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LATERAL ANALYSIS OF ELEVATED REINFORCED CONCRETE SILOS

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Abstract: Silos are industrial structure used for storage of material such as grains or cements. Industrial silo demands a specialist design as a consequence of heavy industrialization. As the height increases they are more vulnerable to earthquake. Earthquakes can also cause damage in the upper portion of the silo if the material contained can oscillate inside the silo during the earthquake. The walls of different type of silos are subject to earthquake loads from the stored mass, and these may substantially exceed the pressures from filling and discharge. The elevated silos response is highly influenced by the earthquake characteristics and is depending on the height to diameter ratio, hence there is need to do seismic analysis of such type of tall and slender structure. In this paper, circular elevated silos with different stored material are considered for study. There are three methods used for calculation of pressure on silo Janssen Method, Airy Method and Reimbert Method. From comparison of these methods results are obtained. The various materials give different pressure for three methods.

Keywords: Lateral pressure, Janssen's method, Airy's method, Reimbert's method.

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INTRODUCTION

Structure used for storing bulk solids are usually called bins, bunkers, silos, or tanks. Shallow structures containing coal, coke, ore, crushed stone, gravel, and similar materials are called bins or bunkers, and tall structures containing materials such as grain and cement are called silos. A number of silos that were damaged or collapsed during recent earthquakes around the world Possible causes of failures and potential measures to prevent damage. Earthquakes frequently cause damage and collapse in silos resulting in not only significant financial loss but also loss of life. The magnitude of the horizontal seismic load is directly proportional to the weight of the silo. As the silo height increases the height of the center of mass of the silo structure also increases. Assuming the horizontal seismic load is applied roughly at the center of mass, the moment arm for the lateral load and the corresponding bending moment at the base increase. The increased bending moment then results in non-uniform pressure distribution at the bottom of the silo, which can be significantly larger than the pressure caused by the gravity loads. In this study, silo is an inclusive term for all structures for the storage of bulk solids. Silos in common use, may be ground-supported or elevated. Typical elevated silos generally consist of a conical roof, a cylindrical shell and a conical hopper and they could be elevated and supported by frames or reinforced concrete columns or on discrete supports. Silos are lifeline structures and strategically very important, since they have vital use in industries.

Silos are special structures subjected to many different unconventional loading conditions, which result in unusual failure modes.

Silos are cantilever structures with the material stacked up very high vertically. The walls of different type of silos are subject to earthquake loads from the stored mass, and these may substantially exceed the pressures from filling and discharge. Coulomb's friction low was used for modeling of wall friction. The elevated silos response is highly influenced by the earthquake characteristics and is depending on the height to diameter ratio. Circular silos (both steel and reinforced concrete) are used for the store material in various industries like cement plants (clinkers), power plants (raw coal), oil and gas industry etc.

In the 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. 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. Failure of a silo can be devastating as it can result in loss of the container, contamination of the material it contains, loss of material, cleanup, replacement costs, environmental damage, and possible injury or loss of life.

Asymmetrical loads created during filling or discharging, large and no uniform soil pressure, corrosion of metal silos.

METHODOLOGY

On the assumption bases for analysis of silos there are three methods used Jansen's method, Airy's and reimbirt method. Janssen's assuming in his analysis that a large portion of the weight of the contained material is supported by friction between material and the wall and only a small portion of the weight is transferred to the hopper bottom. The vertical wall of the silo is subjected to direct compression as well as lateral pressure. Airy's analysis is based on the coulomb' wedge theory of earth pressure. By using this theory it is possible to find the horizontal pressure on the periphery and position of plane of rupture. Reimbert's theory is based on the experimental work conducted on full scale silo. Many silo design codes recommend this theory as an alternative to Janssen's theory for computation of static pressures.

Janssen's method

Following are the Assumption on Jansen's method.

1) Material is homogeneous and isotropic and can be treated as a continuum.

2) The distribution of vertical pressure across any cross section is uniform.

3) The ratio of horizontal stress to vertical stress is constant throughout a silo.

Vertical pressure is calculated from equation 1.

$$\mathrm{pv} = \frac{\mathrm{wr}}{\mu' \mathrm{K}}\left[1 - \mathrm{e}^{-\mu'}.\frac{\mathrm{K}}{\mathrm{r}}\mathrm{h}\right] \quad .... (1)$$

Horizontal pressure is calculated from equation 2.

$$\mathrm{ph} = \frac{\mathrm{wr}}{\mu'}\left[1 - \mathrm{e}^{-\mu'.\frac{\mathrm{K}}{\mathrm{r}}\mathrm{h}}\right] \quad .... (2)$$

The hoop tension act in wall calculated from equation 3 silos is circular in cross-section

$$\mathrm{Ht} = \mathrm{ph}.\frac{\mathrm{D}}{2} \quad .... (3)$$

Along with hoop tension there is additional frictional wall pressure Pw per meter run and calculated from equation 4.

$$Pw = wr\left[h - \frac{r}{\mu'.K}\left\{1 - e^{-\mu'\frac{K}{r}h}\right\}\right] \quad .... (4)$$

Notation used,

w = Density of stored material

r = Hydraulic mean depth = A/P

μ' = tan Φ'

D = Diameter of silo

K = Ratio horizontal to vertical pressure

h = height

Airy's method

Horizontal pressure is calculated from equation 5 in airys theory.

$$Ph = \frac{wh^2}{2}\left[\frac{1}{\sqrt{1+\mu^2+\mu(\mu+\mu')}}\right]^2 \quad .... (5)$$

Frictional wall pressure Pw taken by wall from equation 6

$$Pw = \pi.\frac{wh^2}{2}.\frac{\mu'}{\sqrt{1+\mu^2+\mu(\mu+\mu')}} \quad .... (6)$$

Notation used,

w = Density of stored material

μ=Coefficient of friction

μ' = tan Φ'

h = At any height

Reimbert's method

This expression in equation 7 equated to lateral static pressure at depth Z.

$$P = \frac{wA}{P\mu'}\left[1 - \frac{1}{(\frac{Z}{B}+1)^2}\right] \quad .... (7)$$

The vertical static unit pressure in equation 8 at depth Z below the surface of stored material is,

$$q = wr\left[\frac{Z}{Z\mu{\cdot}K + r}\right] \qquad \text{.........} \quad (8)$$

The vertical friction force calculated from equation 9 on the unit width of wall at depth Z,

$$V = (wZ - q).r \qquad \text{............} \quad (9)$$

Notation used,

ω = Density of stored material

A = Area of horizontal plane

P = Perimeter of the horizontal section

r = Hydraulic mean depth = A/P

Z =Depth from free surface

μ' = tan Φ'

B = Constant

q= vertical static unit pressure

RESULTS AND DISCUSSIONS

Elevated silos generally consist of a conical roof, a cylindrical shell and a conical hopper and they could be elevated and supported by frames or reinforced concrete columns. In present study comparison of methods are done by manual results obtained.

CASE I- ANALYSIS OF SILO WITH DIFFERENT MATERIAL

Case-1 (a): Analysis of wheat storage silo

In this case silo of dimensions height 20m, diameter 5.5m with density of wheat 8.5 kN/m3 is analyzed manually by three methods as Janssen method, Airy method and Reimbert method as shown in figure 1 for maximum lateral pressure on cylindrical shell.

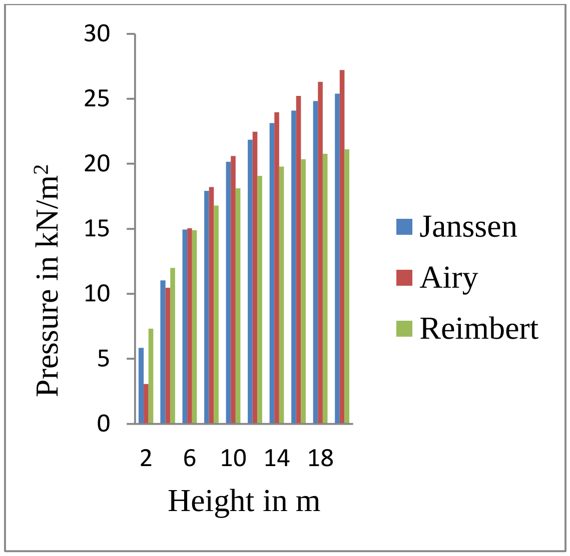

Figure 1 Comparison of lateral pressure

It is observed from figure 1 the difference in lateral pressure at 2m height by Janssen, Airy and Reimbert methods is 40.87%, 51.32% and 17.66% respectively and that at 20m height is 6.52%, 21.65% and 16.18% respectively.

Case-1(b): Analysis of cement storage silo

In this case silo of dimensions height 20m, diameter 5.5m with density of cement 14.4 kN/m3 is analyzed manually by three methods as Janssen method, Airy method and Reimbert method as shown in figure 2 for maximum lateral pressure on cylindrical shell.

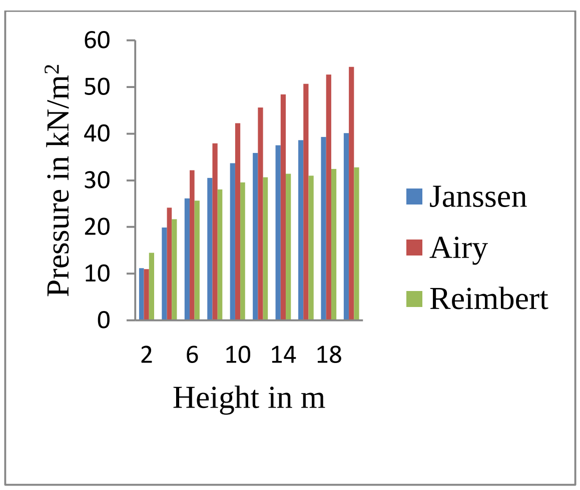

Figure 2 Comparison of lateral pressure

It is observed from figure 2 the difference in lateral pressure at 2m height by Janssen, Airy and Reimbert method is 2.04%, 22.53% and 20.91% respectively and that at 20m height is 25.89%, 38.98% and 17.65% respectively.

Case-1 (c) Analysis of sand storage silo

In this case silo of dimensions height 20m, diameter 5.5m with density of sand 16 kN/m3 is analyzed manually by three methods as Janssen method, Airy method and Reimbert method as shown in figure 3 for maximum lateral pressure on cylindrical shell.

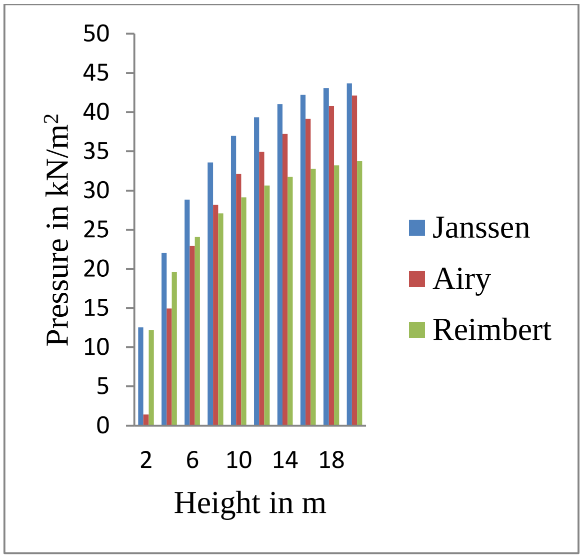

Figure 3 Comparison of lateral pressure

It is observed from figure 3 the difference in lateral pressure at 2m height by Janssen, Airy and Reimbert method is 88.46%, 88.19% and 2.22% respectively and that at 20m height is 3.45%, 19.38% and 22.16% respectively.

CASE II- ANALYSIS OF HOPPER BOTTOM WITH DIFFERENT MATERIAL

In this case analyzed hopper bottom with opening is 0.5m, aspect ratio 5 and slope of hopper bottom 15º, 30º, 45º, 60º, and 75 º.

Case II (a): Analysis of hopper bottom wheat storage silo

In this case silo of height 25m, diameter 5m, aspect ratio 5 and opening 0.5m with varying slope of hopper is analyzed manually using Janssen method for meridonal tension and hoop tension on hopper bottom as shown in figure 4.

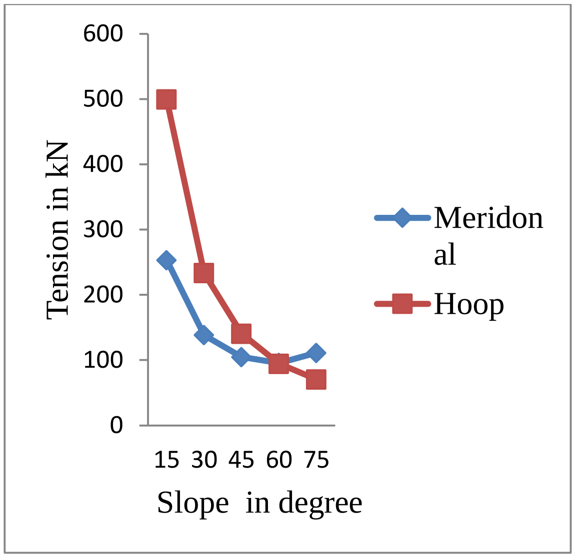

Figure 4 Comparison of meridonal and hoop tension

It is observed from figure 4 that difference in meridonal tension and hoop tension for hopper angle 15º, 60º and 75º is 49.19%, 1.4% and 36.34% respectively.

Case II (b): Analysis of hopper bottom cement storage silo

In this case silo of height 25m, diameter 5m, aspect ratio 5 and opening 0.5m with varying slope of hopper is analyzed manually using Janssen method for meridonal tension and hoop tension on hopper bottom as shown in figure 5.

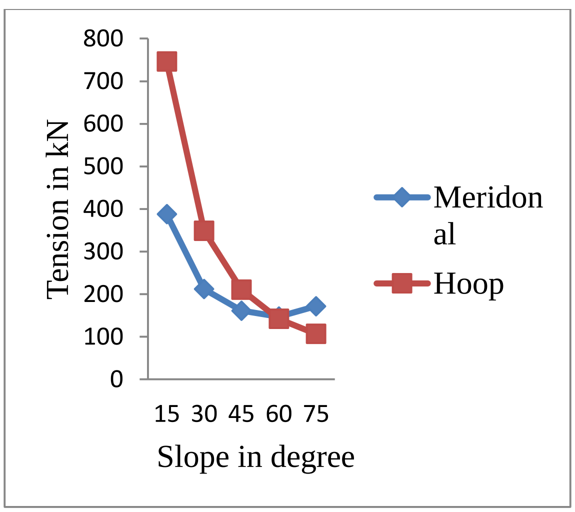

Figure 5 Comparison of meridonal and hoop tension

It is observed from figure 5 that difference in meridonal tension and hoop tension for hopper angle 15º, 60º and 75º is 47.94%, 3.6% and 37.51% respectively.

Case II (c): Analysis of hopper bottom sand storage silo

In this case silo of height 25m, diameter 5m, aspect ratio 5 and opening 0.5m with varying slope of hopper is analyzed manually using Janssen method for meridonal tension and hoop tension on hopper bottom as shown in figure 6. It is observed from figure 6 that difference in meridonal tension and hoop tension for hopper angle 15º, 60º and 75º is 47.76%, 3.9% and 37.68% respectively.

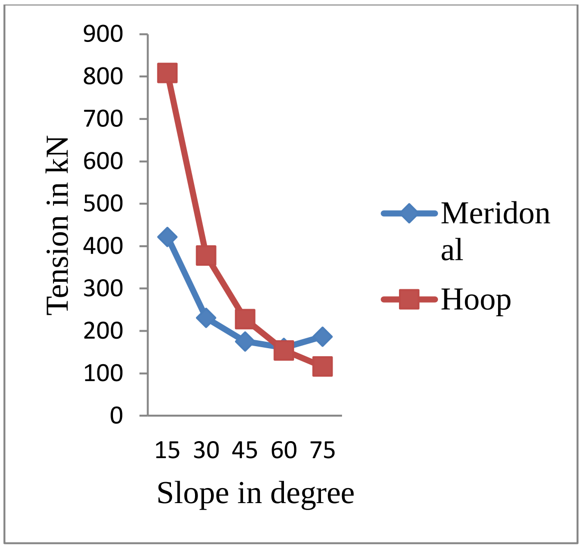

Figure 6 Comparison of meridonal and hoop tension

CONCLUSION

Conclusions derived from this work are listed below.

Lateral pressure for granular material gives maximum pressure during flow condition in Janssen method.

Lateral pressure for powdery material gives maximum Pressure in Airy method.

Reimbert method is based on experimental work in this method actual pressure find out and less pressure value as compare to other this is suitable for all material.

Nature of curve obtain in all cases are found nearly similar which proves that the method of finding pressure is validate the method.

For different values of storing material, hopper angle, hopper opening, height and diameter of silo, minimum value of meridional tension is takes place at 60° angle and values of hoop tension decreases continuously.

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