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ANALYSIS OF LOADS ON CONCRETE SILO STRUCTURE: A REVIEW

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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.

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.

The form of a silo structure might be round, square, or rectangular, and it can be raised or rest on the ground. Rectangular and square silos typically feature a single outlet with a pyramidal bottom, however, a trough bottom with a single elongated outlet or two or more circular or square outlets is occasionally utilized. A circular silo with a flat or conical bottom and a single exit is known as a silo. RCC and reinforced concrete may be utilized to create the silo. The three components of an earthquake ground motion result in formation of structural load that is acting horizontal and vertical directions. The significance of these storage structures has prompted numerous scholars throughout the world to suggest various load computation techniques and design considerations. For the design of silos and bunkers, the working stress method IS 5503-2 (1969) is the solely applicable guideline. Furthermore, several scholars presented various ways for calculating the loads of moving and stacking goods inside silos and bunkers. Silos can be constructed with the help of RCC or steel. These are mostly rectangular or cylindrical in design, though other shapes are also available that depends on types of material used and its storage capacity.

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..

The silos are divided into two categories: shallow bins and deep bins. The term "shallow bin" refers to a bin having relative dimensions are such that the plane of rupture contacts the grain surface before striking the other side. A shallow bin is an example of a squat silo. Tower silos, bunker silos, and bag silos are the three types of silos most often utilized today.

Tower silos: The structures of these silos are cylindrical and they are vertical. Air slides or augers are commonly used to unload grain, cement, and woodchips from tower silos. Unloading is done with rail cars, vehicles, and conveyors. Material stored in tower silos, also known as silos, is usually returned efficiently by weight, except for a few meters above the tip, which weighs less when unloaded. However, for stored commodities such as chopped wood, this might be a disadvantage. Tower silos range in size from 4 to 48 meters in diameter and 3 to 40 meters in height. Wood, steel, or concrete are used to build tower silos. Tower silos are the most prevalent type of silo. The unloading of cement, woodchips, or grain from silos is made easier by air slides or augers. Trucks, conveyor belts, and rail carriages can all be used to offload them.

Fig. 1 - Installed tower silos

Bunker Silos: These are long ditches that are normally surrounded by concrete walls and used to store silage or dry commodities. After the trench has been filled, it is packed using a plastic sheet so that it becomes sealed for air. Bunker silos are cost-effective due to their ease of construction and suitability for large operations. Tractors and loaders are used to fill and pack bunker silos, which are trenches. Concrete walls were used to create them. To keep the bunker silos airtight, a plastic cloth is placed over them. The materials may be unloaded from the bunker silos using a loader or tractor. Bunker silos are used in agriculture and major manufacturing companies to store massive quantities of commodities.

Fig. 2 - Pictorial views of bunker silos

Bag Silos: This is a huge cylindrical plastic bag that is filled with silage and then sealed on both ends. A tractor or a loader is used to unload the silos. The bag is frequently broken in portions while unloading, but if it is not destroyed, it can be salvaged and reused. Bag silos have the benefit of being affordable and are frequently employed as a provisional solution when in the condition of harvest or in growth or harvest; however, some farms utilize them all year. Grain and fodder are stored in bag silos. Plastic or hermetic bags or tubes are used to construct it. Bag silos range in size from 2 to 21 meters in diameter. The height of the silo is determined by the amount of material to be stored.

Fig. 3 - Bag Silos for Grain Storage

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 Wheat Dry sand	10 08 16	0.45 0.40 0.43	33.0 28.0 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 No. 4 No. 7 No. 7 No. 8	13.43 13.71 9.93 13.77 6.35	Cone Flat Cone Flat Cone	Wheat	15	25	21.8	7.88
Chen (2006)	Henan National Grain Reserve	No. 4	7.30	Cone	Wheat	26	25	21.8	8.22

Table 2.3: Comparison of four Codes (Chithra and Indupriya, 2016)

Different Codes	IS 4995 (1974)	ACI 313-97	DIN 1055-6 (2005-03)	BS EN 1991-4 (2006)
Materials stored	Granular & Powdery	Granular	Bulk material	Stored solids
Classification of silo	No	No	Based on slimness & wall thickness	Based on slenderness & wall thickness
Important Parameters	The angle of internal friction (φ), Bulk density (ρ), pressure ratio (λ), and the angle of wall friction (δ)	Bulk unit weight (γ), Friction coefficient (μ), and lateral pressure ratio (k)	Specific gravity (γ), angle of internal friction (ϕ), Friction coefficient (μ), and horizontal load ratio (k)	Friction coefficient (μ), bulk unit weight (γ), lateral pressure ratio (k), angle of internal friction (ϕ)
The numeric value of solid property	Directly given for each material	No values	Determine using test results and report as minimum and maximum value	Determine using test results and report as minimum and maximum value
Load at the time of filling and discharging	Horizontal, vertical, and frictional load	Horizontal, vertical, and frictional load	Symmetric and reference surface load	Symmetric and patch load

Load Computation based on	Material	Material	Silos	Silos
Limitations	No	No consideration due to the hotness of stored material	Geometric, materials, filling, and discharging arrangements	Geometric, materials, filling, and discharging arrangements
Classification of action assessment	No	No	Depends on the capacity of material stored	Depends on the capacity of material stored
The pattern of flow at the time of discharge	No	Asymmetric and concentric wall flow, mass flow and funnel hoppers	Mass flow, funnel flow, and mixed flow	Mass flow, pipe flow, and mixed flow
The shape of the hopper required for the design	All shapes	Conical and pyramidal hoppers	Conical and cuneiform hoppers	Conical and wedge-shaped hoppers
Consideration of Pressure zone	No	For calculation of wall pressure	No	No
Calculation of width of the crack	Check and limitations are given	Code provides calculation	As mentioned in the code	As mentioned in the code
Particle size	Any size	Any size	Should not be larger than 0.03 times dia of core	Should not be larger than 0.03 times dia of core
Detailing reinforcement in the design of column and foundation	Mentioned	Mentioned	No	No

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. 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.

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