REVIEW ON THIN SHELL CYLINDRICAL STEEL SILO

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Abstract - *Thin shell structures has given considerably attention for the at least 6 decades especially during the war time because of their importance in aircraft and missile applications. Shells of various shapes were investigated such as elliptical hemispherical, conical and cylindrical shells. These structures are mostly failing by bucking under external pressure.*

Cylindrical steel silos are tall slender structures used for storing materials like cement, grains, fly ash, carbon black, coal saw dust etc. They are special structures subjected to many different unconventional loading conditions, ranging from few tones to hundreds to thousands of tones which results in unusual failure modes. Failure of a silo can be devastating as it results in loss of the containers, contamination of material it contain, loss of materials environmental damages, and possible injuries and loss of life. Silos are subjected to normal pressure and axial compressive loads along with the self-weight. They also carry lateral loads due to wind and seismic forces.

Key Words: Thin shell, buckling, cylindrical steel silo

1. INTRODUCTION

Silos are most commonly constructed from uniform isotropic rolled plates, welded together to form a structure. For shorter and medium sized silos, corrugated sheets where the corrugations run circumferentially are sometimes used in the construction of the silo body. On the other hand, hoppers are mostly made from rolled plates. The metal plates are usually thin and are made of Steel. Even though lighter grades of steel can be used for roof, it is avoided because the welding and logistics become complicated. So, only a single material is used for the silo structure construction. Steel silos are generally very light and thin size. The radius-to-thickness ratio of the cylinder R/t is generally in the range 200-3000. Squat silos with a height-to-radius ratio less than 2 are being built increasingly. They have a large ratio of stored volume to structural construction cost.

Steel silos are commonly circular in cross-section. It may be ground supported or elevated. There are many advantages for steel silos over cast in situ concrete silos small and medium sized silos can be fabricated and therefore, quality can be controlled, their erection time is considerably short and is relatively easy to disassemble, move and rebuild in another location. The main disadvantage of the steel silo is the necessity of lining on steel walls to prevent excessive wear. Also steel walls are prone to condensation which may damage stored products such as grains and sugar etc. which are moisture sensitive

Silos are special structures subjected to many different unconventional loading conditions, ranging from few tones to hundred or thousand tones which result in usual failure modes. Failure of silo can be devastating as it can result in loss of container, contamination of materials it contain, loss of material, cleanup, replacement cost, environmental damages, and possible injuries and loss of life.

The silo may be externally stiffened or internally stiffened to stabilize the structure against the pressure of the stored material. Rings are provided along the circumference and stringers in longitudinal direction at definite intervals to carry out the reinforcing function. Stiffeners increase the mechanical stability of the silo structure.

Buckling is a mode of failure when the structure experiences sudden failure when subjected to compressive stress. When a slender silo structure is loaded in compression, for small loads it deforms with hardly any noticeable change in the geometry. When the load carrying capacity is at any point of critical load value, the structure suddenly experiences a large deformation and may lose its ability to carry load. This stage of loading is the buckling load.

Steel silos are very complicated in terms of its structural configuration, nature of loads coming on it and boundary conditions. Conventional method of analysis cannot handle the complexity of such structure. Also, experimental studies are not a viable option considering the size of structure involved. Hence, analytical investigations are carried out using Finite Element Method (FEM). It is a numerical technique for representing and simulating physical system. Many software's are available that offers solutions to structural problems using FEM, namely ABAQUS, NASTRAN, ANSYS, Multi Tech, MARC, RFEM, S-FRAME etc.,.

2. LITERATURE REVIEW

J. Michael Rotter (1990) described the results of a study on elastic-plastic collapse of axially loaded internally pressurized perfect thin cylindrical shells adjacent to the shell support. The failure mode often known as "elephant's foot" buckling which governs the design of many practical bin, silo, and tank structures were studied. The results are compared with previous design recommendations and a new simple equation is proposed for use in design.

J.W Carson and R.T Jenkyn (1993) studied some of the problems that can occur in a silo, why they occur and the straight forward steps that can avoid, or at least minimize, such problem. Silo design required specialized knowledge. The designer must first establish the material flow channel geometry, flow and static pressure development and dynamic effect. Problems like ratholing and vibration have to be prevented while assuring reliable discharge at required rate. Non uniform load, thermal load, and effect of non-standard fabrication details must be considered. Above all the designer must know when to be caution in the face of incomplete or misleading information or recommendation that come from the handbook. 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 design will be realized.

Md. Alauddin et al (1995), did full scale analysis of circular silo having different types of supports and subjected to various loading conditions revealed that the conventional method is not adequate in predicting the values of stress resultants required for design of a silo.

J. G. Teng (1997) investigated the effects of various factors on the plastic out-of-plane buckling behavior and strength of ring beam, leading to the eventual development of a simple plastic buckling approximation for design use. An annular plate ring beam at the transition junction of a uniformly-supported steel silo or tank is subject to a large circumferential compressive force derived from the radial component of the meridional tension in the conical hopper. Under this compressive force, the ring beam may fail in one of several possible modes, including out-of-plane buckling.

James G. A. Croll, (2006), when thin cylindrical shell walls of tanks and silos are subject to combinations of internal pressure and axial compression, local form of buckling failure occur. They are axisymmetric and influenced by the end or intermediate support conditions. This paper outline the basis of an analytical solution to the inherently nonlinear elastic–plastic buckling into axisymmetric modes. End constraints and arbitrary radial pressure loading are modeled as essentially loading imperfections. Geometric imperfections are used to predict either first surface or full section plasticity, allowing buckling failure to be summarized in a form that is closely analogous to the Ayrton–Perry formula for the buckling of columns. It is suggested that a suitably simplified form of this general approach to axisymmetric buckling, when combined with buckling into nonaxisymmetric modes, could provide an important alternative to the current procedures for the buckling design of thin-walled, cylindrical, tanks and silos.

Manfred Bischoff (2008), 3-D analyses of shells comparing 3D- shell foundations, three-dimensional solid elements and surface oriented shell formulation were done. Comparison is made with theoretical formulation, finite element technology and consistency. Advantages and drawbacks of the different concepts are discussed. Distinguished the case of thin shells, were locking effect play a predominant role and the analysis of 3D structure. A dilemma appeared, it is impossible to design an element which is completely free of locking and passes the patch test at the same time.

Adem Dagungun et al (2009) Presented the silo damage and failures that occurred in different regions of the world. Failure of a silo result in loss of the container, contamination of the material it contains, cleanup, replacement costs, loss of material, environmental damage, and possible injury or loss of life. This paper provided a review and discussion of the common silo failures due to explosion and bursting, large and nonuniform soil pressure, corrosion of metal silos, deterioration of concrete silos due to silage acids, internal structural collapse, asymmetrical loads created during filling or discharging, and thermal ratcheting. Silo damage and failures due to earthquakes are also presented.

Eugeniusz Hotała et al (2014),conducted a series of experimental tests on ribbed cylindrical shell walls supported discretely showed clearly that short ribs connected by a transition ring are not able to provide the uniform distribution of meridional stresses in the cylindrical silo shell, supported discretely by columns, and silo shell can buckle in the zone placed over the short ribs. It has been demonstrated that the global resistance of the stiffened shells supported discretely is always much smaller from that in similar shells supported uniformly around the perimeter

Ramnatha Dash and Anand Raju (2012) studied the bucking behavior of compression loaded composite cylindrical shells wit reinforced cutouts by ANSYs. They consider composite loaded composite cylindrical circular shells for buckling analysis. The effect of cutouts and how their position influence the buckling strength of the shell were studied. The presence of cut outs can increase the deformation and stress concentration around it. Also critical loading can be increased by reinforcing the cutouts.

Hamdy H.A and Abdel-Rahim (2013) gave the description about the seismic load on silos and their effect on structure. They assed seismic response of the elevated wheat silo such as top displacement, normal forces, shearing forces and bending moments in silo support for earthquake records.

Yang Zhao et al (2013) analyzed buckling design of large steel silos subjected to wind pressure according to euro code. Load case WE (wind and empty silo) and WF (wind and full silo) was considered. The buckling deformation corresponding to the critical point in load case WE were governed by the circumferential compression which is generated in windward direction of the shell. The buckling mode in load case WF took the form of elephant-foot deformation at the bottom part of the shell wall.

Dhanya Rajendran et al (2014), compared lateral analysis of Reinforced Concrete and Steel Silo. Normal pressures and axial compressive loads due to stored materials together with the self-weight of the super structure were considered. Lateral loads due to wind or seismic forces are also considered. From the analysis it was observed that Reinforced Concrete is more useful than Steel silo in industries. Deformations at the middle portion of the Steel silo structure are found to be critical than the concrete silo.

P. Iwicki et al (2014) investigated the stability process in a silo composed of thin walled isotropic plain rolled sheets using a static and dynamic finite element analysis by taking both the geometric and material non-linearity into account during eccentric discharge. Silo shells were subjected to axisymmetric and non-axisymmetric loads imposed by a bulk solid following Eurocode 1. The differences between the results of static and dynamic analyses were comprehensively discussed. The advantages of a dynamic approach were outlined.

Mateusz Sondej et al (2015) studied stability of steel cylindrical silos composed of corrugated walls and vertical open sectional stringers. Comprehensive three-dimensional finite element analyses were carried out with perfect slender, semi-slender and squat silos by means of a linear buckling approach. Corrugated walls were simulated as an equivalent orthotropic shell and vertical open-sectional stringers as beam elements. The FE results were compared with the Eurocode approach. Comprehensive FE computations for axially compressed cylindrical shells composed of an orthotropic shell and stringers were carried out.

Marek Piekarczyk et al. (2015) presented the guidelines of the European standards on procedures for the calculation of shell structures. The analysis is illustrated with examples concerning three types of structures of the type i.e.: a chimney, a silo and a tank. The three design examples of special steel structures constructed from sheets with the cross-sections which are shells of revolution are presented. The wind load was calculated according to Eurocode in order that it provides the largest values for all the different standards. In all cases, the FEM as well as the algorithm described in standard were effectively used for the analysis of the stress state (effort) and displacements of the shells.

Eutiquio Gallegoa et al.(2015) did a comparison of the results obtained in several assays conducted using an experimental cylindrical silo with those calculated using a Finite Element Model (FEM)developed by using ANSYS software package. A mid-scale test silo was used to carry out the assays, which is equipped to measure the normal wall pressures and the friction forces. The numerical pressures predicted by the FEM are quite close of those experimentally obtained, both for filling and discharge. In addition, the mean vertical pressure obtained at transition is the same for both sets of results during the filling process. Numerical model predicts higher mean vertical pressures at transition than those experimentally measured. The FEM predicts higher peak pressures than the experimental ones measured, and at a location closer to the transition than the real position of the sensor placed in the hopper to detect this peak.

Jeroen Hillewaerea et al (2015) Investigated the case of wind-structure interaction using three-dimensional numerical simulations. One-way and two-way simulations are presented, for a single silo and for the silo group. In the one-way, the wind pressure is applied on the structure, disregarding the structural displacements in the wind flow simulation. Two way simulations also take into account the effect of the structural motion on the wind flow. For a single silo, one-way and two-way simulations yield similar results. Silo in the group, the ovalling vibrations are significantly larger in the two way simulations than in the one-way simulations. Aeroelastic effects and/or interactions between the wake-induced excitation and the vibration are present in the silo group for the investigated case. The aerodynamic loading and vibration amplitudes are considerably larger for silos in the group than for a single isolated silo.

John W. Carson (2015) studied the limits of silos design codes. Numerous codes and standards are used to calculate material-induced loads that are needed to design silos. The three most commonly used of such codes do not provide users with consistent information, and many common silo design conditions are not covered. He have done a brief description of each code and its limitations is provided, and common design conditions not covered by any code are identified.

M. Wójcik and J. Tejchma (2015) presented 3D results on stability of thin-walled cylindrical metal silos made from isotropic rolled plates containing bulk solids. The bulk solids behavior was described with a hypoplastic constitutive model. Non-linear FE analyses with both geometric and material non-linearity were performed with a perfect and an imperfect silo shell wherein 3 different initial geometric imperfections. The influence of a stored bulk solid during filling on the buckling strength of silos was compared with the strength of an empty silo and with the experimental results available in the literature. Numerical results indicate a clear strengthening effect of the stored solid on the silo buckling strength as in the experiments, depending upon the wall thickness, wall loading way and imperfection type and amplitude

Syamili V et al (2016), studied on the influence of thickness of shell on the buckling behavior of a typical steel silo under the influence of earthquake loads. . Effect of cutout in buckling was observed and it was clear that the variation of thickness around the cutout portion affects the buckling behavior of the shell structure.

Arne Jansseunea et al. (2016) Provided partial-height U-shaped longitudinal stiffener above each support. Such stiffeners allow for a more gradual load transfer to the supports, increasing the maximum failure load. The main aim was to map the influence of the dimensions of such longitudinal stiffeners on the failure behavior of thick-walled silos. The simulations indicate that for thick-walled silos, failure will always occur plastic yielding. The failure will be in the stiffened zone of the silo just above the supports for silos with stiffeners with a small cross-section. Silo stiffened with larger cross-sections, failure occurs in the unstiffened zone just above the terminations of the stiffeners. The stiffener height only has a positive impact on the failure load when failure occurs in the unstiffened silo wall.

Nicola Zaccari et al(2016) Studied buckling failure of the real silos used in a thermal power plant to store a granular solid material (limestone) is analysed. It has long been recognized that the buckling failure of the silos is due mainly to the eccentric discharge of its stored solid. The main reason for this kind of failure is due to the difficulty, in the design phase, to characterize the pressure distribution caused by eccentric solids flow (funnelling). The pressures caused by eccentric discharge are characterized using the new rules of the European Standard EN 1991-4 that defines the "Actions in Silos and Tanks". The paper exposed the structural behavior leading to buckling during eccentric discharge and proposes a possible reinforcement design of the silos to minimize this kind of problems.

Jozef Horabik et al. (2016) studied the influences of a filling method, seed size and seed aspect ratio on the radial distribution of the vertical pressure at the bottom of a shallow silo model. Central and circumferential filling methods were used. Horse bean, field pea, wheat, vetch and rapeseed seeds were used. The vertical pressure at the bottom was influenced by the filling methods and seed size. A significant dip in the vertical pressure near the centre of the silo radius was observed in each experimental case except the rapeseed case. Discrete element method (DEM) simulations confirmed the impact of the filling methods on the pressure distribution. The pressure increased with increasing radius for central filling and decreased with increasing radius for circumferential filling. Simulations of filling with higher particle kinetic energies showed greatest vertical pressures near the centre of the silo radius, and lowest values were located close to the silo centre and wall.

3. CONCLUSIONS

From the above literatures it is find out that, structural performance of silo depends a lot of factors which includes, material stored, wind structure interaction, type of supports, wall flexibility, staging height, stiffeners etc. The main problem is silos are, they are not much safe under different loading conditions due to lack of its strength and capacity to withstand the worst conditions. Hence design a silo which provides much safety and strength is a challenging task for the engineers. Buckling failure is the main failure occurring in silos due to eccentric discharge of materials.
It is important to know the silo response under various loading, and its failure patterns. Researches on the response study of silo under earthquakes are to be done. Studies on the stiffening of silos for reducing buckling are to be done.

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