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COMPARATIVE ANALYSIS OF REINFORCED CONCRETE AND STEEL SILOS: PERFORMANCE ASSESSMENT UNDER LATERAL LOADS

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Abstract

This article undertakes a comparative investigation into the lateral analysis of Reinforced Concrete and Steel Silos, which are commonly employed in agricultural and industrial settings. These structures bear typical pressures and axial compressive loads stemming from stored materials in addition to their own weight. Furthermore, they must withstand lateral loads resulting from wind or seismic forces. Utilizing finite element software, the analysis aims to juxtapose the performance of Reinforced Concrete and Steel silos. The findings indicate that Reinforced Concrete silos exhibit superior characteristics compared to Steel silos in industrial applications. Specifically, Steel silos demonstrate critical deformations, particularly in the central region of the structure, when compared to their concrete counterparts. Nonlinear time history analyses reveal that Steel silos experience greater displacement and stress levels than concrete silos. Additionally, a graphical representation depicting the structural behavior of Reinforced Concrete and Steel silos across varying thicknesses is provided.

Keywords: Catastropic, Deformation, Final Elemental Model, Ovalisation, Pretension, Ratcheting

1. Introduction

Bunkers and silos, structures designed for storing various materials like coal, cement, and food grains, are typically made of reinforced concrete nowadays, replacing steel structures due to easier maintenance and better architectural qualities. A silo, derived from the Greek word "siros," serves as a bulk material storage unit, supported by frames or reinforced concrete columns. It withstands normal pressures, axial compressive loads from stored material, and additional lateral loads from wind or seismic forces. Silo walls deform significantly under lateral loads, especially for silos with a height-to-diameter ratio exceeding one (H/D > 1), potentially leading to catastrophic collapse and loss of both material and life.
Numerous researchers have examined the buckling behavior of silo structures under lateral loads. For instance, [1] investigated ovalization of circular cylindrical walls in empty ground elevated RC silos, finding critical ovalization at the middle half of the wall height. Their work aids designers in understanding deformation patterns and stress distribution in silo walls. [2] noted the various loads silos endure, necessitating consideration of different design situations and load combinations based on silo type and operating conditions. [3] analyzed the buckling behavior of steel tanks with dome roofs under wind exposure, considering geometric imperfections and thickness reductions' effects on buckling strength. [5] explored

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silo damage and failures, including explosions, asymmetrical loading, soil pressure variations, corrosion, concrete deterioration, internal collapse, and thermal effects.
An analysis of a steel silo at RMC, Ernakulam, modeled in SAP software, compared its behavior with a concrete model by altering material thickness, revealing displacement and stress characteristics through graphical representation.

2. Computational Model

2.1 Finite Element Model

A 100-tonne capacity cement steel silo, supported by 4 steel pipes, has been simulated in SAP software (see Figure 3). The steel pipes connect with the steel cylinder at a height of 2.2m, bearing the entire silo volume along with the conical hopper supporting the material. The steel silo's wall thickness is assumed to be 10mm, with a total height of 11.5m and a diameter of 1.6m for the cylinder. The base of the steel pipe is fixed to the foundation. Maximum deformation occurs near the topmost level, increasing as the height-to-diameter ratio (H/D) of the silo exceeds 2.
A similar model is analyzed by replacing the material with Reinforced Concrete, comparing stress and displacement behavior under wind or seismic loads. Horizontal wind loads on the cylinder are calculated based on wind pressure distribution according to IS 875 Part-III. The steel material is assumed isotropic and elastic, with Young's modulus of 21000 MPa, Poisson's ratio of 0.3, and mass density of 7.8e-9 t/mm^3, while concrete is assumed similarly with Young's modulus of 25000 MPa, Poisson's ratio of 0.17, and mass density of 2.4e-9 t/mm^3.
The 3D silo model is analyzed in SAP to obtain deformation and stress values in various directions—windward, leeward, and perpendicular—under wind or seismic forces.

Figure 1 Steel Silo at RMC, Ernakulam

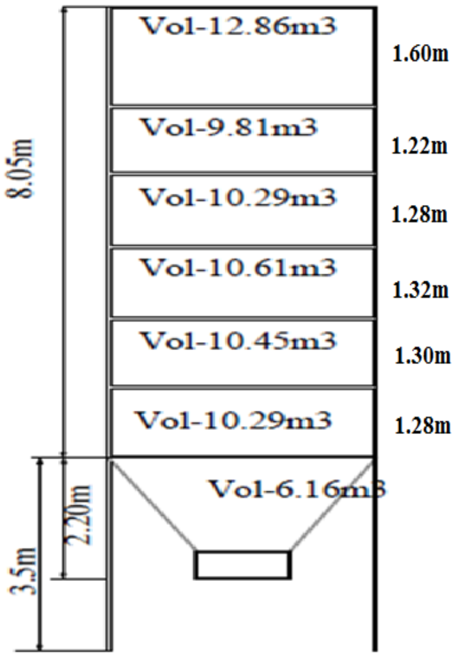

Figure 2 Silo Model in AUTOCAD

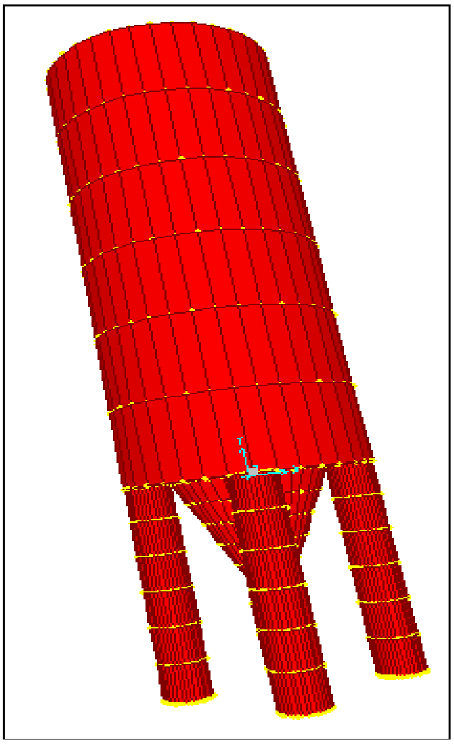

Figure 3 3D Model in SAP

3. Behaviour of Silos Under Lateral Loads

The response of structures to earthquakes is a multifaceted, three-dimensional, nonlinear, dynamic issue. Two analysis methods, linear and nonlinear, are used to represent this response. The analysis aims to ascertain the distribution of forces and deformations induced in the structure by ground shaking. Linear analysis applies to structures responding elastically. Earthquake-induced ground motion can cause structure vibrations. Static analysis can be manual or software-based. The present analysis considers self-weight and two wind load cases. Horizontal wind loads, applied perpendicular to the cylindrical silo face, are calculated following IS 875 (part 3)-1987 procedures and applied to the silo's cylindrical portion nodes. Dynamic analysis provides a nominal measure of expected responses, ensuring adequate structural behavior.

A linear modal analysis is conducted on each model, based on stiffness after the nonlinear pretension load case. Though mode shapes and frequencies may differ if analyzed with the silo in a deformed state, this analysis still provides insight into initial silo behavior. Time history analysis, considering all structure modes, is assumed to yield more accurate results than other linear methods. Altadena earthquakes are chosen for analysis, with the selected accellogram from an earthquake on June 28th, 1992, at 11:57:34, with a magnitude of 7.6 (6.2 MB, 7.6 MS, 7.3 MW, Depth 0.7 mi), occurring 91.7 miles from Altadena Center.

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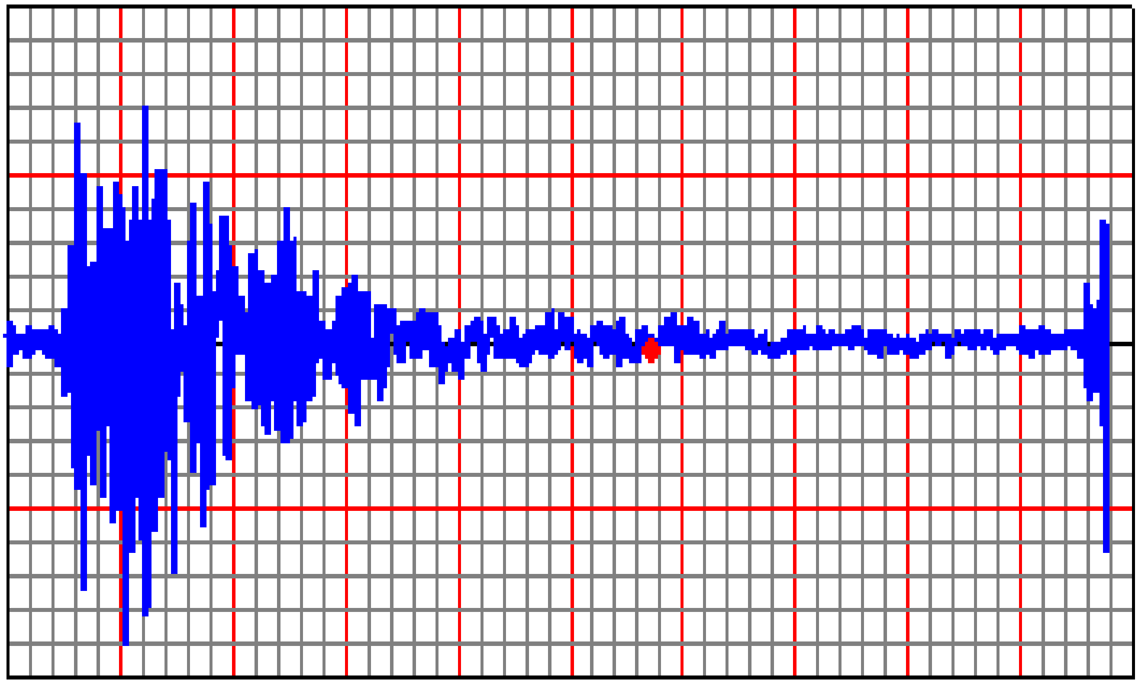
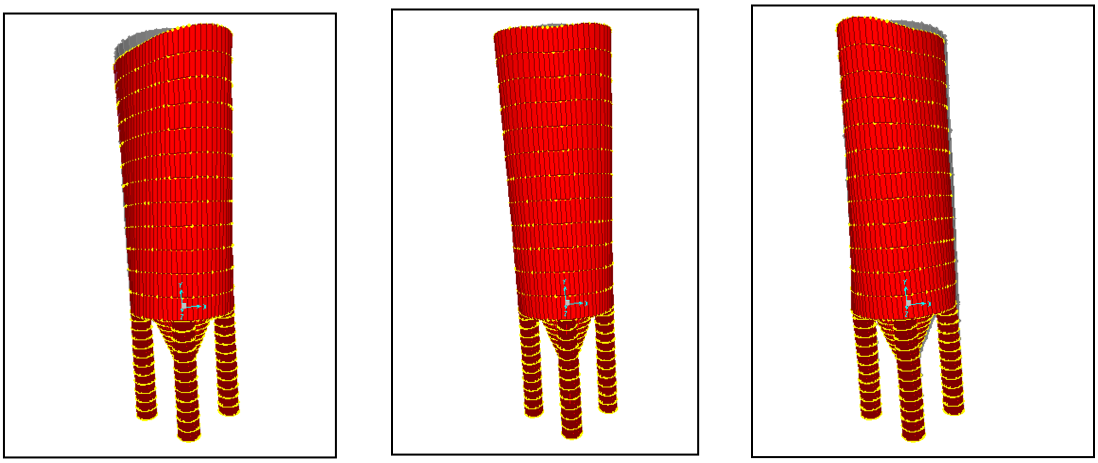


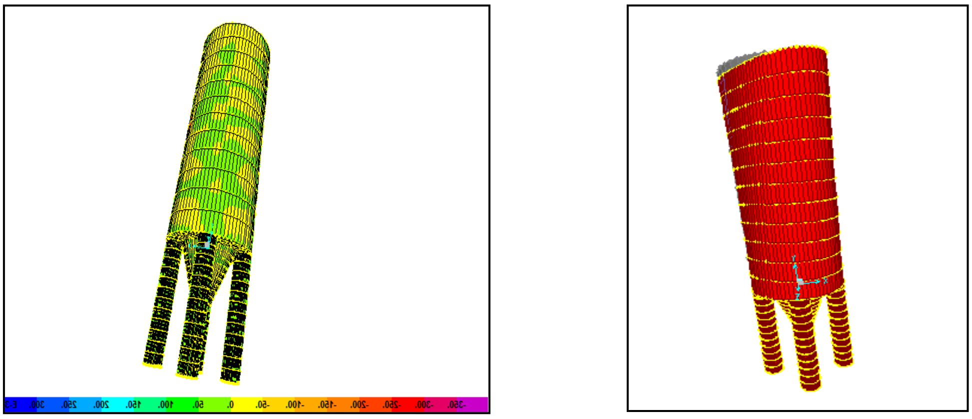


(a)Mode 1 (b)Mode 2 (c)Mode 3

Figure 4 Different modes at time period (a) 0.3718 s (b) 0.14569 s (c) 0.14533 s

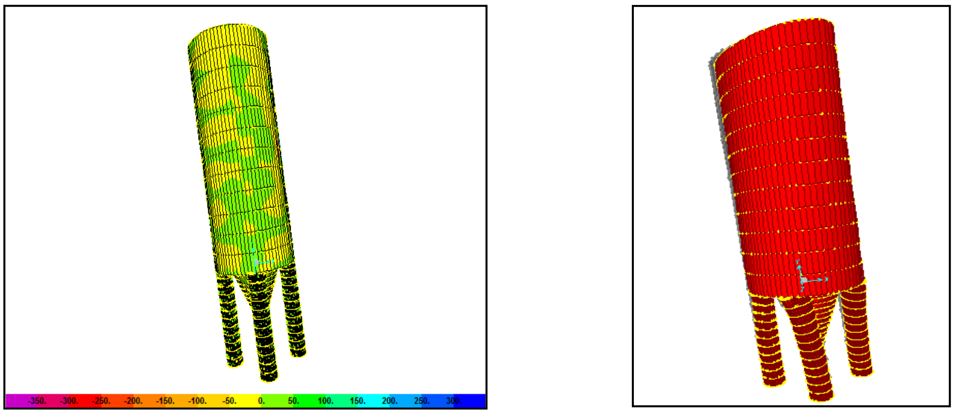
4. Results and Discussion

Figure 5(a) and Figure 5(b) shows the stress diagram and displacement diagram of the model in SAP due to the application of wind load without live load and Figure 6 shows the stress diagram and displacement diagram of the model due to the application of wind load with live load condition. The figure shows that during empty condition deformation and stresses will be more than that of loading condition. By comparing both reinforced concrete and steel silo structures stresses and displacement will be more for reinforced concrete silo structures. From the time history graph also it can be concluded that stresses and displacement will be more for reinforced concrete silo structures shown in the Figure 7 and Figure 8.



(a) (b)

Figure 5 Due to the application of wind load without live load (a) Stress Diagram, (b) Deformed Shape



(a) (b)

Figure 6 Due to the application of wind load with live load (a) Stress Diagram, (b) Deformed Shape

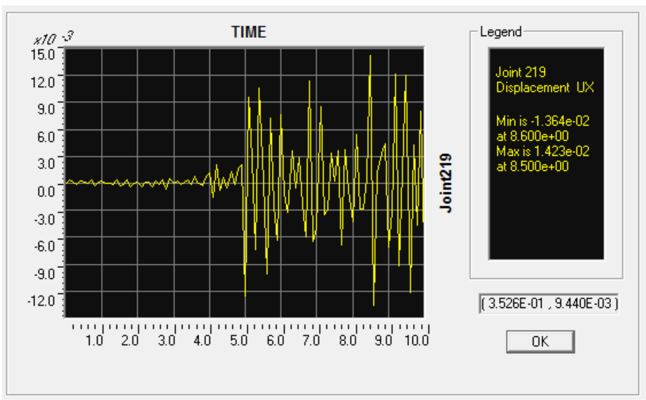


Figure 7 Time History Graph shows the displacement at the top portion of the Steel Silo

Table 1 displays the stress values (in MPa) for steel silo structures subjected to wind loads, with and without live loads. Similarly, Table 2 presents the stress values (in MPa) for reinforced concrete silo structures under wind loads, with and without live loads. The stresses are assessed in three directions: windward, leeward, and perpendicular.

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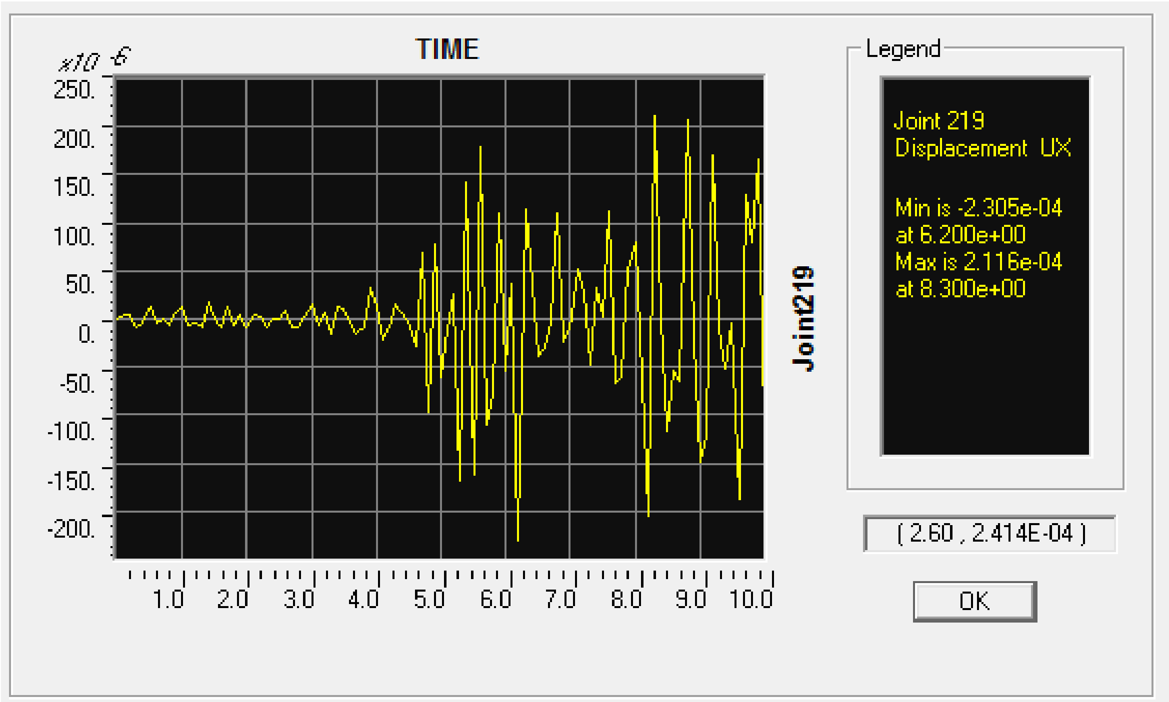

Figure 8 Time History Graph shows the displacement at the top portion of the Reinforced Concrete Silo structure

Table 1 Stress (MPa) on RMC Silo (Steel) due to the application of wind load with and without live load

WINDWARD SIDE	HEIGHT(m)	SOFTWARE (W/0 LOAD)	SOFTWARE (WITH LOAD)
	5	-0.4879	-0.6935
	8	-0.0451	-0.0641
	9	0.0452	0.091
	11.5	0.0651	0.082
LEEWARD SIDE	5	0.123	0.251
	8	0.087	0.094
	9	0.193	0.265
	11.5	0.0422	0.0744
PERPENDICULAR	5	-0.201	0.229
	8	0.4811	0.554
	9	0.548	0.788
	11.5	0.2553	0.528

Table 2 Stress (MPa) on RMC Silo (Concrete) due to the application of wind load with and without live load

WINDWARD SIDE	HEIGHT(m)	SOFTWARE (W/0 LOAD)	SOFTWARE (WITH LOAD)
	5	-0.207	-0.117
	8	-0.0173	-0.0090
	9	0.058	0.0979
	11.5	0.078	0.0941
LEEWARD SIDE	5	0.427	0.593
	8	0.093	0.0968
	9	0.206	0.323
	11.5	0.0651	0.809
PERPENDICULAR	5	-0.276	-0.105
	8	0.516	0.941
	9	0.608	0.807
	11.5	0.399	0.784

Table 3 and Table 4 illustrate how the structure's behavior changes with different materials and varying material thicknesses. Figure 9 and Figure 10 depict graphs representing the behavior of steel and concrete, respectively, as the thickness of the material varies.

Table 3 Displacement and Stress behaviour of steel silo structure at various thickness

THICKNESS OF THE PLATE (mm)	DISPLACEMENT (mm)	TOTAL MAXIMUM STRESS (MPa)
10	83.4418	394.170
20	59.1418	557.508
25	0.0248	3721.611
30	-0.1105	3431.359
40	-0.2157	3029.917

Table 4: Displacement and stress behaviour of concrete silo structure at various thickness

THICKNESS OF THE WALL (mm)	DISPLACEMENT (mm)	TOTAL MAXIMUM STRESS (MPa)
10	-115.4959	0.350
20	-271.1878	0.210
25	-79.7291	0.173
30	16.1447	0.146
40	-16.3032	0.110

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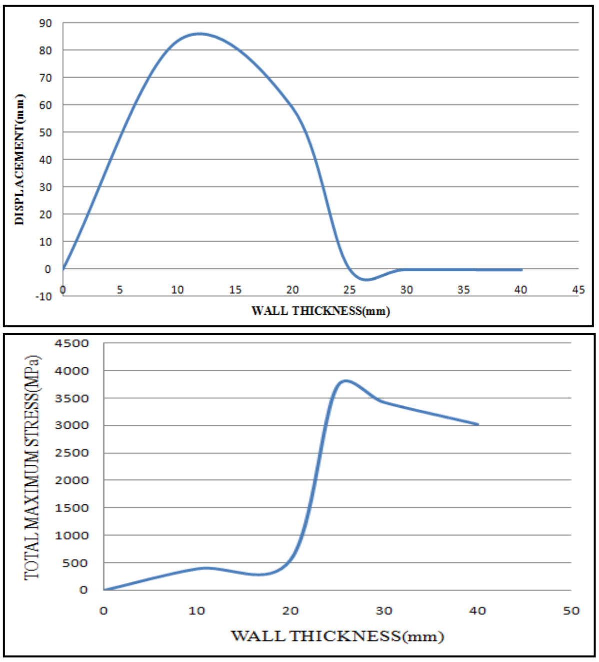

Figure 9 Graph representing the relation between Displacement and Stresses with Wall thickness of Steel silo

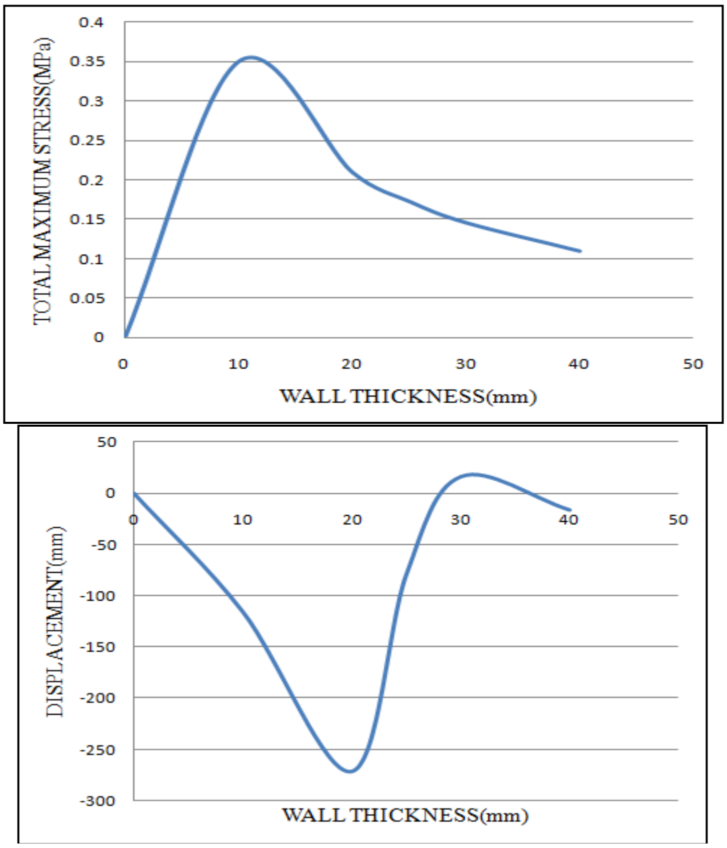

Figure 10 Graph representing the relation between Displacement and Stresses with Wall thickness of Reinforced Concrete silo

5. Conclusion

Stresses resulting from wind loads, both with and without live loads, were analyzed and tabulated at various levels for both Reinforced Concrete and Steel silos. The investigation revealed that Steel silos exhibited higher stress and displacement compared to Reinforced Concrete silos under wind loading conditions. Critical deformations were identified primarily at the middle section of the structure in both cases, with the steel structure displaying a more pronounced effect. Nonlinear time history analysis further confirmed that Steel silos experienced greater displacement and stress compared to Reinforced Concrete silos. Additionally, the behavior of stress and displacement concerning different thicknesses of Reinforced Concrete and Steel silos was documented and graphically represented.
Analysis of the graphs revealed several insights:

- In Steel silos, increasing plate thickness led to reduced displacement but increased stress, although this approach was deemed uneconomical due to escalating costs.
- Conversely, in Reinforced Concrete silos, increasing wall thickness resulted in higher displacement but reduced stress.
- Optimal thickness recommendations were provided: 10mm for Steel silos with 100-tonne capacity, supplemented by 3mm ring stiffeners at intervals to mitigate displacement and stress; and 30mm for Reinforced Concrete silos with the same capacity.
- A notable advantage of Steel silos is their potential for reinstallation in case of failure, whereas Reinforced Concrete silos necessitate costly reconstruction following collapse.

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