bulk solids handling Volume 1 Number 3, September 1981

Non-Symmetrical Bin Flow Problems

H. Colijn, USA and I.A.S.Z. Peschl, Holland

Asymmetrische Bunkerfluß-Probleme
Problémes de l'écoulement asymétrique des réservoirs
Problemas de flujo de recipientes no simétricos
非対称ビンフローに関する問題
非对称性料斗流动问题
مشاكل التدفق غير المتماثل من العلب. بقلم انش كوليجين

Summary

The problems associated with non-symmetrical withdrawal of bulk solids from bins, hoppers or silos can be classified in two areas:

1. Flow problems with the stored materials, such as arching, ratholing, segregation, etc.
2. High localized loadings on the bin or silo walls, that may cause structural failures.

Structural designers are generally more concerned with the structural integrity of the storage facility than with the flow performance of the materials. Unfortunately, the structural aspects are often closely related to the flow patterns inside the bins. It is therefore necessary to carefully investigate the flow of materials and the resulting pressures on the walls, before the structural design can be finalized.

This paper will discuss in general the flow patterns in bins and silos and the resulting pressures on the walls with special emphasis on non-symmetrical flow patterns, caused by either non-symmetrical bin configurations or by improper functioning feeders or gates.

1. Introduction

During the past 20 years, we have seen considerable advances made in the development of theories concerning the flow of granular bulk solids. At the same time, there has been a growing need for engineers to become aware of the fundamentals relating to the design of bulk solids storage and handling systems. This has led to a series of articles and industrial courses. However, it seems to take forever to disseminate the available information among practicing engineers and to prevent many design errors to occur over and over again.

The flow of granular bulk solids and the structural design of storage bins or silos cover various engineering disciplines. The flow of granular bulk solids is influenced primarily by their flowability properties (shear strength) and bulk density, geometric configuration of the hopper, selection of hopper liner materials, etc. As a result of these flow characteristics and flow patterns, pressures are exerted on the containing vessel, tank or silo. This aspect is usually covered by mechanical or chemical engineers, who generally do not get involved with the structural design. The actual structural design is covered by civil engineers, experienced in steel or concrete structures. Quite often, these two areas of engineering and design work independently of each other, resulting in problems with the facility during operations.

Various efforts have been made by national and international organizations to establish standards and codes for silo design. Most of them fail in their purpose, as they do not incorporate the material properties or material flow patterns.

We know that continuing work is being done to come up with a workable code for safe design of bulk solids storage facilities, but it may take some time before we see it in print.

The purpose of this paper is just to emphasize one aspect of silo design, that of non-symmetrical bin flow problems. It does not offer a comprehensive new theory, but only intends to show that this problem must receive careful consideration of the structural engineer.

2. Flow Patterns

Since the early 1950s, certain terms describing flow patterns started to become common in hopper, bin and silo design. Mostly through publications from A. W. Jenike, J. Johanson and others working in this field, the following terminology became accepted [1—10].

From a standpoint of flow patterns, there are basically three types: *mass-flow, funnel-flow* and *expanded flow* (Fig. 1).

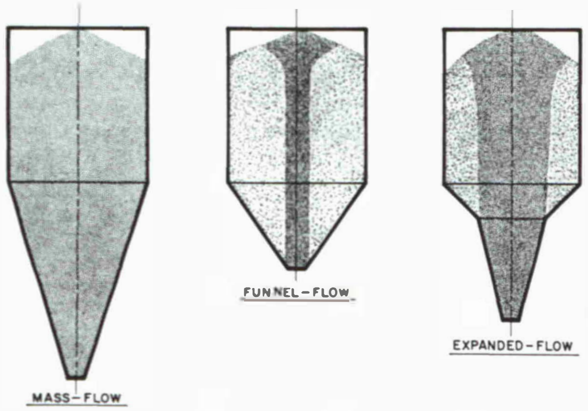


Fig. 1: Flow patterns

Ir. Henk Colijn, Consulting Engineer, H. Colijn & Associates, 423 Franklin Heights Drive, Monroeville, PA 15146, USA; Dr. Ir. I.A.S.Z. Peschl, Consulting Engineer, Silo Project B.V., 8 Kennedy Laan, NL-6029 RE Sterksel (N.B.), The Netherlands

2.1 Mass-Flow

With mass-flow the hopper is sufficiently steep and smooth to cause flow of all the solids in the bin without stagnant regions during discharge.

In mass-flow bins, the flow is uniform and the bulk density of the feed is practically independent of the head of solids in the bin. This frequently permits the use of volumetric feeders for feed rate control. Low level indicators work reliably. In addition, segregation is minimized because, while a solid may segregate at the point of charge into the bin, the first-in, first-out flow sequence enforces the same particle size distribution to exit the hopper as was put into it. This flow sequence also ensures uniform residence time and de-aeration of fine powders.

Generally, mass-flow in bins provides a smooth withdrawal movement of the materials. Occasionally, however, when the design is marginal, a "jerky" movement may develop, caused by partial arching or a slip-stick movement along the walls. This "jerky" movement may set up severe vibratory problems in the structure.

Mass-flow bins are generally recommended for cohesive materials; for materials which degrade with time, for powders, and when segregation needs to be minimized.

2.2 Funnel-Flow

Funnel-flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls or when the outlet of a bin is not fully effective, due to poor feeder or gate design.

In a funnel-flow bin, the bulk solids flow toward the outlet through a vertical channel that forms within stagnant material. The diameter of that channel approximates the largest dimension of the effective outlet. When the outlet is fully effective, this dimension is the diameter of a circular outlet, or the diagonal of a square or slotted (rectangular) outlet. Powders withdrawn at a high flow rate from a funnel-flow bin may remain fluidized due to the short residence time in the flow channel and flush during withdrawal from the bin, making control of the product discharge rate quite difficult.

As the level of the bulk solids within the channel drops, layers slough off the top of the stagnant mass into the channel. This flow behavior is detrimental with cohesive solids, since the falling material packs, thereby increasing the chance of arching. A channel, especially a small, high-velocity channel, may empty out completely (rathole) and powder charged into the bin then flushes through.

Since funnel-flow bins are more prone to cause arching of cohesive solids than mass-flow bins, they usually require larger outlets for dependable flow. These bins also cause segregation of solids and are unsuitable for solids which degrade with time in the stagnant regions. Cleanout of a funnel-flow bin is often uncertain because solid in the stagnant regions may pack and cake.

Funnel-flow bins are only suitable for coarse, free-flowing or slightly cohesive, non-degrading solids when segregation is unimportant.

2.3 Expanded Flow

This is a combination of mass-flow and funnel-flow. The lower portion of the hopper operates in mass-flow. The mass-flow outlet usually requires a smaller feeder than would be the case for funnel-flow. The mass-flow hopper should expand the flow channel to a diagonal or diameter equal to or greater than the critical rathole diameter, thus eliminating the likelihood of ratholing.

These bins are recommended for the storage of large quantities of non-degrading solids. This design is also useful as a modification of existing funnel-flow bins to correct erratic flow caused by arching, ratholing or flushing.

This concept can be used with multiple outlets where simultaneous flowing mass-flow hoppers are placed close enough together to cause a combined flow channel in excess of the critical rathole diameter.

2.4 Symmetrical and Non-Symmetrical Flow

Normally, the above mentioned flow patterns are axi-symmetrical in relation to the bin or silo walls, as the outlet is located in the center line of the bin. This symmetry has many advantages in terms of flow and structural design.

Because of reasons of layout, capital cost or the designer's past practices, many non-symmetrical bins and hoppers are built, or sometimes symmetrical bins with off-set outlets.

Due to this non-symmetrical bin or hopper configuration, eccentric withdrawal from multiple outlets or side outlets, and eccentric loading spouts, the resulting flow patterns can develop severe problems in the storage facilities.

Quite often eccentric withdrawal patterns can also be developed in symmetrical bins when the feeder is not properly designed or selected, or when the cut-off gate is left partially closed. The off-center vertical flow patterns caused by feeders or gates will have the same structural effects on the bin as a non-symmetrical bin.

Fig. 2 shows schematically various types of off-center flow channels. This type of funnel-flow enhances the problems of arching, creates the stable rathole problems, allows a discharge of segregated particle distribution, and causes a non-uniform loading on the bin walls.

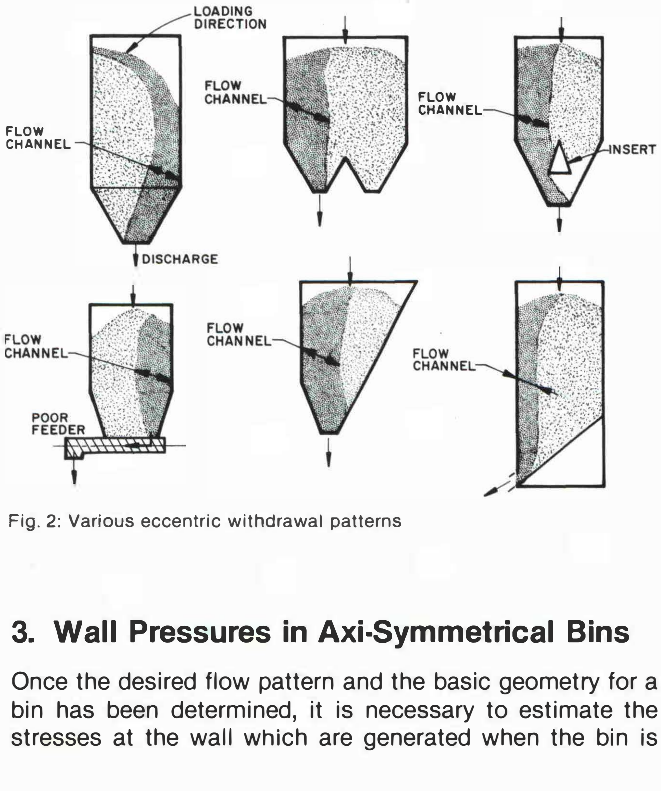


Fig. 2: Various eccentric withdrawal patterns

3. Wall Pressures in Axi-Symmetrical Bins

Once the desired flow pattern and the basic geometry for a bin has been determined, it is necessary to estimate the stresses at the wall which are generated when the bin is operating; such information is required so that the bin structure can be designed economically.

Research relating to wall stresses dates back to the last century when Janssen published his now famous theory [13]. The modern theories of Walker [14, 15], Jenike et al. [16—20], Walters [21—22] and Clague [23] have all been published since 1966 (with the majority of them published since 1974). Examination of these papers shows that the solution of the problem of stress distributions in bins is extremely complex and it is quite obvious that an exact solution will not be determined for some time, if ever. In the meantime, therefore, researchers have had to make approximations and simplifying assumptions in order to obtain any solution at all.

Depending upon the researcher, the following alternative terms are given to the initial and flow pressures on the bin wall:

initial — filling — static
flow — emptying — dynamic.

Some authors prefer the term wall stresses or stresses at the wall, rather than pressures.

Despite the variation in terminology, the following assumptions are made by most researchers. The loads which act on a bin wall are different during the initial stage of filling a bin and during the flow stage from a bin. During the initial stage, when bulk solids are charged into an empty bin, with the gate closed or the feeder at rest, the solids settle as the head of solids rises. During this settlement, the bulk solids contract vertically in the cylindrical section and partially vertical in the hopper section. The major principal stress tends to align with the direction of contraction of the solids, forming what is termed an active or peaked stress field. It is assumed that the solids are charged into the bin without significant impact to cause packing and that powders are charged at a sufficiently low rate so that they de-aerate. It is also assumed that the bin and feeder have been designed correctly so that the solids flow without obstruction.

When the gate is fully opened or the feeder started and the solids start flowing out of the outlet, there is a vertical expansion of the solids within the forming flow channel and the flowing mass of solids contract laterally. The major principal stresses within the flow channel tend to align with the lateral contractions and the stress field is said to be passive or arched.

The region of change (switch) from active to passive stress field originates at the outlet of the bin, when the gate is first opened or the feeder is started, and then rapidly travels upward into the bin as the solids are withdrawn. At the level of the switch, a fairly large overpressure may be present. This overpressure is assumed by a number of authors to travel upward with the switch, at least to the level at which the channel intersects the vertical section of the bin, that is, to the level of the transition in mass-flow bins or the "effective transition" in funnel-flow bins.

Generally it can be assumed that for a bin, consisting of a hopper plus a cylindrical section above it, there are basically five stress fields present [4] during the fill and discharge sequences. These are:

1. in the cylindrical section during initial filling, where the state of stress is peaked or active;
2. in the cylindrical section during emptying, where the state of stress is either peaked (active) or changes to arched (passive), depending upon whether the switch level is assumed to be caught at the transition;
3. in the converging hopper section during filling, where the state of stress is assumed to be peaked;
4. in the converging hopper section during emptying, where the state of stress is assumed to be arched.
5. the switch field, the region in the bin where the peaked stress field established during initial filling is transformed into the arched stress field. This switch starts at the outlet of the hopper, if newly filled from completely empty, and then travels up very quickly as emptying continues, generally to become caught at the transition.

Most of the mentioned researchers agree upon a wall pressure or stress distribution as is shown in Fig. 3, although there is quite some variation in quantitative values (Fig. 4). It is not the intent of this paper to review and evaluate the various computational methods published. A valuable contribution in evaluating these methods was made by P.C. Arnold, A.G. McLean and A.W. Roberts of the University of Newcastle, Australia [4].

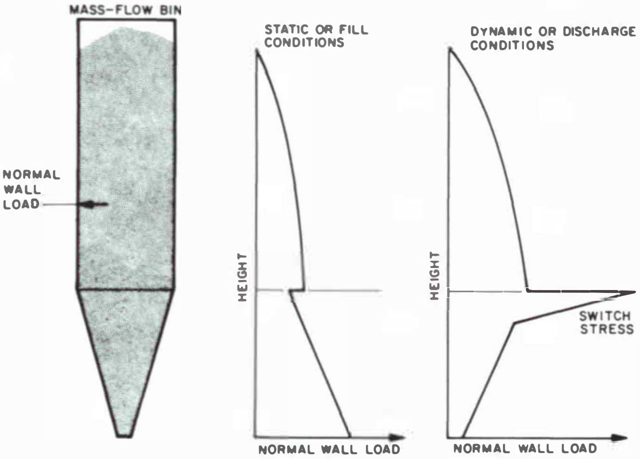


Fig. 3: Wall load distribution

Fig. 4 shows the various results of pressure computations using different methods [28].

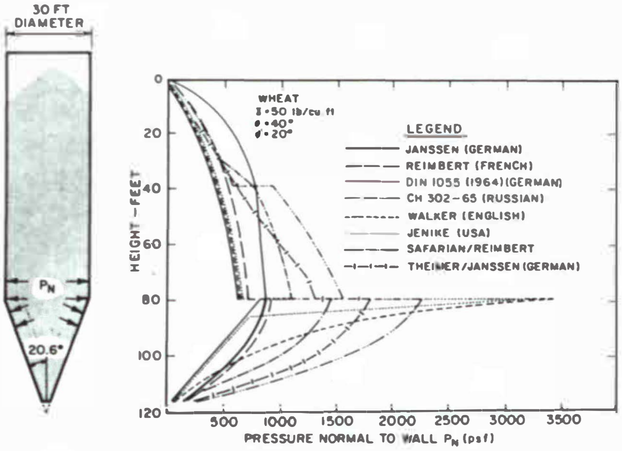


Fig. 4: Computed wall pressures during flow

The basic equation for static wall pressures in cylindrical silos came from Janssen [13]:

$$p_{\text{hor}} = \frac{\gamma D}{4\mu^1}\left[1 - e^{\frac{-4K\mu^1 h}{D}}\right] \text{lbs/ft}^2 \tag{1}$$

and

$$K = \frac{p_{\text{horizontal}}}{p_{\text{vertical}}} \tag{2}$$

where:
γ = bulk density lbs/ft^3
D = silo diameter in ft
μ^1 = sliding friction coefficient along wall
h = silo height measured from top in ft
ϕ = angle of internal friction

There have been many publications concerning the value of K in the design of silos. Although the American Concrete Institute (ACI code 313-77) uses

$$K = \frac{1 - \sin\phi}{1 + \sin\phi} \tag{3}$$

for the cylindrical section of a bin, Peschl and others [32] have found that the K-value is in reality larger. Hence, we have used $K = 1 - \sin\phi$ in the cylindrical portion of the bin as shown in Fig. 5.

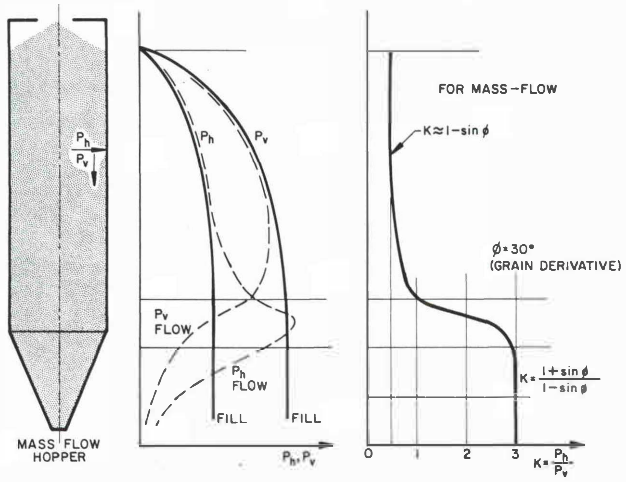


Fig. 5: Typical measured pressure distribution

A number of full scale silo measurements were done in Europe by Peschl to determine the magnitude of wall loadings in concrete and steel silos. Instead of measuring directly the wall pressures, elongation measurements were made of the rebars or steel plates. These strain measurements were subsequently converted into wall pressures. The theoretical high peak pressures at the transition did not show up, although a higher pressure zone was noticeable at the transition.

Fig. 5 shows a typical pressure distribution, as determined by these measurements on a grain-derivative silo. The highest value of horizontal wall pressure during flow at the transition region was about twice that of the horizontal fill pressure (p_h).

From these tests it can be concluded that the switch pressure acts over a fairly large zone and averages at a value not larger than twice the fill pressure (p_h). The strain measurements on the silo walls tend to equalize any local pressure effects, which often show up with direct pressure transducers at the wall.

So far only small laboratory models have been used for direct pressure measurements. It seems that for large silos the strain measurement is the most practical.

Fig. 6 shows an actual measured hoop tension variation as a function of discharge time in a steel silo for potato starch (AVEBE, Delftzijl, The Netherlands). The steel wall was 5 mm thick and the hopper was mass-flow. Strain measurements were made with straingages attached to the outside of the steel wall.

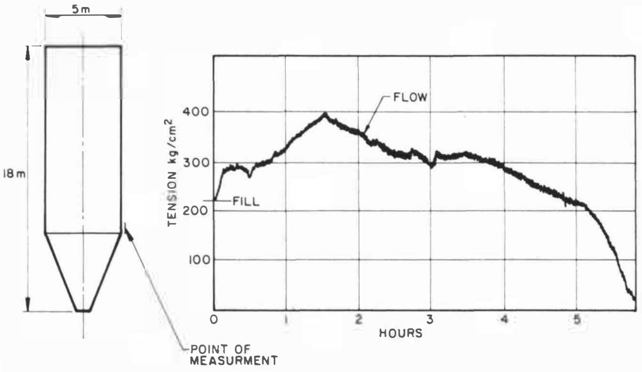


Fig. 6: Measured tension in bin wall (potato starch silo)

4. Non-Symmetrical Flow

As shown in Fig. 2, a non-symmetrical bin or flow tends to develop eccentric funnel-flow type patterns.

These eccentric flow funnels generally cause unequal lateral pressure distributions along the circumference of a silo or bin wall. Generally accepted methods or design codes for silo design, such as DIN 1055 and ACI # 313—77, may not be sufficient to establish the adverse effects of this eccentric flow pattern, depending on the actual geometry.

Some designers [30] are using a finite-element modeling for the silo — bulk solids interaction. This approach is an optimum design rationale which takes advantage of material deformations, the interaction between silo wall, static material and flowing material.

A simplified theory of flow through relatively small channels in a bin can be developed. The stationary material around the flow channel can be assumed to act as a silo wall. The pressures in the flow channel will be determined by the diameter of the flow channel.

It would be quite possible that the pressure in the flow channel is less than the pressure in the stationary mass around the channel (fill pressure of the silo).

A simplified approach may be used to illustrate the problems of eccentric withdrawal. A reasonable assumption to be made is to establish that the maximum horizontal emptying or discharge pressure in the flow channel p_1 is twice as large as the horizontal fill-pressure in the same channel (Fig. 7):

$$p_1 \cong 2\,\frac{\gamma d}{4\mu} \tag{4}$$

where:
γ = bulk density
d = channel diameter
μ = wall sliding friction coefficient.

If p_2 is the maximum static pressure in the silo, then

$$p_2 \cong \frac{\gamma D}{4\mu} \tag{5}$$

where: D = silo diameter

and the pressure differential:

$$\Delta p = p_1 - p_2 = \frac{\gamma D}{4\mu}\left(2\frac{d}{D} - 1\right) \tag{6}$$

Δp will be zero when $\frac{d}{D} = \frac{1}{2}$, which will be limit of the $\frac{d}{D}$ ratio used in this analysis.

The eccentric wall loading can be expressed as:

$$F = \Delta p \cdot d = \frac{\gamma D^2}{4\mu}\left[2\left(\frac{d}{D}\right)^2 - \frac{d}{D}\right] \tag{7}$$

where: $F = 0$ for $\frac{d}{D} = 0$ and $\frac{d}{D} = 0.5$

F = maximum for $\frac{d}{D} = 0.25$

Hence: $F_{max} = -0.125\,\frac{\gamma D^2}{4\mu}$

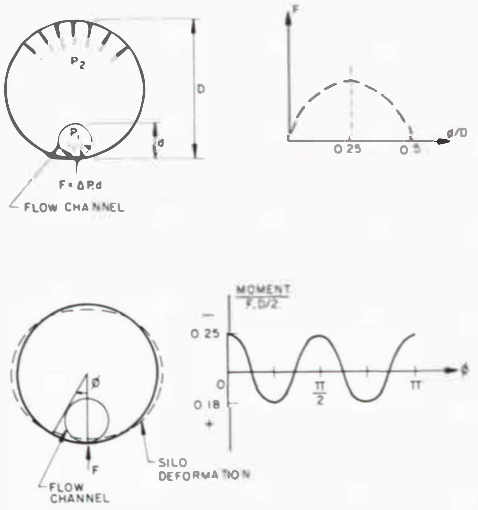


Fig. 7: Forces and moments on silo wall

If the wall loading (F) is transformed in a concentrated line force (Fig. 7), then the equation for the moment in the wall is (Fig. 7):

$$M_{max} \cong -0.25\,F \cdot \frac{D}{2} \tag{8}$$

$$M_{min} \cong +0.18\,F \cdot \frac{D}{2} \tag{9}$$

Field measurements have shown that there is virtually no "damping" of the moment curve with increasing angle ϕ. However, it is conceivable that certain conditions can exist, permitting the moment to decrease to near zero, when $\phi = \pi/2$.

The following example may clarify the application of this computational method. A concrete silo with an ID of 12 m and a height of 70 m is used to store soy bean meal with a specific weight of 0.8 (50 lb/ft³) and a coefficient of friction (μ) on concrete of 0.3. A cross-brace is installed at the transition, creating four quadrants (Fig. 8).

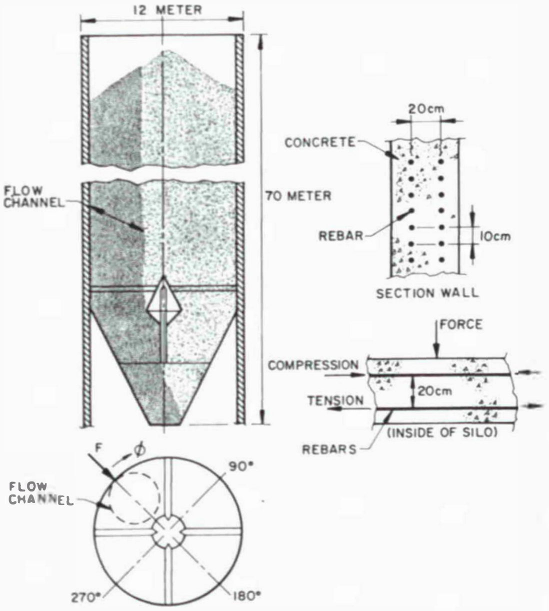


Fig. 8: Storage silo for soybean meal

Although having four possible quadrants (openings) available for flow, it is still quite possible that a slight off-set of the cross-bracing and/or a slight variation in material properties will establish a preferential flow channel through one of these quadrants. Once this occurs, the material above the other stagnant quadrants will be further consolidated, resulting in an even greater resistance to flow and preventing the development of additional flow channels.

The maximum fill pressure (p_h) is 8 ton/m² and the maximum flow pressure would be about 16 ton/m², if symmetrical flow occurs. The maximum hoop tension in the re-inforcing steel is

$$T = \frac{p \times D}{2} = \frac{16 \times 12}{2} = 96 \text{ ton/meter} \tag{10}$$

Reinforcement of concrete wall (Fig. 8) consists of two rows of rebar steel; 10 bars per meter height on inside and outside rows. The allowable stress is 2.4 ton/cm², hence the cross-section of the bars is

$$A = \frac{T}{20 \times \sigma_{allow.}} = \frac{96}{20 \times 2.4} = 2 \text{ cm}^2/\text{bar} \tag{11}$$

or the bar diameter is 16 mm.

Tensions in the bars are for symmetrical flow:

$\sigma_{fill} = 1.2$ ton/cm²

$\sigma_{flow} = 2.4$ ton/cm²

Let us assume now that an eccentric flow pattern develops in this silo with $d \cong 0.25$ D. This can happen when only one quadrant of the cross-bracing creates a preferential flow channel. The maximum eccentric force

$$F_{\max} = 0.125\ \frac{\gamma D^2}{4\mu} = 12\ \text{ton/m} \tag{12}$$

and the resulting moments are

$$M_{\max} = -0.25\,F \cdot \frac{D}{2} = -18\ \text{t.m/m} \tag{13}$$

$$M_{\min} = 0.18\,F \cdot \frac{D}{2} = 13\ \text{t.m/m} \tag{14}$$

The maximum hoop stresses in wall resulting from these moments are

$$T_{\text{M max}} = \frac{-18}{0.20} = -90\ \text{t/m} \tag{15}$$

$$T_{\text{M min}} = \frac{13}{0.20} = 65\ \text{t/m} \tag{16}$$

The additional tensions (originated by the moments) in the rebars become now:

$$\left.\begin{array}{l}\phi = 0\\ \phi = 180^\circ\end{array}\right\}\ \sigma_{\text{M}} = \frac{90\text{T}}{10\text{x}2\ \text{cm}^2} = 4.5\ \text{ton/cm}^2 \tag{17}$$

$$\left.\begin{array}{l}\phi = 90^\circ\\ \phi = 270^\circ\end{array}\right\}\ \sigma_{\text{M}} = \frac{65}{10\text{x}2\ \text{cm}^2} = 3.25\ \text{ton/cm}^2 \tag{18}$$

Of interest are only the tensions, because the compressions are taken up by the concrete.

The total maximum tensions in the rebars become:

inside rebars: $\sigma_{\phi = 0^\circ} = 4.5 + 1.2 = 5.7\ \text{t/cm}^2$
outside rebars: $\sigma_{\phi = 90^\circ} = 3.25 + 1.2 = 4.45\ \text{t/cm}^2$

Considering that the $\sigma_{\text{elastic}} = 4800\ \text{kg/cm}^2$ or $4.8\ \text{t/cm}^2$, and the $\sigma_{\text{break}} = 5500\ \text{kg/cm}^2$ or $5.5\ \text{t/cm}^2$

the above listed stresses in the rebars exceed the elastic limits and the bars will yield in localized areas. This is exactly what happened at a concrete silo of Unilever in Hamburg.

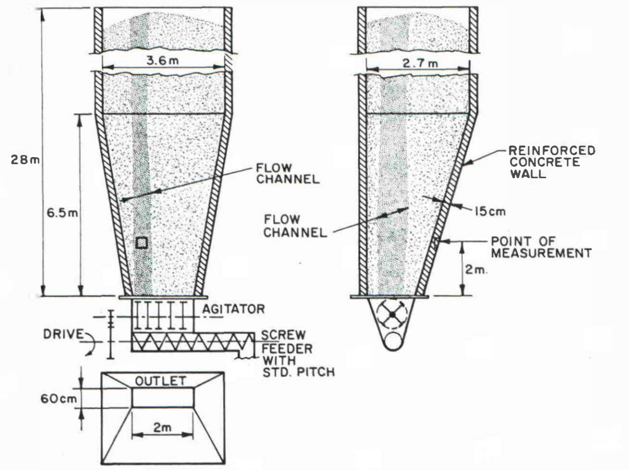


Fig. 9: Storage silo for flour — case I

A second example of problems associated with eccentric withdrawal is shown in Fig. 9, showing a storage bin for flour used by FIDELINKA (Subotica, Yugoslavia). Various types of flours were stored in this bin, with the following material properties:

angle of internal friction	$30^\circ < \phi < 35^\circ$
bulk densities:	
compacted	$50\ \text{lb/ft}^3$
loose	$35\ \text{lb/ft}^3$
aerated	$24\ \text{lb/ft}^3$
coeff. wall friction on concrete	$0.57 < \mu < 0.75$
critical arching dimensions	$57\ \text{cm} < B_c < 105\ \text{cm}$.

The original bin design as shown in Fig. 9 had a paddle-agitator and a screw feeder with standard pitch flights. This design created severe ratholing problems and eventually caused structural damage.

Some of the rebars in the concrete were strain gaged at a level 2 m above the agitator. A typical result of these measurements (stress in rebars) is shown in Fig. 11 (case I). The fill pressure results in a stress value of $\sim 1000\ \text{kg/cm}^2$.

As soon as flow starts, an eccentric flow channel develops and the stresses in the rebar increase. Occasionally, the channel will run partially empty (rathole) and a surge from the top will refill the channel. However, the flour is now highly aerated, resulting in sudden peaks in pressures. As soon as the flour is again de-aerated, the wall pressure returns to its orginal level.

The stresses measured compared favorably with the computed values of the structural analysis.

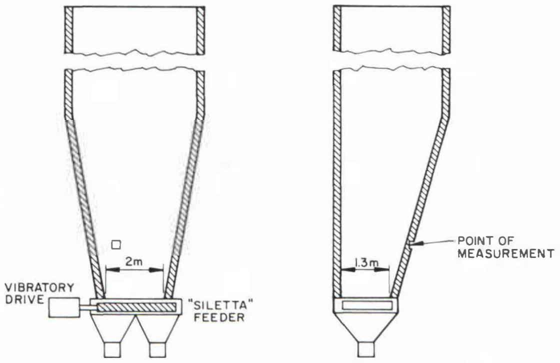


Fig. 10: Storage silo for flour — case II

As a solution to this problem, a *SILETTA*-feeder was installed under the bin, creating a mass-flow condition, as shown in Fig. 10. The resulting stresses were greatly reduced, as shown in Fig. 11 (case II).

The choice of the discharging equipment (feeder) can have a great influence, not only on the desired discharge rate, but also on the flow pattern in the bin and the consequential effect on the bin wall loading. Therefore, it is essential to consider the bin, hopper and feeder as one system, designed to provide the best performance for material storage and discharge at least cost.

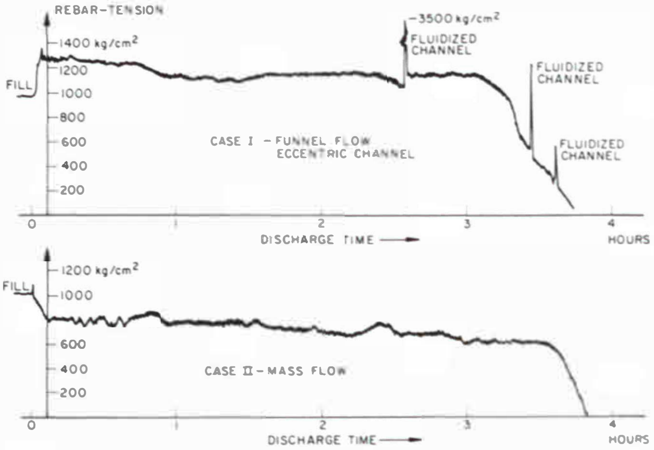


Fig. 11: Stress variations in rebar of storage silo

5. Conclusion

Silo designs require in both functional and structural aspects a careful analysis in order to provide an effective, economical and safe storage facility. In this paper, the interrelationship was emphasized between the geometric bin configuration, material flow characteristics, desired flow patterns and bin wall loadings. Therefore, a bin or silo should not be considered just a *container* with a certain volumetric capacity, but more or less an *operating system* or a *machine*, requiring analysis of static and dynamic responses to varying operational conditions.

A poor selection or design of a gate or discharge feeder can greatly influence the performance of the bin and the resulting pressures may be much higher than initially anticipated.

Material flow characteristics are closely related to compacting pressures and compacting pressures are related to bin size. Therefore, experimental work with small bins do not necessarily reflect the same phenomena to be expected in large bins and extrapolation from small to large models may be erroneous.

With currently available measuring techniques of material flow characteristics and theoretical knowledge of the static and dynamic design of bins, combined with a wide choice of feeders, it is quite feasible to design bins and silos in the industry, which perform well and meet all specified requirements.

Further efforts in development work should be made. Hopefully, one day we may have a design code, useful for most engineers involved in the design of silos, bins and hoppers.

References

[1] Jenike, A.W., "Storage and Flow of Solids", Bulletin # 123, Utah Engineering Experiment Station, University of Utah, Nov. 1964

[2] Johanson, J.R., and Colijn, H., "New Design Criteria for Hoppers and Bins", Iron & Steel Engineer, Oct. 1964

[3] Wright, H., "An Evaluation of the Jenike Bunker Design Method", Journal of Engineering for Industry, Trans. ASME, Series B. Vol. 95, No. 1, 1973

[4] Arnold, P.C., McLean, A.G., and Roberts, A.W., "Bulk Solids: Storage, Flow and Handling", No. ISBN 0 7259 03031, TUNRA Ltd., University of Newcastle, N.S.W., Australia

[5] Peschl, I.A.S.Z., "Silo Failures — An Analysis of the Reasons", Paper presented at the Congress of Construction of Concrete Silos, Fagernes, Norway, Febr. 18 —March 2, 1977

[6] Peschl, I.A.S.Z., "Powder Testing Techniques and their Application on Solving Industrial Problems", Paper presented at the International Conference of Bulk Solids Storage, Handling and Flow, Stratford Upon Avon, England, Nov. 16—18, 1976

[7] Peschl, I.A.S.Z., "Design of Industrial Bulk Powder Handling Facilities", Paper presented at the International Conference of Bulk Solids Storage, Handling and Flow, Stratford Upon Avon, England, Nov. 16—18, 1976

[8] Peschl, I.A.S.Z., "Beitrag zur sicheren Berechnung der Silos" (article), Die Mühle, Oct. 1973 (Germany)

[9] Peschl, I.A.S.Z., "Einfluß der dynamischen Belastung auf die Bruchsicherheit der Silozellen", (article), Die Mühle, March 1970 (Germany)

[10] Peschl, I.A.S.Z., and von Eisenhart Rothe, M., "In-Plant Bulk Materials Handling", Chemical Engineering, March 28, 1977

[11] Peschl, I.A.S.Z. and von Eisenhart Rothe, M., "Schüttgutaustrag und Direktdosierung — Grundlagenuntersuchungen zu einem neuentwickelten System der großflächigen Aktivierung von Bunkerausläufen bei kontinuierlich regelbarem Schüttgutaustrag", November 1977, Aufbereitungs-Technik

[12] Peschl, I.A.S.Z., "Design of Powder Handling Facilities", Presented at the Bulk Handling Seminar at the University of Pittsburgh, December 10—11, 1975

[13] Janssen, H.A., "Tests on Grain Pressure in Silos", Zeitschrift des Vereins Deutscher Ingenieure, Band 39, No. 35, 1895, 1045

[14] Walker, D.M., "An Approximate Theory for Pressure and Arching in Hoppers", Chemical Engineering Science, Vol. 21, 1966, 975

[15] Walker, D.M., and Blanchard, M.H., "Pressures in Experimental Coal Hoppers", Chemical Engineering Science, Vol. 22, 1967, 1713

[16] Jenike, A.W., and Johanson, J.R., "Bin Loads", Journal of Structural Division, ASCE, Vol. 95, No. ST4, 1968, 1011

[17] Jenike, A.W., and Johanson, J.R., "On the Theory of Bin Loads", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 91, No. 2, 1969, 339

[18] Jenike, A.W., and Johanson, J.R., and Carson, J.W., "Bin Loads — Part 2: Concepts", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 95, No. 1, 1973, 1

[19] Jenike, A.W., and Johanson, J.R., and Carson, J.W., "Bin Loads — Part 3: Mass-Flow Bins", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 95, No. 1, 1973

[20] Jenike, A.W., and Johanson, J.R., and Carson, J.W., "Bin Loads — Part 4: Funnel-Fow Bins", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 95, No. 1, 1973, 13

[21] Walters, J. K., "A Theoretical Analysis of Stresses in Silos with Vertical Walls", Chemical Engineering Science, Vol. 28, 1973, 13

[22] Walters, J. K., "A Theoretical Analysis of Stresses in Axially-Symmetric Hoppers and Bunkers", Chemical Engineering Science, Vol. 28, 1973, 779

[23] Clague, K., "The Effects of Stresses in Bunkers", Ph. D. Thesis, University of Nottingham, 1973

[24] Theimer, O. F., "Failures of Reinforced Concrete Grain Silos", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 91, No. 2, 1969, 460

[25] Deutsch, G. P., and Schmidt, L. C., "Pressures on Silo Walls", Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 91, No. 2, 1969, 450

[26] Arnold, P. C., and Roberts, A. W., "A Useful Procedure for Predicting Stresses at the Walls of Mass-Flow Bins", Paper presented at Symposium on "Solids Flow and Handling", AIChE, 80th National Meeting

[27] Walters, J. K., and Nedderman, R. M., "A Note on the Stress Distribution at Great Depth in a Silo", Chemical Engineering Science, Vol. 28, 1973, 1907

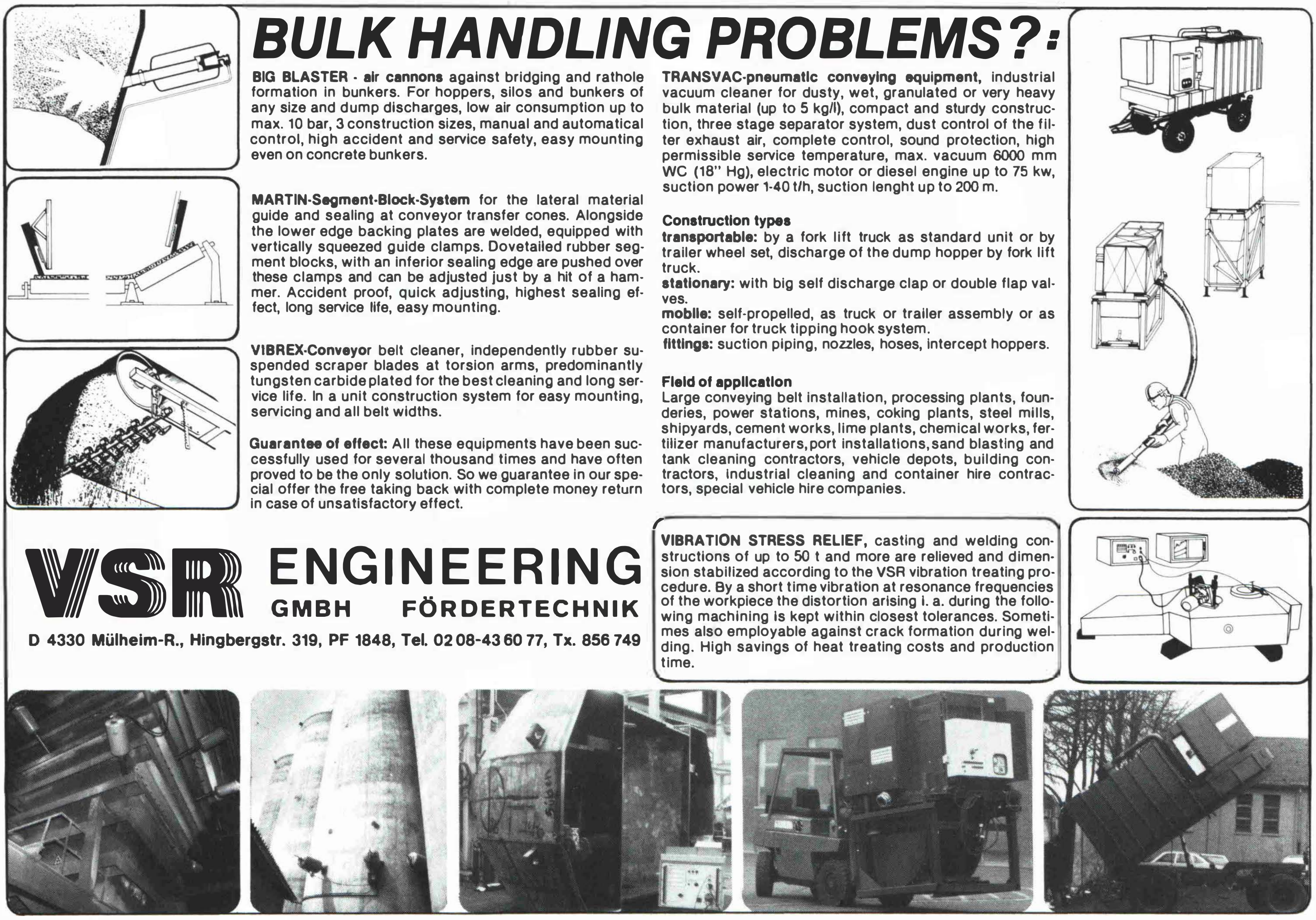
[28] Patterson, W. S., "Pressures in Silos — A Review of Design Methods", Civil Engineering and Public Works Review, May 1970

[29] Jenike, A. W., "Denting of Circular Bins with Eccentric Drawpoints", Journal of Structural Division, Proceeding American Society of Civil Engineering, February 1967

[30] Mahmoud, M. H., "Practical Finite Element Modeling of Silo-Material Interaction", Proceedings of the Technical Program, International Powder and Bulk Solids Handling & Processing Conference, Rosemont, Ill., May 10—12, 1977

[31] Gaylord E. H., and C. N., "Granular Material Pressures in Bins", Paper No. 77-4503, American Society of Agricultural Engineers, Annual Winter Meeting, Chicago, Ill., Dec. 13—16, 1977

[32] Cowin, S. C., "The Pressure Ratio in the Theory of Bin Pressures", ASME Journal of Applied Mechanics, Sept. 1979, Vol. 46



BULK HANDLING PROBLEMS?:

BIG BLASTER - air cannons against bridging and rathole formation in bunkers. For hoppers, silos and bunkers of any size and dump discharges, low air consumption up to max. 10 bar, 3 construction sizes, manual and automatical control, high accident and service safety, easy mounting even on concrete bunkers.

MARTIN-Segment-Block-System for the lateral material guide and sealing at conveyor transfer cones. Alongside the lower edge backing plates are welded, equipped with vertically squeezed guide clamps. Dovetailed rubber segment blocks, with an inferior sealing edge are pushed over these clamps and can be adjusted just by a hit of a hammer. Accident proof, quick adjusting, highest sealing effect, long service life, easy mounting.

VIBREX-Conveyor belt cleaner, independently rubber suspended scraper blades at torsion arms, predominantly tungsten carbide plated for the best cleaning and long service life. In a unit construction system for easy mounting, servicing and all belt widths.

Guarantee of effect: All these equipments have been successfully used for several thousand times and have often proved to be the only solution. So we guarantee in our special offer the free taking back with complete money return in case of unsatisfactory effect.

TRANSVAC-pneumatic conveying equipment, industrial vacuum cleaner for dusty, wet, granulated or very heavy bulk material (up to 5 kg/l), compact and sturdy construction, three stage separator system, dust control of the filter exhaust air, complete control, sound protection, high permissible service temperature, max. vacuum 6000 mm WC (18" Hg), electric motor or diesel engine up to 75 kw, suction power 1-40 t/h, suction lenght up to 200 m.

Construction types
transportable: by a fork lift truck as standard unit or by trailer wheel set, discharge of the dump hopper by fork lift truck.
stationary: with big self discharge clap or double flap valves.
mobile: self-propelled, as truck or trailer assembly or as container for truck tipping hook system.
fittings: suction piping, nozzles, hoses, intercept hoppers.

Field of application
Large conveying belt installation, processing plants, founderies, power stations, mines, coking plants, steel mills, shipyards, cement works, lime plants, chemical works, fertilizer manufacturers, port installations, sand blasting and tank cleaning contractors, vehicle depots, building contractors, industrial cleaning and container hire contractors, special vehicle hire companies.

VIBRATION STRESS RELIEF, casting and welding constructions of up to 50 t and more are relieved and dimension stabilized according to the VSR vibration treating procedure. By a short time vibration at resonance frequencies of the workpiece the distortion arising i. a. during the following machining is kept within closest tolerances. Sometimes also employable against crack formation during welding. High savings of heat treating costs and production time.

VSR ENGINEERING
GMBH FÖRDERTECHNIK
D 4330 Mülheim-R., Hingbergstr. 319, PF 1848, Tel. 02 08-43 60 77, Tx. 856 749