CHAPTER 71

Design of Ore Passes

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71.1 INTRODUCTION

Ore passes are underground conduits for the gravity transport of broken ore, waste rock, and fill from one level of a mine to a lower level. Inclination of ore passes typically ranges from vertical to 30° (Pariseau 1966), and cross sections may be square, rectangular, or circular. Historically, cross-sectional areas were generally less than 5.6 m^2 (60 ft^2) (Peele 1947). In recent years, much larger ore passes have come into use, especially in conjunction with open-pit mines where run-of-mine rock may contain boulders that are more than 1.5 m (5 ft) in size. Ore pass lengths range from 18 to over 180 m (60 to 600 ft), and undoubtedly there are even shorter and longer passes in existence. Fill passes from the surface may be exceptionally long. A level interval of 46 m (150 ft) is perhaps a representative ore pass length.

Ore passes serve two important purposes: transport and storage. The latter is essential to efficient mine operation. Without adequate storage, any slowdown or stoppage in one part of a mine's transport system (for example, a train derailment or conveyor belt tear) could bring the entire system to a costly halt. If ore passes intended for transport and collection of ore do not provide adequate underground storage, then additional storage facilities must be installed. Surface storage bins also help to buffer mine and mill. Total storage needed depends mainly on the production schedules of mine and mill and are thus site specific.

Components of the ore pass system include (1) the ore pass itself connecting (2) two or more levels in a mine; (3) top-end facilities incorporating material size and volume control mechanisms, such as grizzlies, crushers, and surge chambers; and (4) bottom-end structures to control material flow and enable loadout. Figure 71.1 shows a typical ore pass for load-haul-dump (LHD) machines.

71.2 ORE PASS DESIGN FACTORS

71.2.1 Introduction

Design of ore passes for transport requires that broken ore, waste rock, or fill will flow when the ore pass outlet is activated. Flow is essentially a process of continuous shear failure of the muck. The process is driven by gravity and resisted by friction and cohesion. Ore pass muck is thus an engineering material with physical properties that need to be considered in the design of ore passes for flow and stability. Two malfunctions of ore pass operations need to be prevented: (1) failure to flow, which results in hang-ups, and (2) failure to flow over the entire cross section of the ore pass, often referred to as "piping" or "rat-holing." A third design consideration is the stability of ore pass walls.

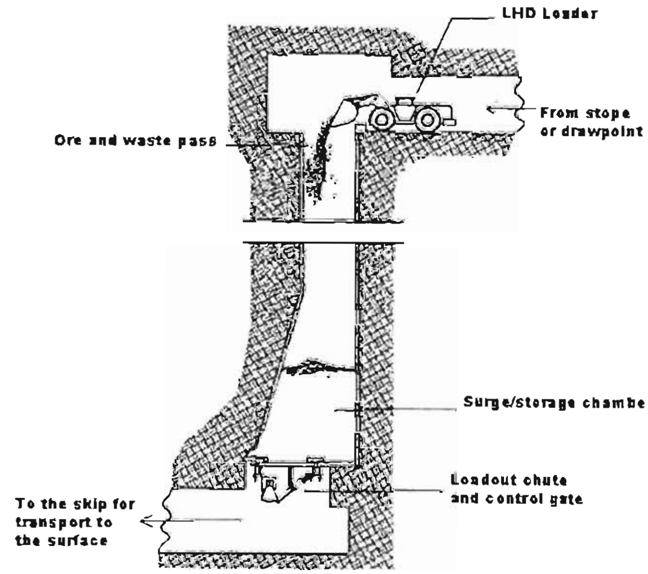

FIGURE 71.1 Typical ore pass for LHDs

71.2.2 Hang-Ups

Two major types of hang-ups in ore passes are boulder arches and cohesive arches. The same types of hang-ups occur in chutes and other transition sections of an ore pass, usually with much greater frequency.

Boulder Arches. A review of the literature, including references from industrial operations handling bulk materials in surface bins and hoppers and laboratory model experiments with sand, indicates that ratios of ore pass diameter to maximum particle diameter of 1:3 (Peele 1947), 1:4.2 (Aytaman 1960), 1:4 to 1:6 (Zenz and Othmer 1960), 1:5 (Jenike 1961), 1:3.6 to 1:45 (Kvapi 1965), and 1:4 to 1:6 (Li et al. 1980) will likely ensure against the formation of boulder arches. A ratio of ore pass diameter to maximum particle size of 5 is likely to result in flow, whereas a ratio of less than 3 is likely to result in a hang-up. A ratio between 3 and 5 is somewhat likely to result in flow. In this regard, ore pass and particle diameters are characteristic linear dimensions when the ore pass is not circular and particles are not spherical.

The distribution of particle shapes and sizes significantly affects the likelihood of hang-ups as well. Particle-size distribution

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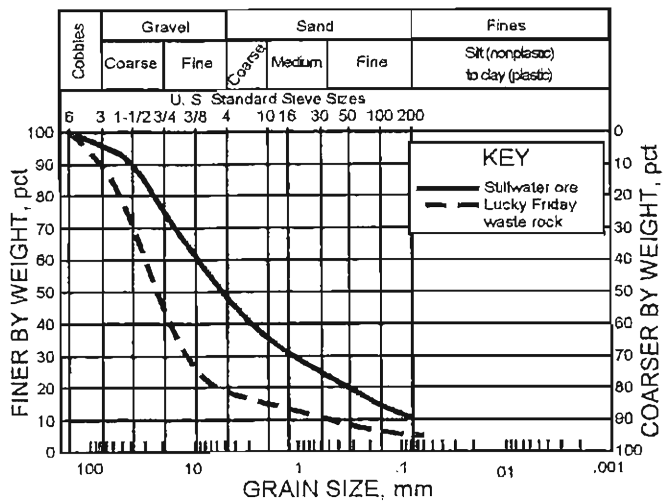

FIGURE 71.2 A typical particle distribution curve from two mines

should be determined from a representative sample of ore pass material after blasting and before the material is dumped into the ore pass. A typical particle distribution curve from two mines is shown in Figure 71.2. If many large boulders are present, then the likelihood of hang-ups is certainly greater than if only a few boulders are present. Hence, these simple, empirical rules-of-thumb for avoiding boulder arches need to be applied with some caution.

The use of a very coarse screen or grizzly that limits the size of the particle entering an ore pass at a dump point is a practical method of ensuring that the maximum particle size is less than one-fifth the ore pass diameter. If oversize material is not prevented from entering the ore pass, then the occurrence of hang-ups will certainly increase, as will operating costs associated with the dangerous task of removing hang-ups. Another factor to consider is that extraneous materials, such as timbers, wire mesh, or rock bolts, often get dumped into ore passes, and these are just as likely to cause hang-ups as oversized rock. Considerable care should be exercised to avoid such a situation.

Cohesive Arches. Cohesive arches are more easily analyzed than boulder arches, but designing for their prevention is also more difficult. The cause of a cohesive arch is usually the stickiness or cohesion of the fine fraction of the broken ore, waste rock, or fill. Fines are subsand-sized particles, that is, those that pass a 200-mesh screen (about 0.072 mm [0.003 in]). The coarse fraction of gravel-sized and larger particles would be retained on an 8-mesh screen (2.4 mm [0.093 in]). Sand-sized particles fall between these limits. Different soil classification schemes for engineering mechanics have slightly different boundaries between gravel, sand, and fines (silt and clay sizes), but the differences are of little practical consequence. Electrostatic surface forces dominate the behavior of fines, while gravity and frictional contact forces govern the behavior of sand-sized and larger particles.

Cohesion of the fine fraction holds the larger particles together to form a continuous arch across the ore pass. The greater the fine fraction, the greater the potential for cohesive arch formation. A rule of thumb in soil mechanics is that when the fine fraction reaches about 20% by weight, the fines may form a continuous matrix in which the coarser particles are embedded. Thus, measurement of soil cohesion is readily done in a direct shear test of the fine fraction, and a representative sample of mine muck containing gravel- and boulder-sized particles is not needed to determine cohesion. Both cohesion c and angle of internal friction ϕ can be determined in the laboratory by a simple standard direct shear test.

Production of fines during ore flow adds to the potential for hang-ups, as does segregation and accumulation of fines, especially at changes in ore pass direction or shape. The cohesion of the fine fraction is seldom constant; extended time between draws often allows for additional consolidation, changes in water content, and increases in cohesion. An increase in moisture introduced by water sprays for dust control and moisture losses during gravity drainage in the ore pass also change cohesion. *Excessive water or uncontrolled water flowing in an ore pass can result in catastrophic inundation and unexpected muck flow at the load-out level and should be avoided at all times.*

Impact loading by ore falling from a dump point may compact ore already in an ore pass and further increase the likelihood of cohesive arch formation before the next draw. Keeping the ore pass active, that is, frequent drawdown, assists in the prevention of cohesive arch formation in cases where cohesion increases with time. What the draw frequency should be necessarily depends on site-specific conditions and experience.

A cohesive arch will fail if the weight of arch W exceeds shearing resistance T where the arch abuts against the ore pass walls. If the arch is of a unit thickness in the vertical direction, then flow occurs provided $\gamma A > \tau P$, where A is the cross-sectional area, P is the perimeter, and τ is the resisting shear stress. Any additional load on the arch from superincumbent material will add to the tendency to flow. Because the arch is unconfined from below, τ is no greater than one-half the unconfined compressive strength of the arch material. Hence, flow occurs if $A/P > (c/\gamma)\cos(\phi)/[1 - \sin(\phi)]$. If D is the diameter of a circular ore pass, the least dimension of a rectangular ore pass, or a long slot, then flow occurs when $D > (1+1/r)(c/\gamma)\cos(\phi)/[1 - \sin(\phi)]$, where $1/r = 1$ for a circular ore pass, D/L for a rectangular ore pass, and 0 for a long slot (Pariseau 1983).

71.2.3 Piping

Piping is not often a problem in an ore pass unless the ore pass is unusually wide. "Wide" in this context means relative to maximum fragment size. A 9-m (30-ft) in diameter ore pass handling dry sandfill would be wide. Some care needs to be given to ensure flow over the entire cross section, that is, flow on a first-in, first-out basis (also called mass flow). If flow does not occur over the entire cross section of the ore pass, then much of the capital cost of excavating the ore pass is wasted. In the event that piping is a concern, then prevention lies in making the transition from the ore pass itself to the chute gate relatively steep and smooth, thus ensuring mass flow action.

Piping or rat-holing occurs when a cohesive material forms a stable annulus between the pipe and the ore pass walls after the material in the flowing portion of the pipe is withdrawn. Such a rathole is stable provided the weight of material above does not overcome the compressive strength at the bottom, thus preventing the more desirable condition of mass flow. The material at the pipe wall is unconfined, and the stress at the pipe bottom is directly proportional to pipe height. *Thus, if the height of the pipe is sufficient, the annulus will fail under its own weight.* The critical pipe height h in this case is given by the ratio of unconfined compressive strength to specific weight of material, that is, by C_o/γ. The unconfined compressive strength may be estimated from cohesion c and angle of internal friction ϕ assuming a Mohr-Coulomb failure criterion. In that case, $C_o = [2c\cos(\phi)/(1 - \sin(\phi)]$. Hence, if $h > [2c\cos(\phi)/(1 - \sin(\phi)]/\gamma$, then flow of the material in the annulus may be initiated. Initiation of flow may destroy or greatly reduce cohesion, so that flow may well continue with further draw of the material even though the height of the material drops below the original critical height. Indeed, with complete loss of cohesion, the critical height for a stable pipe is reduced to zero. However, increased pipe height and therefore weight may increase cohesion by compaction, so there are trade-offs to consider when running an ore pass full to reduce rathole formation.

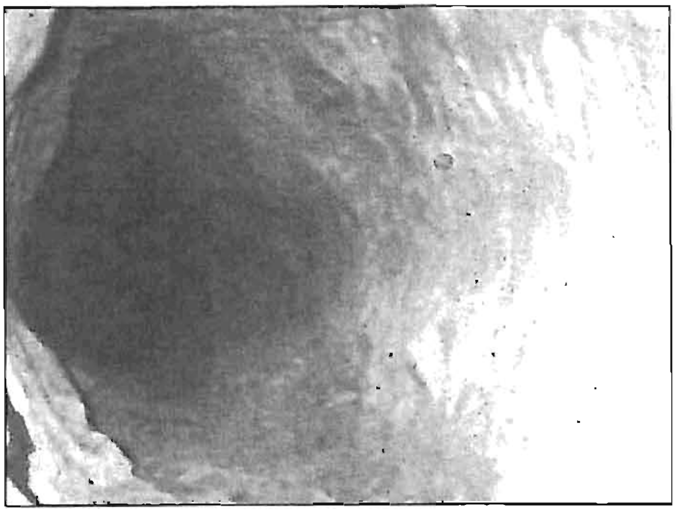

FIGURE 71.3 Extreme case of ore pass borehole breakout

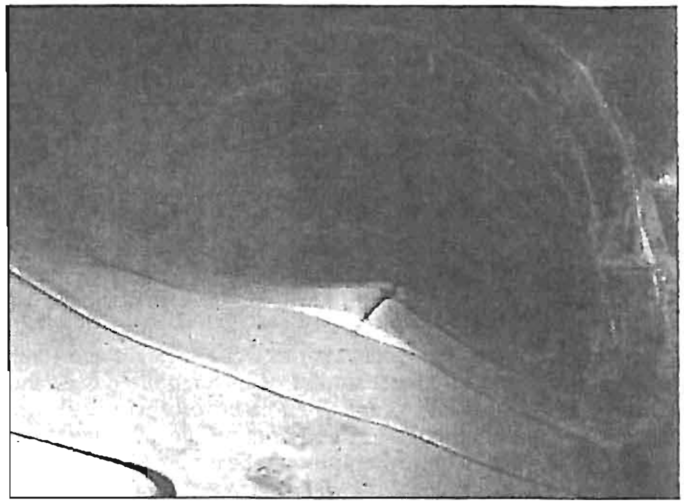

FIGURE 71.4 Steel-lined ore pass that has been subjected to squeezing ground and will require repair or abandonment

71.2.4 Ore Pass Wall Stability

Stability of rathole walls brings into question stability of the ore pass walls proper. Wall stability is a rock mechanics problem that may be addressed by consideration of rock mass strength and stress. Both depend on the properties of joints, fractures, faults, and intact rock between. A convenient index to ore pass wall safety or stability is the traditional engineering factor of safety, a ratio of strength to stress. Thus, factor of safety = C_o/σ_c, where σ_c is peak compressive strength of the ore pass wall. If an appropriate stress concentration factor K is known, then $\sigma_c = K\sigma_o$, where σ_o is a reference stress, usually the premining major principal compression σ_1.

This approach to wall stability assumes that tension at the ore pass walls is absent, a reasonable assumption in most cases. If tension should be present, then a similar analysis may be done to establish a factor of safety with respect to rock mass tensile strength and peak tensile stress concentrated at the ore pass wall. Shape, size of the ore pass cross section, and orientation with respect to in situ stresses are important determinants of stress concentration. Thus, there is an opportunity for engineering design to maximize ore pass wall stability by selecting an optimum shape, orientation, and location. However, what is optimum from a purely rock mechanics view may not be a total optimum. The overall design must consider cost of excavation, lining (if any), and maintenance, especially if the shape selected is unusual—an ellipse, for example.

Ore passes in regions of high stress may be subject to breakouts and excessive wear. Figure 71.3 shows an extreme case of ore pass borehole breakout. It may then be necessary to install a lining for wall stability and proper functioning of the ore pass. Wood linings were often used in the past, but shotcrete and steel liner plates are more often used today where wear is high and erosion of the ore pass cannot be tolerated; for example, in the immediate vicinity of a dump point or chute. Linings generally require repair, periodic maintenance, and sometimes complete replacement. Figure 71.4 shows a steel-lined ore pass that has been subjected to squeezing ground and will require repair or abandonment.

71.3 CHUTE DESIGN

71.3.1 Introduction

The ore pass chute is of critical importance. The design of chutes involves geometric considerations to accommodate transitions in shape and direction, prevention of hang-ups, and structural elements. Chutes are usually sized to fit ore cars or conveyor belts for transport of the ore to shaft loading pockets or the surface. Because chute width is generally less than ore pass width, hang-ups are much more likely to occur in the vicinity of a chute rather than in the ore pass itself. Hydraulic or pneumatic control of the chute gate is a common way of regulating the flow of the muck from the chute. Arc gates and undershot guillotine gates are examples of chutes gates used widely in underground vein mining. Anchor chains are often used to regulate the flow of muck during the loading cycle. Although the type of chute used varies from mine to mine, the common design element is chute width relative to particle size.

The same guidelines for preventing hang-ups in ore passes apply to chutes. A chute width-to-maximum-particle-size ratio of 5 or greater is desirable. Rational design of an associated grizzly then requires that grizzly spacing be no more than five times chute width rather than five times ore pass width. A lesser ratio increases the risk of hang-ups at the chute. In caving operations, where control of maximum particle size is difficult, a relatively close spacing of grizzly bars would lead to the need for secondary breakage of oversized material at dump points, but this is preferable to an increased number of hang-ups at chutes. Well-designed blast patterns produce much less oversized material and the need for secondary breakage at grizzlies.

71.3.2 Static Loads

The main task for structural design is estimating what loads the chute support will take during operation. Both static and dynamic loads need to be considered. A simple equilibrium analysis provides some guidance for estimating static load. An equilibrium analysis of a horizontal layer of material in an ore pass shows that the vertical stress averaged over the cross-sectional area of the ore pass is given by—

$$\sigma_V = \left(\frac{\gamma(A/P) - cM}{M\tan(\phi)}\right)\{1 - exp[-zM\tan(\phi)/(A/P)]\}$$

where σ_V = average vertical stress,

z = depth of muck in the ore pass,

A = cross-sectional area,

P = perimeter,

γ = specific weight of muck,

c = cohesion,

and $M = 1/[1+2(\tan\phi)^2]$.

This formula is an extension of the Janssen (1895) formula and takes into account any tendency for fines to adhere to ore pass walls, as well as friction of muck on walls (Pariseau 1983). The Jannsen formula was originally derived for cohesionless grains in surface silos and forms the basis for silo design in many countries. The derivation is straightforward and has been repeated by many investigators and tested repeatedly in model studies and by measurements on full-scale silos. Most laboratory models use cohesionless model materials, mainly sand. An example within a mining context is the work of Blight and Haak (1994), who report on model studies of inclined ore passes and chute loading. Adhesion to and friction on ore pass walls are likely to be less than cohesion and friction angle of muck on muck. Because flow requires continuous shear failure of the muck regardless of whether slip at the walls occurs, the muck-on-muck cohesion and friction angle are used in this formula rather than the corresponding muck-on-wall properties.

The equilibrium condition can be expressed more compactly as

$$\sigma_V = (C_2/C_1)\{1 - \exp[-zC_1]\}$$

where $C_1 = M\tan(\phi)/(A/P)$

and $C_2 = \gamma - cM/(A/P)$.

In this compact form, one clearly sees that there is an asymptotic limit to the vertical stress exerted by the muck column on the material below. A chute positioned directly below a vertical muck column at depth h sees only a fraction of the total column weight. The bottom load exerted by the muck column is simply $\sigma_V A$. The difference is transferred via shear to the ore pass walls. If W is muck column weight, then the total load delivered in shear to the ore pass walls is $T = W - \sigma_V A$. At a muck depth of about $z = 1/C_1$, the bottom stress σ_V is two-thirds the stress that would be possible in an infinitely deep ore pass. If the ore pass is circular with diameter D and the friction angle is 35°, then $M\tan(\phi)$ is about one-third, and σ_V approaches two-thirds the limit stress at a depth of about three times ore pass diameter.

The greatest limit stress at the column bottom occurs when cohesion is nil. In this case, the limit stress is $3\gamma D$. Because ore pass depth is usually much greater than its diameter, the bottom stress does not increase much with depth beyond $3D$. Hence, for static load chute design, one is justified in using a conservative value, that is,

$$\sigma_V = \gamma(A/P)/M\tan(\phi).$$

A simple adjustment for inclined ore passes is to use a component of specific weight normal to the ore pass cross section, that is, $\gamma\sin(\delta)$, where δ is ore pass inclination. This adjustment should be acceptable within a practical range of gravity flow ore pass inclinations, generally less than 45°.

71.3.3 Dynamic Loads

A dynamic load is delivered to muck at the top of an ore pass during dumping, that is, transmitted through the muck to the chute and also to the ore pass walls. Dynamic loads that arise during dumping are much more difficult to estimate and are often taken to be some small multiple of the static load. Dynamic chute loads may be several times the static load (Blight and Haak 1994; Beus et al. 1998). An approximate approach to quantifying the dynamic effect of dumping is to consider the impact at the top of the muck in the ore pass as an additional stress σ_o. Dynamic equilibrium in a vertical ore pass may then be expressed as

$$\sigma_d = (C_2/C_1)\{1 - \exp[-z_oC_1]\} = \sigma_o\exp(-z_oC_1)$$

where z_o is the muck depth at the time of impact. Thus, the effect of impact loading treated in this quasi-static manner diminishes exponentially with depth, while the limit stress remains the same as in the static case. This allows one to quantify the concept of leaving a muck cushion in an ore pass to protect a chute directly below. Of course, the muck forces are concentrated in the structural supports of the chute and gate, and the actual distribution of axial and bending stresses in the supports must take into account how the muck forces are tranmitted to these supports. Chute design is thus a challenging combination of muck mechanics and traditional structural analysis.

Another source of dynamic chute loading is the sudden release of muck from a hang-up above a chute. In this case, there is likely to be very little muck left in the chute to offer protection against the impact of the muck falling from above. The potential for severe structural damage may be quite high under direct impact of a released hang-up. The dynamic stress, σ_d, produced in a beam loaded at midspan from the impact of a body of weight W falling from a height h is greater than the static stress σ_{st} according to—

$$\frac{\sigma_d}{\sigma_{st}} = 1 + [1 + 2h/\delta_{st}]^{1/2}$$

where δ_{st} is the deflection at midspan under gradual (static) application of the same load (Gere and Timoshenko 1997). If h is zero, the dynamic stress produced by a sudden release of the weight that is just in contact with the beam is twice the stress produced by gradual release of the same weight. Therefore, if the energy losses of material falling down an ore pass are very high, then the dynamic stress on the chute gate in an empty ore pass may be approximated by dynamic stress greater by a factor of 2 over a static stress produced by the same weight. However, if h is large compared to deflection and energy loss is negligible, then the dynamic stress is approximately—

$$\sigma_d = \sigma_{st}\sqrt{2h/\delta_{st}}$$

By off-setting the chute to one side of an ore pass, a common practice, the damaging effects of impact loading may be reduced. Bends and knuckles serve the same purpose. Inclined ore passes may also experience less impact chute loading as muck ricochets from ore pass walls during its fall. Particle trajectories initiated during dumping, even in a vertical ore pass, will almost certainly strike the ore pass wall unless muck is present near the dump point.

An elementary analysis of impact shows that the average force of particle-wall impact is directly proportional to particle velocity and particle weight and inversely proportional to duration of impact (Pariseau 1983). If ore pass wear is caused mainly by impact during dumping rather than by abrasion during draw, then large boulders should be made to move more slowly. As a practical matter, this objective may be approached by leaving an adequate muck cushion in the ore pass and by using a properly sized grizzly. Unfortunately, the potential benefits of a protective muck cushion and of running an ore pass full are not always available. For example, in case of ores liable to sulphide oxidation, with attendant cementation and the creation of fire hazards, residence time in the ore pass is limited and may require drawdown before the cycle of mining and dumping is completed.

71.3.4 Detection and Removal of Hang-Ups

Methods of locating hang-ups include visual inspection, lowering a camera down the ore pass from the top, running a long pole through the ore pass, or sending a helium balloon up the ore pass. Various sensors that use laser, radar, microwave reflection, or ultrasonic technologies to delineate material level and location from the top are also on the market. Investigators at the Spokane Research Laboratory of the National Institute for Occupational

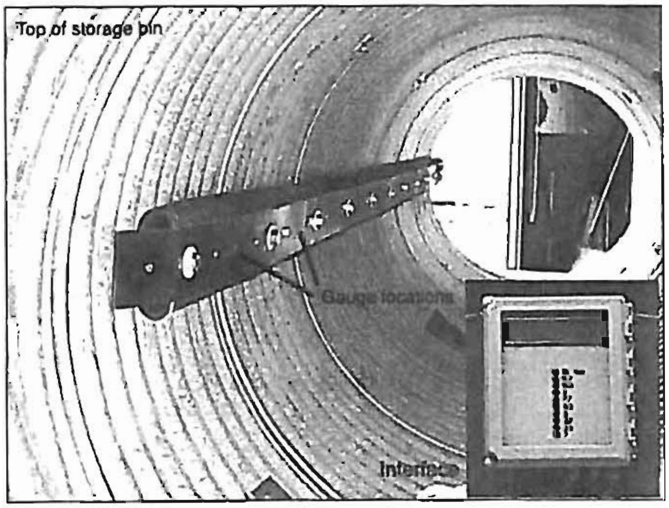

FIGURE 71.5 Ore pass level and blockage indicator

Safety and Health (SRL/NIOSH) have developed an "ore pass level and blockage indicator" (patent pending) based on strain gauge technology. This device can detect bin or ore pass levels as well as voids within the muck column (Figure 71.5). Currently, hang-ups are most commonly dectected by a trammer or chute-puller when a lack of muck is noticed or or an operator attempts to dump muck into a filled ore pass.

A number of methods are used for hang-up removal. The most common and effective method to remove hang-ups is blasting. The method of getting explosives to a hang-up depends on location in the ore pass. For hang-ups high in the ore pass, various devices may be used to "float" an explosive package or "bomb" to the hang-up using air pressure. Another method is to fire a projectile at the hang-up from the bottom of the ore pass. Many hang-ups occur just above the chute gate where flow is constricted and the direction of the ore pass changes. These hang-ups can be removed by mechanical devices, hand tools, or explosives placed with plastic pipe or powder-tamping poles taped together.

Because of the hazards to personnel and the potential for chute and ore pass damage, other safer, nondestructive methods are desirable. Blasting to remove cohesive hang-ups may prove ineffective and only compact the material more. High-pressure air injection directed at or just above the point of arching or controlled water injection directed to undermine the arch may be more effective. Water flushing from a dump point is also used, but care needs to be exercised to avoid impounding water in the voids of the muck that may suddenly break free in a mudflow that can cause considerable damage and possible injury to operators.

71.4 SAFETY CONSIDERATIONS

The hazards related to the operation of ore and waste rock passes have been identified as a significant safety problem in underground metal mines in the United States. Applicable ore pass safety and design criteria, as defined in the Code of Federal Regulations 30 CFR, parts 57.9310 and 9309, state—

a. Prior to chute-pulling, persons who could be affected by the draw or otherwise exposed to danger shall be warned and given time to clear the hazardous area.

b. Persons attempting to free chute hangups shall be experienced and familiar with the task, know the hazards involved, and use the proper tools to free material.

c. When broken rock or material is dumped into an empty chute, the chute shall be equipped with a guard or all persons shall be isolated from the hazard of flying rock or material.

d. Chute-loading installations shall be designed to provide a safe location for persons pulling chutes.

Evaluation of statistics and other information from the Mine Safety and Health Administration (MSHA), particularly narratives from investigative reports, are useful for identifying the underlying cause of accidents. Several accident narratives that illustrate the nature of ore pass accidents are given below.

Fatality: [T]he miners began banging the chute gate against the chute lip...material broke loose and impacted the chute with enough force to separate the chute assembly from the steel beam supports. The material fatally engulfed one of the miners as they tried to escape.

Fatality: Victim was loading ore train using pneumatically operated chute door when very wet ore...broke the chute structure burying the victim.

Fatality: While the skip tender was loading a muck skip, the heavy muck came loose [in the ore pass] causing an overflow of water...overflow washed the miner over and through the shaft guards.

Fatality: Employee was fatally injured when a chute filled with ore blew out covering him with approximately 5 feet of ore.

71.5 RESEARCH AND DEVELOPMENT AT SRL/NIOSH

71.5.1 Introduction

Ore pass research and development activities have been ongoing at SRL/NIOSH for several years and involve laboratory tests, field tests, and computer modeling to validate theoretical formulations for static and dynamic loads and to test new methods of prevention, detection, and removal of hang-ups. Laboratory and field tests have been conducted to validate these theoretical formulations.

71.5.2 Laboratory Tests

A laboratory ore pass facility has recently been completed to facilitate tests in a controlled environment. (Beus and Ruff 1996). Figure 71.6 shows this fully automated facility utilizing an 18.3-m hoist tower to simulate the headframe and shaft. A 5.5-m- (18-ft) deep underground "shaft" lined with concrete sections houses a loading pocket and a measuring cartridge. The ore-hoisting skip has the capacity of about 450 kg (1,000 lb). The ore pass is a 1.03-m (3.5-ft) in diameter corrugated culvert that can be inclined 65° to 90° vertically in 5° increments. Design of the ore pass, chute support frame, I-beams, hanger bolts, and saddle beams are one-third the size of an actual ore pass and chute control gate currently used at an underground mine.

Ore or waste material is loaded through a grizzly and into the skip for hoisting. The skip hoists the ore to the top of a headframe, where it is discharged into a hopper and chute assembly, which routes it to the top of the ore pass. Two types of gravel were tested using the ore pass in a vertical configuration. The impact period at the chute was about 5 s due to the stream effect of discharge into the ore pass. Strain data were collected 60 times per second from each of the eight supporting bolts. Pea gravel of uniform distribution indicated an impact load factor ranging from 1.24 to 1.39 when it was dumped into the empty chute. Coarse gravel of uniform distribution indicated an impact load factor from 1.22 to 1.39. Figure 71.7 illustrates a typical impulse curve from one skip dump of gravel. Several large plugs of material were also dropped to simulate a large boulder or released hang-up directly impacting the control gate. These tests resulted in dynamic loads of up to nearly 30 times the static load.

A full-scale mockup of the reduced-scale chute and gate assembly was also constructed. Three impact tests were conducted in which loads of mine waste rock weighing 808, 1,000, and 563 kg (1,778, 2,200, and 1,238 lb) were dropped

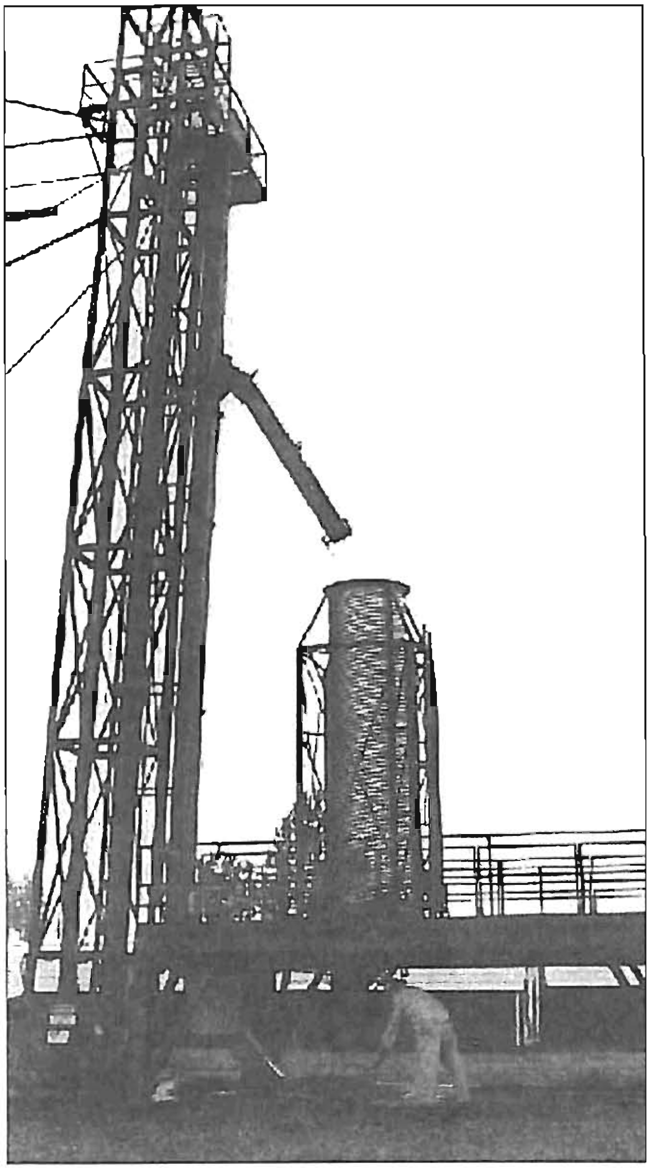

FIGURE 71.6 Automated ore pass test facility with an 18.3-m hoist tower to simulate a headframe and shaft

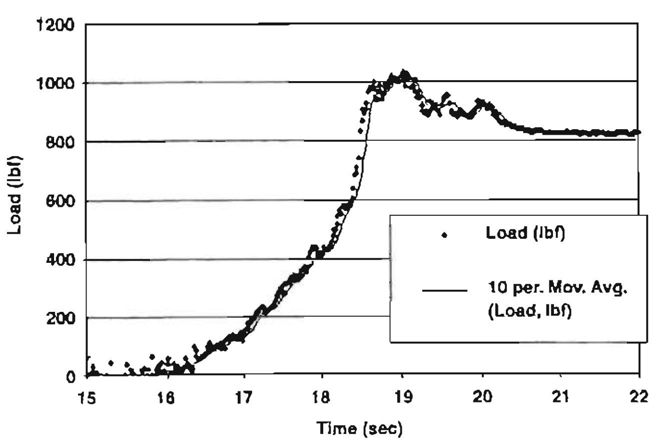

FIGURE 71.7 Typical impulse curve from one skip dump of gravel

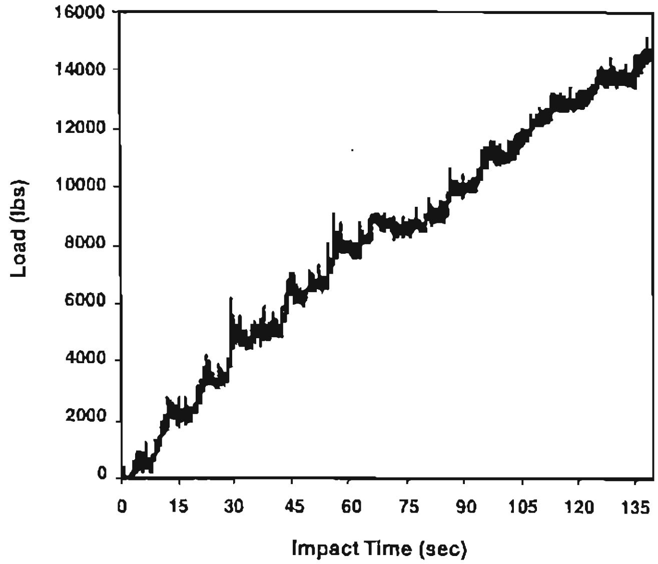

FIGURE 71.8 Typical dump pattern as shown by the total force on all support bolts

from a height of 1.8 m (82 in) into a 2.4-m- (8-ft-) wide, steel-reinforced container sitting on the mockup chute assembly. A front-end loader with a clam shell bucket was used to drop the material into the container. After each drop, the material was removed and weighed. The impact period was about 1 s, and the maximum impact load factor was 2.2.

71.5.3 Field Tests

Field tests were also conducted in mines to determine actual static and impact loads. The ore pass chute and gate systems provided by the cooperators for testing contain offset boreholes and doglegs that direct falling material to the floor of the ore pass to absorb the initial impacts from the falling column of ore or waste. The initial field test was conducted in a deep silver mine in northern Idaho, USA. The approach was based on the system developed and tested on the full-scale mockup. The centerline of the gate assembly was offset 2.4 m (8 ft) from the longitudinal axis of the ore pass so that falling ore did not directly hit it.

Tensile strains produced from eight strain-gauged 3.8-cm (1.5-in) in diameter bolts that support the ore pass chute and gate provided a measurement of the total vertical force acting on the structure as material was dumped into the ore pass. Fourteen loads of damp waste rock from LHD units at 1.53 m^3 (54 ft^3) per load were dumped into an empty ore pass. Figure 71.8 shows a typical dump pattern as shown by the total force on all the support bolts. Load measurements were collected for 10 s for each dump. Twelve of the dumps averaged from 2,270 to 2,730 kg (5,000 to 6,000 lb) of material; two of the dumps (8 and 9) were material from cleaning up the drift and weighed about 270 kg (600 lb) each.

The weight of material dumped in the ore pass was in excess of 27,300 kg (60,000 lb); however, a maximum static load of only 6,800 kg (15,000 lb) was measured. This load was approximately the weight of waste material required to fill the chute. The rest of the static load was carried by timber adjacent to the chute assembly and the ore pass walls. Impact load factors ranged from 1.06 to 1.33 on the chute and gate assembly and were reduced significantly because the chute was offset from the ore pass.

A second field test at another underground mine involved a chute and gate support structure. Figure 71.9 shows four of eight instrumented chute support bolts, after tensioning, using load

FIGURE 71.9 Four of eight instrumented chute support bolts, after tensioning, using load washers to determine total horizontal force on the gate

washers to determine total horizontal force on the gate. During the experiment, the ore pass was consistently blocked and required direct blasts in the chute at the bottom of the ore pass to free the material. Comparing initial bolt tensions with tension data after 24 hr of chute operation, nearly 90% of the initial gate support bolt tension load was lost. It is possible that large dynamic components from blasting may have overloaded the bolts. Dynamic loads on structures from secondary blasting in ore passes is unknown. The shockwave from blasting may have had more effect on chute structural integrity than rock impacts.

71.5.4 Computer Modeling

Computer modeling aims to simulate dynamic and static forces measured in the field on the chute structure, as well as overall particle flow phenomena and the potential for hang-ups. Three-dimensional particle flow PFC^{3d} models (Itasca Consulting Group 1995a, 1995b) were used to simulate flow through the ore pass and truck chute instrumented in the field tests. The static load effect of 40 LHD dumps of about 7 tonnes (7.7 tons) of material each for a total weight of about 280 tonnes (308 tons) were simulated. The rate of increase in gate loads dropped dramatically after about one-third (10 to 15) of the LHD loads had been delivered. Analysis indicates that dynamic loads were a factor on the control gate only during the first three to five dumps.

Comparison of measurements and computer results using particle flow codes indicate that several difficulties remain before realistic determination and modeling of the dynamic effects of

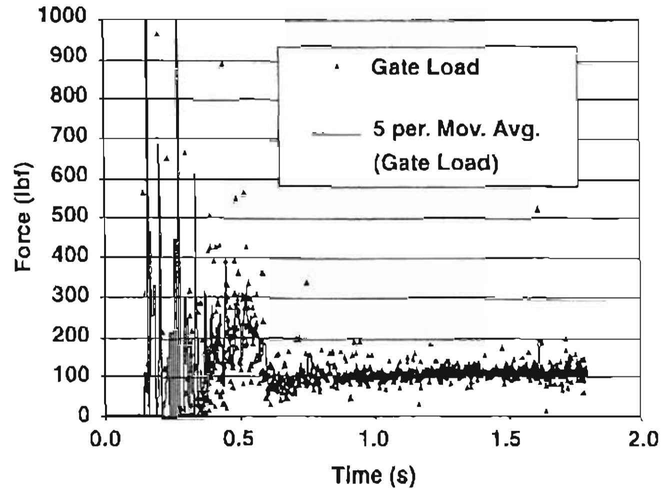

FIGURE 71.10 Dynamic load response on chute gate over impact period

particle flow in ore passes and impact loads on the gates can be achieved. Computer analyses can overestimate the dynamic impact load from the rock compared to impact loads measured in field tests if energy loss during impact is not accounted for in the simulation.

Obviously uniformly graded, smoothly rounded particles used in the PFC^{3d} code are not found in a freshly blasted muck pile prior to transport to the ore pass. The distribution of particle shapes and sizes affects all the behavioral characteristics of the falling muck column. Incorporating more realistic rock particle shapes and distributions of particle sizes in numerical models improves rocklike characteristics during fall and impact. Other factors difficult to model are rock durability, angularity, and rebound characteristics following impact (Larson et al. 1998).

Single dumps in a PFC^{3d} model of the one-third-scale ore pass were compared with load data collected at the ore pass test facility. Shaped particles and appropriate stiffness and friction properties were used from Larson et al. (1998). A damping constant was included to account for energy loss during particle impacts. The particles were formed by clumping four balls together in a tetrahedral geometry. Realistic impact rebound trajectories and particle rotations were achieved. An improved impulse curve compared well with actual dynamic load data from the ore pass test facility. Figure 71.10 illustrates the dynamic load response on the chute gate over the impact period. Note that the first particle impacts have very high dynamic loads, while the later particle arrivals are cushioned by the initial material.

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