RESEARCH ARTICLE

A STUDY OF COMPARISON OF STEEL SILOS UNDER INFLUENCE OF DYNAMIC LOADING IN ACCORDANCE WITH IS-1893:2002

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ARTICLE INFO	ABSTRACT
	Silos are containers used for storing bulk solids. Although there is no generally accepted definition for these terms, shallow structures containing coal, coke, ore, crushed stone, gravel, and similar materials. Silos are special structures subjected to many different unconventional loading conditions, which result in unusual failure modes. In this present study pressure calculation is carried out by Janseen's theory and Reimbert theory for static condition and additional pressure due seismic action is calculated by Theoretical approach. Base shear force generated at bottom of silo is compared with using IS 1893-2002, ASCE 7-05, AIJ 2010. Calculation is completely based on respective codal provision applied to Indian seismic zones, site condition etc.

INTRODUCTION

Theory of silo

1. Silo: - A storage structure, circular or polygonal in plan & intended for storing bulk material in vertical direction. The line of rupture start from bottom edge of bins intersects the wall it is called silo.
2. Bunker: - The line of rupture start from bottom edge of bins intersects the top surface of the material it is called Bunker or shallow bunker.
3. Bins: - Bins is common name for bunker & silos.
4. Silo Loads: - Loads exerted by a stored material on the wall of silo.
5. Pressure: - Force per unit area normal to wall of silo.
6. Initial pressure: - Pressure exerted by bulk solids on the walls of the silo during & after charging, but before any withdrawal of the material.
7. Strain energy: - The energy of a flowing mass of solid which could be recovered by a relaxation of boundary forces & displacement
8. Wall friction: - Force per unit area along the silo wall (vertical or inclined) on account of friction between the bulk material and the silo wall.

9. Flat bottom: - The internal base of silo, when it has an inclination to the horizontal less than 5 degree.
10. Horizontal load ratio K: - A value which specifies the relationship between the mean horizontal load acting on the vertical silo walls, and the mean vertical load at this position in the bulk material.
11. Bulk material: - A term used to describe a granular material ranging from a dust-like to a large-grained variety with and without cohesion, which contains pores in addition to and in-between the individual solid material particles that may be filled with air or moisture.

Types of Silo

1 Flat Bottom Silos
2 Hopper Silos
3 Truck load silos

Load consider for Silo Design

Loads should be applied to the structural design of a silo according to its intended use, size, structure type, materials, design lifetime, location and environment, in order to assure life safety and to maintain its essential functions.

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The applied loads should be as follows, and their combinations should be defined considering the actual probability of occurrence.

(i) Dead loads
(ii) Live loads
(iii) Snow loads
(iv) Wind loads
(v) Seismic loads
(vi) Impulse and suction due to content sloshing, and pressure due to content
(vii) Thermal stresses
(viii) Shock, e. g., by crane
(ix) Fatigue loads
(x) Soil and water pressures
(xi) Others. e.g., load from mechanical device.

Silo Damage and Failures

Silos structure failure frequency higher than other industrial structures. When a silo fails it can be devastating, in more ways than one including: loss of the container, contamination of the material it contains, loss of material, clean-up, replacement costs, and most importantly possible injury or loss of life.

1. Explosion and Bursting
2. Filling and Discharging
3. Soil Condition
4. Corrosion
5. Internal Structure Collapse
6. Deterioration
7. Thermal Ratcheting
8. Earthquakes

Actions on silo

1. Temperature variation
2. Consolidation
3. Moisture Content
4. Segregation
5. Degradation
6. Impact Pressures
7. Rapid Filling and Discharge
8. Powders
9. Wind Loading
10. Dust Explosions
11. Differential Settlements
12. Mechanical Discharge Equipment
13. Roof Loads

The design of silo is based on the strength design method. The design of silos is primarily governed by the type and properties of the stored material. The walls of the silos are typically subjected to both normal pressure and vertical frictional shear or traction produced by the material stored inside the silo. The magnitude and distribution of both shear and normal pressure over the height of the wall depend on the properties of the stored material and whether the silo is being filled or discharged. Design of silo considers both static & dynamic condition. Static & dynamic pressure exerted by the stored

material. Other potential loads, including seismic loads, calculation of seismic load consider silo self weight and material stored in it as a lumped mass and seismic effect of this mass is considered in design of the silo wall. Storage container & silo fails because of many reason. Failure of silo categories depend on silo failure causes which are as follows,

• Failure due to design
• Failure due to construction
• Failure due to usage
• Failure due to maintenance

Collapse of silo in seismic failure is the major failure; occur because of improper assumptions, wrong analysis and design. In this study consider circular flat bottom silo symmetrical about vertical axis & RCC slab provided at the top and bottom of silo by proving small open able hole to top of silo for filling storage material in it. In this study compare various method of silo design and seismic force calculation by using different codal provision like IS, ASCE, AJI, and EURO. The walls of the silos are typically subjected to both normal pressure and vertical frictional shear or traction produced by the material stored inside the silo. The magnitude and distribution of both shear and normal pressure over the height of the wall depend on the properties of the stored material. Calculation of seismic load consider silo self-weight and material stored in it as a lumped mass and seismic effect of this mass is considered in design of the silo wall.

An earthquake analysis effective components acting on silo due to structural loading are the two horizontal and one vertical direction. Silos have effect of seismic vertical loads is small, compare to lateral seismic loads on the tall silos storing heavy material. Seismic load magnitude in lateral direction directly related to the weight of silo. In earthquake analysis increase of lateral load bending moment also increases result of this non uniform pressure at bottom of silo increase as compare to pressure due gravity load.

Fig. 1. Partial collapse of grain silo during 1974 Lima, Peru earthquake

Literature review

Suvarna Dilip Deshmukh and Rathod S. T. conclude that additional pressure due to seismic action need to be considered while designing silo wall and reinforcement is found to varying along depth of wall and found to be more on middle portion of wall. Sesmic effect due to change in H/D ratio is not considered.

Indrajit Chowdhury and Raj Tilak carrid out experimental investigation of dynamic pressure on circular silo under seismic force. Circular silos (both steel and reinforced concrete) are often deployed to store material in various industries like cement plants (clinkers), power plants(raw coal/coke), oil and gas industry(sulfur pellets) etc. Technology that is in vogue for earthquake analysis of such structures is to consider the silo and its content as a lumped mass and seismic effect of this mass is considered in design of the supporting frame only. No effect of this seismic force is considered on silo wall when the content is subjected to seismic vibration. Procedure has been suggested wherein the additional dynamic pressure due to earthquake can be incorporated in analysis of such circular silos. While carrying out this analysis, conventional Jansen's method has been modified to develop the additional dynamic pressure due to seismic force and a parametric study has been done to study the effect of this dynamic pressure on the wall of silo for different structural configuration.

Structural committee of Japan gives seismic design calculations for other types of storage tanks. Design recommendation for sloshing phenomena in tanks has been added. Design spectra for sloshing, spectra for long period range in other words, damping ratios for the sloshing phenomena and pressures by the sloshing on the tank roof have been presented. In this study consider storage cylindrical tanks resting on ground without having any restrain to prevent overturning moment such as anchor bolt. This recommendation shows how to evaluate the energy absorption value given by plasticity of the uplifted bottom plate for unanchored tanks. As the number of smaller under-ground tanks used for the storage of water and fuel is increasing in Japan, the Sub-committee has added them in the scope of the recommendation and provided a framework for the seismic design of under-ground tanks. The recommendation has accordingly included a new response displacement method and a new earth pressure calculation method, taking into account the design methods adopted by the civil engineering fraternity. For silo design, additional local pressure which depends on eccentricity of discharge outlet, and equations which give approximate stress produced by this pressure are given in this 2010 publication.

Aim and Objective

A study of comparison of steel silos under influence of dynamic loading in accordance with is 1893:2002

To achieve aim of the project study based on the following objective,

1. To analyze single and double hopper steel silos for different soil condition in accordance with IS:1893-2002

2. To check performance of steel silos in variation with H/D ratio, Pressure calculation values obtain from the equation is check with pressure calculated by using Janseen theory and Reimbert Theory.

Design of silo

Silos and their supports should be designed to contain all applicable loads taking into account the properties of stored materials, the shape of the silos, methods of material handling. The shape of the silo should be as simple as possible, be symmetrical about its axis, and should have structural members which are proportioned to provide adequate strength. Physical property tests using actual granular materials are expected to find weight per unit volume, internal friction angle; and deformation characteristics. In silos the weight of material stored is supported by bottom of silo and side wall of silo resulting reduction in lateral pressure. Vertical weight carried by wall causes direct compression in wall.
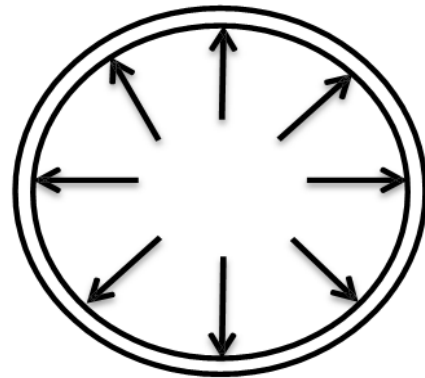
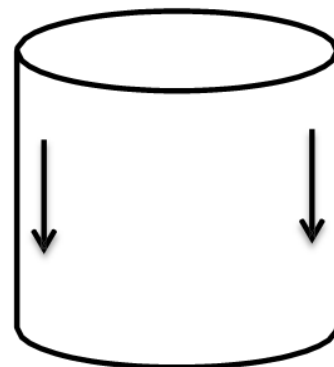**Fig.2. Plan of silo showing horizontal pressure acting on the silo wall**

Fig.3. Elevation of silo showing vertical pressure acting on silo wall

Theories for pressure calculation

Many researchers have provided theories for pressure calculation on silo wall. Some of the theory used are:
- Janssen Theory
- Reimbert Theory

Finite element analysis of silo

For calculation of static pressure on silo wall parameter consider for silo design as per IS code. While calculation done for seismic force parameter used for calculation of seismic force will varies with their respective code condition that parameter.

Software simulation

Finite element Analysis tool STAAD-PRO V8i is used for simulation. The STAAD plate finite element is based on hybrid finite element formulations. A complete quadratic stress distribution is assumed. For plane stress action, the assumed stress distribution is as follows
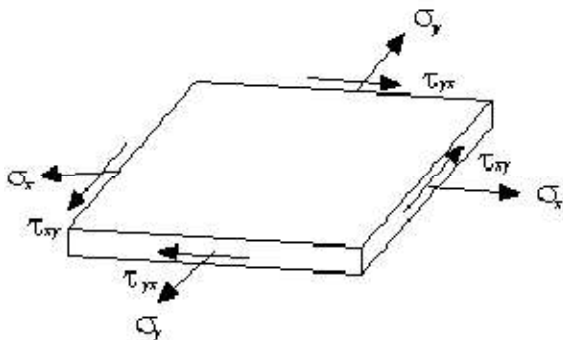

Fig. 4. Complete quadratic assumed stress distribution

$$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{pmatrix} = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 & 0 & x^2 & 2xy & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & y^2 & 0 & 2xy \\ 0 & -y & 0 & 0 & 0 & -x & 1 & -2xy & -y^2 & -x^2 \end{bmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_{10} \end{pmatrix}$$

a_1 through a_{10} = constants of stress polynomials

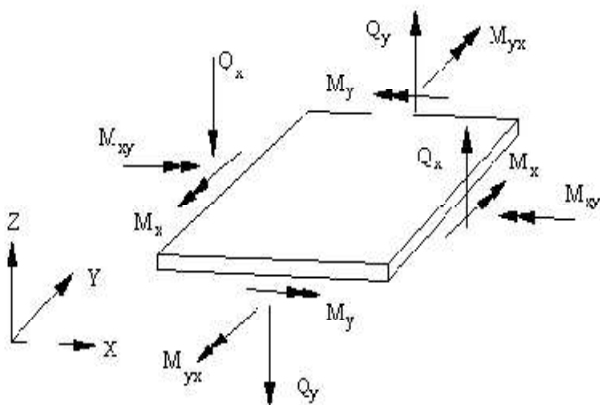The following quadratic stress distribution is assumed for plate bending action:

Fig. 5. Complete quadratic assumed stress distribution

$$\begin{pmatrix} M_x \\ M_y \\ M_{xy} \\ Q_x \\ Q_y \end{pmatrix} = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 & 0 & 0 & x^2 & xy & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y & 0 & 0 & 0 & 0 & xy & y^2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & -xy & 0 & 0 & -xy \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & x & y & 0 & -x \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & -y & 0 & x & y \end{bmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ \vdots \\ a_{13} \end{pmatrix}$$

a_1 through a_{13} = constants of stress polynomials.

Following are the items included in the ELEMENT STRESS output.

SQX, SQY -Shear stresses (Force/ unit len./ thk.)
Sx, Sy, Sxy -Membrane stresses (Force/unit len./ thk)
Mx, My, Mxy- Moments per unit width (Force x Length/length)
(For Mx, the unit width is a unit distance parallel to the local Y axis. For My, the unit width is a unit distance parallel to the local X axis. Mx and My cause bending, while Mxy causes the element to twist out-of-plane.)
Smax, Smin Principal stresses in the plane of the element (Force/unit area)
TMAX Maximum shear stress in the plane of the element (Force/unit area)
ANGLE Orientation of the principal plane (Degrees) VONT, VONB Von Mises stress, where

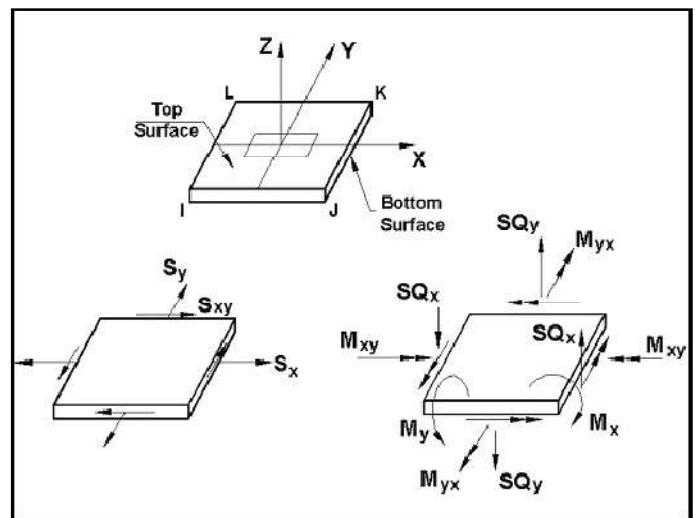$$VM = 0.707\sqrt{(SMAX - SMIN)^2 + SMAX^2 + SMIN^2}$$

Fig. 6. Sign Convention of Plate Element Stresses and Moments

Problem statements

In this paper steel single hopper silos and double hopper silo is analyzed using STAAD-PRO V8i.

Self weight

DL=Volume*Density =25*.02*3*3=4.5 KN/m^2

Load on vertical walls

$P_h = \gamma \ k$
   $= 25*3*0.4$
   $= 30 KN/m^2$
Where k is $0.25 \leq k \leq 0.6$ (Ref. Jansson theory)

Earthquake load

Zone-III
Zone factor-0.16
Soil Condition-Medium
Time Period-$T_a = 0.09h/\sqrt{d} = 0.5 sec$
S_a/g-2.5
Damping Ratio=0.05

Purpose of silo	Storage of cement	Storage of cement
Type	Steel silo	Steel silo
Configuration	A single free standing rectangular shape	Double free standing rectangular shape
Height of silo	12m	12m
length	3m	1.5m
width	3m	1.5m
Thickness of silo	20mm	20mm
Storage product density	15.50kN/m³	15.50kN/m³
Angle of internal friction	25	25
Friction coefficient of tank wall	0.46	0.46
coefficient of wall friction(З)	tanφ	tanφ
Seismic zone	III	III
Grade of Steel	Fe500	Fe500

RESULTS AND DISCUSSION

In this paper single steel silos of 3x3 m is compared with double hopper steel silos of 1.5x1.5m maintaining same areas.
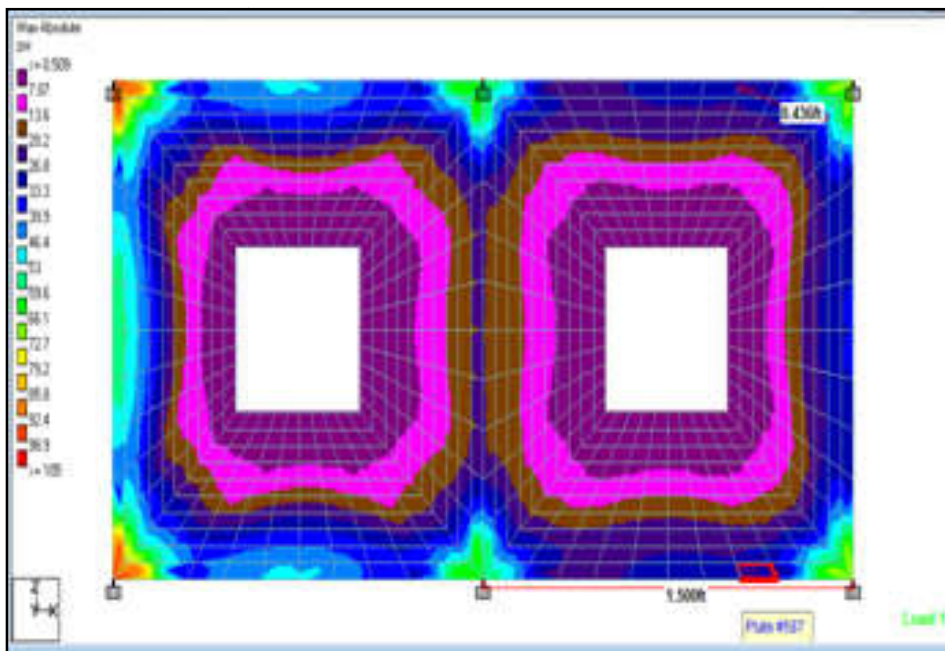

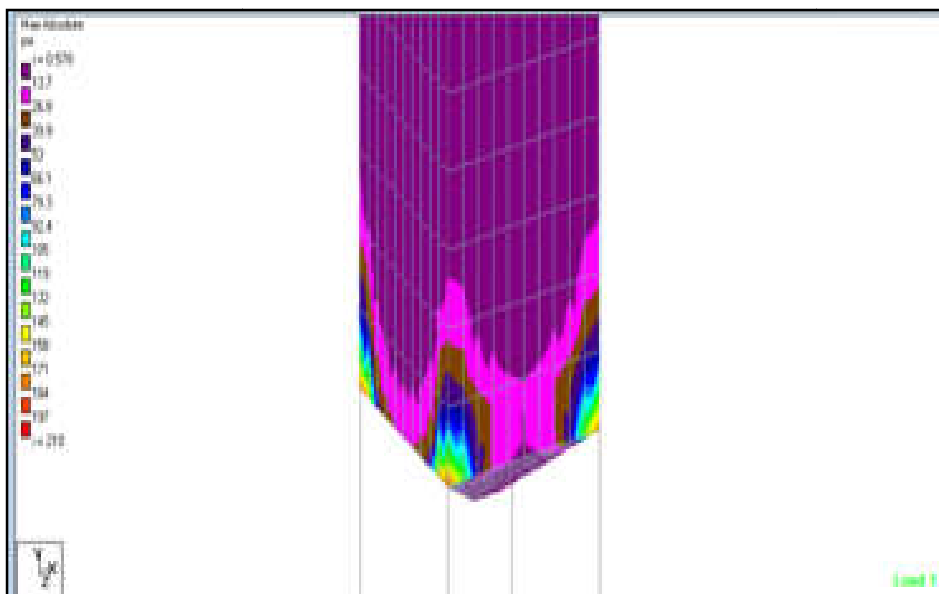**Fig 7. Shear stress develop at corners of double hopper silos**
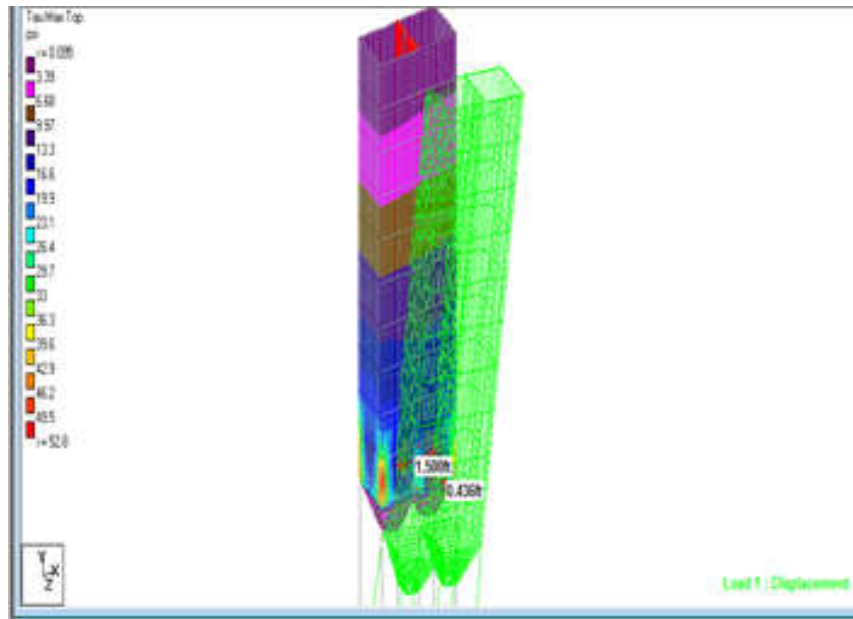

Fig. 8. Shear stress develop at edge of single hopper silos
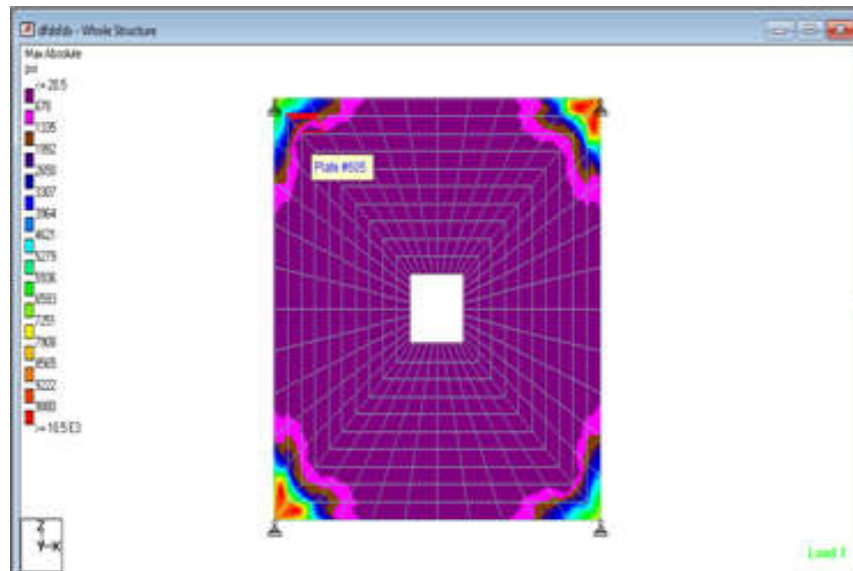
Fig. 9. Deflection of double   hopper silos

Fig. 10. Shear stress develop at edge of single hopper silos

Table 2 Natural frequncy of single hopper silos

Type	Mode N0.	Natural Frequency	Time Period
Double	1	81.599	0.01226
Hopper	2	94.827	0.01055
Steel	3	97.572	0.01025
Silos	4	572.261	0.00175
	5	578.946	0.00173
	6	583.210	0.00171

Table 4. Maximum Displacement Due To Self   Weight+Eq+X

Type of Silos	Displacement X(cm)	Displacement Y(cm)	Displacement Z(cm)
Single Hopper	2.42436E-03	1.59764E-02	3.93727E-04
Double Hopper	4.17374E-01	-2.82001E-03	3.24534E-03

Table 5. Maximum Rotation Due To Self Weight+Eq+X

Type of Silos	Rotation X(rad/sec)	Rotation Y(rad/sec)	Rotation Z(rad/sec)
Single Hopper	1.21048E-05	6.65987E-06	-2.30816E-05
Double Hopper	1.27112E-05	1.93035E-04	-2.43741E-04

Conclusion

In this study single and double hopper steel silos is analyzed under the influence of self weight, pressure on vertical wall and seismic load. It was observe that maximum displacement along X-direction and Z-direction is comparatively less in single hopper silo. But displacement along in Y-direction i.e. along gravity direction is comparatively less in double hopper silo. However nodal rotation are remain nearly same indicates that the torsion movement due to accidental eccentricity will be same in both cases. Natural frequency for first three modes is considerably less and hence time period is more for double hopper steel silo.

Future scope

1) H/D ratio of all types of silos need to be studied this result can be used in IS: 9178 part II 2006
2) Comparison should be made under various type of eccentricity hopper bottom for various soil conditions.

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