1114008: FINITE ELEMENT ANALYSIS OF ROM SILO SUBJECTED TO 5000 TONS MONOTONIC LOADS AT AN ANONYMOUS MINE IN ZIMBABWE

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ABSTRACT

This paper introduces finite element analysis of Run off Mine (ROM) silo subjected to dynamic loading. The proposed procedure is based on the use of theoretical equations to come up with pressure and forces[1] exerted by Platinum Group Metals(PGMs) ore to the silo wall. Finite Element Analysis of the silo involves the use of CAD software (AutoCAD) for3D creation and CAE software (T-FLEX) for the simulationwork with an optimization routine to minimize the mass and also ensure structural stiffness and stability.In this research an efficient way to design and analysis of a silo in 3D T-FLEX (CAD) program was created the silo to stay within the constrains and so as to know the points of failure due dynamic loading.

Key words**:** reinforced concrete silo, Finite element analysis, T-FLEX software

NOMENCLATURE

D= silo diameter

H= silo height

K =Janssen ratio of horizontal pressure to vertical

Z= distance along the silo wall starting at the point of feeders

γ =bulk density

μ= coefficient of sliding friction between bulk solid and wall

∅ = wall friction

v= Poisson ratio

I.INTRODUCTION

A **silo** is a structure for storing bulk materials such as grain, coal, cement, black, woodchips, food products, sawdust and ore. Silos are widely used in agriculture, mining and manufacturing industries to store grain (maize and soya beans), fluids (oil and fuel), cement and platinum ores. There are three types of silos which are commonly used todaymainly tower silos, bunker silos, and bag silos. In this research project mainly focus on ROM Silos for storing PGMs from mining. Silos are used to store the ore temporally waiting to discharge it to the Semi AutogeneousMill (SAG) and there is need of constant supply.

Current designs are based on simplified interpretations of experimental observations in the light of very simple theories. It is widely recognized [1], however, it was found difficult to obtain reliable information from these experiments.Over the last two decades, a major effort in many countries has been put into developing computational models for the behavior of granular solids such as platinum ore (PGMs) in silos [3]

A. BACKGROUND

Many industrial, mining and farm silos, bins, and hoppers for storing powders, bulk solids, experience some degree of failure each year. These silos fail frequency is even much higher than that of almost any other industrial equipment; the failure is attributed to complete and catastrophic collapse of the structure. In other cases, failure involves only distortion or deformation[2]. The silo failure results in a loss of human life, downtime, and need for repair and structural failure is always costly as it is

September evening in 1996 in south-western USA, a 9000 ton silo collapsed after two weeks it was filled to full capacity and theobservation shows that

Figure 1: A 9 000ton silo split apart about two weeks after it was first filled to full capacity

Advanced FEA tools can be vital aided in the assessment of the safety and the serviceability of a proposed design. Safety and serviceability assessment of silo structures are necessary in the development of accurate and reliable methods andin modeling of the silo. In this case the researchers proposed the FEA under using T-FLEX software which is using cheap, easy and accuracy as compared with experimental primitive analysis methods. Moreover closely related to the increase in scale of modern structures arethe extent and impact of disaster in terms of human and economic loss in the event of structural failure and as a result, careful and detailed structural safety analysis[4].There is a need to do periodic checks on the silos and FEA modeling

unplanned in the financial budgets. The owner usually faces extreme expense of lost production and repairs; personnel in the vicinity are exposed to significant danger.The life span of a silo can be divided into three distinct phases: design, construction, and utilization. The phases are the numerous opportunities for errors that can result in structural failure. For example the failure of the fly ash silo in 2003and the majority of structural failures of bins and silos can be attributed to a combination of several deficiencies or errors [3].Moreover there are other factors such as temperature and moisture which also contribute to unusual loading condition and which will result in higher hoop stress.

therewas poor maintenance and overutilization the collapse structure is shown below in Figure 1

is needed so as to predict the life span of the silo to prevent unwanted incidents of silo failures.

B.AIM

To demonstrate the finite element analysis on the effect of 5000tonnes loads on reinforced concrete silo at the mine under study in Zimbabwe.

C.OBJECTIVES

1. To determine the stress subjected to silo and compare to desired threshold
2. To determine the stress factor of the silo and points of failure of the silo

D.SCOPE OF THE STUDY

To carry out the finite element analysis of finite element analysis of ROM silo at the mine so as to predict the life span of the silo.

E.JUSTIFICATION

It is very imperious to implement Finite Element methods in reinforced concrete silo to determine the accurate strength of the silo since these structures deal with human life. The civil engineer can predict the safety factor of the structure according to the load that can be sustained by the structure and able to determine the life span of silo before a failure has been developed. The analysis of creep, vibrational and heat transfer damage processes are more important in civil engineering practice due to the fact that they are the major causes of structure failure. The use of FEA analysis will explore the safety factor and warning before the silo failure to avoid accidents and loss of life.

F. DELIMITATIONS

All simulations shall assume that there was uniform concrete mixing during construction, symmetric ore loading and constant value of wind force. Moreover the simulation is only confined to the structure only and other contributing factors are assumed to be negligible.

II. LITERATURE REVIEW

A.INTRODUCTION

This section presents a review of existing knowledge of concrete structures and other types of silos, with special emphasis on the theories for buckling, stress analysis and silo failure that exist in the design criteria.

B.LOADS ON SILO WALLS FROM PGMs ORE: WALL PRESSURES

1.LOADS IN SILO AFTER INITIAL FILLING

Early designers of silos especially for the storage of bulk solids assumed that bulk materials behaved like liquids and therefore designed the silos which suites for fluid pressures. There were no frictional forces were considered and the weight of the ensiled material was assumed to rest entirely on the bottom of the silo. This created a bias in the calculation of the stress and strain subjected to the silo walls.

In 1882, Roberts made the first tests on models and full-size silos to determine the static horizontal and vertical pressures insilos due to a stored bulksolid[5]. The results of these tests show that the pressures attained a sustained maximum value at a depth of stored material equal were about twice the diameter of the silo(Roberts, 1884). These tests proved that the fluid theory earlier used in the study of silos were incorrect because some of the weight of the stored materials is transferred to the walls by friction, and the horizontal and vertical pressures in the solid are not equal.Janssen confirmed Roberts' conclusion and in 1895 published a theory that describes the pressures on the vertical walls of silos. In this simple theory, the pressures depend on the bulk density of solid, the silo radius, the depth below the effective surface, the coefficient of wall friction and the ratio of horizontal to vertical stress in the stored solid.

2.LOAD IN SILO DURING MATERIAL FLOW

In 1896 it was noticed that pressures during discharge may be larger than those after filling using Janssen equations of 1895 and have been used for the calculation of normal pressures, vertical pressures and frictional forces on the wall from which the values during flow can be estimated[4]. The design values of loads on the silo wall are thus obtained by using flow load multipliers or overpressure factors applied to the Janssen pressure using AC1313 code of 1977 and flow load multipliers were also derived from the minimum strain energy theory of [4] and [5].

III.THEORIES OF CIRCULAR SILO

A. INTRODUCTION

Thin walled circular shell is widely used as structural element so it is therefore necessary to clarify its elastic and plastic stability under various loading.

B. ELASTIC THEORIES

In 1933 Donnel developed equations for the analysis and development of elastic stability of circular silo shells and Timoshenko in 1940 took the consideration of the influence of axial displacement. Sanders came up with his idea of finite deformation in 1963. These three expects came up with theoretical solutions for many buckling problems and elastic stability.

1. ELASTIC BUCKLING

Variety of researches was conducted on the effect of initial imperfections on the buckling strength of cylinders under axial compression. Two methods have mainly been used. One was the directly analyses of the nonlinear post-buckling behavior of cylindrical shells with specified initial deflection and the other was to apply an asymptotic analysis based upon the general theory of the initial post-buckling behavior as developed by [4].

2. PLASTIC COLLAPSE

The foundations of the theory of plasticity were laid by Tresca in 1898 and von Misses in 1913 and made it easier to come up with the plastic deformations of 3D shapes such as silo. More work was done by

Drucker in1954 where he come up with two theorems the upper boundary (kinematic) and lower boundary (static).

3.STRUCTURAL DESIGN OF CONCRETE SILOS (ANONYMOUS MINE ZIMBABWE)

The figure 2 shows the plan of the Mine ROM silo and its basic measurements needed by the researchers to carry out finite Element Analysis.

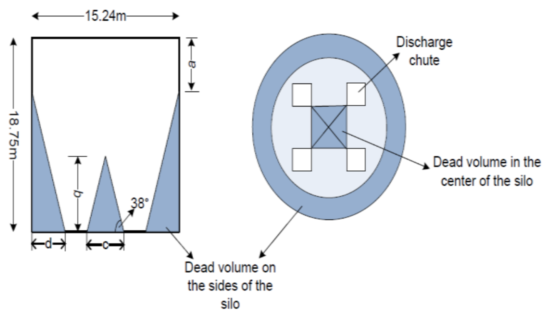

Figure2 shows the plan of the mine silo under study

The silo dimension and construction details calculation are shown as Appendix A

Figure 3 showing mine silo under construction in 2007

The other specifications are shown at the appendix and are used in the calculations.

4. COMPUTER PROGRAMS USED IN SILO ANALYSIS

A variety of computer programs where applied to try and analyze silo geometry, in 1989 Rotter managed analyze stress, buckling and collapse analysis of axisymmetric shells storage structures like silos and tanks usingFELASH (Finite Element analysis for Axisymmetric Shells).The program was able to automatically generate my loading conditions pertinent to silo structures such as wind loading, loadings from stored bulk solids, eccentric discharge and local discrete supports[5]. However Hibbitt and Karlsson in 1992 came up with the development of ABAQUS, which has a greater variety of geometry modeling, kinematics, material modeling, boundary and loading conditions, and analyze. In this research the researcher intend to use the recent computer FEA programs such as T-Flex and Autodesk inventor.

IV. METHODOLOGY

A. INTRODUCTION

This section gives a clear concise description of how the study was carried out. It highlights the research design, data collection tools, sample selection, research instruments and data presentation and analysis procedures that have been used.

B.FINITE ELEMENT METHODS

Finite element method represent discrete element that represent potential energy of the silo and the silo is broken into discrete of finite regions and each individual represent potential energy (preprocessing). The nodal displacement of different elements at common nodes is given displacement. The resulting potential energy expression for the assembled discrete system will form a set of algebraic equations which are reduced to the differential equation of the silo system. The error analysis procedures presented in next chapter of data analysis and are designed to evaluate how well the variation solution produced by the finite element method satisfies the differential equations of equilibrium and the boundary conditions forthe silo (post processing). For the researcher to achieve the objectives using T-Flex the following steps are to be followed

1. build three-dimensional model of the silo
2. Create a study of the silo
3. define more the material used in the construction of silo
4. generate finite element mesh of the silo
5. apply boundary conditions reflecting the essence of the physical phenomenon being analyzed
6. running calculations (simulations)
7. analysis of results

C. PARAMETRIC SILO STUDIES

These are the parameters that are to be used by the researcher to come up with the forces and pressure that are subjected by the PGMs onto the silo walls.

D. VARIATION WITH THICKNESS

The researcher will examine the effect of wall thickness by varying the thickness and other geometric parameters will remain constant .the observations obtained are shown in the next chapter which can provide misleading results.

E. NUMBER OF SUPPORT

The researcher has a closed look on the variation of the buckling strength with the number of the supports. Where the cylindrical shell is supported on a small number of columns of practical width, the buckling strength, as characterized here, is almost constant regardless of the number of supports[3].

F. CONCLUSION

Nonlinear analyses of the discrete supported elastic cylinders were already performed by Rotter in 1993, were finite element method was and perfect and imperfect cylinders of a constant height-to-radius ratio were studied. In this project so the researcher focus on analysis of geometric parameters and buckling using T-Flex CAD software since these parameters are the major causes of silo failure's. T-FLEX 12 student addition did not give the researcher the room to carry out buckling and Von misses stress since it was not registered.

V. DESIGN OF A SOFTWARE SYSTEM SIMULATION OF REINFORCED CONCRETE SILO

Numerical conventional methods based on parametric studies of reinforced concrete silo give strength of the silo just after construction. For further analysis such as buckling, non-symmetric pressure, dynamicloading and crack pattern using FEAsoftware T-FLEX accurate results are obtained.

The results predicted by T-FLEX based on buckling and dynamic loading includes the wall pressure and discharged pressures which results in loss of strength of the silo. Pressure and pressure analysis in silo is an important aspect in Zimbabwe because the failure of silo results in loss of life and production. The failure of silo demand high reconstruction cost and thus cause economic backward as mining is the back bone of Zimbabwe economy. The aim of the study is to have an overview of the weakest points and the points where buckling can develop. The structure of the silo is shown in Figure and the in Figure shows the steps followed during software system development and simulation results using T-FLEX CAD.

A. STRUCTURE OF SILO TO BE ANALYSED

The section shows simulation results of stress, strain and bucking

Analyzed file:

T-FLEX CAD Student Version: 2014

Creation Date: 01/05/2014, 12:45PM

Simulation Author: KELVIN TENGENDE

Advance settings

Avg. Element Size:

Min. Element Size:

Grading Factor:

Max. Turn Angle:

Mass properties of silo

Mass: 1820.39

Volume: 1820.39

Bounding box: X: 258.50 -- 273.75

Y: 172.80 -- 188.05

Z: 0.00 -- 22.96

Centroid: X: 266.12

Y: 180.42

Z: 11.84

Moments of inertia: X: 59627341.12

Y: 129295924.61

Z: 188260851.70

Products of inertia: XY: 87404089.86

YZ: 3887477.77

ZX: 5733888.89

Radii of gyration: X: 180.98

Y: 266.51

Z: 321.59

1. PRINCIPAL MOMENTS AND X-Y-Z DIRECTIONS ABOUT CENTROID:

I: 115933.00 along [1.00 0.00 0.00]

J: 118526.90 along [0.00 1.00 0.00]

K: 82080.15 along [0.00 0.00 1.00]

2. MATERIALS

Name: SSRC (stainless steel Reinforced Concrete)

Mass density: 2.4 g/cm^3

Yield strength 49.6 MPa

General Ultimate Tensile Strength:

Young Modulus 20.8GPa

Poisson Ratio: 0.2

Shear Modulus:4.23387 GPa

Expansion Coefficient:0.05 ul/c

Thermal conductivity:0.3 W/ (mK)

3. OPERATION CONDITIONS

Air pressure due to wind: 1.77kPa

Force: 5000 tones and fixed constrain

B. RESULTS SUMMARY

Equivalent stress min: 481.9Pa

Max: 15981.56Pa

Displacement- Fig 2

Safety factor-Fig 3

Equivalent stress-Fig 4

VI. CONCLUSION

In conclusion the main objective of this project was achieved with the solution analysis of force and pressure exerted by ore in a silo. The other objective was of buckling was not achieved due to the limitations of T-FLEX CAD student edition. The major areas that are affected by dynamic loading were seen and identified during the simulation. Static pressure and wall pressure at the end loading were studied. More research is then needed for the analysis of the foundation so as to prevent mass flow.

VII. REFERENCES

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VIII. LIST OF APPENDICES

APPENDIX A

Silo dimensions

A = 5m

B =3.22

C = 4.4m

D =2.28m

Angle of repose is 38°

PGMs bulk density 1.8t/m^3

Silo calculations

Volume of pyramid $^1/_3$ b × h

= 2× ($^1/_2$×3.22×5.75×2.28) m^3

= 19.228m^3

Tonnage in the pyramid dead ore

Bulk density× pyramid volume

= 1.8×19.225

=34.61t

APPENDIX B

parameter	values
Density (kg/m^3)	1800
Young modulus	168GPa
Poisson ratio	0.3
Wall friction coefficient , α	0.45
Angle of repose	35°
Silo diameter	15.24m
Silo height z	22m

Related calculations

Discharge pressure of silo equation $P_h = \frac{\sigma \times R}{Tan\alpha}$ done by (Pieper and Ravent tests) = 15240 Pa

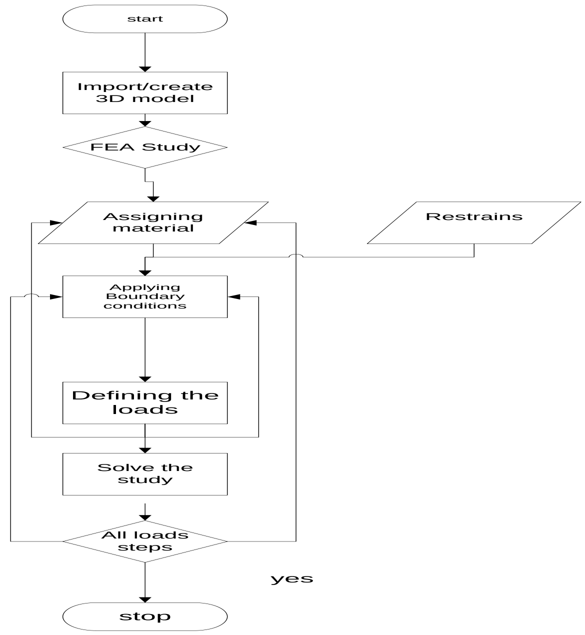
Vertical and horizontal pressure relationship $\frac{P_h}{P_v} = \frac{1-\sin\emptyset}{1+\sin\emptyset}$ therefore P_v is 56238.22Pa

Wall pressure (Janssen, 1895)

$$P = \frac{\gamma W}{2\mu}\left(1 - e^{-\frac{2\mu k\,(H_o - z)}{W}}\right) = 3261.73\ \text{Pa}$$

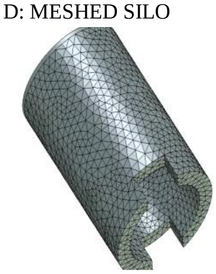
Force exerted by PGMs = 5000000×9.81 = 49050000N

APPENDIX C: FLOW CHART

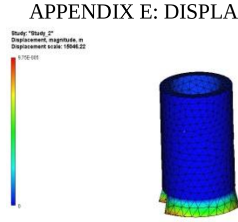


APPENDIX C: SILO 3D

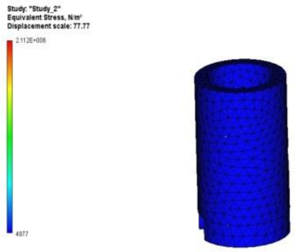
APPENDIX D: MESHED SILO



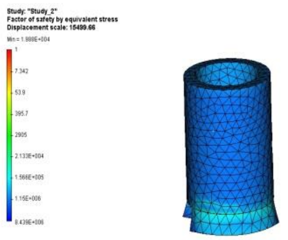
APPENDIX E: DISPLACEMENT MAGNITUDE RESULTS



APPENDIX F: EQUIVALENT STRESS RESULTS



APPENDIX G: SAFETY FACTOR RESULTS



APPENDIX H: EFFECTS ON THE SILO WALLS