SECTION 3

PLANNING – LANDFORM DESIGN CONCEPTS

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3.1 INTRODUCTION

Those in the mining industry have for at least ten years now heard the words "plan for closure". This is a philosophy that is entrenched in all bankable feasibility studies and the investment committees of all major mining houses have it as one of the more important project feasibility assessment criteria. It is all about long term liability as a result of nuisance and negligence created by the remnants of mining. But increasingly it is about reputation as well because a mining company's performance on one site more and more determines its prospects for being welcomed to develop the next site.

Features that remain proud of the original ground level present special problems in planning for closure. Being proud of the ground and infants in geological time, they have still to be shaped and moulded by nature's elements of water, wind and oxygen. Moreover, those that remain on surface but are made up of materials that while buried were benign but once disturbed present significant chemical pollution issues, require especially careful consideration. Waste rock dumps, semi-permanent "stockpiles" and tailings "storages" are foremost among these closure challenges.

In preparing for closure one needs to plan for a number of eventualities. The dump or stockpile, the focus of this presentation and seminar, will:

1. Settle and change shape and thereby change drainage patterns
2. Erode, change shape and release solids to the surrounding environment and potentially expose zones of materials buried within the dump
3. Allow water to infiltrate and seep out of the base and toe along underlying surface drainages
4. Leach contaminants and release these to the ground and surface water...

This presentation examines current and historical practice with retard to the formation of waste rock dumps and stockpiles in the context of the above inevitabilities and provides guidance on alternative approaches and potential design and management regimes that would ease the closure implications. The focus of the presentation is on the landform rather than the infiltration and leaching issues as these are dealt with other presenters in the course of the seminar.

3.2 FEATURES TYPICAL OF WASTE ROCK DUMPS AND STOCKPILES

Let's start by looking at a typical waste rock dump that has been partially closed but is still operational with limited "time to go". Figure 1 below shows a typical waste rock dump or stockpile at a mining operation. In this example parts of the dump have been benched and covered with topsoil in preparation for closure while other parts remain in operation. Acid generating rock has been buried within the dump under the high area. Current planning allows for finishing off the remaining side slopes, flattening the top surface and covering with topsoil, however, no major earthworks to re-shape the dump significantly is planned and essentially current drainage patterns will remain as they are at closure.

It is important to note that the highest part of the dump is to the west, the opposite side to the pit.

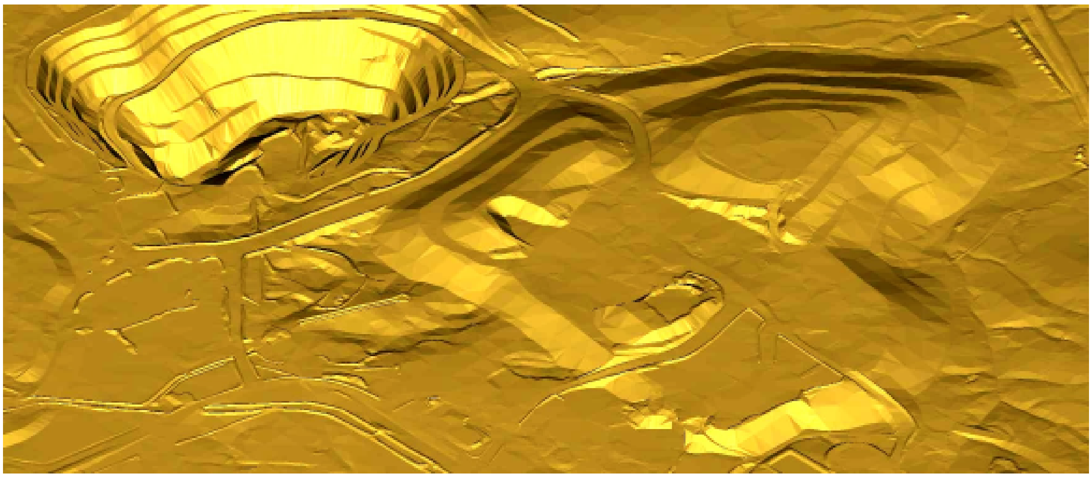

Figure 1: Typical waste rock dump adjacent to an open pit.
What happens over the long term to a dump like this?

Figure 2 below shows the dump after long term erosion as predicted using the program SIBERIA. The following features are evident:

- The extensive erosion of the benched slopes down the sides of the high part of the dump particularly on the western side. This is because the topography of the high surface sloped to the west.
- The extent of gulleying which could well have exposed the acid generating rock materials

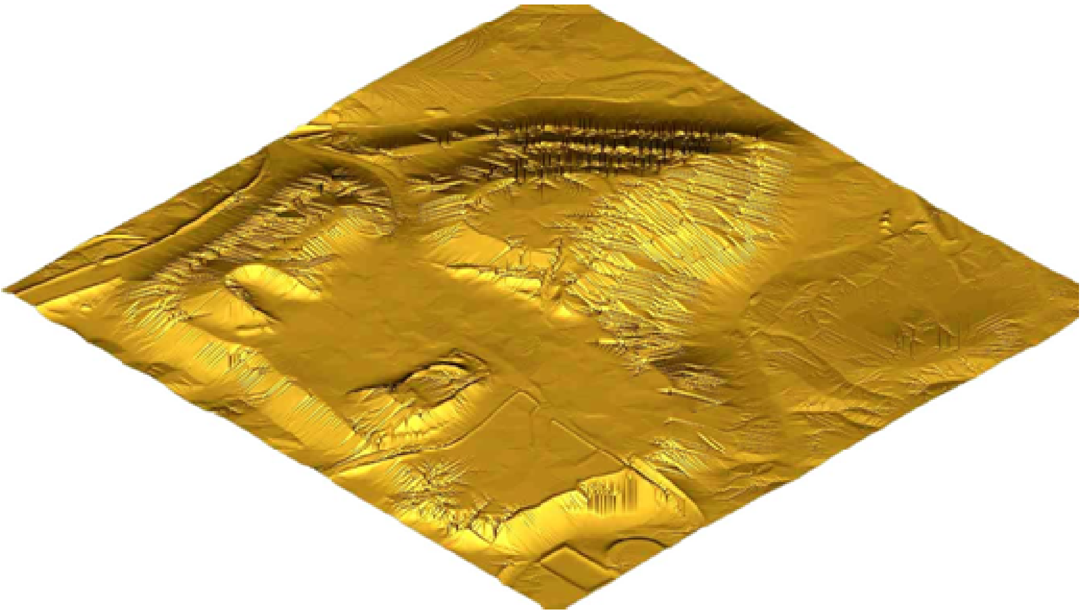

Figure 2: Dump after long term erosion (modelled using SIBERIA)

- The extensive erosion of other slopes where the top surface has drained over the slopes
- The re-deposition of eroded material away from the pit and potentially off the mine property.

It is evident that even with the best of intentions in respect of benching the side slopes the dump has high potential to generate long term liabilities.

3.3 WHAT ARE INDUSTRY TYPICALLY DOING FOR CLOSURE?

Let's assess what industry are commonly doing for closure at present. In respect to slope angles, the 20 degree "rule" is commonly bandied about. The origins of this "rule" are many and varied but it forms part of the current closure guidelines applied by the DMPR and, the word is that if a mining company is looking for closure sign off then the process begins with a commitment to dozing down to this angle.

Often step-backs are left on the slopes to allow access for vegetation establishment or for slope stability reasons. Sometimes these step-backs are sloped inwards to prevent water accumulating on the crest of the slope. However, low areas along step-backs develop as a result of differential settlement of the dump. Material eroded from the slope above the step-back is washed down into the low areas which build up until water overtops the crest opposite the low area. At that stage erosion on the slope below the step-back increases exponentially and cascade failures from one step-back to the next usually develop.

In recognition of the inevitability of low areas it has become common to make use of drainage chutes to manage the drainage of water off the crest or benched areas. These chutes are dozed into the slope and lined with large sized rock so as to control erosion. Experience shows that by concentrating flow into these chutes, thereby increasing the erosive power of the water, even relatively minor storms can generate erosion and maintenance issues on these chutes especially if they are constructed close to or at the natural angle of repose of the rock as gravity works to assist the erosion to a greater extent.

Even on slopes without step-backs, dozed to 20 degrees thereby allowing equipment access for the placement of growth medium, the common practice is to contour-rip the surface to promote the establishment of vegetation. The principles that apply to benches and step-backs apply to the contour ripping as well. As soon as one ridge overtops there is usually a cascade development of an erosion gulley down the entire slope. So it becomes a race between establishing vegetation to hold the growth medium together and erosion of the contours. Tightly controlled contour ripping has, however, shown itself to be effective in assisting vegetation establishment but in many cases inadequate control results in an exacerbation of the slope erosion problem.

The same experiences apply to scalloping of the slopes whereby the dozer is used to gouge depressions into the slope so as to trap and infiltrate water into the growth medium. Well implemented on non-dispersive materials this approach has been shown to be successful. However, if poorly implemented in the wrong materials it has the potential to significantly complicate erosion control.

3.4 HOW EFFECTIVE IS THE 20 DEGREES?

Dozing the slope back to 20 degrees merits more detailed consideration in view of its cost to implement. While it enables equipment to work on the slope and provides a slope face that will reduce liabilities associated with people access up and down the slope, does it actually help to reduce erosion. The short answer to this question is yes it does help. But how much does it help?

Erosion of the slope is about the energy of the eroding medium – the water. Since we are interested in the erosion over time we need to focus on energy over time or, more specifically, look at power, stream power since power is the rate of use of energy. Stream power has the equation $P = \frac{1}{2}\rho Q v^2$ where ρ is the density of the water, Q is the flow rate and v is the velocity. But $Q = vA$ where A is the catchment area. For a 1m width of slope of length L the area A is equal to $L\text{x}1 = L$. This means that stream power is proportional to Lv^3. Manning's equation for open channel flow states that the velocity, v, is proportional to the root of the slope, S. Applying this proportionality to stream power means that the stream power is proportional to $LS^{1.5}$. The table in Figure 3 below shows, in the right-most column the relative changes in erosion potential with slope angle and contributing slope length. For a slope at 37.5 degrees (approximately natural angle of repose) the erosion potential is taken as unity or base case. If the slope is flattened to 20 degrees, notwithstanding the increased slope length, the erosion potential is reduced to 0.6, a reduction of 40%. However, if the top surface above the 35 degree slope begins contributing to the flow the erosion potential increases from unity to 1.9 ie the top slope can almost double the erosion potential – hence the importance of ensuring that top surfaces or bench areas retain integrity.

Slope deg	Slope	Slope 1 to :	height	length	x1	x2	Effective length	Power factor	Relative erosion
37.5	0.767	1.30	30	49.3			49.3	33.1	1.0
20	0.364	2.75	30	87.7		82.4	87.7	19.3	0.6
37.5	0.767	1.30	30	49.3	39.1		92.6	62.2	1.9

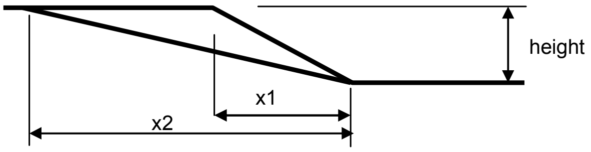

Figure 3: Erosive capacity of 20 degree versus 35 degree slopes

Consider a slope at 37.5 and 500 years of erosion as predicted using SIBERIA and indicated in Figure 4 below and compare this with the 20 degree slope and 500 years of erosion indicated. It is evident that the long term erosion profiles for the two slopes are almost identical.

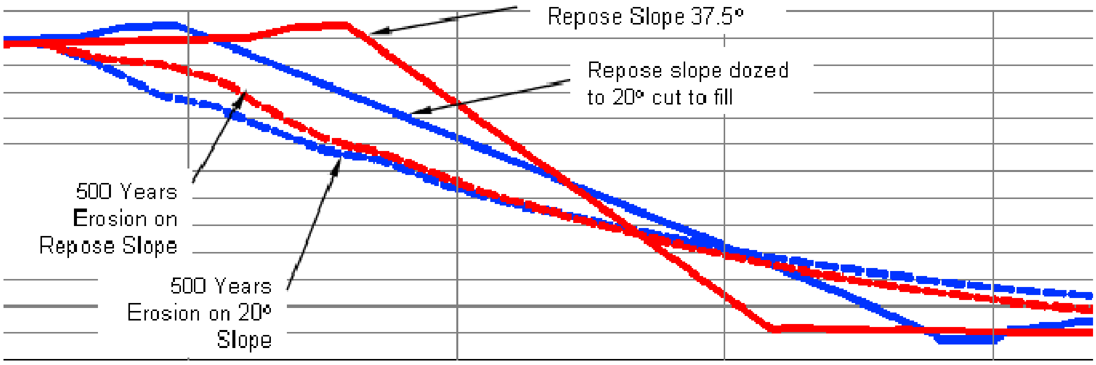

Figure 4: Comparison of long term erosion profiles

This indicates that while the volumes of material that are ultimately moved by natural erosion processes are less by virtue of the pre-dozing, ultimately the slope will adopt its own profile regardless. The difference will be largely in the initial erosion rates where what would have taken place naturally has been effected mechanically instead.

In fact over the long term the net difference in the volume of eroded material between the natural angle of repose slope and the 20 degree slope is only 15% - significantly less than is indicated by the ratio of stream power as indicated in Figure 4 above:

3.5 LANDFORM DESIGN CRITERIA

From the discussion above it is evident that there are a number of common practices that could be further developed and refined to improve long term dump performance. However, before developing these further it is appropriate to first take account of the often competing criteria for dump and stockpile development as promoted by the various parties to the mining activities.

3.5.1 Mining Company Directors

The Directors of the mining company require minimal maintenance after closure and maximum probability of gaining sign-off. As importantly, the directors require that the closed facility have minimum potential for generating long term liability through nuisance or negligence, common law issues they may never be able to relinquish for as long as the company exists and possibly even beyond this.

Then there is the reputational issue. For all the enormous good that mining has done historically in lifting the standard of life it continuously battles the stigma generated by past insensitivity to long term environmental issues. Today, the environmental revolution means that these stigmas stick over much shorter periods. A mining company's poor performance on environmental issues today could significantly affect its ability to develop future projects even in only 20 years time.

Together, the above criteria indicate that it may be essential to be considering long term performance of the dump landform perhaps in the region of 50 to even 200 years.

3.5.2 Regulators

All completion criteria have to be negotiated with and approved by the DMPR and, where operations fall outside of the tribunal between the DMPR and DEP, the DEP. Regardless, these regulators apply the following criteria:

- At closure the dump must be safe, stable and non polluting
- To gain sign-off, it is necessary for the mining company to demonstrate that the agreed closure criteria have been met over an extended period (usually 5 to 10 years) after closure.

However, the common law issues of nuisance and negligence apply equally to the governments departments and these departments remain liable in perpetuity. It would therefore be prudent to be considering landform performance over 200 to 500 years perhaps. Moreover, the assessments documented in this presentation so far, however, indicate that the period to sign-off may not be adequate or that the sign-off process requires modification to include for long term landform modelling.

3.5.3 Mine General Manager/Managing Director

The mine General Manager/Managing Director is performance driven by his or her board and is continually wary of bad surprises creeping in during his or her term of office. Increases in closure provision are typical examples of such bad surprises. Immediately they become evident there is a desire to reduce the cost by postponing costs even at the risk of ultimately further increasing the closure provision. Net present value calculations form the basis for doing this with arguments that it makes better economic sense to do what is least expensive today even at the risk of making closure more expensive because the time value of money dictates that a dollar expended in 10 years time is equivalent to 49c in today's money given an interest rate of 7.5%. However it needs to be borne in mind that ultimately, the cash is needed in order to pay for the decommissioning work, and frequently, if one takes the time and trouble today to do it right using large equipment, the final closure cost, even measured in today's terms, can be significantly reduced. The trade-off is a lower profit today.

3.5.4 Mining Manager

The Mining Manager will claim, validly, that it is hard enough to deal with grades and production rates without having to worry about environmental control and closure. However, the Mining Manager's lot can be made much easier if the closure plan is built into current operations so that the dump development is automatically directed towards closure. Once the appropriate plan is in place the Mining Manager can be left to optimise within a clearly defined framework that automatically includes operational activities that generate a dump that is ready for closure. The key is planning for closure ahead of operations and then minimising the changes necessary to reach closure...

3.6 PLANNING AND LANDFORM DESIGN FOR CLOSURE

The discussion on criteria presented above highlights the following:

- The need to think long term – 200 to 500 years
- The need to integrate the closure plan into current operations

It is therefore essential to begin with determining the desired geometry at closure taking into consideration:

- The management of runoff and long term erosion
- The slope profile that will generate minimum erosion
- The potential effects of differential settlement
- Isolation of chemically adverse material within the dump such that it is unlikely to be exposed by erosion and net percolation of infiltrated rainwater through the adverse material is minimised.

The above may best be illustrated by reference to the dump described at the start of this presentation. Figure 5 below indicates potentially modified dump geometry where the modifications would comprise controlled dumping of on-going arisings as well as re-shaping of existing areas.

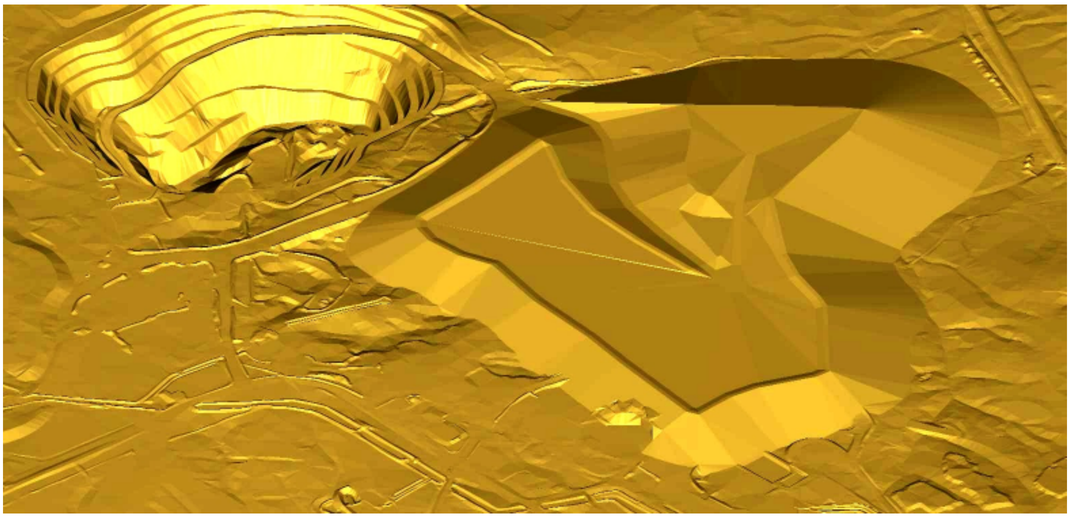

Figure 5: Modified dump geometry

Features of the modified geometry are as follows:

- A drainage channel at a gradient of 1 in 25 has been provided from the central area of the dump to the pit area so that runoff water is directed to the open pit.
- The flat surfaces of the dump have been modified to gently slope towards the drainage channel even from the previous high dump area
- A crest berm has been provided around the southern perimeters
- The berms on the northern and eastern faces have been dozed away to form a continuous slope.

Figure 6 below indicates the long term erosion of the modified dump as predicted using SIBERIA based on the same parameters and time period as for the eroded dump indicated in

Figure 2 above.

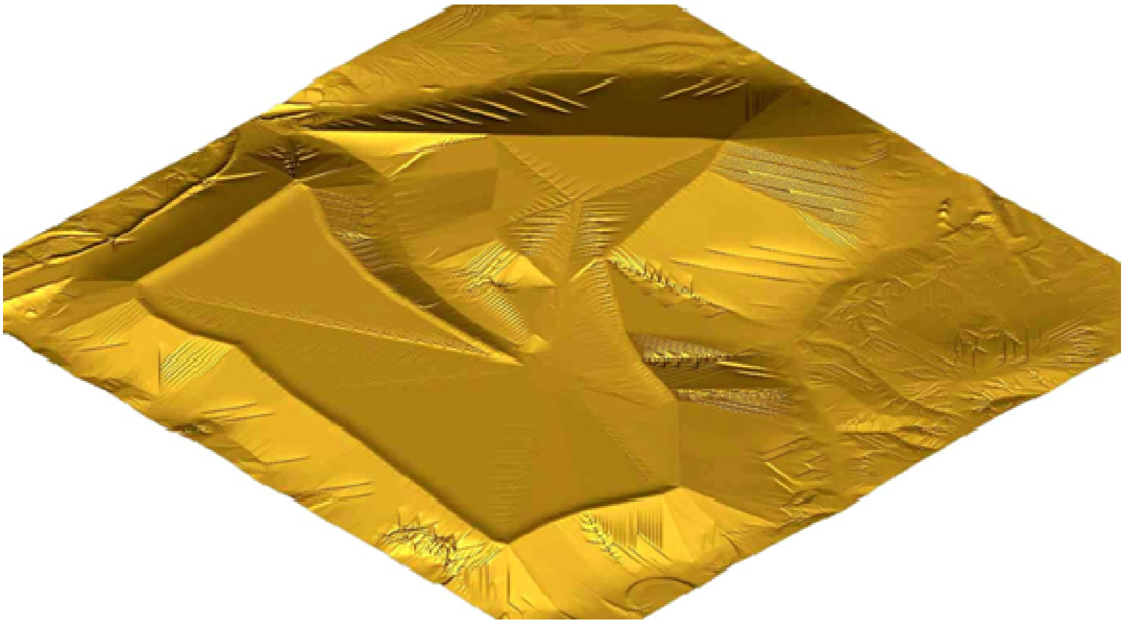

Figure 6: Long term erosion of the modified dump

The following points are evident from Figure 6 as compared to

Figure 2:

- Erosion is significantly reduced on all slopes as the contribution of the flat areas has been eliminated.
- Erosion on the previously benched slope is vastly reduced

Notwithstanding the above improvements, there is still opportunity to improve and optimise. For example:

- There is significant erosion in the “vee’s” that are generated where slopes meet. Erosion is higher in these areas because the flow aggregates down the “vee’s”. This effect can be reduced by rounding the “vee’s” to an extent where water continues to spread down the slope intersection.
- The slopes to the drainage channel could be flattened.
- The slope in the south eastern corner should be reinstated to form a continuous slope

In the case of a new dump it would be possible to incorporate the above features from the outset. In that case, rather than doze down the entire slope at closure it would be more cost effective to plan ramps so as to form a stepped outer profile before hand and then simply doze between the berms. This will very considerably reduce the volume of material to be dozed especially if one considers the fact that on high slopes it is necessary to re-doze the same material several times in order to bring the slope down to the required angle. Moreover, it will be possible to generate a slope profile that approximates that of the long term erosion profile thereby further reducing the volume of eroded material. This is illustrated in Figure 7 below:

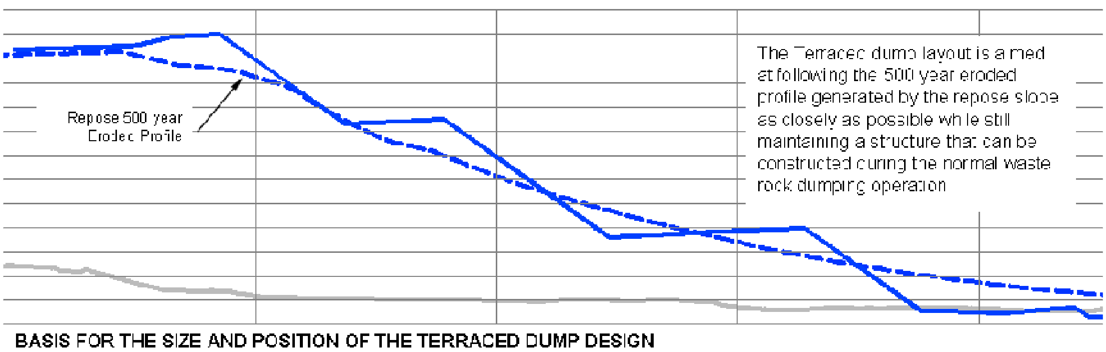

Figure 7: Basis for sizing and locating temporary benches

By “knocking the tops off” the benches at closure it is possible to approximate the 500 year profile indicated in Figure 7. SIBERIA analyses indicate that the erosion volume from such a profile would be approximately 50% of the erosion that would occur from a slope of equivalent height but at natural angle of repose. This should be compared with the 85% figure for the 20 degree slope indicated in Figure 4 above.

If benches or step-backs are unavoidable it would be prudent to make there width approximately 3 times the height of the slope and to provide a crest bund of the geometry illustrated in Figure 8 show suggested criteria.

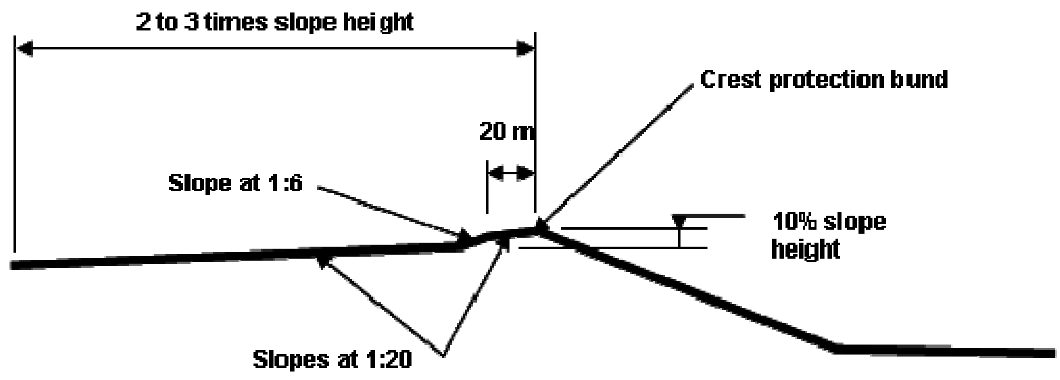

Figure 8: Suggested step-back and crest geometry

3.7 INTERACTION BETWEEN DESIGN, CONSTRUCTION AND FIELD MONITORING PERSONNEL

3.7.1 Ownership

While divisions of responsibilities vary between mining operations it is useful to adopt the attitude that ultimately the dumps should belong to the mining manager and become fully his or her responsibility in the same way that, for example, the tailings storage facility, operation and environmental control are commonly the plant manager's responsibility. This includes management of runoff water, seepage water and erosion. Environmental personnel should provide feedback on the effectiveness of the mining manager's efforts but should not be responsible to ensuring that the dump is constructed correctly or decommissioned correctly.

Notwithstanding this, however, it needs to be borne in mind that it takes a team to get it right, and teamwork is essential.

3.7.2 Design

Integration of the dump planning with mining activity would best be achieved in the case of open pit mining, if:

- The desired waste dump geometry was determined ahead of detailed mine planning, and then,
- Incorporated into mine planning simulations using Vulcan, Datamine or PCMine etc so as to optimise pit development accordingly.
- Short, medium and long term mine planning was developed from the optimised mine plan

3.7.3 Construction

While the mine planners set the course it is the mine operators who turn the plans into reality. For this they need consistent directives that enable the setting of appropriate operating paradigms that can be entrenched across two shifts and possibly four panels in the case of fly-in fly-out operations. The difficulty of communicating the same message across all panels and having the personnel internalise the message is difficult enough with regard to ore production. Further complicating the process with variable waste management directives is inadvisable. It is far better to build the appropriate waste management culture as early and consistently as possible reinforced by a waste dump management plan.

3.7.4 Monitoring

Monitoring of the mine operator's performance against the waste dump management plan should be carried out by the mine planners who are then able to understand any difficulties the plan may generate and then make appropriate modifications. The mine planners should work with the mine surveyors and geologists to monitor:

- Rock type (particularly critical if adverse rock types are to be confined to specific designated areas within the dump). Regular surveys of the dump crests and specifically the zones of adverse material need to be maintained to verify that the dump is being constructed to the required geometry.
- Settlement monitoring which is essential to confirm that allowance for settlement in the design of crest bunds and drainage gradients is adequate.
- Dump geometry. Survey of crest position and surface topography is essential to confirm that drainage gradients and directions are acceptable.
- Erosion. Aerial survey, laser survey or the use of stereo photography provides essential data for checking the calibration of erosion modelling parameters

Monitoring of the dump's environmental performance should be carried out by environmental personnel who should monitor:

- Groundwater quality
- Surface water quality
- Dusting
- Erosion development.

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