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THE MODELING OF GRAVITY FLOW OF ORE IN ORE PASSES

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ABSTRACT

Many industries when volumes of the solid materials are large invariably relay upon the gravity to induce solids to flow out of storage, through channels and reactors. In mining industry ore pass's requirements to less energy (only gravity) have made them very popular both in underground and open pit mines. This paper discusses the major findings of research on 2D Discrete Element Method simulation of gravity flow of ore in ore passes. Results show that ore characteristics, ore pass configuration can significantly affect loads (static, dynamic) on the gate assembly and creation of hang-ups.

INTRODUCTION

Ore passes are widely used in the mining industry because of their advantages of high productivity, high efficiency, low cost, need for less equipment and breadth of geologic application. Not only the productions in most deep underground mines depend on ore passes, but also some open pit mines use them as the primary choice of ore transportation. An ore pass is much the same as a tunnel, with a very large height-to-diameter ratio. Ratios up to 100:1 are not unusual for ore passes.

The configuration, sizes and purpose of ore passes vary widely. They may be located at the surface or underground, vertical or sloped, straight or dog-legged, circular or rectangular in cross-section, designed for intermediate storage, or as a chute, or be part of a mining method (Glory hole method). Figure 1 shows the different configurations of ore passes (Goodwill et al., 1999).

Although ore passes, chutes and gate systems for mining of metal and non-metal mines must meet the requirements specified in the U.S. Code of Federal Regulations (CFR), part 57 and 75. The MSHA database (1987-1996) on accidents and fatalities related to failure or hang-up of ore passes, reports a total 743 nonfatal accidents (e.g., permanent disability, injury, occupational illness) and eight fatalities. There are two major types of hang-ups as followings:

1. Interlocking type of hang-up where large-sized boulders become wedged together to form interlocking arches. This occurs when the relatively few larger fragments form stable hang-up arrangements in the ore pass.
2. The cementation effect of fine and sticky particles (d<0.254 mm) may create a cohesive arch type of hang-up. The presence of moisture in the bulk ore mass will also increase cohesive resistance of the arch.

The findings reported here are concentrated to identify and evaluate the conditions for ore pass gate failure and first type of hang-ups.

MODELING OF GRAVITY FLOW OF ORE

Granular materials can be defined as any material composed of many individual solid particles, irrespective of particle size, chemical components and shape. Thus the term granular material represents a wide variety of particle dimensions and shapes, ranging from the mixtures of ore and waste rock after blasting to the finest icing sugar.

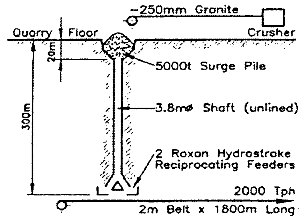
The first significant studies related to the storage and flows of granular materials were reported at the end of nineteenth century. That work originated from the need to store large quantities of grain, and was concerned mainly with wall pressure affecting the structural design of silos and bins. Janssen (1895) for the first time was developed the formula for prediction of the wall pressure. His method is based on the concept of differential slices of infinitesimal thickness, and finite cross-section and perimeter.

Application of Janssen's method to ore pass design (Blight et al., 1994) due to lack of consideration of movement, shape, and blockiness of ore and waste materials has limited to approximate calculation of wall loads, under static conditions.

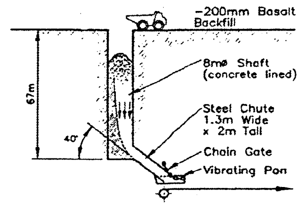
Even to date most silo and bunker design manuals, present a set of empirically derived correction factors for use in conjunction with load predictions. In the past three decades, gravity flow of granular materials has been studied by variety of methods, including:

- Experiments, by analogy with the flow of other materials (e.g., sand) in bins and bunkers,
- Full-scale field studies,
- Large-scale physical models, and
- Numerical modeling.

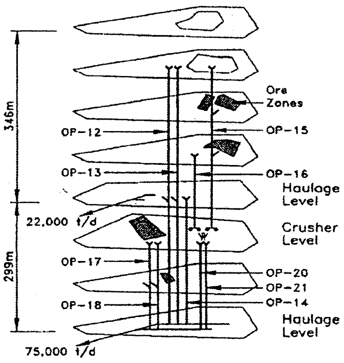
Researchers argued that the gravity flow of rock (ore and waste)



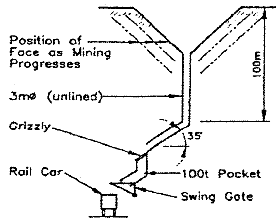
(a) Glory Hole at Glensanda, Scotland



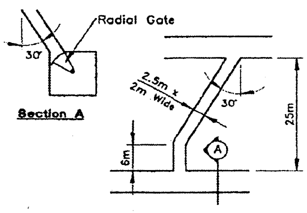
(b) Surface Ore Pass, BMS, Canada



(c) Underground Passes, El Teniente, Chile



(d) Fresnillo Mine, Mexico, Glory Hole



(e) Small Underground Pass with Dogleg

Figure 2. Different Configuration of Ore Passes (After Goodwill 1999)

could not be simulated precisely by the theories developed by the flow of other materials such as sand. This is because the ore shape, size, discharge rates and boundary conditions in the real case were not analogous to experiments condition, (Yenge, 1980).

Figure 3. Fragmented Rocks at Henderson Mine (Mine Visit Sep. 2000)

The full and large-scale studies of gravity flow of ore/waste are generally very expensive and can provide only localized information for a specific case (Lorig, 1995) and (McNearny, 1991).

The introduction of fast computers with large memory provides an opportunity for researchers to use numerical modeling to study the flow of granular materials. Traditionally, continuum theory (Finite Element Method, FEM) has been used to describe granular material behavior. But many bulk-handling systems involve very large-scale, discontinuous dynamic or static behavior. Gradually, Discrete Element method (DEM) with its unique ability for simulating the complete dynamic behavior of discrete, interacting bodies has introduced itself as a very powerful tool for numerical modeling of discontinua.

DEM modeling of granular media is often performed using a system of 2D circular (disk) elements. Disk elements offer several advantages such as: relatively short computation time, and simplicity of contact detection and contact force calculation. But disks can roll excessively, and they demonstrate lower peak friction angles than real materials, (Thomas, 1999).

Basically, it is difficult to simulate real material behavior when the ore is even slightly angular. In the current research, a cluster version of DEM code has been developed. The Cluster-2D code combines the simplicity of dealing with circular disks and the accuracy of modeling ore shape. Each cluster consists of the desired number of disks, connected rigidly together in a specified manner. Figures 3-4 show respectively an example of different shape and size of rock after blasting and three ore-cluster shapes applied in different simulations (see for details Nazeri et al., 2002).

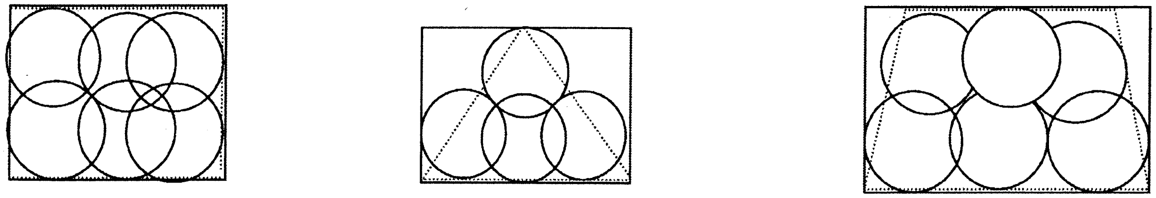


Figure 4.Three Different Ore-Cluster Shapes

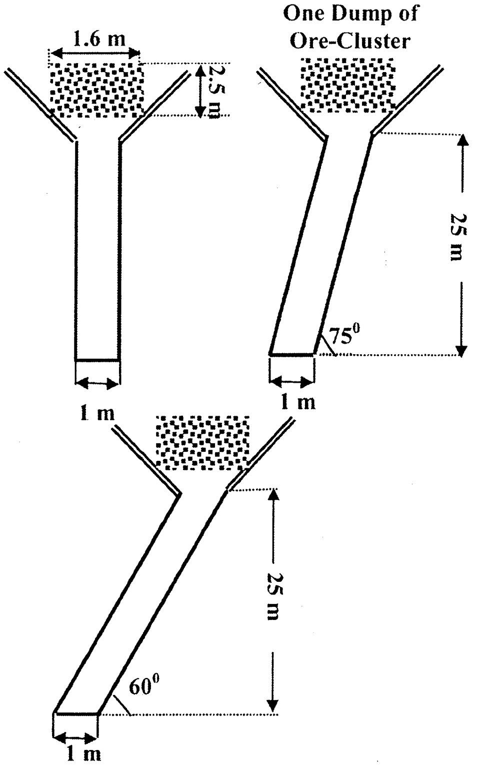


Figure 5. Ore Passes with Different Inclinations (Not to scale)

With respect to the available information from different ore pass operations and the maximum size of an ore-cluster about 0.1 m, a ratio of 25:1 (height/width of ore pass) for the simulation purpose is selected. Primary simulations indicated that a height to diameter ratio of 25:1 allows enough time to flow of ore-cluster for building up the incremental friction force. Also to avoid non-physically high dynamic load due to direct impact of ore material on the ore pass bottom gate, a feeder with an inclination of 60° is defined at the dumping point.

Note that the terms dynamic and static loads refer to the maximum normal impact load on bottom gate of the ore pass and the steady vertical load on the bottom gate (proportional to the weight of ore). The impact factor also is defined as the ratio of total normal load on the bottom gate of ore pass at any moment to the total weight of ore.

SIMULATION RESULTS

The objective of research program was to assess the conditions causing bottom gate assembly to fail and creation of hang-ups. In order to achieve the mentioned goals the effect of these modeling parameters needs to be studied as follows:

1. Ore pass inclination, coefficient of friction (ore/wall), different dumping points design, stiffness of wall and existence of Dogleg, and,
2. Ore shape and size distribution, coefficient of friction (ore/ore and ore/wall) and stiffness of ore material.

In this paper effect of inclination of ore pass on load on bottom gate assembly and also effect of coefficient of friction on flow of ore would be presented.

The inclination of the ore pass must be sufficiently great enough that material can flow easily. This would favor higher inclination (75°-90°). Conversely, in order to reduce the dynamic load on the ore pass gate, the inclination should be as low as possible (Hambley and Singh, 1983). Note, more interactions of ore with ore pass walls; will cause the ore to lose more kinetic energy, resulting in lower impact velocity and load.

Figure 5 illustrate the dimensions of the ore passes with three different inclinations (60°, 75°, 90°) and figure 6 presents the impact factor on bottom gate of ore passes with different inclinations.

Figure 6 shows a strong reduction in both static and dynamic load as the inclination of ore pass is varied from 90 to 60 degree. As expected, the maximum impact factor is for the case of vertical ore pass, when the ore can hit the gate directly with highest kinetic energy.

Conversely the lowest impact factor is for the case of 60°, inclination when the ore impacts the gate with the lowest impact velocity.

In order to investigate the effect of change in coefficient of friction on flow of ore, an inclined (75°) ore pass has been filled within 10 equal dumps of Trapezoidal ore-clusters.

These simulations are performed with the coefficients of friction equal to 0.25, 0.50, and 0.75 respectively. The bottom gate is opened after about 44 seconds of simulations.

Figure 7 shows the snapshots of the ore flow after opening the gate at the end of simulation (time: 48.8). It shows the effect of high coefficient of friction and clogging of ore at the bottom ore pass where the coefficient of friction equals to 0.75. Also clearly illustrates effect of coefficient of friction on angle of repose.

Figure 8 illustrates the time history of mass-flow for different coefficients of friction (from the moment the bottom gate has opened up to end of simulation). As it is expected with lower coefficient of friction the speed of flow is higher. Note as discussed earlier, mass-flow for μ=0.75 due to clogging could not be completed. (Goodwill et al.1999) in his experiments with (-20 mm) crushed stone (very abrasive materials with high angle of internal friction) achieved similar results.

CONCLUDING REMARKS

The simulation results revealed that a rigid cluster of circular disks based Discrete Element Method computer code could predict stresses and loads on gate assemblies/walls, and ore flow in ore passes. The Cluster-2D code is a complex multi-step modeling

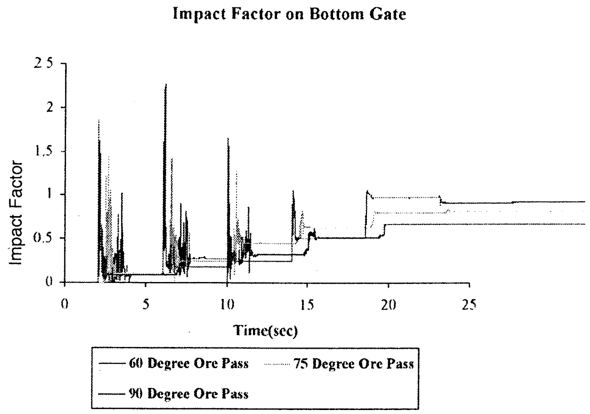


Figure 6. Impact Factor on Bottom Gate of Different Inclined Ore Passes

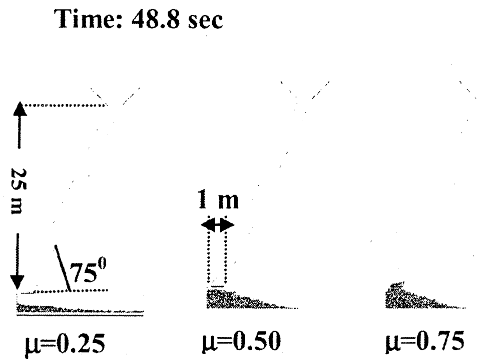


Figure 7. Snapshots of Ore Flow for Different Coefficient of Frictions (Not to Scale)

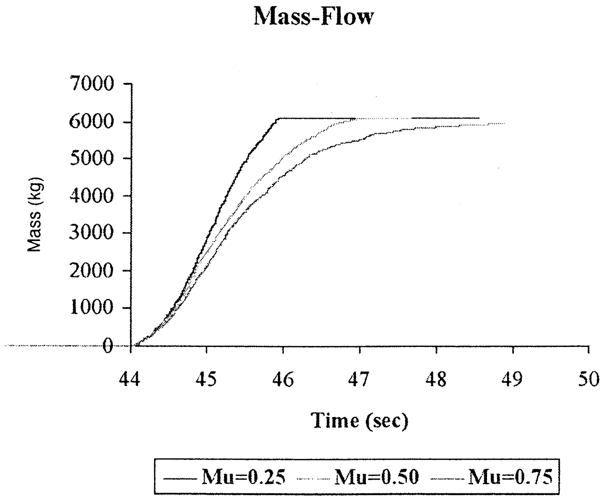


Figure 8. Mass Flow for Different Coefficient of Frictions

method, which allow its users to incorporate the mechanical behavior and characteristics of ore/ore pass in numerical simulations. Simulation results demonstrate the necessity to revise of some empirical formulas such as $\frac{D}{d} = 5$, and consideration of the effect of different ore shapes, inclination of ore passes and friction. Results from this research will help mining engineers to better understanding of gravity flow of ore in ore passes and to a more economical and safer design of the ore pass gate assembly.

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