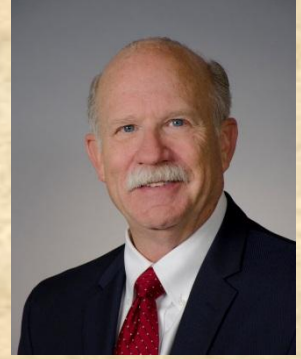
How Proper Silo Design Can Prevent Silo Failures

Presenters:

Joe Marinelli – Solids Handling Technologies Inc.

Gary Chubb – Chubb Engineering, LLC



Gary Chubb
Executive Director & Founder of Chubb Engineering

Bachelor of Science in Engineering Technology from Pittsburg State University in Pittsburg, KS in 1974

25-year career at Peabody TecTank serving as Product Manager and ultimately Chief Design Engineer.

Chubb Engineering founded in 1998

Provides engineering services to both manufacturers and users of storage and handling equipment

Past member of the NFPA 68/69 Committee for Explosion Protection, and a founding and current member of the ASME Structures for Bulk Solids Committee

Performed numerous forensic investigations of tank and silo damage and failure to determine the cause and to provide corrective action.

Joe Marinelli
President of Solids Handling Technologies

- Bachelors Mechanical Engineering, Northeastern University, Boston
- Providing consulting services since 1972.
- Worked with Dr. Andrew Jenike for 23 years.
- Founded Solids Handling Technologies in 1997
- Lectures frequently at: University of Wisconsin, Madison, Powder and Bulk Solids Show, Chicago, Seydlitz Consultants, Denmark.

Flow Problems, Their Effects and Flow Patterns

Definitions

- Silo, bin, bunker, vessel
- Cylinder
- Hopper
- Feeder or gate

Large and Small Storage Capacity

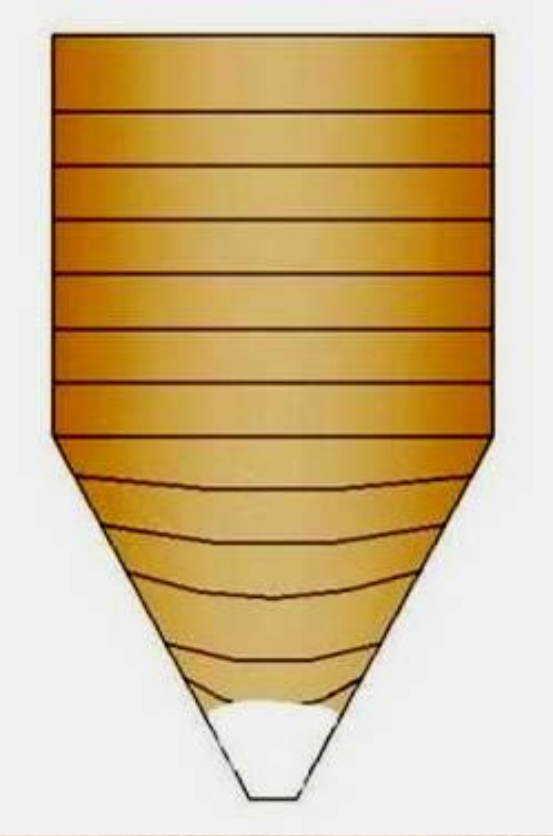
Jenike's theory not affected by vessel size

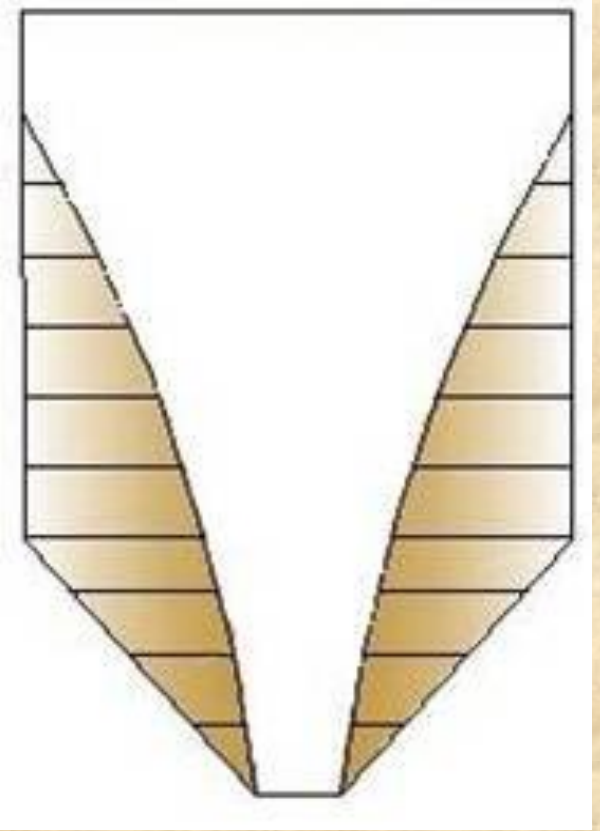
Basic Bulk Solids Flow

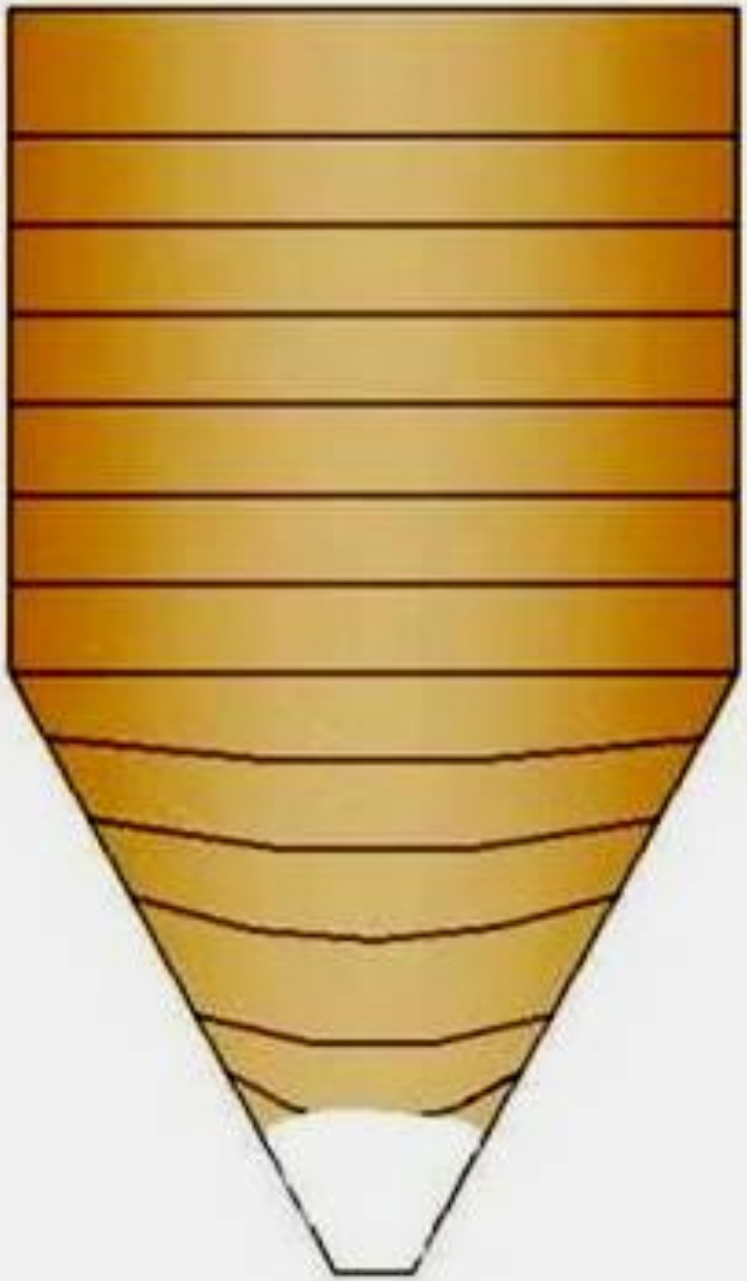
- **Solids flow problems**

Solids Flow Problems

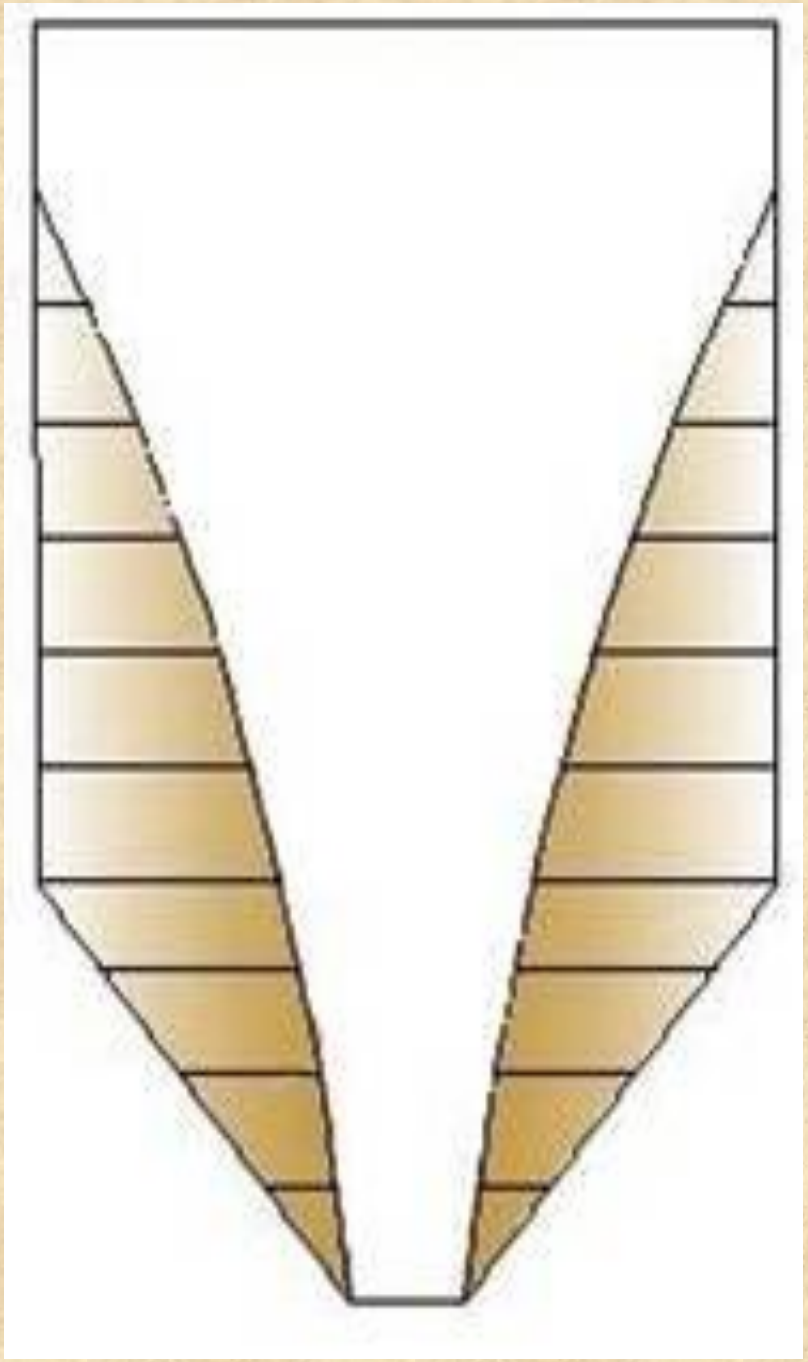
- **No flow due to arch or rathole**



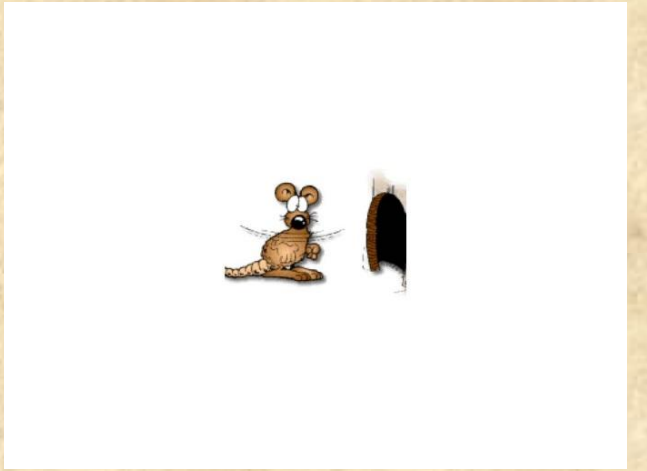




Arch



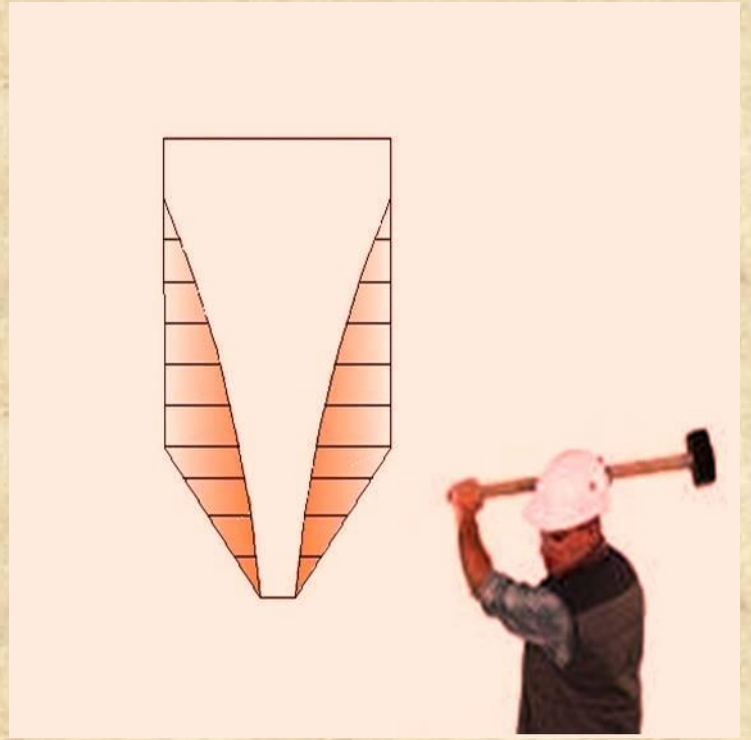
Rathole

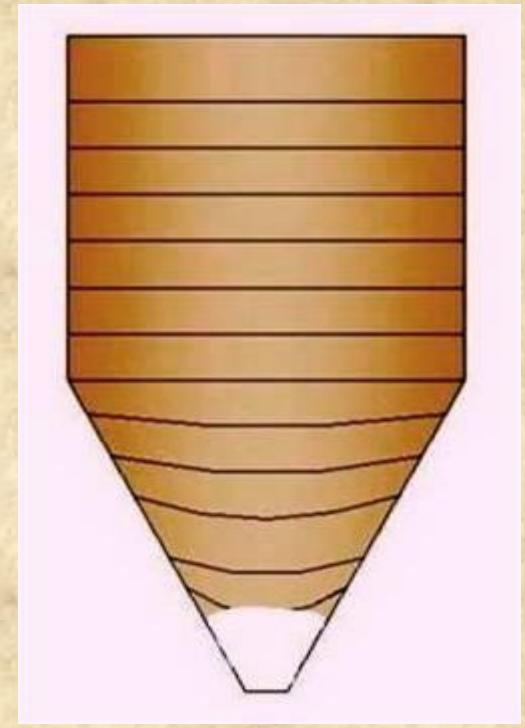



Flow Aid

Solids Flow Problems

- No flow
- Erratic flow





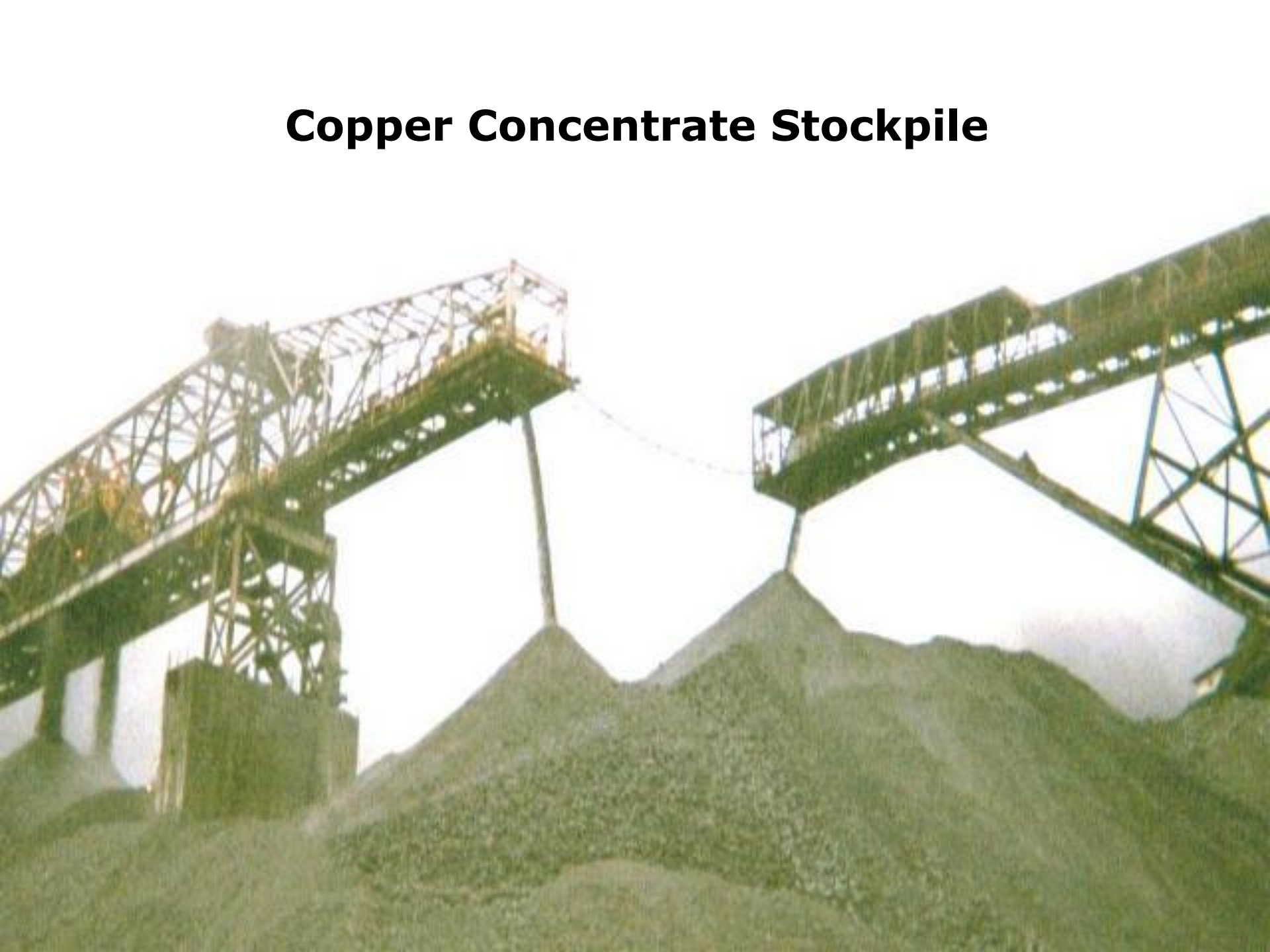
Solids Flow Problems

- No flow
- Erratic flow
- **Flooding**

Solids Flow Problems

- No flow
- Erratic flow
- Flooding
- **Segregation**

Copper Concentrate Stockpile



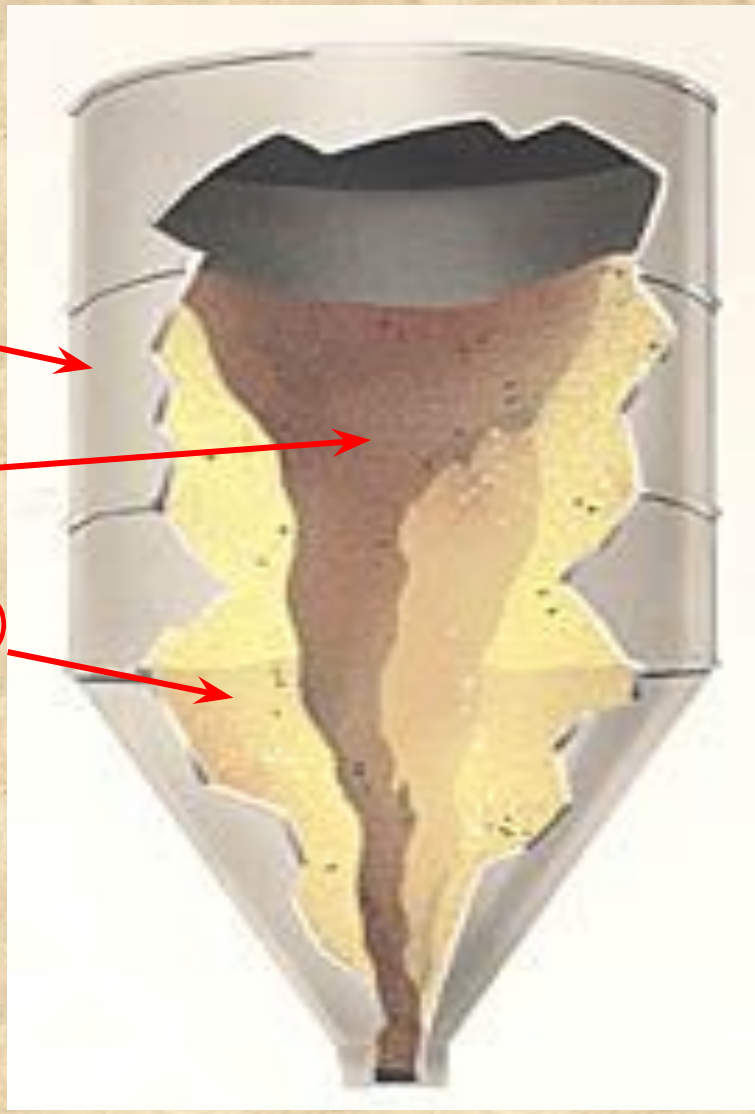
Basic Bulk Solids Flow

- Solids flow problems
- **Results of flow problems**

Results of Flow Problems

- **Limited live storage**
  - **Total Capacity = 4000 ft3 (113 m3)**
  - **Live Capacity = 1200 ft3 (34 m3)**
  - **Stagnant product =2800 ft3(79 m3)**

30% Live



Results of Flow Problems

- Limited live storage

- Caking, spoilage, spontaneous combustion

Results of Flow Problems

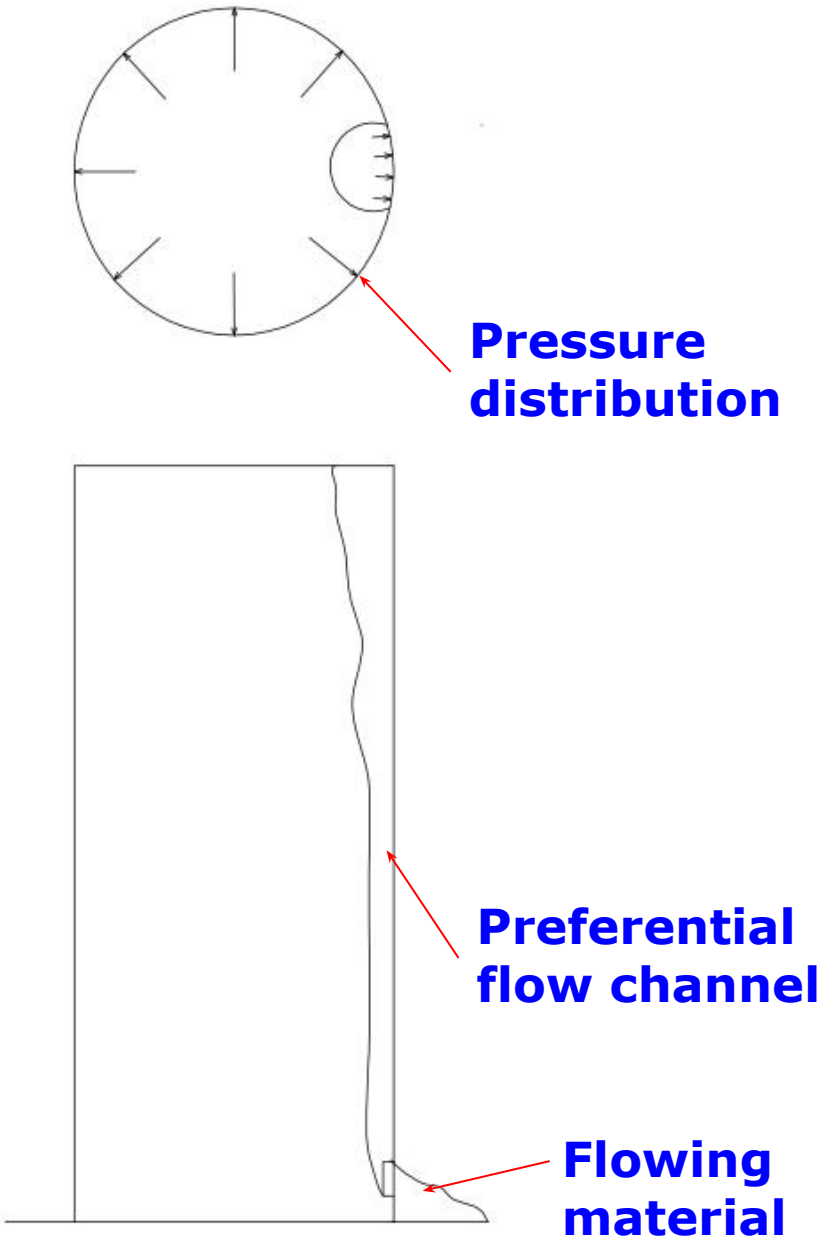
- Limited live storage
- Caking, spoilage, spontaneous combustion
- Shaking (vibration)

Results of Flow Problems

- Limited live storage
- Caking, spoilage, spontaneous combustion
- Shaking
- Structural failure

Vacuum Dent

Flow Dent


Pressure distribution
Preferential flow channel
Flowing material

Remember: Dust Can Explode!

Basic Bulk Solids Flow

- Solids flow problems
- Results of flow problems
- **Flow patterns**

Flow Patterns

- **Funnel flow**

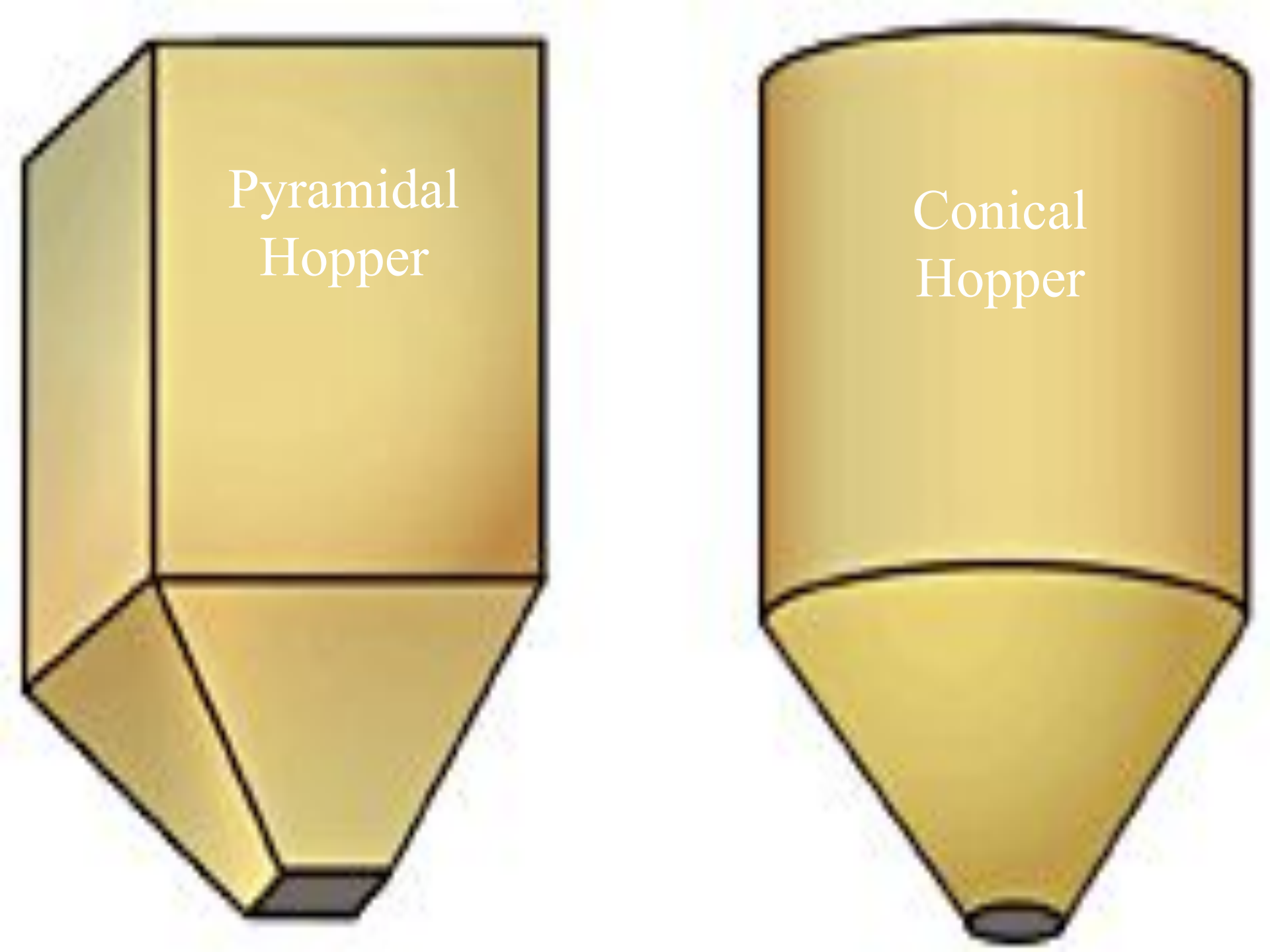
Funnel Flow

- **Definition:**

Some material is stationary while the rest is moving

Features of Funnel Flow

- **Low headroom**


Pyramidal
Hopper
Conical
Hopper

Features of Funnel Flow

- Low headroom
- First-in-last-out flow sequence

Features of Funnel Flow

- Low headroom
- First-in-last-out flow sequence
- Ratholes may develop

Features of Funnel Flow

- Low headroom
- First-in-last-out flow sequence
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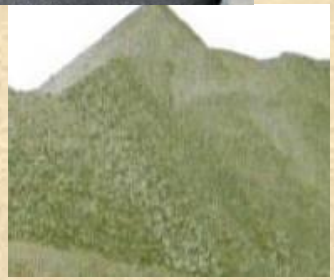
- **Powders will flood**

Features of Funnel Flow

- Low headroom
- First-in-last-out flow sequence
- Ratholes may develop
- Powders will flood
- **Segregation made worse**

Funnel Flow Suitable For:

- Coarse particles
- Free-flowing materials
- Non-degrading solids
- Segregation not important



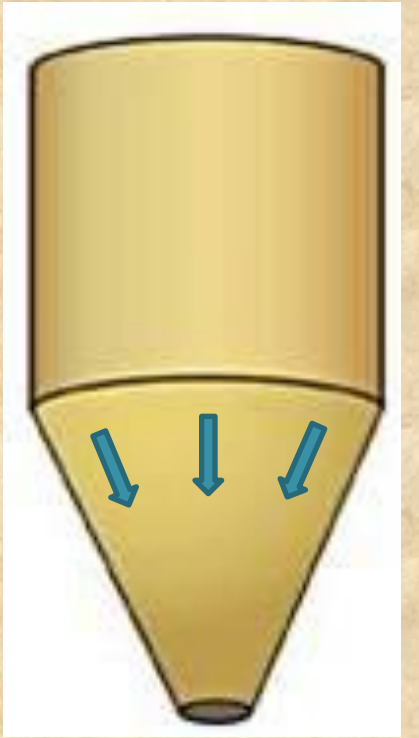
Flow Patterns

- Funnel flow
- **Mass flow**

Mass Flow

- **Definition:**

  All the material is in motion whenever any is being withdrawn



Features of Mass Flow

- **Smooth, steep hopper required**


Transition
Hopper

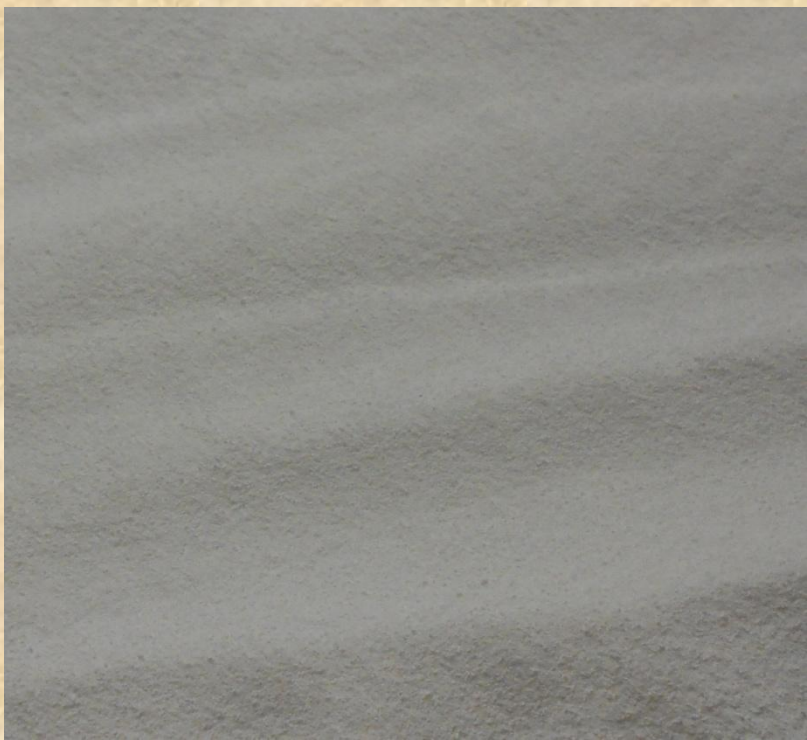

Conical
Hopper

Features of Mass Flow

- Smooth, steep hopper required
- First-in-first-out flow sequence

Features of Mass Flow

- Smooth, steep hopper required
- First-in-first-out flow sequence
- Fine powders deaerate

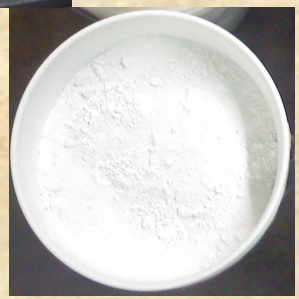


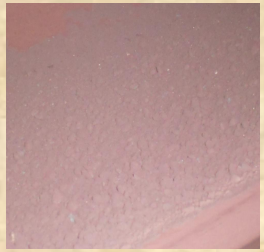
Features of Mass Flow

- Smooth, steep hopper required
- First-in-first-out flow sequence
- Fine powders deaerate
- Segregation minimized

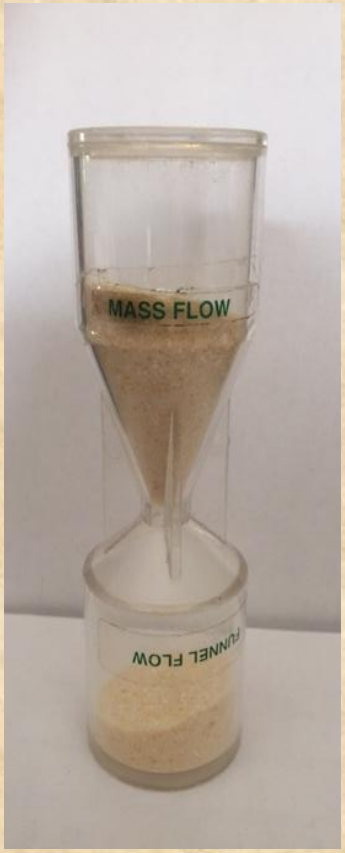
Mass Flow Suitable For:

- Cohesive solids
- Fine powders
- Degradable materials
- Solids which segregate





Mass Flow / Funnel Flow Model

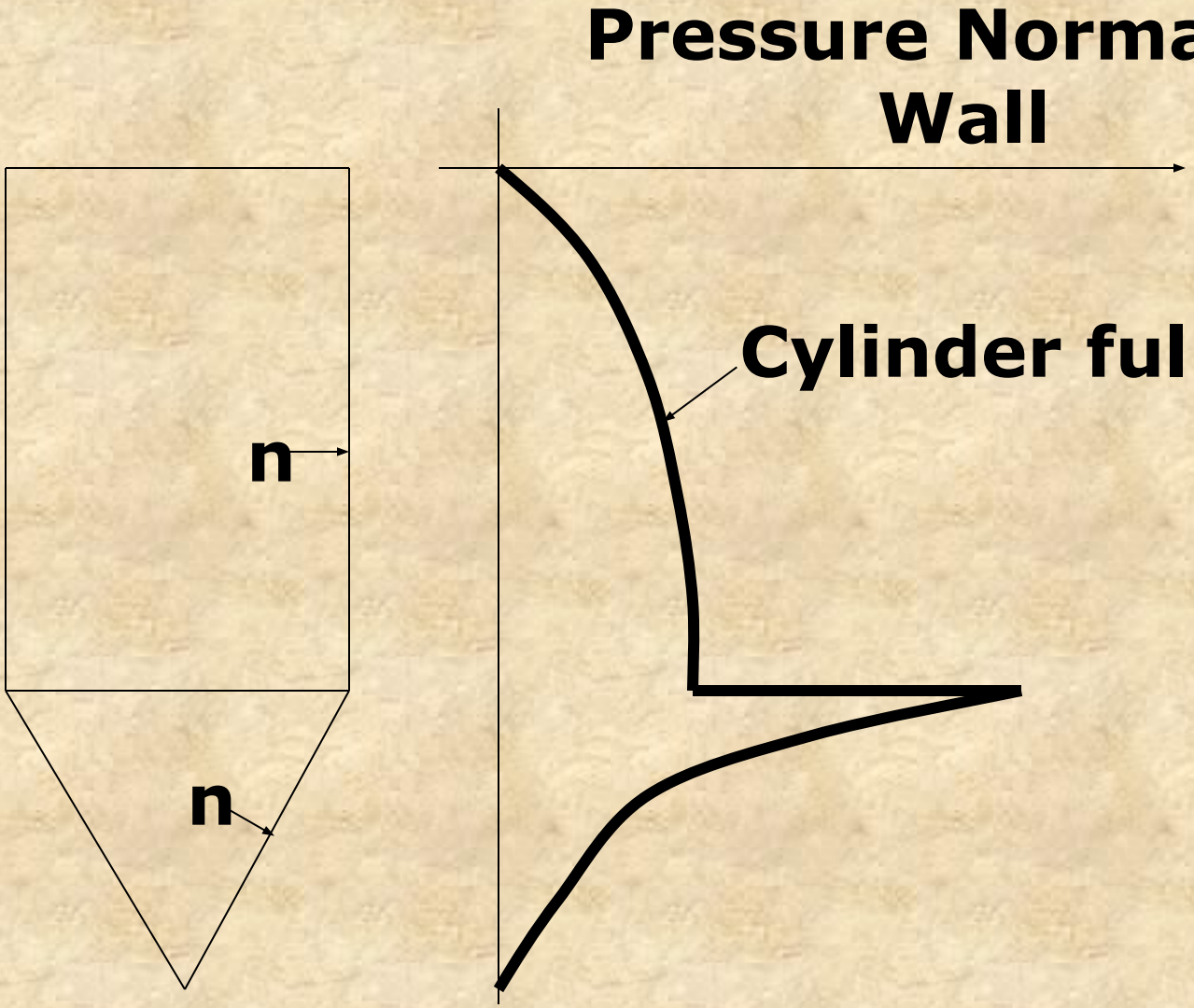


Why Do Silos Fail?

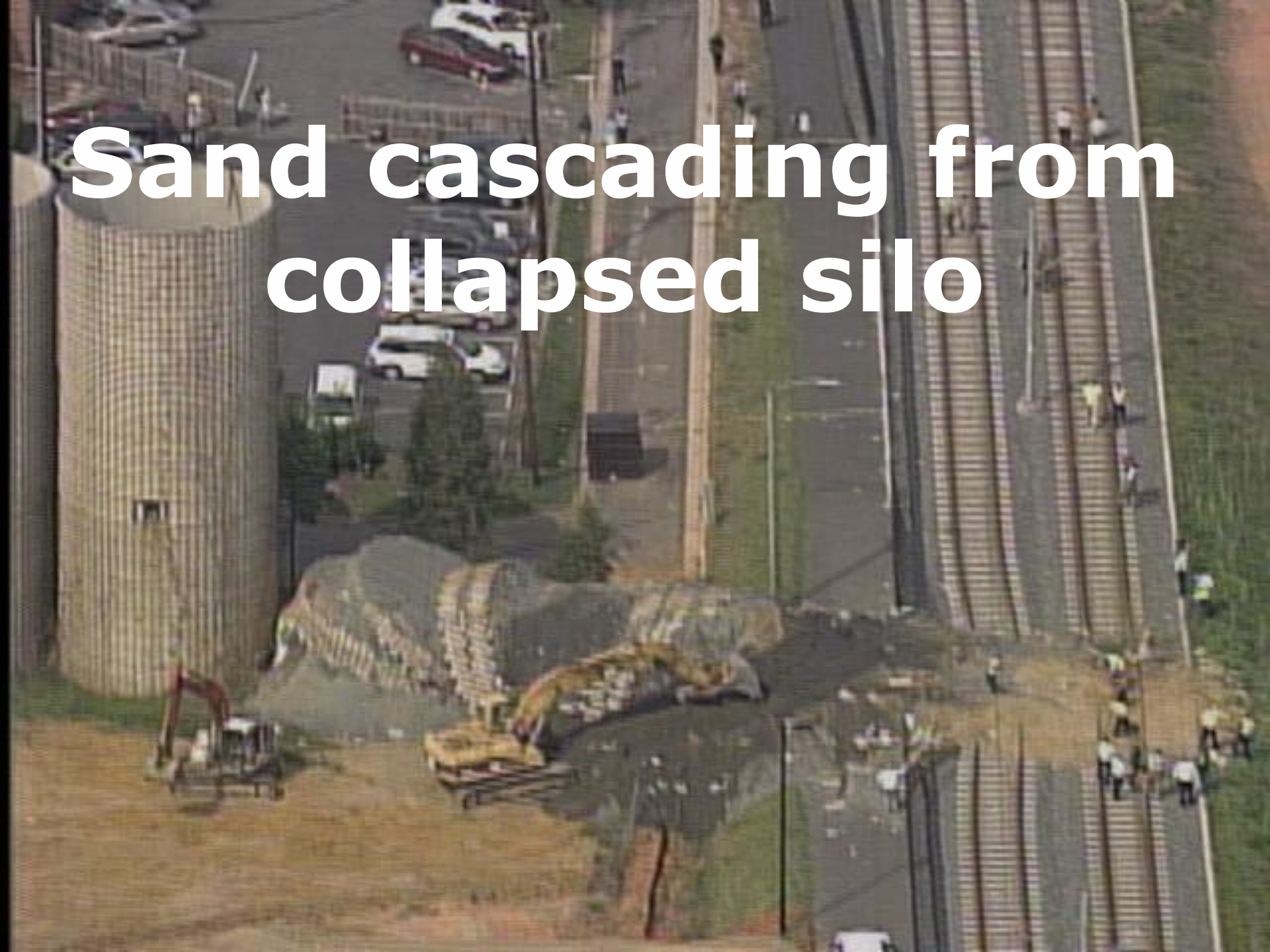
- **Many failures result from loading conditions not anticipated by the engineer**
- **Hundreds of farm silos, bins and hoppers fail each year**
- **Catastrophic collapses, cracking concrete walls, or dent formation not unusual**

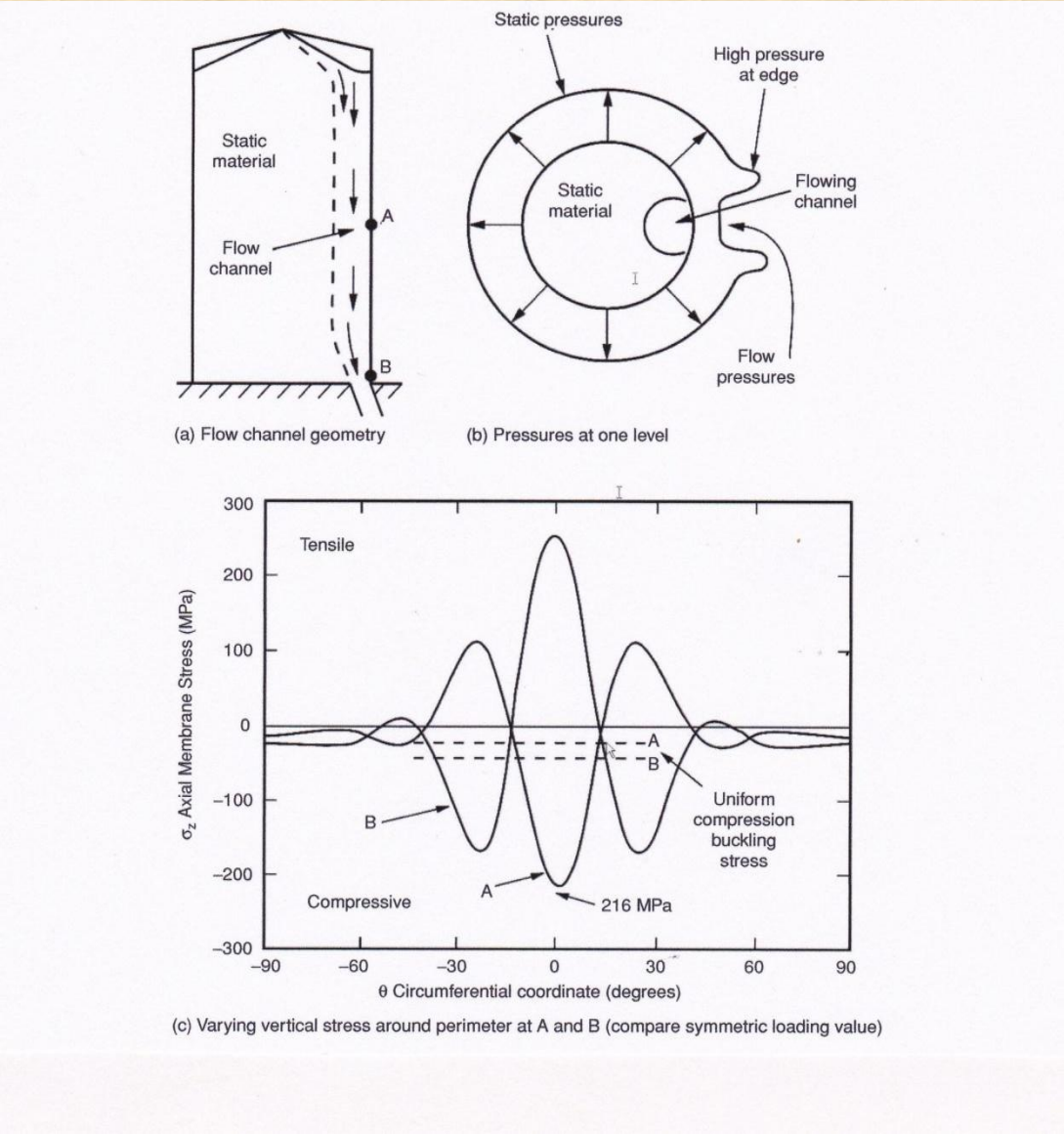
Silo/hopper not structurally designed properly

Collapse due to high vacuum pressure caused by hopper failure



Loads Normal to Walls with Full Cylinder


Sand cascading from collapsed silo



Eccentric loading due to development of preferential flow channel

Pressure in flow channel low while rest of silo under high pressure

Silos Fail Because Of:

- Engineering Design Errors caused by:
  - Bending of circular walls
  - Non-symmetric pressures caused by pant leg hoppers
  - Self induced vibrations
  - Vacuum denting
  - Moisture migration

Failures Due To Engineering Design Errors

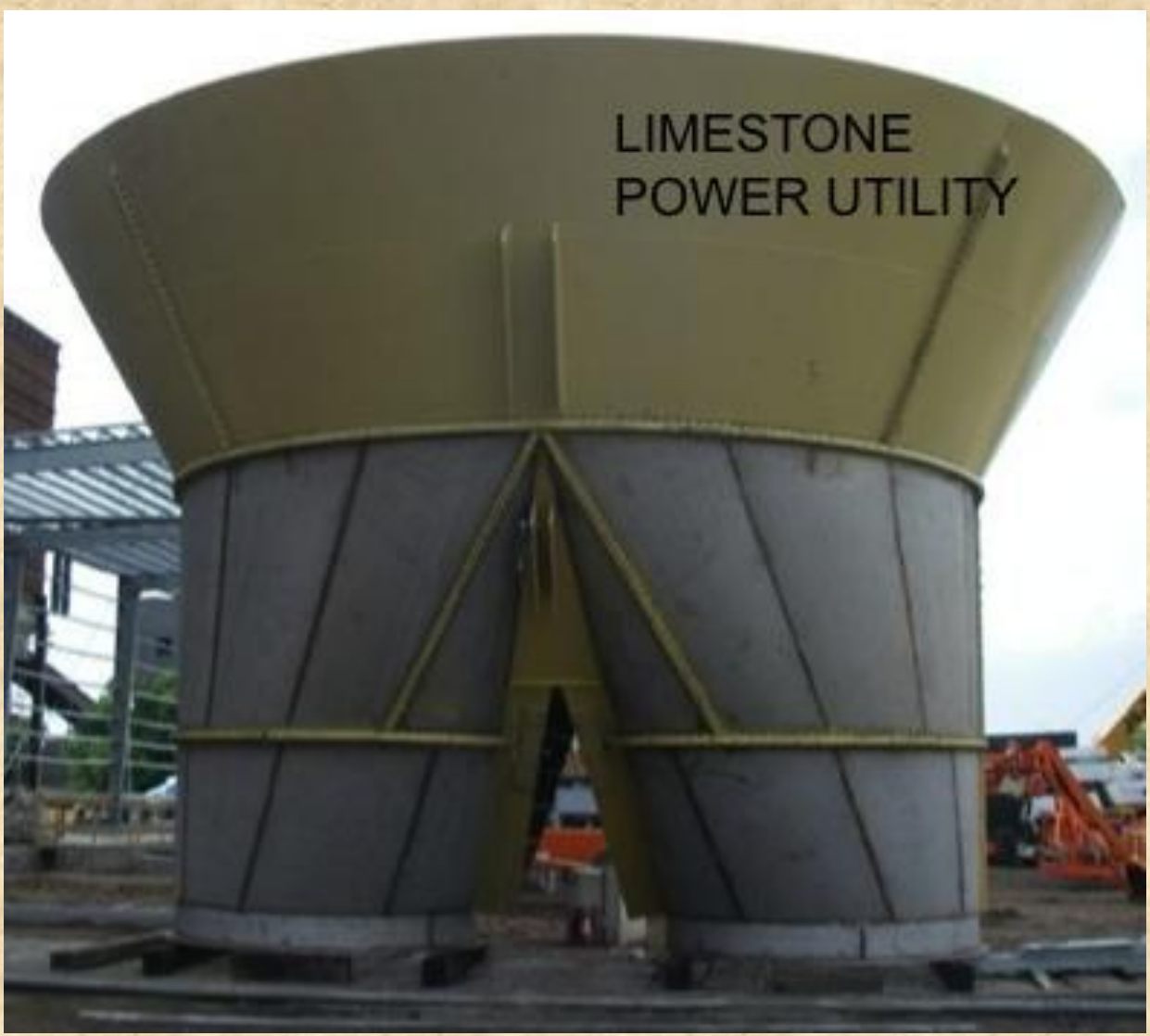
- Bending of circular walls

Failures Due To Engineering Design Errors

- Bending of circular walls

- Non-symmetric pressures caused by pang leg hoppers

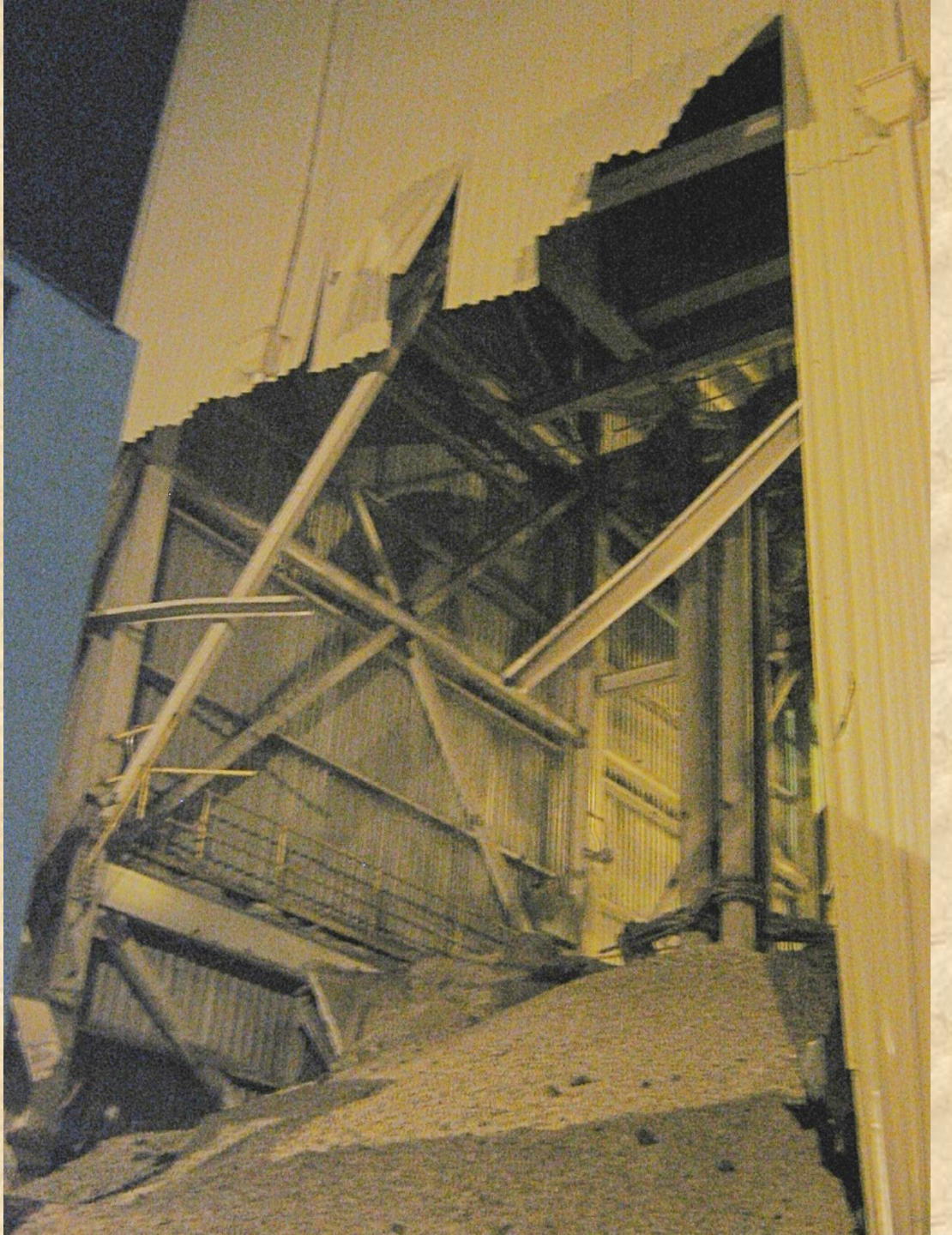
Pantleg



Indoor limestone silo with pantleg hoppers collapsed

One leg shutdown caused preferential flow

Collapsed hopper pushed out side of building




DIAMOND
CONSTRUCTION
UNLIMITED

Failures Due To Engineering Design Errors

- Bending of circular walls
- Non-symmetric pressures caused by pang leg hoppers
- Self induced vibrations

Vibration

Failures Due To Engineering Design Errors

- Bending of circular walls
- Non-symmetric pressures caused by pang leg hoppers
- Self induced vibrations
- Vacuum denting

Vacuum Dents

Failures Due To Engineering Design Errors

- Bending of circular walls
- Non-symmetric pressures caused by pang leg hoppers
- Self induced vibrations
- Vacuum denting
- Moisture migration

- “Heard it creaking and moving everyday and at last day heard a lot, thought it might come down that day.
- Saturday, Jan. 3,noticed the silo leaning against another silo
- Silo two-thirds full of fine-ground, high moisture corn, kinked about 35' up. “

Gary Chubb
Executive Director & Founder of
Chubb Engineering, LLC

Warning Signs of a Failure

- Audible: During discharge of product, does the silo honk, pop, snap, exhibit rhythmic noises or vibrations, produce shock loads, or produce other unusual audible clues?

- Visual: Are there cracks in welds, random broken bolts, doors that don't open, anchor bolts loose, signs of product leakage, unusual dusting? Does the silo exhibit dents, flat spots, bulges, buckles, or other deformations in the shell, hopper, or roof?

- Operational: Does the silo exhibit flow stoppages, inconsistent flow rates, flooding, flow/no flow conditions, stagnant product remaining in silo? Is physical encouragement required to initiate product flow?

Built-In Sources of Damage and Failure

- Fabrication Quality:
  - Flow consultant's recommendations must be strictly adhered to
  - Design engineer's drawings and specifications must be followed
  - Weld quality, bolts, plates, and surface finish are critical to proper operation
- Installation Quality:
  - Contractors should be experienced with bulk material handling systems
  - Project drawings and equipment interface should be followed 100%
  - Do not modify anything without approval of the design engineer
  - Ensure all silo parts and system components are installed correctly
- System Design Quality:
  - Filling and discharge equipment must compliment overall system design
  - Chutes, conveying systems, inlets, and outlets must not restrict product flow
  - Test compatibility of all equipment for the application

Operational and Maintenance Failure

- Physical Modifications:
  - Modifying or changing filling and discharge equipment
  - Installing un-engineered access openings
  - Adding heavy loads
  - Adding discharge spouts
- Operational Modifications:
  - Modifying when discharge equipment starts and stops
  - Increasing time-at-rest cycles
  - Throttling product discharge rates with the slide gate
- Stored Product Modifications:
  - Change in product density
  - Introducing product additives
  - Physical changes to the stored product
- Failure to recognize or appreciate warning signs

Warning Signs

Deflection in hopper due to excessive flow pressures.

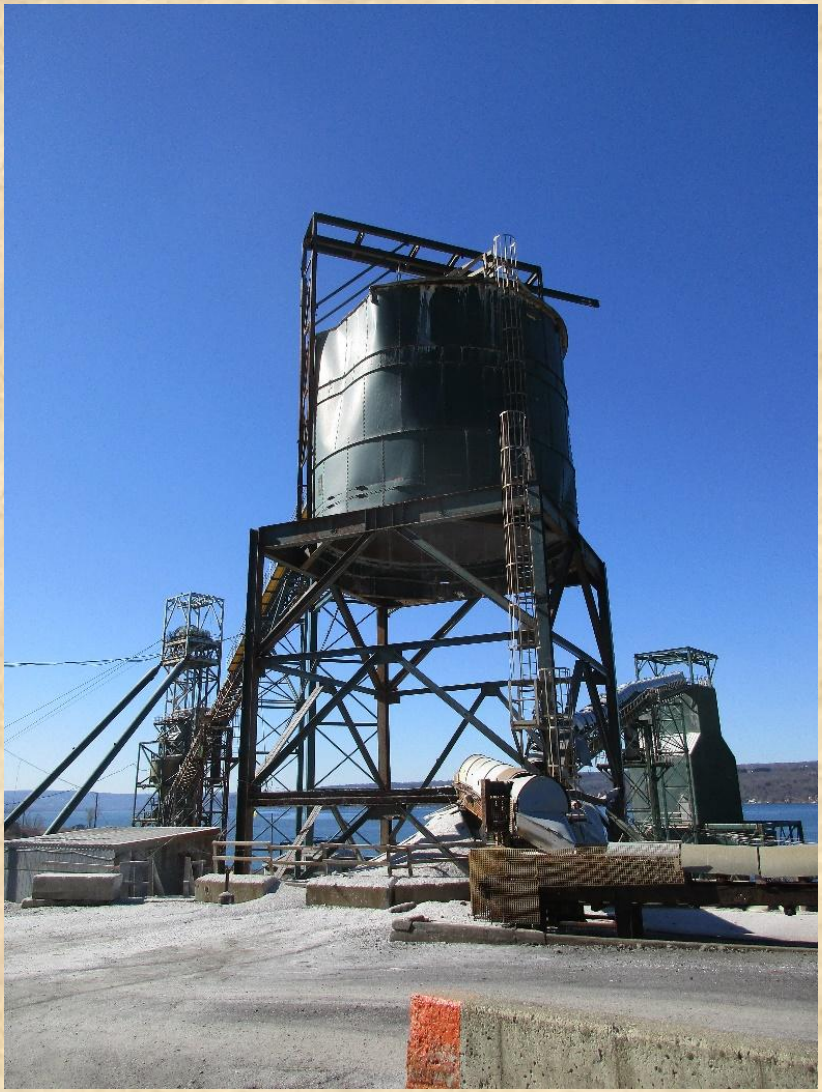
Incomplete product discharge.

Failures That Could Have Been Avoided

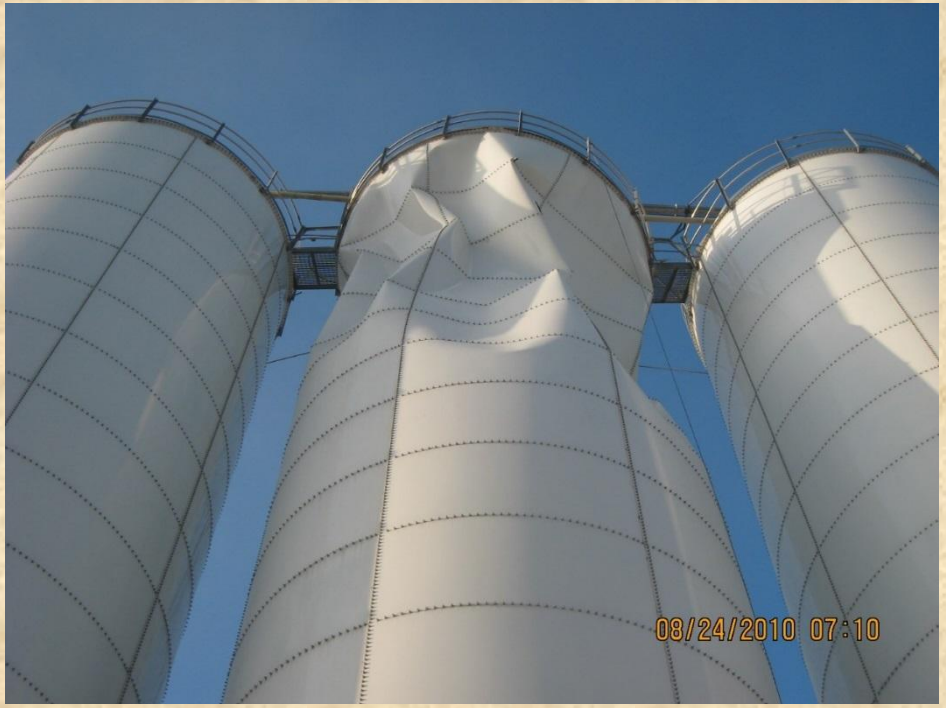
Operational procedures and equipment interface…

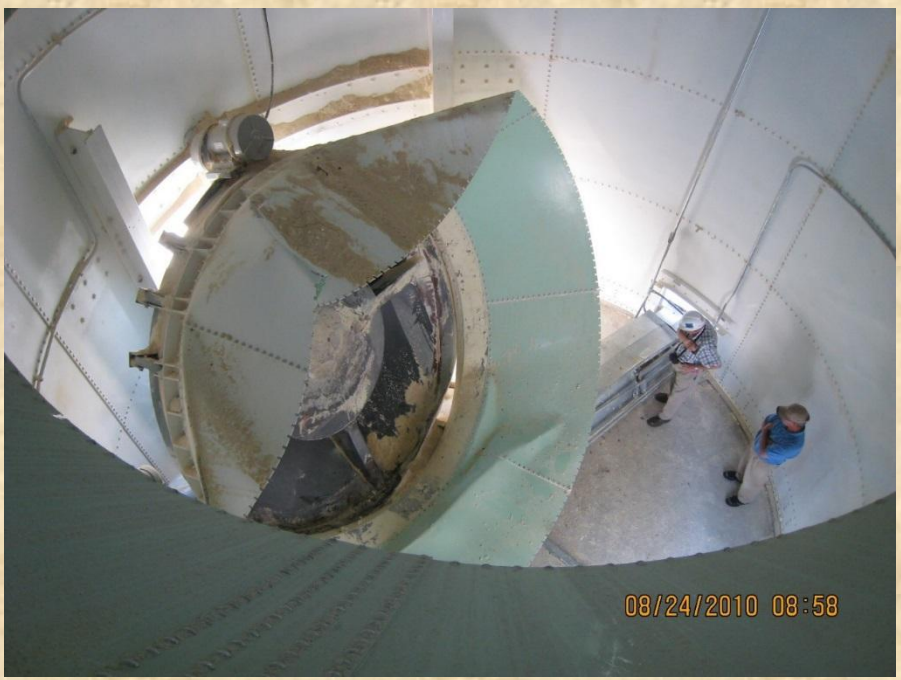
Failures That Could Have Been Avoided

Failures That Could Have Been Avoided



Failures That Could Have Been Avoided





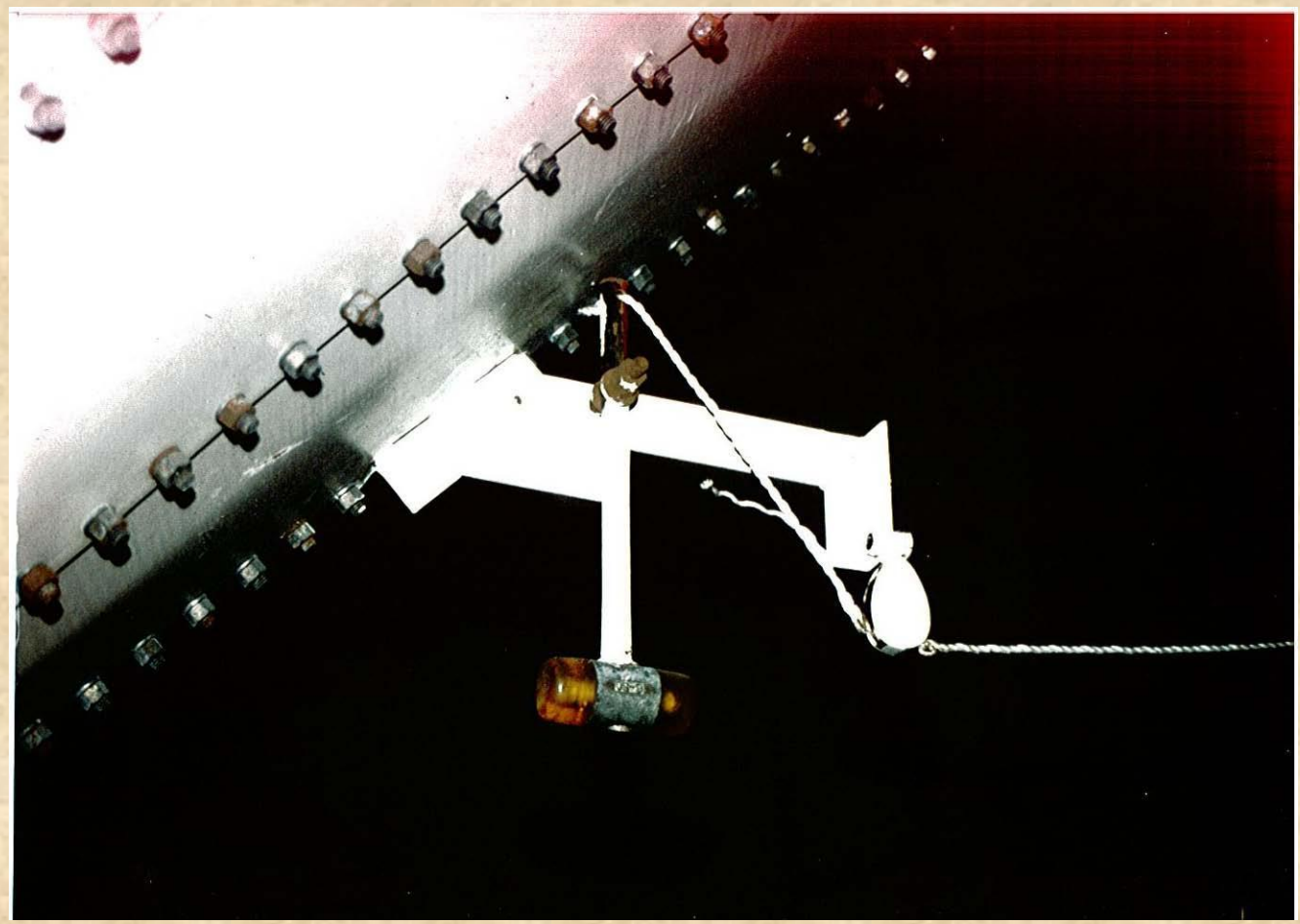
Failures That Could Have Been Avoided

Inexperienced contractors…

Failures That Could Have Been Avoided

These silos are not properly vented.

NOT a Good Flow Aid!!!



Use only properly designed flow aid devices!

Joe Marinelli
President of Solids Handling Technologies

Silos Fail Because Of:

- Engineering Design Errors
- Construction Errors

Failure Due To Construction Errors

- Poor Workmanship
  - Uneven foundation settlement
  - Faulty construction (inadequate reinforcment)
- Changes in details
  - Material specifications
  - Erection procedure

1923 Transcona Grain Elevator tilted upon loading, and began to settle about 1 foot/hour and next day, the structure came to rest at a 63 degree angle. It was later up righted and repaired

Silos Fail Because Of:

- Engineering Design Errors
- Construction Errors
- Silo Usage (or Mis-usage)

Failures Resulting from Silo Usage

- Collapse of large voids

Coal Silo Collapse Claims Worker's Life

MORGANTOWN, WV — The internal structural collapse of a coal silo at the Morgantown Energy Facility prompted an 84-hour effort to rescue a trapped worker.

The victim was trapped under 1,400 tons of coal and machinery when the silo collapsed for undetermined reasons. He was responsible for blending crushed coal after it was fed down a conveyor in the silo.

The unstable nature of the crumbled silo hampered rescue efforts. After three-and-a-half days, rescuers recovered the employee's body. He had worked at the plant since it opened in 1992.

The plant immediately began stabilization efforts following the rescue, pouring concrete as a temporary brace. The silo will eventually be demolished.

The power station burns coal and coal wastes to produce steam heat, and sells electricity. Before the fatality, employees had logged 733,000 man-hours without an incident.

Failures Resulting from Silo Usage

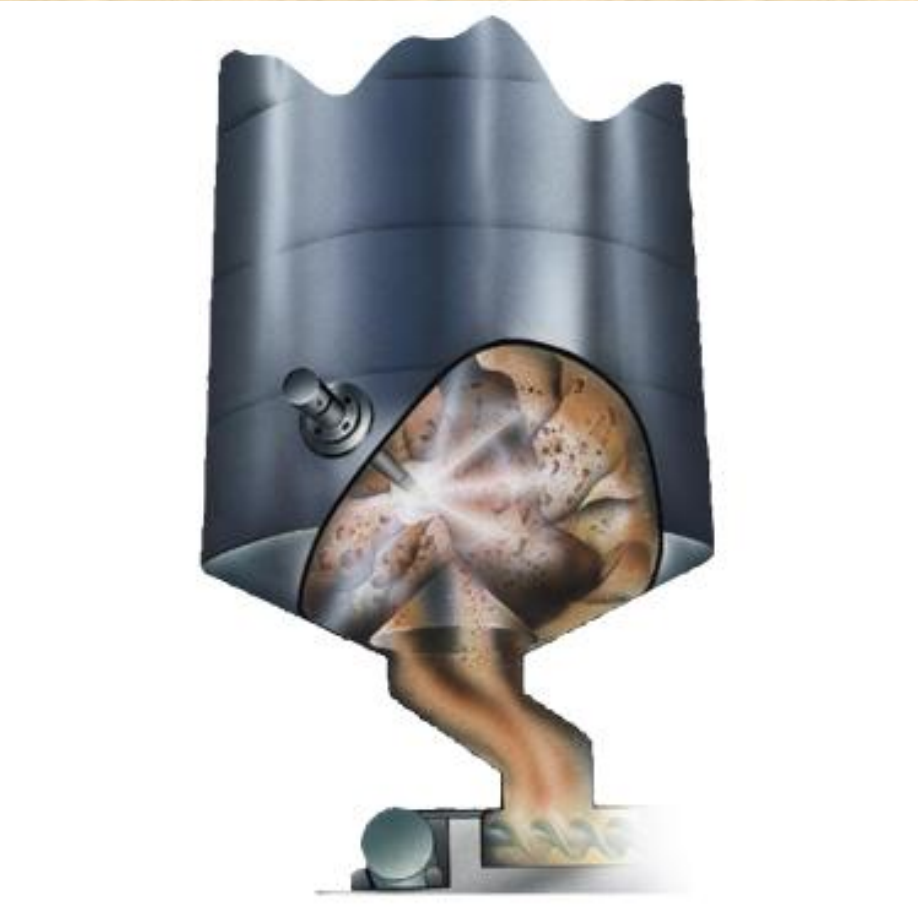
- Collapse of large voids
- Development of mass flow in a funnel flow silo

Development of Mass Flow in a Silo Designed for Funnel Flow

Failures Resulting from Silo Usage

- Collapse of large voids
- Development of mass flow in a funnel flow silo
- Drastic means of flow promotion

Cardox Systems



Development of Large Voids and Drastic Means of Flow Promotion

Failures Resulting from Silo Usage

- Collapse of large voids
- Development of mass flow in a funnel flow silo
- Drastic means of flow promotion
- Dust Explosions

Dust Explosions

Failures Resulting from Silo Usage

- Collapse of large voids
- Development of mass flow in a funnel flow silo
- Drastic means of flow promotion
- Metal fatigue
- Dust Explosions

- Special material problems (honking!)

Honking Silo

Feeders

- Make sure that your feeder is designed properly
- It should maintain mass flow
- It should not create preferential flow channels


Domes are a common means to provide large capacity storage


But this can happen!


This was deadly
Bin Entrapment
Giant clump of corn due to moisture and mold