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A Review on the behavior of Concrete Structure Under Various Loads Conditions

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ABSTRACT

Design's efficiency and stability are evaluated. The study provides insights into how different seismic zones affect RCC silo behavior, ensuring that the structure can withstand seismic forces while maintaining structural integrity. Various load combinations, including dead load, live load, and seismic loads, are considered to determine the most critical conditions. The project aims to enhance the understanding of RCC silo design by optimizing structural parameters through analytical modeling in Staad Pro. By comparing different models, we assess their response to seismic activity, helping engineers make informed decisions for safe and efficient silo construction. The findings contribute to the development of more resilient storage solutions in industrial applications..

Key Words:- Dead load, Live load, and Seismic loads, Staad Pro, silo construction

Introduction

Grains, cement, fly ash, coal, and other powdered or granular substances. The demand for silos has increased significantly due to industrial advancements and the growing need for efficient storage solutions in various sectors. With the rapid industrialization and the push for modernization in sectors like agriculture, cement, and steel, the role of silos will continue to expand. Innovations such as smart silos equipped with IoT-based monitoring systems are gaining traction, ensuring efficient storage and management of bulk materials. Structural and Functional Considerations. These are commonly used in industries where durability, easy maintenance, and quick installation are key factors. They are suitable for storing cement, fly ash, and grains. Made from reinforced cement concrete, these silos provide higher durability and resistance to environmental factors. They are often used in large-scale storage applications like cement plants and bulk material handling facilities.

Loading and Unloading Mechanism: Silos must be designed to ensure smooth material flow, preventing blockages and segregation.

Aeration and Ventilation: Proper aeration systems help maintain material quality by preventing moisture accumulation.

Structural Stability: The choice between deep and shallow silos depends on the material type, storage capacity, and site conditions.

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.

Weiwei Sun et al. (2021) highlight the crucial role of high-blending-efficiency central cone silos in the cement manufacturing process. Through a multi-scale experimental study, they conducted filling and discharge tests on central cone silos with different aspect ratios to examine material flow patterns and pressure distribution on both the wall and cone. Their findings indicate that the central cone significantly influences pressure distribution within its height range, where wall pressure initially peaks before gradually decreasing, while cone pressure steadily reduces with increasing depth. As aspect ratios increase, the overpressure factors of both the wall and cone slightly decline. The discharge modes have minimal impact on the wall's maximum overpressure factors, whereas the cone's maximum overpressure factors vary notably depending on the discharge method. The pressure on the upper section and cone can be reliably estimated using the factors k1 and k2.

Evgeny Rabinovich et al. (2021) presented a new design process and a parametric study for wedge-shaped (planar) silos. Their research includes updated experimental findings and analyses of parameter influences. The study revealed that the mass–funnel flow boundaries remain largely unaffected by the roughness of the bin sidewall. Additionally, recent findings suggest that mass flow can still occur even with highly rough hopper walls; however, in such cases, a layer of stagnant material forms along the hopper walls. Finally, a new approach to planar silo design was proposed, which can significantly enhance process efficiency by helping silo operators and designers improve the accuracy and flexibility of granular flow regime assessments.

Changnv Zeng et al. (2020) investigated the dynamic behavior of multi-story, base-isolated buildings with significant plan irregularity. In this study, high-damping rubber bearing isolators were used in conjunction with friction slider isolators. The research utilized a nonlinear dynamic analysis (NLDA) and a response spectrum linear dynamic analysis (RS) to assess the performance of the base-isolated structure. Compared to NLDA, the RS approach was found to be less conservative regarding displacements. Given the implementation of the new Italian seismic code (NTC 2018), this comparative study holds particular significance in evaluating both displacements and stresses.

Weiwei Sun et al. (2020) conducted research to investigate the purpose of filling and discharge tests in assessing pressure distribution and overpressure evolution on the walls and channels of both full-scale and reduced-scale squat silos with aboveground conveying channels. The filling experiments revealed that the channel significantly influences the pressure distribution at the wall bottom. While Jaky's calculation tends to overestimate the lateral pressure on the wall, Rankin's active earth pressure equation offers a more accurate approximation. The filling pressure on the channel wall is linked to the height of the stored materials due to the repose cone. It is crucial to consider the balance between the wall friction equilibrium effect and the arch effect of the channel in squat silos. Findings from the discharge experiments indicate that the overpressure coefficient remains unchanged as discharge eccentricity increases. Additionally, the aspect ratio has a considerable impact on the overpressure coefficient. Multi-scale discharge testing demonstrates the presence of overpressure on the channel's side and upper walls. Therefore, it is advised that the discharge load calculation takes the channel's overpressure coefficient into account.

Akshita Meshram et al (2019) RCC Silos are used by a spacious range of industries to store bulk solids in quantities ranging from a few tones to hundreds or thousands of tones. The term silo includes all forms of particulate solids storage structure that might otherwise be referred to as a bin, hopper, grain tank or bunker. Silos are very demanding in cement industries. Hence RCC silos are widely used for storage of granular materials as they are an ideal structural material for the building of permanent bulk-storage facilities for dry granular like fillings. Initially concrete storage units are economical in design and reasonable in cost. Concrete can offer the protection to the stored materials, requires little maintenance, is aesthetically pleasing, and is relatively free of certain structural hazards such as buckling or denting. In this project, we are designing the RCC silo situated in all seismic zones with the help of structural software Stead Pro. The design concept include, providing all dimensions of structural component based on trial and error method. The Analysis of silo, using Equivalent lateral force method and study the performance of structure located in all seismic regions in term of Comparison of different models of concrete silo for earthquake such as nodal displacement, stress and vertical or horizontal pressure on walls etc. The Presentation of the results is in tabular and graphical look. This method is carried out for volume of 180 m3. All the designs have been based on the recommendations of I.S 4995 -1974 (part 1&2) and I.S 456 – 2000 codes, Based on these designs, that dimension of silos shows least amount of concrete and steel. These findings will be useful for the designers of silos.

Lakshmi E. Jayachandran et al. (2019) emphasize the necessity of thoroughly understanding the loads and structural behavior of silos. Limited research has been conducted on the effects of stored grains on silos. This study focuses on storing rough rice in a flat-bottomed, farm-level bamboo-reinforced concrete (BRC) silo. A full-scale 3D finite element (FE) model of the BRC silo was developed, and ANSYS software was used to simulate the progressive grain filling process. The interactions between the silo structure and stored grain were modeled with minimal simplifications while accounting for the unique properties of both rough rice and the BRC. The study provides an in-depth analysis of the factors influencing stress variations and predicts stress distribution in small to medium-sized farm silos, highlighting the complexities of FEM and the variations in analytical outcomes.

J.M. Rotter et al. (2019) conducted research on the stress regime within stored solids in squat and intermediate aspect ratio silos, utilizing a finite element model to predict filling pressures in rectangular silos with flexible walls, which was experimentally validated. The model estimates the pressures exerted on the flexible walls of the silo and the level of tension within the stored solid. At the end of the filling process, the non-uniform horizontal pressure distributions at each depth are analyzed. Computational predictions were found to closely align with an empirical relationship for horizontal pressure variation on each straight wall, derived from previous experimental measurements. The coefficients of this relationship depend on the relative stiffness of both the silo walls and the stored solid, varying with depth below the stored solid surface. After conducting multiple computations involving different solids, an empirical relationship suitable for practical design was established for a range of stored materials with known relevant properties. The resulting expression provides a silo design pressure recommendation based on theoretical rather than empirical findings, making it well-suited for determining filling pressures in rectangular silos.

Lydia Matiaskova et al (2019) this study emphasizes the importance of thermal loading in high-temperature silos and how it affects the design of structurally required reinforcement. This is carried out using a summary of background data to ascertain thermal loads based on the summary of the literature and additionally, by using specialized analysis to look at thermal load actions in a case study of a concrete silo used to store bulk cement. They concluded that in silos where the high-temperature cement or clinker is added to the structure, there may be considerable temperature gradients. Calculating the associated temperature gradients, as well as the ensuing internal forces and moments, is required in such situations. Adding reinforcement to the layer closest to the cooler face will help it withstand thermal bending forces. It is possible for the horizontal reinforcement near the top of the silo to endure temperature loads more than the reinforcement intended to bear structural loads

C. Bywalski et al (2019) Researcher talks about how the over-chamber reinforced concrete ceiling of a cylindrical silo used to store extracted rapeseed meal failed. The collapse was caused by the material column moving down and an arch that had developed in the chamber giving way. Researcher demonstrated that the significant exceedance of the major reinforced concrete beams' bending load capability was the primary cause of the breakdown of the over-chamber roof of the cylindrical silo used to store extracted rapeseed meal. Incorrect design and improper use were the secondary reasons. Researcher introduced the silo usage manual provided rules that should be properly followed in order to minimize the possibility of arching above the insert or above the junction between the chamber walls and the funnel. To avoid the creation of arching, it is also important to utilize solutions that assist the flow of material.

Zhen Chen et al. (2018) investigated the construction of large-diameter reinforced concrete silos designed for coal storage in compliance with environmental protection regulations. This study presents an experimental analysis and 3D FEM modeling of a reinforced concrete silo with a diameter of 136.5 m and a height of 19.35 m, addressing the limited literature on the effects of temperature patterns. Vibrating string strain gauges were employed to monitor strains in the circumferential and vertical steel bars under varying temperature conditions influenced by sunlight exposure and seasonal changes. Data were collected over a period exceeding a thousand days and transmitted via GPRS. Meanwhile, the Drucker-Prager elasto-plastic criterion and the elasto-plastic damage model were incorporated into an ABAQUS-based finite element model to account for the nonlinear behavior of both soil and reinforced concrete. The numerical simulation results closely aligned with the experimental data, allowing for a detailed assessment of temperature fluctuations on the silo wall. The study's findings provide a crucial reference for the design of large-scale silos.

Marek Maj (2017) the researcher finds the mechanisms of the failure of silo walls as well as the reasons why reinforced concrete silos fail. One of the most crucial factors to consider during the silo's design, building, and operation phases is the durability of its cracked walls. Temperature, stored material pressure, live loads, moisture, the impact of building joints, thermal insulation, an active environment with chemicals, and so on are some of the causes of both horizontal and vertical fractures. Researcher concluded that, a structure cannot be designed such that all of its components lose reliability at once. Periodic repairs are required for all structures in order to restore the designed resistance. However economic and technological aspect decides about the repair. During the initiate construction design process should be consider and indicate the places with maintaining the durability of materials It should be condition to avoid mechanisms of destruction serial system. It should be to provide to avoid connection of reinforcement rods in a one line or row.

Alberto Tascón et al (2017) in certain design scenarios, dust explosions are included as an unintended action for load combinations in the "Eurocode 1 - Actions on structures - Part 4: Silos and tanks" EN 1991- 4. The most popular technique for lessening the consequences of explosions is venting. The structural design of the silo and the development of internal overpressures in the event of an explosion will be determined by the area size of the venting devices installed in the silo. In this study, a variety of situations, including varying silo diameters, materials (barley and wheat flour), and venting device activation pressure and inertia values, have been calculated to examine the DIN-Report 140. Lightweight concrete slabs, explosive doors, and exploding panels are the three types of venting devices that have been investigated. The study's results show significant disparities between the three techniques examined. There have been identified and addressed limits and uncertainties with DIN-Report 140. The ultimate objectives of this research are to offer recommendations for calculating explosive loads and to aid in the creation of a single, standard procedure for silo venting.

Qing-shuai Cao et al (2017) this paper proposes and discusses a new kind of silo structure called the cellular silo. The clustered construction of individual hexagon silos, which may be constructed by varying the number and layout of cell silos, is the performance advantage of the cellular silo. First, the structural system for the cell silo is established by comparing the plate model with the 3D-stiffened plate models. It is demonstrated that the 3D-stiffened plate Assembly, which is quite different from the shell structure fit for circular silos, is feasible for the cell silo and consists of shell elements and beam elements. While the horizontal solid pressure helps circular silos buckle, it hinders cell silos, and it is the horizontal pressure that primarily determines buckling design instead of the vertical frictional pressure. By taking into account load scenarios that are determined by the quantity of operational cell silos and their placement within the group, the buckling behavior of group silos is examined. This summarizes the general characteristics of group silos during buckling and serves as a guide for the structural design of cellular silos. It is stated that the full loaded condition governs the buckling design of the cellular silo and that it can be finished by optimizing the individual cell silos and their combinations.

Luis A. Godoy (2016) over the last 20 years, there has been a notable rise in research on the structural behavior and buckling of vertical aboveground tanks used for the storage of fuels and oil. The cost of the infrastructure is not the only factor driving interest in this shell form; breakdowns in the event of an accident or natural disaster can result in significant losses to the economy, the environment, and society. The focus of this review is on buckling issues with these types of tanks under static or quasi-static stresses, such as wind, fire, foundation settling, and uniform pressure. Buckling is seen as a static process under all circumstances. Each case's load specification is discussed, and then buckling experiments at previously established pressures or temperatures are conducted. First, the structural configuration of tanks is explained in order to identify the unique characteristics of this structural form. To put each contribution in a larger context, the theoretical background for stability and buckling is next briefly discussed. The explanation of each loading situation is followed by a brief description of the tests or case studies, a review of computational analytical modelling, and a note of the efforts being made to improve the design.

John Carson et al (2015) An engineer needs to know every load that will probably be applied to a silo in order to structurally construct it. Among these are loads caused by the bulk solid that has been stored, wind, earthquake, and external forces. The methods for calculating the latter (also known as solids-induced loads) are specified by a number of regulations and standards. The four most often used among them in the modern world are as follows: 1. Eurocode 1 - Actions on buildings - Part 4: Silos and Tanks, British Standard BS EN 1991-4:2006 2."Standard practice for design and construction of concrete silos and stacking tubes for storing granular materials" (American Concrete Institute, ACI 313-97). 3. "Loads exerted by free-flowing grain on bins" (ANSI/ASAE EP433 DEC1988 (R2011)) published by the American Society of Agricultural Engineers 4. AS 3774-1996 Australian Standard "Loads on bulk solids containers" In the event that load scenarios are not addressed by the codes, the structural and design engineer has two options: 1. Use utmost caution while assessing applied loads. Even though this method can be quite costly, it might not be sufficiently cautious to keep the silo from collapsing. 2. Put your trust in design engineers who have a lot of experience figuring out silo load

A. Couto et al (2012) Full-scale silos are found in relatively few experimental sites worldwide, and very few experiments have been performed on them. Because of this, there are still a lot of unanswered problems that need to be investigated in order to be able to anticipate with any degree of accuracy how the material contained in these sorts of structures would behave. The design of a fullscale test station for measuring pressure in silos is described in this article. The setup essentially consists of a full-scale, cylindrical silo with load cells to monitor pressure and variable-frequency drives attached to each electric motor powering the screw conveyors for filling and discharging in order to investigate how the speed at which the silo is filled or discharged affects pressure. Due to this innovative design, the majority of the factors governing the behavior of the material in storage may be obtained, and various theoretical models that were employed to conduct calculations and establish current standards can be compared and validated.

F. Nateghi et al (2011) The primary objective of this research was to investigate the influence of the interaction between granular materials (such as stored grain, sand, or other bulk solids) and the structure of reinforced concrete (RC) silos during seismic events. Specifically, the study aimed to assess how the effective mass of granular material within the silo impacts its seismic response and structural damage. This model considers the interaction between the stored granular material and the silo walls, incorporating the influence of the bulk material on the dynamic response of the structure. This model neglects the effects of the granular material and assumes the silo walls experience seismic forces independently of the stored material. The study revealed that the seismic behavior of RC silos is significantly affected by the effective mass of the granular material. This suggests that the interaction between the silo walls and the stored material plays a crucial role in amplifying the seismic forces acting on the structure. The absence of interaction modeling likely resulted in an unrealistic distribution of seismic forces, leading to concentrated shear stress at different heights. The interaction between granular material and the silo structure must be considered in seismic analysis to achieve accurate predictions of structural behavior. The findings emphasize the need for advanced numerical models that incorporate granular material dynamics when designing and assessing RC silos in seismic-prone regions. This study highlights the critical role of granular material mass and its interaction with structural elements in determining the overall seismic resilience of silos, offering valuable insights for engineers working on seismic-resistant storage structures.

A.J. Sadowski et al (2011) this paper investigates the behavior of five thin-walled cylindrical silos with sequentially decreasing wall thickness and aspect ratios ranging from very squat to very slender, all of which were specially constructed for and analyzed under the EN 1991–4 concentric discharge loading condition. The behavior and design of silos are determined by the aspect ratio, thus it's critical to make sure that a conclusion that holds true for one can also be applied to the others. The computed load factor outperforms the partial safety factor in design by a significant margin over a broad variety of aspect ratios, according to the nonlinear finite element analyses, indicating that the design process was done with extra caution overall. The causes of these differences are investigated. This paper serves as the first of two. The behavior of the identical set of sample silos under the EN 1991–4 eccentric discharge loads is examined in the second article, which comes to essentially different findings.

A.J. Sadowski et al (2011) this paper investigates the behavior of four cylindrical silos with thin walls that have aspect ratios ranging from moderate to very slender and wall thicknesses that vary sequentially under the standardized EN 1991-4 eccentric discharge pressures. It is demonstrated that a silo design that was determined to be extremely safe when subjected to EN 1991-4 concentrated discharge pressures turns out to be extremely dangerous when subjected to eccentric discharge. Furthermore, it is currently unclear if the standard has specified an appropriate range of aspect ratios over which the codified eccentric discharge model is to be applied. This is because it is well known that the aspect ratio has a significant impact on the flow pattern when discharging granular solids and that slender silos exhibit very different flow patterns from squat silos.

Suvarna Dilip et al (2008) highlights the importance of considering seismic forces in the design of RCC silos. By comparing IS 4995, Eurocode, and ACI provisions, they examined failure modes and structural behavior under static, dynamic, and seismic loads. Their findings suggest that reinforcement distribution should be optimized along the wall depth, with increased reinforcement in the middle portion for better performance.

D. Dooms et al. (2005) studied wind-induced oval ling oscillation, an aero elastic phenomenon affecting circular cylindrical shell structures. This research validates a finite element model of a silo using experimental data from a silo where oval ling was observed. A three-dimensional finite element model, accurately representing the silo's connection to its supporting structure, aligns closely with the measurement data. The boundary conditions for axial displacements significantly influence Eigen frequencies and axial displacements. The study compares and contrasts results obtained from a three-dimensional model and a symmetric model. To facilitate future fluid-structure interaction simulations predicting the onset flow velocity, the silo model can be simplified to two dimensions using the finite strip approach for integration with a two-dimensional wind flow model.

A.Y. Elghazouli et al (1995) Researcher looks at the particulars of how wellperforming circular silos made of reinforced concrete function. First, important findings are emphasized and two case studies of recent UK circular silo failures are presented. Suggested values of design parameters are compared and methods for determining internal horizontal pressures acting on silo walls are explored. Also included is a succinct summary of the findings of an analytical study on common silo layouts drawn from the case studies. The analysis considered potential variations in the qualities of the silo walls and stored material, which increases the amount of uncertainty in the calculation of internal pressures. Furthermore, a summary is provided on the stresses generated in the steel reinforcement and the corresponding concrete cracking in the crucial wall sections. The anticipated reasons for the damage seen in this kind of building are finally described. It is specifically determined that, insufficient attention to durability and crack control requirements makes the structure more vulnerable and may result in early failures, especially over an extended period of time.

Methodology

Behavior under Static Loads

Concrete structures exhibit predictable stress-strain behavior under static loads. The load-carrying capacity of concrete primarily depends on its compressive strength, tensile strength, and modulus of elasticity. While concrete performs well under compression, it is weak in tension, necessitating reinforcement using steel bars or fibers. The failure modes of concrete structures under static loads include crushing in compression zones, tensile cracking, and bond failure between concrete and reinforcement. Proper mix design, curing, and reinforcement detailing enhance the performance of concrete under static conditions.

Behavior under Dynamic and Impact Loads

Under dynamic loads, such as those induced by machinery, seismic events, and explosions, concrete structures experience stress variations at high loading rates. The strain rate significantly affects the mechanical properties of concrete, with increased strain rates leading to higher apparent strength and stiffness. However, repeated dynamic loading can cause progressive damage, micro cracking, and fatigue failure. Impact loads, such as those from vehicle collisions or projectile strikes, lead to localized crushing and spelling, requiring the use of high-performance concrete, fiber-reinforced concrete, or external strengthening techniques to mitigate damage.

Behavior under Cyclic Loading and Fatigue

Structures subjected to cyclic loads, such as bridges, pavements, and offshore structures, experience material fatigue due to repeated stress reversals. Over time, micro cracks develop and propagate, leading to strength degradation. The fatigue life of concrete depends on the stress amplitude, loading frequency, and the presence of reinforcing elements. Research indicates that fiber-reinforced concrete and high-performance concrete improve fatigue resistance by enhancing crack-bridging capability and toughness.

Behavior under Seismic Loads

Seismic forces induce complex loading patterns, including shear, flexure, and axial forces, which can lead to significant structural deformations and failure. The ductility of reinforced concrete elements plays a crucial role in earthquake resistance, allowing structures to dissipate energy and prevent sudden collapse. Design strategies such as ductile detailing, confinement reinforcement, and base isolation techniques enhance the seismic performance of concrete structures. Specially designed earthquake-resistant concrete, incorporating high-strength reinforcement and supplementary cementations materials, further improves resilience against seismic events.

Behavior under Environmental and Thermal Loads

Environmental factors, including temperature variations, moisture changes, and chemical exposure, impact the long-term durability of concrete structures. Thermal loads cause expansion and contraction, leading to cracking, especially in restrained elements. Freeze-thaw cycles, sulfate attack, alkali-silica reaction (ASR), and chloride penetration accelerate deterioration, reducing the service life of concrete structures. Protective coatings, corrosion-resistant reinforcement, and the use of supplementary cementations materials (SCMs) enhance the durability of concrete under harsh environmental conditions.

Behavior under Combined Load Conditions

In real-world applications, concrete structures often experience multiple loads simultaneously, such as a combination of axial, shear, bending, and torsional forces. The interaction between different loading conditions influences failure mechanisms and structural performance. Advanced numerical modeling and experimental studies help predict the combined effects of multiple loads, leading to optimized design and construction practices.

Conclusion

Concrete structures are subjected to a variety of loading conditions throughout their lifespan, including static, dynamic, cyclic, impact, and environmental loads. Understanding how concrete behaves under these loads is critical for designing safe, durable, and efficient structures. Based on a comprehensive review of concrete behavior under different load scenarios, the following conclusions can be drawn. The behavior of concrete structures under various load conditions is a critical aspect of structural engineering. Understanding these behaviors enables engineers to design resilient, efficient, and long-lasting structures. The development of advanced materials, reinforcement techniques, and computational modeling tools continues to improve our ability to predict and enhance concrete performance under diverse loading conditions. Future research should focus on sustainable materials, self-healing concrete, and adaptive structural systems to further enhance the safety and durability of concrete structures in challenging environments

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