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Understanding rock flow mechanism in ore pass using working model 2D

SJ Jung, K. Biswas, and H. Lee
Dept. of MMMG Eng., University of Idaho
Moscow, Idaho

ABSTRACT: The main objective of this paper is to enhance the understanding of the underlying mechanisms of bulk solid flow through a constrained passage based on design parameters. In this study, ore pass design parameters, information on size distribution of rock fragments in ore/waste dumps are used for a computer simulation. One of the important parameters in ore pass design is the angle of the ore pass itself. Various inclined ore pass models were created in Working Model 2D®. Rock flows were simulated utilizing these models to investigate the relationship between the angle of ore pass inclination and the impact loads on the gate and ore pass walls.

Introduction

To transport excavated rock (ore and waste) utilizing gravitation, ore passes are most commonly used in underground mines. Typically, an ore pass is a vertical or near vertical shaft excavated in host rock mass with a gate assembly located at the bottom of the pass. Excavated rock is dumped onto a grizzly located at the top of the ore pass to screen boulders as they may cause hang-ups in the ore pass and may damage the gate assembly in case of direct impacts. Rock is withdrawn at the bottom of the ore pass at regular interval. Synchronization problems with dumping and withdrawal of loads may result in accumulation in the ore pass for a certain period of time. Attempt to withdraw loads of excavated rock fragments after a considerable accumulation in the ore pass may result into hang-ups, which is a most common hazard associated with ore pass safety. The occurrence of hang-ups in an ore pass may also depend on other parameters including shapes and sizes of rock fragments, ore pass geometry, dumping characteristics, presence of moisture, characteristics of surrounding rock formation etc. Accidents are common while dealing with hang-ups in ore passes and due to failure of the gate assembly. This paper investigates the flow mechanism of bulk solids in an ore pass using Working Model 2D®, a simulation software.

There are four different types of ore passes to choose from when designing the chute. The rockslide version does not operate full of material in ore pass. Less steep angles are required to allow flow to occur. Simple pass with reclaim by mobile equipment requires equipment to reclaim the ore frequently. The ore pass is from the horizontal to promote gravitational flow. Another type of ore pass design is the dogleg pass with reclaim by mechanical feeder. The "dog leg" acts as a cushion to falling ore and protects the mechanical feeder. The last design is the surge bin/ore pass combination. Using this design allows the ore pass to be kept full at all times reducing the chance that the falling stream may form any arching or doming. The main key is to keep the outlet the correct size to prevent arching (Goodwill, 1999).

There are three different types of outlet hopper to choose from when designing the ore pass. The first, mass flow is steep and low enough to allow friction to maintain the flow of all particles without sluggish regions when withdrawn. The mass flow is recommended when handling ores containing large amounts of cohesive fines. The gate should not interfere with the flow of material to maximize the design efficiently. If the ore pass is going to be dormant most of the time and filled occasionally, do not use this method considering liner abrasion due to impact of the falling stream of rock can be severe. The funnel flow is when "the hopper is not sufficiently steep enough and low in friction to force material to slide along the converging hopper walls". This type of outlet hopper is useful for ore that is coarse, abrasive, free flowing. The design helps the ore from possibly wedging because of its coarseness and steep falling, also has a rate of less wear and tear on the hopper walls. Expanded flow hoppers are a combination of a funnel hopper and a mass flow hopper. This hopper type is used when handling coarse ores with up to 10% fines. Like the mass flow hopper, ore must be present in the ore pass either all or partially all the time. A typical size distribution of rock fragments in ore pass, which was obtained from the local mine, is illustrated in Table 1.

Table 1. Typical size distribution of fragmentation in ore pass

Range of particle size (mm)	% by weight
Less than 0.075 mm	10
0.075 - 0.5	13.84
0.5 – 2	10.72
2-4.75	13.04
4.75 - 19.28	26.96
19.28 – 75	21.52
Larger than 75 mm	3.92

Due to the limitation of Working Model 2D®, the effects of size redistribution are beyond of the scope of this study. To understand the basic mechanism of flow behavior, an attempt has been made to discuss some directions in terms of dealing with fines in an ore pass.

A simple simulation with a four-particle load in a vertical load will be used to their interlocking behavior. Figure 1 illustrates the arching behavior with four circular fragments in a vertical ore pass. The center particle will push two lower particles against the ore pass wall due to gravitational forces. At this time, two lower particles will tend to rotate, and positioning to more stable location against wall of ore pass. One particle, which is falling onto the interlocking arch, will add more force to create tighter interlocking arch.

It is also possible for small particles to form an interlocking arch. However, the probability of such an arch to form has less than larger ones and it can be deformed easily by its own weight or by the potential energies of the following particles or the dumps, which land on top of the arch. Small particles, in general, form an weak interlocking arch for the following reasons;

1. Each particle expose smaller surface area for cohesive forces to act
2. Each particle has too small mass to form a firm arch
3. Many weak joints within an arch
4. Thickness of an arch is thin or not massive.

Besides the shape and size of the ore pass, the impact pressures and minimizing arching dimensions have great impact on the ore pass development. When particles flow down the ore pass, the pressures at the points of impact increase with the height of the fall and cause arching or doming. Large rocks create high impact stresses and the fines develop the cohesive strength needed to sustain an arch or dome. There are many pressures, physical factors and other dynamics to figuring out the impact pressures and dimensions of the ore pass (Goodwill, 1999).

Figure 1 Formation of interlocking arch

The consolidating pressure caused during gravity flow according to Jenike can be "approximated" as:

$$\sigma_1 = \frac{B\gamma}{(1+m)}$$

Where :

B = size of the flow channel, i.e. the diameter of a conical hopper or the width of a wedge-shaped hopper

γ = bulk density of the solid

m = 0 if the hopper is long rectangular

= 1 for a circular or square hopper

The impact of the stream of matter causes a vertical impact pressure that can be estimated by:

$$\sigma_{imp} = \frac{wv}{gA}$$

Where:

w = weight flow rate

v = velocity at the

g = gravitational constant (9.81 m/s^2)

A = area of impact

The velocity of a particle can be determined by the square root of 2gh until terminal velocity is reached. An estimated terminal velocity of falling coarse rock is about 60 m/s according as stated in the paper written by Goodwill, Craig and Cabrejos.

Geometry of an ore pass and rock flow

The flow mechanism of any bulk solids through a conduit is a very complicated process as it is characterized by enormous number of collisions, energy losses and redistributions, static and dynamic loadings on the structures, friction characteristics, etc. To enhance the understanding of ore pass design criteria, bulk solid flow phenomena in ore passes are investigated by simulating the flow of rock fragments in an ore pass in the Working Model 2D®, a simulation software.

To maximize the haulage distance and minimize hang-up, there are a few different ore pass geometries being utilized including combinations of rectangular, square or circular, inclined or vertical, straight or with bends (doglegs and knuckles). Vertical ore passes result into higher static and dynamic loads on the gate compared to inclined ore passes. The effect of ore pass inclination on the resulting dynamic load has been studied using Working Model 2D®. Figure 2 demonstrated effect of ore pass inclination on dynamic loads on the gate that has been simulated in Working Model 2D® to estimate the change in dynamic loads with changes in ore pass inclination.

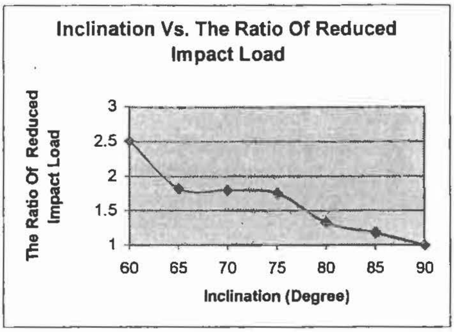

Figure 2. Effect of ore pass inclination on dynamic loads on the gate

As shown in the Figure 2, the impact loads can dramatically be reduced by 251 percent with 60 degrees inclination compared to a vertical ore pass. When blasted rocks are dumped in an inclined ore pass, the potential energies of the fragments are quickly reduced as they tend to rotate on the inclined footwall of the ore pass compared to the free falls of the rock fragments with occasional collisions with the ore pass walls in a vertical ore pass. Initially, right after a load is dumped in an inclined ore pass, the fragments roll down along the inclined footwall with different velocities depending on their shapes, sizes, and frictional properties. The flow of rock particles through an inclined ore pass has been simulated in Working Model 2D® and it is illustrated in Figure 3. In an inclined ore pass, the dynamic load on the gate is dramatically be reduced as a considerable amount of potential energy of the fragments will be lost, even for the largest fragment in the dump, before hitting the gate assembly.

Inclined ore pass has an advantage to minimize the impact energy on the gate, however, slow particle movement may cause hang-ups in ore pass. In a similar fashion, static loads on the gate assembly can be dramatically reduced by utilizing inclined ore passes. To utilize above advantages, ore pass with two different inclination angle was simulated to understand the behavior of rock flow (dogleg concept). As material starts accumulating in the ore pass, the effectiveness of inclined ore passes to reduce static loads on the gate and the accumulated materials becomes more effective. The static loads based on accumulation in the ore pass will be distributed on the inclined footwall as shown in the Figure 4. The coefficient of friction, along the contact areas between particles and wall, is the major key to reduce the static loads as well as the dynamic loads on the gate in an inclined ore pass. However, there are some disadvantages of using an inclined ore pass such as; possible collapse of the hanging wall, higher drilling cost compared to an equivalent vertical ore pass, and severe damages of the footwall.

To ensure more effective flows of rock fragments with a minimum loss of momentum, it is important to keep the directions of knuckles/doglegs same as the direction of the inclination. Obviously, for the better flow of rock fragments in an inclined ore pass, any angles higher than 60 degrees from the horizontal are recommended (Hambley, 1987). Inclinations greater than 60 degrees is an absolute necessary when a large percentage of fine and wet particles are handled. Inclined ore passes are less likely to experience hang-ups compared to vertical ore passes as the compaction of the accumulated materials by the new dumps is much less compared to the compaction if the same in a vertical ore pass. A dogleg is an inclined extension of an ore pass as shown in figure 4. A dogleg helps to reduce impact loads on the gate by allowing the rock fragments to hit the ore pass walls first before they roll down to the gate with much lower energy. With a dogleg in an ore pass, care should be taken to minimize the damages of the impacting points on the footwall of the ore pass.

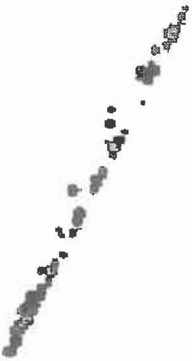

Figure 3. A typical rock flow pattern in an inclined ore pass.

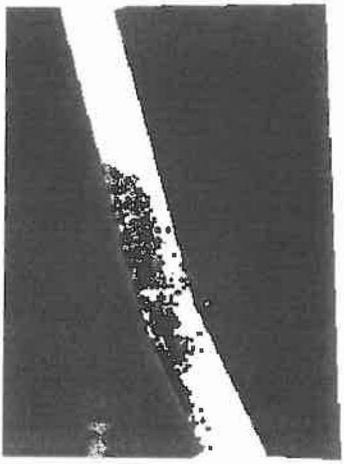

Figure 4. Rock flows in an inclined ore pass with two different inclination angles.

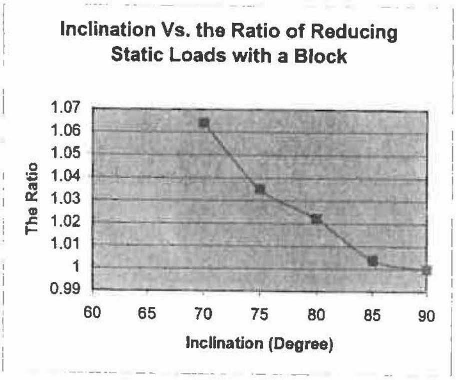

Figure 5. The factor of reducing static loads with a block is shown for each inclination.

Conclusions

Working Model 2D$^{®}$ can be used to model and simulate rock flow through an ore pass with a reasonable accuracy. The simulation output includes the measurement of forces, stresses and energy losses of the structures of interest. The particles can be analyzed as they flow through the ore pass if the number of particles is kept within a workable range. The main limiting factor of utilizing the software is processing time as large number of particles result in a large number of collisions and the software requires more time to carryout all the required calculations at every step and to reconfigure all the particles for next step.

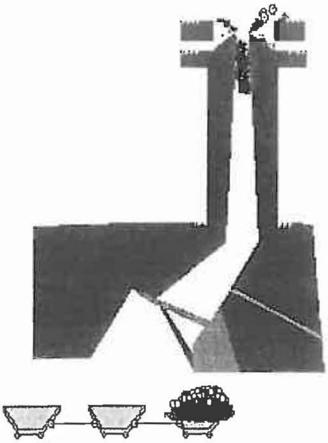

Figure 6 Working model simulation with dogleg application

To minimize fine rock fragments in the loads before they are dumped into an ore pass can be eliminated by using inclined screens near the opening of the ore pass. When the load from a LHD is dumped, it can be allowed to pass over strategically located grizzlies, so that majority of the fine materials present in the load can be separated before the load reaches the opening of the ore pass. Elimination process of fine particle will definitely minimize the chances of formation of cohesive arches but will introduce additional cost of handling fines separately.

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