**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# EFFECT OF IMPACT AND SEISMIC LOADS ON CONCRETE SILO STRUCTURES

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**A B S T R A C T**

Silos are a unique structure that is subjected to a variety of peculiar load circumstances, resulting in distinctive failure mechanisms. Furthermore, silos are cantilever structures with material piled vertically quite high. The earthquake behavior of silos used to store bulk materials changes depending on whether they are raised or supported directly on the ground. The stored material exerts seismic stresses on the walls of various types of silos, which may be significantly greater than the pressures experienced during filling and discharge. The effect of impact and seismic stress on reinforced cement concrete (RCC) rectangular and circular silos is explored in this study. IS 4995 (Part-I): 1974 was used for silo loading calculations, while IS: 4995 (Part-II): 1974 was used for silo design requirements. For analysis of the circular and rectangular silos, the method of static equivalent is used. After designing the silos, it is again analyzed using the STAAD Pro software. Now the displacement, base shear, and base moment are obtained for the silo structure made of concrete.

***Keywords****: Silo, Seismic behavior, Base shear, Lateral displacement, STAAD Pro*

## 1. INTRODUCTION

At the time of construction of storage for grains, the first and foremost option in our mind is construction with the help of concrete. This material concrete proves to be a highly valuable since it gives very flexible design and construction solution that every sector needs while remaining within budgetary constraints. A silo, bin, or bunker is a bulk solids storage container. Although there is no one meaning for all of these names, they are commonly used to store coke, coal, crushed stone, gravel, ore, and other similar materials. Silos are tall buildings that are used to store grains and cement. The majority of companies utilized silos to store bulk materials in quantities ranging from a thousand to a few hundred tonnes. A silo is used to store bulk material in power plants, cement plants, gas plants, and many other small and large businesses where bulk material storage is required.

Vertical seismic loads have a little impact on relatively heavy silo structures; however, lateral loads can have a major impact, particularly on taller silo that stored material of heavy weight. The weight of the silo is mostly depends on the amount of the horizontal seismic force. With the increase in height of the silo centre of mass of silo also increased. The lever arm of laterally applied force and the developed moment due to bending at the foundation level rises if the seismic force (horizontal) is placed nearly near to center of the body. The additional bending moment causes a non-uniform pressure distribution at the silo's bottom, which can be substantially greater than the pressure induced by gravity loads. Earthquakes can potentially harm the top most section of these silos, when the material within the silo may vibrate during the earthquake.

If the material may oscillate, lateral loads due to material flow and lateral seismic loads must be evaluated simultaneously. The design of silos relies heavily on wall pressure. It has a significant impact on silos' safety and efficiency. Individual solid particles are encased in a continuous phase, generally gaseous, to form bulk solids. The interaction between these particles and the continuous phase is complicated, making a thorough and correct theoretical representation of the situation extremely challenging. The types of material held in the silos, as well as its qualities, are a determining element in their design. The bulk material density, frictional characteristics, and pattern of material flow all vary significantly, and the applied loads and load-caring mechanism in structures like silos differ significantly from those in other typical structures. Silos are constructed as a unique construction that follows the strength design process. Failures in storage containers and silos can occur for a variety of causes, including design flaws, construction flaws, usage flaws, and maintenance flaws.

The biggest failure in seismic failure is silo collapse, which occurs as a result of incorrect assumptions, analysis, and design. Consider a circular flat bottom silo that is symmetrical around its vertical axis and has RCC slabs at the top and bottom, with a tiny open able hole at the top for filling storage material. The storehouse partitions are frequently subjected to both normal weight and vertical frictional shear or footing caused by the material stored inside the storehouse. The qualities of the put away material determine the size and conveyance of both shear and regular weight over the height of the divider. Seismic load calculation considers the self-weight of the silo and the material stored in it as a lumped mass, and the seismic effect of this mass is factored into the silo wall design..

## 2. LITERATURE REVIEW

Bins, bunkers, silos, and tanks are common names for bulk solids storage containers. Although there is no universally recognized meaning for these terms, shallow buildings carrying coal, coke, ore, crushed stone, gravel, and other similar materials are commonly referred to as bins or bunkers, while towering structures containing grain and cement are sometimes referred to as silos (Li 1994). For the storage of commodities, the silo is essential in the agricultural, industrial, and military domains. People used to keep items in bins that were constructed by guesswork until the 1960s. Andrew W. Jenike's 1960s study laid the groundwork for the bin design. Traditional approaches' silos are insufficient owing to the implementation of simplistic solutions in complicated settings (Wojcik et al., 2003). Earthquakes frequently cause damage to silos and/or their collapse, causing not only huge financial losses but also fatalities. For example, after the 2001 earthquake in El Salvador, three people died as a consequence of a silo failure (Mendez 2001).

Determining the tasks acting on a structure is an important first step in the design process. Boxes and silos for bulk storage are no exception. Unfortunately, it is difficult to calculate and understand the loads of solids on the walls and interior of such buildings. As a result, silos and bunkers disintegrate much faster than other industrial equipment. Defecting a part can lead to deformation or deformation, which is unpleasant, but does not affect safety or operation. In some cases, failures lead to complete collapse of the structure, leading to discontinuation of use and death (Carson 2000). In the last 50 years, many attempts have been made to encode the inductive force of a solid acting on a silo wall. The German Standard DIN 1055 Part 6 "Design loads for buildings: Loads in silo bins" was established through rigorous testing by the researchers (Pieper et al., 1964), who published the first code to offer useful instructions to design engineers estimating silo loads. This standard was initially published in 1964, and it has been considerably altered and republished twice since then, in 1987 and 2005.

Ayuga et al., (2005) worked experimentally in a silo with a cylindrical diameter of 1.9 m and a height of 5 m from a vertical wall designed with three different eccentricities. The walls are made of flat steel and sufficient thickness and rigidity are taken into account. These silos are equipped with sensors specially designed to measure lateral pressure and friction between the wall and the bulk material. A horizontal pressure cell uses four extensometers to measure the deformation of a round sheet, and a friction force sensor measures the deformation of a small cantilever beam with two extensometers.

Song (2004) studied the structural behavior of circular steel silos under loading patches. Studies have shown that linear elastic analysis (LA) has a significant effect on the state of stress of a silo. Nonlinear and initial pressures have beneficial effects. The Fourier attenuation of a two-square patch load shows that the effect of the patch load shape depends not only on the harmonic index, but also on the specific voltage component. For low voltages with harmonic indices (eg cos h, cos 2h), only limited effects were observed for all voltage components. The pressure of the intermediate harmonic indices (cos4h, cos6h) has a great influence on the compression stress, and the harmonic index is high. The effect was significant for von Mises equivalent stress. Analysis of nonlinear and nonlinear bending of materials shows that the effect of patch loading can be offset by a certain percentage increase in normal friction, provided that the approximation of patch loading is sufficient to represent wall pressure in a circular plane silo.

Eccentric loading causes higher chances of silo failures compared to other types of loading conditions, and this is a kind of first report in this area to address this issue rationally, based on a basic model presented by various researchers (Rotter 1986, 2001). Some of the complexity arises due to different methodologies adopted by different researchers, this can be treated using action assessment class (AAC), in association with patch loads. Many applications require knowledge of the pressures happening in silos and other types of containers packed with powders or bulk materials (Schulze 2021):

- Structural design of silo
- Design of silo for flow
- Load acting on inserts as well as feeders
- Feeders driving force
- Silo design where the stress does not exceed permissible stress

**Table 2.1: Geometrical data and material properties of deep silos (Sun et al., 2018)**

| References | Model materials | Dia D (mm) | Height H (mm) | H/D | Bulk solids | ϒ (kN/m3) | µ | φ (°) |
|---|---|---|---|---|---|---|---|---|
| Liu and Hao (1995) | Plexiglass | 300 | 600 | 2.0 | Coal | 10 | 0.45 | 33.0 |
| | | | | | Wheat | 08 | 0.40 | 28.0 |
| | | | | | Dry sand | 16 | 0.43 | 32.5 |
| Zhang et al. (2017) | Plexiglass | 500 | 1200 | 2.4 | Standard sand | 17.4 | 0.43 | 31.1 |
| Ruiz et al. (2012) | Stainless steel | 1000 | 2000 | 2.0 | Wheat | 8.38 | 0.2 | 34.22 |
| Munch-Andersen et al. (1992) | Epoxy | 700 | 5000 | 7.14 | Dry sand | 15 | 0.67 | 40 |

Wind and earthquake loads, stress owing to temperature differences, possible expansion of the material stored, and foundation settlement must all be addressed throughout the design phase (Dogangun et al., 2009). The four codes mainly used to design silos and bunkers are compared by the researcher (Chitra and Indupriya, 2016). The codes are: IS 4995 (1974), British Standard BS EN 1991-4 (2006), German Standard DIN 1055-6 (2005-03), and American Concrete Institute ACI 313-97.

**Table 2.2: Geometrical data and material properties of squat silos (Sun et al., 2018)**

| References | Test location | Silo number | *h* (m) | Pile type | Bulk solids | *D* (m) | *φ* (°) | *δ* (°) | *c* (kN/m3) |
|---|---|---|---|---|---|---|---|---|---|
| Yuan (2004) | Xuzhou National Grain Reserve | No. 4 | 13.43 | Cone | Wheat | 15 | 25 | 21.8 | 7.88 |
| | | No. 4 | 13.71 | Flat | | | | | |
| | | No. 7 | 9.93 | Cone | | | | | |
| | | No. 7 | 13.77 | Flat | | | | | |
| | | No. 8 | 6.35 | Cone | | | | | |
| Chen (2006) | Henan National Grain Reserve | No. 4 | 7.30 | Cone | Wheat | 26 | 25 | 21.8 | 8.22 |

## 3. METHODOLOGY

The determination of loads is crucial in case of silo design. These structures are used for storing the wholesale commodities where the loads imposed by the storage items must be considered in accumulation to seismic and wind stresses. The design of the silo is governed by many laws and standards. Though a silo's analysis and design cannot be accomplished with only one code, the absence of interoperability amid the numerous codes makes it challenging for designers to create the silo. Minor changes in the analysis and design of the silo allow for the construction and operation of a safe and cost-effective silo. The density of the stored material and the internal friction angle are used to create the silo. The material creates lateral and vertical stresses in the silo wall. One of the final challenges many designers face is the precise assessment of tasks and the associated design of these structures.

When these storage buildings are subjected to lateral seismic stresses, they become increasingly friable. Significant progress has been made in the design of the Silos. The three components of an earthquake ground motion result in structural loads in the vertical and two horizontal directions. Vertical seismic loads have a little impact on relatively heavy silo structures; however, lateral loads can have a major impact, especially on taller silos storing heavier material. The weight of the silo is exactly proportional to the amount of the horizontal seismic force. As the height of the silo construction rises, so does the height of the silo's center of mass.

Earthquakes can potentially harm the upper section of the silo if the material within the silo can vibrate during the earthquake. If the material may oscillate, lateral loads due to material flow and lateral seismic loads must be evaluated simultaneously. The design of silos relies heavily on wall pressure. It has a significant impact on silos' safety and efficiency. Individual solid particles are encased in a continuous phase, generally gaseous, to form bulk solids. Because the amount of the horizontal seismic load is exactly proportional to the weight of the silo, the effect of lateral loads can be considerable, especially on bigger silos carrying heavier material (Dogangun et al. 2009). The different methodologies which are carried out for the model development of silos are the calculation of load and, its analysis. All the aspects are taken in according to the Indian standard code procedures and different calculations and procedures that are done in this study are represented in a step-by-step representation, the following are the methodologies that are covered during this study.

- Model development
- Load calculations
- Load combinations
- Analysis Procedure

## 4. RESULTS AND DISCUSSION

While analyzing and designing of the square silo structure some manual calculation is carried out for the feeding of data to the STAAD Pro software. As per the Indian standard code of practice data is taken for calculation and result is obtained. After the calculation of wind intensity and seismic parameter these values are entered for the analysis purpose. Predefined sizes of the silo structure were used for which results are obtained in term of deflection, shear bending and design of elements. Most of the results are obtained using the software. Various results obtained by analysis and design of silo structure are shown with the help of figures. Support reaction on the structure is obtained from the STAAD Pro software (see figure 4.1). In this figure all the forces and moments in all three directions are shown. After analyzing and designing the silo using STAAD Pro these conclusions were drawn:

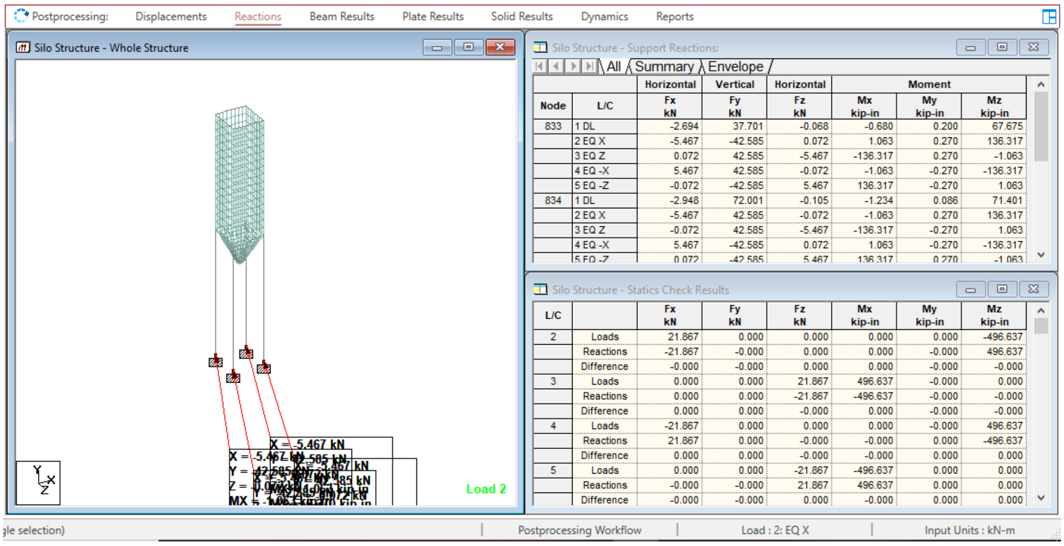


**Figure 4.1: Different values of support reaction obtained in x, y and z direction**

Maximum absolute stress value corresponding to both z and x direction obtained (see figure 4.2 and 4.3).

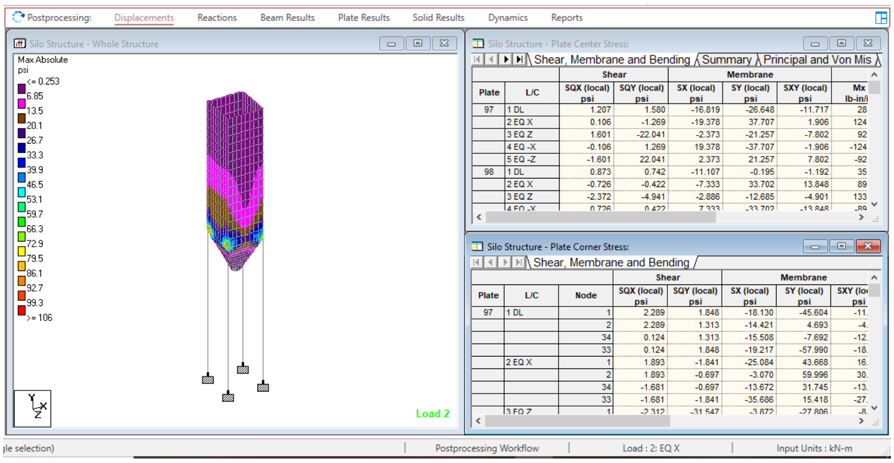


**Figure 4.2: Maximum absolute stress corresponding to z direction**

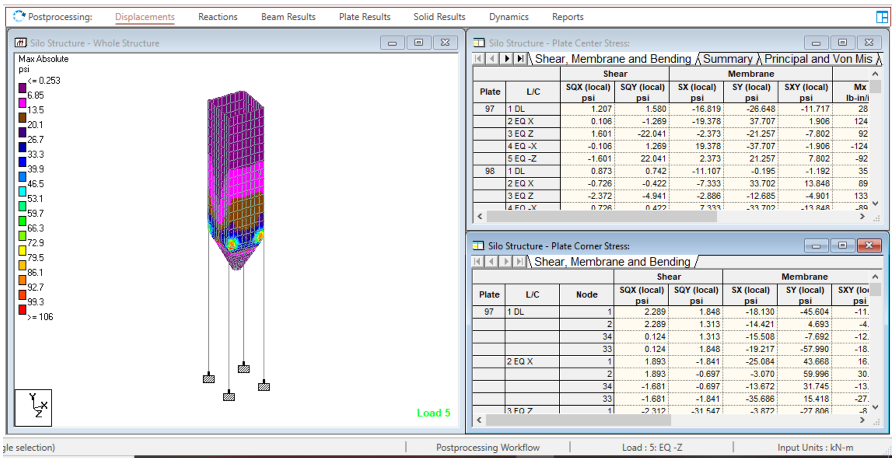

**Figure 4.3: Maximum absolute stress corresponding to x direction**

## 5. CONCLUSIONS

Many academics have researched various stresses operating on silo structures in an attempt to improve their performance. Soft stories, mass irregularities, and poor quality of building materials, bad construction procedures, soil, and foundation have all been identified as major causes of failure. Engineers require keenly observing the response of structures against various loads and loading combination so that the different structural parameter can be accurately examined and designing of structure can be done with the help of STAAD PRO software to the desired accuracy. After analyzing and designing the silo using STAAD Pro these conclusions were drawn:

- Movement of silo in addition to plate element are in good condition and it is lower than permissible value.
- As the height of the silo increases, the amount of deformation increases
- The analysis shows that the values of deflection at the windward side are very important in the middle half of the silo height.
- Lateral displacement increases with increasing mass and rigidity
- Silos supported by shear walls experience less lateral displacement than silos supported only by floating column.

**Acknowledgements:**

I express my deep sense of gratitude to my Supervisor, Head of the Department and Principal of our Institute for their cooperation in completing this work.

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