# SEISMIC ANALYSIS OF ELEVATED STEEL SILOS UNDER DIFFERENT FILLING CONDITIONS

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**ABSTRACT**

*Silos are industrial storage facilities used for many materials. Seismic analysis for such structures are more complex and thus be designed to resist several loading conditions and their seismic response. The main objective of the study is to determine the behavior of seismic responses (base shear variation, overturning moment, roof top displacement, and time period) for different cases depending on the filled conditions as 100%, 75%, 50%, 25% and 0% and to understand the behavior in order to meet up safety objective in conjugation with construction and maintenance cost. A cylindrical elevated silo is modelled in Staad Pro V8i with axi-symmetric geometry solids and seismic load is applied on the same for the above mentioned 5 cases. A Parametric study of the responses developed in the silos is presented. IS 1893 (part I): 2002 is considered while designing the silos and Clinkers are considered as the silo content.*

***Keywords: Base Shear, Clinkers, Elevated Silos, Dynamic Analysis, Staad Pro V8i.***

## I. INTRODUCTION

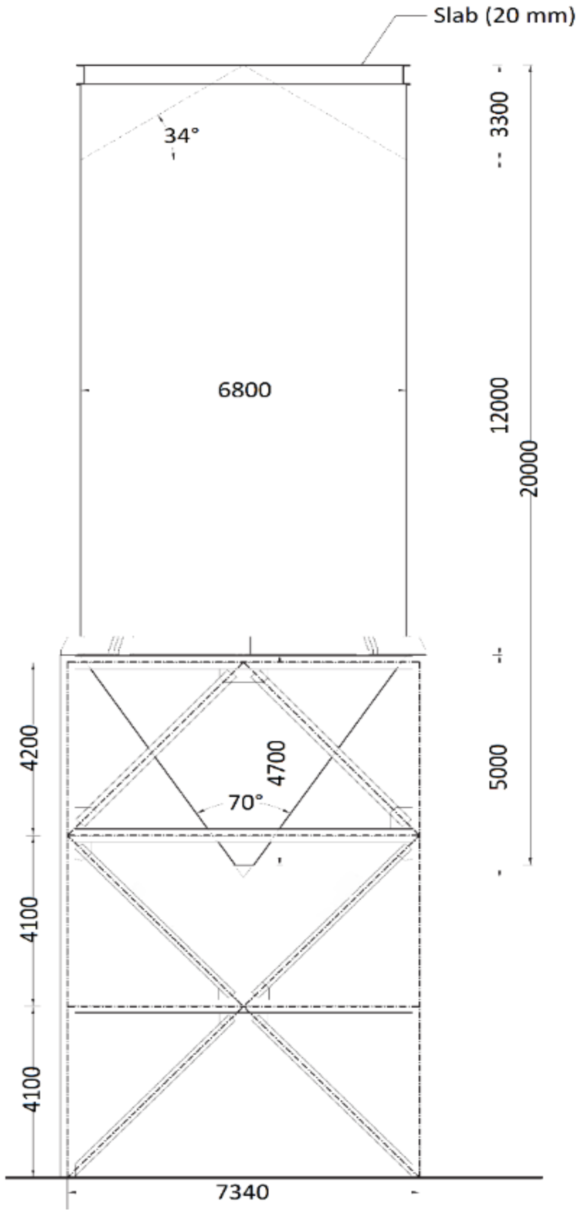
Elevated Silos are very vital structures subjected to different unconventional loading acting like a cantilever with the stored material stacked up very high vertically, thus susceptible to earthquake. Even though Silos account for very less number but their importance is very high, and deformation in its shape leads to accumulation of stresses, thus influencing significant wall pressure [Haroun and Housner, 1981]. More over the Codes are very old and do not cover many aspects as dynamic fluid structure interaction, anisotropy, etc. Many researchers have developed an approximated numerical models, and almost all the researchers have studied and concludes the importance of pressure on the stored material on the walls, especially during the discharge phase, but very little attention has been given for the seismic response of the same. It is essential to ensure that the utility functions are not hampered during an earthquake and also after it. The dynamic response of other storage structures like water tank, etc. has been carried out widely for the past 50 years but still not much work has been carried out on Silos, resulting in Silos failure every year and loss of life too, thus imposing an urgent need to investigate on itself. Due to the complex behavior of stored material it becomes even more complex to analyse the response, also the interaction between the stored material and the silo wall is nonlinear. This interaction make it very difficult to formulate a theoretical problem statement. For example, the earthquake can damage the upper portion of the silo if it tends to oscillate the material inside the silo, also the response of lateral flow is unaccounted for which plays a key role in it response. The wall pressure is the main parameter while analysing the silo, defining the safety, maintenance and efficiency of silo. Thus there is urgent need to safeguard the structure, as for the seismic activities are increasing their frequency over the period of time. In this paper a silo is modelled in StaadPro considering clinkers is as the stored material and the silo is filled in different layers

(0%, 25%, 50%, 75%, 100% filled cases). Seismic behavior of the different conditions was analysed and their pattern was noted, all in according with IS 1893: 2002.

## II. STRUCTURE DESCRIPTION

Elevated Steel Silo of circular shaped is to be analysed. The Silo is located in Dehradun City which is having Special moment resisting frame. The height of container is 17.7m up to slab top of container. For circular shape diameter is 6.8m. The staging of structure contains 4 No. of columns as ISHB 350. Also diagonal braces are ISMC 350 and the horizontal bracing are ISHB 300. The beam (C Channel) at the top of hopper connecting the silo to the stand is taken as ISLC 400.

| | | | |
|---|---|---|---|
| **Wall thickness** | 6mm | **Modulus of elasticity** | 20000MPa |
| **Radius** | 3400mm | **Poisson's ratio** | 0.29 |
| **Total Height** | 20000mm | **Density of clinkers** | 16.5 kN/m3 (IS 4995 part I): 197 |
| **Cylindrical height** | 12000mm | **Angle of friction between wall and clinkers** | 36° (IS 4995 part I): 197 |
| **Hopper Height** | 5000mm | | |
| **Hoper half apex angle** | 35° | **Coefficient of wall friction(μ)** | 0.7 |




## III. METHODOLOGY

Design of new silos and safety evaluation of existing silos should be carried out with a great level of accuracy because the failure silos during an earthquake, may be disastrous. The work presented in the paper is directed towards analysing the elevated silo by finite element method, as it is most efficient method available today for analysis. This method can be used for analysis of having any combinations and type of loading. Taking into account these facts, the following objectives have been put forward.

1. To compare the dynamic response of elevated reservoir.
2. After verification of results, linear dynamic analysis of elevated steel silo is carried out by using STAAD Pro, V8i, for ascertaining the seismic capacity of structure by considering changes in storage levels such as for empty condition, 25%, 50%, 75% and 100% storage levels.

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3. A comparison is done between their responses.

## IV. DISCUSSION

In designing a silo, the forces induced depends upon many factors, like material properties like particle (moisture, temperature, consolidating pressure, etc.),flow pattern( mass flow, funnel flow, eccentric flow,etc.) , Silo type, type of silo wall, etc. In this problem, the silo is considered to be of steel, of a uniform thickness (6mm), considering clinkers as the stored material, and the flow induced is found to be mass flow for the material. Janssen equation is used to find out the pressure on the cylindrical walls of thickness D, it is given by:

$$p = (\frac{\gamma D}{4\mu})[1 - e^{-4\mu K_j \frac{z}{D}}] \quad \ldots \quad (1)$$

$$\tau = \mu * p \quad (2)$$

$$\mu = \tan\phi' \quad (3)$$

Here $z = z_1 + z_2$ (z starts with 0 at the top).

While, for the Hopper; the pressure is given by;

$$p = \gamma\left[\frac{h-z}{ni} + \left(\frac{q}{\gamma} + \frac{h}{ni}\right)\left(1 - \frac{z}{h}\right)^{ni+1}\right] \quad (4)$$

$$n_i = 2\left(1 + \frac{\tan\phi'}{\tan\theta_c}\right) - 3 \quad (5)$$

Where;

h = hopper height

$K_j$= Janssen ratio of horizontal to vertical pressure

p =pressure acting normal (*i.e., perpendicular*) to a silo or hopper wall

q = vertical pressure acting at top of hopper

z = vertical coordinate

$z_1$ = vertical distance along cylinder wall starting at point of intersection of top pile

$z_2$ = additional vertical height added to $z_1$ to account for pile height

□= bulk density

□$_c$= conical hopper angle (measured from vertical)

□= coefficient of sliding friction between bulk solid and wall surface

□= shear stress acting along wall surface in direction of flow

□ □= wall friction angle between bulk solid and wall surface

The mode shaped considered is 100. This was carried out to increase the mass participation factor to more than 90 percent, as specified by IS 1893: 2002 (part 1), also it suggests a missing modal weight percentage to be a maximum of 10 %. Almost for all the cases, the codes specification was obtained after 60- 70 mode shapes.

## V. RESULT

Results for the important seismic parameter is shown below, in tabular and graphical representation.

Note: Seismic force is applied in X direction, where X & Y are horizontal direction (along the ground) while Z is the Longitudinal direction.

### 5.1 Maximum Roof Top Displacement:

For the roof top displacement maximum displacement in Z direction was observed for half-filled condition. This effect can be explained by the effect of buckling, as the combined effect of horizontal pressure and vertical load (due to the weight of clinkers) gave the critical condition for this case. It is also observed that the displacement increases 4.5 - 5.5 times from empty to completely filled case (for X and Y range).

| Filling Condition (%) | X (mm) | Y(mm) | Z(mm) |
|---|---|---|---|
| 100 | 9.833 | 1.663 | 0.01 |
| 75 | 6.938 | 1.179 | 0.01 |
| 50 | 5.319 | 0.941 | 0.02 |
| 25 | 3.768 | 0.634 | 0.01 |
| 0 | 2.216 | 0.305 | 0 |

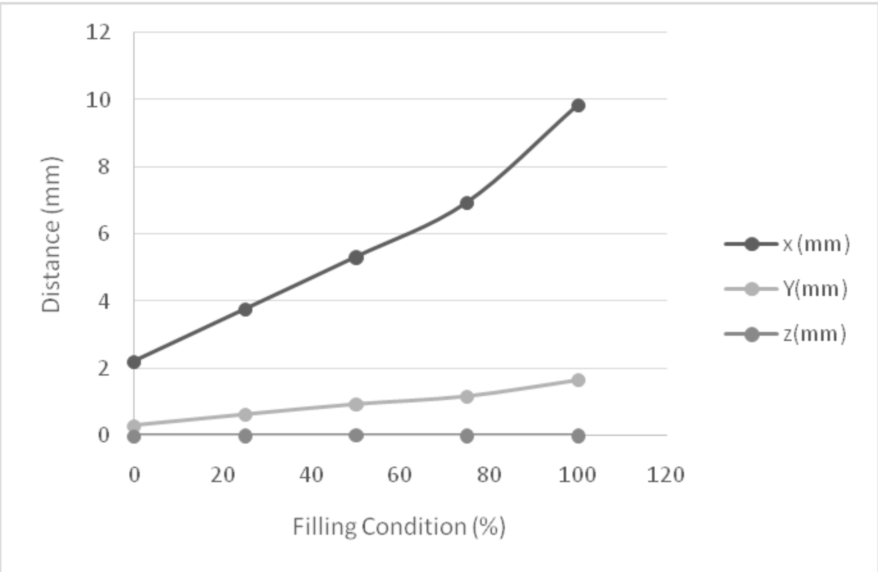


**Figure 1: Comparison of maximum roof top displacement.**

### 5.2 Maximum Jacket (at the top of Hooper) displacement:

Similar to the roof top displacement it is observed that the deflection increases to 5-5.8 times in case of 100% filled case with respect to completely empty condition (for X and Y range)

| Filling Condition (%) | X (mm) | Y(mm) | Z(mm) |
|---|---|---|---|
| 100 | 4.275 | 1.698 | 0.343 |
| 75 | 3.036 | 1.192 | 0.241 |
| 50 | 2.287 | 0.936 | 0.19 |
| 25 | 1.546 | 0.625 | 0.119 |
| 0 | 0.855 | 0.292 | 0.045 |

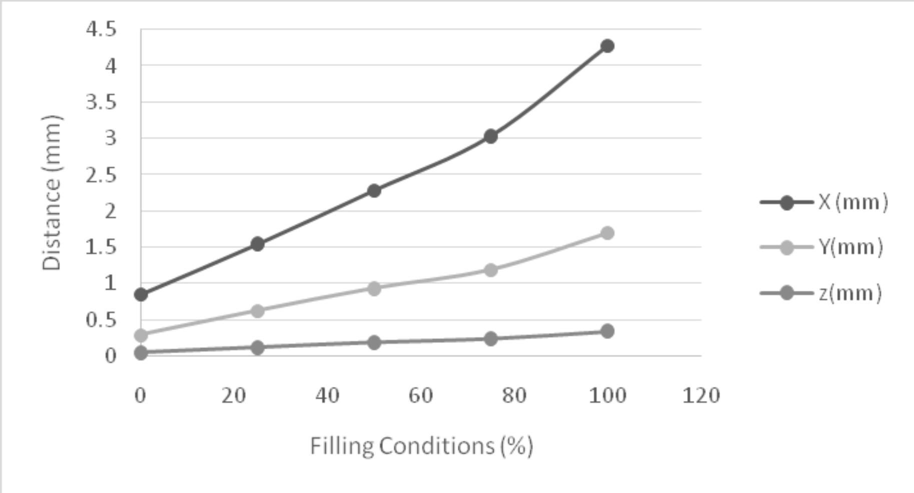


**Figure 2: Comparison of the maximum displacement at the hopper top**

### 5.3 Base Shear Variation

It was found that the minimum base shear was 27.94 kN while the maximum was obtained to be 124.03 kN for 0 % and 100 % filled cases respectively. Here the increase from completely empty condition to completely filed case was found to be about 4.4 times

| Filling Condition (%) | Base Shear (kN) |
|---|---|
| 100 | 124.03 |
| 75 | 89.97 |
| 50 | 70.86 |
| 25 | 45.72 |
| 0 | 27.94 |

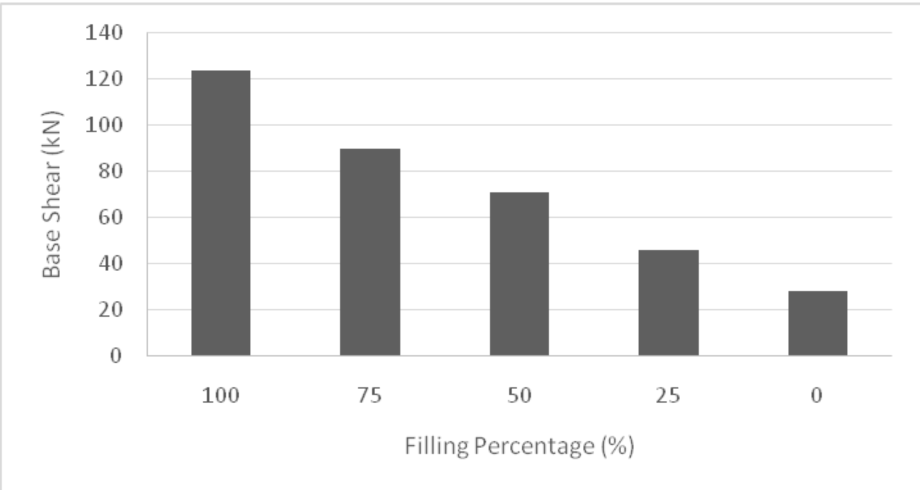


**Figure 3: Base Shear Variation**

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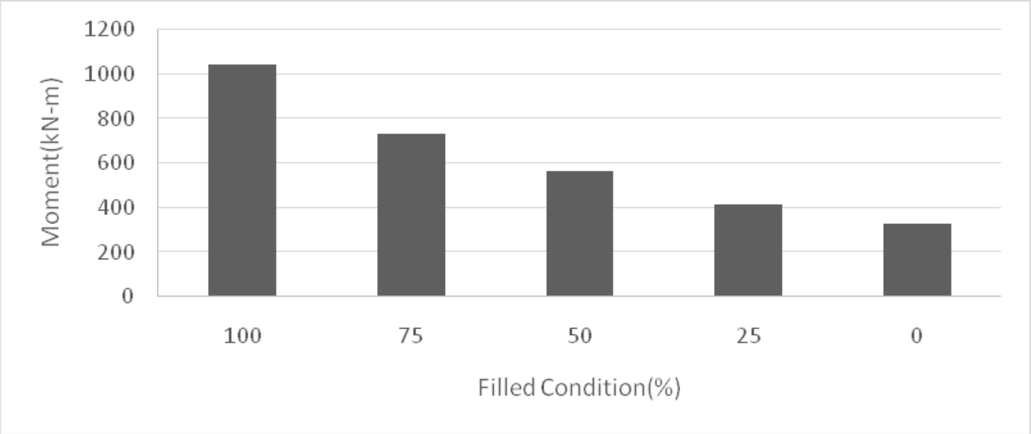
### 5.4 Maximum Overturning Moment Variation

It is seen that the maximum overturning moment is 1043.79 kN-m while the least is 328.93 kN-m, and the increase is seen to be 3.2 times.

| Filling Condition (%) | Moment (Mz)(kN-m) |
|---|---|
| 100 | 1043.79 |
| 75 | 732.6 |
| 50 | 563.04 |
| 25 | 414 |
| 0 | 328.93 |

| | Time Period (Seconds) | | | | |
|---|---|---|---|---|---|
| Filling Condition (%) | Mode 1 | Mode 2 | Mode 3 | Mode 4 | Mode 5 |
| 100 | 0.457 | 0.455 | 0.402 | 0.395 | 0.395 |
| 75 | 0.381 | 0.379 | 0.308 | 0.3 | 0.299 |
| 50 | 0.333 | 0.332 | 0.248 | 0.209 | 0.206 |
| 25 | 0.295 | 0.294 | 0.248 | 0.179 | 0.177 |
| 0 | 0.277 | 0.276 | 0.248 | 0.178 | 0.176 |

**Figure 4: Variation of maximum Overt urning moment**




### 5.5 Time Period Variation for first 5 modes

Time period of first 5 modes are shown below, while 100 modes are considered for the calculations. It is also clear from the readings that the completely filled case gives a much higher time period reaction that other cases, as usual the least is found for completely empty condition.

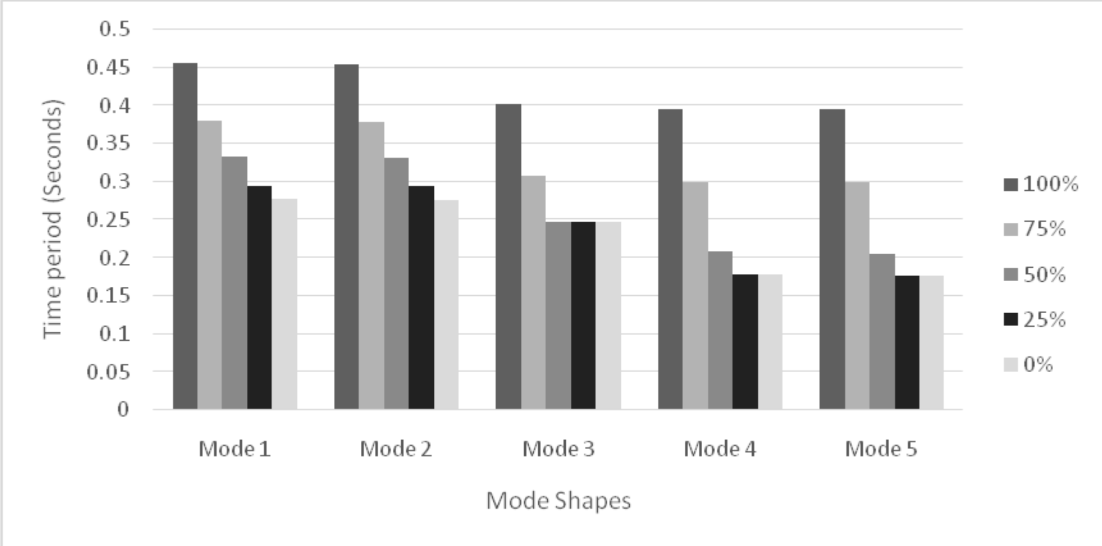



**Figure 5: Time Period variation for first 5 modes.**

## VI. CONCLUSION

1. From base shear variation it is concluded that as storage level increases base shear for Silo is also increases.
2. From Overturning moment variation it is seen that the overturning moment is maximum for 100 % filled, and it gets diminished till 0 % case.
3. From time period variation for silo it is concluded that, time period variation for 100% filled storage level is maximum while it is least for 0% filled level. Thus we can say that, as storage level increases time period also increases.
4. From the roof top displacement variation it is observed that, for reservoir empty condition displacement is minimum while for 25% filled case displacement is maximum, this is so because this condition induces the least buckling to the cylindrical wall. While it is observed that maximum displacement is observed in 100 % filled case at the hopper junction with the frame.
5. Also from the displacement curves it is clear that till about 75 % the displacement follows a linear pattern, beyond it increases drastically, thus for better safety reason about 75% filled case would be optimum for the work to be in progress.

## VII. FUTURE SCOPE

1. The study may be carried out with an opening for the movement of vehicles (i.e. removing diagonal bracings either on one side or two side for the first storey).
2. The Study may be carried out with other materials carrying different flow pattern.
3. Analysis study can be carried out for typically filled conditions where there is no pressure induced on the cylindrical wall (i.e. only for material filled in hopper plus the repose material forming cone).
4. The study may be carried out with other types of silo with different specifications.

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