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Review of Structural Considerations Due To Load Development In Silo Design

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Abstract— The loads which bulk materials exert on silo structures are generally divided into two categories: one due to initial fill and second which resulting due to the flow. Initial fill loads develop, as the name implies, when an empty silo is filled without any withdrawal taking place. The term flow-induced loads are on the other hand, to some extent of a misnomer since it implies that the material must be in motion for these loads to build up. The loads which bulk materials exert on silo structures are generally divided into two categories: one due to initial fill and second which resulting due to the flow. Initial fill loads develop, as the name implies, when an empty silo is filled without any withdrawal taking place. The various types of flow are Initial Fill, Mass Flow – Single Outlet, Funnel Flow – Single Outlet, and Multiple Outlets Material Flow Properties. Force resultants factors like tension, vertical force & upper section, bending in flat walls, horizontal bending on a circular wall vertical bending of upper wall, vertical force on a flat bottom and tension and forces on ring beam are also considered in the review.

Keywords— Silo, Design, Loads, Janssen Theory, Ring Beam, Stress.

INTRODUCTION

Studies of the design and construction of silo started in 1882 when Roberts made his first test on silo of rectangular shape 15m high for calculating pressure. The first lateral and vertical pressure were defined in 1895 by Janssen. After that, his formulas have been continuously applied, although to date problem have not been ceased[1]. Around the nineteen sixties a strong drive was undertaken to define calculate the pressure produced by the stored material on the wall hopper.

The economic cost of repairs to this essential –though frequently neglected – component of a bulk material handling system is generally on a very high. The owner faces direct financial losses due to production and repairs, personnel in the environs are exposed to danger. In this paper I shall elaborate on some of the problems that can occur causing the reason of failure

SILO LOADS FOR DESIGN CONSIDERATIONS:

The loads which bulk materials exert on silo structures are generally divided into two categories: one due to initial fill and second which resulting due to the flow. Initial fill loads develop, as the name implies, when an empty silo is filled without any withdrawal taking place. The term flow-induced loads are on the other hand, to some extent of a misnomer since it implies that the material must be in motion for these loads to build up. In fact, the lone requirement is that there be some extraction of material which allows the flow induced loads to build up. As this occurs, flow can be stopped and then restarted without having any appreciable consequence on the silo loads. In addition, the velocity of discharge is usually not an important variable in affecting the magnitude of the silo loads. The primary reason for it is that most bulk materials are not viscous or visco-elastic, so their velocity of movement has little effect on their frictional properties[2].

INITIAL FILL

As with all of the loading conditions explained herein, it is suitable to consider first the vertical-sided portion of the silo (also called as the cylinder section), and after that the hopper (i.e., sloped/inclined section of the silo were the cross-sectional area is changing with height). If a silo is filled at a point that is coinciding narrowly with the silo's center line, the loads which develop on the cylinder walls are normally of smaller amount than those which are flow induced and are therefore of little interest as far as structural design is apprehensive about. If there is some reason to consider these loads, Janssen equation is recommend with a 'Kj' value (ratio of pressures, horizontal to vertical) of 0.4 and with wall friction angle 'f¢' equal to a value determined from. For a circular cylinder of diameter D, the Janssen equation is:

$$p = \frac{\gamma D}{4 \mu}\left[1 - e^{-4\mu K j Z I D}\right] \qquad (1)$$

$$\tau = \mu p \qquad (2)$$

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

Refer TAXONOMY section at end of paper for a description of terms in equations[8].

Other types of fill conditions can result in loads on the cylinder walls which are bigger than those which are flow-induced. In particular, consider the conditions which occur when filling is off-centered in a silo, or if it is filled along a ridge (such as would occur if a continuous belt tripper fill system are used). Pressures around the silo perimeter at any elevation caused by these conditions can be calculated using the following method[9]:

a) At any point on the cylinder's perimeter, measure vertically up the wall to the elevation where the material surface contacts the wall, z_1.
b) Cut the surface profile with a horizontal slice at the elevation just determined (i.e., where the contact of material to the surface the wall). Calculate the volume of the surcharge above that slice, and then divide that volume by the area of the slice, to give an effective additional head above the slice, z_2.
c) Apply Janssen's equation, using $z = z_1 + z_2$.
d) Repeat the same for sufficient points around the perimeter of the silo to define the distribution.

Even as this condition is usually rather localized to a region immediately below the material surface, it can take place at any height as the silo is being filled. As far as the hopper section is concerned, we believe that the following equation satisfactorily predicts the preliminary fill pressures which act normal (i.e., perpendicular) towards the walls of a converging conical hopper, independent of what type of flow pattern occurs during discharge.

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

$$ni = 2\left(1 + \frac{\tan\phi}{\tan\theta c}\right) - 3 \tag{5}$$

Note that "z" in equation (4) begins with a zero value at the top of the hopper, not at the top of the cylinder as in equation (1). The value of q can be calculated by taking the Janssen horizontal pressure p at the bottom of the cylinder and dividing by Kj (0.4 is the recommended value)[3]

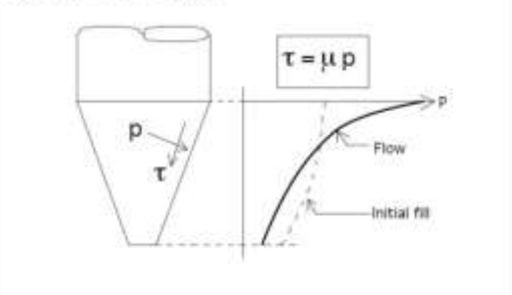
For hopper geometries other than conical, numerical integration of the equations of equilibrium is essential. As will be shown below, in the case of a mass flow hopper the initial fill loads preside over the structural design of the hopper in more or less, its bottom two-thirds, whereas flow-induced loads govern in the upper third as shown in Fig.1. In the majority funnel flow hoppers, their structural design can be based upon initial fill loads.

MASS FLOW – SINGLE OUTLET

Mass flow is a condition in which *the entire* material is in motion even if a single part is withdrawn. As indicated in the SILO DESIGN segment above, particles are able to be flow at different velocities and still satisfy the necessities for mass flow as long as they are moving.

A mass flow bin or silo can still exhibit a no flow condition of arching if the outlet is too small relative to the particle size (arching due to interlocking) or if the outlet passage is too small relative to the cohesive strength of the materials. Mass flow silos can also develop self-induced vibrations as material discharges[7].

Fig. 1: Mass flow hopper



If we assume that the outlet size is large enough to put off the formation of a stable arch, and in addition that self-induced vibrations do not occur on discharge, the loads that develop on the silo walls are moderately well defined. In the cylinder section, a good quality starting point is to use the Janssen equation but with a range of Kj and wall friction values as follows:

$$0.25 \leq Kj \leq 0.6 \tag{6}$$

$$\phi' \text{ calc.} = \phi' \text{ meas.} \pm 5° \tag{7}$$

The “plus” sign must only be used in this equation when calculating upper limit of shear stresses for cylinder buckling calculations, or else the “minus” sign should be used. If an applicable silo code predicts higher pressures, it must be used in the hopper sector; it is also recommend that the use of the following equation [8] to calculate flow induced loads in conical hoppers:

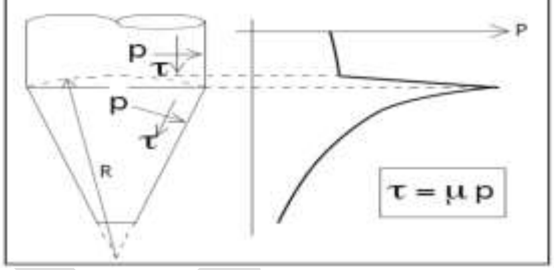
$$p = \gamma Kf\left(\left(\frac{h-z}{ni}\right)+\left(\frac{q}{\gamma}-\frac{h}{ni}\right)\left(1-\frac{h}{ni}\right)^{ni+1}\right) \tag{8}$$

$$Kf = \frac{1}{\left(\frac{3}{2}\left(1+\frac{\tan\phi}{\tan\theta c}\right)-\frac{1}{6(\sigma'/\gamma B)\tan\theta c}\right)} \tag{9}$$

$$nf = 2Kf\left(1+\frac{\tan\phi}{\tan\theta c}\right)-3 \tag{10}$$

The value of “z” starts at zero in equation (8) at the top of the hopper, as in equation (4). The value of q can be computed by taking the Janssen horizontal pressure ‘p’ at the cylinder bottom and dividing by ‘Kj’. To be conservative, a minimum value of ‘Kj’ be supposed to be used for the calculation of ‘p’. These equations result in high pressures in roughly the upper third of the mass flow hopper than occur during preliminary fill, but lower pressures at the bottom two-thirds of the hopper segment. Refer Fig. 1. Since the rapid switch in the state of stress which occurs at the top of a mass flow hopper section, a little increase in wall pressure is time and again experienced in the section of the cylinder just above the hopper top. To account for this condition, it is recommended that the crest pressure be spread all along the vertical wall as depicted in Fig. 2. First, draw a circular arc centered on the theoretical apex of the conical hopper, and passing through the top of the cone. The elevation of the highest point on the arc is approximately the utmost elevation on which the peak pressure increase is experienced. The wall pressure allocation below this elevation (down to the top of the cone) may be assumed linear. A silo in which the filling and the withdrawal points are positioned along the vertical centerline, and which also behaves in mass flow, will probably experience a little non-uniformity of pressures in the region of its circumference.

Fig. 2: Spreading of mass flow pressure peak into cylinder section



This could be caused by the wall being out-of-round or out-of-plumb, the intrusion of manufacture joints, or segregation of the contained bulk material. It is common practice, although by no means always correct, to balance for these effects by multiplying the calculated wall pressure ‘p’ by some “over pressure factor” for purpose of design. Recommendation is that this should be a *minimum* requirement, and that a designer be supposed to make a rational attempt to calculate approximately pressure non-uniformities and their effects.

FUNNEL FLOW – SINGLE OUTLET

It have been noted above, there is no flow all along the hopper walls in a funnel flow pattern (except when the hopper is being emptied at the closing stages of the ejection sequence), it is rational in most cases to consider with the intention of the design pressures acting normal to the hopper walls are similar to those which occur during initial fill. Therefore no additional calculations are desirable for the hopper section. This presumes that the outlet size in addition to feeder arrangements are such that no arching or rat holing can occur as material is discharged. It is also important so as to, there be no self-induced silo vibrations acting to magnify pressures.

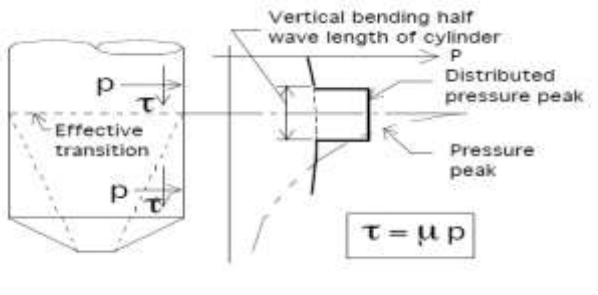
As far as the cylinder section is concerned, there are two main circumstances to consider. First, if the flow channels do not overlap the cylinder wall, it will be safe and reasonable to presume so as to the pressures acting alongside the walls will be the same as throughout initial fill. If, on the other hand, the flow channel do interconnect the cylinder wall, one must consider whether or not the flow channel is centered (*i.e.,* cylinder wall intersects at the same elevation approximately its circumference). If the flow channel is centered, one can presume a Janssen stress field above *the effective transition* (*i.e.,* the height at which the flow channel intersects the cylinder walls).

With mass flow cylinder pressures, it is recommended using a range of 'Kj' and wall friction values as described above. At the efficient transition wherever the flow channel strikes the wall, there is a rapid enhancing in wall pressure owing to the convergence which the material is undergoing. Within the flow channel itself, it is rational to assume that the pressures would vary as if this was a mass flow hopper other than with the hopper angle replaced by the flow channel angle, as well as the wall friction value replaced by the internal friction of sliding particles on each other. It have not been well defined as how this pressure distribution is transmitted to the vertical walls. It is safe, but probably somewhat conventional, to assume so as to, the pressure which acts normal to the cylinder walls is the same pressure which acts normal to the flow channel.

As by means of the conditions which occur at the bottom of a cylinder just above a mass flow hopper, there is a few sequence of this pressure peak, which occurs just above the effective transition in a funnel flow silo. It is recommend that the total radial external force given by the peak pressure, multiplied by the effective area in excess of which it acts and converted in to smaller uniform pressure spread over a wall height equal to one vertical bending half wave length. This ought to be centered at the elevation of the effective transition. Refer Fig. 3.

Several studies have been conducted in an attempt to predict the shape of flow channels in funnel flow bins. One of the older and better known studies was performed by Giunta[11]. He postulated that for a silo having a circular outlet by means of a diameter large and sufficient enough to prevent arching and rat holing, the flow channel shape would consist of a cone emanating from the outlet and flaring out to some diameter. In the upper portion of the bin or silo, he postulated that the flow channel shape should be cylindrical with a diameter set by the maximum size of the conical flow channel. Giunta tested his theory on eighteen inches diameter flat-bottom bin having a single, central outlet. Test materials included pulverized coal, industrial starch, and iron ore concentrate. He found reasonably good agreement between the actual flow channel shape and his theory. There are a number of restrictions in applying Giunta's work as pointed out by Carson *et al.*

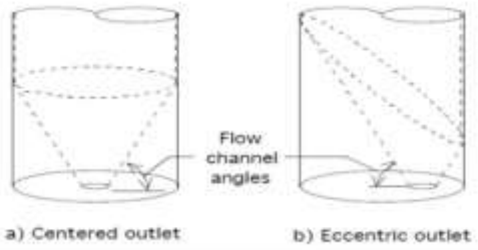
Fig. 3: Funnel flow hopper – flow channel intersecting cylinder wall



In both of the above cases, the wall pressure will be fundamentally constant at any elevation unless the outlet is near the wall. Only after that will the steep flow channel intersect the wall. However, if this occurs, the resulting horizontal bending moments can be exceptionally large because of the extremely non-uniform wall pressures. Furthermore, the authors found that by means of eccentric outlets, the resultant flow channel expanded at roughly the same angle as in a bin with a centered outlet, as well as the eccentric flow channel's axis of symmetry if approximately vertical. Refer Fig. 4.[8][11]

Unfortunately, the studies failed to recognize any correlation between steady state flow channel angle and material flow properties such as useful angle of internal friction or angle of repose.

Fig. 4: Flow channels with centered and eccentric outlets in a funnel flow bin or silo



Clearly, much more work needs to be done with larger models, additional bulk solids, and full scale silos previous to any definitive conclusions can be reached[4][5].

MULTIPLE OUTLETS

If more than one outlet is there in a silo, it is necessary to design the silo structurally to withstand the worst possible loading condition. This usually occurs when one or more of the outlets are active while the others are inactive. Even if all of the outlets be active but are discharging at different rates, preferential flow channels can develop even though functionally it is designed for mass flow silo. To account for these various design conditions, the silo need to be designed as funnel flow loading conditions with an off-centered flow channel occurring above one or more of the active outlets. The nearly all severe combination of flow channels must be considered when calculating the eccentric loads.

MATERIAL FLOW PROPERTIES

Most silo design codes include, either in the code itself or in the commentary section, a tabulation of “distinctive” properties of a numeral of bulk materials. One should approach the data in such tables very vigilantly. Interpolating properties or guessing properties on the basis of superficial similarities in the description of materials must be strongly avoided. It is important to remember that it is not possible to know, or to look up, the requisite flow properties of a granular material from its generic name alone. This is true not only of the bulk material by means of itself, but also of the surface on which it is sliding. For example, providing values or a range of values, intended for wall friction of “coal on steel” sounds simple but can be very misleading. Before using such data, one be supposed to consider the following questions[3]:

- What type of coal (*e.g.,* bituminous, lignite, anthracite) that was considered for developing the data in this table?
- The particle size, moisture content, ash content, etc. of the coal that is to be described?
- Type of steel and what surfaces finish were used for the tests? If carbon steel be used, was the variation as of smooth, polished surface to a rough surface (*e.g.,* due to corrosion) considered? In case of stainless steel is used, was the surface rough (mill finish plate) or smooth (2B finish sheet or polished plate)? If the steel have been mechanically polished, was the direction of polish lines taken into account? Such tabulations make available a disservice to designers in that they tempt the engineer to use them in spite of the warnings provided either within the table or in accompanying text. An engineer can be lulled into a sense that they have some quantitative data that is functional for design, whereas in fact, no assumption is valid.

Material flow tests ought to be run whenever possible to precisely quantify the flow properties (and range of flow properties) of the bulk material to be handled. This is predominantly important when the bulk material being handled is not free flowing, or as soon as its flow properties are unknown, uncertain, or variable. Defining whether or not a material is “free flowing” is to some extent subjective and a matter of debate. In our opinion, the best way to define this is to base it on the flow property of the bulk material and how do the flow properties dictate the type of flow which will occur in a given bin or silo. For example, if it is recognized (either through experience or through flow properties tests) that a given bulk material will not form a steady arch or rathole in a given silo or bin, one might rationally conclude that the material in this silo should be “free flowing.” This same material in another silo having a different flow pattern or silo dimensions may no longer be considered “free flowing.” [11] If tests are to be done, we recommend the following:

- ✓ *Effective angle of internal friction and Flow function:* Material’s cohesive strength and internal friction angles measurement generally, run on the fine fraction of the bulk material, since it is the fines which exhibit most strength. Furthermore, concentrations of fines are generally inescapable because of particle segregation. Once these parameters have been measured, it is possible to follow design process to calculate minimum outlet dimensions to prevent arching as well as decisive rat hole diameters. *Bulk density* usually this is measured by consolidating the bulk material to various pressures and after that measuring the resultant bulk density at those pressures. Such tests should be run both on the fine fractions well as on the full particle size range. The bigger value must be used while calculating bin loads.
- ✓ *Wall friction.* Generally it is easier to execute this test on the fine fraction of the material, and the resulting values typically don’t differ significantly by means of particle size. It is significant to run this test on both the material of construction of the cylinder section as well as with the purpose of the hopper. Consideration is supposed to be given to variations in the preliminary condition of the silo walls as well as situation that can occur subsequent to usage owing to abrasive wear, corrosion, etc. In general, the smoother the wall surface, the higher the wall pressure acting against it.
- ✓ *Abrasive wear.* A tester is accessible which can quantitatively predict the actual life of a bin or silo wall material due to a bulk material sliding along it. This tester may also be used to determine the change in wall friction due to wear. Each of the parameters can vary by means of the same bulk solid if any one or more of the following conditions change:
    - ❖ Moisture content
    - ❖ Time of storage at rest
    - ❖ Particle size distribution
    - ❖ Temperature
    - ❖ Chemical changes

Note that we have not incorporated in the above listing the measurement of the value of Kj. In our opinion, this parameter is more silo dependent than material-dependent. Therefore, attempts to measure its value for a given bulk solid are inappropriate.

FORCE RESULTANTS

TENSION

In a circular bin or hopper wall with uniform pressure lying on the circumference, the lone horizontal force resultant is the ring tension. It is easy to calculate and accommodate during the design phase. If the hopper bottom is supported at the top edge (*i.e.*, the junction with the vertical wall), it will be loaded in tension the length of the line of slope, along with the ring tension. This becomes easy to calculate and design but it is important to check for meridional bending[11].

VERTICAL FORCE & UPPER SECTION

There are vertical compressive forces in the walls of the upper silo section due to the buildup of wall friction effects from the top surfaces downward to the level of the support. This is the sum of the horizontal outward pressures at every addition of depth, multiplied by the depth increment and the wall friction coefficient. Include to it any loads from the roof closure as well as self weight. The decisive buckling stress in the wall is the decisive factor governing the thickness requisite to carry this vertical compression. This condition seldom dictates the depth of reinforced concrete walls;[4] however is a major consideration in designing thin-walled steel or aluminum silos.

BENDING IN FLAT WALLS

Flat walls come into view in rectangular bins or hoppers, or in a chisel-shaped hopper between circular upper sections along with a slotted outlet. This type of bending is always in combination with tension in the plane of the wall. Within the upper section of a bin, vertical compression might also be present. A flat reinforced concrete wall in bending must have two layers of reinforcement, sufficiently anchored at the ends by lap splices running into the adjoining walls. In a steel design it is regularly assumed that the tension and or compression are carried by the wall plate, and the bending is carried by the external stiffeners[8].. The horizontal walls of a rectangular or conical/ chisel-shaped hopper, operating in mass flow, have to remain as practically flat as possible, or the pattern of mass flow may be lost.

HORIZONTAL BENDING ON A CIRCULAR WALL

This occurs majorly due to resultant of a funnel flow, single eccentric flow channel reaching the upper bin wall. The horizontal radial external pressure of the material on the wall is not uniform on the circumference, so out-of-round bending is induced. Non-uniform pressures inside symmetrically filled and emptied silos can also result in bending which needs to be evaluated. Combined bending along with tension effects can best be calculated using a finite element model of the bin wall which is loaded by the internal pressures is calculated over the whole circumference and height. Alternatively, a hand calculation for bending plus tension on the ring can be performed. The most important effect on a steel plate shell is the reduction in vertical buckling strength resultant from an increase in the radius of curvature when the shell deflects out-of-round. In case of construction of reinforced concrete, the reinforcing steel must be provided in two layers, with sufficient capacity for the bending and ring tension at any point. [7]

VERTICAL BENDING OF UPPER WALL

In mass flow, and also in case of funnel flow at the point so as to the flow channel strikes the wall and a peak pressure develops at the effective transition. This might be on the full perimeter or an isolated patch, and is also transient. In funnel flow this crest pressure possibly will be several times greater than the pressures above and below, and occurs on a very shallow band. The resultant force is bending in the vertical direction. In a concrete wall the result may be the development of horizontal cracks.

VERTICAL FORCE ON A FLAT BOTTOM

It is calculated using a value of ‘Kj’ which will maximize the vertical pressure. One must retain information that a huge portion of the gross weight of contained material is carried by the bottom when the diameter to height ratio is small[9]. This portion decreases quickly as the height-to-diameter ratio increases.

FORCES AT RING BEAM

Perhaps the most common and typical, design of a steel silo is circular, with a vertical upper section and conical bottom hopper, supported at discrete points all around the circumference of a ring beam at the junction amid the two parts. A R.C.C. silo will usually have a steel bottom hopper supported from a ring beam which may be separate from the vertical wall, or constructed into the wall.

This ring beam accumulate the meridional tension as of the hopper shell, in addition to, possibly the gross weight of the bin by vertical friction load from the upper wall.[2] A horizontal and vertical component of tension is contributed from the hopper.

The horizontal factor from the hopper creates compression within the ring beam. The summation of the vertical forces creates bending, shear, and torsion in the ring beam. The bending moments are negative (tension at top) above the support points, and positive at mid-span. Shear occurs at the supports. The curvature of the beam allows the torsion to develop, and is at a maximum at the points of contra flexure of the spans[11].

An extra force results is the rolling moment. The line of action of the vector sum of the forces applied to the ring beam is unlikely to pass all the way through the shear center of the beam cross section. The beam therefore tends to be rolled inside out. The net result of rolling is an extra vertical moment, applied at all points on the circumference. The ring beam have to be designed to provide accommodation all these forces in combination.

OTHER CONSIDERATIONS: FEEDER DESIGN

In addition to the geometry and construction materials (MOC's) of the silo, equally important is the type of feeder which is used, as well as details of the interface between the hopper and the feeder. This is particularly important if a mass flow design is to be considered in which, the feeder must ensure that the outlet area is fully "live". Feeder design is equivalently important with funnel flow or expanded flow silos since, depending upon the details of the interface, the flow channel[12] may either be centred or eccentric. Also important is the operation of a gate at the outlet. If a gate is used in whatever thing should be a full open or full closed position, it may upset the development of mass flow or the type of flow channel that may develop in funnel flow or expanded flow. A partially closed gate – even if only just projecting into flowing material – can avert flow along significant portions of the hopper wall.

CONCLUSIONS

The best approach to the design any silo, hopper or bin, for bulk materials is one which is reasoned, thorough, conservative, and based on parameters measured. Design engineers are not legally protected by only following a code of practice. Compliance with the local codes is, of course, essential, but it should never, by itself, be regarded as a sufficient condition to the performance of a acceptable satisfactory design. It is the accountability of the design engineer to ensure that the design is based on complete and sound knowledge of the materials being handled, that the design is competent, and that it covers all anticipated loading combinations.

The construction of any silo, hopper or bin, should be always executed by a qualified and experienced team that understands the stipulation and specifications as per the design and the consequences of not following them. It is the joint responsibility of the designer, builder, and owner that structure constructed/fabricated is of an acceptable standard and satisfactorily fulfills the intent of the design.

It is then the accountability of the owner to properly maintain the structural and other components. It is also the owner's responsibility to ensure that any intended alteration in usage, liner material, discharge geometry or hardware, or any other specified or pre defined parameter, is preceded by a design review for strengthening applied as required.

The design, construction, and utilization of a silo, at all phases, it is supposed to be bear in mind that if a silo is designed, built/fabricated and erected, and operated properly it will have a long and safe life. It must also be noted and understood, that in the event of a failure, the cost of repairs or re-fabrication or reconstruction, litigation, and insurance approximately always add up to several times the cost of doing the job properly in the first place.

TAXONOMY

D = cylinder diameter

h = hopper height

K_f = defined by equation

K_j = Janssen ratio of horizontal to vertical Pressure

n_f = defined by equation

p = pressure acting normal 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 z1 to account for pile height

γ = bulk density

θc = conical hopper angle (measured from vertical)

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

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

ϕ'= wall friction angle between bulk solid and wall surface

REFERENCES

[1] R. T. Jenkyn and D. J. Goodwill, Silo Failures: Lessons to be Learned, *Engineering Digest*, Sept. 1987.
[2] A. W. Jenike, Effect of Solids Flow Properties and Hopper Configuration on Silo Loads, In *Unit and Bulk Materials Handling*(Loeffler, F.J., and C.R. Proctor, eds.), ASME, 1980, pp 97-106.
[3] T. Johnston, Analysis of Silo Failures from Asymmetric Flow, *Presented at the 1991 Spring Convention, American Concrete Institute*, Boston, MA, March 17-21, 1991.
[4] Blight G E 1985 Int. J. Bulk Solids Storage in Silos
[5] Carson J W and Goodwill D J, The Design of Large Coal Silo for Safety, Relibality and economy. Bulk Solid Handling Vol. 4 No.1,pp 173-177,1984.
[6] J. W. Carson and R. T Jenkyn, How to Prevent Silo Failure with Routine Inspections and Proper Repair, Powder and Bulk Engineering 4 No. 1, January 1990
[7] J. W. Carson and R. T Jenkyn, Load Development and Structural Consideration in Silo Design
[8] A challenge for designers of steel silos - Jim Durack & Professor Charlie Tranberg – USQ
[9] Silo Problems – Juan Ravenet, Bulk Solid Handling Vol.1 Number 4, December 1981.
[10] Giunta J.S. Flow Pattern of Granular Materials in Flat Bottom Bins, Translations of the ASME Journal of Engineering Industry, 91,Ser. B, No.2, Pg. No. 406-413.
[11] J. W. Carson and R. T Jenkyn Load Development and Structural Consideration in Silo Design, Jenike & Johansosn Inc.
[12] Jenike A.W.: Effect of Solid Flow Properties and Hopper Configuration in Silo Loads Unit of Bulk Material Handling (Loeffler. F.J. and C.R. Proctor,eds), 1980 ASME, PP. 97-106