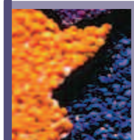
Flow of Solids

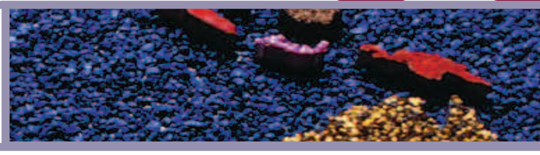
JENIKE & JOHANSON INCORPORATED

Bulk Solids: Science / Engineering / Design

The Newsletter of Jenike & Johanson, Inc.

Fall 2001





Silo Failures: Why Do They Happen?

At approximately 10:00 pm on a cool September evening in 1996 in south western USA, a thunderous cracking sound rang out to shatter the calm. The only employee in the vicinity of a new 80 ft diameter fly ash silo realized that he had just heard the warning sound of imminent danger. In the dark of night, he had only his instincts to lead him at full speed away from the failing structure. The first rays of the next morning's sun revealed the devastated silo and the very spot he'd stood, not 30 feet away, buried under 20 feet of fly ash.

The purpose of this brand new bolted steel silo was to store 9000 tons of fly ash from the adjacent coal fired power generation station. The silo split apart about two weeks after it was first filled to capacity. Up to this point, no ash had ever been discharged. Curiously, the collapse occurred at night when the silo was being neither filled nor emptied.

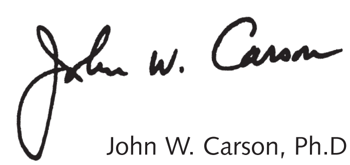
During the course of the investigation into this failure, several deficiencies were revealed. Calculations showed that the silo was underdesigned and did not identify or account for a phenomenon called *thermal ratcheting*. The walls of outdoor metal silos expand during the day and contract at night as the temperature drops. If there is no discharge taking place and the material inside the silo is free flowing, it will settle as the silo expands. However the material cannot be pushed back up when the silo walls contract, so it resists the contraction, which in turn causes increased tensile stresses in the wall. The effect is repeated each day that the material sits at rest.

The investigation also revealed that some cost-cutting measures taken by the silo supplier during the construction of the silo contributed to the failure. The design specified that bolts of a particular classification, size and strength be used in the construction. Bolts of the specified type have a distinct marking on their head which identifies that the bolts have been tested and meet recognized standards.

continued on page 2

The Inside View

Recently, we celebrated the 35th anniversary of our U.S. company, and the 25th anniversary of our Canadian company. We appreciate the many opportunities to serve you, our clients, over the years. By challenging us to develop and apply the science of bulk solids to an extremely wide range of engineering and design problems, you have allowed us to expand the boundaries of our technology, and develop better ways to provide the reliable, quality, and timely service you deserve. Thank you!!



John W. Carson, Ph.D.,
President, Jenike & Johanson, Inc.

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Silo Failures:
Why Do They Happen?

Less than 1% of the bolts that were recovered from the failed fly ash silo had the specified marking and none of the marked bolts had been used in the critical vertical seams. Strength tests on the unmarked bolts revealed that some had tensile strengths less than the specified minimum.

Why did this silo collapse? The answer to this question is not straightforward. There were many contributing factors that acted together and if any one had not been present the collapse of the silo might have been avoided. Had the potential for thermal ratcheting been recognized at the design stage and had correct design parameters been selected, the collapse may not have occurred. If proper bolts had been purchased and used, the silo collapse may have been avoided. If the silo had been inspected by an independent silo expert either during the construction or after construction was complete, perhaps the incorrect bolts would have been noticed and corrective action could have been taken. Had the operation of the silo been such that material was discharged more frequently, the condition of accumulated stresses that precipitated the collapse could have been prevented.

Hundreds of industrial and farm silos, bins and hoppers, storing powders or bulk solids, experience some degree of failure each year. In fact, silos and bins fail with a frequency which is much higher than almost any other industrial equipment.

Sometimes the failure involves complete and catastrophic collapse of the structure. In other cases, failure only involves distortion or deformation. A similar variation can be found in the severity of the consequences of structural failure. Whether it results in a loss of human life, downtime, or simply a need for repair, a structural failure is always costly. The owner faces the immediate expense of lost production and/or repairs, personnel in the vicinity are exposed to significant danger, and the design engineer and builder face possible litigation because of their liability exposure.

The life of a silo can be divided into three distinct phases: Design, Construction, and Utilization. In each of these phases there are numerous opportunities for errors that can result in structural failure. As in the fly ash silo failure described above, the majority of structural failures of bins and silos can be attributed to a combination of several deficiencies or errors.

Please refer to page 4, for information on how to obtain a copy of the complete paper, from which this article is summarized. For assistance with silo loading, a structural design review, or in the analysis of a failed silo, please contact us at Jenike & Johanson.

Behind the Scenes:
Meet David Goodwill

Title: President
Jenike & Johanson Ltd.
Toronto, Canada

Joined J&J: 1976

Job Description: David is co-founder and president of our Canadian company, Jenike & Johanson Ltd, which celebrated its 25th anniversary earlier this year. He has consulted for hundreds of clients in Canada and around the world, on a wide range of bulk solids handling projects encompassing all aspects of J&J's business. David has been retained by most major Canadian mining corporations as special consultant on many large projects. He was instrumental in founding Jenike & Johanson Chile Ltda., our South American company.

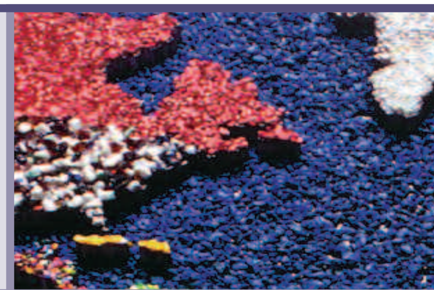
Of note: Dr. Goodwill received his B. Eng. (Hons.) and Ph.D. degrees in civil and structural engineering from the University of Sheffield (U.K.). He is a registered professional engineer in Canada and a chartered engineer in the U.K.

He is Canadian representative to the International Standards Organization (ISO) working group on silo design, and also serves on the American Concrete Institute Committee ACI 313 on silo design. David is the author of many technical articles and frequently leads J&J bin design seminars in Canada and Chile.

"Twenty five years of practice in the field of bin and feeder design have only reinforced my conviction that Dr. Andrew Jenike's contribution to this branch of engineering science was monumental. His Bulletin 123 "Storage and Flow of Solids," first published in 1961, remains today, 40 years on, virtually unrevised and unchallenged. Jenike's complex mathematical solutions to the problems of flow of rigid-plastic solids in converging channels are works of true genius."

Congratulations Tracy!!!

Tracy Holmes, a professional engineer in our Canadian office, was honored recently by AIChE at a Bin Design seminar held in Toronto. Tracy was presented with a certificate confirming her as the first ever female presenter of an AIChE educational seminar.

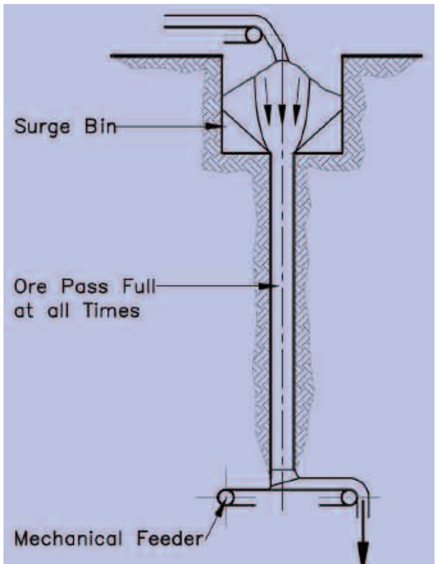


Ore Pass Design

Ore passes are commonly used in mines to transfer ore, waste rock, or mine backfill material to a lower level by gravity flow. They are, in effect, silos excavated out of rock which may also be used for surge storage.

An ore pass usually has a very large height-to-diameter (H/D) ratio, such as 100:1. Sizes in the range of 10 ft. diameter by 1,000 ft. tall are not uncommon. For bins and silos, H/D ratios are typically 5:1 or less. Regardless, the principles involved in ore pass design are similar to those developed by Dr. Jenike for bin design.

The configuration, size, and purpose of ore passes vary widely. They may be located at the surface or underground; vertical or sloped; straight or "dog legged"; circular or rectangular in cross-section; lined or unlined; designed for intermediate storage, or as a chute; or be part of the mining method (e.g. glory holes). The rate of flow from them may be controlled by a shovel or loader operation; by a "slide and gate" arrangement; or by a mechanical feeder such as a vibrating pan, reciprocating plate or apron feeder.



Common Surge Bin / Ore Pass Combination

Ore passes are popular because they can provide a low cost means of moving and storing ore, waste rock, and back fill materials. However, they are not without their problems.

Hang-ups due to the formation of arches are common, and explosives often have to be used to restore flow. In the case of surface ore passes and glory holes, run-of-mine ore or rock entering the pass is often wet and, in winter, may contain snow or ice. If the ore also contains significant quantities of fines, the active flow channel in the pass often reduces in diameter, and hang-ups result. If there is free water running in the rock fissures and this drains into the pass, frozen obstructions will occur when the water encounters rock at sub-zero temperatures.

Freeing hang-ups in ore passes can be a dangerous operation as hundreds or even thousands of tons of material may suddenly slide or fall to the bottom of the pass impacting the gate and feeders.

Other common problems encountered with ore passes include rock wear on the sides of unlined passes leading to the rock "unravelling" or caving in; severe wear on the sides of ore passes lined with concrete or even railroad rails; and severe crushing and abrasion of the rock during its passage leading to unacceptably high levels of fines.

Mine engineers must be alert to the differences between open channel chute flow and bin flow. In open channel chute flow, there is always a free surface. The chute slope is usually chosen to be about 10° steeper than the wall friction angle, which can be determined by a Jenike wall friction test.

Open channel chutes, often referred to by miners as "rock slides", are typically 30° to 40° less steep than ore passes which operate full or partially full.

This can be a big advantage if the ore needs to be moved horizontally as well as vertically. However, to gain this advantage and to have reliable flow, the rock slide must never be allowed to fill. Should this happen, hang-ups are almost always the result.

Please refer to page 4, for information on how to obtain a copy of the complete paper, from which this article is summarized. For assistance in the design of an ore pass, please contact us at Jenike & Johanson.

Did you know?

Jenike & Johanson, Inc. is celebrating its 35th year in business - longer than any other consulting engineering firm that provides solutions to bulk solids handling and processing problems. How can we make this claim? Easy. Dr. Jenike developed the theories that our company is based on. He is regarded by many in the industry as the father of bulk solids flow theory. As we like to say, Dr. Jenike wrote the book, and we continue to add chapters.

Q&A with J & J

Q "Mechanically, I can double the speed of my feed equipment, but the discharge from my surge bin maxes out after only a 50% increase. Why is this happening, and what can I do to meet increased packaging rate requirements for my bread mixes?"

A Discharge rate limitations can occur with any type of bulk solid. With fine powders such as flour, the permeability can be measured to predict such limitations in handling.

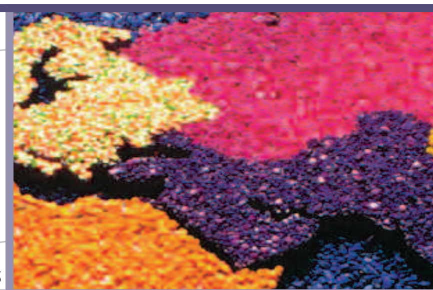
Possible solutions include a larger bin outlet, air permeation system, or fluidized handling (not typical for packaging applications). With additional system information and testing, Jenike & Johanson can recommend the best solution for your application.

If you have any bulk solids handling questions, or if you have suggestions for future articles, please contact:

Flow of Solids® Newsletter
Jenike & Johanson, Inc.
One Technology Park Drive
Westford, MA 01886-3189
E-mail: newsletter@jenike.com
Voice: 978-392-0300
Fax: 978-392-9980

Flow-of-Solids Industry Calendar

"You get the benefit of years of experience."
"Instructors were very knowledgeable, well prepared, and professional"
- From course attendee evaluations of recent Jenike & Johanson presentations



Nov. 21-23, 2001, Viña del Mar, Chile
Two in-house courses will be presented at Jenike & Johanson, Chile S.A..

- Bin and Feeder Design
- An Introduction to Pneumatic Conveying

Dec. 3&5, 2001, Arlington, VA
Institute for International Research. Jim Prescott, senior consultant with Jenike & Johanson will be giving presentations titled:

- Troubleshooting Blend and Content Uniformity Problems
- Equipment Considerations for Achieving Content Uniformity

Feb. 6-7, 2002, Newport Beach, CA
AIChE course, Flow of Solids in Bins, Hoppers, Chutes, and Feeders††.

February 8, 2002, Newport Beach, CA
AIChE course, Pneumatic Conveying of Bulk Solids††.

April 24-25, 2002, Baltimore, MD
AIChE course, Flow of Solids in Bins, Hoppers, Chutes, and Feeders††.

April 26, 2002, Baltimore, MD
AIChE course, Pneumatic Conveying of Bulk Solids††.

May 6-9, 2002, Chicago, IL
27th annual Powder and Bulk Solids Conference/Exhibition. Jenike & Johanson personnel will present the following seminars and workshops†:

- Solve Solids Flow Problems in Bins & Hoppers
- Design of Transfer Chutes to Minimize Buildup, Abrasive Wear, and Dust Generation
- How to Select or Troubleshoot Volumetric and Gravimetric Feeders to Ensure Reliable Flow
- Blending and Segregation and their Effects on Product Quality
- Advanced Topics in Solids Handling

Stop by and see us at booth 15110.

Week of June 10, 2002, San Antonio, TX
AIChE courses, Flow of Solids in Bins, Hoppers, Chutes, and Feeders; and, Pneumatic Conveying of Bulk Solids††.

Week of Aug. 5, 2002, Chicago, IL
AIChE courses, Flow of Solids in Bins, Hoppers, Chutes, and Feeders; and, Pneumatic Conveying of Bulk Solids††.

Week of Oct. 14, 2002, Houston, TX
AIChE courses, Flow of Solids in Bins, Hoppers, Chutes, and Feeders; and, Pneumatic Conveying of Bulk Solids††.

Week of Dec. 9, 2002, Jacksonville, FL
AIChE courses, Flow of Solids in Bins, Hoppers, Chutes, and Feeders; and, Pneumatic Conveying of Bulk Solids††.

†To register, contact Reed Exposition Companies, (203) 840-5848, or visit www.reedexpo.com.

††To register, contact AIChE, (800) 242-4363, or visit www.aiche.org.

More complete course information is available at www.jenike.com/pages/education/dates.html

Hot Off the Press

Silo Failures: Why Do They Happen?
by J.W. Carson and T. Holmes, *Powder and Bulk Engineering*, November 2001

Ore Pass Design for Reliable Flow
by D.J. Goodwill, D.A. Craig, and F. Cabrejos, *Bulk Solids Handling*, 1/99, pp.13-22

Designing Storage Bins for Bulk Solids: A Step-by-Step Procedure
by E.P Maynard, *Chemical Processing*, Volume 64, Number 9, September 2001, 200 Powder & Solids Annual, pp. 4-8

Effective Chute Design
by T.A. Royal and D.A. Craig, Proceedings of The Seventh International Bulk Materials Storage, Handling and Transportation Conference, The University of Newcastle, New South Wales, Australia, Oct. 3-5, 2001

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Jenike & Johanson, Inc.
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Canada
Jenike & Johanson, Ltd.
400 Carlingview Drive
Toronto, Ontario
M9W 5X9 Canada
Voice: (416) 674-8595
Fax: (416) 674-8520

South America
Jenike & Johanson, Chile S.A.
Av. Libertad 798, Of. 701
Viña del Mar, Chile
Voice: (+56) 32 690 596
Fax: (+56) 32 690 596