Dynamic Analysis of Silos For Different Zones

Mr.Vikram Wakale[1], Prof. M. N. Shirsathi[2]
[1]Dept of Civil Engineering
[2] Assistant Professor, Dept of Civil Engineering
[1, 2] G. H. Raisoni College of Engineering and Management, Ahmednagar, India

Abstract- *In order to reveal the dynamic response mechanism of silo-storage-foundation system under seismic wave loading, the silo is simplified as a thin-walled cylindrical shell structure with fixed bottom and free upper part. Considering geometric nonlinearity, dynamic elastic modulus, damping and other factors, the nonlinear vibration differential equations of the silo under dynamic loading are established. The vibration differential equations and the definite conditions with solution ideas are given. Subsequently, the dynamic action system of tube supported reinforced concrete silos is studied by using the shaking table test method. The similarity theory of silo model test is constructed, and the experimental model of the silo storage foundation interaction system with the geometric ratio of 1:20 is established, where three seismic waves in the suitable engineering background are selected to carry out the shaking table test. The acceleration peak value at different heights of the model is measured, and the dynamic amplification factor of the silo model along the height direction is studied under different seismic intensity and different material condition.*

I. INTRODUCTION

Silo, bins, or bunker are container used for storing bulk solids. Although no specific definition for all these terms, shallow structure use for storing coke, coal, crushed stone, gravel, ore & other similar material are usually called bunkers & bins. Tall structures use for storing grains, cement is often called silos. Most of industries used silos to store bulk solids, quantity ranges from a thousand tones to hundred to few tones. Power station, cement plant, gas work in many more short and big establishments where storage of bulk material is necessary, for the purpose of storing material silo is used.

Silo structure may be elevated or rest on ground have circular, square or rectangular in shape. Rectangular or Square silos usually have single outlet with pyramidal bottom, but sometimes a trough bottom is used with a single elongated outlet or two or more circular or square outlet. Silo which is in circular shape have flat bottom or conical bottom with single outlet. Material used for construction of silo may be RCC & reinforced concrete.

Governing factor in design of silos are the type of material stored in it and there properties. Bulk material density, frictional properties & pattern of material flow varies generously, the applied loads and load caring system different in structure like silo than other traditional structure. Silos are designed as special structure & also design is based on the strength design method.

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

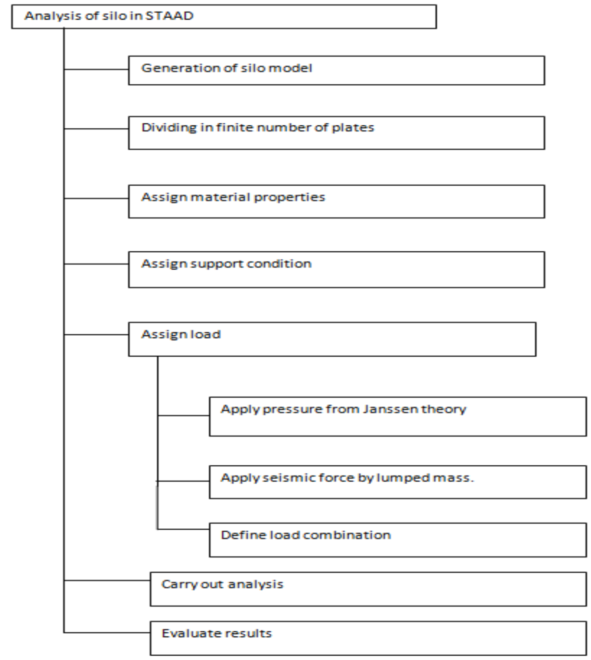
Fig. 1 Partial collapse of grain silo during 1974 Lima, Peru earthquake

II. METHODOLOGY

Dynamic analysis and seismic behavior of RCC silo and avoid failure of RCC silo during earthquake seismic force calculated by using IS code. Results will cross check by using structure design software.

1. Calculation of pressure acting on the wall of silo using height to diameter ratio and angle of internal friction by using Janssen's theory.
2. Design of silo using IS specifications.
3. Modeling and analysis of different shapes of silo by using software..
4. Calculation and comparison of natural frequency, time period and displacement for different mode shapes.
5. Calculation and validation of natural frequency, time period using Rayleigh ritz method.

2.1 General STAAD procedure:



2.2 Theory of Silo:

2.2.1 Terms

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.

2.3 Types Of Silo

2.3.1 Flat Bottom Silos

Used for long-term storage of large quantities of grain, seeds and granular products.

Fig. 2 Flat bottom silo

Fig. 3 Hopper silo

2.3.2 Hopper Silos

Used for Storage of grains (cereals, seeds, legumes, industrial products and other products) that requires special storage conditions.

2.3.3 Truck load silos

This are used for the storage and subsequent delivery of bulk products

Fig. 4 Truck load silo

2.4 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.
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,
(ix) Fatigue loads
(x) Soil and water pressures
(xi) Others.

Dead Loads: - Dead loads are the sum of the weights of the silo, its associated piping and equipment and other fixed appurtenances.

Live Loads: - Live loads should be considered forces from stored material (including overpressures and under pressures from flow), floor and roof live loads

Snow Loads: - Snow loads should be defined by considering the location, topography, and environment, density of the snow, snow accumulating period, and the shape and temperature of the tank.

Wind loads: - Wind loads should be defined by considering the shape of the tank, its structural Characteristics, the location, and environment.

Seismic Loads: - Design seismic loads for above-ground storage tanks should be calculated by either one of the following methods:

(i) Seismic Coefficient Method, or
(ii) Modal Analysis

Thermal loads: - Thermal loads include those due to temperature differences between inside and outside faces of wall.

Shock loads: - Shock load including those due to crane movement, crane use for storing material in silo.

Soil and water load: - If silo situated below the ground then soil load act on silo and water load act on silo depend on water table available.

Other loads: - Other loads include equipment connecting to silo.

III. 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.

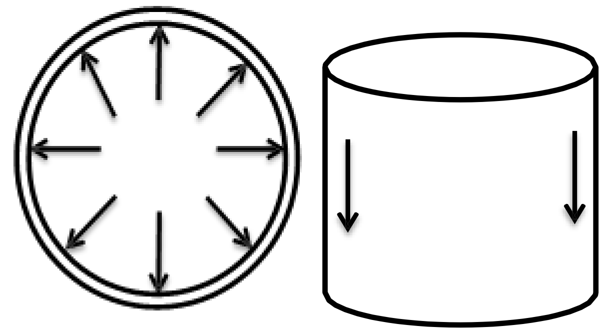


Fig. 5 Plan of silo showing horizontal pressure acting on the silo wall and
Fig. 6 Elevation of silo showing vertical pressure acting on silo wall

31 Seismic Pressure In Silo

Theoretical approach is given by Indrajit Chowdhury and Raj Tilak in which conventional Jansen's method has been modified to develop the additional dynamic pressure due to seismic force. estimated the acceleration the silo is subjected to base on its first two fundamental time period the same can be fitted into Jansen's theory. We take here a strip of the material stored in silo of depth dz and apply the applicable forces as shown in the figure below. The difference here is the additional force exerted on the wall due to the seismic force generated by the stored material is also included

3.2 Software Simulation

Finite element Analysis tool STAAD-PRO V8i is used for simulation. In analysis following assumption are made:

1. Base of silo is assumed to be fixed.
2. Pressure applied is based on Janssen Theory.
3. Stored materials is uniformly distributed throughout silo depth.
4. Silo is having flat bottom having cylindrical shape.

After analysis following result is obtain to understand behavior of silo.

1. Lateral Deflection along depth of silo wall.
2. Membrane stress S_Y along depth of silo wall.
3. Bending Moment M_X along depth of silo wall.

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

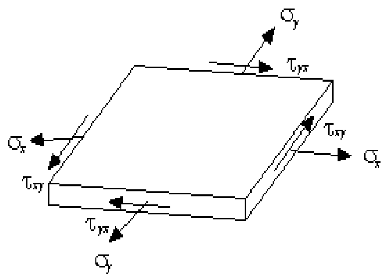


Fig.7 Complete assumed plate stress distribution

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

a_1 through a_{10} = constants of stress polynomials.

The following stress distribution is assumed for plate bending action:

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

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

Following are the items included in the ELEMENT STRESS output.

S_{QX}, S_{QY} -Shear stresses (Force/ unit length/ thickness.)

Sx, Sy, Sxy -Membrane stresses (Force/unit length./ thickness)

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)

T_{MAX} Maximum shear stress in the plane of the element (Force/unit area)

Angle Orientation of the principal plane (Degrees)

V_{ONT}, V_{ONB} Von Mises stress, where

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

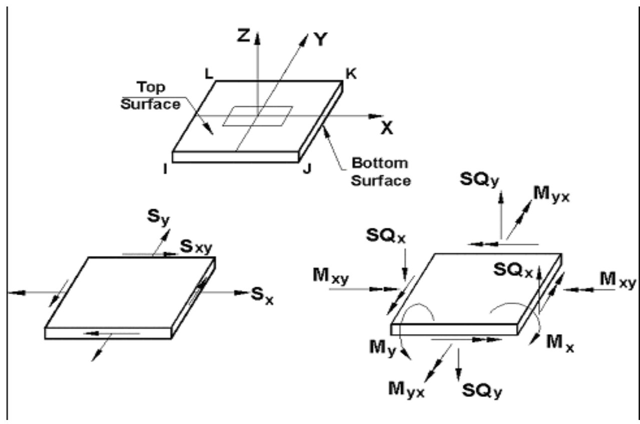


Fig. 8 Graphical representation of stresses on plate element

3.3 Problem Statements

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

1 Self weight

DL=VolumexDensity =25x0.02=0.5 kN/m^2

2 Load on vertical walls

$P_h=\gamma hk$

=25x3x0.4

=30kN/m^2

Where k is 0.25 ≤k≤ 0.6(Ref. Jansson's theory)

3 Earthquake load

Zone-III

Zone factor-0.16

Soil Condition-Medium

Time Period-Ta=0.09h/$\sqrt{d}$=0.5sec

Sa/g-2.5

Damping Ratio=0.05

Type of support-Fixed support

3.4 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.

Following data consider for calculation of silo pressure

Type	RCC silo	RCC silo
Purpose of silo	Storage of cement	Storage of cement
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(3)	tanφ	tanφ
Seismic zone	III	III
Grade of RCC	Fe500	Fe500

3.5 Validation Of Model

Single hopper silo is verified using single degree of freedom system. Natural frequency and time period of silo is compared against values of STAAD-Pro (Refer Table no.)

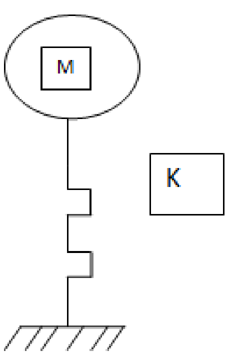


Fig.9 SDOF MODEL OF SINGLE HOPPER SILO

3.6 Stiffness matrix

The total number of columns having the same size in each storey =6

Therefore, $k = 6(12EI/h^3)$

Where, $E = 2.05\times10^5 N/mm^2$

Stiffness of column=9.269×10^3

Mass of silo=7.53kN

Mode Shapes Equations (characteristic Equation)

$$(k - \omega^2_n m)\,\phi_n = 0$$

The right hand side of the equation is zero.

Either $\phi_n = 0$ or $[k - \omega^2_n m] = 0$

But ϕ_n cannot be zero because it leads to trivial solution implying u=0, which means no motion.

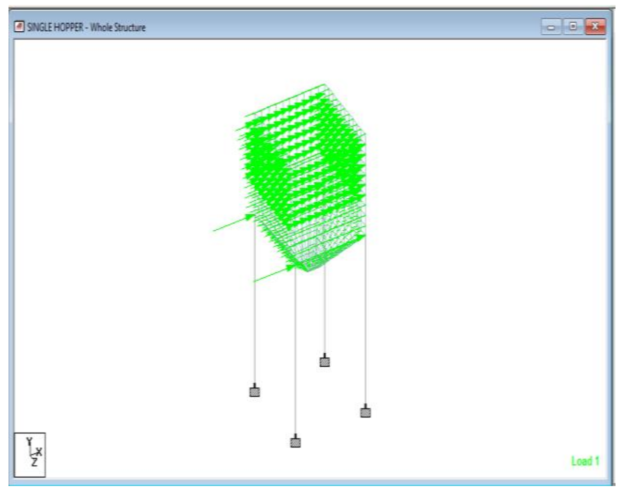


Fig.10 Vertical load

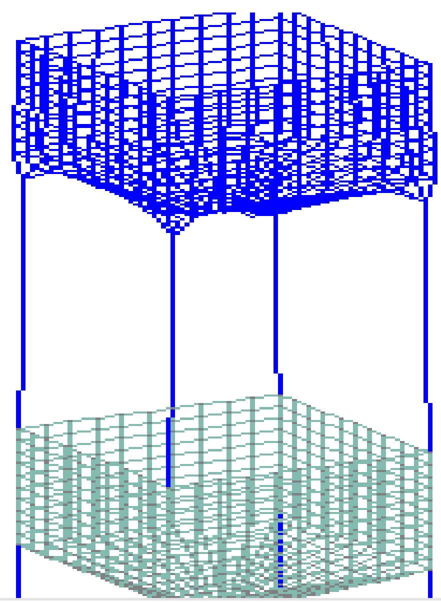


Fig .11 Mode Shape No.1

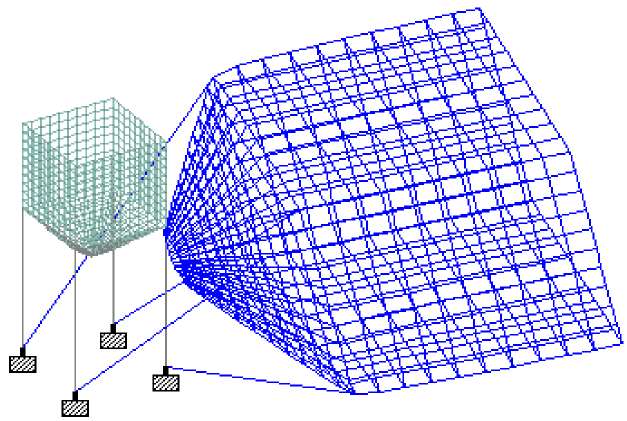


Fig .12 Mode Shape No..2

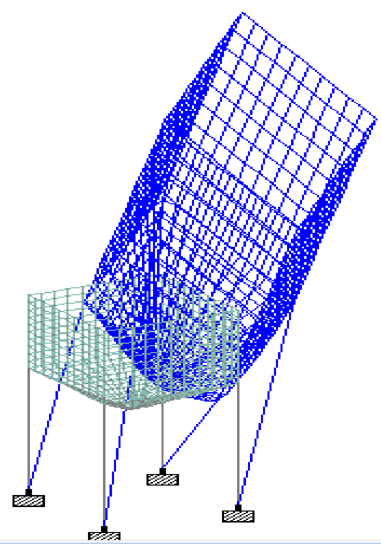


Fig.13 Mode Shape No.3

IV. CONCLUSION

- It is seen that if height to diameter ratio increases then the effect of wind load appear in critical load combination for Zone-III whereas for Zone-V earthquake load be a part of critical load combination for lateral displacement
- This study describes a concise review of the bunkers and silos including their stability against failures & causes, and the factors required for economic and effective design.
- It is concluded that the results based on the generalized SDOF system have good agreement with those used the distributed mass and the sequential analysis models. The proposed design procedure using the generalized SDOF system can be simply used in seismic design of LCS
- Present paper proposes a method, based on which one can estimate such dynamic pressure that could generate on the bunker walls and arrive at a more realistic design.

V. 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.Same models should be verified and analyzed for non-linear buckling due to wind load in accordance with IS: 875 part 3.

REFERENCES

[1] Afzal Ansari, Kashif Armaghan, Sachin S. Kulkarni ' Design and Optimization of RCC Silo' Volume 4 Issue VI, June 2016, pp. 458-466.
[2] Chirag L. Korat1, Jasmin A. Gadhiya ,Hardik A. Patel 'A Review on Parametric Study of Circular RCC Silo having Hopper Bottom' Volume 4, Issue 11, November -2017,pp 495-499.
[3] Christoph Butenweg, Julia Rosin,*and Stefan Holler 'Analysis of Cylindrical Granular Material Silos under Seismic Excitation' July 2017, pp. 1-12.
[4] K.Dharani, D.Jeyakumar 'A Brief Review on Bunkers and Silos' Volume 4 Issue X, October 2016, pp. 323-327.
[5] Ms Rini Riyansi.E1; Mrs. Abida Justus2 'Comparative Study of Silo Supporting Structure Using RCC & RCC' Vol. 3, Issue 35, April 2017, pp. 133-145.
[6] Pradnya P.Dhamdhere, Y.R.Suryawanshi 'A Study of Comparison of RCC Silos under Influence of Dynamic Loading In Accordance With Is-1893:2002' volume1,Issue2,June 2017.
[7] Pooja. B. Suryawanshi Prof. H. G. Sonkusare 'Review Paper on Collapse Analysis of Seismically Designed RCC Braced Frame' Volume 2 | Issue 07 | January 2016, pp. 118-119.
[8] Sagar R. Aambat, Sunil M. Rangari and Priyanka A. Jadhav 'Effect of Height to Lateral Dimension Ratio on Dynamic Behaviour of Rcc Circular Silo' Volume 7 Issue 6 Ver I || June 2018,pp.62-68.