

# Optimization of RCC Silo for Granular Material - 2

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**Abstract**— RCC Silos are used by a wide range of industries to store bulk solids in quantities ranging from a few tones to hundreds or thousands of tones. Silos are very demanding in cement industries. Hence RCC silos are widely used for storage of granular materials as they are an ideal structural material for the building of permanent bulk-storage facilities for dry granular like fillings. In the past, design of silos was based only on static pressure (BIS code), with no allowance to the pressure difference due to material flow, which creates bending stresses on the silo wall in filling area. Euro code gives guidelines to take care-of these wall stresses for designing RCC silos. In order to structurally design a silo, an engineer must determine all loads that are likely to be applied to it. These include, among others, wind, seismic, external, and loads induced by the stored bulk solid. Numerous codes and standards specify means to calculate the latter.

In previous paper the various pressure are acting at silo wall with different height to diameter ratio are derived from the ANSYS workbench, which are used for the stress and deformation calculation in this paper. Optimization of the silo are done using Multiple Objective Genetic Algorithm (MOGA) in the ANSYS Workbench. In this investigation, the diameter to height ratio is varied and has been designed and finally, the most economical size is found out. All the designs have been based on the recommendations of British Standard BS EN 1991-4:2006 and EN 1998-4:2006.

**Index Terms**— Optimization, RCC silo, ANSYS Workbench, Eccentric silo, Weight optimization.

## I. INTRODUCTION

Silos are designing structures broadly utilized as a part of enterprises and ranches to store, nourish and process mass solids that is fundamental to horticultural, mining, mineral handling, synthetic, delivery and different businesses. Silos are for the most part worked from solid, steel and aluminum. Regardless of broad test and hypothetical investigations of Silo issues, Silos come up short with a recurrence substantially higher than the rate of auxiliary disappointment of other mechanical structures.

In a silo vertical walls are considerably taller than the lateral dimension resulting in tall structure. Consequently, the plane of the rupture of the material stored meets the top horizontal surface of the material. Due to high ratio of height to the lateral dimension, a significant portion of the load is resisted by friction of the total weight of the material acts on the floor of the structure. For a structure to be classified as silo,

$$H > B \tan \left( \frac{90 + \phi}{2} \right)$$

Where, B = Breadth

H = Height of the structure

## Types of Silos as per Eurocode

As per EUROCODE the silos are divided by their Height to Diameter ratio. Slender silos and squat silos are widely used in industrial area. On other hand the retaining silos are used in farms to store, feed and process bulk solids that is essential to agricultural.

SR. NO.	Types of Silo	Condition
a	Slender silo	$2 < h_c / d_c$
b	Intermediate slenderness silo	$1 < h_c / d_c < 2$
c	Squat silo	$0.4 < h_c / d_c < 1$
d	Retaining silo	$h_c / d_c < 0.4$

The main objective is to optimize the **Weight** of RCC silo for Granular material considering different height to diameter ratio of 125m<sup>3</sup> volume for eccentric discharge.

## II. LOAD CALCULATION

Fig.1 shows the Excel input interface for optimization of steel lattice tower. There are some blank boxes in the interface. The user has to fill geometry data, material data and shape optimization constraints.

### 1. Symmetrical discharge load:

For silos in all Action Assessment Classes, the symmetrical discharge pressures  $P_{he}$  and  $P_{we}$  should be determined as:

$$P_{he} = C_h P_{hf}$$

$$P_{we} = C_w P_{wf}$$

Where,

$C_h$  is the discharge factor for horizontal pressure

$C_w$  is the discharge factor for wall frictional traction.

$$P_{hf}(z) = P_{ho} * Y_J(z)$$

$$P_{wf}(z) = \mu * P_{ho} * Y_J(z)$$

$$P_{vf}(z) = \frac{P_{ho}}{K} * Y_J(z)$$

In which,

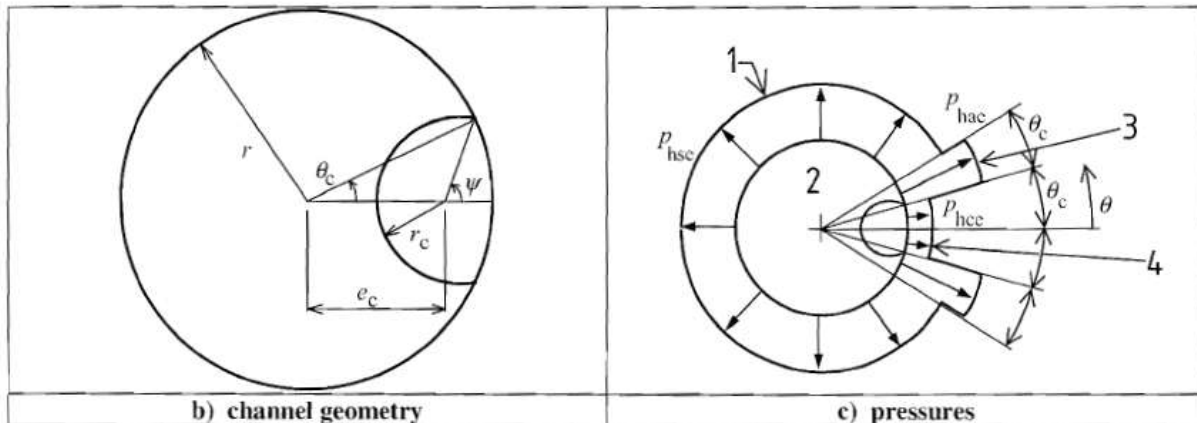
$$P_{ho} = \gamma * K * Z_0$$

$$Z_0 = \frac{1}{K\mu} \frac{A}{U}$$

$$Y_J(z) = 1 - e^{-\frac{z}{Z_0}}$$

**2. Wall pressures under eccentric discharge:**

The pressure on the vertical wall in the flowing zone depends on the distance  $z$  below the equivalent solid surface and should be determined as:



**Fig. Eccentric Discharge pressure**

$$P_{hce} = P_{hco} (1 - e^{-\frac{z}{Z_0}})$$

and the frictional traction on the wall at level  $z$  as:

$$P_{wce} = \mu P_{hce}$$

in which:

$$P_{hco} = \gamma K Z_{oc}$$

where:

$\mu$  = the wall friction coefficient for the vertical wall;

$K$  = the lateral pressure ratio for the solid.

**III. DATA IN ANSYS STUDY**

**A. Geometry Data**

Geometry data contains overall height and the diameter of the silo. Which is various with different Model. But from the Eurocode for Granular material different data to be provided in the Ansys workbench.

**B. Material Data**

Material data contains allowable stress, modulus of elasticity and density of RCC. This data is added to the Ansys. Here the Granular material Wheat is considered and the data should be taken from Eurocode EN-1991 Part 4.

Wall surface category considered	D3
Modification coefficient for lateral pressure ratio ( $a_k$ )	1.14
Modification coefficient for wall friction coefficient ( $a_w$ )	1.24
Mean value of lateral pressure ratio ( $k_m$ )	0.53
Mean value of wall friction coefficient ( $\mu_m$ )	0.53
Modification coefficient for internal angle friction ( $a_\phi$ )	1.14
Mean value of internal angle friction ( $\phi_m$ )	31
Patch load solid reference factor ( $C_{op}$ )	0.5

**C. Optimization Constraint**

Our problem is to optimize the overall weight of the silo subjected to certain conditions which are called constrains.

So, our **Objective Function** is to minimize the overall weight

Total weight = Weight of cylinder + Weight of hopper bottom

$$W_{Total} = W_{Cylinder} + W_{Hopper}$$

$$W = \rho A L_1 + \rho A L_2$$

$$= \rho A_A L_1 + \rho L_2 \left( \frac{AB+AC}{2} \right)$$

Where,

$$A_A = \frac{\pi}{4} (D_{oA}^2 - D_{iA}^2)$$

$$= \frac{\pi}{4} (D_{oA} - D_{iA}) (D_{oA} + D_{iA})$$

$$= \frac{\pi}{2} (t) \frac{(D_{oA} + D_{iA})}{2}$$

$$= \frac{\pi}{2} (t) (\text{avg. of } D_A)$$

$$A_B = \frac{\pi}{4} (D_{oB}^2 - D_{iB}^2)$$

$$= \frac{\pi}{4} (D_{oB} - D_{iB})(D_{oB} + D_{iB})$$

$$= \frac{\pi}{2} (t) \frac{(D_{oB} + D_{iB})}{2}$$

$$= \frac{\pi}{2} (t) (\text{avg. of } D_B)$$

$$A_C = \frac{\pi}{4} (D_{oC}^2 - D_{iC}^2)$$

$$= \frac{\pi}{4} (D_{oC} - D_{iC})(D_{oC} + D_{iC})$$

$$= \frac{\pi}{2} (t) \frac{(D_{oC} + D_{iC})}{2}$$

$$= \frac{\pi}{2} (t) (\text{avg. of } D_C)$$

$$W_{Total} = \rho L_1 \frac{\pi}{2} (t) [\text{avg. of } D_A] + \frac{\rho L_2}{2} \frac{\pi}{2} (t) [\text{avg. of } D_B + \text{avg. of } D_C]$$

$$= \rho L_1 \frac{\pi}{2} (t) \left[ \frac{(D_{oA} + D_{iA})}{2} \right] + \frac{\rho L_2}{2} \frac{\pi}{2} (t) \left[ \left\{ \frac{(D_{oB} + D_{iB})}{2} \right\} + \left\{ \frac{(D_{oC} + D_{iC})}{2} \right\} \right]$$

$$= \rho L_1 \frac{\pi}{2} (t) [\text{avg. of } D_A] + \frac{\rho L_2}{4} \frac{\pi}{2} (t) [(D_{oB} + D_{oC}) + (D_{iB} + D_{iC})]$$

$$= \rho L_1 \frac{\pi}{2} (t) [\text{avg. of } D_A] + \frac{\rho L_2}{4} \frac{\pi}{2} (t) [\text{sum of outer dia. At B + sum of inner dia. at C}]$$

The **constrained conditions** are as follows:

1. Thickness (t) in mm  
t ≥ 100 mm
2. Outer diameter and inner diameter  
0 m ≤ D<sub>i</sub>, D<sub>o</sub>
3. Direct Hoop tension  
σ ≤ σ<sub>0</sub> Allowable

Where, ρ = density of steel

A = total area of member

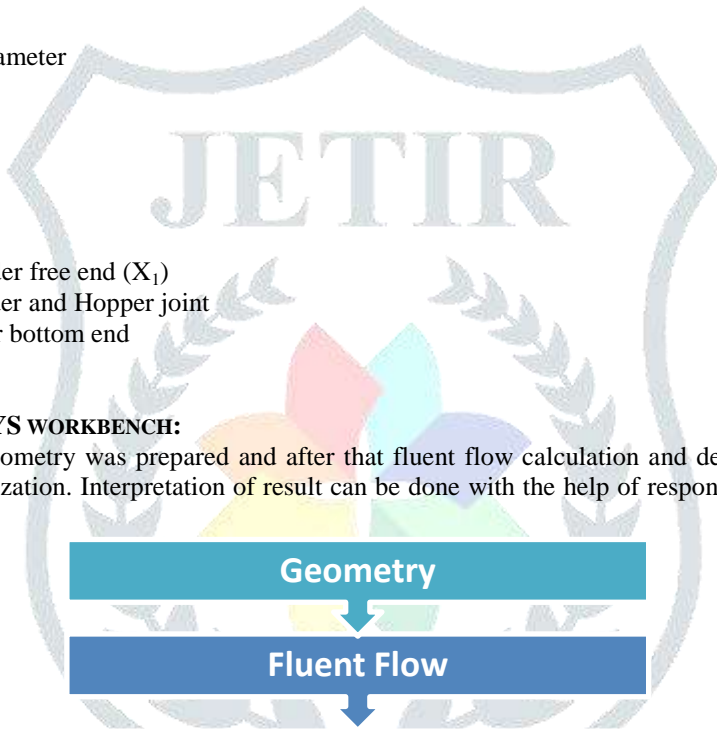
L = length of member (X<sub>2</sub>)

D<sub>A</sub>=dia. Measured at Cylinder free end (X<sub>1</sub>)

D<sub>B</sub>=dia. Measured at Cylinder and Hopper joint

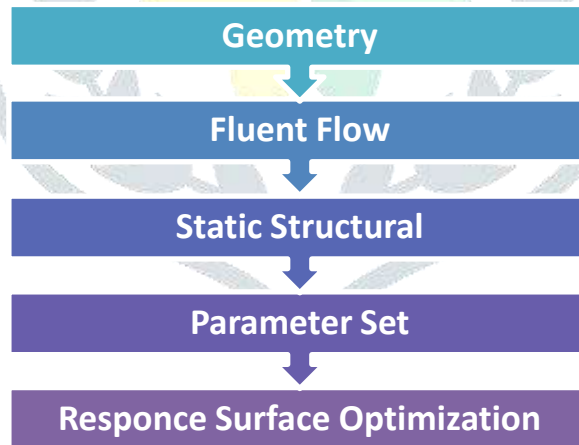
D<sub>C</sub>=dia. Measured at hopper bottom end

t = wall thickness



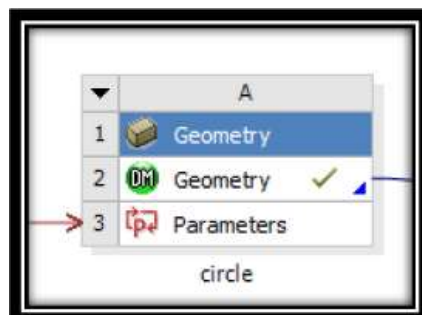
**IV. CURRENT MODELLING IN ANSYS WORKBENCH:**

In the ANSYS® Workbench, the geometry was prepared and after that fluent flow calculation and deflection are carried out for different points in the response surface optimization. Interpretation of result can be done with the help of response graphs as well as from the candid points.



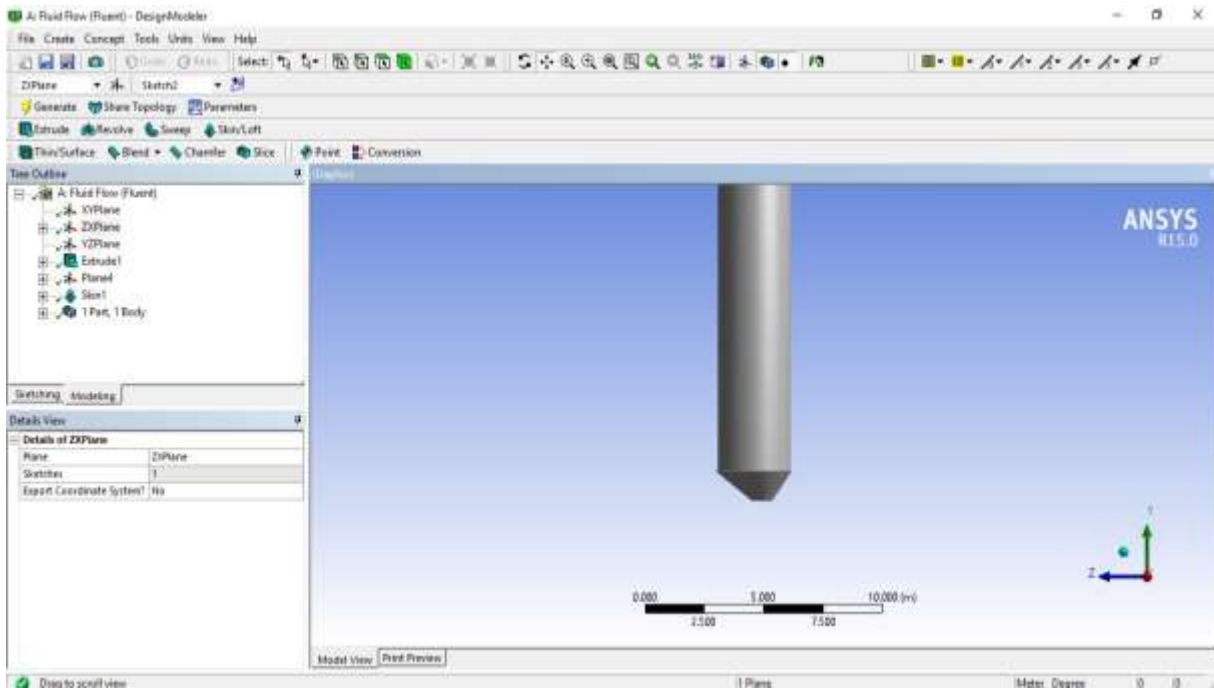
**Step 1: Geometry**

In this step first of all geometry section is added to the working window.



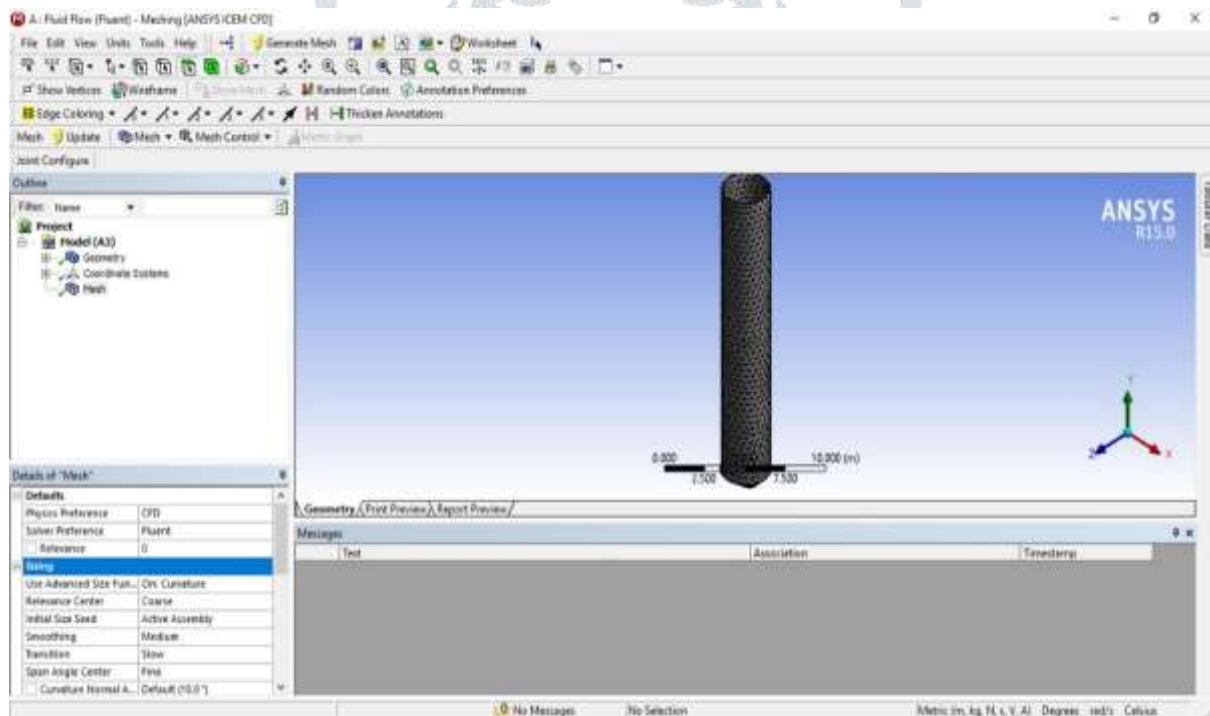
After that in the Design Modular (DM) geometry is prepared. The new plane is prepared at the height desired for our height of the structure.

The desired shape is drawn at both of our plane and appropriated dimensions are given. After that, with the help of skin final geometry is prepared as shown below.



**Step 2: Fluent flow**

After that, in the model sub-component mesh is generated.



Then after the Physical properties of Granular materials are setup in the fluent flow. First of all, applied velocity in downward direction.



In Multiphase model applied Eulerian Multiphase model with Dense Discrete Phase Model. And in Viscous model apply K-epsilon model with standard wall function. Apply the Group injection above the silo for Granular material and define the Granular material properties. Run the calculation with Phase coupled Simple solution method and we will get the pressure on the wall silo surface.

Here, Concrete and steel are not connected to each other. So, applied Stell APDL command and Concrete APDL Command for both and then after connect in the Static solution field via Pre processor command.

**CONCRETE COMMANDS:**

```
ET,MATID,SOLID65
R,MATID,0,0,0,0,0,0
RMORE,0,0,0,0,0
```

```
MP,EX,MATID,29250
MP,PRXY,MATID,0.2
MPTEMP,MATID,0
```

```
TB,CONCR,MATID,1,9
TBTEMP,22
TBDATA,1,0.3,0.8,1.5,25
```

**REBAR COMMANDS:**

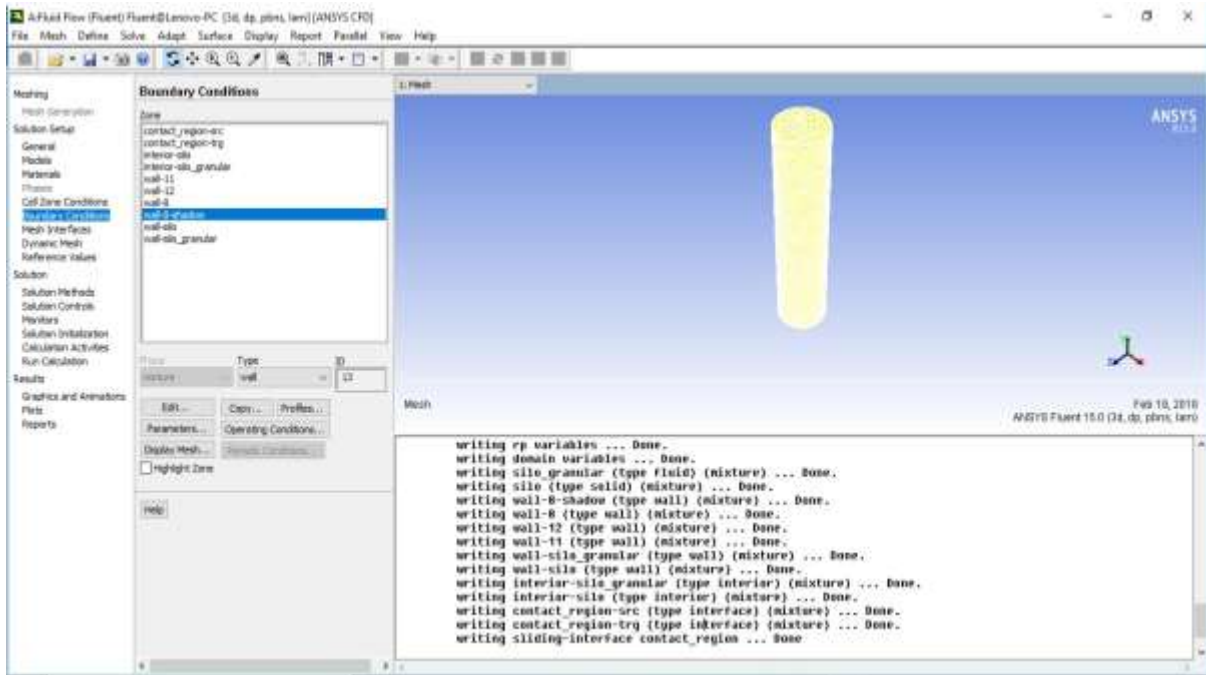
```
ET,MATID,LINK180
MPDATA,EX,MATID,,2e5
MPDATA,PRXY,MATID,,0.3
TB,BISO,MATID,1,2
TBDATA,,460,2100
R,MATID,12,,0
```

**PRE PROCESSOR COMMANDS:**

```
/PREP7
ESEL,S,ENAME,,65
ESEL,A,ENAME,,180
ALLSEL,BELOW,ELEM
CEINTF,0.001,
ALLSEL,ALL
/SOLU
OUTRES,ALL,ALL
```

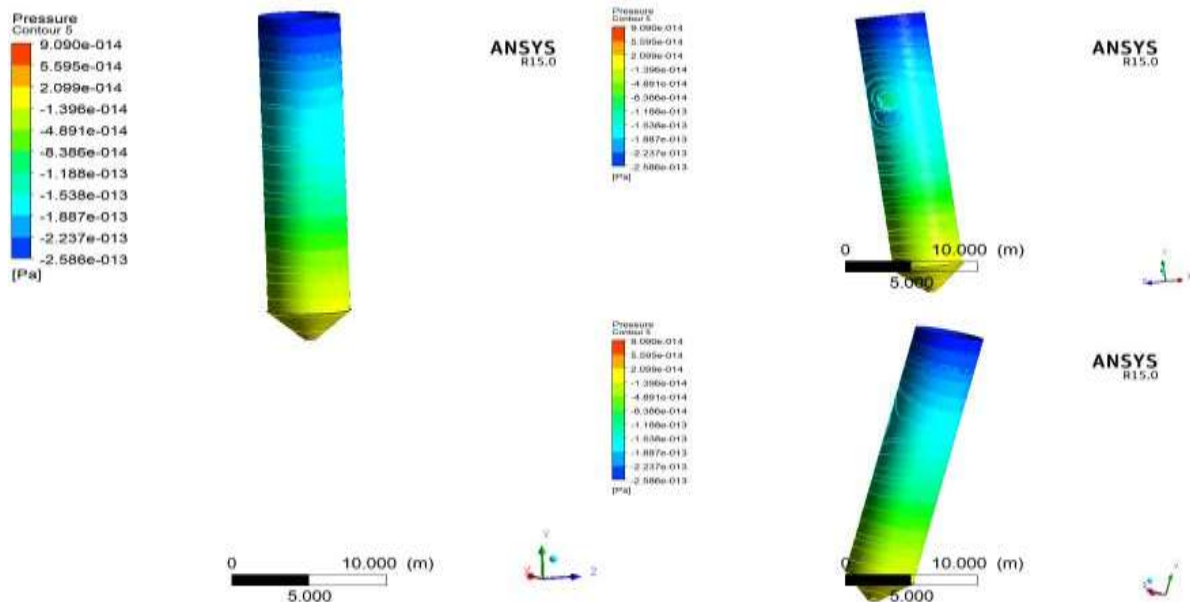
**Set Material and Physics in fluent flow:**

Set the material and the boundary condition of the silo as per the data, which is gives the velocity and the pressure distribution of the silo.



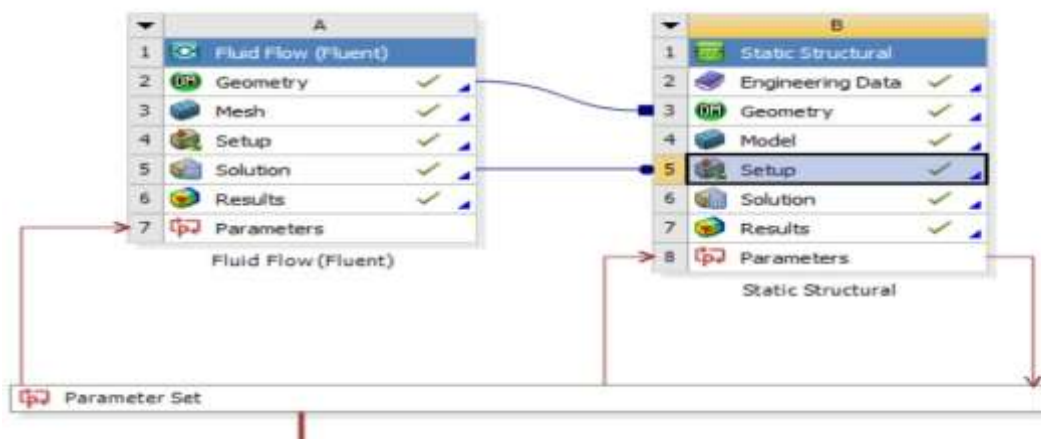
**Step 3: CFD-Post:**

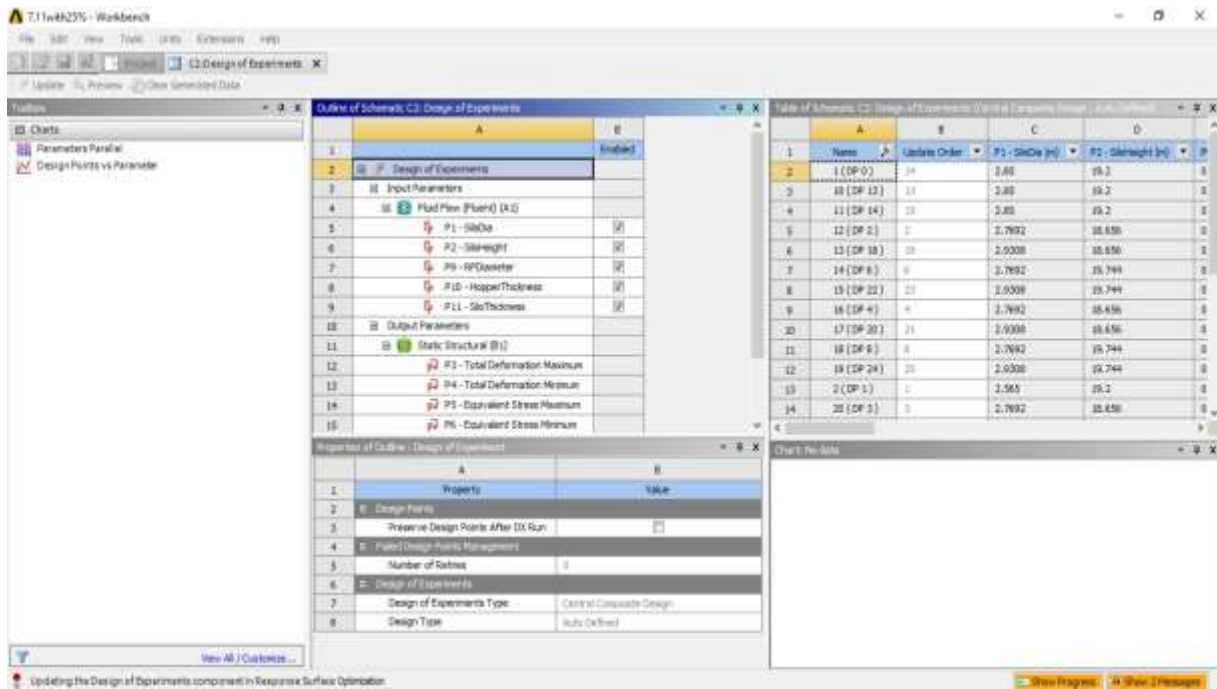
In CFD post we got the pressure variation and velocity with particle tracking.



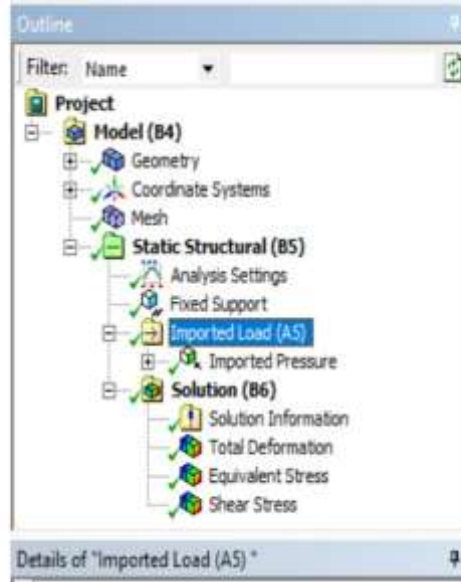
**Step 4: Static Structural**

Then after various supports and loads are applied in the setup sub-component.





Import the Wall silo pressure from the Fluent flow and apply on the geometry. After applying the loads various output parameters are established in the solution. In our case the desired output are deformations and



Equivalent (von-Mises) Stress. After solving the analysis various desired outputs are mate as follows:

**Step 5: Parameter Set**

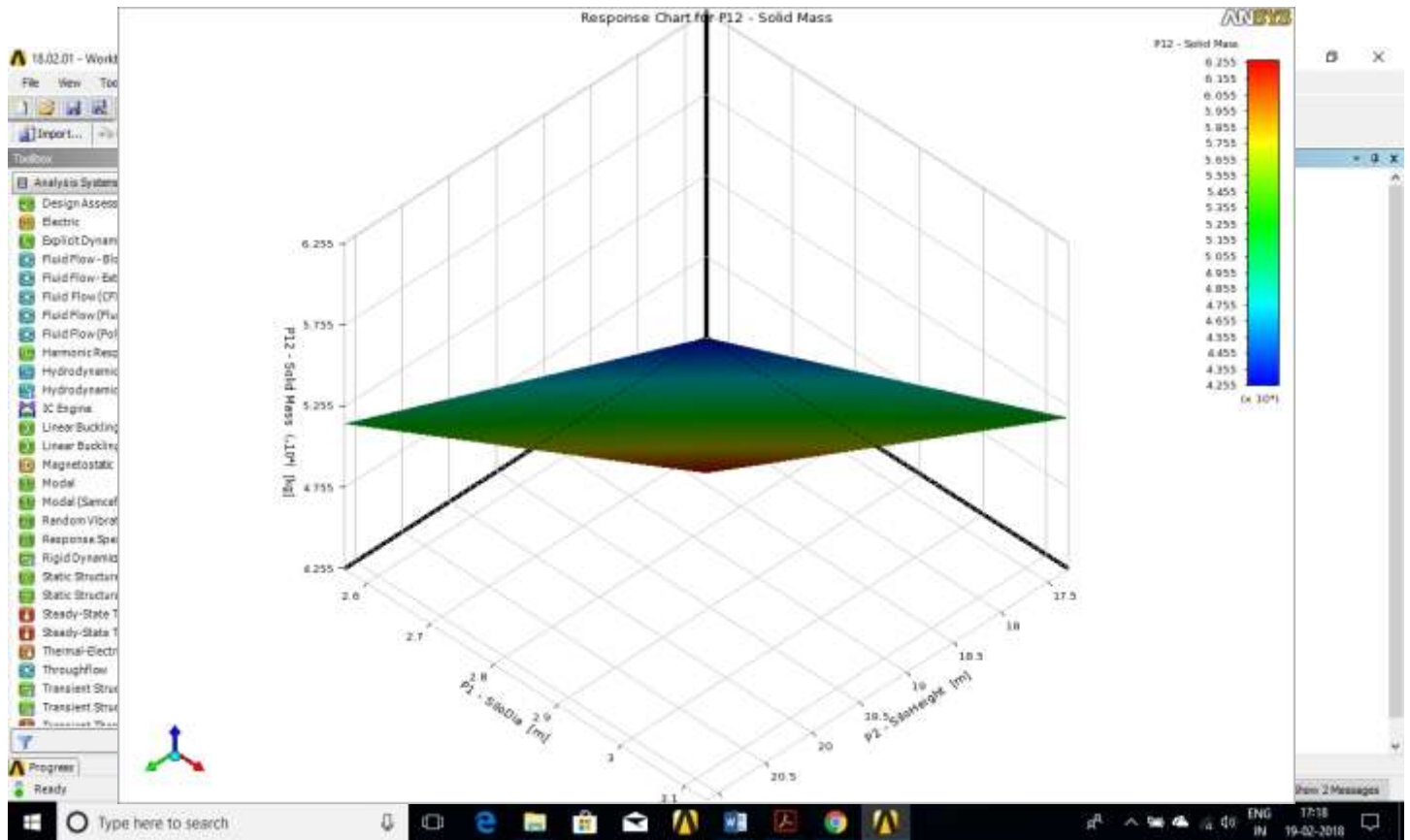
In this section various input and output parameters are selected. Various parameters are set in appropriate component. It will set by tick marking the check box at left side of the value.

**Step 6: Response Surface Optimization**

It is attached to the Parameter component. This is the very important component for the interpretation of final result.

**Design of Experiments (DOE):**

In the Design of Experiments (DOE) sub-component the values for the input parameters are given. There will be Lower Bound as well as Upper Bound of the value should be given. There are many methods available for the DOE like Central Composite Design, Optimal Space Filling Design, Box-Behkan Design, Custom, Sparx Grade Initialization and Latin Hypercube Sampling Design. We have used Sparx Grade Initialization for the Circle geometry and Optimal Space Filling Design with Full Quadratic Modal Samples in the sub-step for all other



geometry.

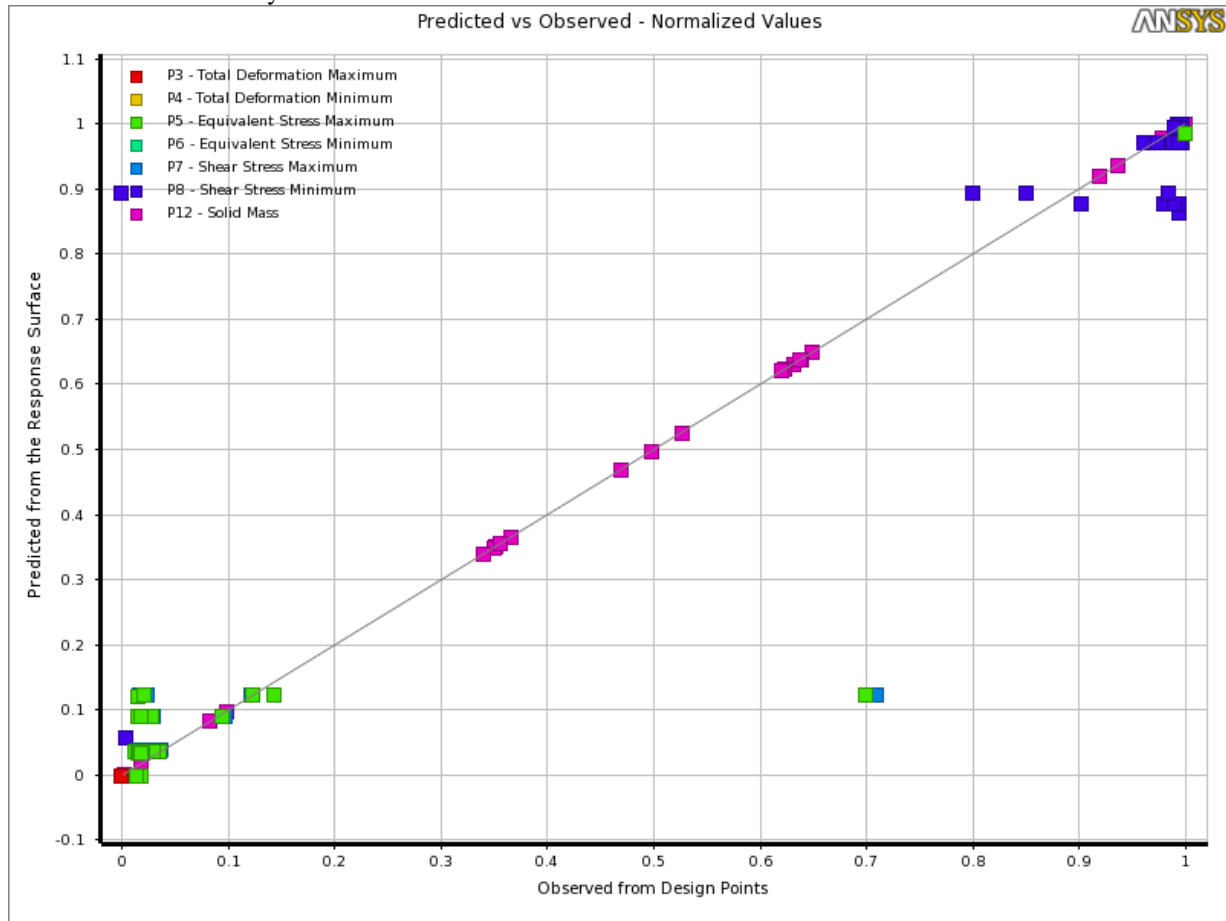
After updating the all Design Points, the values of various output parameters are obtained as shown below:

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Name	P1 - Side Dia (m)	P2 -	P3 - RFD... (m)	P3 - Hopper Thick... (m)	P11 - Skid Thickness (m)	P3 - Total Deformation Maximum (m)	P4 - Total Def... Min... (m)	P5 - Equivalent Stress Maximum (Pa)	P6 - Equivalent Stress Minimum (Pa)	P7 - Shear Stress Maximum (Pa)	P8 - Shear Stress Minimum (Pa)	P12 - Solid Mass (kg)
2	1 (DP 0)	2.85	19.2	0.01	0.12	0.12	6.999E-18	0	1.302E-08	3.936E-13	8.030E-09	-2.905E-09	32116
3	10 (DP 13)	2.85	19.2	0.01	0.12	0.108	2.210E-18	0	4.420E-09	1.222E-13	2.289E-09	-7.872E-10	46991
4	11 (DP 14)	2.85	19.2	0.01	0.12	0.132	6.837E-19	0	1.513E-09	6.407E-14	7.356E-10	-2.322E-10	57280
5	12 (DP 2)	2.7692	18.656	0.0097167	0.1166	0.1234	1.119E-18	0	3.474E-09	8.402E-14	1.4619E-09	-4.082E-10	50604
6	13 (DP 16)	2.9308	18.656	0.0097167	0.1166	0.1166	1.849E-17	0	5.530E-08	3.268E-12	2.896E-08	-7.593E-09	30392
7	14 (DP 6)	2.7692	19.744	0.0097167	0.1166	0.1166	5.576E-19	0	1.099E-09	1.094E-14	5.655E-10	-1.821E-10	30491
8	15 (DP 22)	2.9308	19.744	0.0097167	0.1166	0.1234	4.090E-18	0	1.022E-08	1.018E-13	5.287E-09	-1.453E-09	36461
9	16 (DP 4)	2.7692	18.656	0.030283	0.1166	0.1166	4.504E-19	0	1.152E-09	5.949E-14	5.918E-10	-1.628E-10	47846
10	17 (DP 20)	2.9308	18.656	0.030283	0.1166	0.1234	7.794E-19	0	2.121E-09	4.072E-14	1.098E-09	-2.966E-10	53498
11	18 (DP 8)	2.7692	19.744	0.030283	0.1166	0.1234	1.876E-19	0	4.605E-10	6.893E-15	2.338E-10	-7.217E-11	53410
12	19 (DP 24)	2.9308	19.744	0.030283	0.1166	0.1166	1.898E-18	0	4.365E-09	1.873E-13	2.241E-09	-6.388E-10	53385
13	2 (DP 5)	2.85	19.2	0.01	0.12	0.12	3.692E-18	0	9.254E-09	6.898E-14	5.178E-09	-8.802E-10	47012
14	20 (DP 3)	2.7692	18.656	0.0097167	0.1234	0.1166	3.672E-17	0	8.878E-08	1.129E-12	4.533E-08	-1.572E-08	48005
15	21 (DP 18)	2.9308	18.656	0.0097167	0.1234	0.1234	6.892E-19	0	1.941E-09	8.585E-14	1.053E-09	-2.363E-10	53671
16	22 (DP 7)	2.7692	19.744	0.0097167	0.1234	0.1234	2.209E-16	0	4.643E-07	1.26E-11	2.446E-07	-7.833E-08	53570
17	23 (DP 23)	2.9308	19.744	0.0097167	0.1234	0.1166	1.500E-18	0	3.156E-09	1.063E-13	1.572E-09	-5.603E-10	53557
18	24 (DP 5)	2.7692	18.656	0.030283	0.1234	0.1234	3.007E-17	0	7.489E-08	2.136E-12	3.767E-08	-1.175E-08	50764
19	25 (DP 21)	2.9308	18.656	0.030283	0.1234	0.1166	8.810E-19	0	2.426E-09	2.179E-13	1.311E-09	-5.488E-10	50764
20	26 (DP 9)	2.7692	19.744	0.030283	0.1234	0.1166	2.863E-18	0	6.029E-09	1.535E-13	3.219E-09	-1.089E-09	30650
21	27 (DP 25)	2.9308	19.744	0.030283	0.1234	0.1234	1.733E-18	0	3.809E-09	1.595E-13	1.870E-09	-4.433E-10	50633
22	3 (DP 26)	3.135	19.2	0.01	0.12	0.12	1.287E-19	0	3.347E-10	3.84E-14	1.846E-10	-8.851E-11	57257
23	4 (DP 10)	2.85	17.38	0.01	0.12	0.12	2.796E-18	0	8.293E-09	9.502E-14	4.514E-09	-1.251E-09	47172
24	5 (DP 17)	2.85	21.12	0.01	0.12	0.12	2.969E-18	0	5.138E-09	1.725E-13	2.239E-09	-7.649E-10	57060
25	6 (DP 11)	2.85	19.2	0.009	0.12	0.12	4.894E-18	0	1.146E-08	3.579E-13	5.796E-09	-1.877E-09	52116
26	7 (DP 16)	2.85	19.2	0.011	0.12	0.12	4.894E-18	0	1.146E-08	3.579E-13	5.796E-09	-1.877E-09	52116
27	8 (DP 12)	2.85	19.2	0.01	0.108	0.12	2.480E-16	0	6.666E-07	4.773E-12	3.468E-07	-7.908E-08	53825
28	9 (DP 15)	2.85	19.2	0.01	0.132	0.12	6.290E-19	0	1.747E-09	5.355E-14	9.681E-10	-2.306E-10	52411

**Response Surface:** After that in Response Surface component various graphs are prepared. Many graphical representations are provided in the response surface such as response surface graphs, goodness of fit, local sensitivity chart, etc. In the response chart they show the values of various output parameters with respect to input parameters in the form of graph. There are many methods available for Response Surface like Standard Response Surface, Kriging, Non-parametric Regression, Neutral Network and Sparx Grid. We have used Standard Response Surface method for the Circle.



In the min-max search, it will show the min and max value of all the output parameters with respect to variable inputs. Goodness of fit indicates the accuracy of result.



**Optimization:** This is the final step. In this step finally, the optimization of weight is done with certain conditions which are called constrained conditions. In our analytical work the constrained conditions are in the form of deformation and Max. Von-misses Stress. There are many methods available in the optimization toolbox for the optimization like Screening, MOGA (Multi Objective Genetic Algorithm), NLPQL (Nonlinear Programming by Quadratic Langrangian) and MISQP (Mix-Integer Sequential Quadratic Programming). We have used MOGA method in our case.

The image shows two windows from the ANSYS Workbench software. The top window is titled "Outline of Schematic D4: Optimization" and contains a table of optimization settings:

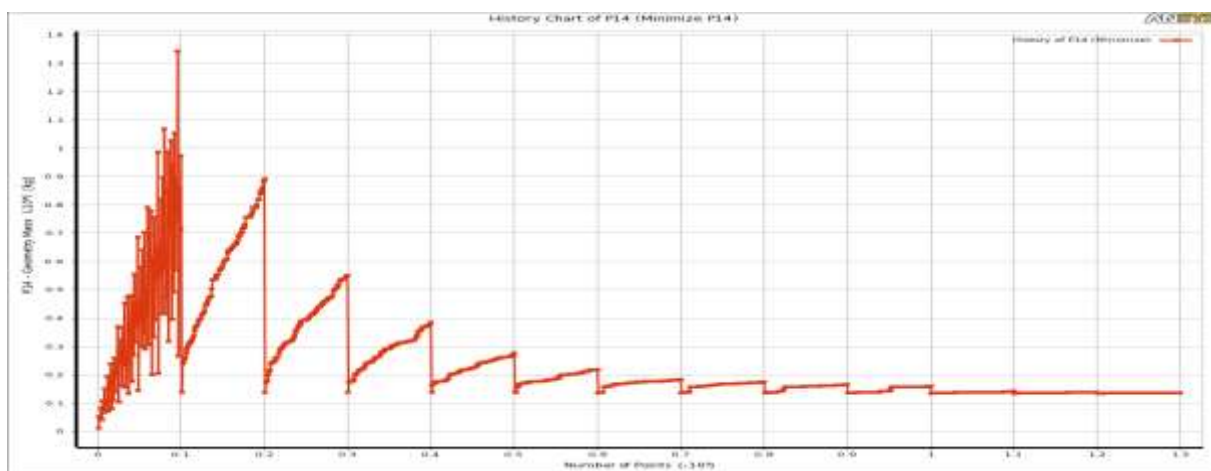
	A	B	C
1		Enabled	Monitoring
2	Optimization		
3	Objectives and Constraints		
4	Minimize P12		
5	P5 <= 1.35E-09 Pa		
6	P3 <= 0.01 m		
7	Domain		
8	Fluid Flow (Fluent) (A1)		
9	P1 - SiloDia	<input checked="" type="checkbox"/>	
10	P2 - SiloHeight	<input checked="" type="checkbox"/>	
11	P9 - RFDiameter	<input checked="" type="checkbox"/>	
12	P10 - HopperThickness	<input checked="" type="checkbox"/>	
13	P11 - SiloThickness	<input checked="" type="checkbox"/>	
14	Parameter Relationships		
15	Results		

The bottom window is titled "Properties of Outline A2: Method" and shows the configuration for the MOGA method:

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	<input checked="" type="checkbox"/>
4	Export Project for Each Preserved Design Points	<input type="checkbox"/>
5	Failed Design Points Management	
6	Number of Retries	0
7	Optimization	
8	Method Name	MOGA
9	Verify Candidate Points	<input type="checkbox"/>
10	Number of Initial Samples	100

After the optimization process, optimized results are obtained from the response surface graphs and the candidate points are found. Each candidate point is then verified by the actual analysis.

How the actual optimization of weight is done, it can be understood easily by the graph shown below. After the analysis of vast number of sample point, the final optimized results can be obtained.

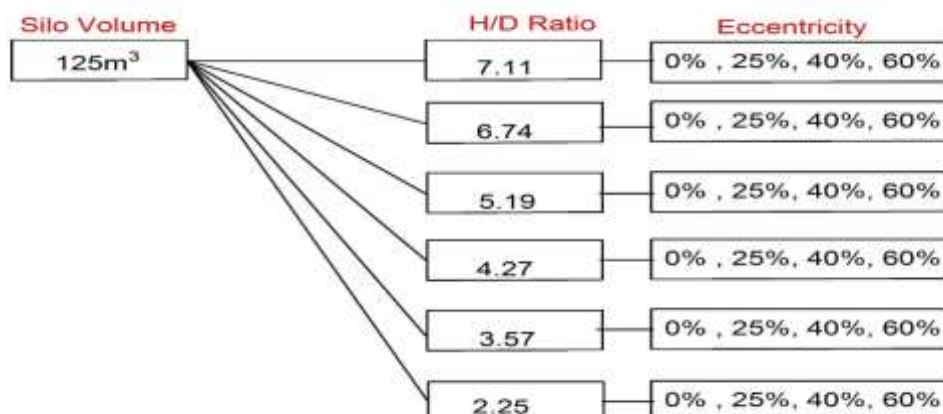


### V. NUMERICAL EXAMPLES

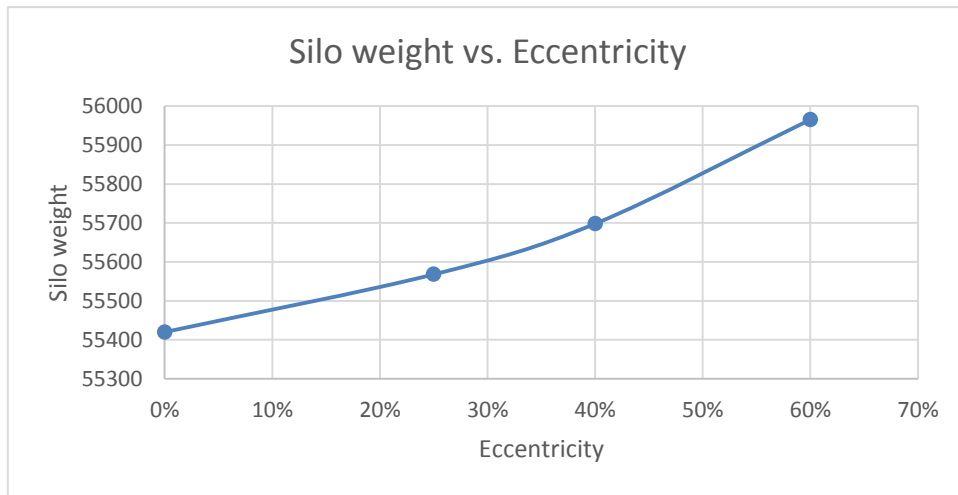
Material property and section database is kept same for all examples.

As described above, total 24 models of different height and diameter are considered in thesis work. The details of all the models are described below:

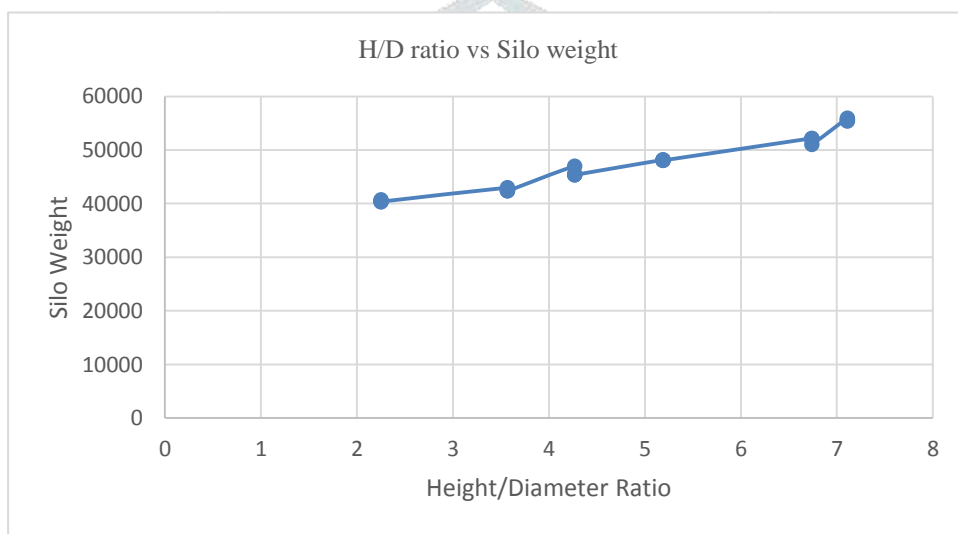
Sr.No	Height of cylindrical portion (m)	Top dia (m)	H/D Ratio	Height of frustum cone (m)	Bottom dia of hopper (m)	Volume of cylindrical portion (m <sup>3</sup> )	Volume of frustum cone (m <sup>3</sup> )	Total volume (m <sup>3</sup> )	Eccentricity
1	19.9	2.8	7.11	1.15	0.5	122.53	2.86	125.39	0%, 25%, 40%, 60%
2	19.2	2.85	6.74	1.18	0.5	122.48	3.03	125.51	0%, 25%, 40%, 60%
3	16.1	3.1	5.19	1.3	0.5	121.51	3.88	125.40	0%, 25%, 40%, 60%
4	14.1	3.3	4.27	1.4	0.5	120.59	4.69	125.28	0%, 25%, 40%, 60%
5	12.5	3.5	3.57	1.5	0.5	120.26	5.60	125.86	0%, 25%, 40%, 60%
6	9.1	4.05	2.25	1.78	0.5	117.23	8.70	125.93	0%, 25%, 40%, 60%



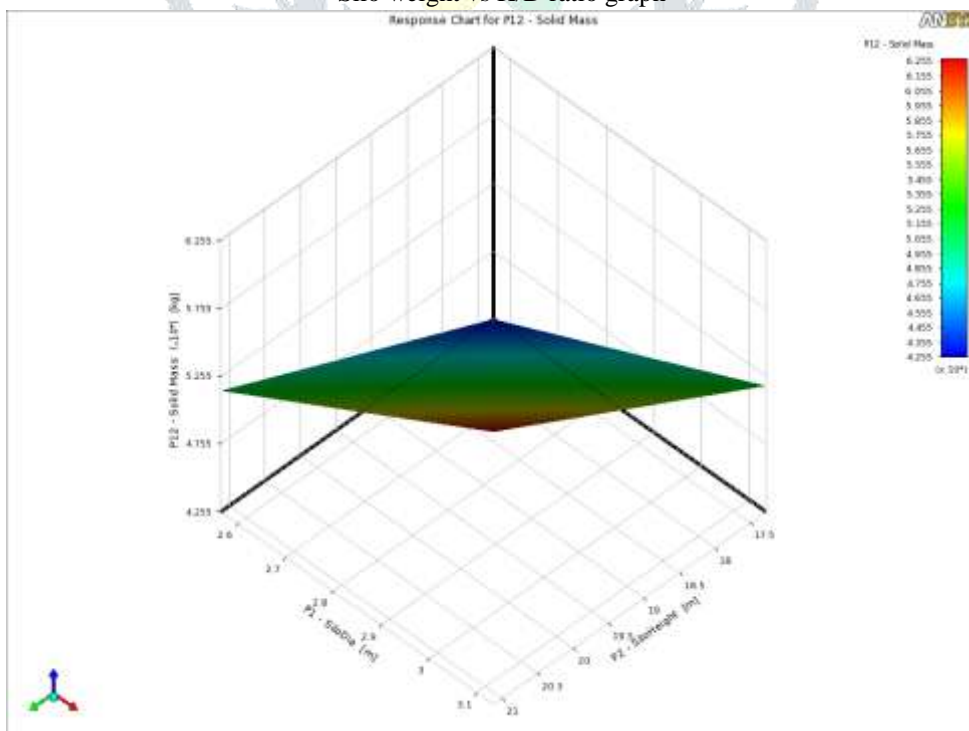
VI. RESULT



Silo weight vs Silo Eccentricity graph



Silo weight vs H/D ratio graph



Response Surface Optimization graph for the Silo Mass vs Silo Height vs Silo Diameter

## VII. CONCLUSION

Here, Total Six cases are considered for the different Height to Diameter ratio of the silos. The Eccentricity of the silos are considered as 25%, 40% and 60% in the outlet diameter of the hopper. So that it was considered as Outlet Eccentricity and the difference in the pressure are observed in the ANSYS workbench. After that the Silo pressure is Imported in Static Structural and Compute the Deflection and Stresses in Silo. In Response Surface Optimization the optimization of silo to be done and find the Optimum weight of Silo.

The conclusions achieved from present work are:

1. When the depth of silo is increased the pressure is also increased it is independent from the eccentricity of the Silo.
2. Pressure on wall in falling zone is continuously decreasing when the Eccentricity of the Silo is increasing from 25 percent to 60 percent, on different cases of silos these pressure is gradually decreasing when the Height to Diameter of Silo is decreasing.
3. High pressure on wall at static zone is continuously increasing when the Eccentricity of the Silo is increasing from 25 percent to 60 percent, on different cases of silos these pressure is gradually increasing when the Height to Diameter of Silo decreasing.
4. When the Eccentricity of Silo is increased from 25 percent to 60 percent the Silo weight is also increased with them and deformation is also increased with the Eccentricity of the Silo.
5. When the Height to Diameter ratio is decreased the overall weight of the silo is also decreased, from the Graph we can easily say that when the Height to Diameter ratio is around 2.0 the Optimum weight of the silo we can get. These geometry dimensions are optimum dimensions of the silo.

In the present work, Using ANSYS workbench tool of “FLUENT FLOW” and “STATIC STRUCTURAL” we can easily find the optimum dimension of the RCC eccentric Silo for Granular material.

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