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SEISMIC EVALUATION OF STEEL SILOS WITH DIFFERENT ASPECT RATIO

Dr. S. K. Hirde[1], Aartika S. Mohabansi[2]

1. *Professor & Head, Applied Mechanics Department, Government College of Engineering, Amravati, Maharashtra, India.*
2. *PG student, Structural Engineering, Government College of Engineering, Amravati, Maharashtra, India.*

Abstract

Silos are structures that are used to store cement and ash in ready mix concrete plants, coal in power plant, grains in flour mills. The elevated cylindrical storage silos are lifeline structures and strategically very important, since they have vital use in industries. Dynamic effects are different in character in terms of distribution patterns and their magnitudes when compared with the static effects. This paper reports on the results of parametric study, which examines the effects of varying aspect ratios on the dynamic response of elevated cylindrical steel silos under earthquake loading using SAP2000. Elevated silos generally consist of a roof, a cylindrical shell and conical hopper and they supported with steel frame. The main objective of the study is to determine the behaviors of seismic responses (Base shear variation, overturning moment, roof top displacement).

Keywords: Steel silos, Hopper, Aspect ratio

1. Introduction

The term "silo" refers to any type of particle solid storage structure, whether it's referred to as a bin, hopper, grain tank, or bunker. The design of silo to store material involves stored material properties, geometric and structural considerations. Stored material properties consideration is important because the frictional and cohesive properties of material differ from one material to another. An earthquake ground motion has three components resulting in structural loads in the vertical and two horizontal directions. The effect of vertical seismic loads on the relatively heavy silo structures is usually small, whereas the effect of lateral loads can be significant especially on the taller silos containing heavier material. The magnitude of the horizontal seismic load is directly proportional to the weight of the silo. As the silo height increases the height of the center of mass of the silo structure also increases. Assuming the horizontal seismic load is applied roughly at the center of mass, the moment arm for the lateral load and the corresponding bending moment at the base increase. The increased bending moment then results in nonuniform pressure distribution at the bottom of the silo, which can be significantly larger than the pressure caused by the gravity loads. Earthquakes can also cause damage in the upper portion of the silo if the material contained can oscillate inside the silo during the earthquake. The lateral loads due to material flow and lateral seismic loads must be considered simultaneously if the material can oscillate.

There are three types of loads caused by stored material in a bin structure.

1. Horizontal load due to horizontal pressure (P_h) acting on the side walls
2. Vertical load due to vertical pressure (P_v) acting on the cross-sectional area of the bin filling.
3. Frictional wall loads due to frictional wall pressure (P_w) introduced into the side walls due to wall friction.

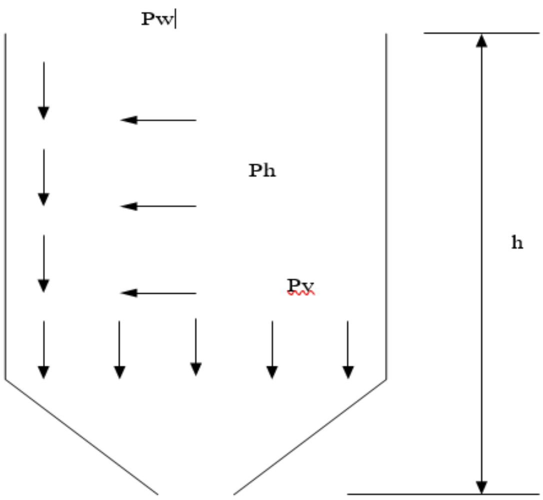

Fig.1 Bin load

Elevated silos are very vital structures subjected to different unconventional loading acting like a cantilever with the stored material stacked up very high vertically, thus susceptible to earthquake. Even though silos account for very less number but their importance is very high, and deformation in its shape leads to accumulation of stresses, thus influencing significant wall pressure. Due to complex behavior of stored material, it becomes even more complex to analyze the response, also the interaction between the stored material and silo wall is nonlinear. This interaction makes it very difficult to formulate a theoretical problem statement. Earthquake can damage the upper portion of the silo if it tends to oscillate the material inside the silos, also the response of lateral flow is unaccounted for which plays a key role in its response. The wall pressure is the main parameter while analyzing the silos, defining the safety, maintenance and efficiency of silo. This there is urgent need to safeguard the structure, as for the seismic activities are increasing their frequency over the period of time. In this paper a silo is modelled in SAP2000 considering cement and wheat as the stored material with different aspect ratio.

2. Literature Review

Adem Dogangun; Zeki Karaca; Ahmet Durmus; and Halil Sezen [1] presented different cause of Failure of a silo can be devastating as it can result in loss of the container, contamination of the material it contains, loss of material, clean-up, replacement costs, environmental damage, and possible injury or loss of life. Also provided are a review and discussion of the common or spectacular silo failures due to explosion and bursting, asymmetrical loads created during filling or discharging, large and nonuniform soil pressure, corrosion of metal silos, deterioration of concrete silos due to silage acids, internal structural collapse, and thermal ratcheting. Silo damage and failures from several earthquakes are also presented.

Atul Kulkarni and J. Chavez Sagarnaga [3] discussed failure due to design errors. Silo design requires specialized traits, which includes knowledge of stored material behaviour and loads exerted on the silo walls. How these loads interact with the entire structural system is normally not well understood at the design stage. some of the most common causes of steel silo failures due to design errors are given in this paper like failure due to flow pattern change, Failures due to ignoring the effects of eccentric discharge.

Qing Shuai Cao Yang Zhao, Ru Zhang [5] presented a comprehensive study of the buckling behaviour of various slenderness large circular steel silos with capacity of 40,000-60,000m3, which are subject to large eccentricity filling solid pressures. The buckling deformations of steel silos under large eccentricity filling are non-symmetrical, where the radial displacement in the eccentric side is much larger than that in the opposite side at the same depth. The geometrical nonlinearity is beneficial while material nonlinearity is strong and detrimental to buckling behaviour of example silos. The effect of weld imperfection is also harmful to buckling resistance of silo, which is more serious for relatively slender silos than squat silos. The buckling design of steel silos under large eccentricity filling is mainly governed by the nonuniform distribution of the solid pressure other than other influential factors as the weld imperfection, geometrical and material nonlinearity, compared with the load case of symmetrical filling.

A.J. Sadowski & J.M. Rotter [6] presented behaviour of five thin-walled cylindrical silos with step wise varying wall thickness and aspect ratios varying from very squat to very slender. In cylindrical silos under concentric discharge, axial compression in the silo wall is caused by friction between the wall and the stored granular solid. The compressive axial membrane stress resultant is cumulative with depth, so that the risk of buckling is substantially increased towards the base of the silo. Aspect ratio significantly influences the relative magnitudes and patterns of normal pressure (p_h) and frictional tractions (p_w) exerted by the stored granular solid on the silo wall.

Hazim Sharhan [8] investigate the stress concentrations at junctions of cylindrical-conical shell structures using the finite element method. The most significant behavior of the cylindrical-conical shell occurs at the junction between the two shell components. Due to the geometrical discontinuity at the junction, the structure undergoes an inward radial deflection which causes concentrations of compressive inplane circumferential stresses as well as meridional bending stresses.

Hamy H.A. Abdel-rahim, studied [10] 7 RC wheat silos with different ratio has been utilized and subjected to earthquake records considering the ensiling materials. The dynamic analysis concludes that the seismic response of silos is significantly affected by earthquake characteristics. The effect of the ground motion on the silos taking into the account the ensiling material has highly influence by the earthquake characteristic. In particular, it is found that the ensiling material may increase maximum pressure by 3 – 5 times the FE filling pressure in tall silos (h/d = 3 - 6). The maximum pressure occurs at the silo base. In silos characterized by squat geometrical configuration (h/d = 1 – 2) and in large diameter silo, vibration of ensiled material increases the silo wall pressure by two times the FE filling pressure without earthquake. The maximum occurs at 0.65h from the silo top. The silo top displacement time history provides pronounced significant responses due to strongly variation of displacement impulsations in the squat silos of small height and large diameter with ratio (h/d = 1 – 2) while, in tall silos having the same diameter the seismic load causes the extreme top displacement with small and quiet fluctuations due to the large mass of ensiled materials in tall silos. The pressure increase due to the ensiled wheat during the ground motion is considerable larger than that recommended discharging pressure resulting from multiply Janssen equations by some factors. Consequently, these dynamic pressures appear due to the ensiled materials govern the practical design of those silos. The actions provoked by the earthquake ground motion on the ensiled material led to remarkable increase in the normal, shear forces and bending moments on the supports the effect of ensiled material turns out to be noticeably in large diameter silos.

3. Numerical Study

The numerical study showed all the drafting research regarding aspect ratio, all the study parameters and all the inputs sources. Which has been described further above.

3.1. Model overview

Circular steel silos with capacity 150 m^3 referenced in practical engineering are used as illustrative examples in this paper, and the geometries of 6 silos examined are listed in Table 1. The examined silos are divided in three category of silos slenderness slender ($2.0 \leq \frac{h}{d} \leq 4.0$), Intermediate slender ($1.0 \leq \frac{h}{d} \leq 2.0$), Squat ($0.4 \leq \frac{h}{d} \leq 1.0$). Steel silos with Staging height is 3m and structure contains 8 no. of columns as ISMB 600. Also contains ring beam of size ISMB 100. Structure contains horizontal and vertical stiffeners of size 65*65*6 mm for preventing plate from local buckling. For finding effect of horizontal and vertical pressure on structure, we consider two types of material i.e. cement and wheat.

Table1. Geometrical properties of the considered silos

Specimens	Material and capacity (m^3)	Density of Material (KN/m^3)	Opening (mm)	Angle of Friction	Height m	Diameter m	Thickness of shell (mm)
Aspect ratio 3	Cement (150)	15.50	1500	25°	12	4	8
Aspect ratio 1.8			1500		8.6	4.7	8
Aspect ratio 0.9			1500		5.6	6	8
Aspect ratio 3	Wheat (150)	8.50	1500	28°	12	4	8
Aspect ratio 1.8			1500		8.6	4.7	8
Aspect ratio 0.9			1500		5.6	6	8

3.2 Material property data

Silos are model in SAP2000 software, with structure are considered to be fixed at their support with eight no of column, the general structure of the wall, the bottom of the hopper and the column are connected by a ring beam for load distribution. Steel silos consider as thin shell element of 8 mm thickness and grade of steel is 345 F_y. For seismic analysis we consider Zone V, Medium soil.

3.3 Material Pressure

Stored material inside the silos exerts pressure on the sidewalls. During Seismic excitation pressure exerted by stored material increases. We evaluated two different kinds of materials to determine the impact of material pressure on a structure. Due to complex behavior of stored material, it becomes even more complex to analyze the response, also the interaction between the stored material and silo wall is nonlinear. Obtaining zero dynamic material pressure values along a greater depth of the silo from top surface of the silo for the considered height wise distribution of dynamic material pressure.

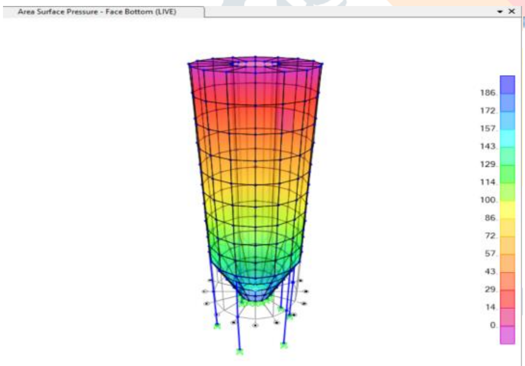

Fig 2 (a)

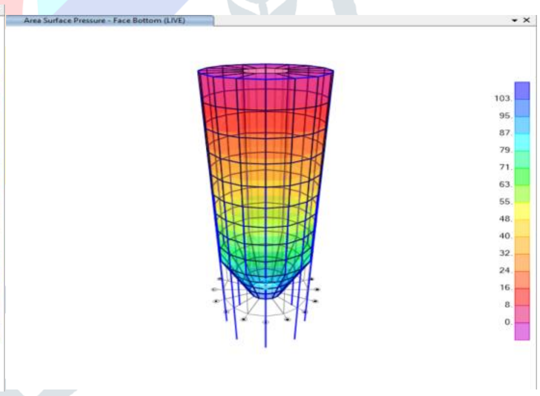

Fig 2 (b)

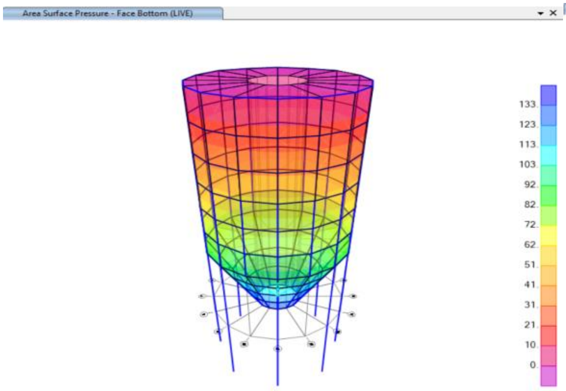

Fig 2 (c)

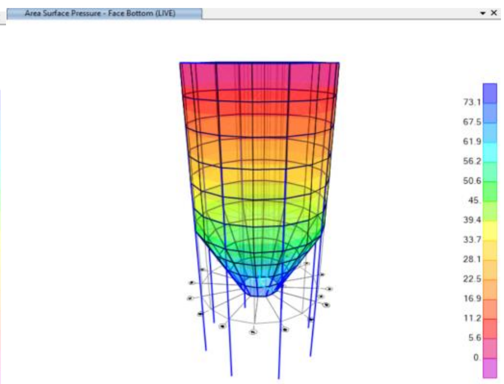

Fig 2 (d)

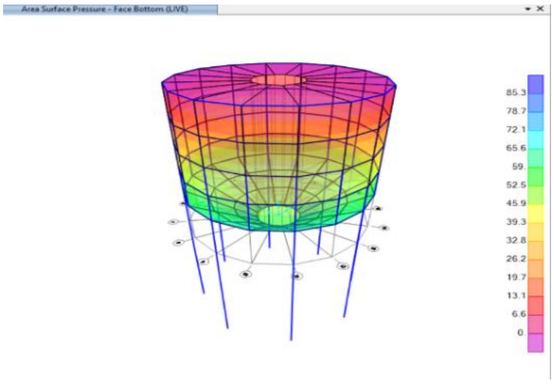

Fig 2 (e)

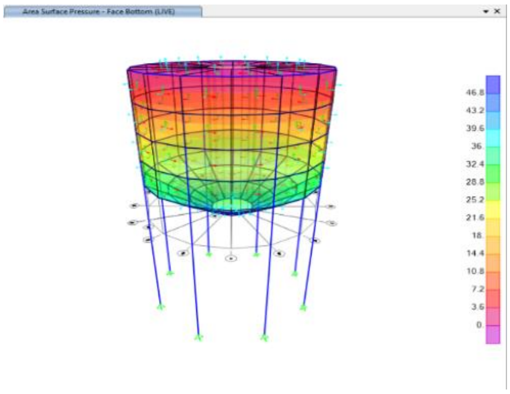

Fig 2 (f)

Area surface Pressure distribution for different aspect ratio and material
Fig 2 (a) for aspect ratio 3- cement, Fig 2 (b) for aspect ratio 3- wheat,
Fig 2 (c) for aspect ratio 1.8- cement, Fig 2 (d) for aspect ratio 1.8- wheat,
Fig 2 (e) for aspect ratio 0.9- cement, Fig 2 (f) for aspect ratio 0.9- wheat

3.4 Dynamic Time history Analysis

The dynamic time history preferred for analysis, as existing structures have similarities and output refers to displacement and base shears. For Time History Analysis Bhuj Earthquake data used shown in Fig 3.

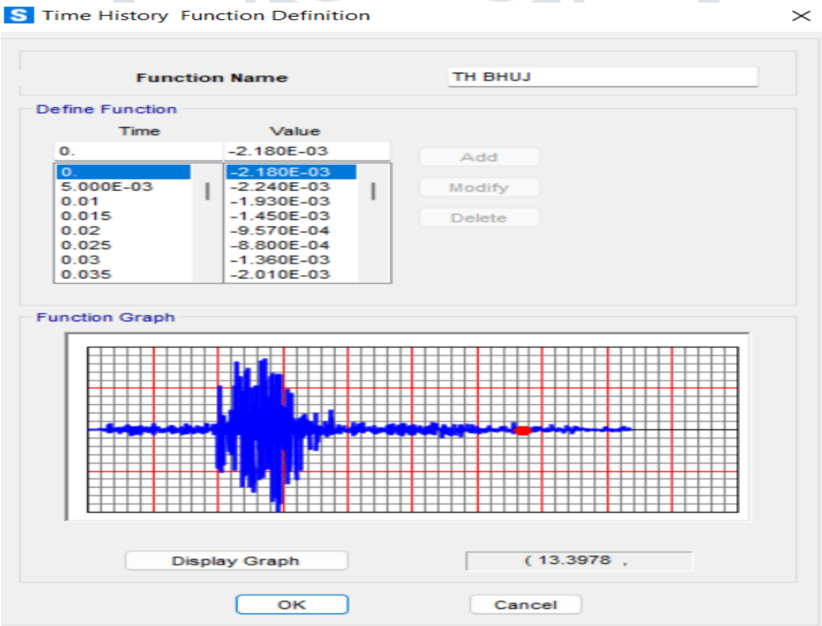

Fig. 3 Graph obtained from Bhuj time history data

4.Results of Analysis and Discussion

Slenderness, defined as the height/diameter ratio, can have major effect on the seismic behavior of silos. Taking into consideration the evaluation of silos in the technical literature of three main classes, squat, intermediate slender & slender, this study analyzes three different aspect ratios. Results shows that slenderness also affects the dominant modes of the silo wall in addition to the behavior of the bulk material. The behavior of the system is also affected by the geometry of the silo, the mechanical properties of the stored material and the silo wall. Therefore, in addition to the interaction between the bulk material and the silos wall, material pressure on the silo wall and the effects on the silo bottom may show significant changes based on the slenderness. In order to examine the effect of slenderness on seismic behavior, obtained results are discussed parametrically in terms of horizontal displacement, equivalent base shear force and the overturning moment in the following sections.

4.1. Horizontal Displacement

The obtained peak values of lateral displacement of the wall in the earthquake direction for three different aspect ratios are presented in Table 2. The deflection of the three silos is compared, it can be analyzed the slender silos gives more deflection as compared to Intermediate and squat silos.

Aspect ratio	Displacement in Cement (mm)	Displacement in Wheat (mm)
3	112.97	148.28
1.8	79.69	87.23
0.9	42.84	61.36

Table 2. Variation of displacement

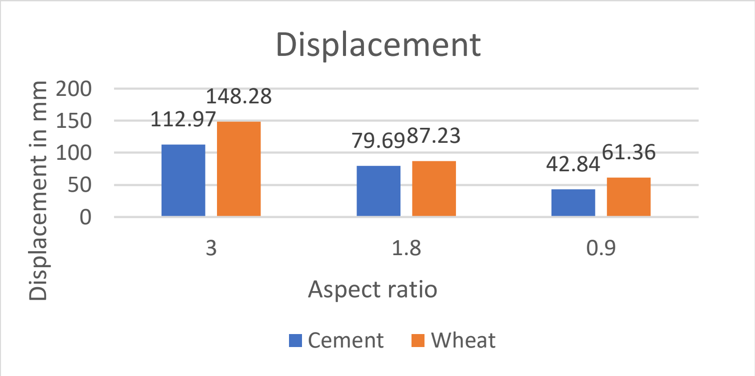

Fig. 4 Variation of displacement in cement and wheat

4.2. Base shear forces

The obtained peak values and their occurrence instants for the maximum base shear are given in Table 3. It is clear that the mass increases with the increasing silos height and accordingly it is normal to expect an increase in base shear force. From below we can conclude that slender silos gives maximum base shear at bottom. Base shear increases up to 18-25% due to material densities. Depending on densities of the given material the frictional force developed varies. Higher the density more will be the frictional force offered. Due to this reason the base shear will be more for structure holding material with higher density.

Aspect Ratio	Base Shear for Cement (kN)	Base shear for Wheat (kN)
3	1371.279	1133.323
1.8	1261.118	1052.166
0.9	1187.695	896.23

Table 3. Variation of Base shear

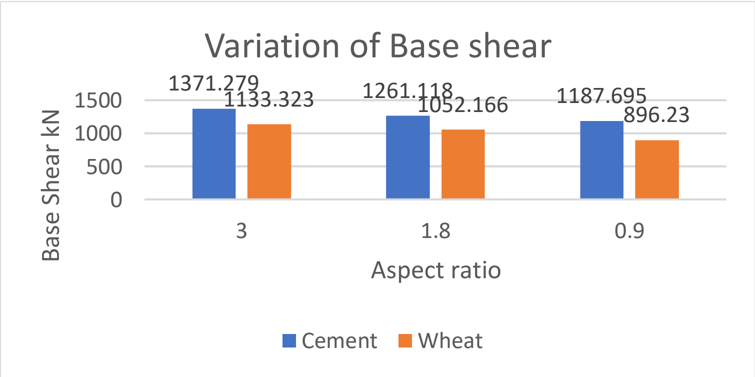

Fig. 5 Variation of Base Shear in cement and wheat

4.3. Overturning moments

The deviation of maximum equivalent overturning moments obtained for three aspect ratios of the silo wall are given in Table 4. Similar overturning moment responses obtained with the base shear force responses. Due to Earthquake lateral load induces increasing in bending moment results into non- uniform pressure at bottom of silo which increase as compare to pressure due to gravity load.

Aspect ratio	Overturning moment for Cement (kN-m)	Overturning moment for Wheat (kN-m)
3	6989.56	3080.120
1.8	3314.02	3046.28
0.9	2019.87	1724.97

Table 4. Variation of overturning moment

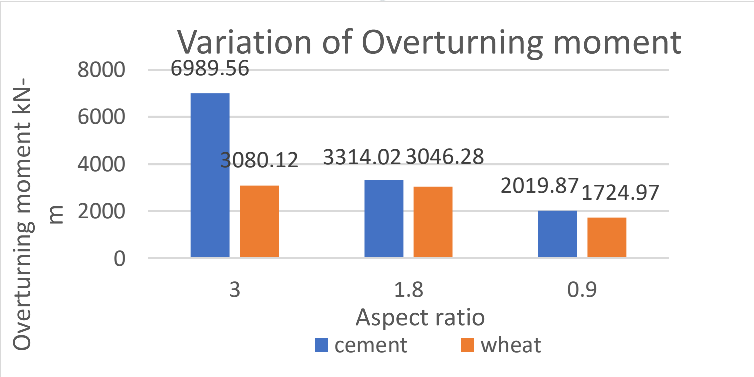

Fig 6 Variation of Overturning moment in cement and wheat

5. Conclusion

Seismic analysis on silos carried out to determine the seismic response of silos through non-linear time history data of Bhuj earthquake

1. The earthquake-induced ground motion on stored material caused a remarkable increase in shear forces and overturning moments on the supports. The effect of stored material is very important in large aspect ratios.
2. After analysing the desired system, it can be concluded that the slenderness may cause considerable effects on structure. Squat silos have less horizontal and vertical pressure as compared to intermediate slender and slender silos.
3. It can be concluded that, along the height of the silos the percentage of deformation increases. Although the thickness of the plate is considered uniform throughout the height of the silo.
4. Seismic weights of the material increased due to its varying densities & it has an effect over stress at the junction of wall and hopper section.
5. Results showed that displacement for squat silos are quite small and negligible for structural system. Slender silos had a great increase in these displacement as compared to squat silos and results in unserviceability of the structure.
6. Earthquake analysis showed that, the increase in lateral load increases the bending moment generated and results into non-uniform pressure at bottom of silo, which is more as compare to gravity load.
7. Base shear increased up to 18-25% due to the effect of material densities. So it has been concluded that the base shear depends upon the density of the material.
8. For aspect ratio 3 cement storing silos gives a greater overturning moment than wheat storing silos. Also, analysis showed that Squat silos give less overturning moment than intermediate slender & slender category silos.
9. The effect of geometrical non-linearity, material nonlinearity, and Dynamic pressure on steel silos are very complex and closely correlated with the slenderness of silo structures.

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