BULK MATERIALS HANDLING IN THE MINING INDUSTRY

MADENCİLİK ENDÜSTRİSİNDE MALZEME NAKLİ

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ÖZET

Bu makale, madencilik endüstrisinde malzeme naklinin bazı konularını incelemektedir. Silolar, serbest yığmlar, yeraltı depolama ve malzeme yolları gibi malzeme depolama sistemlerinin dizaynı gözden geçirilmekte ve güvenilir boşaltma akışı sağlayacak besleyici dizaynı ile ilgili hususlar verilmektedir. Depolama silolarının duvarlarında, statik ve akış halindeki gerilim alanlarının oluşturduğu, yükleme anlatılmaktadır. Kullanılan ekipmanda oluşan aşınma problemleri kısaca anlatılmaktadır.

ABSTRACT

This paper reviews various aspects of bulk materials handling in the mining industry. An overview of bulk storage systems design, including bins and silos, gravity reclaim stockpiles, underground storage facilites and ore passes, is presented and aspects of feeder design for reliable discharge flow is given. The loadings in wall of storage bins is discussed in relation to stress fields under both static and flow conditions. Problems of wear in handling plant are briefly discussed.

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1.   INTRODUCTION

Bulk materials handling operations perform a key function in the mining and mineral processing industries. In such industries the relative costs of storing, handling and transporting bulk materials are, in the majority of cases, very significant. It is important, therefore, that handling systems be designed and operated with a view to achieving maximum efficiency and reliability.

Over the past three decades much progress has been made in the theory and practice of bulk solids handling. Reliable test procedures for determining the strength and flow properties of bulk solids have been developed and analytical methods have been established to aid the design of bulk solids storage and discharge equipment. There has been wide acceptance by industry of this technology and, as a result, there are numerous examples throughout the world of modern industrial bulk solids handling installations which reflect the technological developments that have taken place. The purpose of this paper is to briefly highlight the present state of knowledge associated with bulk handling.

2.   GRAVITY FLOW BIN DESIGN - BASIC CONCEPTS

The general theory pertaining to gravity flow of bulk solids is fully documented. The salient aspects are briefly reviewed. As is now well established, there are two basic modes of flow, namely, mass-flow and funnel-flow.   These are illustrated in Figure 1.
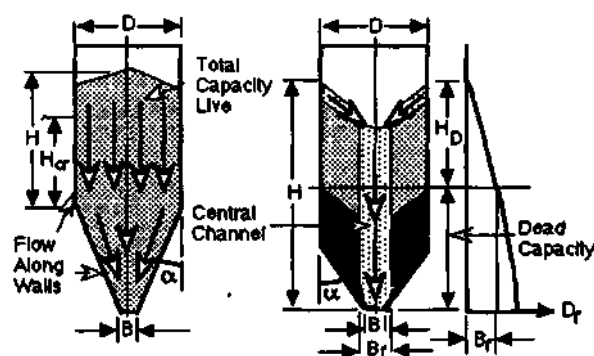
(a) Mass-Flow   (b) Funnel-Flow

Figure 1. Modes of Flow

In mass-flow, the bulk solid is in motion at every point within the bin whenever material is drawn from the outlet. There is flow of bulk solid along the walls of the cylinder (the upper parallel section of the bin) and the hopper (the lower tapered section of the bin). Mass-flow guarantees complete discharge of the bin contents at predictable flow rates. It is a 'first-in, first-out' flow pattern with the ability to re-mix the bulk solid during discharge should the solid become segregated upon filling of the bin. Mass-flow requires

steep, smooth hopper surfaces and no abrupt transitions or in-flowing valleys. Mass-flow bins are classified according to the hopper shape and associated flow pattern. The two main hopper types are conical hoppers which operate with axi-symmetric flow and wedged-shaped or chisel-shaped hoppers in which plane-flow occurs. In plane-flow bins, the hopper half-angle a will usually be, on average, approximately 8° to 10° larger than the corresponding value for axi-symmetric bins with conical hoppers.

Funnel-flow occurs when the hopper is not steeply sloped and the walls of the hopper are not sufficiently smooth. In this case, the bulk solid sloughs off the top surface and falls through the vertical flow channel that forms above the opening. Flow is generally erratic and gives rise to segregation problems. Flow will continue until the level of the bulk solid in the bin drops an amount HD equal to the draw-down. At this level, the bulk strength of the contained material is sufficient to sustain a stable rathole of diameter Df as illustrated in Figure 1(b). Once the level defined by HD is reached, there is no further flow and the material below this level represents 'dead' storage.

For complete discharge, the bin opening needs to be at least equal to the critical rathole dimension determined at the bottom of the bin corresponding to the bulk strength at this level. However, for many cohesive bulk solids and for the normal consolidation heads occurring in practice, ratholes measuring several metres are often determined. This makes funnel-flow impracticable. Funnel-flow is a 'first-in last-out' flow pattern which is unsatisfactory for bulk solids that degrade with time. It is also unsatisfactory for fine bulk solids which may aerate, giving rise to flooding problems or uncontrolled discharge.
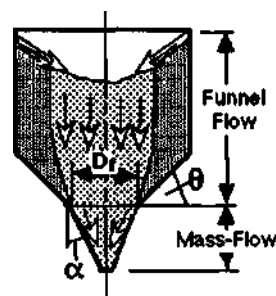

Figure 2. Expanded Flow

The disadvantages of funnel-flow are overcome by die use of expanded-flow, as illustrated in Figure 2. This combines the wall protection of funnel-flow with the reliable discharge of mass-flow. Expanded-flow is ideal where large tonnages of bulk solid are to be stored. For complete discharge, the dimension at die transition of the funnel-flow and mass-flow sections must be at least equal to the critical rathole dimension at that level. Expanded-flow bins are particularly suitable for storing large quantities of bulk solids while maintaining acceptable head heights. They are quite effective for multiple outlets.

The mass-flow and funnel-flow limits are based on the assumption that a radial stress field exists in the hopper (JENIKE 1964). The limits depend on the hopper half-angle a, the effective angle of internal friction δ and the wall friction angle $. Once δ and § have been determined by laboratory tests, the hopper half-angle may be selected. The bounds for conical and plane-flow hoppers are plotted for three values of δ in Figure 3. In the case of conical or axi-symmetric hoppers, it is recommended that the half-angle be chosen to be 3° less than the limiting value. For plane-flow, the bounds are much less critical and the design limit may be selected.
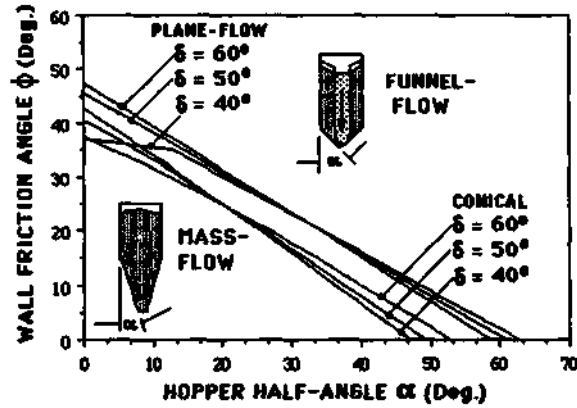

Figure 3. Limits for Mass-flow for Conical and Plane-Flow Channels

Basically the aim in mass-flow design is to determine the hopper geometry to give reliable flow. Primarily, the requirement is to determine the hopper half angle a and opening dimension B to give the required flow rate without a cohesive arch forming.
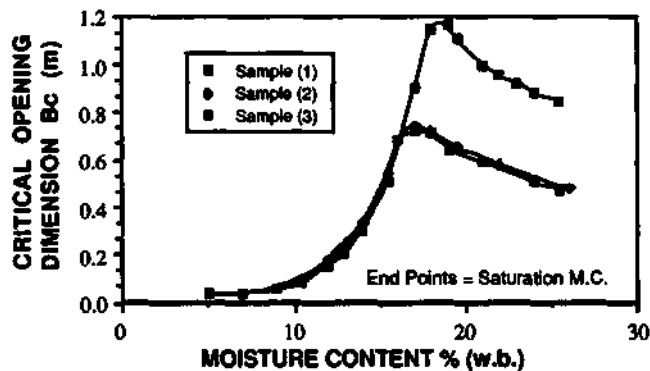

Figure 4. Critical Opening Dimension BÇR as a Function of Moisture Content for Three Coal Samples - Stainless Steel 304-2B Lining

Undisturbed storage time and changes in moisture content can significantly influence the unconfined yield strength of the bulk solids. By way of illustration, the critical hopper

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opening dimension B for three Australian coals plotted as a function of moisture content are shown in Figure 4 (ROBERTS 1991,92). This figure shows three coal samples, Sample (1) being a Raw Open Cut Coal, Sample (2) a washed version of (1) and Sample (3), a blend of (2). The high strength of the raw, unwashed coal is clearly evident. Experience has shown that the peak bulk strength of coal may occur at a moisture content somewhere between 70% and 90% of the saturation limit.

3. BIN WALL LOADS

Bin wall loads are directly related to the flow pattern developed in the bin. In mass-flow bins, the pressures acting normal to bin walls vary from the static or filling conditions to the dynamic or flow conditions. The pressure distributions are well defined and, using current theories (ROBERTS 1992) may be predicted with confidence. It is to be noted that in the flow situation a high switch stress occurs at the transition where the tapered hopper joins the upper parallel or cylindrical section of the bin. The magnitude of this switch stress is several times the corresponding static value. Further, the wall pressures acting in the cylindrical section during flow may be higher than the static values. For a perfectly parallel cylinder, the wall pressures during flow would be the same as the static values. However, when imperfections such as weld projections or plate shrinkage give rise to flow convergences, peak stresses occur. The stresses are taken into account by computing the locus of all such possible peak pressures.
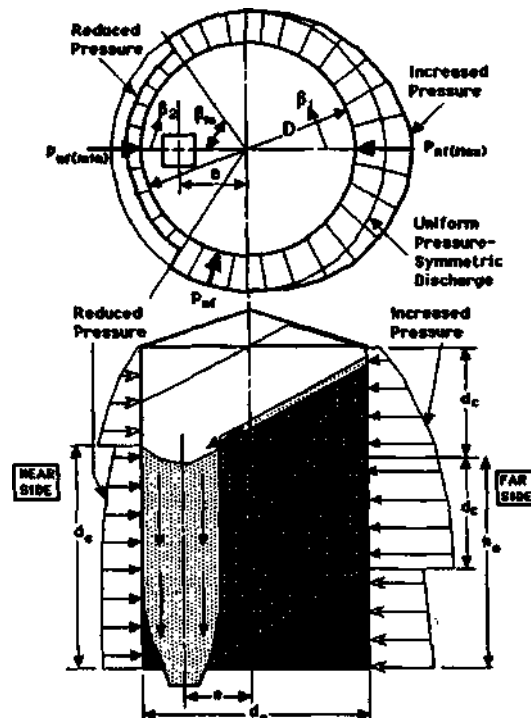

Figure 5. Circumferential Pressure Variation due to Operation of One Eccentric Outlet

In the case of symmetrical funnel-flow bins, wall pressures may be determined with a high degree of confidence. However, wall loadings in bins with multiple outlets and eccentric discharge points are far more difficult to estimate. Under eccentric discharge, the walls are subject to bending stresses in addition to hoop stresses.

In recent years there has been considerable activity in several countries of the world in the development of new or revised codes for bin wall loads. Of particular note is the new Australian Standard "AS-3774-1990 Loads for Bulk Solids Containers", which presents a comprehensive review of the loads acting in bin and silo walls under the full range of operating conditions likely to occur in practice. As an example, Figure 5 shows the wall loadings determined on the basis of this new Standard for a large coal bin having seven outlets; the pressure profiles correspond to one possible mode of discharge involving the operation of one eccentric outlet only.

4. FEEDING OF BULK SOLIDS

In general, a feeder is a device used to control the flow of bulk solids from a bin. While there are several types of feeders commonly used, it is essential that they be selected to suit the particular bulk solid and the range of feed rates required. It is particularly important that the hopper and feeder be designed as an integral unit so as to ensure that the flow from the hopper is fully developed with uniform draw of material from the entire hopper outlet.
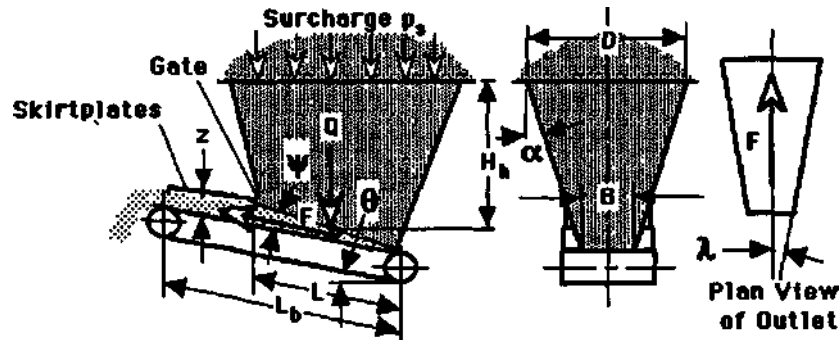

Figure 6. Belt and Apron Feeder

For example, in the case of a belt or apron feeder, a tapered opening is required as illustrated in Figure 6. The use of vertical triangular plates in the hopper bottom are an effective way to achieve the required taper. The gate on the front of the feeder is used only for flow trimming and not for controlling the flow rate. The height of the gate is adjusted to give the required release angle y to achieve uniform draw along the slot Once correctly adjusted, the gate is then fixed in position and the feed rate is controlled by varying the speed of the feeder.

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In **the** case of vibratory feeders, there is a tendency for feed to occur preferentially from **the** front. It is recommended, therefore, that the slope angle of the front face of the hopper be increased by 5° to 8°. Alternatively, the lining surface of the front face in the region of the outlet may selected so as to have a higher friction angle than the other faces.
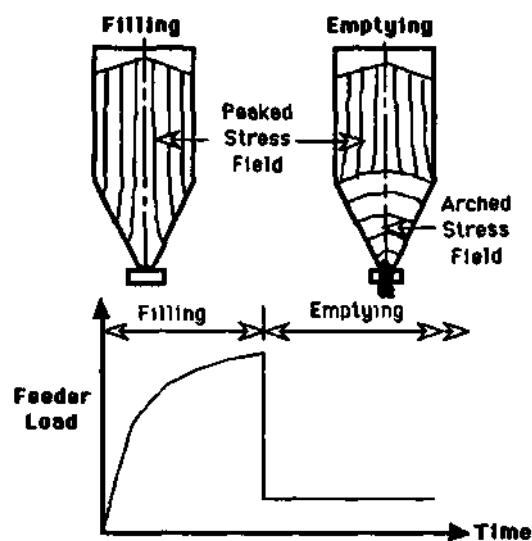

Figure 7. Load Variations on a Feeder

The determination of feeder loads and drive powers requires a knowledge of the stress fields generated in the hopper during the initial filling condition and during discharge. Under filling conditions, a peaked stress field is generated throughout the entire bin as illustrated in Figure 7. Once flow is initiated, an arched stress field is generated in the hopper and a much greater proportion of the bin load is supported by the hopper walls. Consequently, the load acting on the feeder substantially reduces as shown in Figure 7. It is quite common for the load acting on the feeder under flow conditions to be in die order of 20% of the initial load. The arched stress field is quite stable and is maintained even if the flow is stopped. This means that once flow is initiated and then the feeder is stopped while the bin is still full, the arched stress field is retained and the load on the feeder remains at the reduced value. The subject of feeder loads is discussed in some detail in the literature (ROBERTS et al 1984,92).

The loads on feeders and the torque during start-up may be controlled by ensuring that an arched stress field fully or partially exists in the hopper just prior to starting. This may be achieved by such procedures as:

. Cushioning in the hopper, that is leaving a quantity of material in the hopper as buffer storage.
. Starting the feeder under the empty hopper before filling commences.

.   Raising the feeder up against the hopper bottom during filling and then lowering to the operating clearance prior to starting.

5 .   GRAVITY RECLAIM STOCKPILES

Gravity reclaim stockpiles, when properly designed, operate under expanded-flow, as illustrated in Figure 8 (ROBERTS and TEO 1989, 90). Discharge will take place by funnel-flow in the main body of the stockpile, with the flow expanded through the mass-flow hopper. In this way, reliable flow to the feeder is assured. Flow will continue until the draw-down head ho is reached; flow then ceases as a stable pipe or rathole is formed. The draw-down is consistent with critical rathole dimension Df which forms at the draw-down level. The shape of the rathole depends on the consolidation conditions within the stockpile, the particle or lump size range of the stored bulk solid and the moisture content.

Complete draw-down, as illustrated in Figure 8, corresponds to the critical rathole dimension Df_m at the base of the stockpile. For complete draw-down to occur, it is necessary for the diagonal dimension of the hopper transition to be at least equal to Df_m. Since values of Df_m may be several metres, complete draw-down is often not practical. For this reason, the design of stockpile reclaim hopper and feeder systems requires consideration of the various options available with a view to optimising the reclaim performance within specified practical and economic limits.
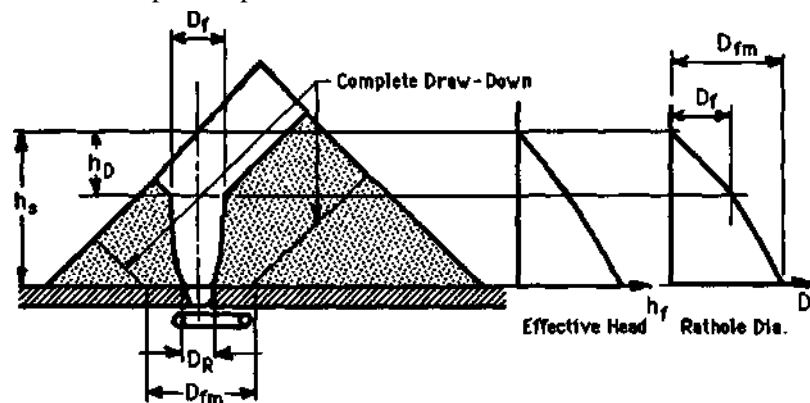

Figure 8. Draw-Down in Stockpile

The use of multiple hopper systems to obtain intersection of the flow channels permits good reclaim performance to be achieved. By employing the modelling capabilities of CAD systems together with the measured flow properties of the bulk solid, the reclaim performance of stockpiles of varying shapes can be readily examined. As an illustration, a typical 3-dimensional model of an iron ore stockpile is illustrated in Figure 9. Careful selection of the reclaim hopper spacing permits optimum live capacity to be assured.
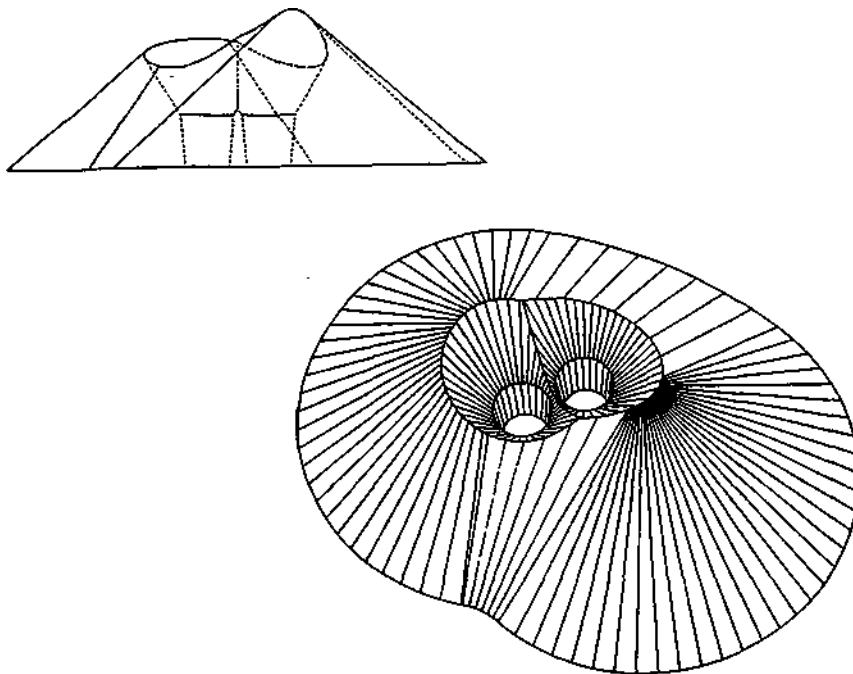
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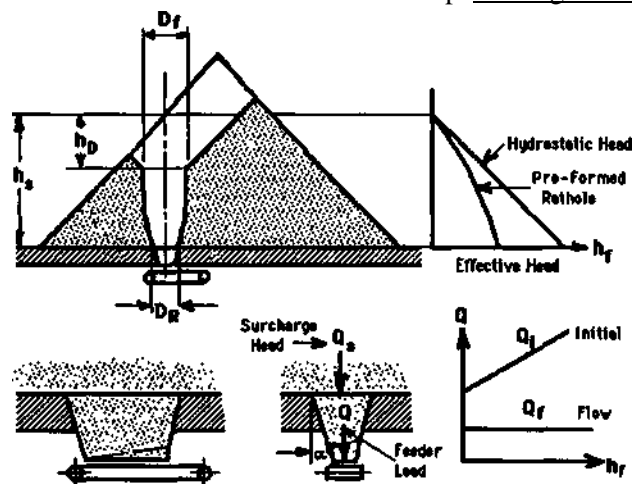Figure 9.   3-Dimensional CAD Model of Stockpile having Two Outlets-

Figure 10. Loads on Stockpile Feeders

The loads on reclaim hoppers and feeders and the corresponding power to drive the feeders varies from the "initial " to the "flow" condition as discussed in Section 4. The loads are illustrated in Figure 10. The initial load occurs when the stockpile or crater above the feeder is filled. The surcharge load Q_s depends on the consolidation condition in the stockpile . The worst case corresponds to the hydrostatic pressure. However, if a

rathole has been pre-formed, then the surcharge load will be reduced. When an arched or flow stressed field has been formed within the mass-flow reclaim hopper, die load on the feeder will be greatly reduced and is independent of the head.

6.   DESIGN OF UNDERGROUND BINS AND ORE PASSES

The concepts of bin and stockpile design may be readily applied to underground bins and ore passes. By way of illustration, a case study example is presented (SCOTT and CHOULES 1991) which refers to an upgrade of a copper mine located in Irian Jaya. A major rearrangement of the ore handling was proposed. This included very large underground ore bins, associated ore passes and conveyor systems.

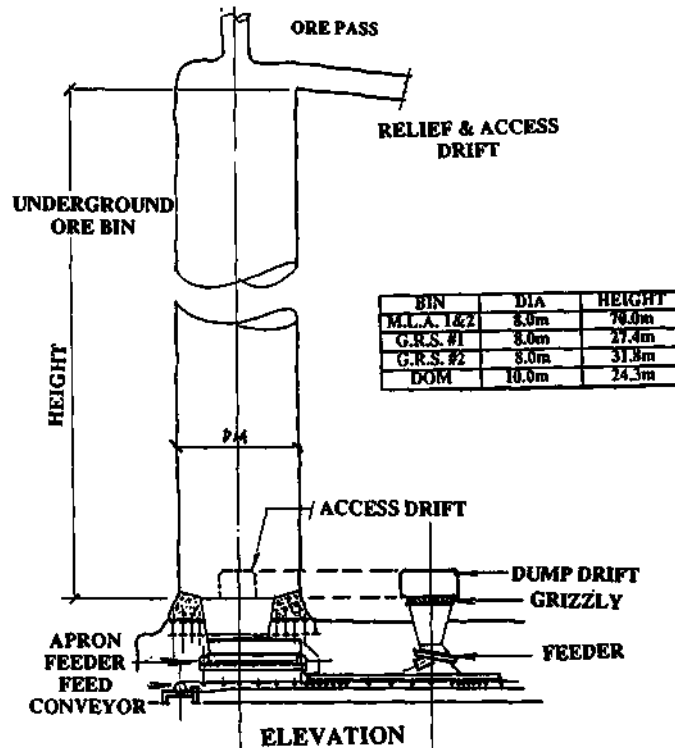| BIN	DIA	HEIGHT
M.L.A. 1&2	8.0m	70.0m
G.R.S. #1	8.0m	27.4m
G.R.S. #2	8.0m	31.8m
DOM	10.0m	24.3m

Figure 11. General Arrangement of Underground Bin and Feeder.

The concept involved up to nine bins with initially proposed cross sections ranging to 17m to 7m excavated as enormous caverns to 70m high each with a potential total capacity in excess of 15 000T and live capacity of 8500T. These storage bins with vertical infeed ore passes to 450m height and associated crushing and conveyor systems would help overcome dependency on an overhead cableway system that transported all ore from the mine at 3700 metres elevation to the mill site stockpile at 2700 metres. Additionally the

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upgrade would allow for increased mine output and development of ore reserves. The proposed overall annual throughput is in the order of 18 MT.

While there are numerous instances of underground ore bins in use throughout the world, the scale of the proposed bins and their remote location in an area of very high rainfall inspired a degree of caution in the design. With an average daily rainfall of 19mm the possibility of major water ingress into the ore stream or directly into the bin via aquifers was a possibility to be addressed. Prediction of the behaviour of the ore under these circumstances and of possible extreme load cases for the bin and associated equipment if filled with saturated ore had to be prepared.

Paramount at all times was the need to prepare a design which would provide reliable flow of ore under all circumstances while having the necessary structural integrity. Experience at the site suggested that the ore was at times difficult to handle. Blockages in the reclaim area of the mill feed stockpiles were not uncommon while underground stope draw points and dump locations had a long history of obstructions requiring in some cases continuing manual intervention to maintain flow. Figure 11 illustrates schematically the general arrangement of the underground bin that was proposed for this installation.

7. WEAR IN HANDLING PLANT

The performance of hoppers, feeders and chutes depends greatly on friction at the boundary surface. There are a great many lining materials on the market, and while cost is a significant consideration, it is most important that the lining material be selected on the basis of service life and performance. Factors to be considered include:

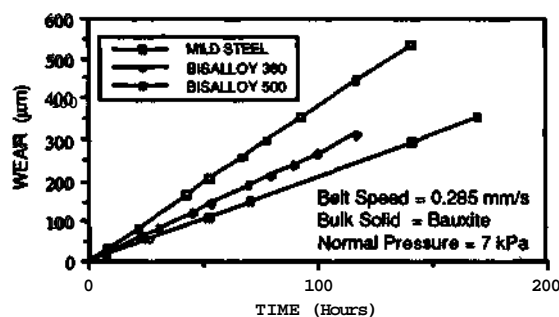|	
Surf ace friction and adhesion	Resistance to abrasive wear
Resistance to impact, if appropriate	Resistance to corrosion
Installation cost and maintenance	Initial cost

Figure 12. Wear with Bauxite

Research at the University of Newcastle, Australia, (ROBERTS et al 1988), has focused attention on this subject. A special abrasive wear tester has been developed and this allows ready comparisons to be made of various lining materials to suit a particular bulk solid. This is illustrated by a typical set of test results in Figure 12. From this information, absolute wear life can be predicted.

10. CONCLUDING REMARKS

An overview of the storage, flow and handling of bulk solids in relation to the mining industry have been presented. There is no doubt that significant advances have been made in research and development associated with bulk handling systems. It is gratifying, therefore, to acknowledge the increasing industrial awareness and acceptance throughout the world of modern bulk materials handling testing and plant design procedures.

It is recognised that industrial plant and processes continue to become more sophisticated, the demands for better quality control become more stringent and both national and international competition requires more efficient and cost-effective performance. This reinforces the need for ongoing research and development.

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