Volume : 2 | Issue : 11 | Nov 2013 • ISSN No 2277 - 8160

Research Paper Engineering

Study of Types of Failures in Silos

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ABSTRACT

Silos and bins fail with a frequency which is much higher than almost any other industrial equipment. Sometimes the failure only involves distortion or deformation which, while unsightly, does not pose a safety or operational hazard. In other cases, failure involves complete collapse of the structure with accompanying loss of use and even loss of life. The design, construction, operation and maintenance of silos are not being described in any national legislation or industrial standard. Therefore, it is the responsibility of the owner to establish related written procedures to ensure its safe use. Here we review the common mistakes, faulty erection, limits of design, improper maintenance, etc.

KEYWORDS : Silo, Failures in Silo

INTRODUCTION:

Studies of the design and construction of silo started in 1882 when Roberts made his first test on rectangular silo 15m high in order to calculate pressure. The first lateral and vertical pressure were defined by Janssen in 1895. Since then, his formulas have been constantly applied, although to date problem have not been ceased. During the nineteen sixties there began a strong drive to define calculate the pressure produced by the stored material on the wall hopper.

No statistical figures are available but, hundreds of industrial and farm silos, bins, and hoppers fail in one way or another each year thorough out the world. Sometimes the failure is a complete dramatic structural collapse. Other times cracks are found in a concrete wall, or dents in a steel shell, either of which might appear harmless to the casual observer. These indicate that corrective measures are probably required.

The economic cost of repairs to this essential –though frequently neglected – component of a bulk material handling system is never small. The owner faces the immediate costs of lost production and repairs, personnel in the vicinity are exposed to danger. In this paper I shall elaborate on some of the problems that can occur causing the reason of failure.

SILO DESIGN

The design of bins / silos to store bulk solids involves bulk material, geometric, and structural considerations. *Bulk material* considerations are important because the frictional and cohesive properties of bulk solids vary from one solid to another, and these properties affect material behaviour considerably. In addition, a given bulk solid's flow properties can vary dramatically with changes in numerous parameters, including particle size, moisture, temperature, and consolidating pressure. This variability of properties makes testing at actual conditions more important for proper bin and silo design .

When considering the *geometric* design of a silo, potential problems include arching across an outlet, rat-holing through the material, and the flow pattern during discharge. A bulk material's propensity to arch or rathole is primarily related to it's cohesiveness, while its flow pattern during discharge depends upon internal friction as well as the friction that develops between the material and the silo's hopper walls. The goal of geometric design is to maximize the useable capacity of a silo while minimizing its capital cost, overall height, etc.

Established design procedures include selection of the optimum hopper angles and minimum outlet dimensions. The ideal discharge mode is one where, at steady state, all material flows without obstruction. This is referred to as *mass flow*. The discharge mode where only some of the material flows is called funnel flow. In mass flow, the Material does not necessarily move at a uniform rate throughout: velocity variations across any horizontal cross section are possible.

Of the three major aspects of silo design (bulk material, geometric, and structural), the silo loads aspect of structural design is the least understood. But unless the structural design is done properly, the integrity of the silo may be compromised. This is very apparent when one considers existing codes of practice. There is very little detailed guidance concerning the various loading conditions – some static, some dynamic – which can co-exist. An engineer may have the right to exercise independent engineering judgment when creating a design, and may even go back to first principles. But if a problem occurs and the engineer must justify his design, he will have difficulty doing so unless it is as good as the minimum provided by the applicable code (or codes). In fact even flow experts often cannot agree on where a flow channel will form in a funnel flow bin or silo, its size, shape, etc. Because of this uncertainty in the ability to predict the occurrence of flow channels, some designers feel that it is prudent to assume the occurrence of worst case flow channels if there is any doubt at all.

Several committees in various countries are currently working to revise silo design codes. Many are having great difficulty in enacting new measures for the design of silos to accommodate flow channels even though they know that they occur and they know that many silo failures have been caused by such flow channels. Every day there are new engineers who are charged with the design of new silos. Most of these new engineers look first to the codes for information on the design of these structures, hoping and expecting that the codes will point them in the right direction. To do this, a code need not be perfect, but it must reflect the latest in technology and be rational.

CAUSES OF SILO FAILURES

There are different causes of silo failures: shortcomings in the design procedure, construction, usage, maintenance, or some combination thereof. This, in turn, means that more than one individual or group often bears some responsibility when a failure occurs. Potentially responsible parties include the designer, builder, building material supplier, owner, user, and others.

FAILURES DUE TO DESIGN ERRORS

Silo design requires specialized knowledge. The designer must first establish the material's flow properties, and then consider such items as flow channel geometry, flow and static pressure development, and dynamic effects. Problems like rat holing (Compaction on the side of a silo. This not only reduces the operating volume in a silo but it also compromises quality control by disrupting the first in first out cycle.) and vibration has to be prevented, while assuring reliable discharge at the required rate. Non-uniform loads, thermal loads, and the effects of non-standard fabrication details must be considered. Above all, the designer must know when to be cautious in the face of incomplete or misleading information, or recommendations that come from handbooks, or from people with the "it's always been done this way" syndrome.

Having customary the design criteria, a competent design has to follow. Here the designer must have a full understanding of load combinations, load paths, primary and secondary effects on structural elements, and the relative flexibility of the elements. Special attention must be given to how the most critical details in the structure will be constructed so that the full requirements and intent of the design will be realized.

Flow-related loading conditions which, unfortunately, many designers fail to anticipate include:

- ✓ Bending of circular walls caused by eccentric withdrawal. If the withdrawal point from the hopper is not located on the vertical centreline of the silo, and if the resulting flow channel intersects the silo wall, non-uniform pressures will develop around the circumference of the silo leading to horizontal and vertical bending moments. Many silo designers incorrectly account for these non-uniform pressures by only increasing hoop pressures. The problem of bending moments is particularly common when using silos with multiple outlets/hoppers in which only one or two of the outlets/hopper outlets are used at a time.
- ✓ Non-symmetric pressures caused by inserts. Support beams and other types of internals can impose non-symmetric pressures on the silo wall leading to unacceptable bending stresses.
- ✓ Self-induced vibrations: Bins and silos sometimes vibrate. This can be either a high frequency, low amplitude type of cyclic vibration, or a low frequency, high amplitude erratic vibration leading to shocks. The latter have been known to cause structural failures.
- ✓ Local peak pressure at a point where a funnel flow channel intersects a silo wall.
- ✓ Mass flow occurring when funnel flow was expected.
- ✓ Migration of moisture from wet to dry particles within the stored solids, which causes the dry particles to expand and impose large radial loads on a silo. (This is an uncommon problem.)

FAILURES DUE TO CONSTRUCTION ERRORS

Mistakes that can lead to structural failure can also be introduced during the construction of the silo and its supporting structure. Discretion must be used in the selection of the construction team, who must be cognizant of the importance of their role. Poor quality workmanship is the most common way in which construction related mistakes are made. The other cause of construction problems is the introduction of badly chosen, or even unauthorized, changes during construction in order to expedite the work or reduce costs. Design specifications must be carefully followed and if any situation arises during construction that requires design modifications the structural design engineer should be consulted

Construction Errors: Poor Quality Workmanship

Close inspection of contractors' work is important in order to ensure that design specifications are being followed. This includes checking for use of correct bolts (size, strength, etc). The design engineer should have a representative on site, during construction, to ensure that the correct procedures are followed and that events are properly sequenced. Fabrication and erection plays a vital role in Silo failure, proper care is required to be take to ensure proper fabrication and erection procedures are followed during the erections and fabrication work.

Incorrect Material

Close inspection of contractors work is important in order to ensure that design specifications are being followed. This includes checking for use of correct weld / bolts (size, strength, etc.).

Uneven Foundation Settlement

Foundation design for silos is not appreciably different than for other structures. As a result, uneven settlement is rare. However, when it does occur, the consequences can be appalling since usually the centre of gravity of the mass is well above the ground.

Design Changes During Construction

Unauthorised changes during construction can put a silo structure at risk. Seemingly minor details are often important in ensuring a particular type of flow pattern (especially mass flow), or in allowing the structure to resist the applied loads.

FAILURES RESULTING FROM SILO USAGE

A properly designed and properly constructed silo should have a long life. Unfortunately, this is not always the case. Problems can arise when the flow properties of the material change, the structure changes because of wear, or an explosive condition arises.

If a different bulk material is placed in a silo than the one for which the silo was designed, obstructions such as arches and rat holes may form, and the flow pattern and loads may be completely different than expected. The load distribution can also be radically changed if alterations to the outlet geometry are made, if a side outlet is put in a centre discharge silo. The designer or a silo expert should be consulted regarding the effects of such changes before they are implemented.

Some of the problems which can occur include:

- Collapse of large voids. A collapsing arch or rathole induces tremendous dynamic loads on the structure, which can cause the structure to fail. Vibrating bin dischargers have also been known to fall off bins and silos because of this mechanism.
- Development of mass flow in silos designed structurally for funnel flow. Mass flow can develop if the walls become smoother with time or if the properties of the bulk solid being stored change. This generally results in much higher loads at the top of the hopper section, which can result in structural failure.
- Dire means of flow promotion. High pressure air cannons and even dynamite are sometimes used to restore flow. The result may be more dramatic than the user and designer anticipated!
- Buckling of an unsupported wall below an arch of stored bulk material.
- Metal fatigue caused by externally-mounted bin vibrators.
- Dust explosions.

SPECIAL CONSIDERATIONS PERTAINING TO TEMPERATURE AND MOISTURE:

The walls of outdoor metal silos can 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, it 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. This phenomenon, which is repeated each day the material sits at rest, is called thermal racketing.

Another unusual loading condition can occur when moisture migrates between stagnant particles, or masses of stagnant particles, which expand when moisture is added to them. If this occurs while material is not being withdrawn, upward expansion is greatly restrained. Therefore, most of the expansion must occur in the horizontal plane, which will result in significantly increased lateral pressures on, and hoop stresses in, the silo walls.

DYNAMIC LOADS DUE TO COLLAPSING ARCHES OR RAT HOLES, SELF-INDUCED VIBRATIONS, OR EXPLOSIONS:

When a poorly flowing material is placed in a silo which was not designed to store and handle it, flow stoppages due to arching or rat holing are likely. Sometimes these obstructions will clear by themselves, but, more often, operators will have to resort to various means to clear them. No matter which method is used, the resulting dynamic loads when an arch or rat hole fails can collapse the silo. Self-induced silo vibrations can also result in significant dynamic loads for which most silos are not designed to withstand. In addition, few if any silos can withstand the loads imposed by an explosion either internal or external.

CHANGES IN FLOW PATTERNS:

Changing material properties or polishing of the inside surface of the silo may cause mass flow to develop in a silo which was structurally designed for funnel flow. (The opposite can also occur – funnel flow in a silo designed structurally for mass flow – but this generally is not as serious a problem.) Mass flow will result in a dramatically different wall pressure loading than with funnel flow, particularly at the top of the hopper section.

BUCKLING OF UNSUPPORTED WALL

A pressurised cylinder is more resistant to compressive buckling than an unpressurised one. In addition, if this pressure is caused by a bulk solid, it is even more resistant. The reason is as follows: Gas or liquid pressure is constant around a silo's circumference and remains unchanged as the silo starts to deform. On the other hand, the pressure exerted by a bulk solid against a silo's wall increases in areas where the walls are deforming inward, and decreases where the walls are expanding. This provides a significant restraining effect once buckling begins. Now consider what happens if an arch forms across a silo's cylinder section and material below it is withdrawn. Not only is the restraining effect of the bulk solid lost, but the full weight of the silo contents above the arch are transferred to the now unsupported region of the silo walls. Buckling failure is likely when this occurs.

FAILURES DUE TO IMPROPER MAINTENANCE

Maintenance of a silo comes in the owner's or user's domain, and must not be neglected. Two types of maintenance work are required. The first is the regular preventative work, such as the periodic inspection and repair of the walls and/or liner used to promote flow, protect the structure, or both. Loss of a liner may be unavoidable with an abrasive or corrosive product, yet maintaining a liner in proper working condition is necessary if the silo is to operate as designed. Other examples of preventative maintenance items include roof vents, level probes, feeders, dischargers, and gates.

The second area of maintenance involves looking for signs of distress (*e.g.,* cracks, wall distortion, tilting of the structure) and reacting to them. If evidence of a problem appears, expert help should be immediately summoned. An inappropriate response to a sign that something is going wrong, including the common instinct to lower the silo fill level, can cause a failure to occur with greater speed and perhaps greater severity.

Corrosion and erosion

Silo walls thinned by corrosion or erosion are less able to resist applied loads than when they were new. This is a particular problem when handling abrasive materials or when using carbon steel construction in moist or otherwise corrosive environments. Combining the effects of abrasion with corrosion significantly accelerates the problem. This can occur, for example, with special aging steels. Abrasive wear causes the surface layer to be removed, thereby exposing new material and speeding up the aging process which significantly weakens the structure.

LACK OF ROUTINE INSPECTION

Silo failures often cause significant damage and sometimes result in death. Often these failures could have been prevented or the damage could have been minimized with information that could have been gained through routine inspection.

Improper reaction to signs of distress

A common reaction to signs of silo distress is to ignore them, often because personnel are unaware of both the meaning and consequences of doing so. Another common reaction is curiosity. People have lost lives because, due to their curiosity, they were in the wrong place at the wrong time. Even if danger signs are understood, it is common for inappropriate action to be taken in an attempt to "reduce" the chance of failure. In some extreme cases, catastrophic failure has been induced where, with appropriate action, the damage could have been relatively minor.

CONCLUSIONS

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

The construction of a silo, bin, or hopper should be executed by a qualified and experienced team that understands the specifications set out in the design and the consequences of not following them to the letter. It is the joint responsibility of the design engineer, builder, and owner that construction be of an acceptable standard and fulfills the intent of the design.

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

The design, construction, and utilization of a silo. At all phases, it should be borne in mind that if a silo is designed, built, and operated properly it will have a long and safe life. It should also be remembered that in the event of a failure, the cost of repairs or rebuilding, litigation, and insurance almost always add up to several times the cost of doing the job properly in the first place.

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