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Seismic Analysis of RC Silos Dynamic Discharge Phenomena

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Abstract:- This paper presents the characteristics of the flow pattern and wall pressures observed during filling and emptying of cylindrical silo during gravity discharge. The paper presents recent and current researches on these phenomena. The dynamic discharge phenomenon is influenced by various factors related to the type of flow pattern developed in the silos and the flow properties of the bulk material of particular, and the velocity at critical sections in the silo during discharge. Moreover, In order to ensure the accuracy for modified finite element model that is presented in paper; it is verified with other's experimental results. Under different three types of earthquake ground excitations; Al-Aqba, 1995, Northridge, 1994, and El-Centro, 1940; the paper is dissected the silo discharge phenomenon; which has a stress peak during the dynamic discharge of the silo. Caused by that fact, the modeling of silo should be taken this phenomena effect in the simulation. Especially, this phenomenon has great effect on the silo mass distribution which reflects on the flow of granular material during filling and discharge. In order to ensure the presented finite element results; it is investigated for a real case study, Silo of Royal El-Menia Factory in Upper Egypt to be checked a model results with ACI 313-97 provision results to evaluate and comment on results.

Index Terms: Silo, Seismic analysis, Dynamic discharge phenomena

I. INTRODUCTION

Worldwide the estimation of the relevant pressures on a silo structure due to bulk materials is still based on the well-known analytical model of Janssen [1]. This silo model in Fig.1 can only be used for bins with symmetric cross-sections and material at rest. In practice a lot of silos are built with eccentric outlets and inlets respectively or non-circular cross-sections. The relevant non-symmetric dynamic discharge pressure, which can be several times greater than the filling one, cannot be estimated with this simple model. To overcome this problem the wall loads due to Janssen are increased by more or less empirical overpressure coefficients. This practical approach is unsatisfactory and can lead to an uneconomical or in some cases to an unsafe design, as the high failure rate in silos demonstrates [2]. Great effort has been made to improve the knowledge about the flow of granular material in silos. Nevertheless, many important aspects such as wall pressures, to which silo structures are subjected, still appear uncertain. Numerical simulations based on the finite element method have become a valuable tool to simulate the behavior of granular material in silos during at rest conditions and during flow and to estimate the actions the structure has to be designed.

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Silo loads resulting from the flow of the granular media stored in them, still are a great challenge due to their complex behavior and adequate formulation. Besides the simulations performed with the aid of discrete elements, the use of the Finite Element method is well established. Especially for the simulation of active and passive stress states within the bulk, simulations by [2] are known. This called switch phenomena, which is the subject here, is a stress peak resulting from the active and passive stress states within a silo. This phenomenon occurs both for mass and semi-mass flow silos as shown in Fig.2. While the stress state in the silo is purely active after the filling process, a stress peak called "switch" shown in Fig.3 is assumed to occur during the dynamic discharge.

In Fig. 3, the cause for this peak is the wedge shown in black, which is acting on the passive reacting bulk within the conical part of the hopper. For mass flow silos, the stress peak is supposed to remain at the junction, while for semi mass flow silos it is believed to move further upward. The uncertainty of its magnitude and distribution is also reflected in the different handling in the international codes. As an example, the patch pressures according to DIN 1055 part 6 [3], Euro Code (EC) 1 part 4 [4]; While the German and the EC1 code recommend "switch" patch pressures only for mass flow silos at the junction of the vertical and inclined wall, the Australian guidelines also include a force varying in height for the cylindrical part of the silo corresponding to the pressures occurring in semi-mass flow situations, [5].

From the mentioned before it can be clearly seen that more accurate methods to determine the relevant loads due to bulk materials are urgently needed. A numerical simulation seems to be an appropriate method to get a better understanding of granular flow and the relevant phenomena. Experiments are very time consuming, difficult to conduct and only the reaction and not the behavior of the bulk material within the bin can be studied.

Finite Element simulations of granular flow in silos based on a continuum approach are becoming more and more popular due to the increasing computer power and the capacity of the available program in the last decades. Nevertheless it must be recognized, that the simulation of granular flow in silos is still a demanding task. Some aspects will be discussed in the following.

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$$A\frac{\partial P_V}{\partial z} + P_W.U.dz - \rho.g.A = 0.0$$

$$P_V = \frac{\gamma.A}{K_s.\mu.U}.\left[1 - e^{-\frac{\mu.K_s.U}{A}.Z}\right]$$

$$P_W = \mu.P_h \qquad P_h = K_s.P_V$$

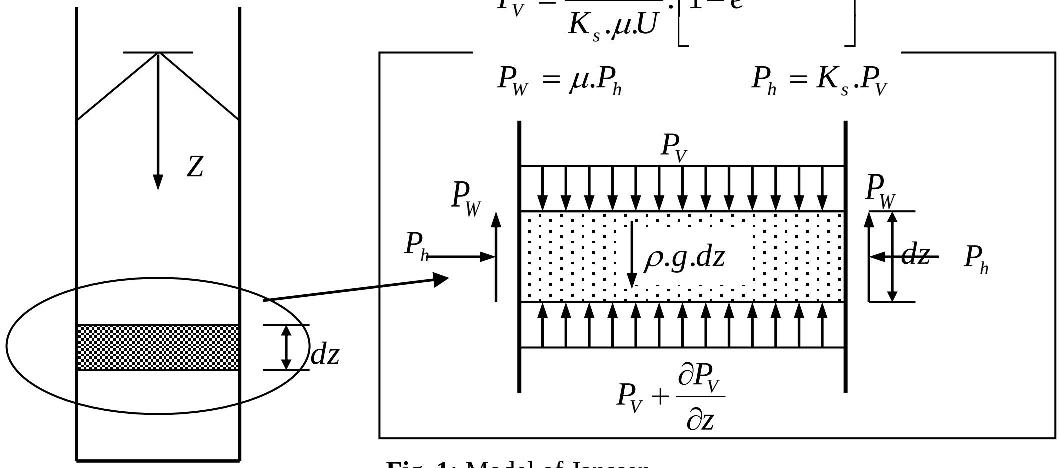
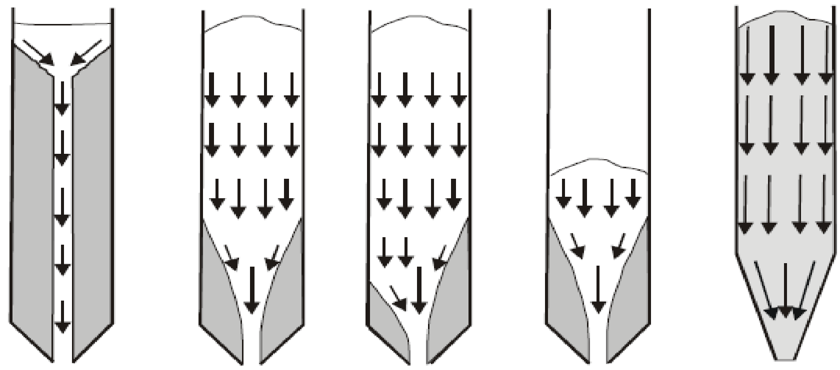


Fig. 1: Model of Janssen



Funnel flow Semi mass flow mass flow

Fig. 2: Flow profiles according to DIN 1055 part 6.

Filling State Begin of the emptying Station emptying situation

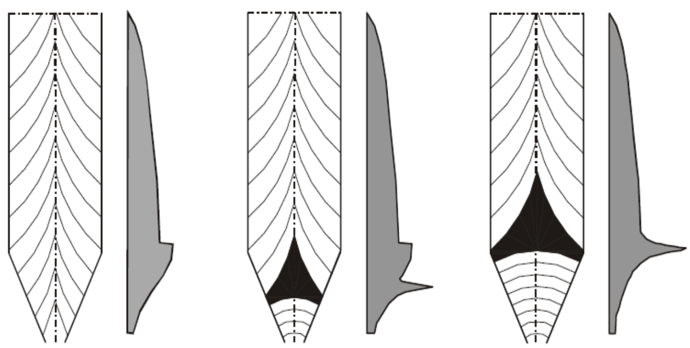


Fig. 3: Qualitative stress trajectories and wall pressures for mass flow structures [Thorsten W.R. Keiter, Guenter A. Rombach (2002)]

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II. CASE STUDY

The principle objective of modeling and analysis tools is to obtain the silo wall stress pressure values during filling and emptying under gravity discharge and earthquake excitation. Where, the discharge phenomena of granular material is defined as live load case as it was cleared in ACI 313-97 [6] definition of live load; so it will be controlled designed stress case; especially, the dynamic phenomena is affected all time of silo working stage in filling and emptying.

In Upper Egypt, The silo that was constructed in the Royal El-Menia factory at 2007 has a capacity of 900 ton. That silo is presented in the paper as a case study for real reinforcement concrete silo. Fig. 4a, b shows the elevation and plan cross section of the silo, respectively. The main concrete dimension, wall thickness, silo shaft inner and outer diameters, and levels are clarified in Fig. 4a, b.

The granular material is simulated in finite element model taking in consider the natural material properties in simulation according to case study. Table 1 contains on the natural and mechanical properties of filling silo material.

The modified finite element model of the silo body will be taken in consider the contact relationship between internal materials to the inner surface of silo body is presented, and the performance of motion through the filling and emptying stages of silo contents. The simulation element that used in modeling will be discussed deeply in the next finite element modeling stage.

Table 1: Material parameters for wheat in FE simulation.

Material Parameter	Value
Effective angle of internal Friction of bulk material, Φi	33.0°
Modulus of elasticity, E (kPa)	4838
Poisson's ratio	0.31
Wall friction coefficient, μ	0.25
Weight density, γ (kN/m3)	8.5
Eccentricity of outlet	0.0

The Finite Element method is a suitable technique to analyze the structural behavior of silos with arbitrary shape. The interaction between the silo wall and the bulk solid is considered as well as the nonlinear behavior of the bulk material itself. As will be shown later, the material law and the interaction criteria has to be chosen with great care, as both have a great influence on the results of the simulations. The following important aspects have to be considered when using a Finite Element Program to simulate granular flow:

A. Contact simulation

In the present study, the silo wall is considered to be made of pre-stressed concrete. Wheat is used as bulk material stored in the bin. As it can be clearly understood, the behavior and properties of both materials are completely different. Hence, it is very important to select an adequate contact model in order to get accurate results. In the FE-analyses the walls have been considered as rigid in order to simplify the Finite Element model. ANSYS [7] uses a surface-to-surface contact model, where both the target surface and the contact surface have to be specified. The former one is supposed to be the rigid surface meanwhile the latter one is the deformable surface.

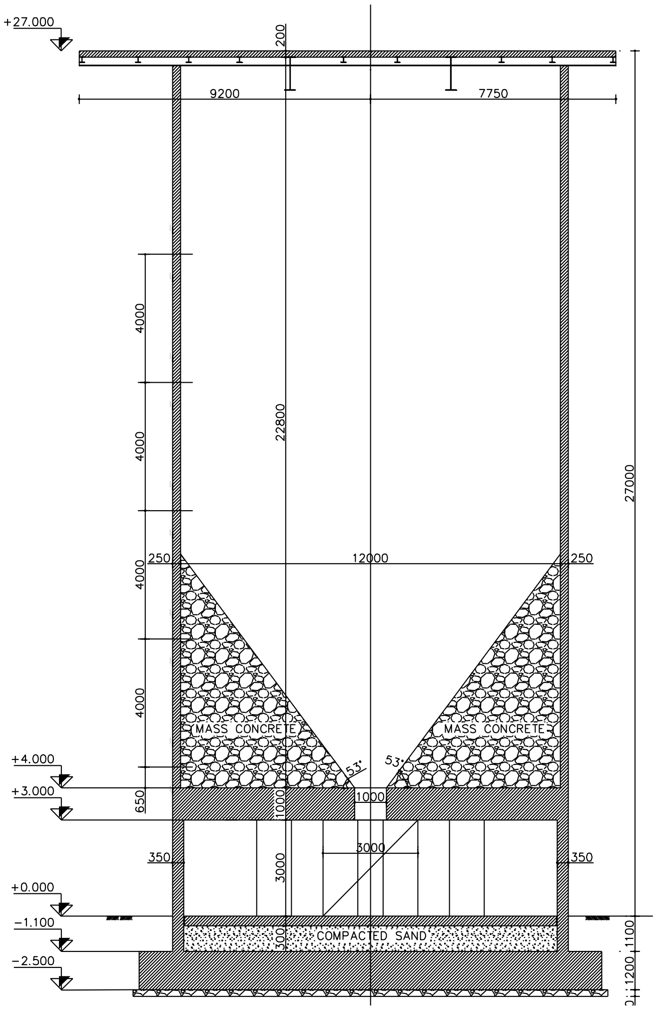

Fig. 4a: Elevation cross section of silo.

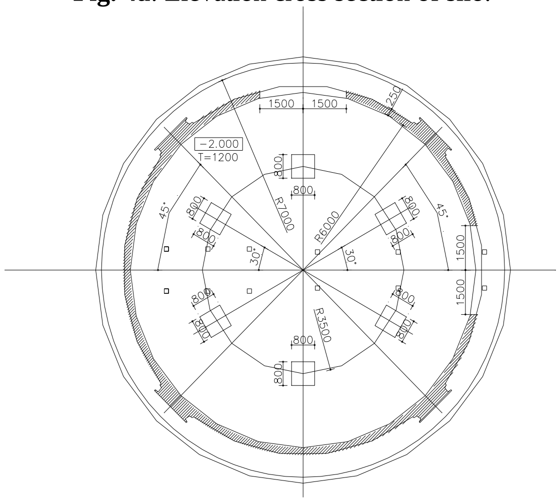

Fig. 4b: Plan cross section of silo.

Hence, the target surface is defined as the silo wall and the contact surface is represented by the boundary surface of the bulk material in this analysis.

In ANSYS Ver.10.0 [7], one of the most important factors to create a contact model is the contact stiffness factor (FKN), whose value controls the stiffness of the contact element and the amount of artificial penetration in the wall.

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As in this study the walls are considered to be rigid, this value should be as high as possible to avoid any kind of penetration. The reference [8] showed in some geometries that when FKN is lower that a specific value, the wall normal pressures are overestimated in the hopper meanwhile they are underestimated in the bin.

The well-known Coulomb's friction model Equation (1) is used to describe the interaction between the walls and the granular media.

$$\tau = \mu p + c \qquad (1)$$

Where:

τ = equivalent shear stress; μ= wall friction coefficient;

p = wall normal pressure; and c = cohesion sliding resistance.

The wall friction coefficient is the only parameter needed for this model. It can be obtained by simple shear tests.

B. Material model

It is obvious that the reliability of any FE-analysis depends on the assumptions and simplifications of the numerical and mechanical model. Here the constitutive model for the bulk material is of greatest importance.

Granular materials are usually path - and rate dependent. Thus the history of the load process has to be known to determine the stress state of the material, because there is no unique correlation between strains and stresses. The material exhibits a different response that depends on the load rate when stresses become greater than the elastic limit.

Because of this complexity, many mathematical models have been developed to simulate the behavior of granular media. First, many elastoplastic formulations were published. A very extensive description of this type of material model can be found in [9]. In this study the Drucker-Prager elastoplastic criteria has been used in ANSYS. The elastic part has the common linear approach. Hence, the modulus of elasticity and the Poisson's ratio are the required parameters Table 1. On the other hand, the Drucker-Prager perfect plastic criterion has been considered. In this case, the cohesion and the angle of internal friction are needed. In addition, ANSYS gives the possibility of taking into account non-associative flow rules and, therefore, the angle of dilatancy of bulk material is the third parameter required by this program. The material parameters for the model are given in [10]

C. Filling procedure

The silo has to be filled numerically layer by layer. This is of great importance in case of bins with inclined walls [5].

D. Dynamic analysis of granular flow

Usually the greatest pressures in silos don't occur during at rest conditions but during emptying of the bin. Therefore one must model the discharge phase. This requires a dynamic mechanical model and code.

E. Boundary conditions

The interaction between the granular media and the silo structure has to be modeled. Interface elements and accurate material models (e.g. friction) are required.

F. Numerical algorithms

The numerical algorithms must be fast and robust. Correct convergence criteria must be defined. The stresses in the granular media stored in bins are significantly dependent on the interaction between the bulk material and the silo walls. Several interface algorithms like e.g. point to surface elements, spring elements, and contact elements had been studied. The often used point to surface elements has caused great numerical problems. It should be noted that the bulk material is always in contact with the silo walls. Fortunately a linear friction model (Mohr-Coulomb) is sufficient enough in most relevant cases.

Simulations of the discharge processes are extremely time consuming. The size of the element mesh and the analyzed discharge time are mostly limited by the time for the computation. Most effort is required for solving the linearized global equilibrium equations. Various solvers based on the Gauss algorithms or iterative procedures had been tested.

For this reason it was decided to develop a global three-dimensional model using the F.E.M. which would permit the study of stress and behavior in static mode silos. The type of elements used and characteristics of the model will be described in broad terms.

The following basic elements operate in all parts of the silo:

-Stored granular material

-Silo wall, supporting the above

-Friction between stored materials and silo wall.

In order for the model to reflect reality as closely as possible these three elements must be included in the simulation, with the appropriate properties and characteristics. First, those elements which most closely replicate the stored grain, the silo wall, and the friction, must be chosen, and these are:

The three dimensional isotropic element Fluent6.3, selected from the ANSYS program element library to represent the stored grain. This type element is appropriate for simulating flow three-dimensional masses, permitting the incorporation of elastic or elastic-plastic behavior as, for example, Drucker-Prager, frequently used for the simulation of granular materials. It has been used on numerous occasions previously [11] and has been shown to display behavior appropriate to the type of model desired. In this case plastic behavior was chosen for stored material.

2. For the silo wall, a membrane element representing the thin wall was required. The element chosen was SHELL43, a membrane element suitable for the simulation of thin shell structures, which permits the incorporation of elastic or plastic-elastic behavior, as well as the possibility of varying membrane thickness according to the requirements of the simulation. In this case, elastic wall behavior was selected.

3. Friction between the two is generated by a contact pair. A contact pair is defined by two surfaces; one in contact with the silo wall, which corresponds to the inner surface of the shell in contact with the grain (target surface); and the other which limits the volume of the grain, that is, the exterior surface of the stored material (contact surface). For the target surface an element called TARGE170 was used, whilst the element called CONTA173 was used to simulate the contact surface, as shown in Fig.5. Surface-surface and flexible-flexible was the type of contact selected, which permits deformation both of the stored grain and of the simulated silo wall.

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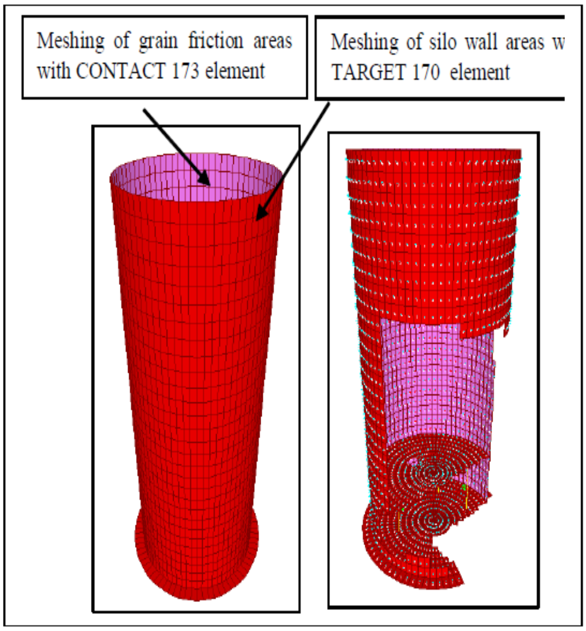

Fig. (5): Three dimensions modeling view.

Once the various elements have been selected, they must be assigned the appropriate characteristics, in order for the simulation to be as realistic as possible. The properties introduced vary according to the type of element chosen. Thus, a specific thickness must be introduced for the membrane element, whereas the property of thickness would have no sense if applied to solid stored material, so that the parameter solid does not include this property. Once the properties for each element have been introduced, meshing can begin, that is, the division of the different parts which constitute each element (Fluent6.3, shell, contact or target). As has been mentioned previously, it is one of the objective of this paper to give an in-depth analysis of the model created, thus it will merely be commented that a regular meshing of 0.5m in the upper two thirds of the structure, and 0.25m in the lower third was found to be the most suitable for this type of simulations.

Lastly, the loads and pressures can be incorporated into the model. The main load is basically the weight of the stored material (for the specific weight under consideration, the model silo has a capacity for over 2000 tons, although silo wall weight is also introduced, as well as a load of over 0.16 kN/m uniformly distributed at the edge, with the intention of stimulating structure buckling), which represents the weight of a lightweight covering structure.

III. Experimental Work Study on the Discharge Effect on the Wall Pressure

As reported in the experimental studies by [12], quaking is known to occur in tall mass-flow silos in which the height of a critical height Hcr where Hcr ≈ D, as depicted in Fig. 6.

Fig. 6 shows a test silo 1.2 m diameter 3.5 m high and fitted with a stainless steel hopper. Load cells which measure normal and shear stress simultaneously are fitted into the silo walls; fourteen load cells were fixed on the silo body as it cleared in Fig. 6. Above the height Hcr, plug-type flow occurs with the velocity profile substantially uniform across the cross-section. Below the critical level, in the region of the transition, the flow starts to converge due to the influence of

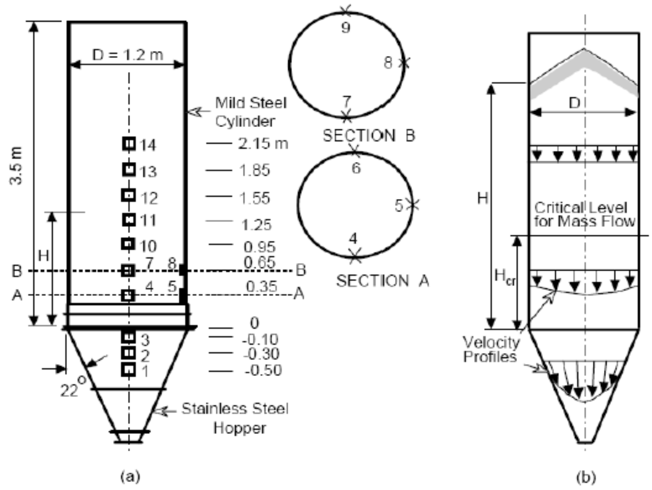

Fig.6: Mass-Flow test bin (a) test bin showing load cell locations; Velocity profiles,[5].

the hopper and the velocity profile is no longer uniform, as it was cleared in Fig. 6.

To verify the accuracy and computational efficiency of the new modified FEM modeling that was explained in previous section, the [12], steel silo was modeled by the same philosophy of the new modified model that is presented in this paper to compare the experimental measured and FEM results; absolute peak normal and shear stress on silo wall are Summarized in Table 2. To get a clear vision of the response of FEM compared to experimental results, the error ratio, [R] was calculated as following:

R= (FEM results- Experimental results)/ (Experimental results).

It should be mentioned that the error ratio R not exceed than 10 % compared to the experimental results.

There is a very good matching between the results. The good matching presented in this section at different levels of sections over the silo wall to confirm the capability of computer code ANSYS and also the new FEM modeling to predict the stress value over the silo wall during filling and emptying cases under the gravitational force.

As it is clarify, from the comparison between the experimental results and the results of the modification FEM, which is presented in this paper; it can be clearly understood, the behavior and properties of both materials is completely different. Hence, it is very important to select an adequate contact model in order to get accurate results. In the FE-analyses the walls have been considered as rigid in order to simplify the Finite Element model and experimental results.

ANSYS uses a surface-to-surface contact model, where both the target surface and the contact surface have to be specified. The former one is supposed to be the rigid surface meanwhile the latter one is the deformable surface. Hence, the target surface is defined as the silo wall and the contact surface is represented by the boundary surface of the bulk solid in this analysis; that is given a way to simulate the relation between the bulk material surface and the silo wall.

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Table 2: The Verification comparison between the Experimental and predicted FEM results

Height of silo wall above the adjacent zone	Experimental results(Roberts and Wensrich, 2002)		FEM results		R% Error ratio	
	Normal stress *P*, (kN/m^2)	Shear stress *V*, (kN/m^2)	Normal stress *P*, (kN/m^2)	Shear stress *V*, (kN/m^2)	Normal stress *P*	Shear stress *V*
0	0.10	0.37	0.110	0.368	10	0.54
0.35	0.20	0.5	0.197	0.489	-1.5	-2.2
0.65	0.25	0.55	0.254	0.58	1.6	5.5
0.95	0.28	0.9	0.283	0.92	1.1	2.2
1.6	0.35	1.2	0.358	1.25	2.3	4.2
1.85	0.41	1.4	0.402	1.45	2	3.6
2.2	0.6	1.9	0.611	1.93	1.8	1.6
2.5	0.75	2.0	0.763	2.13	1.7	6.5

IV. STATIC AND SEISMIC ANALYSIS OF ROYAL EL-MENIA SILO

In this stage, after verification of the FEM technique that is developed to simulate the relation between silo body and bulk material; that is explained deeply and verified in previous stage.

The numerical analysis and comment in the actual case study of Royal El-Menia silo in Upper Egypt will be presented and discussed. The numerical analysis is investigated under two different types of loadings; first type, static case; where the bulk material flow is filling and emptying under the gravitational force with different flow outlet discharge.

Second type, earthquake analysis where the bulk material flow in filling and emptying is exposed to three real earthquake excitations, namely the El-Centro 1940, Northridge, 1994, and Al-Aqba, 1995 (Egyptian earthquake excitation). These earthquake components are applied in two orthogonal directions, the maximum absolute silo wall stress will be the target value, especially, and the case study of silo is symmetry in both directions.

Northridge, 1994, and El-Centro, 19404 are classified as severe and moderate ground excitation, respectively. Also, they are typical for hard sites and extensively used in past by many researchers. Al-Aqba, 1995 is the famous Egyptian earthquake ground excitation with available complete time history; it is classified as a weak type. Fig 7 shows the time history of the three earthquakes in the longitudinal and transversal directions, respectively.

A. Static Analysis for the Initial Filling and Dynamic Discharge State

The peak values for the wall shear stress of Royal El-Menia silo that mentioned before are plotted in Fig. 8. From this figure, the shear stress of silo wall is presented over the silo wall height under static load at rest case, and emptying static discharge with different outlet flow 100 mm/sec, 200 mm/sec, and 300 mm/sec, respectively with no eccentric out let of silo.

The trend of silo wall shear stress distribution at rest state under static analysis is presented in Fig. 8. The shear stress has linear directly proportional increasing stress with depth of silo, where the bulk material has increased pressure; this trend is cleared for the above level of silo hopper at the transition point for hopper silo wall the shear stress has amplification with rate reach to 35% compared to its above shear stress of silo hopper. This can be explained by the change of the bulk material velocity that will be cleared in the case of the discharge with different discharge out flow rate. Where at the hopper the velocity of bulk material is increased. On other side, the inclined angle of hopper is affected on its velocity of bulk material which is reflected directly on the stress distribution in that critical zone; that is cleared in Fig. 2.

Discharge simulations are usually faster than discharging processes in reality to save computation time. The evolution of the material velocities depends on various parameters of the constitutive models for the bulk material. Whether the time factor has some influence or not, should be part of the further investigations.

During the discharge case of bulk material the velocity of material has increased on the hopper zone due to the inclined silo wall. Also, the velocity of material depends on many parameters like the inclined angle for the hopper beside the outlet flow discharge that was controlled by the outlet discharge rate.

B. Dynamic Discharge State

Silos and stacking tubes shall be designed to resist all applicable loads, including:

a- Dead load: weight of the structure and attached items including equipment dead load supported by structure.

b- Live load: forces from stored material (including over pressure and under pressures from flow); that referred to all flow phenomena that may effect on the silo pressure. Floor and roof live loads, snow, equipment loads, positive and negative air pressure, either wind or seismic load (which ever controls), finally the weight and pressures due to stored material (for static and discharge phenomena) shall be considered as live load, (ACI 313-97) [7].

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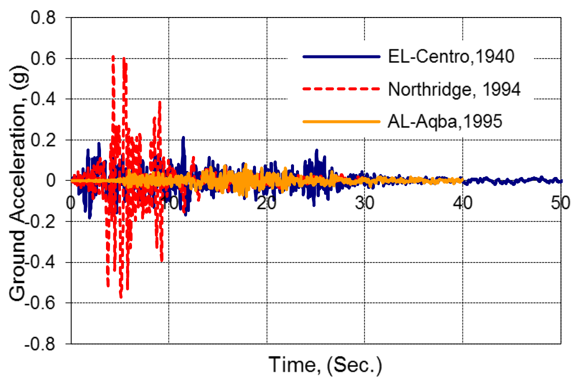

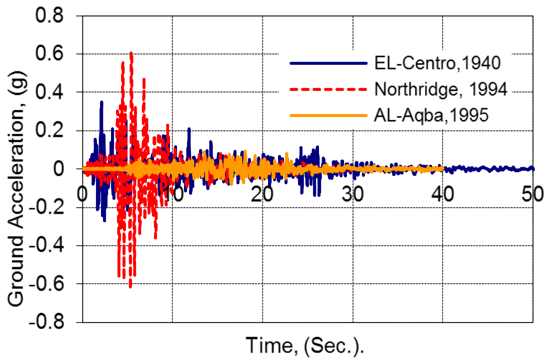

Fig.7: Accelerogam from El-Centro, 1940, Northridge, 1994, and Al-Aqba, 1995 earthquakes in orthogonal direction, respectively

The results of absolute maximum normal (P), and shear stress (V) on silo wall in different section levels are presented in Table 3. The sections are appeared in the silo elevation at the top, the middle of silo wall above the transition section and the out let level to have a clear decision for the stresses distribution all over the silo wall. The table presents the stresses once under static analysis and the other under real earthquake ground excitations; Northridge, 1994, El-Centro, 1940, and Egyptian earthquake Al-Aqba, 1995.

Table 3, presents the peak shear and normal wall stress at different sections levels on the silo wall under variable types of earthquakes excitation Northridge, 1994, El-centro, 1940, and the Egyptian earthquake Al-Aqba, 1995. In discharge state under earthquake analysis, the fluctuation of the bulk material has a great effect that is reflected on the velocity of material at outlet flow; this is the main reason that explains the amplification rate of the stress on silo wall; Especially, at the hopper and transition point where already the material velocity is increased and fluctuated due to discharge rate.

It was found that during discharge two different kinds of fluctuations occur. The slower fluctuations are caused by shear bands which develop at the transition from shaft to hopper. The momentary fluctuations are due to the fact that ''steady state'' flow in the hopper is not ''steady state'' at the microscopic scale, where the fluctuations are severe. Earthquake loading has a clear role to that amplification for the bulk material velocity especially at the transition zone.

For the earthquake analysis case of filling state; as it is cleared in Table 3, the shear wall pressure has the same trend as in static case with amplification value increased by 10%, 25%,and 37% due to Al-Aqba,1995, el-Centro,1940, and Northridge,1994, respectively; compared to the ambient vibration case. On other side the stress in the transient point between the hopper and the vertical silo wall has great significant increasing in shear and normal stress reached to 20% to 15%, respectively under al-Aqba, 1995 ground excitation. That increasing rate in stress under earthquake ground excitations Northridge,1994, El-Centro,1940, and Al-Aqba,1995 may be backed to the fluctuation of bulk material on the hopper that play to amplification the its velocity by rate reach to 25%, 15%, and 10% , respectively; compared to the static analysis.

It should be emphasized that the results presented here should be taken with caution until a more detailed study in conducted taking were propagation through different silos height and shape into consideration.

V. Comparison of Predicted FEM, and ACI 313-97 Provision

ACI 313-97pressure and loads for silo wall divided to two stage.

A. *Pressure due to initial filling*

In these computation it depend on the Janssen`s method.
It presented in brief and clearance in stage to compared to the FEM results
-Initial vertical pressure (q)

$$q = \frac{\gamma R}{\mu}\left[1 - e^{-\mu K \gamma / R}\right] \tag{2}$$

Where:
R effective radius
- μ=tan Φ the coefficient of wall friction angle
- Φ angle of internal friction of bulk

B. *Initial horizontal pressure (P)*

$$P=k.q \tag{3}$$

Where:
(k) The ratio of lateral to vertical pressure k=1-sinΦ
- Φ angle of internal friction of bulk
- The vertical friction load per unit length of wall perimeter at depth Y below the surface of the material shall be computed by:

$$V = (\gamma Y - q)R \tag{4}$$

C. *Initial (filling) pressures below the top of the hopper:*

a- The initial vertical pressure at depth h_y below top of the hopper shall be computed by

$$q_y = q_o + \gamma h_y \tag{5}$$

Where: qo is the initial vertical pressure at the top of the hopper computed by Eq.2.

b- The initial pressure normal to the hopper surface at a depth hy below top of the hopper shall be the larger of

$$P_n = \frac{q_y \tan\theta}{\tan\theta + \tan\phi} \tag{6}$$

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OR

$$P_n = q_y(\sin^2\theta + k\cos^2\theta) \quad (7)$$

c- The initial friction force perunite are of hopper wall surface shall be computed by:

$$V_n = P_n \tan\phi \quad (8)$$

When Eq. (6) is used to determine Pn and by

$$V_n = q_y(1-k)\sin\theta\cos\theta \quad (9)$$

When Eq. (7) is used to determine Pn

D. Funnel flow hoppers

Design pressure at the below of the top of a funnel flow hopper shall be computed using Eq.5 through (9) with q_o multiplied by an over pressure factor of 1.35 for concrete hopper that is the case study in paper; and 1.5 for steel hopper,(ACI313-97) [6].

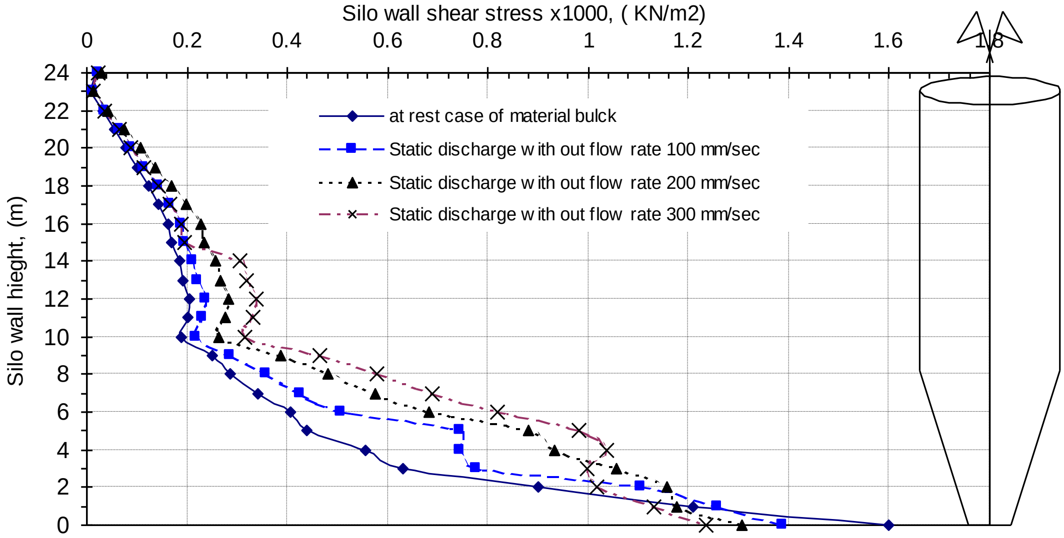

Table 3: Peaks of Normal and shear stress on silo wall at different sections under an ambient and Egyptian earthquake analysis.

Initial Filling State								
Section level	Static load case		Earthquake Analysis					
			Northridge,1994		El-centro,1940		Al-Aqba,1995	
	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)
	207.9	76.59	293.21	78.98	273.1	70.21	256.84	64.32
	701.2	259.37	1254.6	246.9	993.4	241.39	871.99	217.75
	1147.92	424.39	2134.6	614.30	1930.3	482.23	1712.8	428.10
	1345.80	497.65	3356.0	801.5	3121	720.49	2823	649.30
Discharge state with discharge rate 200 (mm/sec)								
Section level	Dynamic Discharge		Earthquake Analysis					
			Northridge,1994		El-centro,1940		Al-Aqba,1995	
	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)	V_n (kN/m^2)	P_n (kN/m^2)
	297.26	109.89	365.10	82.22	330.21	75.71	320.98	73.61
	1001.66	370.37	1390.01	270.21	1187.45	264.98	1089.98	250.47
	1362.9	503.94	2438.13	832.11	2329.10	674.12	2141.50	492.42
	1597.5	590.37	3887.2	931.44	3975.43	840.22	3528.12	705.61

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If the FE results compared to the stress result due to ACI provision see Table 4; it will be cleared ACI gives over estimated compared to the FEM reached to 10%-15% for the hoper zone when compared to static load analysis of filling stage of silo. These may be referred to the miss simulation for the material fluctuation in the hopper zone especially under discharge flow. On other hand, ACI gives under estimation values for normal and shear stress at the sections of silo body above the hopper zone compared to the finite element model simulation. Moreover it is not taken the velocity effect of the bulk material on the stress distribution pressure on the silo wall especially on the critical regions like hopper of silo. Regarding to experimental work that published by others it was urgently taking the flow outlet effect on the stress on the hopper sections. Form that comparison between the ACI313-97 to the numerical finite element that try to cover all these shortage points in the stress distribution on silo body; that can be consider ACI more conservative in results under especially condition like the case study in that search. On other hand may be need to take in consider others urgent factors that may be not cleared; that mentioned before.

VI. CONCLUSIONS

Most results of ANSYS modeling compared to the experimental work are in good agreement, especially in static analysis or in dynamic cases when there is a reduced flow. ANSYS uses a surface-to-surface contact model, where both the target surface and the contact surface have to be specified. The former one is supposed to be the rigid surface meanwhile the latter one is the deformable surface. Hence, the target surface is defined as the silo wall and the contact surface is represented by the boundary surface of the bulk solid in this analysis; that is given a way to simulate the relation between the bulk material surface and the silo wall.

Discharge simulations are usually faster than discharging processes in reality to save computation time. The evolution of the material velocities depends on various parameters of the constitutive models for the bulk material. Whether the time factor has some influence or not, should be part of the further investigations.

Small changes in the filling process can have a very marked effect on the solids flow pattern under concentric conditions. It is believed that the reason for the sensitivity to filling method lies in the dilation requirement for the solid to pass from its packed density to the critical density required for flow. Where internal flow occurs, loss of symmetry in wall stresses is not significant and the wall stresses are rather similar to those for filling conditions.

Under mixed flow, great variation and marked asymmetry of the wall stresses occurs during discharge. This loss of symmetry is so strong that it is probably more important than any symmetrical overpressure.

It was found that during discharge two different kinds of fluctuations occur. The slower fluctuations are caused by shear bands which develop at the transition from shaft to hopper. The momentary fluctuations are due to the fact that the macroscopic ‘‘steady state’’ flow in the hopper is not ‘‘steady state’’, where the fluctuations are severe. These fluctuations cannot be found in numerical FEM simulations because the macroscopic approach of the FEM is unable to consider microscopic effects.

ACI313-97, [6] provision has more conservative results compared to the FEM by percentage 10% to 15% depended on silo wall material increased for metal compared to concrete due to the grain bulk relation to silo wall material.

It should be emphasized that the results presented here should be taken with caution until a more detailed study in conducted taking were propagation through different silos height and shape into consideration.

NOTATIONS

A Cross section area of silo
Ks Janssen ratio of horizontal to vertical pressure
μ Coefficient of sliding friction between bulk solid and wall surface
γ Weight per unit volume for stored material
U Contact surface area for the inner silo wall

REFERENCES

[1] Janssen HA (1895). Versuche über den Getreidedruck in Silozellen, VDI Zeitschrift 35, pp. 1045-1049.
[2] Guenter A, Rombach, Frank N (2004). "3-D Finite Element Modeling of Granular Flow in Silos 17 th ASCE Engineering Mechanics Conference. June 13-16,2004, University of Delaaware, Newark,DE.
[3] E-DIN 1055-6: 2000-09 (2000), Einwirkungen auf Tragwerke: Einwirkungen aus Silos und Flüssigkeitsbehlter,NormenausschussBauwesen im DIN Deutsches Institut für Normung e.V., Berlin, Germany.
[4] Euro Code 1 Part 4 (ENV 1991-4:1996) (1996). Basis of design and actions on structures, Part 4.Action on silos and tanks.
[5] Thorsten WR, Keiter, Guenter A, Rombach (2002). Accurate handling of pressure peaks in FE-simulations of granular media, EM 2002, New York, 2-5, June, 2002.
[6] ACI 313-97 (1997). Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials, Reported by ACI Committee 313, America.
[7] ANSYS 10.0. (2007). ANSYS User's Manual. Ver. 10.0. Houston: Swanson Analysis Systems, Inc. Houston (USA).
[8] Gallego E, Goodey RJ, Ayuga F, Brown CJ (2004). Some practical features in modelling silos with finite elements. ASAE Paper No. 044150. St. Joseph, Mich.: ASAE. Proc. of the 2004 ASAE/CSAE Annual International Meeting. Ottawa, August 2004.
[9] Andres de Juan, Julia Moran, Pedro Aguado, and Pablo V (2003).” STUDY OF BUCKLING STRESSES IN STEEL SILOS” 16th ASCE Engineering Mechanics Conference, July 16-18,2003, University of Washington, Seattle.
[10] Rombach G, Eibl J (1995). Granular Flow of Materials in Silos - Numerical Results. Bulk Solids Handling, Volume 15, No. 1, 1995, pp. 65-70.
[11] Moran J, Aguado PJ, Juan A, Yotros (2002). “Effects of Thermal Loads On Agricultural Silos” 15th A.S.C.E. Engineering Mechanics Division Conference. Columbia University. New York (N.Y.)
[12] Alan WR, Christopher MW (2002). ” Flow Dynamics or’Quaking’ in Gravity Discharge from Silos” Journal of Chemical Engineering Science 57 PP. 295-305.

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