Examine Material Flow Patterns and Pressure Distribution on Silo Structure

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Abstract

The design of silos requires accurate pressure calculation for structural stability and safety. Janssen's Theory is the preferred method in most cases due to its consideration of wall friction, while Airy's Theory provides a simplified approach useful for deep silos. The choice of method depends on silo geometry, stored material properties, and required precision in design. Structures used for storing bulk solids are referred to as bins, bunkers, silos, or tanks. While there is no universally accepted definition for these terms, shallow structures holding materials like coal, crushed stone, and gravel are commonly called bins or bunkers, whereas tall structures storing substances such as grain, cement, and wheat are typically known as silos. Elevated silos generally feature a conical roof, a cylindrical shell, and a conical hopper, and they can be supported by frames or reinforced concrete columns. Circular silos, made of either steel or reinforced concrete, are widely used across various industries, including cement plants (for clinkers), power plants (for raw coal), and the oil and gas sector (for sulfur pellets). The performance of elevated steel and reinforced concrete circular silos during earthquakes varies; reinforced concrete silos gain stability with the inclusion of shear walls, while steel silos improve their earthquake resistance when steel panels are added on opposite sides. The use of shear walls reduces structural displacement and enhances stiffness. This study presents the calculations for loads, load combinations, load assignments, earthquake parameters, and their analysis. The results are displayed and compared across different models, with maximum absolute and shear stresses represented through contour diagrams, tables, and graphs. Additionally, the minimum reinforcement requirements for beams and columns are specified.

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Key Words:- Dead load, Live load, and Seismic loads, Staad Pro, silo construction, Airy's Theory, Janssen's Theory

Introduction

The basic shape of a silo is circular; however, depending on requirements, it can also be square, rectangular, or polygonal. Silos are equipped with a roof and a bottom, which may be conical, pyramidal, or flat. They are typically supported by multiple columns, with the structure's wall, hopper bottom, and columns interconnected by a ring beam to evenly distribute the load. A silo is designed to withstand both vertical and horizontal pressure. These storage structures are commonly used in industries such as cement manufacturing and power plants. In thermal power plants, silos must be capable of storing high-temperature ash. Compared to steel silos, RCC silos offer superior performance due to their ease of construction and maintenance.

This synopsis focuses on the design and analysis of an RCC fly ash silo for a thermal power plant, covering the sequence of plan preparation, load and load combination calculations, structural analysis using STAAD PRO, and design as per Indian Standards. According to IS 4995 (Part I): 1974, a height-to-diameter ratio of at least two helps reduce lateral pressure over greater heights. Accurately calculating pressure is challenging due to various factors affecting the material during filling and emptying. Several loads act on the silo structure, and during the design process, these loads are considered based on the silo's intended use, size, structural type, material, design life, and environmental conditions to ensure safety and functionality.

IS 4995 (Part I): 1974 recommends two methods for calculating silo loads—Janssen's Theory and Airy's Theory. Silos are tall structures with a height significantly greater than their lateral dimensions. Their design is primarily based on the density and internal friction angle of the stored material. The walls of silos experience both lateral and vertical pressure due to the stored materials. Accurately estimating these forces and designing silos accordingly remains a major challenge for many engineers. These storage structures become particularly vulnerable when subjected to lateral earthquake forces, and their failure is often brittle and catastrophic.

Considerable research has been conducted on silo design, with most studies focusing on specific components using analytical and numerical methods. Ding Hua and Japing [3] investigated the lateral pressure on reinforced concrete silo walls and discussed methods for calculating both static and dynamic pressure caused by the integral flow of granular material during discharge. Zhen and Jin [4] analyzed hoop stress in deep reinforced concrete silos, finding that its absolute value at the same height increases with a higher height-to-diameter ratio but decreases with increased wall thickness. Kian and Bake [5] explored the use of fibrocement in constructing squat grain silos, concluding that fibrocement could replace steel due to its economic and structural advantages.

Due to their significant height and volume, silos are highly susceptible to earthquake damage. If not properly designed, seismic forces can lead to structural damage or even complete collapse. For instance, during the 2001 El Salvador earthquake, a silo failure resulted in three fatalities [6]. The design of silos is typically carried out using two main methods.

Literature Review

Prajakta B Pingale et al (2024) analyzing how different aspect ratios impact the structural behavior of circular silos made of reinforced cement concrete (RCC)**.** The study follows Indian Standard (IS) 4995:1974 (Part I **and II)** to determine the loading conditions and design parameters, **and** IS 456:2000 for RCC design. The modeling and structural analysis will be conducted using STAAD Pro software. Below is a detailed breakdown of the study. The present research examines how the different aspect ratio affects the circular silos made of reinforced cement concrete. The load intensity and structural dimensions are determined using IS 4995:1974 part I and part II. IS: 4995 (Part-I): 1974 will be used to compute the silo loading in accordance with Janssen's theory, and IS: 4995 (Part-II): 1974 will be used for determining the silo design requirements. Also, IS 456:2000 for RCC design is going to be use. The silo's construction will be modeled and analyzed using STAAD pro software. Three models will be created of three different aspect ratios in the STAAD pro. The top and bottom principal stresses, absolute stresses, shear stresses, moments in X, Y and XY direction, will obtain for circular silos of different aspect ratio. The literature reviews on silos were used as the basis for this report.

Sajid Rahman et al (2023) Tanks, silos, bunkers, and bins are structures designed for storing bulk solids. There is no universal term for these buildings; towering structures used for storing materials like coal, wheat, and cement are referred to as silos, whereas shallow storage buildings for coal, gravel, crushed stone, and similar materials are called bins or bunkers. Elevated silos can be supported by reinforced concrete frames or columns. These silos typically consist of a cylindrical shell, a conical hopper, and a conical roof. Various industries, including cement, power, and oil and gas sectors (where sulfur pellets are stored), as well as cement plants (which store clinkers), utilize circular silos made of steel or reinforced concrete for material storage. The seismic performance of elevated steel and reinforced concrete circular silos highlights their behavior during earthquakes; reinforced concrete silos gain stability through shear walls, while steel silos achieve stability with steel panels on the opposite side. The inclusion of shear wall panels reduces movement and increases stiffness. This study documents the load calculations, load combinations, load assignments, seismic parameters, and analysis, along with findings that have been presented and compared. Model outputs are displayed, including the minimum required values for beams and columns. Contour diagrams, tables, and graphs illustrate the maximum absolute stresses and maximum shear stresses for each model.

Methodology

This study follows a structured approach for model development, load calculations, and structural analysis, adhering to the guidelines of Indian Standard (IS) codes. The various methodologies employed are systematically represented step by step. The key aspects covered in this study include:

Model Development

- ❖ Creation of structural models using appropriate software tools.
- ❖ Consideration of material properties, dimensions, and reinforcement details.

Load Calculations

- ❖ Estimation of dead loads, live loads, wind loads, and seismic loads based on IS code provisions.
- ❖ Calculation of self-weight, imposed loads, and other relevant forces acting on the structure.

Load Combinations

- ❖ Application of different load combinations as per IS 875 (Part 5) and IS 1893 for seismic considerations.
- ❖ Consideration of safety factors and worst-case scenarios for structural stability.

Analysis Procedure

- ❖ Structural analysis using Finite Element Method (FEM) or other analytical approaches.
- ❖ Evaluation of stress distribution, deflections, and failure criteria under various loading conditions.
- ❖ Comparison of results for different structural configurations.

Results and Discussion

A contour stress diagram is a graphical representation of stress distribution in a structure. It uses color gradients or contour lines to indicate variations in stress levels across a component or structure. The maximum absolute stresses (both tensile and compressive) are typically highlighted in these diagrams. Contour stress diagrams provide a visual and numerical representation of stress distribution in a structure under critical loading conditions. They help engineers in failure prediction, design optimization, and safety assessment, making them a crucial tool in structural analysis.

Table 1. Maximum absolute stresses

Model	Maximum absolute stresses N/mm2
Base Model D7-H20	1.02
Base Model D7-H25	1.29
Base Model D7-H30	1.57

Conclusion

Our project focuses on designing RCC silos for seismic zones using STAAD Pro, analyzing their behavior under seismic forces, and optimizing material usage. Here are a few suggestions to enhance your study:

Seismic Analysis: Since you are using the Equivalent Lateral Force Method, you may also compare it with Response Spectrum Analysis for better accuracy in dynamic response.

Material Optimization: Consider advanced concrete grades and reinforcement techniques to further minimize material usage while maintaining structural integrity.

Comparison of Seismic Zones: Highlight how different seismic intensities impact the structural performance of silos, including lateral deflection, stress distribution, and base shear.

Graphical Representation: Use 3D modeling and stress contour analysis in STAAD Pro to provide a clearer visualization of structural performance.

Foundation Design: Since silos are heavy structures, detailing the foundation design based on soil type would be crucial.

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