IMPACT OF GRANULAR FLOW DYNAMICS ON THE DESIGN AND MODELLING OF THE BUNKERS

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ABSTRACT

Silos and bunkers are widely used in the storage, storage and distribution of granular materials, of particular importance in the management of handling, transport and conditioning operations. The distribution of seeds at the filling and emptying stage of the bunker examines the main loading and unloading hypotheses leading to different limit states for its structure. This paper will present the results of causes such as the maximum pressure perpendicular to the vertical wall of the silo, the maximum stretching effort due to friction with the vertical wall, the vertical pressure on the basis of it and the maximum load on the bunker funnel, resulting in the implementation of new design and modeling solutions. At the same time, the dynamics of the granular flow in the bunkers, including flow regimes, design and optimal shapes, will be described to avoid the loss of energy generated by the collision of macroscopic particles inside it.

INTRODUCTION

Technological development within the agricultural machinery sector is aimed at achieving higher yields, while maintaining the highest quality, reducing production costs, and limiting the environmental contamination. Consequently, existing agricultural machinery designs are now modified, with brand new solutions – created using state-of-the-art technologies – that are developed and introduced. [5]

The granular flow in silos and pressures acting on the silo walls have been studied in the last period intense. Whilst some aspects such as mass flow in silos in relatively simple geometries are now reasonably well understood, many challenges still remain in design of silo. Thereby, the granular solid stored in a silo is subjected to compression and shearing action during filling and emptying.

The behaviour of the stored solid under compression and shearing is therefore vital for providing an additional perspective into the silo phenomena. [23]

Furthermore, the gravity-driven flow of granular material has fascinated mankind for over a century, whether from hour-glass devices to track time or silos to store grain and other granular produce [12,14]. In these times, industrial processing of granular materials is ordinary and silos are regularly used as storage vessels. Granular flow physics in general is under-developed when compared with that of traditional Newtonian fluids such as water [9], mostly because of the different states (solid-like, liquid-like, gas-like) in which the granular material may exist [29].

In most industrial situations, powders and bulk solids have to be stored in and discharged from bins and silos. This can lead to – often unexpected – problems, e.g., flow obstructions or segregation. Most of these issues can be avoided by covenient design of equipment with respect to the flow properties of the bulk material to be stored. Especially important is the design of the hopper and all downstream equipment (e.g., feeder) that has an influence of the flow in the hopper.[16]

The terms silo, bunker, bin and hopper are often used to refer to similar containers in different industries. Here, the word 'bunker' is exclusively used with a special meaning for the converging part leading to a gravity discharge outlet. All complete storage containers are designated as silos, regardless of the stored solid, geometry and industrial sector. A characteristic form to describe the parts of the silo is indicated in Figure 1. The transition, that lies at the junction between the vertical wall and the bunker, should be remarked.[22]

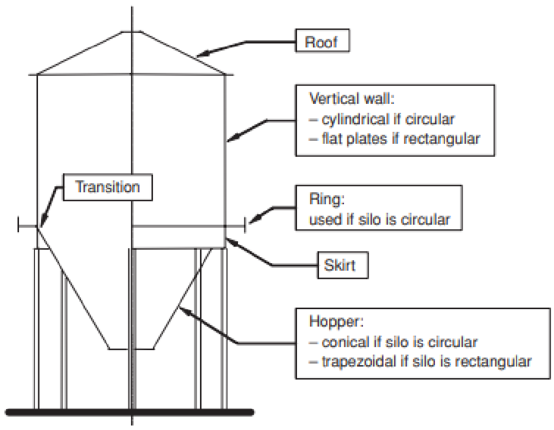


Fig. 1. The componets of a classic silo [22]

Bunkers are used in industry for the protection and storage of powdered materials. These must be designed such that they are easy to load. More importantly, bunkers must be designed to be easy to unload. The way the bunker is designed affects the rate of flow of the powder out of the hopper, if it flows at all. Also, the way the hopper is designed affects how much of the stored material can discharge and whether there mixing of solid sizes or dead space that reduces the effective holding capacity of the hopper. These and other issues discussed here are important to consider when designing storage hoppers.[10]

Because of the lack of any reliable formula for predicting the flow rate of granular solids the design of bins is somewhat empirical in nature. It is the objective of this paper to investigate the flow of granular materials and the the dynamics of the granular flow in the bunkers, including flow regimes, design and optimal shapes, will be described to avoid the loss of energy generated by the collision of macroscopic particles inside it.

MATERIAL AND METHOD

The study of the flow pattern in silos during discharge is usually coupled with severals. Due the opaque nature of granular solids, only visual observations of the top surface are possible without any further aid. [23]

In the majority of cases where granular materials are stored in bins, the material is removed from bins through an opening in the center of the bottom. If the material flows freely, it usually does from the bin in one of the three types of pattern shown in Figure 2.[3]

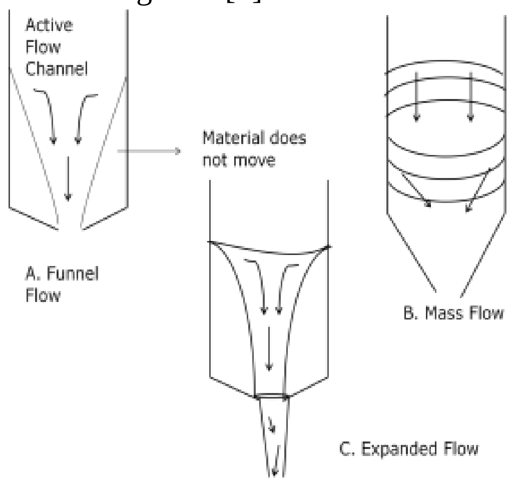


Fig. 2. Flow pattern of a silo [3]

The common definition of flowability is the ability of a powder to flow from a particular item of plant equipment at a desired degree of flowability. Flowability is generally quantified by a range of mobility, from 'free flow' to 'non-

flow' which can, at times, be measured in a laboratory with specific flow property instrumentation.[23]
While significant progress has been made in classifying granular behaviour experimentally [4,15] and using mathematical modelling [2,13], further work remains needed to fully understand the physics of granular phenomena. For silo flows, in particular, there is a large body of experimental and numerical work [6,25], for example. Most silo studies focus on the situation where there is a single silo opening (where the particles discharge under gravity) located at the centre of the silo. However, there has been a growing interest in variants of this standard case including the eccentric positioning of a single opening [21,27], a vertically oriented opening [18], submerged silo flows [1,11] and in silos with particles of non-spherical shape [8,28].

The design quantities for the basic shapes of the hoppers as shown in Fig. 3. It can also be applied to other hopper shapes.

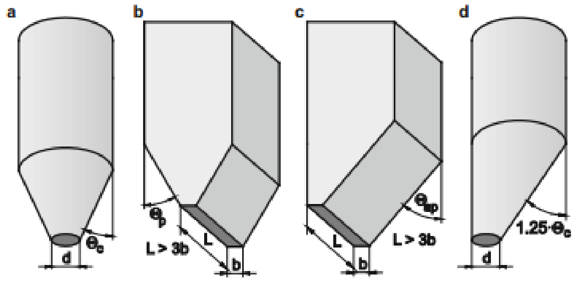


Fig.3. Basic shapes of silo [24]

There are presented further possibilities in Figure 4. [17,24]. If a cylindrical vertical section is combined with a wedge-shaped hopper, designs according to Fig. 4a, b are possible. Also in these applications the length, L, of the rectangular outlet has to be at least three times its width, b. If the end walls are inclined as in Fig. 4a, their slope must not exceed Θc, i.e., the maximum wall slope of a conical hopper.

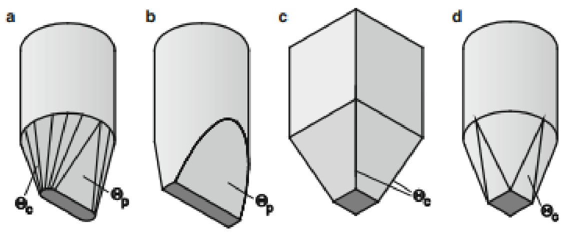


Fig.4. Different shapes of silo[16]

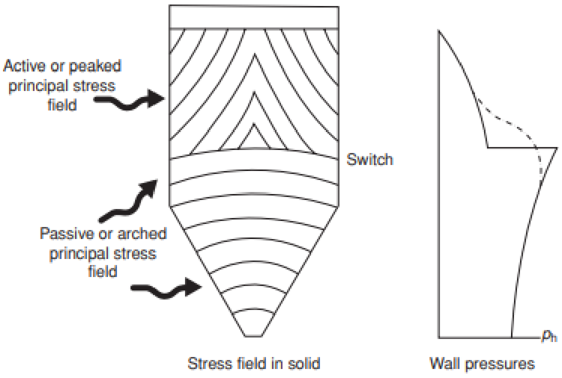
RESULTS AND DISCUSSIONS

A brief historical account of understanding the development of silos may seem strange in a chapter that provides advices on the design and management of silos, but there are good reasons for it. The field of silo pressures is full of misunderstandings and misinterpretations, and many of these continue and are repeated today, so that appreciating the reasons for some misconceptions provides a valuable background.

Furthermore, in some of the earliest experiments according to Ketchum (1907) it was discovered that the pressures often increased when the silo was emptied. The increase was not often to a fixed value, but the pressures tended to rise and fall with time. [27]

Increases ranged from perhaps 10 to 30% as stable values, whilst very short-term local rises wereprobably observed 2 or 3 times the Janssen value. Since the concept being used was that the Janssen theory gave the first measure of silo effects, it was natural to believe that there was a 'pressure' at every level, so that this single pressure could be measured using a single pressure cell. Thus, the high pressures were imagined to appear as symmetrical high pressures at every point where they were observed. [20]

Moreover, some effort went into trying to understand why these high pressures might occur, but the key idea came from Nanninga (1956) who suggested that the solid was in an active Rankine state after filling (higher vertical pressures than horizontal) and that during emptying it must be in a passive state (declining vertical pressures whilst the horizontal ones were retained). The transition between these two states would lead to a rapid increase in the value of K, whilst the vertical stress, in equilibrium across this change, would remain constant.[26]



Lines of principal pressure during developing flow

Fig.5. Precision farming technology [22]

A circular silo with a part-circular flow channel in contact with the wall is represented in Figure 6 , together with the characteristic pressure distribution that is found in experiments. The vertical stresses induced in the wall by this unsymmetrical pattern are also shown to indicate the dramatically large effect on this silo. In particular, take note of the highest compression stress occurs around the mid-height of the silo in the middle of the flowing channel.[10]

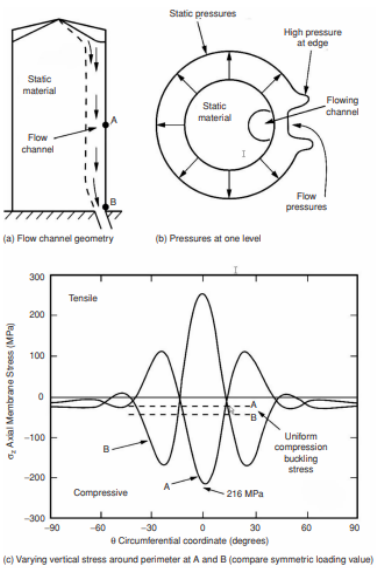


Fig.6. Flow channel geometry, typical pressure pattern and vertical wall stresses during eccentric discharge [22]

Many of the problems that are associated with bin and hopper design can be avoided by designing the hopper to operate in mass flow mode. The angle of the cone required from the vertical axis for mass flow to occur ranges from 40° to 0°. Mass flow is not required in all cases. In some situations a mass flow hopper design is not practical due to the head room required. Table 1 summarizes the key advantages and disadvantages of both mass flow and funnel flow hoppers. In most applications if you have a choice you want mass flow; but in the extreme cases or in cases in which mass flow is not really necessary then you may opt for the shorter funnel flow hopper design.[22]

Table 1. Advantages and Disadvantages of Mass and Funnel Flow Hoppers [22]

	MASS FLOW	**FUNNEL FLOW**
ADVANTAGES	Flow is more consistent Reduced radial segregation Stresses on walls are more predicable Effectie use of full bin capacity First-in =First-out	Low head required
DISADVANTAGES	More wear of wall surfaces Higher stresses on the walls More head room required	Rat holing Segregation First in=Last out Time consolidation effects can be severe Poor distribution of stresses on the walls may cause collapse Flooding Reducing of effective storage capacity

CONCLUSIONS

Bunkers can be very problematic, resulting in increased cost of plant operation, low product yield, extended time to market with new products, quality/product performance problems and safety and health issues. Typical problems include process stoppages, feed rate and process control issues, and product quality concerns due to particle segregation, attrition, degradation or buildup. Other common problems are: difficulty in properly cleaning the vessel, difficulty of dust containment and shortened equipment life due to wear, corrosion or inadequate structural integrity.

This scientific paper has given a summary of the key aspects of silo pressure phenomena and their implications for potential damage to silo structures and the importance of the design.

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BIBLIOGRAPHY

[1] Andreotti B, Forterre Y, Pouliquen O. (2013) *Granular media: between fluid and solid. Cambridge, UK: Cambridge University Press.*

[2] Börzsönyi T, et al. (2016) *Packing, alignment and flow of shape-anisotropic grains in a 3D silo experiment. New J. Phys. 18*

[3] Bouzid M, et al. (2013) *Nonlocal rheology of granular flows across yield conditions. Phys. Rev. Lett. 111*

[4] Breard E. C. et al (2016) *Coupling of turbulent and non-turbulent flow regimes within pyroclastic density currents. Nat. Geosci. 9, 767–771. Advances in Big Data and Cloud Computing. Advances in Intelligent Systems and Computing, Vol 750. Springer, Singapore*.

[5] Chase G.G. (2010), *Solids notesThe University of Akron*

[6] Chen, J.F., et al. (2005) *Flow pattern measurement in a full scale silo containing iron ore. Chem. Eng. Sci., 60(11), 3029–3041.*

[7] Choi J, et al. (2005) *Velocity profile of granular flows inside silos and hoppers. J. Phys. Condens. Matter 17*

[8] Cleary PW. 1999 *The effect of particle shape on hopper discharge. In Proc. 2nd Int. Conf. on CFD in the Minerals and Process Industries, Melbourne, Australia, 6–8 December 1999, pp. 71–76. Clayton, Australia: CSIRO Publishing.*

[9] Dhir S. (2013) *Study of flow of granular solids through horizontal orifices, Department of Chemical Engineering, National Institute of Technology, Rourkela*

[10] Dohrn-van Rossum G. (1996) *History of the hour: clocks and modern temporal orders. Chicago, IL: University of Chicago Press.*

[11] Fullard LA et al. (2013) *Modelling powder mixing in mass flow discharge: a kinematic approach. Adv. Powder Technol. 24, 499–506.*

[12] **Garfınkel Y, Ben-Shlomo D, Kuperman T. (2009)** *Large-scale storage of grain surplus in the sixth millennium BC: the silos of Tel Tsaf. Antiquity 83, 309–325.*

[13] **Härtl J. (2008)** *A study of granular solid in silos with and without an insert , The University of Edinburgh*

[14] **Henann DL, Kamrin K. (2013)** *A predictive, size-dependent continuum model for dense granular flows. Proc. Natl Acad. Sci. USA 110, 6730–6735.*

[15] **Jenike, A.W. (1964/1980)** *Storage and flow of solids. Bull. No. 123, 20th Printing, revised 1980. Eng. Exp. Station, Univ. of Utah, Salt Lake City. Available at: The University of Utah, Utah Engineering Experiment Station, 1515 Mineral Square, Room 138, Salt Lake City, UT 84112-1109, USA*

[16] **Jop P, Forterre Y, Pouliquen O. (2006)** *A constitutive law for dense granular flows. Nature 441, 727–730*.

[17] **Ketchum, M.S. (1907)** *Design of Walls, Bins and Grain Elevators, 1st edn. McGraw-Hill, New York (2nd edn, 1911; 3rd edn, 1919).*

[18] **Koivisto J. et al. (2017)** *Friction controls even submerged granular flows. Soft Matter 13, 7657–7664.*

[19] **Maiti R, et al. (2016)** *Flow field during eccentric discharge from quasi-twodimensional silos—extension of the kinematic model with validation. AIChE J. 62, 1439–1453*

[20] **Marcinkiewicz J. et al. (2019)** *DEM simulation research of selected sowing unit elements used in a mechanical seeding drill, MATEC Web of Conferences 254.*

[21] **MiDi G. (2004)** *On dense granular flows. Eur. Phys. J. E–Soft Matter 14, 341–365.*

[22] **Nanninga, N. (1956)** *Gibt die ubliche Berechnungsart der Drucke auf die Wande und den Boden von Silobauten Sichere Ergebnisse. Die Ingenieur, 68(44).*

[23] **Rotter J. M. (2008)** *Bulk Solids Handling: Equipment Selection and Operation,* Blackwell Publishing, pp. 99-134.

[24] **Schulze D. (2016)** Storage and Discharge of Bulk Solids, Springer International Publishing, pp. 425-475 Switzerland

[25] **Schulze, D.(2008)** *Powders and Bulk Solids – Behavior, Characterization, Storage and Flow. Springer, Berlin*

[26] **Sielamowicz I, Kowalewski TA, Błonski S. (2004)** *Central and eccentric granular material flows in bins/hoppers registered by DPIV optical technique. Acta Agrophys. 4, 519–531*

[27] **Wilson T, et al. (2014)** *Granular discharge rate for submerged hoppers. Papers Phys. 6*

[28] **Woodcock, C.R., et al. (1987)** *Bulk Solids Handling. Leonard Hill, Glasgow*

[29] **Zhou Y,et al. (2017)** *Experiments on, and discrete and continuum simulations of, the discharge of granular media from silos with a lateral orifice*