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Design and Analysis of Circular RCC Silo Having Different Aspect Ratio under Seismic Zone III Using STAAD pro Software

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Abstract

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.

Keywords: RCC Silos, circular Silo, Aspect Ratio, Seismic Analysis, Maximum absolute Stresses, Maximum shear stresses

Introduction

The term "Silo" comes from the Greek word "Siro." It began life as a grain and agricultural content storage facility and was later expanded to store a wide range of other materials, such as cement, ash fly, etc. In order to handle the expansion of the cement industry, these silos underwent modifications that increased material storing and decreased silo failure. Silos refer to bunkers and storage structures (like bins) for storing various kinds of goods. Bunkers and silos are classified based on the plane of the rupture. A bin is referred to as a bunker if its plane of rupture intersects its upper surface. A bin is said to as a silo if its plane of rupture interacts with its opposing side. Silos are typically circular in shape, although depending on the needs, they can also be square, rectangular, or polygonal. The silo has a roof, and bottom shape is either flat, pyramidal, or conical. Silos are held up by several columns, and to spread the weight, the ring beam connects the column, hopper top, and main structural wall. The diameter is less than the height in silos. According to IS code 4995(Part I):1974 for the decrease of lateral pressure across the big height, a height/diameter ratio more than or equal to two is required. Various loads are simulated during the silo's structural design in accordance with the purpose for which it was designed, structure type, size, design lifetime, material, location, and environment in order to ensure vital functions and life safety. When designing a building, it is important to consider its self-weight, the live load on the roof, the location-specific snow load, and the wind load as specified by the updated IS: 875 (Part III):2015 code. The cyclonic factor must be considered. Every structural design must include seismic load because of the bigger mass located above the narrow section and the stored material load acting in a vertical and horizontal manner. Not to be overlooked is the frictional pressure. When comparing the impact of vertical seismic loads to horizontal seismic loads on tall silos, the former is less significant. A silo's weight has a direct relationship with the size of the seismic load in a horizontal direction.

Method of Analysis

IS-4995 (Part I):1974 provides two approaches for calculating silo loads: Airy's Theory and Janssen's Theory.

Janssen's Theory

The supposition that only a small amount of the material's weight is transported to the hopper bottom and that the majority of the material's weight is sustained by friction between the material and the wall. This makes it impossible to apply directly to the lateral pressure theories of Coulomb (1776) or Rankin (1857). There is both lateral pressure and direct compression applied to the silo's vertical walls.

Airy's Theory

On Coulomb's wedge theory of earth pressure, Airy's analysis is built. According to this theory, Ritz or Eigen vectors, response-spectrum analysis, and time-history analysis may be used to compute the horizontal pressure per unit length of the perimeter and the location of the plane of rupture vibration modes for both linear and nonlinear behavior.

Objectives

1. To study how to design RCC circular silo structures using STAAD Pro software.
2. To analysis the circular RCC silo design according to IS code.
3. To design circular RCC silos with different aspect ratio
4. An analysis that compares the silos of different aspect ratio constructions while taking seismic zone III into account.

Literature Review

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.

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.

Weiwei Sun et al (2021): High-blending-efficiency central cone silos can play a significant role in the cement industry's manufacturing process. Through a multi-scale experimental program, filling and discharge tests of central cone silos with various aspect ratios are carried out to look at the material's flow pattern and the pressure distribution on the wall and cone. They finds the conclusion as, the pressure distribution of the wall and cone is significantly influenced by the central cone in the cone's height range, where the pressure on the wall peaks and then begins to diminish, while the pressure on the cone progressively reduces as the depth increases. As the aspect ratios rise, the overpressure factors of the wall and cone somewhat decrease. The discharge modes don't really affect the wall's maximum overpressure factors. While the maximum overpressure factors of the cone vary significantly depending on the discharge method, the maximum overpressure factors of the wall remain rather constant. The pressure on the top area and the cone may be reliably predicted by the factors k1 and k2.

J.M. Rotter et al (2019): Researcher looked at that the stress regime in the stored solid in squat and intermediate aspect ratio silos is predicted using a finite element model of filling pressures in rectangular silos with flexible walls that has been experimentally confirmed. The model forecasts the pressures applied to the silo's flexible walls and the level of tension in the solid that is being stored. At the conclusion of filling, the no uniform horizontal pressure distributions at each depth are investigated. It is known that the computational predictions closely agree with an empirical relation for the horizontal pressure variation on each straight wall that was determined from experimental measurements in a previous work. The coefficients of this relation are shown to depend on the relative stiffness of the silo walls and the stored solid, and to change with depth below the stored solid surface. An empirical relationship appropriate for practical design for a variety of different stored solids whose pertinent characteristics are known is obtained after several computations involving various solids. The resultant expression offers a silo design pressure suggestion that is based on theoretical, rather than empirical, findings, and is well adapted to the practical determination of filling pressures in rectangular silos.

Changnv Zeng et al (2020): Researcher examines the dynamic behaviour of multi-story, base-isolated buildings with considerable plan irregularity. In this case, high damping rubber bearing isolators were used and positioned parallel to friction slider isolators. A nonlinear dynamic analysis (NLDA) and a dynamic analysis with response spectrum LDA (RS) have been used to examine the behaviour of the base isolated structure. When compared to the use of a nonlinear dynamic analysis (NLDA), the dynamic analysis using response spectrum LDA (RS) proves to be less conservative in terms of displacements. Given the new Italian seismic code NTC 2018, the comparative study carried out here both in terms of displacements and in terms of stresses has particular importance.

Weiwei Sun et al (2020): Researcher examined that the purpose of the filling and discharge tests is to examine the pressure distribution and overpressure evolution on the wall and channel of both full-scale and reduced-scale squat silos that include aboveground conveying channels. According to the filling experiments, the channel has a big impact on the pressure distribution on the wall bottom. While Jaky's calculation overestimates the lateral pressure on the wall, Rankine's active earth pressure equation provides an accurate approximation. The heights of the stored materials as a result of the repose cone are connected to the filling pressure on the channel wall. It is important to recognize the balance between the wall friction equilibrium effect and the channel's arch effect in the squat silos. The results of the discharge experiments indicate that the overpressure coefficient remains constant as the discharge eccentricity increases. Concurrently, the overpressure coefficient is significantly impacted by the aspect ratio. In multi-scale discharge testing, an overpressure is seen on the channel's side and upper walls. It is recommended that the discharge load be computed considering the channel's overpressure coefficient.

Lakshmi E. Jayachandran et al (2019): silos require a solid understanding of their loads and structural performance. The impact of stored grains on silos has been the subject of few researches. Rough rice is intended to be stored in a flat-bottomed, farm-level bamboo reinforced concrete (BRC) silo. The BRC silo's full-scale 3D finite element (FE) model has been created, and the ANSYS software has been used to simulate the grain filling in progressive layers. With only minor simplifications, the interactions between the silo body and stored grain have been modelled while considering the distinctive characteristics of both rough rice and the BRC... A detailed discussion is held on the causes of variations in stress patterns. The research predicted the stresses in small and medium-sized silos meant for usage on farms while revealing the complexities of the FEM and the analytical results.

Zhen Chen et al (2018): Large diameter silos made of reinforced concrete were constructed for the purpose of storing coal in accordance with environmental protection regulations. This research describes the experimental analysis and 3D FEM modeling of a reinforced concrete silo with dimensions of 136.5 m in diameter and 19.35 m in height, in light of the paucity of literature on the impact of temperature patterns. Vibrating string strain gauges were used to measure the strains in the circumferential and vertical steel bars under various temperature patterns caused by variations in sunlight and season. For more than a thousand days, the data were gathered and sent via GPRS transmission. In the meanwhile, the Drucker-Prager elasto-plastic criteria and the elasto-plastic damage model were utilized in an ABAQUS software-built finite element model to adjust the nonlinearity of soil and reinforced concrete. The test data and the outcomes of the numerical simulation correspond well. The impact of temperature fluctuations on the silo wall was carefully examined. The paper's findings offer a vital foundation for large-scale silo design.

F. Nateghi et al (2011): In this paper, researcher tried to determine how the interaction between the granular material and the structure affects the seismic behavior of reinforced concrete silos. The findings indicate that more severe tension damage occurs in the silo walls when the effective mass of the granular material is equal to 80% of the total mass of the granular material. Shear cracks have developed in the height of the silo in the second model, which ignores the granular material-structure interaction. In both models, flexural cracks have developed in the lowest part of the silo walls near the symmetry plane and transform into shear cracks by moving around the perimeter.

D. Dooms et al (2005): Wind-induced ovalling oscillation is an aeroelastic phenomena that affects circular cylindrical shell constructions. The experimental data collected on a silo where ovalling has been seen are used in this work to validate the finite element model of a silo. The silo's interconnection with the supporting structure is represented in the findings of a three-dimensional finite element model, which best matches the measurement data. Eigen frequencies and axial displacements are significantly impacted by the boundary condition for the axial displacements. Results achieved with a three-dimensional model and one that uses symmetry are compared and contrasted. In order to integrate the silo model with a two-dimensional wind flow in upcoming fluid-structure interaction computations that seek to forecast the onset flow velocity, we can reduce the silo model to two dimensions using the finite strip approach.

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.

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 full-scale 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.

A.Y. Elghazouli et al (1995): Researcher looks at the particulars of how well-performing 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.

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.

Evgeny Rabinovich et al (2021): In this research, a new design process and a parametric study for wedge-shaped (planar) silos are presented. This work presents updated experimental findings along with parameter influence studies. The mass–funnel flow boundaries were discovered to be essentially unaffected by the roughness of the bin sidewall. Furthermore, as per the latest findings, it is possible to get the mass flow mode even with extremely rough hopper walls; nevertheless, in that scenario, a layer of stagnant material is present adjacent to the hopper walls. Lastly, a fresh approach to planar silos design was put out. The novel approach may greatly increase process efficiency by assisting silo operators and designers in improving the precision and adaptability of the granular flow regime assessment.

A.J. Sadowski et al (2011): This paper investigates the behaviour 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 analysed under the EN 1991–4 concentric discharge loading condition. The behaviour 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 behaviour 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 behaviour 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.

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 loads.

Luis A. Godoy (2016): Over the last 20 years, there has been a notable rise in research on the structural behaviour 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.

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 behaviour 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.

Methodology

In this study we 3 models of RCC circular silos with different aspect ratio.

Type	RCC silo	RCC silo	RCC silo
Purpose of silo	Storage of cement	Storage of cement	Storage of cement
Height of silo	10m	12m	15m
Diameter	2.6m	3m	3.5m
Aspect ratio	3.8	4	4.2
Thickness of silo	200mm	200mm	200mm
Storage product density	15.50kN/m^3	15.50kN/m^3	15.50kN/m^3
Angle of internal friction	25	25	25
Friction coefficient of tank wall	0.46	0.46	0.46
coefficient of wall friction(ȝ)	tan φ	tan φ	tan φ
Seismic zone	III	III	III
Grade of RCC	25	25	25

Following steps are perform in STAAD pro software. Methodologies which are carry for this are model development, load calculations, analysis, and designs. All the aspects are taken in according to the Indian standard code procedures, different calculations and their procedures that are done in this study.

- Model of Three circular RCC silos of different aspect ratio create in STAAAD pro
- Assigning Properties
- Assigning loads
- Load combinations
- Analysis Procedure
- Design Procedure

MODELLING

The structure was modelled using the Structure Wizard input method, which follows the procedures listed below. Staad Pro analysis and design software was utilized for the modelling process.

- Start a project using the units of a meter and a kilogram. For the input method, choose space template and the run structure wizard tool.
- Choose the cylindrical plate model under the plate models section of the structure wizard tool.
- Click the "Change Property" button to enter the cylinder's values.
- Merge the Staad pro model with it.
- Model the circular beam at the bottom by connecting the nodes and forming the beam using the add beam option.
- Using the translational repeat tool, copy the nodes on the beam in the negative y direction while selecting the connection nodes that will create the columns.
- Establish a reference node at the bottom of the hopper and use three nodded plates to create the bottom hopper slab.
- Create the properties for the slabs, columns, and beams and assign them to the appropriate elements.
- Examine the model's definition in the 3D rendered view; if not, choose the appropriate elements and remodel them.
- Examine the model for duplicate plates or mode beams; if any are discovered, remove them.
- Assign the bottom nodes to fixed supports.

LOADING AND ANALYSIS

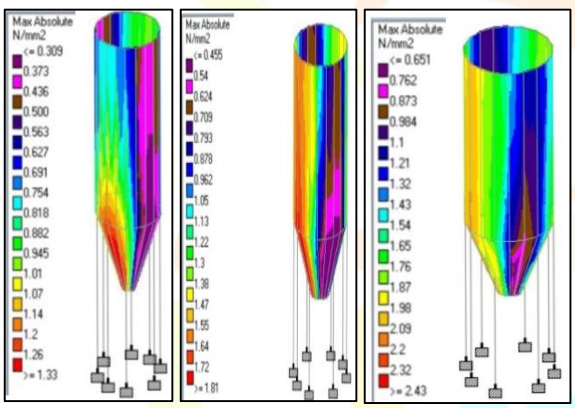
The procedures to be performed in Staad pro while assigning loads are as follows:

- On the page setup tab, choose loads and definitions. Choose the definition first and provide the earthquake data at beginning.

- In the load situation specifics choose the seismic load option and provide loads in the x, z, and positive and negative directions. By default, seismic loads will be allocated.
- For the lateral and surcharge loads, create plate loads.
- By choosing the appropriate plates to which the load has to be applied, assign the loads to the related plates.
- Make a case for dead loads and assign self-weight.
- For the surcharge on the bottom slab and the lateral load on the wall, create two live load cases.
- Select Auto load combinations by clicking on commands > loadings.
- Choose the Indian code, then create automatic load combinations.

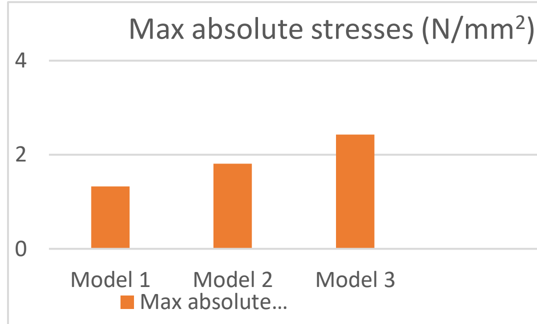
Result and comparison

Following diagram shows the maximum absolute stresses

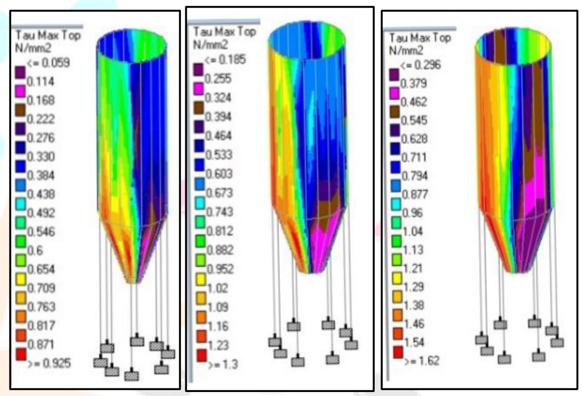


Model	Max absolute stresses(N/mm^2)
Model no. 1(aspect ratio-3.8)	1.33
Model no. 2 (aspect ratio-4)	1.81
Model no. 3(aspect ratio-4.2)	2.43

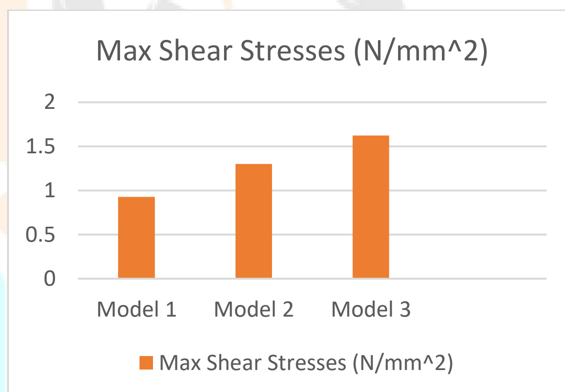
Model 1 Model 2 Model 3



Following diagram shows the maximum shear stresses



Model 1 Model 2 Model



Conclusion

- The maximum absolute stress for model 3(diameter-3.5m, height-15m) - 2.43 N/mm2 is more as compared to

Model	Max shear stresses(N/mm^2)
Model no. 1(aspect ratio-3.8)	0.925
Model no. 2 (aspect ratio-4)	1.3
Model no. 3(aspect ratio-4.2)	1.62

model 2(diameter-3m, height-12m) -1.81 N/mm2 & model 1(diameter-2.6m, height-10m) -1.33 N/mm2.

- We can observe that the maximum absolute stresses rise in parallel with an increase in the aspect ratio.
- The maximum shear stress for model 3(diameter-3.5m, height-15m) – 1.62 N/mm2 is more as compared to model 2(diameter-3m, height-12m) -1.3 N/mm2 & model 1(diameter-2.6m, height-10m) -0.925 N/mm2.
- We can observe that the maximum shear stresses also rise in parallel with an increase in the aspect ratio.

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