ISSN NO: 2770-4491
Date of Publication:28-06-2023

Study The Various Failure Cases of The Reinforced Concrete Silos: A Literature Review

Hawra Mohamed Ali M. Taher
Department of civil Engineering, University of Kerbala, Karbala, Iraq
hawra.m@uokerbala.edu.iq

Abstract: Silos are unique structures that are put under a wide variety of abnormal loading conditions, which causes them to fail in unusual ways. The failure of a reinforced concrete silo can have highly destructive or damaging effects because it is possible for this to result in the misplacement of the utensil, the pollution of the substance that it houses, the absence of the substance itself, the need for cleanup, the costs associated with replacing the container, damage to the environment, and even the possibility of a person's death. This study offers a comprehensive overview and discussion of the everyday or extraordinary reinforced concrete silo failures because of the risk of explosion and bursting, the creation of asymmetrical loads while filling or discharging, as well as excessive and nonuniform soil pressure, the degradation of concrete silos brought on by silage acids, the collapse of the internal structure, and thermal ratcheting. These failures occurred for a variety of reasons, such as blowing up or rupturing; weights that are not evenly distributed when being filled or emptied; large and nonuniform damage to silos and failures as a result of multiple earthquakes are also presented here. Errors in construction, usage, and design have been identified as the primary reasons for the failure of silos.

Keywords: silo, failure, reinforced concrete, deterioration

1. Introduction

The usage of storage silos is commonplace in many technical contexts, including those in the construction industry, the agricultural sector, the industrial sector, and even the aerospace sector. The ability to store a wide variety of materials, substances, both liquid and solid, that aid manufacturing operations, treatments, and products is the primary function of the kinds of buildings that are designed in this way. In point of fact, the term "silos" refers to large storage containers used to hold granular bulk solids in large numbers. There is a wide variety of sizes available, with capacities ranging from tons to thousands of tons, depending on the type of material being stored [1].

It is important to point out that silos are indispensable components of a variety of business sectors and consist of structures that are frequently involved in a great number of accidents. These mishaps result in significant financial losses, personal injuries, and damage to the natural environment. In general, critical facilities have been shown to be subjected to large damages and catastrophic consequences in the past during potentially dangerous events such as earthquakes. In addition to this, it demonstrates that the design methods used for new industrial structures have non-negligible uncertainties, particularly when it comes to extreme events [2].

The vast majority of silos are cylindrical structures made of steel or reinforced concrete and are based on mat foundations. It was possible for them to be elevated at times and assistance from frameworks or columns made of reinforced concrete. The nature of the material being stored, and its characteristics are the primary factors that influence the layout and construction of silos. The loads placed on a silo and its supporting infrastructure are distinct from those placed on regular buildings. This is due to the fact that the qualities of grains, cement, coal, carbon black, and other bulk materials can vary substantially in density, flow, and friction. As a direct consequence of this, silos are developed and analyzed as unique structures. At the moment, the only guideline that has been published in the U.S that is silo design and construction and other storage structures like these is the ACI 313 document that was published in 1997.[3]

Typically, the material that is being stored inside of the silos will cause the walls of the silos to be subjected to not only normal pressure but also vertical frictional shear or traction. This is because the material is causing the walls to be pulled or sheared in a vertical direction. Shear and normal pressures along the silo wall vary in intensity and distribution depending on the material being stored and whether or not the silo is being filled or

ISSN NO: 2770-4491
Date of Publication:28-06-2023

emptied at the moment. The characteristics of the material that is being stored include. During the design process, it is imperative to take into account not only the seismic and wind loads but also other potential loads such as stresses caused through the action of temperature gradients between the silo wall and the bulk solids that are being stored, the possibility of the material being stored expanding, and differential settlement of the foundation or support columns. The catastrophic collapse of an entire silo is typically the result of the failure of a single structure within the silo. This is mostly due to the fact that most cylindrical shell structures do not have sufficient structural redundancy, and they also do not have an alternative load path, which makes it after a localized collapse or damage, it is difficult to disperse the stresses and forces that are within the structure. has taken place. The subsequent collapse of the entire structure leads not only to the loss of the material that was contained but, in some instances, also to the loss of human life. The failures of the silos are typically abrupt and brittle, and they are sometimes brought on by explosions. If the silo were to collapse, its debris may fall onto a nearby barn or industrial facilities, causing even more damage and perhaps harming or killing people and animals., as well as causing additional property damage [4].

Failure of silos is a relatively common occurrence in the industry that deals with bulk solids. Every year, a large number of silos that have been reported to have failed as a result of improper design, poor installation, are brought to light. Failures can range from a minor deformation in the silo shell all the way up to a catastrophic rupture and the structure's complete collapse. Indications of structural damage should not be ignored, and correct design and construction practices should be enforced at all times, regardless of the degree to which the structure has failed. The failure of a silo can result in significant financial losses, personal injury, and even death in extreme cases. Silos made of reinforced concrete and various other shells have been constructed for decades. Cracked silo wall vitality, also known as durability, when planning, building, and making use of these shells as storage containers, is one of the most crucial factors to consider. Horizontal and vertical fractures can form for a variety of reasons, including changes in temperature and pressure, live loads like wind and the dynamic character of wind, moisture, the influence of building joints, thermal insulation, and the active chemistry in the environment. These factors all contribute to a reduction in the carrying capacity of the walls of the silos and a lower state of reliability. Horizontal and vertical cracks have the potential to cause corrosion in concrete and steel reinforcement bars, a reduction in the stiffness of the contraction, an increase in the amount of deflection, an increase in the carbonation of the concrete cover, and dampness in the concrete wall [5].

Condensate water is able to enter the wall through cracks both horizontal and vertical in nature. The presence of a greater number of cracks in concrete shells is leading to an increase in both the local and global imperfections of the shells. When these factors are considered, it becomes clear that lowering the strength parameters of the reinforced concrete structure as a whole will shorten its service life and eventually lead to its failure. The technology used to repair cracked walls needs to take into account the model of failure, which can be as simple as one parameter or as complex as series or parallel system models. Failure rates for silos and bins are significantly higher than those of virtually all other types of industrial equipment. In some cases, the failure consists only of a distortion or deformation, which, despite being unsightly, does not present a threat to either occupational safety or public health. In other instances, the failure results in the total collapse of the structure, which leads to a loss of functionality and potentially even human lives. Errors in construction, usage, and design have been identified as the three primary reasons for the failure of silos. Numerous case histories are utilized to illustrate common blunders, limitations of design, and valuable life lessons. Failure rates for silos and bins are significantly higher than those of virtually all other types of industrial equipment. In some cases, the failure consists only of a distortion or deformation, which, despite being unsightly, does not present a threat to either occupational safety or public health. In other instances, the failure results in the total collapse of the structure, which leads to a loss of functionality and potentially even human lives [6].

There is no longer any room for debate on whether or not modern engineering projects must consider the environmental friendliness of a development infrastructure, as such consideration is already a mandate. The first stage in building reinforced concrete structures and establishing their degree of reliability is to perform a thorough examination of all potential activities, including direct, indirect, and environmental factors. When the silo is loaded, the walls push back against the applied forces and bending moments (also known as permanent loads, pressure from stored material, overpressures generated during filling or discharge, as well as abrasion and impact loads), and asymmetrical flows as well as rat holing and bridging). Other potential

ISSN NO: 2770-4491
Date of Publication:28-06-2023

loads, such as those induced by earthquakes and winds, material expansion while being stored, and differential settling of the foundation, must also be accounted for throughout the design phase.
Environmental influences, which include the physical and chemical effects of the circumstances in the vicinity, have a significant role in determining the longevity of silos because they are often constructed in natural environments. Environmental elements such as changes in ambient temperature, humidity, sun radiation, wind, snow, and ice, and the presence of hostile compounds in the air can have a major impact on the operation of a silo due to the thin wall compared to the other dimensions of the cylinder. Among the many potential causes of a silo wall's deterioration are reinforcing corrosion and chemical attack on the concrete. The high temperature of the stored material and the temperature strains caused by solar radiation are other important considerations. Changes in temperature and pressure gradients can lead to cracking in concrete. An abundance of research has been conducted over the past two decades to learn how concrete cracking and reinforcing corrosion affect the performance of concrete buildings. When concrete cracks too much, it can compromise the structure's strength and shorten its lifespan. When it comes to cracking in the concrete and corrosion of the reinforcement, both should be maintained to a minimum so that the structure may continue to serve its purpose and survive for a reasonable amount of time without becoming unsightly. The structural system can be altered by large fractures, which can have consequences for the building's usability, durability, and even stability. The thermal activities on cylindrical concrete silos and the stresses that arise have been illustrated in a number of research articles [7].
Experimental and numerical methods have been utilized to examine the temperature and stress distribution in silos that have been subjected to grain pressures and the thermal gradient generated by solar radiation. Experimental investigations and numerical evaluations have also been conducted by subjecting storage silos to a wide range of temperatures. In a positive turn of events, silos nearly always show signs of flaws before they entirely collapse. Unwanted occurrences in the silo can be inferred from the appearance of telltale signs including certain fracture patterns, concrete chunks laying around, delamination, and spalling. Problems that arise in cement silos are unique to them (e.g., thermal shock). Poor planning, shoddy workmanship, careless use, and/or neglect all play a role in these catastrophes [8].

2. Failure causes of silo structures

The failure of the reinforced concrete silos may be traced back to issues with the material, the design, the design codes, and the silos' capacity to last for an extended period of time. When we speak of the durability of a material or construction, we are referring to its capacity to preserve its structural, aesthetic, functional, and mechanical features over the course of its useful life. This is what we mean when we use the term "durability." Using fire durability, crack width limitations, limit deflections, and construction resistance, as well as construction resistance, it is possible to predict the longevity of concrete-reinforced structures such as silos made of reinforced concrete and other concrete-reinforced structures. The total durability of the construction is increased because to all of these different variables. The integrity of the structure is affected not only by its ability to bear normal wear and tear, but also by secondary factors like as the filling and discharge pressure, the wind, and thermal actions that are linked to variations in the temperature of the environment around it [9]. In a nutshell, the most typical factors that lead to the collapse of reinforced concrete silos can be placed into one of the following six classes:

2.1 Failure as a result of design

Expertise is needed for silo design, as The designer needs to start off by determine the movement of the material parameters and then take into account the flow's shape changing, the flow's static pressure growing, and the flow's dynamic effects. Assuring consistent discharge at the necessary rate necessitates avoiding issues like ratholing and vibration. The designer must be aware of when to exercise caution in the face of incomplete or deceptive information or suggestions from a handbook, particularly when dealing with nonuniform loads, thermal loads, and the consequences of nonstandard manufacturing details. A thorough understanding of the load combination, load path, primary and secondary impacts of structural elements, and the relative flexibility of element is required here once the designer has defined the design requirements a competent design must adhere to. To ensure that all of the design's requirements and intentions are met, careful consideration must be paid to the building process's most crucial components. The improper design of a grain silo leads to its eventual collapse. Silo construction calls for a high level of expertise. The design engineer needs to know the

ISSN NO: 2770-4491
Date of Publication:28-06-2023

functional design objective of the silo and collect a large amount of data first. The latter comprises details like the quantity and nature of the bulk materials that will be processed, as well as information about the geometry, like size and shape, and the operations, including feed/discharge schedules, procedures, and rates. All bulk solids that will be processed in the silo must have their flow characteristics determined. Once this data has been collected, structural design may receive the attention it deserves. After the design criteria have been set, a good design must be created. In this case, the design engineer needs to have an in-depth familiarity with the various combinations of loads, load pathways, primary and secondary effects on structural parts, and element stiffness and deflection are all factors to consider. The shape of the flow channel, the rise in static pressure, and the dynamic consequences of things like rathole collapse and silo vibration caused by the structure's own motions are all factors that need to be taken into account. The design engineer needs to be aware of the potential consequences of unusual loading scenarios, such as non-uniform and/or heat loads. There needs to be thought put into the design for how everything will be built and built, with the use of industry standards whenever possible. For the silo and its supporting structure to perform as intended, careful consideration must be paid to the most minute of details [10].

2.2 Failure as a result of inaccuracies in construction

Poor craftsmanship is the leading cause of construction-related difficulties. Uneven foundation settlement and improper construction (including the use of the wrong materials or a lack of necessary reinforcing, such as an insufficient number of rebar) are two examples. During the phase of construction. There are two ways that problems can arise; the most prevalent is poor craftsmanship. There are two ways in which problems can arise during the construction phase: design flaws and material defects. In addition, poor workmanship is the most common of these two ways that problems can be created. In most cases, this may be avoided by ensuring that only qualified builders are hired, by conducting thorough inspections during the building process, and by enforcing a specification that is defined very specifically [11].

The introduction of ill-considered or even unlawful adjustments throughout the construction process in order to complete the work more quickly is the other factor that contributes to construction issues. Both the builder and the silo designer have an obligation to pay careful consideration to any alteration in the specifics, material specifications, or erection technique.

Another large number of errors were committed both during the construction of the concrete reinforced silo walls as well as their ongoing maintenance. The following is how we can differentiate between them: too close of a gap between the use of movable formwork in building shells; the presence of vertical and horizontal steel bars in the concrete wall; a lack of attention to detail during the construction of the concrete; the premature drying of the wall; Joining shells together is a common technique; incorrect joint design too lengthy of a break between successive concrete fillings; the use of vibrators that are inappropriate for the diameter of the steel bars and the distances between them; steel bars that are either too thin or too thick[12].

2.3 Failure as a result of misuse

It is reasonable to expect that a well-designed and well-built silo will have a lengthy service life. The number of silo failures that occur each year is, sadly, fairly large. Failure is possible for any silo, regardless of how well it was designed or built. When designing a silo, certain factors are taken into consideration, and if any of the actual parameters deviate from those taken into consideration during design, there is a possibility that the silo will not function properly. It is vital that a silo be used solely for the purpose for which it was designed, as well as that suitable prioritizations of inspections and maintenance be created and carried out, in order to guarantee a silo has a long and risk-free life span [13].

When a silo is used to store a bulk material other than the one it was designed for, the flow pattern and the loads may be drastically altered. Large shifts in load distribution are possible with modifications to outlet shape. The designer should be asked for input on the potential outcomes of making such changes before they are implemented. Massive void collapse is one potential issue; when an arch or rathole collapses, it can place enormous dynamic pressures on the surrounding structure, eventually leading to its collapse. This mechanism, which involves the creation of mass flow in silos that are structurally constructed for funnel flow, has been observed to cause vibrating bin discharges to slide off of bins and silos. It is possible for there to be mass flow if the wall grows smoother over time or if the characteristics of the bulk solid change while it is being stored. Because of this, the area around the hopper's apex has a weight that is excessively heavy, which puts the entire structure in danger at risk. Extreme flow promotion measures, such high-pressure air cannons or even

ISSN NO: 2770-4491
Date of Publication:28-06-2023

explosives, are often required for flow restoration. But the end result can be much more severe than either the user or the designer had planned for. Unsupported walls can buckle when an arch of bulk material presses down on them [14].

2.4 Failure as a result of negligence in upkeep

The upkeep of a silo falls under the purview of the owner or user, and this trust must not be ignored. There are two distinct categories of upkeep that need to be completed. The first type of work is the routine preventative maintenance. The second part of the maintenance process entails looking for symptoms of distress (such cracks, wall deformation, and tilting of the building) and taking action in response to those signs [15].

2.5 Failure as a result of explosion and bursting

Failures caused by internal explosions or bursting are more common in silo systems than in regular frame structures since traditional frame structures are often not subjected to loads of this nature. Flow pressure studies in theory show that many silos will explode due to the presence of extremely high pressures in specific areas of the wall. This is suggested by the fact that these pressures are likely to cause the silos to burst. Because the stored forage or fodder undergoes fermentation, certain silos are vulnerable to the explosion of methane, which is produced as a byproduct of the process. In spite of this, the occurrence of a burst or explosion is rather uncommon [16].

2.6 Failure as a result of earthquakes

Silos are regularly damaged and even brought to their knees by earthquakes, which leads in not only significant financial loss but also loss of life. The damage and/or collapse can be induced in a variety of ways. The ground motion caused by an earthquake is composed of three distinct components, which, when brought together, cause structural loads to be applied in two horizontal and one vertical direction. In most cases, the impact of vertical seismic stresses on moderately huge silo buildings is not one that can be considered extremely significant. On the other hand, the effect of lateral seismic loads can be very significant, particularly for higher silos that transport heavier goods. This is because lateral loads tend to be more distributed. The magnitude of the horizontal seismic stress has a direct and proportional relationship with the weight of the silo. This relationship is a one-to-one correspondence. The height of the structure's center of mass likewise rises to accommodate the new height of the silo whenever the height of the silo is increased. Taking into account that the horizontal seismic force is generally applied at the center of mass, When the lateral load increases, so does the bending moment at the base, and the moment arm.. This is due to the fact that there is also a rise in the height of the structure. As a consequence of this, there is a nonuniform pressure distribution at the bottom of the silo as a result of the increased bending moment, and this pressure may be far higher than the pressure that is created by the gravity loads. If the material that is stored in the silo is able to shake while the earthquake is taking place inside the silo, then the vibrations can also cause the upper part of the silo has sustained some damage.If the material is capable of oscillation, then it is necessary to take into consideration not only the lateral loads caused by material flow but also the lateral seismic stresses. If the material can oscillate, then the structure must be designed to withstand both types of loads [17].

3. Conclusions

The bulk of structural failures that occur in reinforced concrete silos can be traced back to a group of various different variables. When it comes to the layout of a silo for the storage of bulk materials, there are a few key considerations, the strategy that is reasonable, exhaustive, conservative, and founded on measured qualities is the one that will yield the best results. Only adhering to a code of practice will not provide design engineers with enough legal protection. Conformity to the norms established locally relevant code is, of course, vital; nevertheless, it should never, on its own, be viewed as a enough situation to the performance of a successful design. Rather, compliance with the code should be considered as a condition that is necessary but not sufficient. The design engineer is responsible for ensuring that the design is competent, that it covers all potential loading combinations that may be predicted, and that it is founded on sound, detailed understanding of the materials being handled. The creation of a silo, bin, or hopper ought to be carried out by a group that is both capable and experienced, since this group ought to be aware of the design's requirements as well as the implications that would arise from failing to adhere to those criteria to the letter. It is the job of the design engineer, the builder, and the owner to ensure that the construction is up to an acceptable quality and that it

ISSN NO: 2770-4491
Date of Publication:28-06-2023

accomplishes the goals of the design. After that, it is up to the owner to ensure that all of Both the structural and mechanical elements are maintained in satisfactory conditions. It is also the obligation of the owner to ensure that a design review is conducted prior to any proposed if the liner material, geometry of discharge, or other defining characteristics of the system alter, or if the intended use of the system shifts, and that any necessary strengthening is performed. This is yet another of the many responsibilities that fall on the shoulders of the owner of the business. Deficits or errors that occur during a silo's life, including the design and building of a silo, as well as the utilization of a silo, in their respective stages. It is vital to keep in mind that a silo will have a long-life expectancy with no risks associated with it provided that it is built, constructed, and operated in line with best practices at each stage. It is important to keep in mind that in if it fails, repairs or rebuilding, in addition to the cost of insurance and litigation, usually total multiple times the cost of performing the job properly in the first place. It is important to keep this in mind because it will almost always add up to several times the cost. It is essential to keep this in mind because, in almost all cases, the total amount will end up being significantly higher than the original estimate.

4.References

[1] Hasan, Muttaqin, Azzaki Mubarak, and Rijalul Fikri. "Crack and strength assessment of reinforced concrete cement plant blending silo structure." Materials Today: Proceedings 58 (2022): 1312-1318.
[2] Dawood, Mustafa B., and Hawra Mohamed Ali M. Taher. "Various methods for retrofitting prestressed concrete members: A critical review." Periodicals of Engineering and Natural Sciences (PEN) 9.2 (2021): 657-666.
[3] Jayachandran, Lakshmi E., B. Nitin, and Pavuluri Srinivasa Rao. "Simulation of the stress regime during grain filling in bamboo reinforced concrete silo." Journal of Stored Products Research 83 (2019): 123-129.
[4] Bywalski, C., and M. Kamiński. "A case study of the collapse of the over-chamber reinforced concrete ceiling of a meal silo." Engineering Structures 192 (2019): 103-112.
[5] Taher, Hawra Mohamed Ali M., and Mustafa B. Dawood. "Shear strengthening of continuous prestressed concrete beams with precast SIFCON laminates subjected to monotonic and repeated loads." Materials Today: Proceedings 60 (2022): 2004-2009.
[6] Maraveas, Chrysanthos. "Concrete silos: Failures, design issues and repair/strengthening methods." Applied Sciences 10.11 (2020): 3938.
[7] Matiaskova, Lydia, Juraj Bilcik, and Julius Soltesz. "Failure analysis of reinforced concrete walls of cylindrical silos under elevated temperatures." Engineering Failure Analysis 109 (2020): 104281.
[8] Saleem, Muhammad Umair, et al. "A Simplified Approach for Analysis and Design of Reinforced Concrete Circular Silos and Bunkers." The Open Construction & Building Technology Journal 12.1 (2018).
[9] Guo, Kunpeng, et al. "Seismic vulnerability assessment of reinforced concrete silo considering granular material-structure interaction." The Structural Design of Tall and Special Buildings 25.18 (2016): 1011-1030.
[10] Nateghi, F., and M. Yakhchalian. "Seismic behavior of reinforced concrete silos considering granular material-structure interaction." Procedia Engineering 14 (2011): 3050-3058.
[11] Matiaskova, Lydia, Juraj Bilcik, and Julius Soltesz. "Failure analysis of reinforced concrete walls of cylindrical silos under elevated temperatures." Engineering Failure Analysis 109 (2020): 104281.
[12] Carson, John W., and Tracy Holmes. "Silo failures: why do they happen?." TASK quarterly 7.4 (2003): 499-512.
[13] Maj, Marek. "Some causes of reinforced concrete silos failure." Procedia Engineering 172 (2017): 685-691.
[14] Bilčík, Juraj, et al. "Causes of Failures in Circular Concrete Silo Walls, Particularly Under Environmental Influences." Slovak Journal of Civil Engineering 29.4 (2021): 1-8.
[15] Khalil, Mohammad, Sergio Ruggieri, and Giuseppina Uva. "Assessment of Structural Behavior, Vulnerability, and Risk of Industrial Silos: State-of-the-Art and Recent Research Trends." Applied Sciences 12.6 (2022): 3006.
[16] Maj, Marek, and Andrzej Ubysz. "Estimation of loads’ main statistics for hot materials silo." IOP Conference Series: Materials Science and Engineering. Vol. 869. No. 5. IOP Publishing, 2020.
[17] Cho, Woo-Min, and Yoon-Suk Changa. "An Assessment of Concrete Silo Responses to Blast Load Dependent on DIF Relations." (2021).