Finite Element Analysis of A Stiffened Steel Silo

Dr. Alice Mathai[1], Ann Stifily Steephen[2], Elizabeth Thomas[3], Neethu Kumaran[4], Shema Sara Mathew[5]

[1]Associate Professor, Department of Civil Engineering, [2345]Undergraduate student,
[12345]Mar Athanasius College of Engineering Kothamangalam, India

Abstract: **Silos are tall structures used for storage of wide range of materials like cement, grains, carbon black, coal, sawdust etc. They are subjected to many different static and dynamic loading conditions, mainly due to the unique characteristics of stored materials. It is very difficult to determine the magnitude and distribution of stresses and their corresponding failure modes. In the present study, a steel silo stiffened externally with stringers and rings at equal intervals is adopted and a linear static analysis is conducted to determine the stresses and displacement occurring in it. Wind and earthquake loads often undermine the stability of the silos. This study also examines the effect of wind loads on the silo.**

Keywords: **ANSYS 14.5, Mechanical ADPL, Finite element modeling, linear static analysis, wind load, earthquake load.**

I. INTRODUCTION

Silos are tall structures used for storage of wide range of materials like cement, grains, carbon black, coal, sawdust etc., They are subjected to a variety of static and dynamic loading conditions, all dependent on the nature of material stored in it. It is very difficult to determine the magnitude and distribution of these stresses and their corresponding failure modes. High collapse rate of silos and lack of adequate remedial measures to counter it pushes forth the importance of a detailed study in the matter. Conventional methods of analysis are insufficient to handle the complexity of such a structure. Hence, analytical investigations are carried out using Finite Element Method. A linear static analysis of a cement storing steel silo is conducted to examine the nature of stresses and displacements occurring in the structure.

The silo considered is externally stiffened to stabilize the structure against the pressure of the stored material. Rings are provided along the circumference and stringers in longitudinal direction at definite intervals to carry out the reinforcing function. The effect of these stiffeners in increasing the stability of the structure is studied. Apart from the self weight of the silo and its internal pressure, there are wind and earthquake forces acting on it. These loads have many a times proven to be very detrimental to a silo structure. Various load combinations involving these loads have also been considered in detail in the analysis.

II. LITERATURE REVIEW

Sergio A Elasker and Luis A Godoy [1] studied the wall pressures in silos during gravity discharge of materials through it. Imperfections in the inner wall of the silo were found to bring about more pressure variations than the outer ones.

P. Vidal et al, [2] performed a three-dimensional finite element analysis of the filling of cylindrical silos having an eccentric hopper, using different boundary conditions—silos supported at the transition or on discrete columns

Adam J. Sadowski and J. Michael Rotter [3] explored the buckling in a moderately slender perfect silo with eccentric discharge condition.

S. Ding et al, [4] conducted a novel finite element analysis to explore the development of pressures and tractions on the wall of a full scale shallow hopper when it is filled with sand.

Shelly Thomas et al, [5] performed a non-linear dynamic analysis as well as pushover analysis of a 115m high chimney which was collapsed during an earthquake in Turkey and its response was studied using SAP 2000 software.

III. DETAILS OF SILO

The steel silo adopted for the case study is used for storing cement. It consists of a cylindrical portion fitted with external stiffeners (both in circumferential and longitudinal directions), a bottom hopper and a roof with an opening at the top. The cylindrical portion rests on staging support.

Dimension of the various parts are listed below:

1. Radius of cylindrical portion = 1.75 m
2. Height of cylindrical portion = 12 m
3. Silo roof has a slope of 60^0 with respect to horizontal
4. Thickness = 6 mm

Material properties of the steel:

1. Poisson's ratio = 0.3
2. Specific weight = 78.5 kN/m^3

Details of stiffeners used:

1. For horizontal stiffener: Inverted T section – ISNT 250 , 250 X 180 mm
2. For vertical stiffener: Inverted T section – ISNT 80, 80 X 80 mm

IV. LOADS ON SILO

Silo walls are mainly subjected to hoop tension due to the pressure exerted by the cement particles on the wall and axial compression due to the friction mobilized at the interface, in addition to the wall self weight. The magnitude and distribution of both shear and normal pressure over the height of the wall depend on the properties of the stored cement and whether the silo is being filled or discharged. The internal pressure of the silo was determined using Janssen's theory.

Silo, being a tall and slender structure, is also invariably affected by wind. Wind loads are an important factor to be considered in design of a silo. The distribution and magnitude of wind pressure on silo structure is to be calculated in accordance with IS 875 (Part 3) – 1987.

V. SILO MODEL USING ANSYS SOFTWARE

ANSYS is versatile finite element analysis software with many features aiding the modelling and analysis of a complex structure like silo. ANSYS Mechanical ADPL 14.5 is used for conducting the analysis for this study.

The thickness of the silo is very less when compared to its length. Also, membrane and bending deformations occur along its curved surfaces. To accommodate these features, a shell element was chosen. Of the various shell elements available in the ANSYS package, SHELL 181 was selected. For modelling the stiffeners, BEAM 189 element was chosen. The various geometric characteristics of the elements are discussed in Figure 1 and 2.

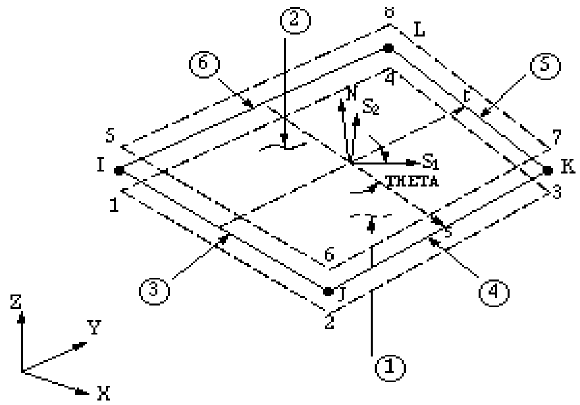


Fig.1: Shell 181 used for modeling silo structure

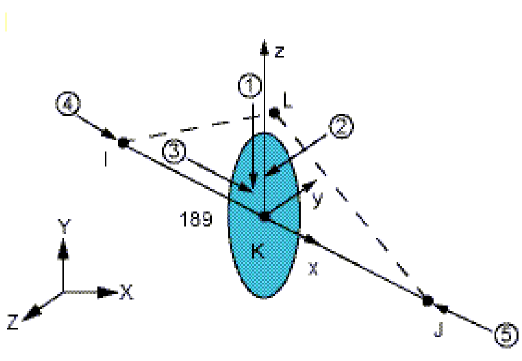
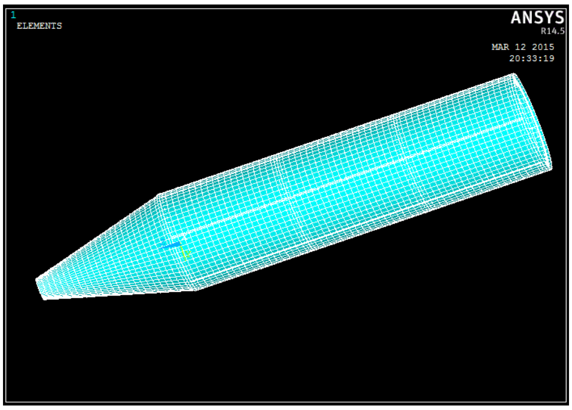


Fig.2: Beam 189 used for modelling the stiffeners in the silo

Vol. 3, Issue 1, pp: (1-5), Month: April 2015 - September 2015, Available at: www.researchpublish.com

Analysis of Stiffened Steel Model:

The analysis is done by idealizing the geometry, material and boundary conditions. The model of the stiffened steel silo and stiffeners are shown in Figure 3 and 4 respectively.



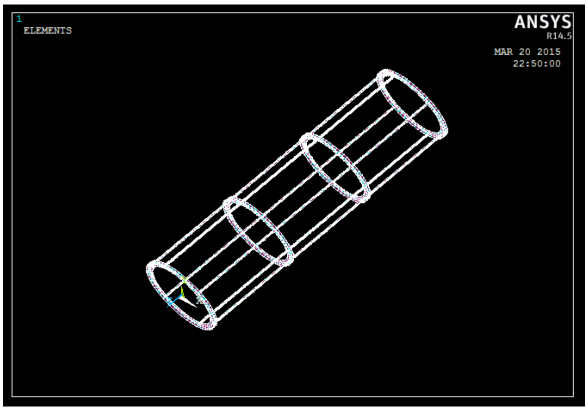


Fig. 3: Finite element model of silo

Fig. 4: Model of stiffeners

The behaviour of the silo under the following load combinations were considered;

Case 1: 1.5 (DL + LL)

Case 2: 1.2 (DL+LL+WL)

Case 3: 1.5 (DL +WL)

Fixidity is provided at the intersection between the cylindrical portion and hopper. The model of silo complete with boundary conditions is shown in Figure 5.

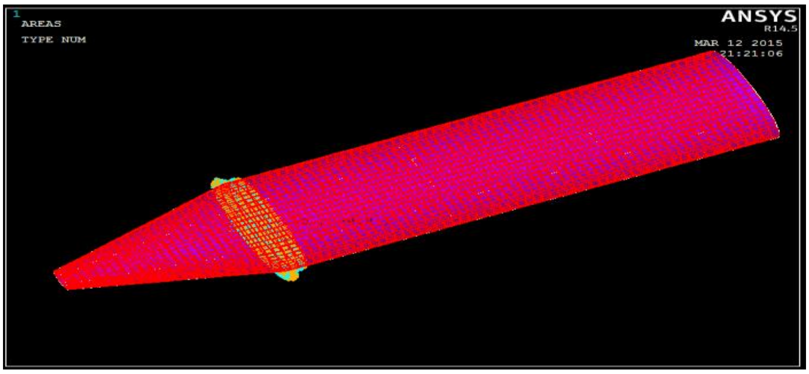
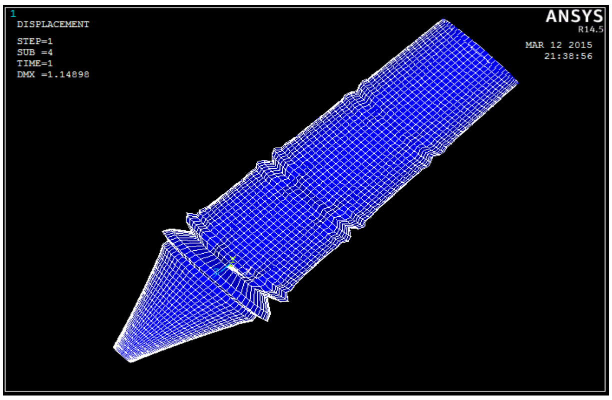


Fig. 5: Model with applied boundary conditions and loading

The deformed shape and stress intensities for Case 1 load combination is depicted in Figure 6 and 7 respectively.



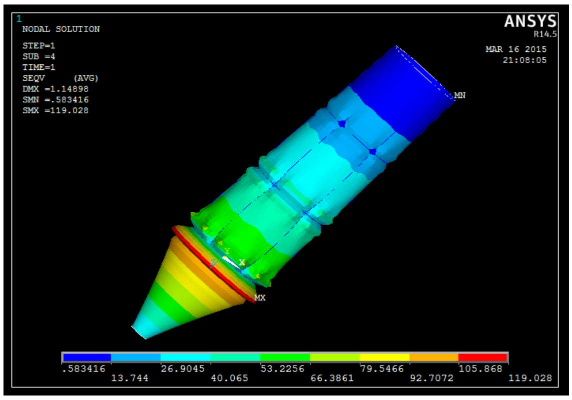


Fig. 6: Case 1- Deformed shape

Fig. 7: Case 1- Nodal solution for von Mises stress

There is negligible bulging of silo wall at stiffener locations and the bulging increases at distances away from the stiffeners. Also less stress value at stiffener locations. A maximum deflection of 1.14 mm was observed to be near the intersection between cylindrical portion and hopper. The maximum stress intensity was obtained to be 119.028 N/mm^2 at the portion below the transition ring.

Figure 8 and 9 shows the deformed shape and stress intensities for Case 2 load combination.

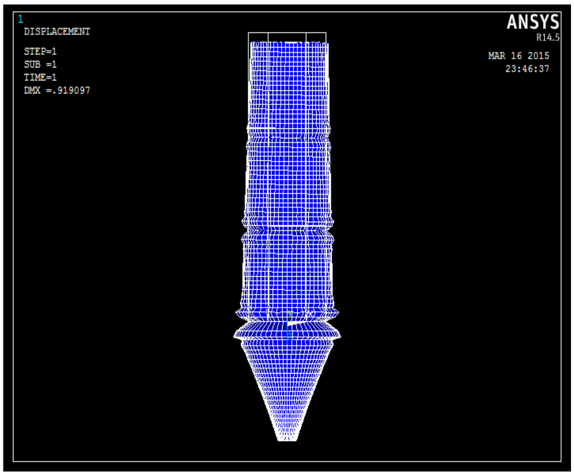


Fig. 8: Case 2 – Deformed shape

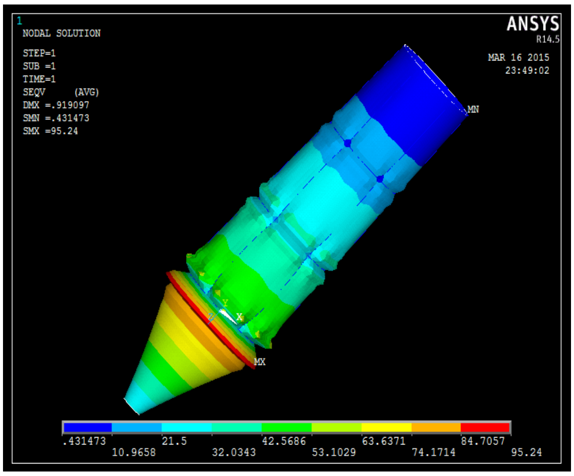


Fig. 9: Case 2 – Nodal solution for von Mises stress

A maximum deflection of 0.92 mm and maximum stress intensity of 95.24 N/mm^2 was obtained. The wind pressure acting on the external surface of silo wall is much smaller compared to the pressures exerted by granular solids acting on internal surface of silo wall. The positive wind pressure in the windward region is counter- balanced by part of the solid pressures and the negative wind suction is integrated with the solid pressures. This accounts for the lower value for deflection in load Case 2.

Representation of deformed shape and stress intensity for Case 3 load combination is given in Figure 10 and 11 respectively.

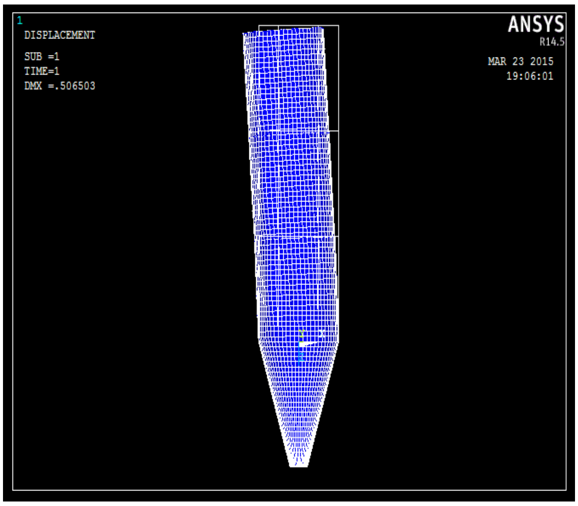


Fig. 10: Case 3 – Deformed shape

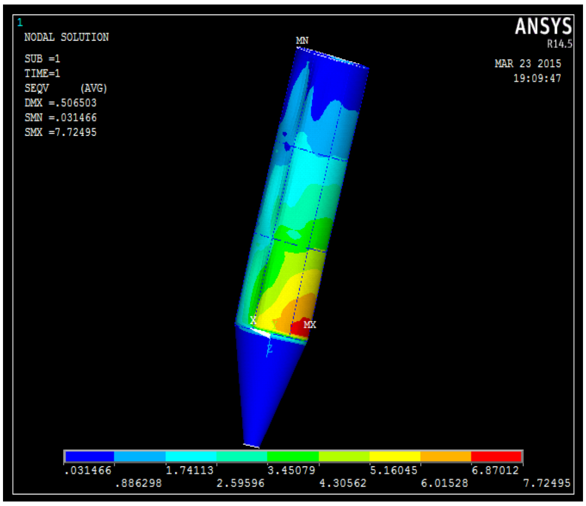


Fig. 11: Case 3 – Nodal solution for von Mises stress

A maximum deflection of 0.506 mm occurred near the upper portion of the cylindrical shell. The maximum stress intensity was found to be 7.72 N/mm^2 in regions above the transition ring.

VI. CONCLUSION

For the load cases 1, 2 and 3, the stiffener was found to perform its reinforcing action perfectly. Deflection and stress value was found to be minimal at the location of stiffeners and progressively increases away from it. All the stresses occurring in the silo in these load cases was also found to be within the permissible limit of steel. In combinations involving wind load, buckling is found to occur. This can be countered by reducing the spacing between stiffeners or by providing anchorage bolts. Load Case 2 as compared to Load Case 1 gave the least value for deflections due to the counterbalancing effect of live and wind loads.

REFERENCES

[1] Sergio A Elasker and Luis A Godoy, Effect of geometric distortions on wall pressures in silos during gravity discharge, PhD Thesis, University of Cordoba, Argentina.

[2] [2] P. Vidal, E. Gallego, M. Guaita, F. Ayuga, Finite element analysis under different boundary conditions of the filling of cylindrical steel silos having an eccentric hopper, Journal of Constructional Steel Research, Volume 64, Issue 4, April 2008, 480–492.

[3] Adam J. Sadowski and J. Michael Rotter, Buckling of very slender metal silos under eccentric discharge, Engineering Structures, 33(4), 1187-1194.

[4] S. Ding, J.M. Rotter, J.Y. Ooi, G. Enstad and D. Xu, Normal pressures and frictional tractionson shallow conical hopper walls after concentric filling: predictions and experiments, PhD Thesis, University of Adger, Norway.

[5] Shelly Thomas, Dr.Jaya V and Manju M, Non-linear analysis of reinforced concrete chimney, International Journal of Civil Engineering and Technology, 2012.

[6] Eugeniusz Hotala, Lukasz Skotny, Experimental investigations on the stability of stiffened cylindrical shells of steel silos, Journal of Constructional Steel Research, 2014.

[7] Yang Zhao, Qingshuai Cao, Liang Su, Buckling design of large circular steel silos subject to wind pressure, http://www.elsevier.com