Babylonian Journal of Mechanical Engineering
Vol.2023, **pp**. 20–28
DOI: https://doi.org/10.58496/BJME/2023/003; ISSN: 3006-5410
https://mesopotamian.press/journals/index.php/BJME

Research Article

Analysis and Design of Steel Silo using STAAD.ProV8i

Khalil Ur Rehman[1,*], KangLe Wang[2]

[1] *Department of Applied Mathematics, University of Waterloo, Canada*

[2] *School of Mathematics and Information Science, Henan Polytechnic University, Jiaozuo, China*

ARTICLE INFO

Article History

Received 19 Jan 2023
Accepted 01 Mar 2023
Published 20 Mar 2023

Keywords

Steel Silo

Analysis

STAAD.Pro V8i

Structural Engineering

ABSTRACT

Generally silo is a storage structure for heavy bulk materials such as cement coal, wood, food products and saw dust. Its design involves materials, geometry, and structural considerations. This research considered a special structure steel silo treated with myriad conventional and unconventional loading conditions, varied from some tonnes to many of tonnes which findings in uncommon modes of failure. Silo Specifications of 14m height and 3m diameter was designed with section ISMB 300 and ISA 70x70x10mm as per Indian standards. In addition, the plan and section of the silo wad done by the AutoCADD 2018 software. modelling, dynamic analysis and designs were completer in STAAD PRO V8i.Besides, the silo was designed as per Indian standards IS 800.The maximum axial force and shear force of the steel silo were 15.9 KN and 0.037 KN respectively. The aim of this paper was to determined the Plate stress, contour lines, and critical support of the silo, beam end force summary and steel take off of the silo structure.

1. INTRODUCTION

The silo is cylindrical in design, with four supporting legs at the bottom. Silo was originally used in fields to store agricultural goods like rice, millets and so on. It is a high-rise structure that can be made of composite concrete or steel. Silos are currently employed in maritime works and offshore manufacturing. Stones, concrete, and steel have all been used to construct silos. Any concrete manufacturing includes the usage of a silo for cement storage. It has a cylindrical form and four supporting legs at the bottom of the silo. [1]. Silos are buildings used to store granular materials. Steel silos have extremely few uses in the domestic market, but concrete silos have several. In many circumstances, structural steel cylinder silos are less expensive than composite concrete silo structure. The circular silo is a representative rotating thin shell building, with structure damage caused by difficult structure performance and unrealistic design criteria. Once the calculation bases have been identified, installation of each structural element required a unique design. Concrete silos require special attention to footing and fissures that emerge walls ,steel bunkers in the walls. Steel silos differ primarily from concrete silos in that they are much lighter structures, much faster installation and also dismantle, carry its loads via various mechanism under the structural engineering, deform readily and reversibly when the silo structure subjected to the unsymmetrical loading conditions, and place minimum loads on its footings [2]. The stability of steel bunkers against wind impacts while empty must be tested. The results of experimental testing on the load resisting capacity of the steel silo structures silos revealed that small ribs are connected closely with the circumferential ring beams were the preferred way of reinforcing steel silos. To stabilise the silo against the pressure from the stored materials, the bunkers might be internally or externally strengthened. To carry out reinforcing function, rings are given throughout the circle and also stringers in the lengthwise at predetermined gaps. The mechanical stability of the silo construction is improved with stiffeners. Buckling is a type of failure that occurs when a structure is exposed to stress due to compressive loads. When a thin bin structure is loaded in compression, it deforms with no perceptible change in geometry for slight loads. When the load resisting capacity reaches a critical load value, the structure deforms dramatically and lose its capability bear weight. It is called as buckling load stage of force[3].Metal silos are now manufactured in a variety of dimensions and shapes, such as rectangular, circular, and square silos, squat silos, and high-rise cylinders, silos with smooth walls, stiffened walls built from either vertically or horizontally corrugated sheets with orthogonal stiffeners, or patented special wall forms, ground-supported silos, and skirted or column-supported silos. Steel silos and bunkers can be structural, constructed of steel plates, or sheet metal, constructed plain or corrugated metal. Steel

*Corresponding author. Email: kurrehman@uwaterloo.ca

plates have limited bending strength unless corrugated or stiffeners are used. Horizontally, circular unit walls work as a tension member. However, these walls subjected to the compression loads and buckling [9]. The buckling of the vertical columns was found to be the primary cause of failure in big cylindrical steel bunkers, which were made of horizontally corrugated steel sheets and also upright stiffeners. Service reliability is likely to improve. The structural analysis and design, as one of three key parts of silo design such as bulk material, structural and geometric, defines safe service life of the silo. In order to conduct a finite element analysis study of steel silo, it is critical to define reasonable parameters and construct a suitable model based on the actual engineering usage condition. Steel circular silo design is determined by the kind material and its density ,response angle, horizontal pressure from the silo walls and H/D ratio.

- Research the IS 4995- 1974 Parts I and II for general requirements, as well as the assessment of bin loads and standard designs.
- Investigate the h/d ratio in the analysis of horizontal pressure at various heights.
- Design of silos for various kinds of materials while keeping h/d fixed in consideration.

2. BACKGROUND

Nickola et al (2018) Steel silos failure is a common issue in industrial fields, affecting structural integrity and safety. Major causes include design, construction, and utilization errors. This study analyzes a buckling failure in a thermal power plant, primarily due to eccentric discharge of stored solid. The study focuses on characterization of pressure distribution caused by eccentric solids flow in silos and tanks. It uses new rules from European Standard EN 1991-4, allowing realistic calculations on shell buckling conditions. The paper explores structural behavior leading to buckling during eccentric discharge and proposes reinforcement design to minimize problems [4].

Dr.Alice Mathi et al (2015) considering the particular properties of stored materials, silos are subjected to a wide range of static and dynamic loading situations. It is extremely critical to establish the size and distribution of stresses, as well as the failure modes associated with them. A steel silo reinforced externally with stringers and rings at equal intervals is used in this study, and a linear static analysis is performed to estimate the stresses and displacements that occur in it. Wind and seismic loads frequently jeopardise the silos' stability. This research also investigates the impact of wind loads on the silo. [5].

Mohammad Khalil et al (2022) The literature compendium on structural performance, vulnerability, industrial silo risks, focusing on circular steel silos. It addresses issues such as interaction of the content container, structural and seismic response, and uncertainties in design and assessment processes. The study proposes a state-of-the-art approach for silos response, effects of imperfections, stored material properties, uncertainties, failure modes, and risk mitigation strategies. It summarizes recent research trends and highlights open issues in risk and vulnerability reduction [6].

Neethu Elsa Aml et al (2022) Silos are used in various industries to store bulk solids in various quantities. They are made of steel or reinforced concrete and can be closed or open. They face various static and dynamic loading conditions, including wind and earthquake loads. Static and dynamic analysis is conducted on steel silos, focusing on geometry, material, and boundary conditions [7].

Than Zaw Oo et al (2019) the analysis and design of the steel silo for various applications, including cement storage, bunker silo, bins, sand and salt silo, bags silo. Steel silos are analyzed for their economic and safety benefits. The thickness is 8.4412 mm, but CP Live Stock Company's silo wall thickness is 6 mm, requiring 78 stiffeners for safety. The foundation's stress is higher than the vertical stress, ensuring design satisfaction. Wind load and its pressure are calculated at various elevations, and wind stress is less than wall strength, resulting in design satisfaction [8].

Kishore et al (2017) Steel silo analyzed and designs large cylindrical by horizontally corrugated sheets with vertical stiffeners. It uses STAAD Pro software for 3D FE calculations, comparing grain pressures and external loads. The results show that the hoop stress values in derived manual calculations and STAAD Pro are matching, except for top and bottom plates, indicating correct assumptions in silos modeling [9].

S.K.Hirde et al (2022) Silos are crucial industrial structures for storing materials like cement, coal, and grains. With increased seismic excitation due to ground shaking, it is essential to analyze silos for their performance. Failures can result in property loss, material storage loss, pollution cleanup, replacement costs, maintenance, and injury or death risks. Designers and researchers have been closely monitoring silos' performance in recent years [10].

Zhang Ledao et al (2016) Change in temperature in a small steel silo was studied using a three-dimensional numerical model in a quasi-steady condition. The study demonstrated that temperature of the grain is regulated by temperature of the wall, height of stacking grain, and distance from the grain to wall. Finally, author was concluded the model can estimate grain temperature in a steel silo [11].

Dr. S. K. Hirde, Aartika S. Mohabansi (2022) Elevated cylindrical storage silos are crucial in industries, storing cement, coal, and grains. A parametric study examined the effects of aspect ratios on seismic response in elevated silos under earthquake loading using SAP2000. The study aimed to determine seismic responses, such as base shear variation, overturning moment, and roof top displacement [12-19].

3. MATERIALS AND METHODS

Material storage, wind interaction, supports, wall flexibility, staging height, and stiffeners all enhance silo structural performance. This chapter examines software evaluation of the silo structure.

TABLE I. 1-DETAILS AND DESCRIPTIONS

Details	**Descriptions**
Cylinder Diameter	3m
Cylinder Height	9m
Thickness of the silo wall	8mm
Height of the conical hooper	3m
Opening in conical Hooper	500 mm
Total Number of the supports	4
Diameter of the supports (concrete)	0.2m
Height of the Supports	5m
Ring beam material	ISA 70X70X10
Silo wall material	ISMB 300
Poisson Ratio (steel)	0.3
Specific Weight (steel)	78.55kN/m^3
Behavior of material	Isotropic Elastic

In this project, silo supporting structures made of steel were analysed, designed, and subjected to comparative research. The modelling analysis and design carried out using the structural program, STADD PRO v8i, while the plan and section drawings were generated by the drawing software, AUTOCAD. The stiffness matrix approach may be used to do the structural analysis, and the design was carried out in accordance with IS code criteria.

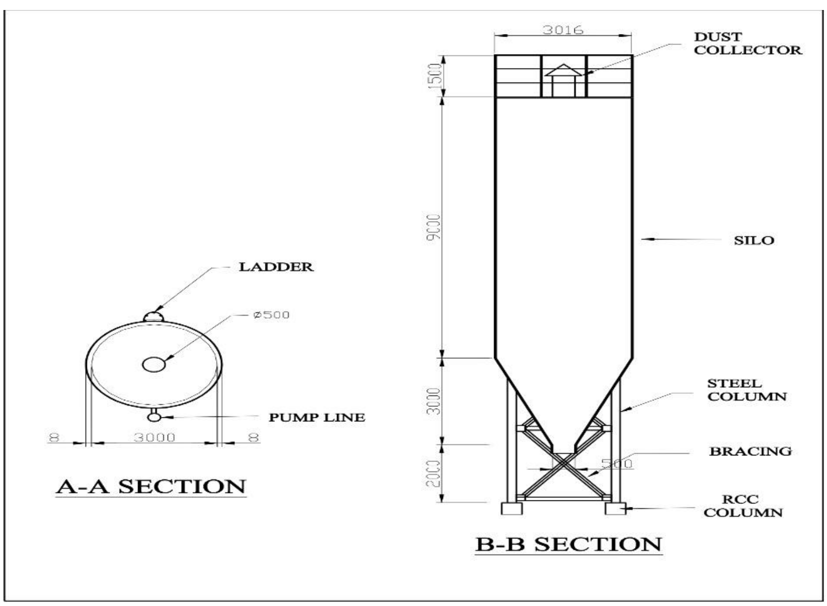

Fig. 1. Detailed Sectional Drawing of a Silo with Dust Collector and Support Structure

4. RESULTS

The various structural loads that a building must normally support. Gravity loads, such as dead loads, living loads, and equipment loads, act vertically. Silo was designed with the lateral load resisting system to withstand horizontally acting forces like wind. As lateral loads are applied to the structure, horizontal diaphragms (floors and roofs) convey the load to the lateral load resisting system. The modelling view, top view, rendered view and plate stress were shown in figure 1(a), (b) and figure 2 (a), (b).

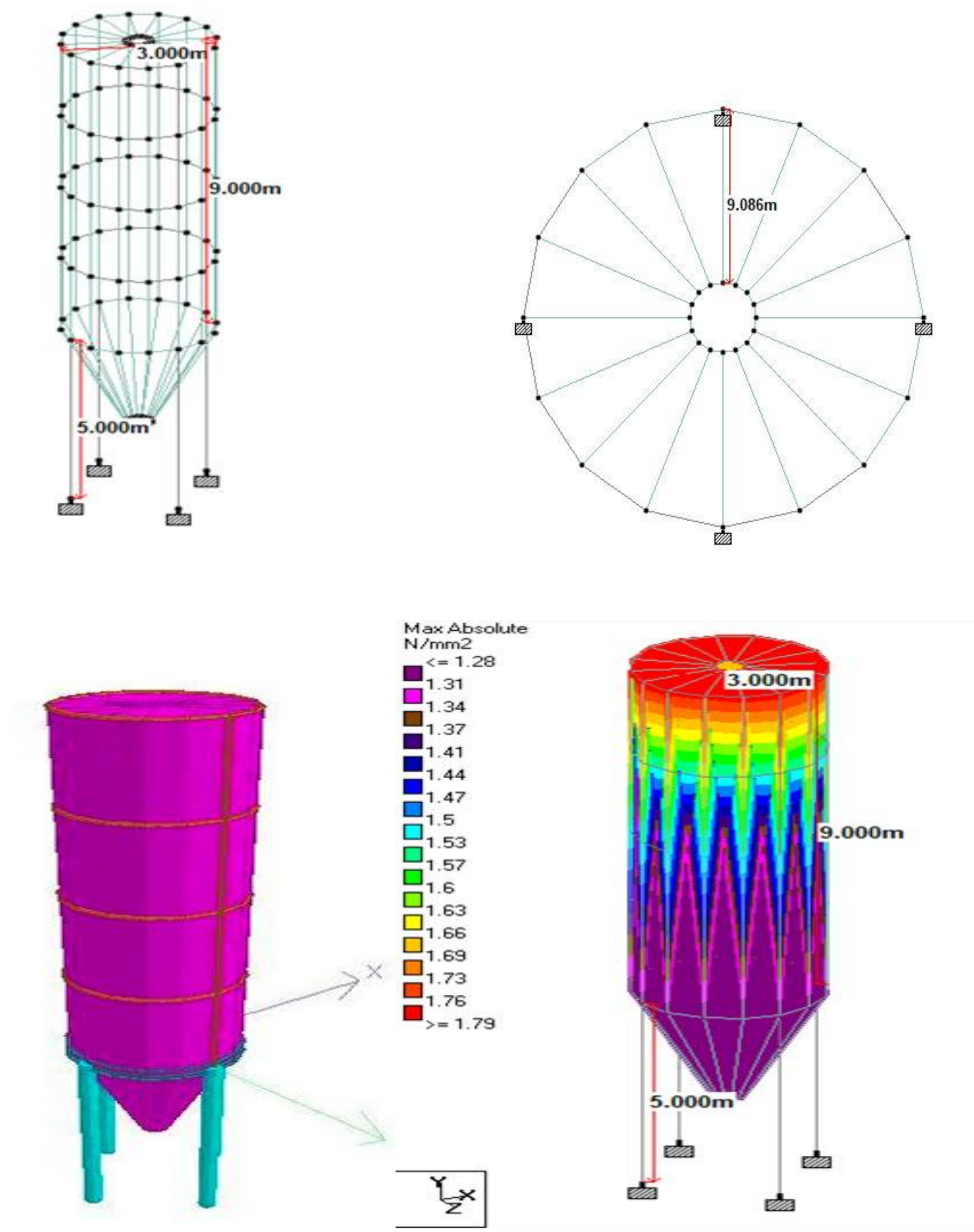

Fig. 2. - (a) Rendered view; (b) Plate stress

The contour lines, critical column, and shear force Diagram and axial force diagram were shown in the figure 3(a),(b),figure(4), figure(5).

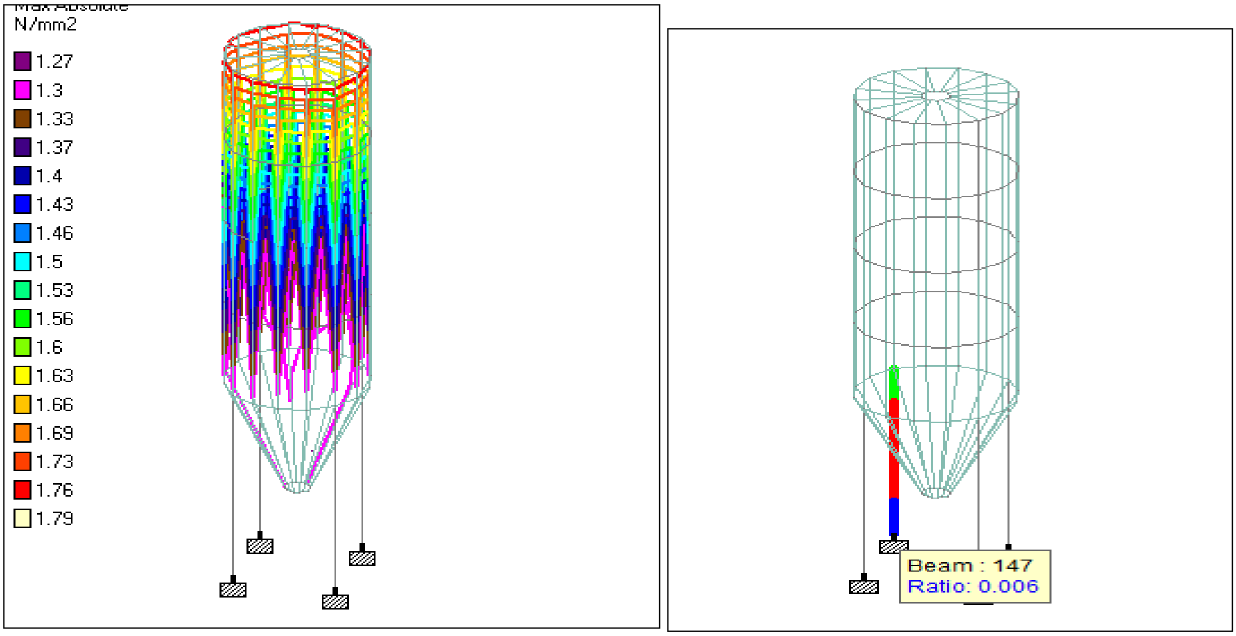

Fig. 3. - (a) Contour lines; (b) Critical Column

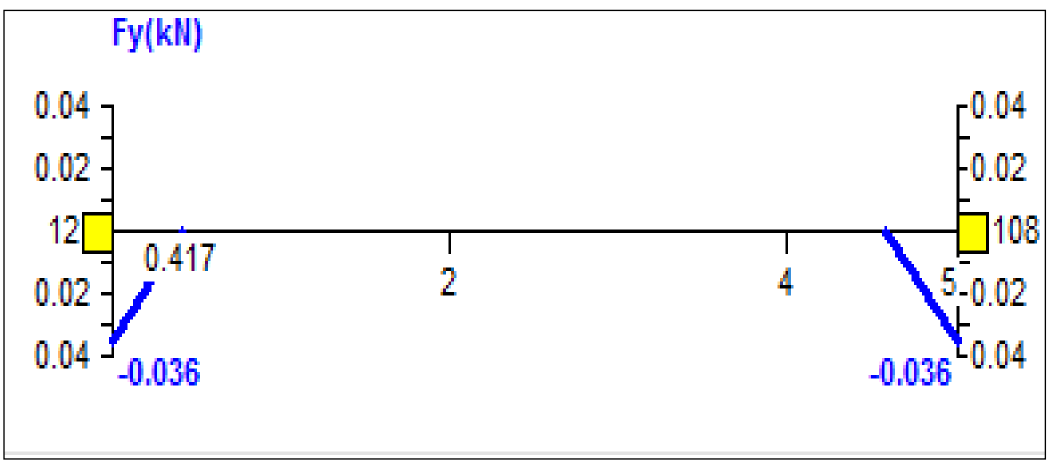

Fig. 4. Shear Force Diagram

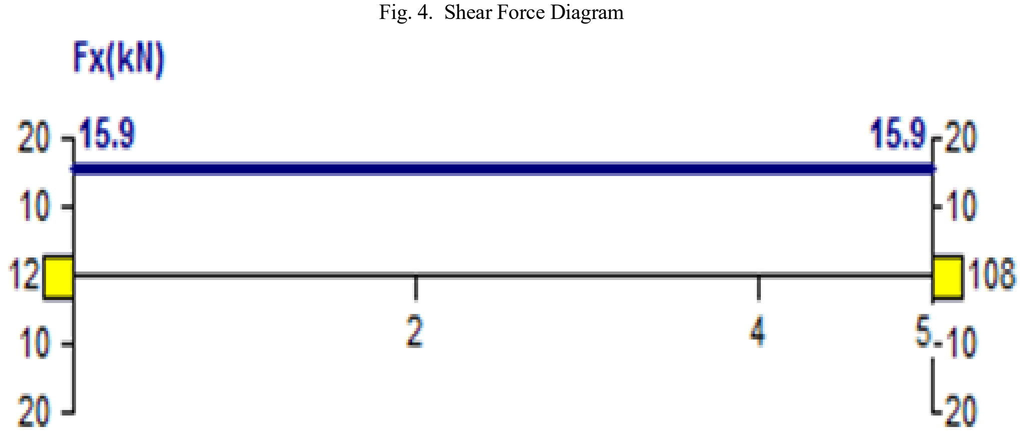

Fig. 5. Axial Force Diagram

TABLE II. BEAM END FORCE SUMMARY

				Axial	Shear		Torsion	Bending	
	Beam	**Node**	**L/C**	**Fx (kN)**	**Fy (kN)**	**Fz (kN)**	**Mx (kNm)**	**My (kNm)**	**Mz (kNm)**
Max Fx	147	12	1: LC 1	15.930	-0.016	0.000	0.000	0.000	0.000
Min Fx	22	12	1: LC 1	-8.505	0.000	-0.008	0.000	0.000	0.000
Max Fy	230	112	1: LC 1	0.557	0.057	0.006	0.000	0.000	0.000
Min Fy	247	128	1: LC 1	0.557	-0.057	-0.006	0.000	0.000	0.000
Max Fz	230	112	1: LC 1	0.557	0.057	0.006	0.000	0.000	0.000
Min Fz	22	12	1: LC 1	-8.505	0.000	-0.008	0.000	0.000	0.000
Max Mx	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000
Min Mx	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000
Max My	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000
Min My	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000
Max Mz	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000
Min Mz	2	1	1: LC 1	-8.473	-0.000	-0.008	0.000	0.000	0.000

```
STEEL TAKE-OFF
--------------

   PROFILE                    LENGTH(METE)       WEIGHT(KN   )

ST   ISMB300                       9.36              4.223
ST   ISA70X70X10                  46.46              4.639
                                             ----------------
                                  TOTAL =            8.862
```

Fig. 5. Steel Take-Off

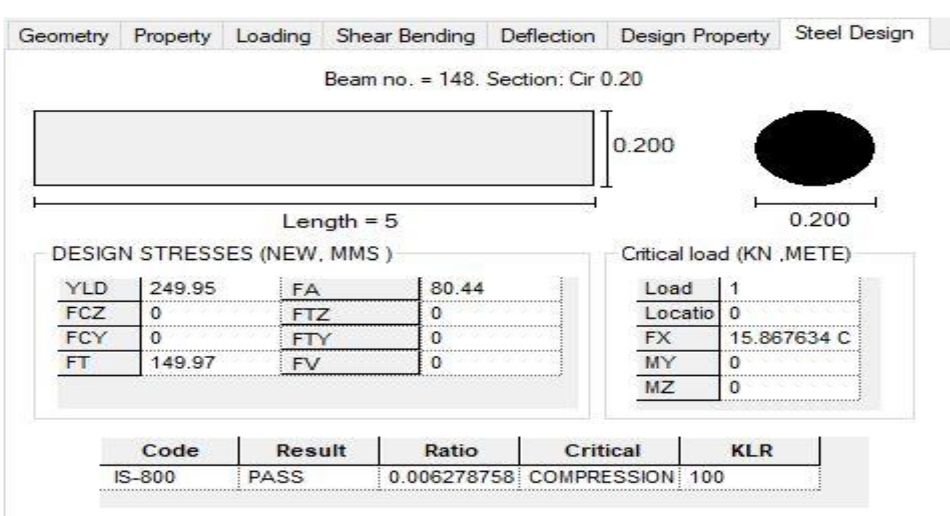

Fig. 5. Design of steel column

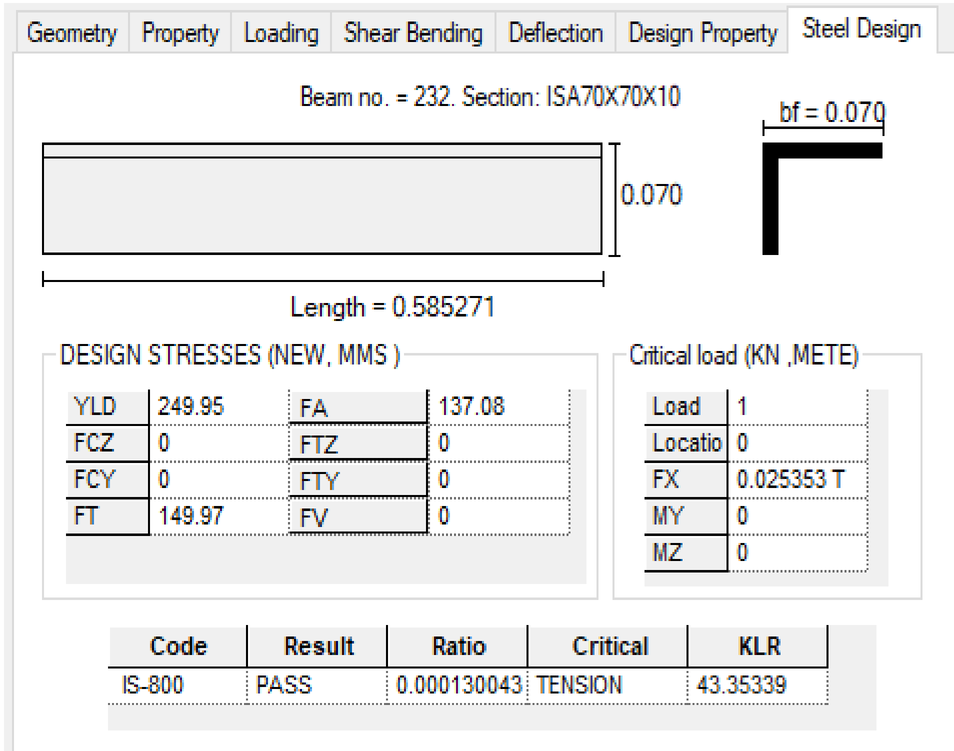

Fig. 6. Ring Beam Design

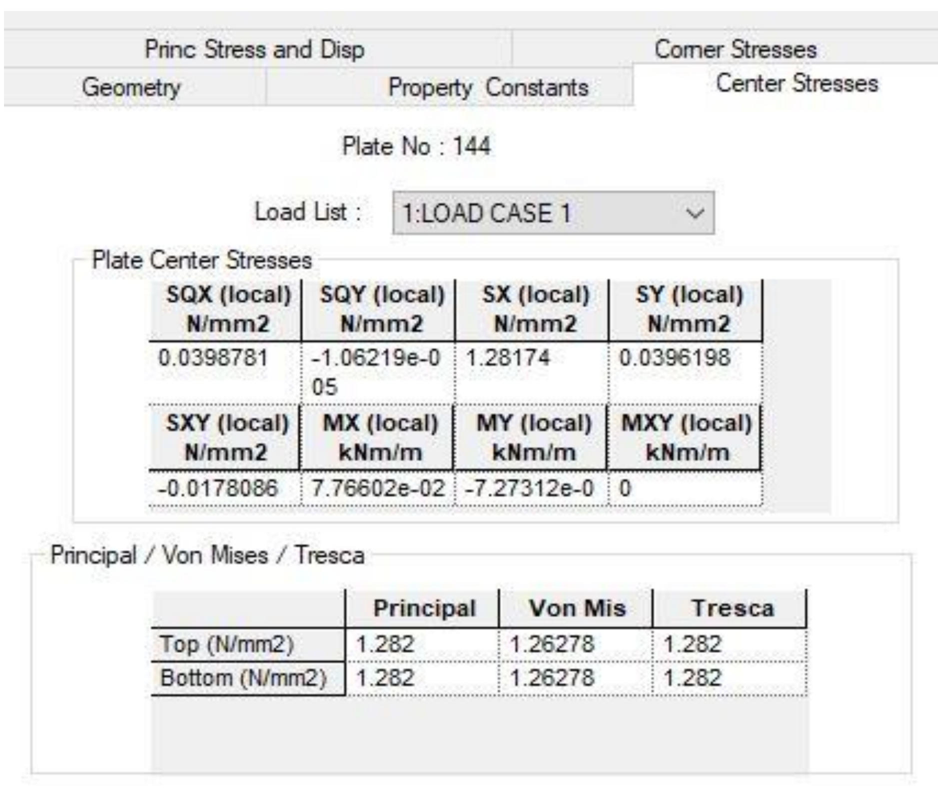

Fig. 7. Centre Pressure on the Shell

5. CONCLUSION

This paper examines silos in the industrial sector, which store mass solid material with capacities up to nearly thousand of tons. It covers research topics on structural configuration, bulk material properties, loads, failure modes, and silo assessment. Silos are low thickness walled shell structures with inherent sensitivity to structural configuration, undergoing conventional and unconventional loadings based on usage. The entire silo structure was analyzed under the dynamic analysis and steel take off was found. While, the plate stress, centre pressure of the shell and contour lines of the special structure also determined this investigation. Apart from this, the supports and ring beams were designed under the Indian code IS 800.

Conflicts of Interest

None

Funding

None

Acknowledgment

None

References

[1] R. K. Janghel and R. C. Singh, “Dynamic analysis of cylindrical steel silo structure with the effect of shear wall,” Int. J. Adv. Res. Ideas Innov. Eng. (IJARIIE), vol. 4, no. 5, pp. 407–412, 2018.

[2] R. Prince and N. Jose, “International Research Journal of Engineering and Technology (IRJET),” Int. Res. J. Eng. Technol., vol. 4, no. 5, May 2017.

[3] N. C. Michele, “Steel silos failure and reinforcement proposal,” Eng. Fail. Anal., 2016. doi: 10.1016/j.engfailanal.2016.02.009.

[4] A. Mathai, A. S. Steephen, E. Thomas, N. Kumaran, and S. S. Mathew, “Finite element analysis of a stiffened steel silo,” Int. J. Civil Struct. Eng. Res., vol. 3, no. 1, pp. 1–5, Apr.–Sep. 2015. [Online]. Available: www.researchpublish.com.

[5] M. Khalil, S. Ruggieri, and G. Uva, “Assessment of structural behavior, vulnerability, and risk of industrial silos: State-of-the-art and recent research trends,” Appl. Sci., vol. 12, p. 3006, 2022. doi: 10.3390/app12063006.

[6] N. E. Anil and L. P., “Comparative study of finite element analysis of steel silos with rectangular and I stiffeners,” Sustainability, Agri, Food Environ. Res., vol. 10, 2022. [Online]. Available: http://dx.doi.org/

[7] T. Z. Oo, N. Y. P. Thet, and A. M. S. Hlaing, “Design and pressure analysis of steel silo (8000 tons),” Int. J. Trend Sci. Res. Dev. (IJTSRD), vol. 3, no. 5, Aug. 2019. [Online]. Available: www.ijtsrd.com.

[8] K. B. Vaghela and H. J. Shah, “To study the analysis, design and behavior of corrugated steel silo,” Int. J. Sci. Res. Dev. (IJSRD), vol. 5, no. 5, 2017.

[9] S. K. Hirde and A. Mohabansi, “Seismic evaluation of steel silos with different aspect ratio: State of art,” Int. J. Multidiscip. Educ. Res., vol. 11, no. 5(5), May 2022.

[10] L. Zhang, X. Chen, H. Liu, W. Peng, Z. Zhang, and G. Ren, “Experiment and simulation research of storage for small grain steel silo,” Int. J. Agric. Biol. Eng., May 2016. [Online]. Available: http://www.ijabe.org.

[11] S. K. Hirde and A. S. Mohabansi, “Seismic evaluation of steel silos with different aspect ratio,” JETIR, vol. 9, no. 9, Sep. 2022. [Online]. Available: www.jetir.org.

[12] IS 875 (Part 1) – 1987: Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Dead Loads (Unit Weight of Building Materials and Stored Materials).

[13] IS 875 (Part 2) – 1987: Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Imposed Loads.

[14] IS 875 (Part 3) – 1987: Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures – Wind Load.

[15] S. K. Kothiya, H. L. Kheni, and J. Gadhiya, “A review on parametric study on design of silo,” Int. J. Adv. Eng. Res. Dev. (IJAERD), vol. 2, no. 3, pp. 603–606, 2015.

[16] D. H. Pambhar and S. R. Vaniya, “Design and analysis of circular silo (R.C.C) for storing bulk materials,” Int. J. Adv. Res. Eng. Sci. Technol. (IJAREST), vol. 2, no. 5, pp. 1–5, 2015.

[17] N. K. Shenbagam, M. S. Loganayagan, and N. V. Manjunath, “Studies on economical design of bunkers,” Int. J. Adv. Res. Comput. Sci. Softw. Eng. (IJARCSSE), vol. 4, no. 9, pp. 417–429, 2014.

[18] A. Ansari, K. Armaghan, and S. S. Kulkarni, “Design and optimization of RCC silo,” Int. J. Res. Appl. Sci. Eng. Technol. (IJRASET), vol. 4, no. 6, pp. 458–466, 2016.

[19] C. Thomas, S. Singh, and D. Jaishree, “Analysis and design of a multi-compartment central cone cement storing silo,” Int. J. Res. Eng. Technol. (IJRET), vol. 4, no. 5, May 2015.