The influence of rockpass excavation and operation on the structural design of box fronts

by S. Achilleoudes* and G.J. Krige*

Synopsis

This paper describes the various factors that contribute to the maximum design pressures acting on box fronts and how these factors influence the mass and economy of box front steelwork. The influence of material density, rock size and moisture content on the incidence of hang ups and mud rushes in the rock pass is also highlighted.

The loads acting on any box front are a function of several different parameters. These include natural, operational and excavational parameters. A case study analysis was carried out using UG2 ore and a typical box front structure to demonstrate the relationship between the mass of the box front and the material pressures resulting from variations in the above parameters.

Based on the results of this case study, the required design mass of a side mounted box front for a rock pass containing platinum UG2 increases in (close to) linear proportion to % overbreak and is also linearly proportional to the pressure on the face of the box front beyond saturated conditions.

The mass of the box front structure also doubles with a 100% increase in over-break which emphasises that a box hole excavation that is as neat as possible will yield a lighter and more econimical box front structure.

Introduction

A box front comprises any structure closing the bottom end of a rockpass. This includes a chute and gate or gates, supporting structural steel, concrete structures and foundations. The box front is used to control the storage of material in the rockpass and the flow of material into hoppers on the haulage level, a potentially hazardous operation. There is generally a large number of rockpasses in a mine, many of which are operated only for a few years, before new rockpasses are excavated and the box fronts moved. Although it is crucial that box fronts allow safe operation of rockpasses, it is also important that they are not unduly heavy and expensive. A tight balance must thus be maintained between safety and economy in the provision of box fronts.

This paper will explore the various factors contributing to the maximum design pressures, which box fronts must resist, and then use simplified relationships between the strength of steel members and their mass to show how these factors influence the required mass of box front steelwork.

There are two major points of concern in designing box fronts as follows:

> What static pressure should the box front be designed to resist? The problem is similar to that of estimating the pressure on the floor of a silo. Because the walls of an ore pass are usually very rough, a form of Janssens's silo theory for an off-vertical silo seems appropriate under dry conditions. However, what is the effect of fully saturated and slurry type ore on the box front size and mass?
> Size of box hole; this may vary depending on the amount of overbreak. The size of the box hole should not be bigger than the opening size of the box front chute. However, due to over excavating and blasting, the box hole may be over excavated, which significantly affects the required size and mass of the box front structure.

Design forces

The forces acting on any box front are a function of several different parameters. Some of these parameters are natural, and thus cannot be changed. Other variables depend on how the rockpass is operated, and still others depend on how the box hole and lower portion of the rockpass are excavated. A case study has been conducted on a typical side mounted box front for UG2 platinum ore. The important parameters are described below:

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* *Anglo Operations Limited.*

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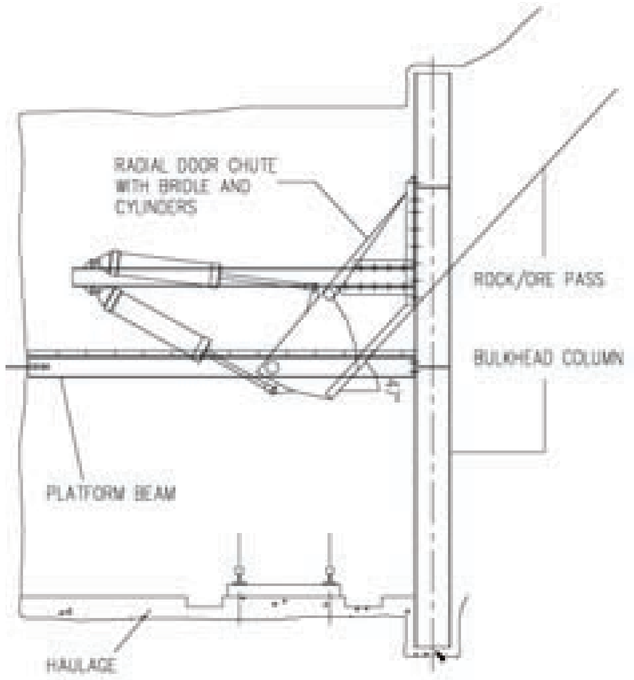

Figure 1—Elevation on a side mounted box front

Natural parameters

Ore pass height and inclination

The height of the ore pass is an important factor in the design of the box front structure. ore passes vary in height from 10 m to up to 100 m. Figure 2 shows the change of pressure on the box front with height under the following conditions:

Dry conditions

Submerged conditions (saturated, undisturbed)

Hydrostatic conditions (saturated, disturbed—slurry)

In accordance with SABS 0208—4, if it can be shown that hydrostatic pressure conditions will not be developed, then dry conditions may be assumed. However, if this cannot be shown, then the load applied to box fronts shall be based on hydrostatic pressure p_n (slurry conditions) obtained from the following equation:

$$p_n = \rho g h_b$$

where:

ρ is the density of the ore pass contents

g is the acceleration due to gravity = 9.81 m/s^2

h_b is the height of the ore pass, in metres, for heights up to 30 m or equal 30 m for ore passes of height in excess of 30 m.

The inclination of an ore pass must be sufficiently great for the material to flow. The prevalence of inclined ore passes is due in part to the belief, held by many engineers, that hang-ups (blockages) are less likely in inclined as opposed to vertical ore passes (Pfeider and Dufresne, 1961). A further consideration in favour of inclined ore passes is that there is less damage to the walls from the richochet of blocks than in a vertical ore pass. Material in inclined ore passes tends to slide down the footwall. Inclined ore passess sometimes have inclinations less than 60°, but this is not common practice and troubles arise when wet fines are dumped. Actually, inclinations greater than 70° may be required if the material handled contains a large percentage of wet fines.

Rock density

Ore consists of broken rock that is usually damp or wet, and often contains fine particles that may be clayey. The density of the ore, which is an important parameter in the design of the box front, varies depending on the degree of saturation and void ratio of the material. E.g. the bulk density of platinum UG2 ore typically varies from 28 to 32 kN/m^3, while the saturated density is lower at 25 kN/m^3. The higher the density of the ore, the higher the static pressure on the box front door and the more robust the box front and chute are required to be. The density of the ore also affects the operation of the ore pass, as a form of hang-up may occur

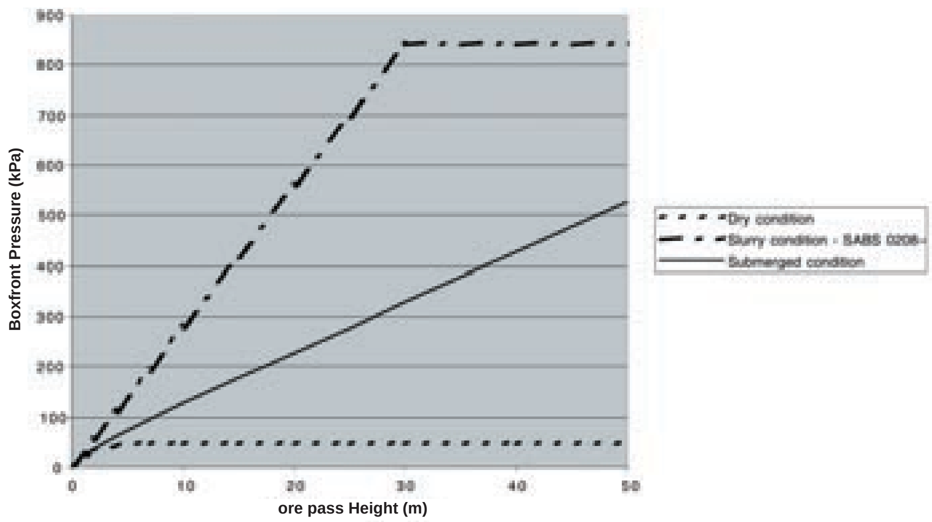

Figure 2—Variation of ore pass pressure with height

where sticky, fine particles, which are present in the ore, adhere to each other. This cohesive resistance is enhanced if moisture is present. If the strength of the fines is sufficient, a stable arch may form across the ore pass. This hang-up may however, be easily removed by undermining using high-pressure spray methods.

Operational parameters

Water content

Moisture conditions in ore usually increase cohesiveness, but a large amount of water will destroy the cohesion between the material particles, bringing the fines into a slurry state and reducing the effective normal stress between the particles. In the extreme case, a full hydrostatic head may develop and a dangerous mud rush results. Trying to stop a mud rush with a strong chute system is difficult, and allowing the mud rush to continue is often the only solution with an escape way for the chute operator. In accordance with the Minerals Act and Regulations (50/1991) no person may enter a rockpass at the discharge end while it contains any water, mud or broken rock.

Size of rocks in rockpass

The size of rocks in an ore/rockpass has an important effect on the operation of the pass. For example, A form of hang-up known as an interlocking arch occurs as a result of large sized boulders becoming wedged together to form an obstruction. The probability of forming such arches depends on the percentage of large fragments in the material handled, on the size of the particles relative to the size of the ore pass and outlet, on the shape of the rock fragments, and on the velocity profile across the flowing ore. At the draw point or box front, a criterion has been developed for avoiding these hang-ups as follows:

$$D_o >= 3d$$

Where:

D_o = width of outlet (m)

d = maximum dimension of largest block, (m)

Clearing hang-ups

Even if ore passes are well deisgned, hang-ups may still occur. If hang-ups occur at the drawpoint, it is relatively easy to dislodge them, whether they are composed of interlocking blocks or cohesive fines. If hang-ups occur away from the drawpoint, removal is more complicated.

First, the location of the hangup relative to the drawpoint must be determined. Hang-ups relatively near the drawpoint are normally dislodged by passing one or more lengths of blasting stick (25 mm by 50 mm plank), to which explosives are attached, up the ore pass to the hang-up and detonating the explosives electrically. The hang-up may also be broken by a method known as barring. This involves inserting a barring pole through the opening above the gate into the ore pass, and hopefully releasing the hang-up if it is sufficiently close to the ore pass opening.

For more remote hang-ups, explosives could be placed in long drill holes that intersect the hang-up. The U.S Bureau of Mines has developed a 'Hang-up Clearance Module' that fires an explosive charge toward a hang-up.

When the hang-up is released, the ore above the hang-up falls down the ore pass and impacts on the gate. The gate must be designed to resist the resulting dynamic pressure; however, this is not often the case. A dog leg is introduced which reduces the impact of the falling hang-up; however, its effectiveness has not been proven conclusively.

Excavation parameters

Box hole size

The size of the box hole has an important influence on the design of the box front. The box front has to support all forces that are not carried directly by the rock mass or indirectly by structural connection through the rock anchors into the rock mass. Thus if the box hole size is over excavated, then the box front must be designed to carry the pressure exerted on the full projected area of the box hole.

Figure 4 shows the effect of over-excavation on the required mass of the box front.

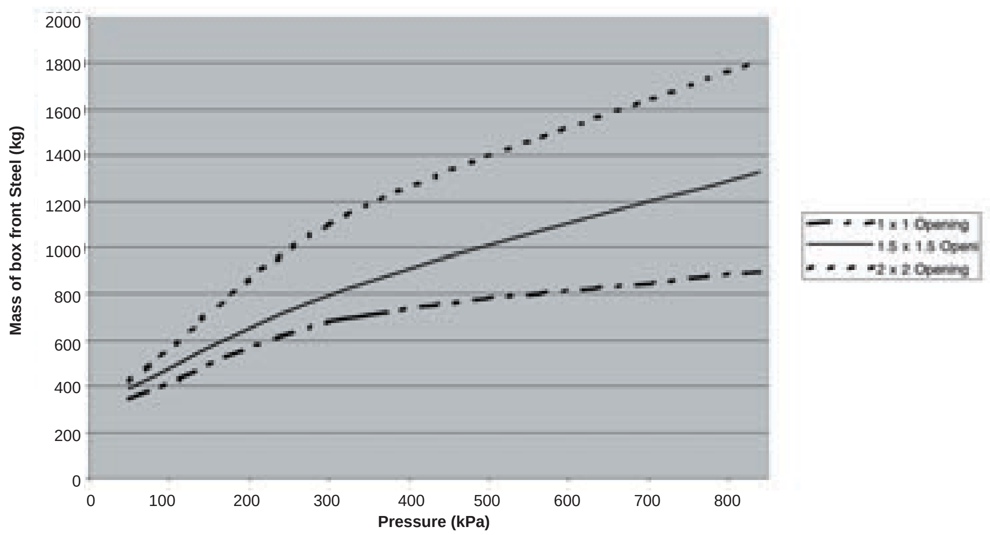

Figure 3—Graph of mass of steel of box front versus pressure on box front

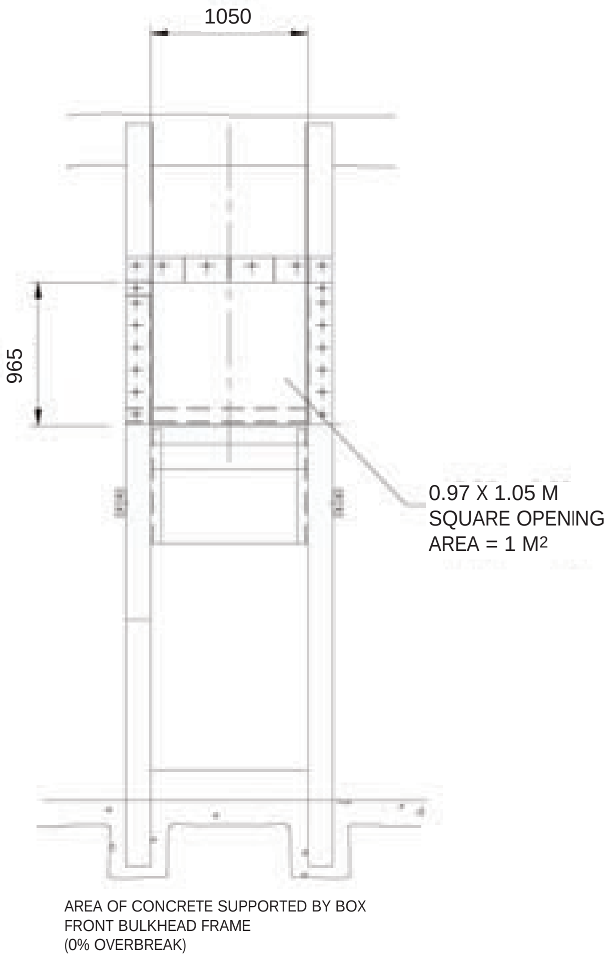

Figure 4—No overbreak

Effect of operation on box front design

The ore used in this analysis is platinum UG2 ore with the following densities:

Saturated density 2,5 t/m^3
Bulk density 2.8–3.2 t/m^3

Janssen's equations have been used to determine the vertical pressure (σ_v) on the box front door due to the ore under dry conditions and saturated conditions, whereby in both cases, silo conditions are assumed. In accordance with SABS 0208—part 4, the maximum height of the silo is assumed to be 30 m. Due to the silo effect, any material above 30 m is assumed to have no affect. Hydrostatic conditions are assumed for the ore in a wet disturbed state, (slurry conditions).

A series of 3D models was constructed for the different opening sizes and design pressures resulting from the variation in ore densities described above.

Figure 3 shows the required mass of steel versus opening size for dry, saturated and slurry conditions. It will be seen from this graph that the curves become linear at around 340 kPa, (saturated pressure) and the gradients of each vary with the size of the opening for a maximum height of 30 m.

Effect of excavation on box front design

A series of models were also compiled for differing percentages of overbreak. Figures 4–6 show the openings, which vary from 1 x 1 m to 2 x 2 m, which simulate the effect of overbreak on the box front structure. The overbreak is assumed to be 0, 50 and 100% relative to the chute opening size of approximately 1 x 1 m. It is assumed that the load on the box front face, arising from the ore pass contents, is carried by the concrete filler and the face of the chute door to two steel support columns. These columns transfer the horizontal components of force in bearing into the rock at the top of the columns and through kick rails to the opposite side of the haulage. Overbeak will be filled with non-structural concrete, which will not be anchored in anyway to the side or hanging-wall.

Figure 7 shows a graph of mass of box front bulkhead steel versus percentage overbreak. The inclincation and height of the ore pass have been kept constant in all cases, viz. 60° and 30 m. It will be seen from this graph that the relationship between the mass of steelwork required to resist the material loads is linear with respect to the overbreak in the box hole.

Overbreak in excess of 100% value will be filled with concrete anchored to the side wall to provide stability to the filler concrete. Thus the relationship between the mass of steelwork and opening size will vary depending on the degree of support provided by the rockpass.

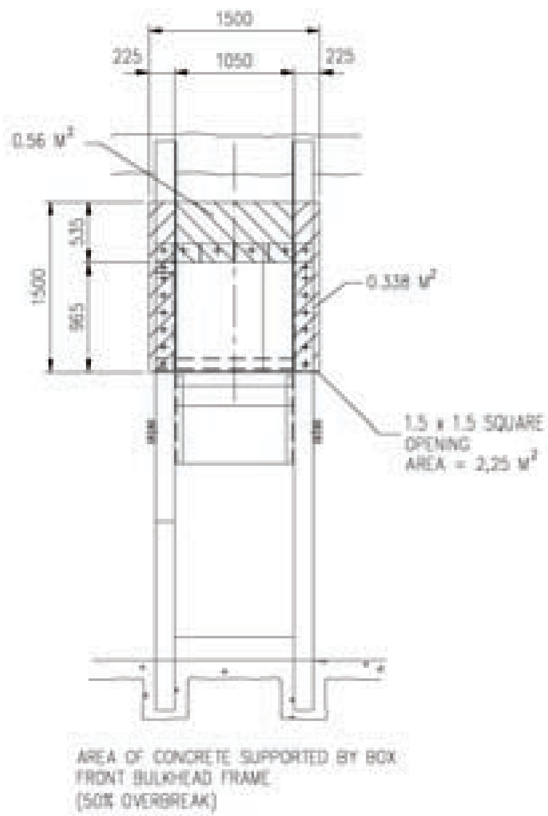

Figure 5—50% overbreak

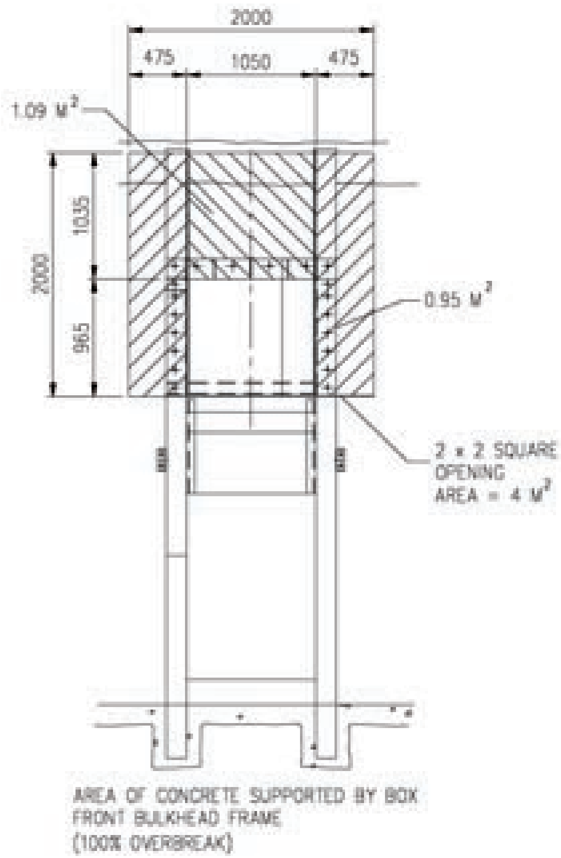

Figure 6—100% overbreak

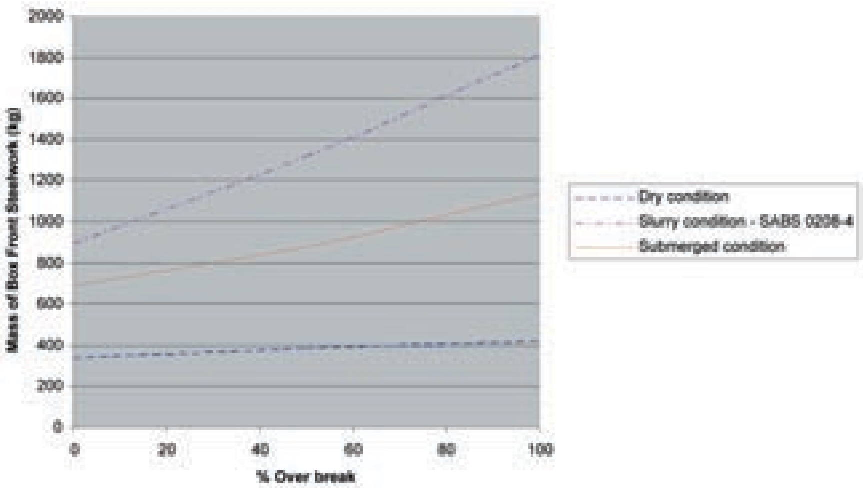

Figure 7—Graph of mass of box front frame versus % overbreak of box hole

Discussion and conclusion

Based on the results of the case study it has been confirmed that the required design mass of a side mounted box front for an ore pass containing platinum UG2 increases in (close to) linear proportion to % overbreak, and is also linearly proportional to the pressure on the face of the box front between 340 kPa, which is saturated conditions, and a maximum hydrostatic pressure of 840 kPa under slurry conditions. A similar exercise may be necessary in order to determine the above relationships for hanging wall box fronts and side-mounted box fronts of differing design.

From the case study, the box front mass increases from 900 kg at 0% overbreak to 1 800 kg at 100% overbreak under slurry conditions, which equates to double the material cost and a similar increase in labour and installation time as the heavier structure is more difficult to install and the larger excavation requires more filler concrete. This emphasizes that an excavation that is as neat as possible is beneficial both from a cost and an installation point of view.

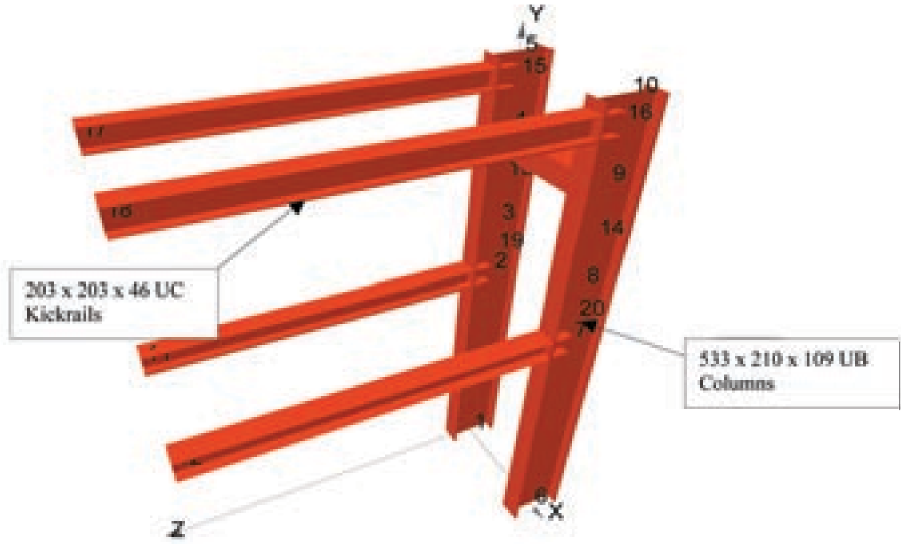

Figure 8 – Size of typical box front for a 2 x 2 opening under slurry conditions

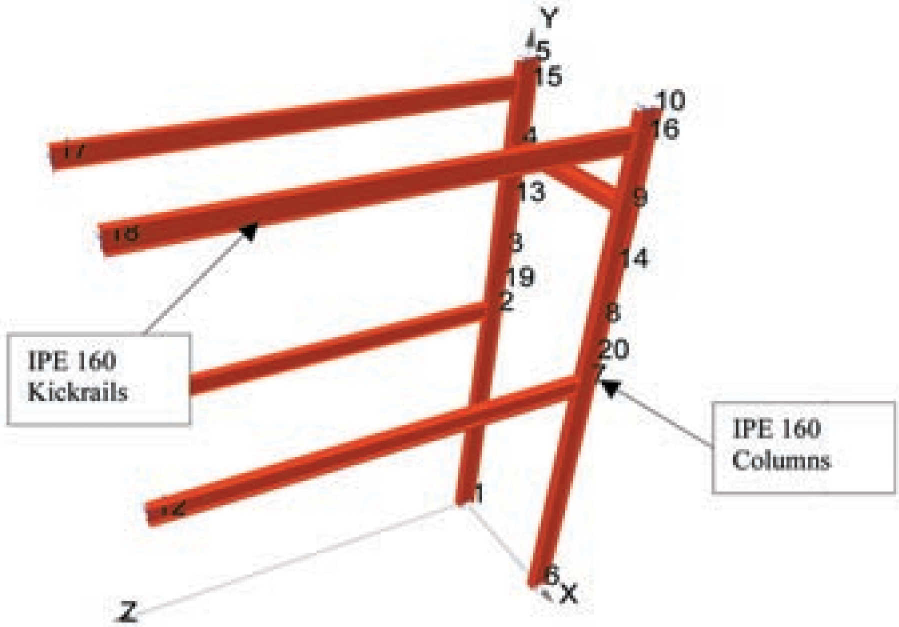

Figure 9—Size of typical box front for a 1.0 x 1.0 opening under dry conditions

Mining personnel have often expressed their concern that box front steelwork necessary to support the imposed loads and conform with design standards is too sophisticated for easy erection by mine labour. Thus box front design must be not only robust enough to carry the design loads, but must also be easy install and erect on site.

Hang-ups have a critical effect on the operation of a box front and depend on various parameters such as ore density, rock size and moisture content. Blasting and barring are methods of clearing hang-ups; however, safety risks are associated with each method. Mud rushes are also an operational hazard, and better methods for detecting and controlling mud rushes is crucial in preventing injuy or loss of life due to the uncontrolled release of a slurry through the box front in the event of a mud rush.

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The economics of platinum group metals*

It has become a familiar refrain to report on the effect of rapidly increasing Chinese demand having a major impact on the global supply-demand balance. It is, however, perhaps less common to note that, in the case of platinum and palladium, the driver is rising Chinese consumption in jewellery rather than in industrial production. The new report from market analysts Roskill, notes that in 2004, Chinese jewellers purchased some 31 t of platinum and 22 t of palladium, representing about 45% and 77% respectively of world platinum group metal demand for jewellery, and almost 12% of world platinum group metal demand.

The Economics of Platinum Group Metals (7th Edition, 2005) forecasts that demand for platinum and palladium is expected to grow by about 3% pa and 5% pa respectively up to 2010.

Autocatalysts are main end-use for platinum group metals

The use of platinum, palladium and rhodium to catalyze the conversion of noxious exhaust emissions from petrol- and diesel-driven vehicles is by far the largest use for platinum group metals. Emissions standards in the EU, North America and Japan have little further room to be tightened, and platinum group metal loadings in converters have largely been optimized. However, autocatalysts will continue to drive the market as car production grows in China and India, and emission standards are tightened and enforced.

In Europe, where Stage IV emissions limits came into force in 2005, demand for platinum autocatalysts has risen steeply as sales of fuel-efficient diesel cars continue to grow in response to higher fuel prices. Car makers in North America are moving back to palladium catalysts for petrol-driven cars, in response to the decline in palladium prices since 2001. In Japan, demand for platinum autocatalysts rose steeply in 2003 and 2004 because of new regulations governing emissions from heavy-duty diesel vehicles.

Use of platinum and palladium in electrical and electronic applications

The use of palladium in electrical and electronic applications, once its largest market, has declined sharply since 2000 because of miniaturization, and substitution by nickel in multi-layered ceramic capacitors. Platinum is being used in increasing volumes to enhance storage capacity density on hard drive disks for computers, digital cameras, mobile phones and other devices.

Development of new platinum group metal mining projects

In 2005, 22 mines owned by eight companies were producing platinum group metals as a primary product, while a further three operations in Russia and Canada were producing substantial amounts as a by-product of nickel. The primary mines are in South Africa (18), Zimbabwe (2), the USA (1) and Canada (1). Anglo Platinum, Norilsk Nickel, Implats and Lonmin are the world's principal platinum group metals mining companies, together accounting for 82% of primary platinum supplies and 84% of palladium in 2004.

Although some 19 platinum group metal mining projects were being developed or were under consideration in 2005, most were being reassessed because of the adverse impact of the strong rand in South Africa, and political uncertainty in Zimbabwe. In 2005, Falconbridge's Nickel Rim South project, Aquarius's Everest project, ARM/Implats' Two Rivers project, Barplats'/Salene's Crocodile River expansion and Implats' Marula ramp-up appeared to be the most likely to be developed.

Platinum and palladium prices

In 2001, speculative selling, weakening economies and falling palladium prices pulled platinum prices down to a low of US$420/oz. Thereafter, good physical demand and uncertainty about Russian export quotas caused prices to firm. This trend continued almost unbroken until March 2004, when prices reached US$883/oz. In the first half of 2005, the platinum price moved up slowly in response to continued speculative investment and good market conditions, reaching $874/oz on the LPPM fixing in July 2005.

In January 2001, the London fix for palladium was $1.094/oz, but weakening industrial demand, because of switching to lower priced alternatives in autocatalysts, electronics and dental alloys, large inventories and economic slowdown in consumer countries, resulted in a price collapse. From October 2003 to mid 2005 the palladium price has remained largely in the range $180 to $240/oz and most movements were attributable to speculative buying and selling. In 2005, palladium experienced both investor and physical demand, and speculation that jewellers and car makers would stock up on a metal that was being so undervalued, pushed the price to almost $200/oz in March and April.

The Economics of Platinum Group Metals (7th edition, 2005) is available at £2100/US$4200/EUR3675 from Roskill Information Services Ltd, 27a Leopold Road, London SW19 7BB, England. Tel: +44 20 8944 0066.
Fax: +44 20 8947 9568. E-mail: info@roskill.co.uk u

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* *Issued by: Matthew Davidson,*
Tel: +44 20 8944 0066,
Fax: +44 20 8947 9568, E-mail:
matthew@roskill.co.uk