

Design and Optimization of Silo using FEM

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Abstract

Circular cylindrical silo structures are prone to cross-sectional distortion (ovalisation), when subjected to pressure and wind loading. This ovalisation is resisted by the ring beam at the junction of intersection of silo wall and its supporting tower as well as in plane rigidity of the silo roof. This paper deals with such phenomenon using a finite element model in Ansys. A case study has been carried out using the pressure and wind load distribution as per relevant IS code of practice. Results obtained from the three dimensional finite element model of the silo clearly support the fact of transverse bending of the silo wall, which was empirically supported by the analytical model. It also shows that the values obtained thus are much on lower end compared to the results of analytical model in bending of silo wall in transverse direction, whereas it also evaluates longitudinal stresses, which are equally significant. Also the effect of cross-sectional distortion of the silo wall, i.e., the ovalisation is found to be critical only at middle one-half height of the silo wall.

Keywords: Silo, Design, Optimization, FEM

1. Introduction

Silos are widely used in a great many different industries for storing a huge range of different solids. The sizes of these silos may vary from capacities less than 1 tone to the largest containing as much as 100 000 tones. The size of the silo has a strong bearing on the number of different considerations required: small silos generally do not produce structural problems, but in large silos many different aspects need careful attention [1].

The designs used for silos also vary very much. In some industries (e.g. grain storage), there is a competitive industry producing standard silo products which function extremely well and cost-effectively provided the conditions remain those anticipated. In other industries (e.g. cement and mineral ore storage) very large silos are used and every silo must be individually designed for the special conditions. It should be noted that each silo is normally designed to contain a very limited range of solids, and that the use of a silo designed for one kind of solid to store different solids can easily cause damage. Bulk solids vary very much in their properties, and a silo

that is perfectly adequate to store one material may be very dangerous for another [2].

The terms silo, bunker, bin and hopper are often used to refer to similar containers in different industries. Here, the word 'hopper' is exclusively used with a special meaning for the converging part leading to a gravity discharge outlet. All complete storage containers are referred to as silos, irrespective of the stored solid, geometry and industrial sector. A characteristic form to describe the parts of the silo is shown in Figure 1. The transition, which lies at the junction between the vertical wall and the hopper, should be noted [3].

This chapter provides a brief outline of the development of understanding of pressures that develop in silos and their consequences for the safety of the silo structure. More structural failures occur in silos than in any other engineered structural form, considering the numbers of each, and these failures occur in all countries and all industries. Structural design considerations for silos are therefore a key aspect of bulk solids handling systems [4].

2. Modeling of silo structure

Modeling of silo is done in Pro-E, a 3D modeling package. The geometric details of the silo considered in this thesis are as follows.

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A 2000 tons capacity cement storage silo supported on 6 no's columns (Figure 1) has been considered. The column heads are connected with a ring beam at level (+) 12.0m, which is supporting the entire silo volume together with the conical hopper supporting the material. The silo wall thickness has been assumed as 200 mm and the other relevant-general arrangements have been shown in Fig 5.1. The main objective of this study is to evaluate the deformation of 30.0 m high silo wall when subjected to wind load and infer about the necessary steps to be taken up by the designers practicing professionals. It's important to note that the height of silo wall to diameter ratio is very close to 2.0 and hence may be considered as long [5-6].

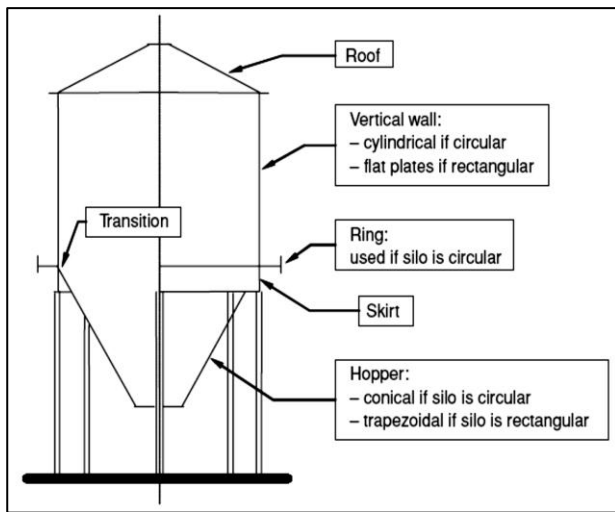


Fig. 1 Terminology for parts of a typical silo

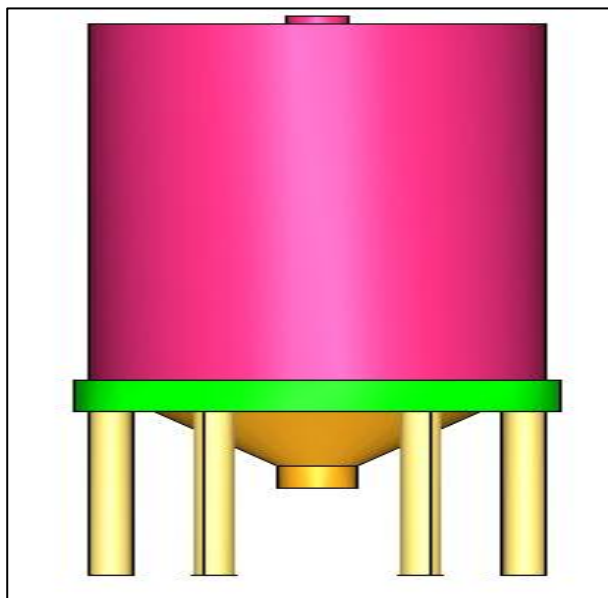


Fig.2 Silo structure designed in Pro-E

It is connected to the ring beam. So at the ends, the wall may well be assumed as rigidly connected, leading thereby deformation to its minimum. The bottom of the wall has been considered as fixed to the ring beam as it provides a good rigidity to arrest lateral sway of the combined. Although the topmost level is free to deflect, due to in plane rigidity and diaphragm action of the roof slab the total deflection is also minimized. If the end/support conditions are properly simulated with above knowledge in the mathematical model, one can readily understand that the maximum deformation takes place at a level close to the topmost level. The extent of this deformation of silo wall, i.e., ovalisation effect increases as the ratio of HID of silo increases beyond 2. In all cases the transverse shear due to wind load has been assessed following the method laid down by relevant IS code of practice, applicable to such Silo Structures. To derive the response of silo wall subjected to wind load, an annular ring of height unity has been considered and the same has been taken at the level between (+) 10.0m to 15 m. The horizontal load on such ring due to wind is calculated based on wind pressure distribution as per IS 875 Part – III[20] [7-12].

3. Material properties

Table.1 Material properties considered for silo

Material used	Youngs modulus (GPa)	Yield strength (MPa)	Poissons ratio	Density (Kg/m ³)
Steel	210	550	0.266	7860
Concrete reinforcement	250	300	0.17	2400

4. Results & discussion

4.1 Static Analysis

Static comparison between Steel and Reinforced Concrete Silo Structure are shown below with the help of Radial stress, Tangential stress, longitudinal stress, Von Misses stress, deflection plots and their comparative graphs are displayed along with the stress plots [13].

Silo storage Structure is shown in Figure 3 shows the Von Misses Stress value levels of according to the load and stricture, color bar is used to indicate the value range on model. Von-Misses stress depends on the von-misses theory of failure [14].

Silo storage Structure is shown in Figure .4 shows Von Misses Stress value levels according to the load and stricture, color bar is used to indicate the value range on model. Von-Misses stress depends on the von-misses theory of failure.

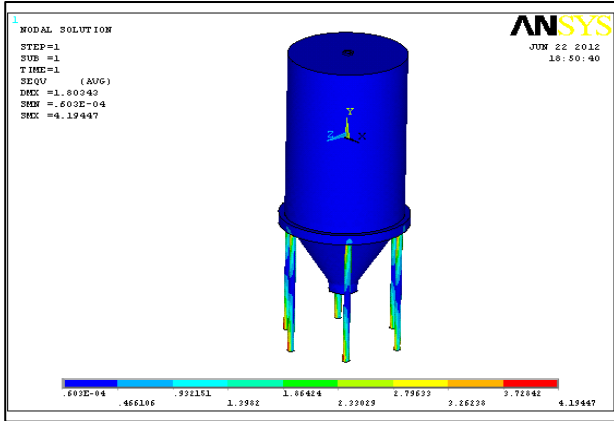


Fig. 3 Von Misses Stress 200 thick of Concrete Reinforcement

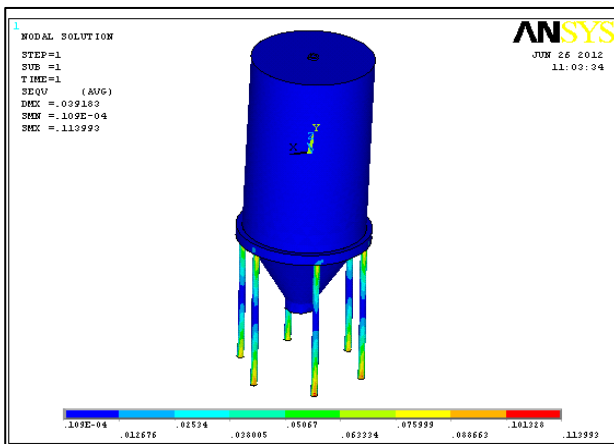


Fig. 4 Von Misses Stress 200 thick Steel

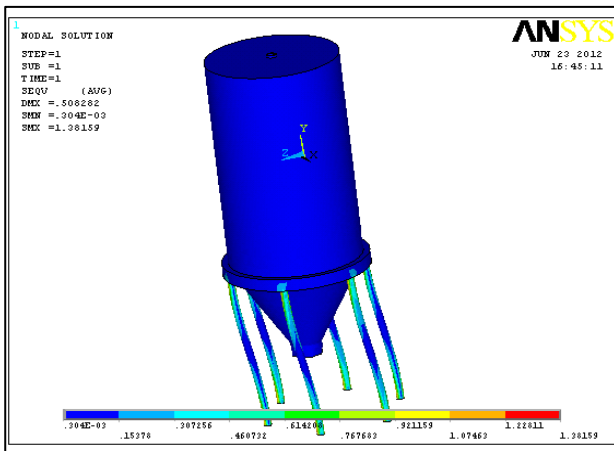


Fig. 5 Von Misses Stress 110 thick of Steel

Silo storage Structure is shown in Figure 5 shows Von Misses Stress value levels according to the load and stricture, color bar is used to indicate the value range on model. Von-Misses stress depends on the von-misses theory of failure [15].

4.2 Modal Analysis of Silo Structure

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable [16].

The types of equations which arise from modal analysis are those seen in Eigen systems. The physical interpretation of the Eigen values and eigenvectors which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes.

It is also possible to test a physical object to determine its natural frequencies and mode shapes. This is called an Experimental Modal Analysis. The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct (for example, correct material properties and boundary conditions were used) [17].

Here modal analysis is done for finding the natural frequencies, and how they vary under different conditions. The following figures represent the first six mode shapes of the Silo Structure of both Steel and concrete reinforcement [18].

4.2.1 Mode shapes of Steel structure with 200thick

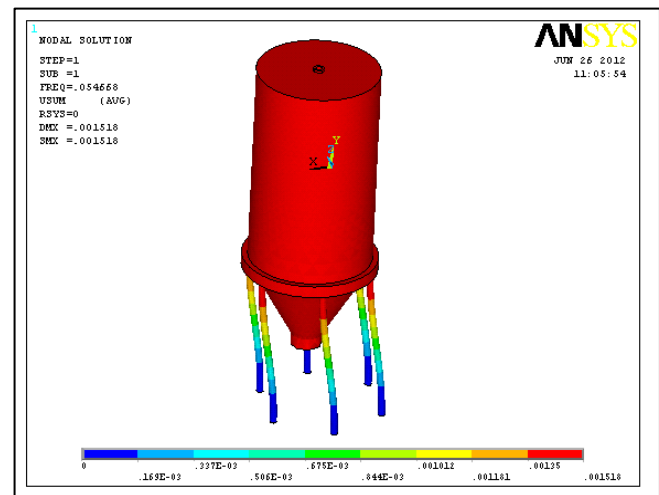


Fig.6 (a) First mode shape

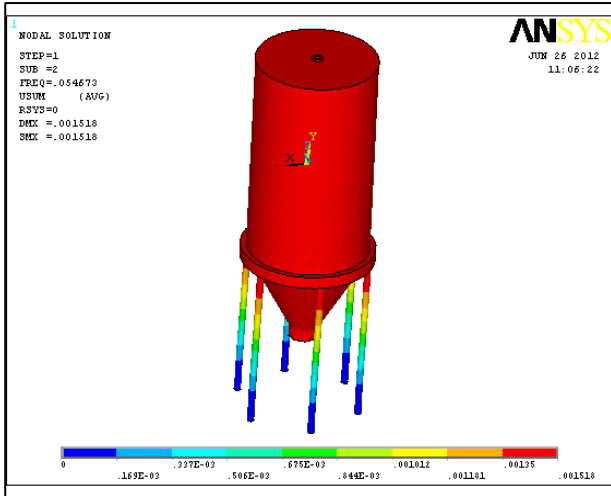


Fig.6 (b) Second mode shape

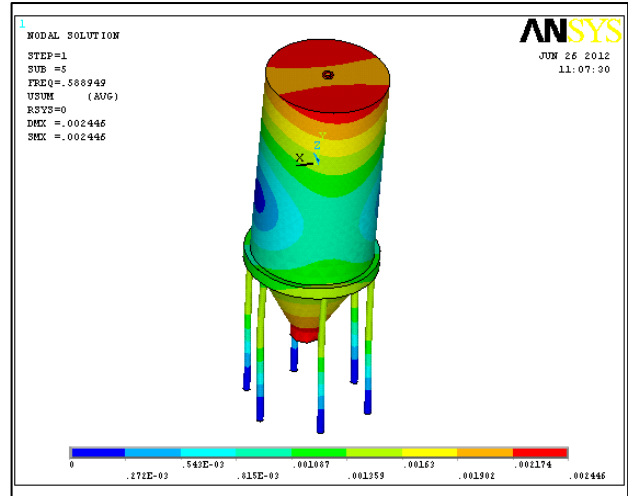


Fig.6 (e) Fifth mode shape

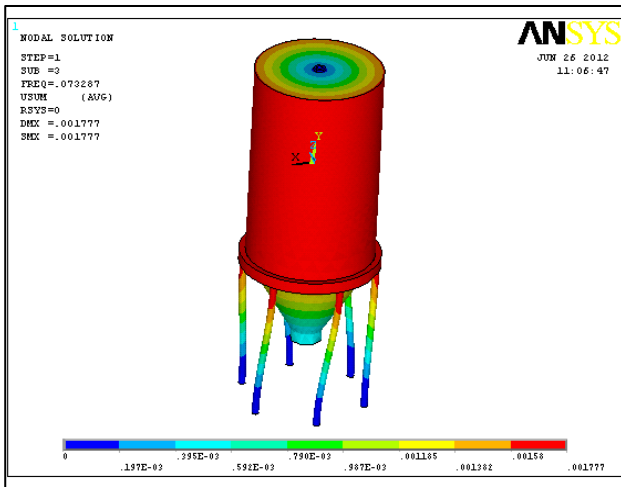


Fig.6 (c) Third mode shape

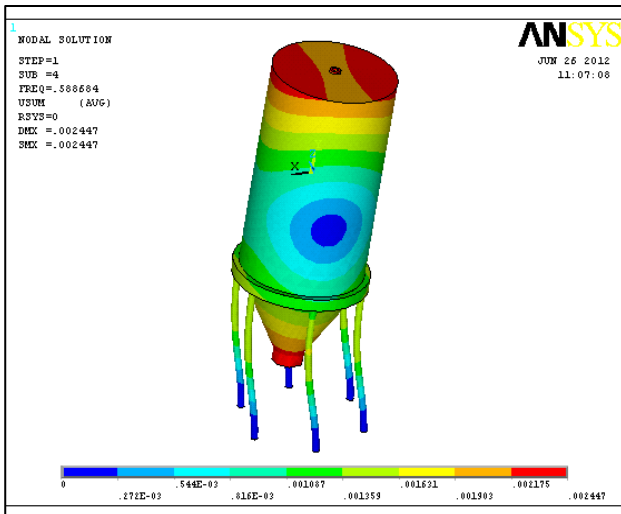


Fig.6 (d) Fourth mode shape

The above plots represent the first five mode shapes of Silo storage Structure. These values consider as natural frequency.

4.2.3 Mode shapes of Steel structure with 110thick.

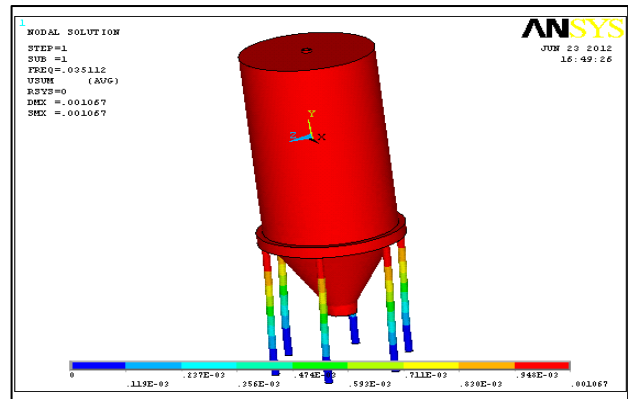


Fig.7 (a) First mode shape

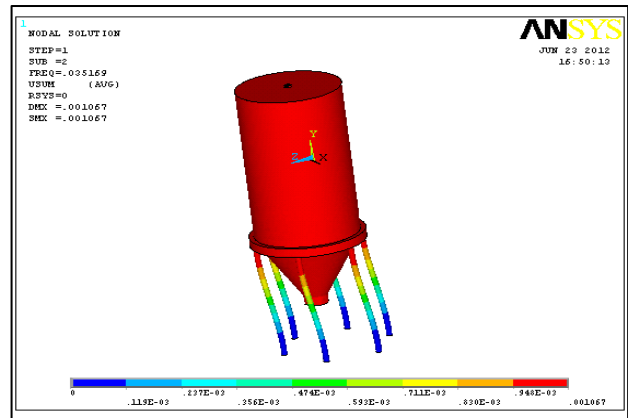


Fig.7 (b) Second mode shape

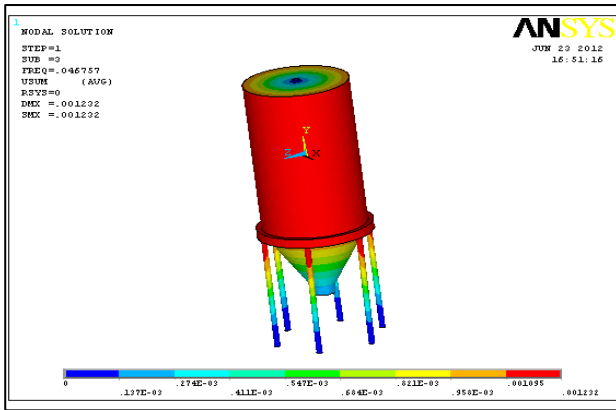


Fig.7 (c) Third mode shape

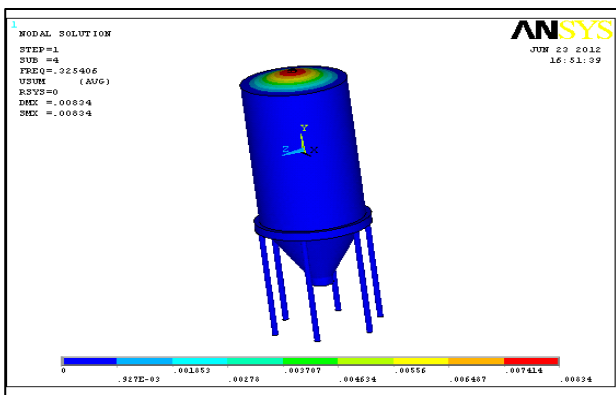


Fig.7 (d) Fourth mode shape

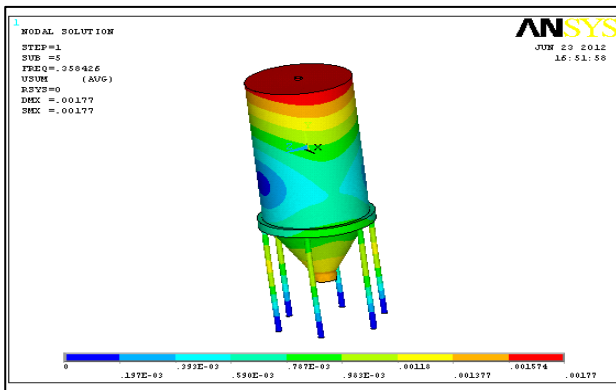


Fig.7 (e) Fifth mode shape

The above plots represent the first five mode shapes of Silo storage Structure. These values consider as natural frequency.

4.3 Harmonic analysis.

Commonly harmonic analysis is used to test the geometry under harmonic loads and also for the earth quack conditions.

4.3.1 Harmonic results for concrete.

Table 2 Modal Analysis summary

Natural Frequency	5	0.298116	0.588949	0.358426	6.34E-07
	4	0.297981	0.588868	0.325406	3.33E-07
	3	0.36749	0.073287	0.046757	2.16E-07
	2	0.27727	0.54673	0.035169	0
	1	0.27726	0.54668	0.35112	0
Mode shape	Concrete Reinforcement 200mm	200mm thickness	110mm thickness	80mm thickness	
		Mild steel			

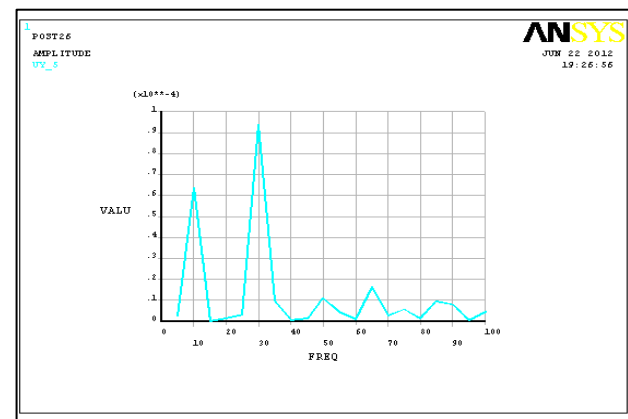


Fig.8 Middle of the Storage tank

4.3.2. Harmonic results for steel 200thick.

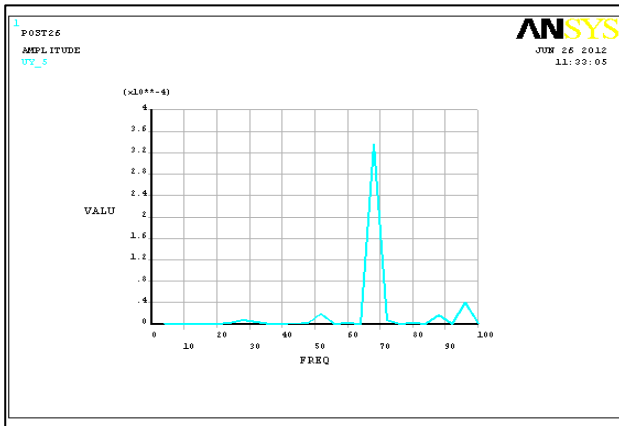


Fig.9 Middle of the Storage tank

4.3.3. Harmonic results for steel 110thk.

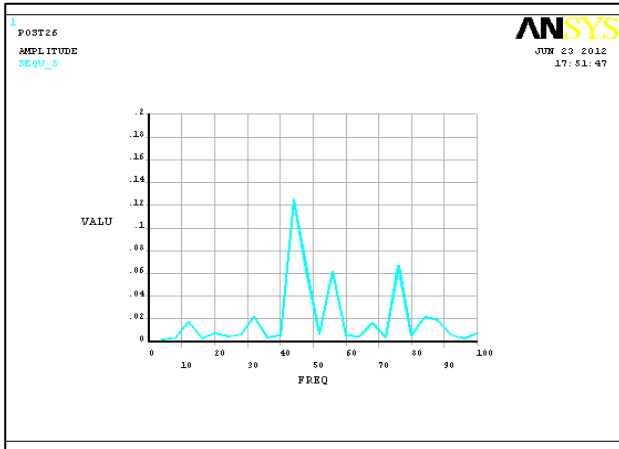


Fig.10 Middle of the Storage tank

4.3.4. Harmonic results for steel 80thick.

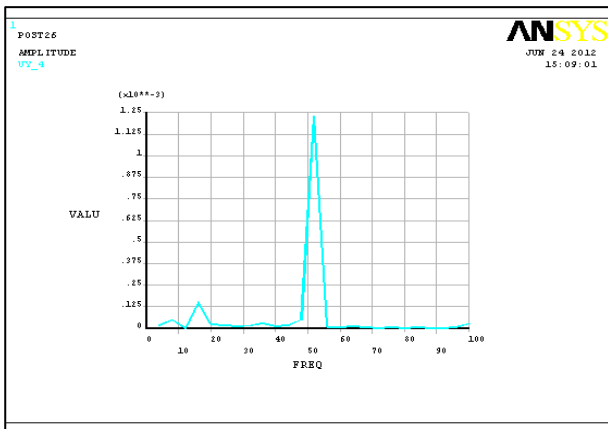


Fig.11 Middle of the Storage tank

The above graphs show displacement with the combination of frequency levels.

Table 3 Harmonic Analysis summary

Y-Directional shape deviations due to harmonic loads	Top of Storage tank	1.12E--4	1.70E-04	0.14	9.00E-04
	Middle of the Storage tank	9.00E-05	3.30E-04	0.12	1.24E-03
	At Beam	4.50E-05	5.70E-04	0.105	7.20E-04
	On pillar	2.40E-05	1.20E-04	0.091	4.50E-04
	At Base	5.60E-05	1.40E-04	2.60E-02	4.50E-04
Mode shape	Concrete Reinforcement 200mm	200mm thickness	110mm thickness	80mm thickness	
					Mild steel

4.4. Buckling analysis of Silo Structure

Along with the structural analysis and modal analysis of silo, buckling analysis is also done to study the deformation of the silo under buckling loads. First the loading conditions for buckling analysis are shown and then followed by the results of the analysis.

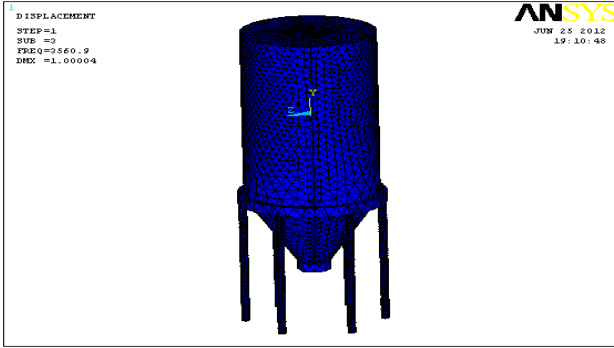


Fig.12 Buckle mode shape 3 for concrete

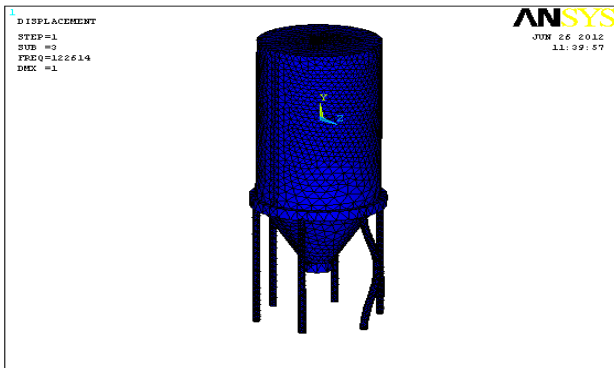


Fig.13 Buckle mode shape 3 for Steel 200thick

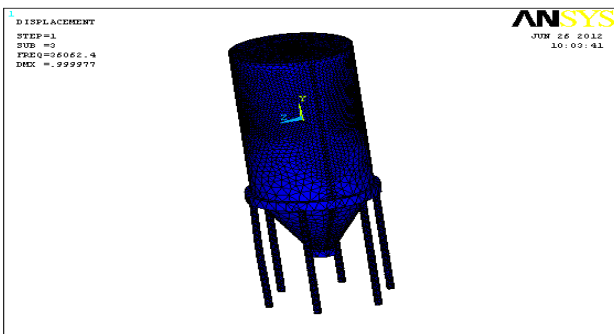


Fig.14 Buckle mode shape 3 for Steel 110thick

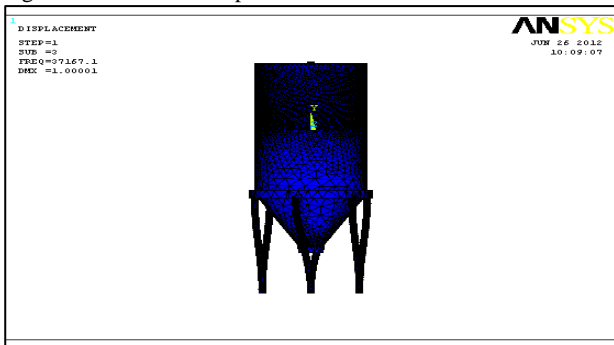


Fig.15 Buckle mode shape 3 for Steel 80thick

The above figure shows the displacement value under buckle load conditions.

Table 4 Buckling analysis summary

Displacement due to buckle loads				
Mode shape	1	2	3	
Concrete Reinforcement 200mm	1964	3545.1	3560.9	
Mild steel	200mm thickness	67043	120806	122614
	110mm thickness	16265	317088	36062
	80mm thickness	26290	26387	37167

Table 5 Cost analysis of silo structures

Design Considerations (Rupees)	Total Cost	12338087	116031410	73677995	6756350
	Cost of structure	2460087	102031410	59677995	53563510
	Maintenance	500000	875000	875000	875000
	Land usage	7500000	11500000	11500000	11500000
	Construction logistics	1500000	1375000	1375000	1375000
	Quality control	378000	250000	250000	250000
	Concrete Reinforcement	Steel 200mm thick	Steel 180mm thick	Steel 80mm thick	
	Materials used for silo structures				

6. Conclusion

Detailed three-dimensional numerical simulation on Steel and Concrete Reinforcement silo structure were carried out. Large internal loads were applied for static, modal, harmonic and for buckle analysis the structure is loaded internally and externally. The following conclusions can be made from this work.

1. The results revealed that in the case of static analysis the stress values varied when the thickness of wall is modified from 200mm to 110mm & 80mm.
2. Modal analysis shows the safety of the structure as the steel and concrete reinforcement structure easily undergoes the heavy loads applied on it, thereby giving uniform incremental Natural Frequencies
3. With the help buckling simulations carried on the on steel and concrete reinforcement silo structure we came to encounter that the structure may fail at the center region of legs.
4. The cost estimated to build silo structure designed in the report for steel is 6756350 Rupees, concrete reinforcement is 12338087 Rupees.
5. Here with the help of the complete study carried out in this project we came to know that the concrete reinforcement structure does compete with the steel structure in all aspects in a positive. This leads us to compare the Design Considerations.

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