Pressure
Filling Patch Pressure
Discharge Patch Pressure
Large Eccentric Discharge, k= 0.25
Large Eccentric Discharge, k= 0.4
Large Eccentric Discharge, k= 0.6

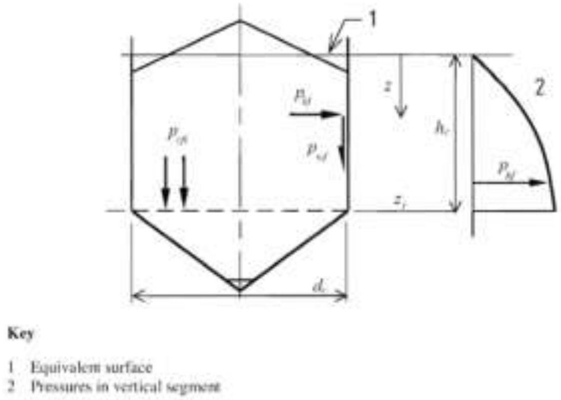

Fig 1 Horizontal and vertical pressures action on a Silo

2.5 Results of Manual Pressure Calculations (EN 1991-4)

The pressures are calculated according to Eurocode 1 for six different storage materials and a comparison of the horizontal pressures for the same is given below

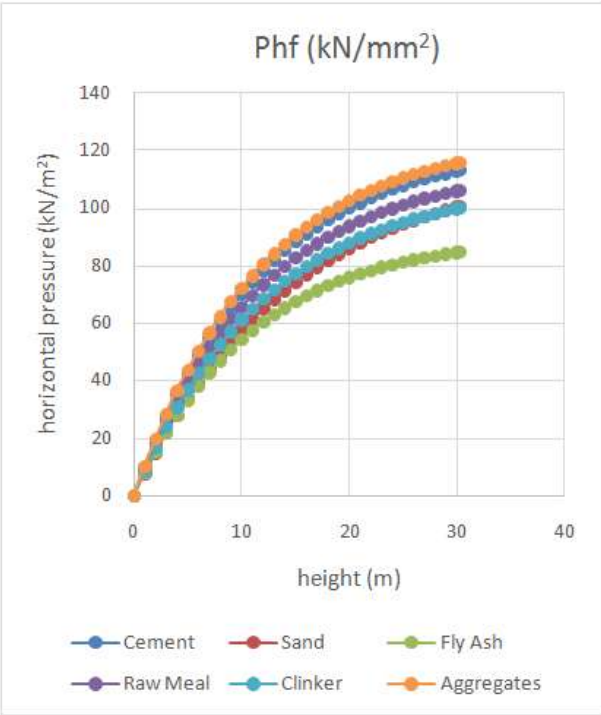

Fig. 2 Comparison of Horizontal pressure for six different storage materials with same and different unit weights

III. Foundation Design

Net safe bearing capacity of soil, qns	=	550	kN/m^2
Depth of Foundation, Df	=	3	m
Unit Weight of Soil, Ys	=	18	kN/m^3
Gross Safe Bearing Capacity of Soil, qgs	=	496	kN/m^3

The soil data is collected from the site after performing the required site investigations on soil. This data is used for the design of foundation

Moment Calculation- Eq Load (0.8 LL+1.5 DL+ 1.5 EL)

3.1 Foundation Check:

DEPTH OF RAFT	=	3		
WT OF FOOTING	=	17331.2		
WT OF SOIL	=	7749.27		
Z	=	1560.63		
A	=	385.139		
P(DL)	=	97784.7		
M	=	391261		
M/Z	=	250.708		
P/A	=	253.895		
P/A+M/Z	=	504.603	<	741.5 SAFE
P/A-M/Z	=	3.18679		
%UPLIFT	=	0.63		

IV. Design of Shell Wall

Governing Load case:
1.5 Large eccentric discharge k 0.25 + 1.5 DL + 1.5 LL
1.5 Large eccentric discharge k 0.40 + 1.5 DL + 1.5 LL
1.5 Large eccentric discharge k 0.60 + 1.5 DL + 1.5 LL
Pressures due to eccentric discharge as described in Eurocode

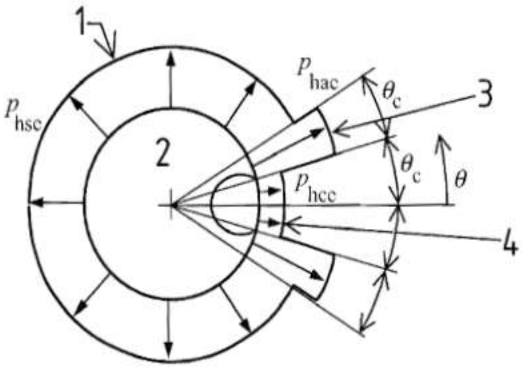

Fig 3 Eccentric discharge pressure distribution

Application of eccentric discharge load in staad for three different k values, where k is the eccentric discharge coefficient is shown in fig 4, 5 and 6

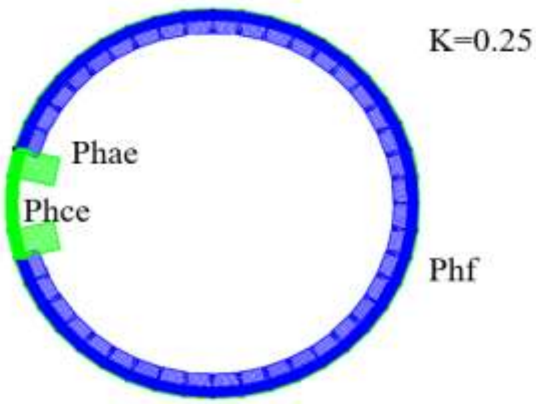

Fig 4 Eccentric discharge k =0.25

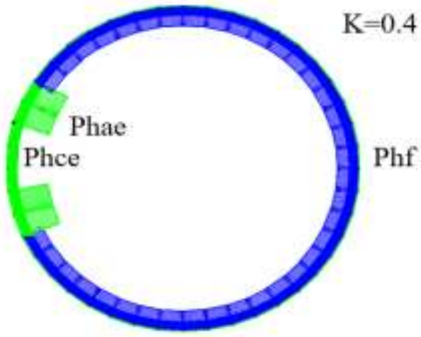

Fig 5 Eccentric discharge k= 0.40

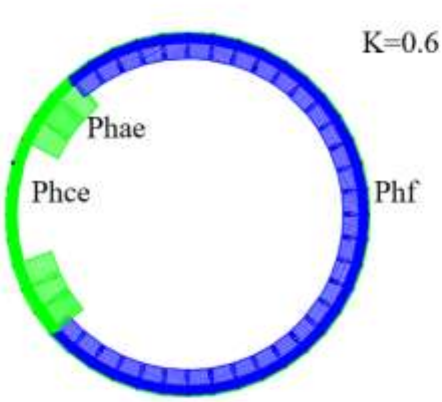

Fig 6 Eccentric discharge k = 0.60

Compared to the other pressures, the stress due to large eccentric discharge will be maximum and will govern the design of shell wall.

Load Case	Stress, Sx (N/mm²)
Symmetrical Filling	2.61
Symmetrical Discharge	3.06
Filling patch load	0.26
Discharge patch load	1.04
Large eccentric discharge k=0.25	**3.97**
Large eccentric discharge k=0.40	**4.31**
Large eccentric discharge k=0.60	**4.42**

Fig 7 Analysis Results

V. Staad Analysis Results

Stress in x-direction
Case 1: (L/C- 1.5 Large eccentric discharge k 0.25 + 1.5 DL + 1.5 LL)
Sx Local

Fig 8 Sx (local) N/mm2, k= 0.25

Case 2: (L/C- 1.5 large eccentric discharge k 0.4 + 1.5 DL + 1.5 LL)
Sx (local)

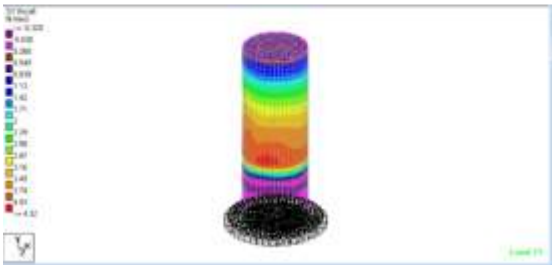

Fig 9 Sx (local) N/mm2, k= 0.40

Case 3: (L/C- 1.5 large eccentric discharge k 0.6 + 1.5 DL + 1.5 LL)
Sx (local)

Fig 10 Sx (local) N/mm2, k= 0.60

Stress in y-direction
Case 1: (L/C- 1.5 Large eccentric discharge k 0.25 + 1.5 DL + 1.5 LL)
Sy (local)

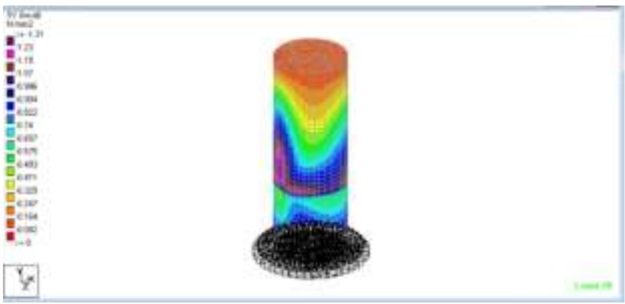

Fig 11 Sy (local) N/mm2, k= 0.25

Case 2: (L/C- 1.5 Large eccentric discharge k 0.4 + 1.5 DL + 1.5 LL)
Sy (local)

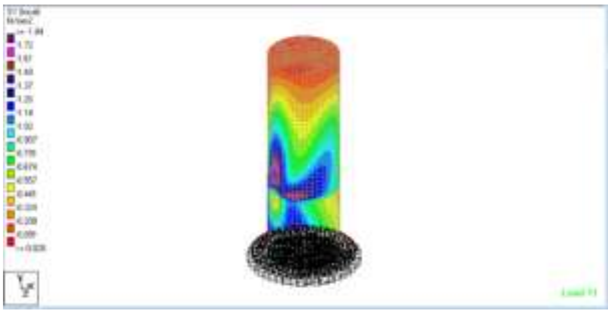

Fig 12 Sy (local) N/mm2, k= 0.40

Case 3: (L/C- 1.5 Large eccentric discharge k 0.6 + 1.5 DL + 1.5 LL)
Sy (local)

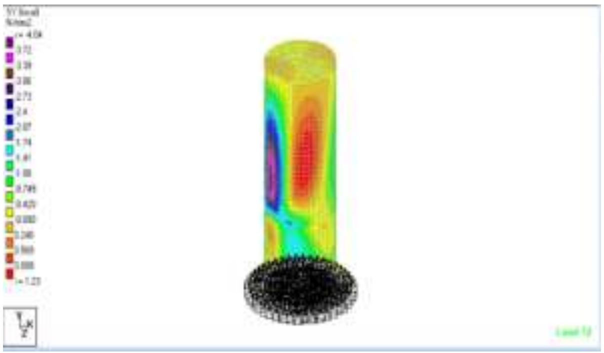

Fig 13 Sy (local) N/mm2, k= 0.60

The maximum Stress in x and y directions are taken from the staad analysis and is used to design the reinforcement in the shell wall. It is seen from fig 4 to fig 9 that the load case 3 (k=0.6) hasmaximum stress 4.42 and 1.23 N/mm2 in x and y direction respectively.

4.1 Design of Shell wall:
Reinforcement details:
Provide 2 layers of 20mm dia bars at 250mm c/c as Vertical reinforcement and 2 layers of 25mm dia bars at 150mm c/c as transverse reinforcement

VI. Finite Element Analysis

Filling Material: Cement

Finite element analysis is done in Abaqus/CAE (static linear). Only the Shell wall of the silo is modelled because if we change the storage materials only the silo shell wall will be affected due to change in pressure so it is enough to analyse the shell wall for various storage materials.
The shell wall is designed for storing Cement. Firstly this shell wall is analysed for the pressures due to storage of Cement then it is analysed by replacing the pressure due to cement with other storage materials

Model- Shell wall

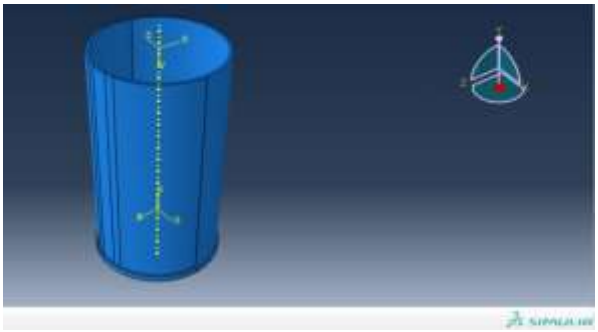

Fig 14 Silo model in Abaqus

Meshing

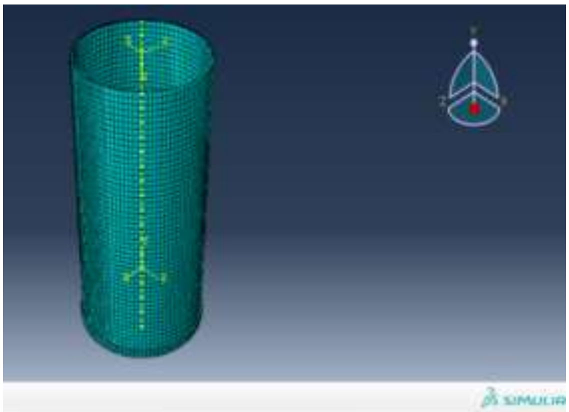

Fig 15 Meshing- (C3D8R- 8 node linear brick mesh is generated)

5
Load:

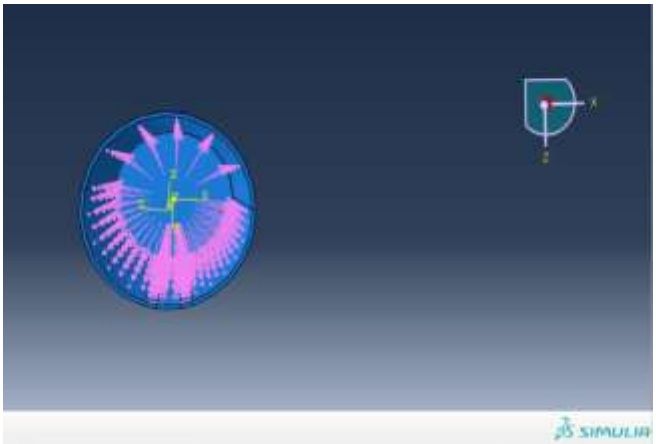

Fig 16 Application of loads

The Silo is analysed only for large eccentric discharge load case as it causes maximum stress in the wall than the other load cases.

Stress results
Large eccentric discharge k =0.25

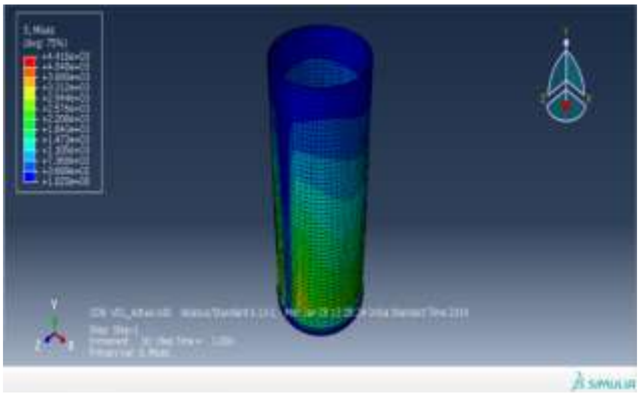

Fig 17 Von misses stress for large Eccentric discharge k= 0.25

Large eccentric discharge k =0.4

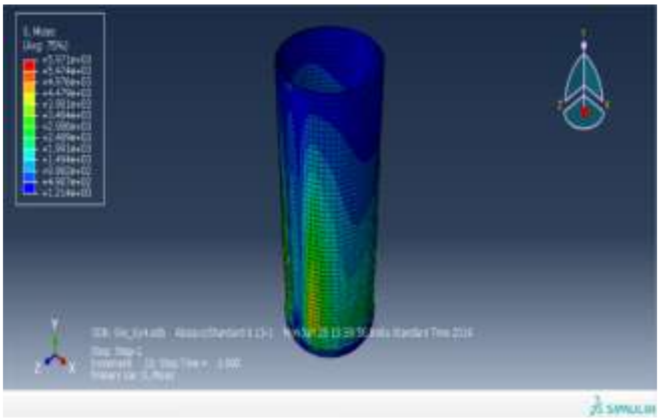

Fig 18 Von misses stress for large Eccentric discharge k= 0.4

Large eccentric discharge k =0.6

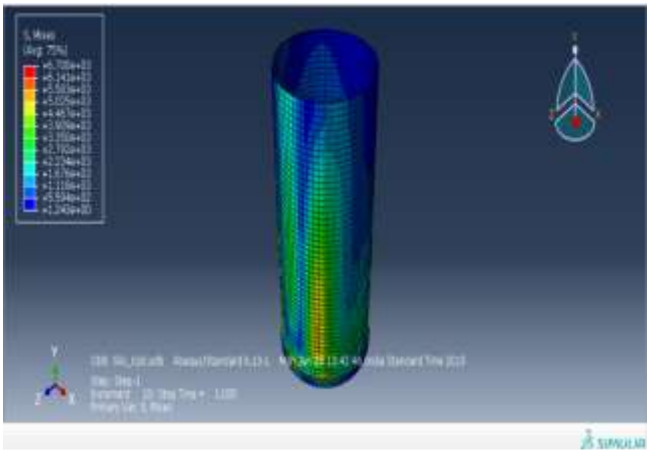

Fig 19 Von misses stress for large Eccentric discharge k= 0.6

Stress Results for cement

Load case	Max Stress (N/mm²)
Large eccentric discharge, k= 0.25	4.41
Large eccentric discharge, k= 0.40	5.97
Large eccentric discharge, k= 0.60	**6.7**

From the above table 10 it is seen that the stress for large eccentric discharge, k=0.6 is maximum

Work to be done:
Analysis using FE Software for 5 ensile materials
Comparison of Results and Conclusion

VII. Conclusion

The difference in pressure is calculated manually first using Euro code 1 and then the silo is analysed in staad to find the maximum stress the shell wall can take due to storage of cement, then the shell wall of the Silo is designed for the maximum stresses of Cement. Now the silo is modelled in Abaqus with all the design data as input and the various material pressures are acted on the shell wall one at a time and is analysed and compared.

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