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Hopper Wall Simulation in ANSYS to Determine Displacement Due to Single Ball Impact

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ABSTRACT

Deformation of the silo wall due to the single ball impact is modeled in ANSYS. The material in silo, as a Winkler bed, is replaced by spring-damper elements and the spring stiffness and damper coefficients are evaluated of the granular material and wall properties. The granular material deformation under the specified force is measured to evaluate the granular stiffness to be used for determining the appropriate spring stiffness in ANSYS model. Geometrical parameters and boundary conditions are set according to the properties of a laboratory silo containing magnetite concentrate. Effects of impact parameters including the ball size and the impact position on the hopper displacement are taken into account. Comparison of simulation results with experimental data confirms that the wall displacement is an indicator of the ability of impact to solve obstruction. Simulation will be an alternative to expensive and time consuming experimental procedures for specifying the optimal impacts for obstruction solution.

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1. INTRODUCTION

The vertical silos are widely used in mineral and agricultural industries to store materials for up-going processes. In abnormal conditions, the material flow may have problems. The problems include funnel flow regime and obstruction due to dome or dense packing. To solve these problems, auxiliary ways are employed. One way to solve silo obstruction is impacting the hopper body. It is usually done by a hand-pendulum where the obstruction is not a common occurrence. When it occurs repeatedly, the hand-pendulum is not applicable [1]. Its ability depends on the impact conditions, material properties and silo wall properties. The experimental results obtained from a laboratory silo showed that the obstruction can be solved by impact depending on material properties [2]. Using other ways of obstruction solution is conventional. Maynard [1] suggested the feeder on the hopper outlet and also improvements on the hopper design to facilitate the material flow in a cement silo. Nazhat and Airey [3] examined soil under the impact force of a plate to determine the response of soil to impact loading. Over the silo researches, software simulations limited to the stress distribution in material and wall of the silo [4] or discharge behavior by DEM models [5]. Zhu et al. [6] evaluated the lateral pressure distribution and deformation of silo wall due to the eccentric granular flowing. Kaminski and Maj [7] presented the data collection of pressure distribution in silo for design purposes. Literature review reveals the need for using a simple method to determine the wall displacement by software models. To model this, the granular material can be replaced by spring dampers as suggested by Gerolymos and Gazetas [8]. Nateghi and Yakhchalian [9] studied the vibration induced by the interaction of material with the silo body.

While the experimental data have been given which indicate the hopper displacement through the ball impact [10], the procedure which gives the optimum impact conditions without the laboring and costs of experimental procedure will be welcomed. In the present work, the hopper wall of a silo is modeled in ANSYS to determine wall displacement due to single ball impact. The novelty is replacing the soil as a bed by equivalent springs which are evaluated according to the soil properties.

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2. SILO OBSTRUCTION

The material in silo experiences the loads including the gravitational force, the internal pressure, friction and cohesive tension as illustrated in Figure 1.

When the silo outlet is opened, breakage lines should be produced resulting in material flow. The breakage lines lie on the maximum shear stress surfaces [11]. The main force of producing material flow is the gravitational force which overcomes internal friction and cohesiveness. In some cases, the internal friction and cohesive force are greater than the gravitational force and the flow does not occur. The criterion is the yield locus on Mohr circle. If the state of stress lies under the yield locus the flow does not occur while the obstruction does. The jamming on the silo outlet is another mechanism of obstruction through handling the large grains. Large particles produce bridges as illustrated in Figure 2, which the upper pressure amplifies it. One way to solve obstruction is impacting the silo wall by a hand-pendulum. This is not a justified procedure when the obstruction occurs repeatedly. Using the pneumatic hammers with specified frequency and energy would be an alternative. However, impact conditions should be evaluated to have optimal performance. Here, the effect of impact parameters on silo displacement is investigated.

3. IMPACT

The major parameters which affect the performance of impact to solve the silo obstruction are the impact energy and impact position. Experimental procedures employing the laboratory silo can be used to determine the optimal impacts.

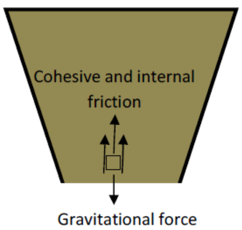


Figure 1. Forces act on material in silo

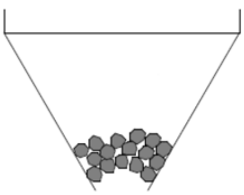


Figure 2. Obstruction in form of bridging

However, this is expensive, time consuming and laborious. By studying the impact on silo wall in more detail, it is understood that the reciprocating motion of the silo wall is the cause of solution of obstruction. What happens due to single impact is illustrated schematically in Figure 3. The impact deforms the hopper wall rapidly and the wall undergoes a reciprocating motion. Over the return period, the internal pressure moderates or is weakened instantly. It will be sufficient for the gravitational force to produce fracture lines and make the material to flow. Flowing upper materials provide an added exciting factor which helps the material to flow. It means that the impacts which produce more optimal reciprocating amplitude will be appropriate. If there was a way to determine the silo wall displacement due to impact it could be an alternative to the experimental procedures. Here, ANSYS is used to model the problem and determine the deformation of silo wall due to single impact.

4. SIMULATION

ANSYS software is used to model the impact between a single ball and plate. Plate represents the hopper wall containing the pressured material on behind so it is modeled by a Winkler bed. In software, the Winkler bed is modeled by spring-damper elements [12]. Boundaries 2 and 3 (Figure 3) are considered hinged and boundary 1 is deformable and is modeled by spring elements. To specify the spring stiffness, the material pressure should be taken into account to be modeled equivalently as illustrated in Figure 4.

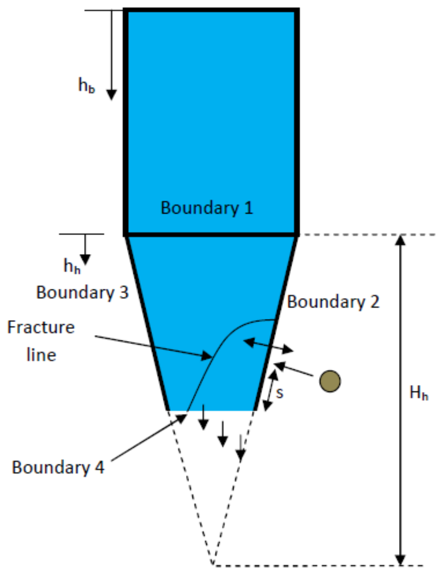


Figure 3. Impact position and geometrical parameters of hopper wall

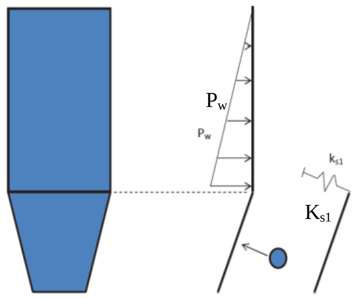


Figure 4. Pressure distribution on body wall and equivalent spring on boundary 1

The pressure P_w is expressed by the following relation [11]:

$$P_w = \frac{\rho g}{\pi D \mu k}\left(1 - \exp\left(\frac{h_b}{\pi D \mu k_1}\right)\right) \tag{1}$$

In which P_w is the material pressure in silo body, g is the gravity acceleration, ρ is the material density, D is the silo width, μ is the internal friction, k_1 is the Janssen coefficient, h is the height from the top of the silo and k is a parameter which is given as follows [11]:

$$k = (m+1)\frac{\mu_w k_1}{tan\theta} \tag{2}$$

In which m is a coefficient that is considered 1.4 [8], μ_w is the wall friction and θ is the hopper angle. The material pressure in hopper is stated as follows [11]:

$$P_h = \frac{\rho g H_h}{k-1}\left[\frac{H_h - h_h}{H_h} - \left(\frac{H_h - h_h}{H_h}\right)^k\right] + P_{h0}\left(\frac{H_h - h_h}{H_h}\right) \tag{3}$$

In which P_h is the pressure in silo hopper, P_{h0} is the pressure at $h_h=0$, H_h and h_h are illustrated in Figure 3. Evaluating the pressure helps us to appropriate the correct stiffness coefficients to the springs of boundary 1. The plate which is modeled in ANSYS is illustrated in Figure 5. Plate is made of the poly-methyl methacrylate whose properties are given in Table 1.

Material is Magnetite concentrate with density of 2200 kg/m^3. A simple test as suggested by Bolton and Wilson [13] conducted to determine magnetite displacement due to the specified force. For this aim a cylinder of 75mm in diameter weight of 10kg is put on the material and indentation is measured which is about 9mm. The material stiffness then will be 2.63MN/m^3. Over each 5×5mm^2 of plate a spring-damper is considered equivalent to the magnetite concentrate. The spring stiffness will be 1041N/m if the magnetite is free and non-pressured. The effect of internal pressure should be added [14]. The material pressure in hopper versus the hopper height is evaluated by Equation (3) and is illustrated in Figure 6.

The spring stiffness will be modified by the following relation:

$$K_{se}\, x = P_h A_s + k_s x \tag{4}$$

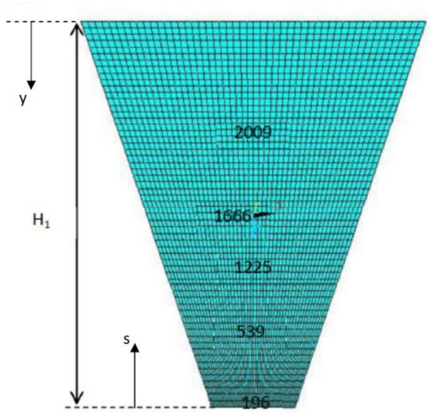


Figure 1. Meshed plate for simulation in software

TABLE 1. properties of the hopper wall

Thickness Strength (mm)	Density (kg/m^3)	Modulus of Elasticity (Gpa)	Poisson's ratio (Mpa)
6	1150	2.5	0.38

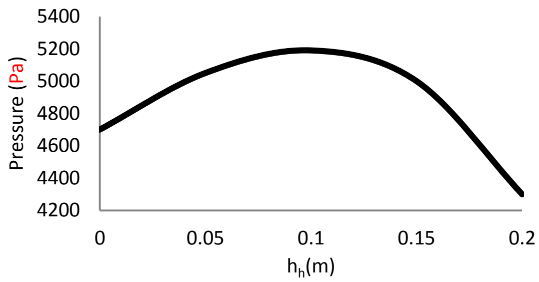


Figure 6. Variation of the material pressure with respect to the hopper height

$$K_{se} = \frac{P_h A_s}{x} + k_s \tag{5}$$

where K_{se} is the equivalent stiffness, x is the hopper deflection, A_s is the area on which a spring is considered (here is 1×1cm^2) and k_s is the stiffness of non-pressured material. As it can be seen in Equation (5) the equivalent stiffness is nonlinear. Damping ratio is considered *0.7N.s/m* for the present material [15]. 28 springs with stiffness *1100N/m* are considered equivalent to the material pressure at boundary 1.

Plate, spring-damper and ball are modeled by Shell163, COMBI165 and Mass166 elements respectively. The impact parameters include the ball size and impact position. Impact position measured from the bottom of hopper as illustrated in Figure .

5. RESULTS AND DISCUSSION

After modeling the geometry, the ball is given the specified velocity to impact the plate. The ball returns and the plate undergoes a reciprocating motion which can be obtained from the software postprocessor. The simulation results are compared with the experimental data obtained from a laboratory silo [2]. The impact positions in experimental data are: *s=40; s=100 and s=170mm*. The comparison of the simulated point displacement on vertical centerline with experimental data is illustrated in Figure 7. Plate undergoes vibration motion whose intensity depends on the impact position, ball size and speed. Optional nodes are selected to study the effect of the impact parameters on plate response. The nodes and their position are given in Table 2.

Displacement of these nodes over time is illustrated in the following figures. We can see a reciprocating motion damped rapidly. The graphs are obtained from the software and don't have the same abscissa range by default.

As we can see in Figure 8, the maximum displacement occurs at node 539, which is close to the impact point (s=40) and at node 196, which is on the free boundary 4. It seems an obvious result that the displacement at impacted point maximizes. In order to determine the optimum impact position, the displacement due to impacting different points is illustrated in Figure 9.

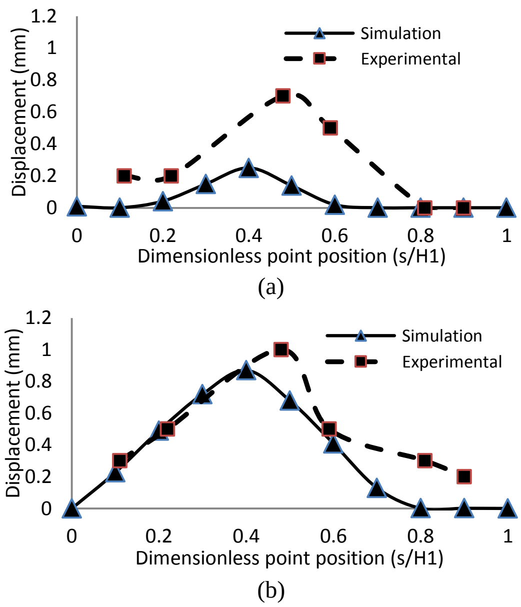


Figure 7. Comparison of the displacement on vertical centerline of plate obtained of simulation and measured on laboratory silo, a) ball 20mm, velocity 2.8 m/s, impact position *s=100mm*, b) ball 25mm, velocity 2.8 m/s, impact position *s=100mm*

TABLE 2. Node number and their position

Node	196	539	1225	1666	2009
Numbers(mm)	0	50	100	140	170

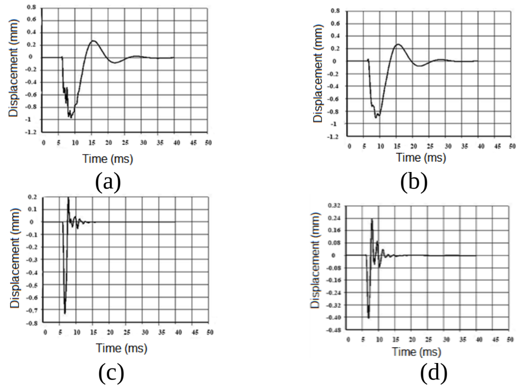


Figure 8. Displacement of node versus the time, ball 30mm, velocity 2.8m/s, s=40mm, a)node 196, b) node 539 c) node 1225 d)node 1666

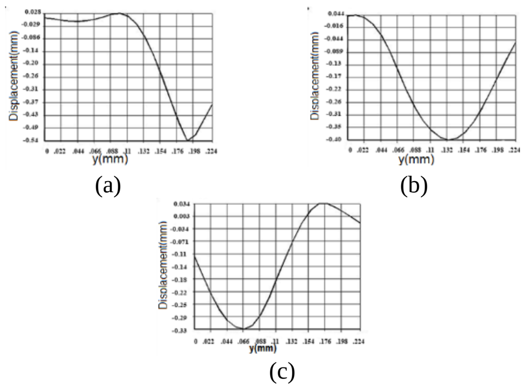


Figure 9. Displacement of nodes on vertical center line, a) s=40mm b) s=100mm c) s=170mm

As we can see in Figure 9, the maximum displacement occurs when the impact position is *s=40mm (i.e. y=180mm).* Experimentally impacting many points has its difficulties but it is possible to be done in software model. The results are shown in Figure 10.

Results showed that the impact at *s=40mm (y=180mm)* gives the maximum displacement. It says that *s=40* may be the optimum impact position for obstruction solution.

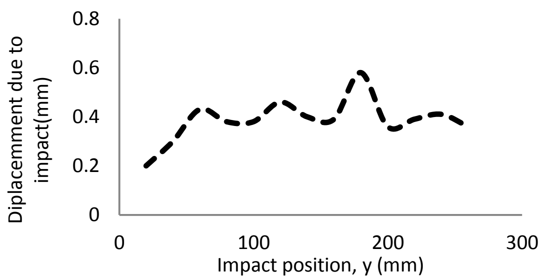


Figure 2. Displacement due to impact at different positions on hopper vertical centerline

The other parameter which may affect the obstruction solution is the period of reciprocation. More period allows the fracture lines to be produced. The variation of period versus the impact position is illustrated in Figure 11.

From the displacement point of view, *s=40mm* is the best position. From the period point of view, we have also the appropriate impacts at *s=40mm*. There are experimental data obtained from a laboratory silo [2] to compare with simulation results. Obstruction occurs in the laboratory silo when it is filled with magnetite concentrate. Ball impacts are used to help the material flow and solve the obstruction. Several impacts at *s=40;100;170mm* are tried. The number of impacts required to provide the material flow are given in Figure 12-a which the minimum is as *s=40mm*. Simulations give the identical result from the displacement point of view. It means that the wall displacement relates to the ability of impact for obstruction solution. The other result is that the simulations can give valuable results about the impact ability of obstruction solution.

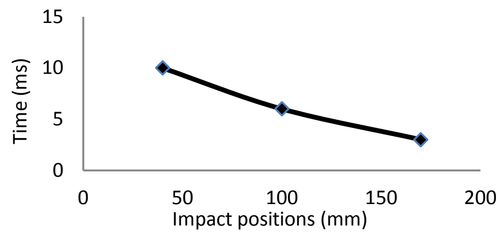
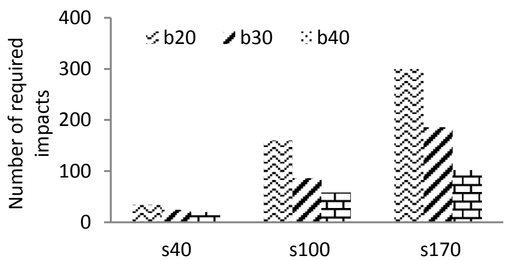
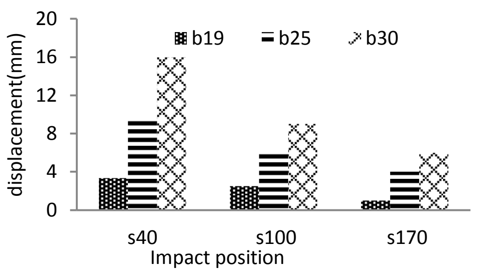


Figure 3. Period of reciprocation



(a)



(b)

Figure 12. a) Required number of impacts to solve obstruction b) Wall displacement at the impacted point

The simulation is a simple method of deformation study which enables us to model the large scale operating silo. Experimental data and simulation results reveal that larger balls better act in obstruction solution (Figure 12-a) and wall displacement (Figure 12-b). It was an obvious result because that the impact energy enhances as the ball size increases.

6. CONCLUSIONS

ANSYS software is used to simulate the single ball impact on a flat plate on a soil-bed. Winkler bed is replaced by spring-damper elements. Simulation parameters are obtained from a laboratory silo containing magnetite concentrate. Simulation gives the maximum displacement where the experiments give the minimum required number of impact. The best position of impact is 40mm from the hopper outlet. Simulation method can be used to study the optimal impacts on large scale operating silo.

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چکیده

تغییر شکل بدنه سیلو در اثر برخورد گلوله در نرم افزار انسیس مدل می‌شود. مواد دانه‌ای درون سیلو بعنوان یک بستر وینکلر در نظر گرفته شده و با فنر و دمپر جایگزین می‌شود و ضرایب آنها بر حسب خواص مواد و خواص فیزیکی بدنه سیلو تعیین می‌شود. با یک وزنه مشخص که بر روی مواد قرار داده شده و میزان جابجایی تحت آن اندازه گیری می‌شود، ضریب الاستیک مواد برای استفاده در نرم افزار تعیین می‌شود. پارامترهای هندسی و شرایط مرزی برای سیلویی که حاوی ذرات مکنتیت است مشخص می‌گردد. اثر پارامترهای ضربه شامل اندازه گلوله و محل برخورد بر جابجایی بدنه سیلو بررسی می‌گردد. مقایسه نتایج مدلسازی مربوط به تغییر شکل بدنه سیلو و نتایج آزمایشگاهی مربوط به قدرت رفع انسداد ضربات نشان می‌دهد که جابجایی بدنه یک پارامتر تاثیرگذار در رفع انسداد سیلو است. مدلسازی نرم افزاری می‌تواند بعنوان جایگزین روش پرهزینه و زمان بر آزمایشگاهیجهت تعیین برخوردهای بهینه برای رفع انسداد سیلو استفاده گردد.

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