Behavior of Circular RCC Silo under Earthquake Forces

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Abstract- *The dissertation provides an idea of considering the earthquake loads for the analysis of circular RCC Silo. Analysis of silo is done using Equivalent lateral force method and Response spectrum method. These silos are studied for varying column height i.e. 5m, 14m, 23m and varying zones of seismicity and for different soil conditions from hard soil to soft soil. The analysis is done using Staad Pro as per IS 1893 (Part I): 2002 in order to compute the natural period, displacements and base shear of the silo for different conditions is tabulated.*

Keywords- Silo, Response spectrum method, natural period, displacement.

I. INTRODUCTION

Earthquake is the vibrations occurred, when rocks in the earth crust are disturbed releasing vibrations in all direction. Many areas throughout the world are prone to earthquake with high seismicity. Earthquake resistant design of structures is to be done considering the seismicity. Various codes are adopted by respective countries throughout the world. Every code considers its own criteria for design of the structures. Earthquake is the important criteria is to be considered now a days in order to design a building as it may cause damage to the life and property and also may lead to loss of material. Although it is impossible to calculate earthquake for particular building at particular zone, Practices are made to make the structure resistant to earthquake. The seismic waves travel, the result of which causes ground motion causing the lateral load to act on the structure hence it is necessary to calculate these horizontal forces that act on the structure during the design of the building. Earthquake forces depend on various factors such as magnitude, intensity site geology etc. The philosophy of earthquake design is to prevent the damage which is not structural in small ground shaking, is to prevent damage that is structural and reduce non-structural destruction in moderate occasional ground shaking and to avoid sudden fall down or serious damage in rare large ground shaking. An earthquake ground motion has three components two horizontal components and a vertical component in the structure. The earthquake is measured in terms of qualitative and quantitative measures where the magnitude of the earthquake is quantification of earthquake measured as the released energy whereas the qualitative measure is intensity which is the effect or damage at that place. Richter scale is measure of magnitude whereas modified Mercalli intensity scale which is measure of intensity at that place.

1.2. Silo

The storage of raw materials in any industry in large scale is done with the help of large containers these containers are called as bins. Bins are the storage structures used for storage of grains, coal, crushed materials, cement and various granular materials in various industries. The tall structures whose height is large as compared to lateral dimension are called as silo. Silo is a structure where in the angle of rupture cuts the opposite sides. The design of silo is given attention and treated as special structure for design as considering its importance. Generally silos are made up of steel or concrete. Silos may be supported either on steel column with concrete pedestal or concrete columns. Type of stored materials and its properties affects the silo design, the properties such as density; friction of stored material affects the design of silo. The design of silo is done for both horizontal pressure and vertical pressure due to stored material.

The silo walls are subjected to pressure in terms of vertical friction that is engendered by the material that is stored within the Silo and walls of Silo, the properties of material stored are the cause for the quantity and distribution, of both vertical and horizontal pressure over the wall height and additionally it depends on the whether the silo is being filled or evacuating case. The variant of loads that can act are self-weight of the Silo, wind loads, temperature stress, and seismic loads, properties of material to be stored, and differential settlement of substratum, and various loads should be considered during design.

The failure of the silo generally results in entire structure failure in terms of collapse. The failure of silo structure in the industries may also result in fall on adjacent industrial equipment, resulting in an additional loss and also may result loss to the human life, or injuring employees. The structural failure not only effects in loss of life and structure but also failure of material stored in structure.

The material stored in silo exerts vertical pressure and horizontal pressure on the side walls which varies during process of emptying and filling. The pressure analysis exactly is difficult. The amount of pressure in silos where the friction between wall surfaces exists and stored material can be found by following theories.

The design of silos is done generally by two methods:
1. Janssen's Theory
2. Airy's Theory

1. Janssen's Theory

The assumption of this theory is that the friction between the material stored and walls of silo supports the large portion of weight of material store and hopper bottom supports only small portion of weight. Hence Rankine's or coulomb's theory of lateral pressure cannot be directly applied, the walls of silo are subjected to direct compression as well as lateral pressure. [2]

2. Airy's Theory

This theory uses coulomb's theory of earth pressure. Due to which it is possible to determine the horizontal loads on walls per unit length of the periphery and position of plane of rupture.

II. ABOUT THE STRUCTURE

The aim of analysis is to check the behavior of the circular RCC silo under various forces and to calculate the effect of silo under earth quake forces, analysis is carried out by two methods namely

1. Equivalent lateral force method.
2. Response spectrum method.

2.1. Data considered

Type of silo = R.C.C circular silo.
Total height of silo = 23 m.
Type of material stored = Cement.
Density of material stored = 16 kN/m^3.
Diameter of silo = 6 m.
Depth of cylindrical portion = 18 m.
Height of conical hopper = 2.5 m.
Opening of hopper bottom = 1m.
Coefficient of friction = 0.70.
Angle of repose = 25˚.

1. Circular silo with column height 5m
2. Circular silo with column height 14m
3. Circular silo with column height 23m

2.2. Modelling and analysis

The modeling is done in Staad Pro V8i software with the dimensions taken under consideration. The model shown in figure below consists of 6 columns with fixed supports. The model of silo is done using nodes and lines. Once the model is finished the various desired specification and properties of columns, plates and beams are assigned to the structure. Complete model consists of beams, plates and nodes. Fig 1 shows the plan in Staad Pro.

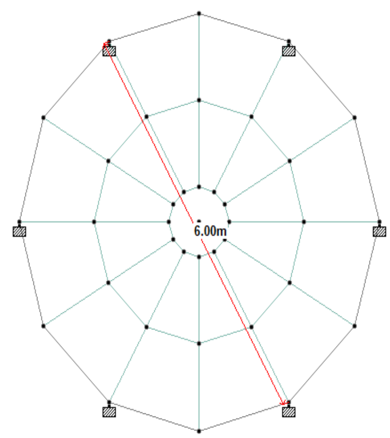

Figure 1. Plan of circular silo.

2.3. Section properties

Table 1. Section properties

Section	Member Property	Dimension (L X B)
Column	Cross section	300 mm X 600 mm
Plate	Thickness	200 mm
Beam	Cross section	300mm X 300mm

III. LOADING CONSIDERED FOR ANALYSIS OF STRUCTURE

Once the modeling is completed next step is loading. The loading consists of various loads, the pressure due to stored cement on the walls of silo with the appropriate direction of the load. The pressure applied is normal to the wall of the silo and is applied in local coordinates. Fig 4.7 shows application of pressure on plates.

The various loads considered for the analysis are as follows:

Horizontal pressure on cylindrical walls = 33.07 kN/m^2.
Horizontal pressure on at hopper bottom = 33.53 kN/m^2.
Vertical pressure on structure**:**
On cylindrical portion = P_v = (P_h / n)= 33.07/0.4 = 82.723 kN/m^2.
On hopper bottom = surcharge load at hopper bottom = 272.55 kN
Load on each node = 22.72 kN.

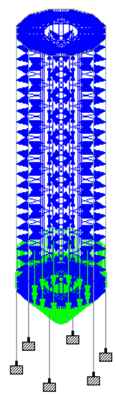

Figure 2. Horizontal pressure on cylindrical portion.

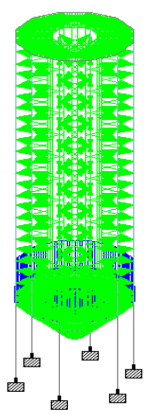

Figure 3. Vertical pressure acting on the plates.

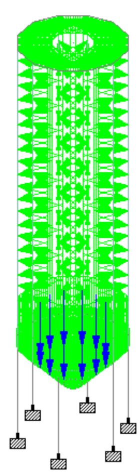

Figure 4. Vertical pressure at hopper bottom.

IV. RESULTS AND DISCUSSION

4.1. Natural period

The time period of the structure of vibration during earth quake is termed as natural period.

Table 2. Natural period

Sl. No.	Model	Natural Period	Mode
2.	Silo with 14m height of column	1.61438	1
3.	Silo with 23m height of column	1.59519	1

4.2. Displacement

Earthquake induces displacement which is time varying. Displacement at various heights i.e. 5m, 14m, 23m in circular RCC silo are obtained from the analysis and tabulated as below.

Table 3. Displacement of structure on Soft soil in Zone III

Sl. No.	Model	Height (m)	Displacement(cm)
1.	Silo with 5m height of column	5	7.62
		23	9.35
2.	Silo with 14m height of column	5	6.20
		14	7.75
		23	7.60
3.	Silo with 23m height of column	5	7.67
		23	10.11

Table 4. Displacement of structure on Soft soil in Zone IV

Sl. No.	Model	Height (m)	Displacement(cm)
1.	Silo with 5m height of column	5	9.66
		23	11.86
2.	Silo with 14m height of column	5	11.43
		14	14.28
		23	14.01
3.	Silo with 23m height of column	5	11.51
		23	15.17

Table 5. Displacement of structure on Soft soil in Zone V

Sl. No.	Model	Height (m)	Displacement(cm)
1.	Silo with 5m height of column	5	14.50
		23	17.79
2.	Silo with 14m height of column	5	17.14
		14	21.42
		23	21.09
3.	Silo with 23m height of column	5	17.27
		23	22.75

4.3. Base shear

Due to motion of ground during the earthquake maximum total lateral force acts at the base of the structure is estimated in terms of base shear. Which is influenced by various factors like height, acceleration response of structure, its mass, natural period and soil conditions According to IS 1893 (Part I): 2002 the parameter base shear can be calculated using formula,

$V_B = A_h$ x W

$A_h = (Z/2)$ x (I/R) x (S_a/g)

Where

Z = Zone factor

I = Importance factor

R = Reduction factor

(S_a/g) = Average response acceleration coefficient

The obtained results of various models of silo are tabulated as below.

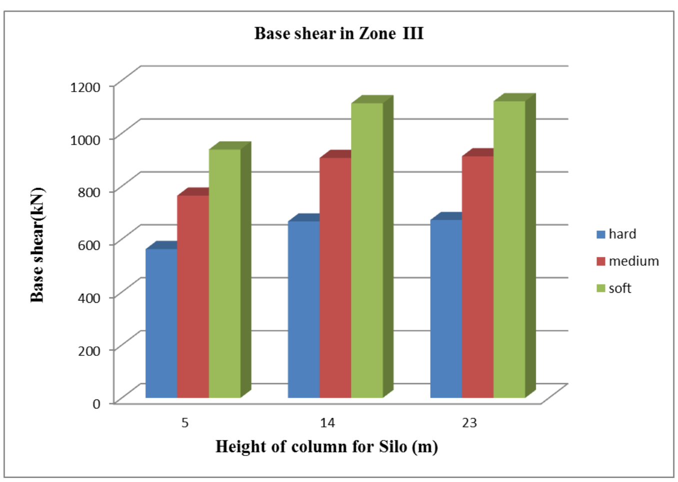

Figure 5. Graph of base shear of silo in zone III.

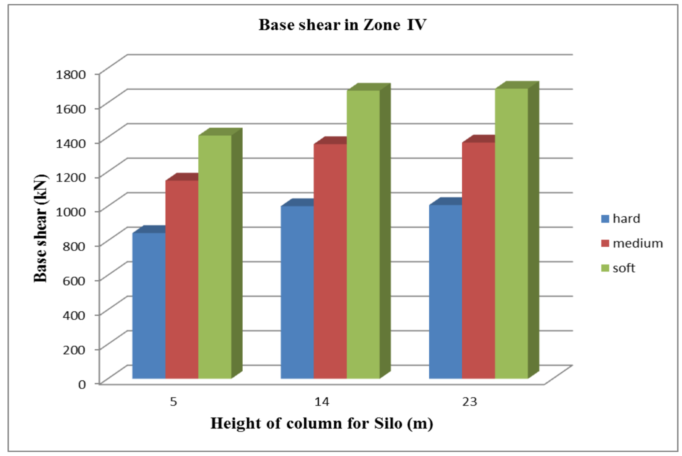

Fig 6. Graph of base shear of silo in zone IV.

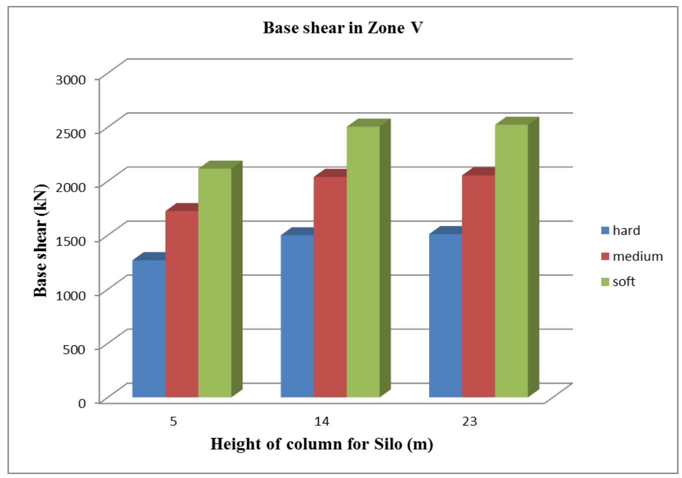

Fig 7. Graph of base shear of silo in zone V.

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VI. CONCLUSION

1. The base shear of the silo structure increases as the Zone of seismicity increases from zone III to zone V.

For Zone III

a. Base shear of Silo structure with 14 m column height increases by 15.7% when compared to Silo structure with 5 m column height.

b. Base shear of Silo structure with 23 m column height increases by 0.7% when compared to Silo structure with 14 m column height.

For Zone IV

a. Base shear of Silo structure with 14 m column height increases by 15.57% when compared to Silo structure with 5 m column height.
b. Base shear of Silo structure with 23 m column height increases by 0.66% when compared to Silo structure with 14 m column height.

For zone V

a. Base shear of Silo structure with 14 m column height increases by 15.48% when compared to Silo structure with 5 m column height.
b. Base shear of Silo structure with 23 m column height increases by 0.73% when compared to Silo structure with 14 m column height.

2. Time period of Silo structure with 23 m height of column increases by 1.2% when compared with Silo structure 14 m height of column.
3. Displacement of the silo structure increases depending on the zone of earthquake

For Zone III

a. Displacement of Silo structure with 14 m column height decreases by 18.71% when compared to Silo structure with 5 m column height.
b. Displacement of Silo structure with 23 m column height increases by 24.82% when compared to Silo structure with 14 m column height.

For Zone IV

a. Displacement of Silo structure with 14 m column height increases by 15.34% when compared to Silo structure with 5 m column height.
b. Displacement of Silo structure with 23 m column height increases by 7.64% when compared to Silo structure with 14 m column height.

For zone V

a. Displacement of Silo structure with 14 m column height increases by 15.64% when compared to Silo structure with 5 m column height.
b. Displacement of Silo structure with 23 m column height increases by 7.29% when compared to Silo structure with 14 m column height.

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