Theoretical and engineering aspects of slimes-dam construction

by G. W. DONALDSON*, M.Sc. (Eng.)(U.C.T.), D.I.C. (Visitor)

SYNOPSIS

The paper reviews the recommendations made in 1959-60 as a result of research into slimes-dam construction and finds that these recommendations are still valid. The requirements for pollution control, vegetating, *in situ* leaching, and future development of slimes dams as building areas are considered as they affect the engineering aspects of slimes-dam construction, and it is found that these requirements can be met without any major changes to current recommended slimes-dam construction practice.

SAMEVATTING

Die verhandeling gee 'n oorsig oor die aanbevelings wat in 1959-60 as gevolg van navorsing in verband met die bou van slykdamme gemaak is, en vind dat hierdie aanbevelings nog geldig is. Die vereistes vir die beheer van besoedeling, beplanting, loging ter plaatse en die toekomstige ontwikkeling van slykdamme as bougebiede word oorweeg aangesien hulle die ingenieursaspekte van slykdamkonstruksie raak, en daar word bevind daar aan hierdie vereistes voldoen kan word sonder enige belangrike veranderings aan die huidige aanbevole praktyk vir slykdamkonstruksie.

INTRODUCTION

The art of slimes-dam construction grew with the gold-mining industry in South Africa as a result of experience with successful dams and with failures. (The failures are more important when it comes to learning about the properties of materials and the mechanisms by which failures occur.) Slimes-dam construction developed in this way for fifty years, and it was only in 1953 that a major investigation was launched to study the whole problem of the stability of slimes dams from an engineering point of view. The results of this investigation were published in detail in 1959[1] and were summarized in a more practical form in a technical paper[2].

The basic theories relating to the consolidation of soil materials that have been deposited hydraulically and subjected to atmospheric drying, as well as the theories underlying the methods of stability analysis, which are recognized in soil mechanics practice, were adapted to slimes-dams practice. Since 1959, there has been no significant modification of these theories, and there is therefore no need to devote a great deal of this paper to these theories.

The experience gained during ten years' use of the recommendations contained in the above-mentioned reports has proved their validity. This paper can therefore do no more than reiterate the most important considerations in the engineering approach to slimes-dam construction, with reference to possible changes in attitudes to certain aspects of their use.

*Head, Geotechnical Division, National Building Research Institute, CSIR, Pretoria.

THE PURPOSE OF SLIMES DAMS

The success of any engineering structure is measured in terms of its ability to serve the purpose for which it was built. It is obvious that the main purpose of a slimes dam is to provide for the effective and economic disposal of waste material. The basic engineering requirement therefore is a method of construction that will ensure that the material remains where it is placed with the minimum of effort in manpower and finance, both in initial construction and in maintenance. During the life of the mine or, more specifically, during the active life of the slimes dam, this is the paramount consideration.

There are, however, certain other objectives that may influence construction techniques. Firstly, there is control of pollution by run-off from the outer surfaces and by seepage from the dam. Secondly, the possibility of *in situ* leaching to remove additional minerals from the slimes may have to be considered. The requirement for the vegetating of slopes and surfaces of dams presents a third set of conditions. Finally, the dam may ultimately be used as a site for building.

These various requirements must be borne in mind when the design and construction of dams are considered. Most of them can be accommodated with minor modifications to existing practice, but in some cases divergent requirements have to be reconciled in a compromise solution. Some of these requirements will be considered in the following discussion of the various engineering aspects of slimes-dam construction.

ENGINEERING ASPECTS

Foundation soils and drainage

Both research and practical experience have shown that the drainage of the foundation soil is one of the most important factors affecting the stability of slimes dams. In the first place, the slimes material gains strength by consolidating, and the rate of consolidation is governed by the lengths of the drainage paths in the mass. If the foundation is impermeable, the drainage path to the surface is twice as long as it would be if the base were permeable. Secondly, the shear strength of the slimes material is diminished by the build-up of pore-water pressures, and therefore, for stability reasons, good underdrainage is necessary to ensure that pore-water pressures do not build up, especially under and in the outer walls. This fact is clearly recognized, and, while it is often not possible to site a slimes dam entirely on well-drained foundation soil, care is taken to see that all wall areas are adequately underdrained by the provision of artificial drains where necessary.

Although this is not true of the gold-mining industry, there are slimes dams where the seepage effluent contains harmful pollutants, such as the gypsum dams for the fertilizer industry. In these cases it is essential to provide an impermeable base to the dam to prevent the effluent reaching the sub-soil and polluting the underground water. A similar situation arises where *in situ* leaching processes are used and a permeable base will lead to loss of the leaching solution. In the latter case, however, a high degree of lateral permeability is required near the base of the dam to extract the leaching solution. The answer to these specific requirements is found either by the selection of a site with an impermeable foundation soil or by the laying of an impermeable base over the site. In the case of a dam with noxious seepage water, the stability of the structure is assisted by the provision of underdrains above the impermeable layer, under the outer walls of the dam. The lateral drainage for *in situ* leaching is provided by an extension of the drainage network across the whole foundation of the dam.

The use of peripheral underdrainage on poorly drained sites means that the outer walls are relatively dry and stable but the central area remains damp and soft. An examination of disused dams that had been idle for a number of years showed that, while the central surface was dry and relatively strong for a considerable depth, the lower central area remained wet and soft and would be a limiting factor in the use of these dams for building purposes. Underdrainage extending well into a slimes dam would eliminate or greatly reduce the occurrence of such weak zones where dams are built on badly drained ground.

Strength of foundation soil

Where the foundation soil is weaker than the slimes in the dam, the failure surface of a breakaway of the outer wall is likely to pass through the foundation layer. It is fortunate therefore that most natural soils in South African mining areas have strengths considerably greater than the strength of slimes. Danger areas occur when dams are situated in low-lying marshy areas along stream-beds and vleis. In these areas there is often a surface layer of soft, fine mud that has a very low shear strength. Where possible, these areas should be avoided as foundations for outer walls, and, if outer walls do have to cross such areas, the worst material should be removed and underdrainage should be provided. The aim should be to ensure that the foundation soil will be at least as strong as the slimes material in the wall.

Slope and height of dam, and rate of rise

In the use of an earth material for embankment construction, it is possible to set up relationships between shear strength, slope of embankment, and height of embankment for various factors of safety, conditions of moisture flow, and foundation shear strengths. Slimes is a granular material and is therefore cohesionless, having an angle of friction of 35°. A series of relationships for possible shear strengths of slime were set up[1]. As one would expect, if the shear strength and factor of safety remain constant, the safe height to which a dam can be built increases as the slope is flattened. Considered differently, if the height remains constant, the factor of safety increases as the slope is flattened.

To conserve area, it has been normal practice to build slopes as steeply as they will stand. This has the drawback that, while a steep slope will stand well initially, its stability will reduce with height, and, when the wall becomes unstable, it is too late to flatten the existing slope. Measures such as rock buttresses have the effect of flattening the lower slopes, and stepping back reduces the overall slope so that wall building can continue to a greater height. It is, of course, better to estimate the strength of the slimes and then derive a safe slope and height for the tonnage of slime that has to be deposited.

The strength that is developed in a granular material such as slimes depends on the increase in intergranular stress due to the deposition of overlying material and the reduction of pore-water pressures by consolidation. In slimes-dams practice, this means that strength development is directly related to the rate of rise of the dam and to the conditions of drainage in the foundation. Blight[3] used rate of rise for these two conditions as a substitute for strength, and produced curves relating height to safe slope angle at a factor of safety of 1,5 for various rates of building. This provides a reasonable method for the establishment of safe slope and height before construction commences. On this basis it appears that, even on badly drained sites, a dam can be built to a safe height of 40 m at an angle of 30° at a rate of 3 m per year. As the rate of building increases, the safe height and/or the angle of slope must be reduced.

There are, however, other factors that affect the angles of external slopes. The greatest of these is the question of surface erosion. It has long been contended that a steep slope gives a small projected area, therefore less water falls on it, and so surface erosion is kept to a minimum. On the other hand, erosion is dependent not only on the volume of water but also on its velocity, and therefore, while more water will fall on a flatter slope, its run-off velocity will be reduced and there may, in fact, be less erosion. Surface erosion is, of course, a form of pollution if the wash material reaches watercourses or dust blows off the surface. The control of erosion from these slopes is today being achieved by vegetating of the slopes. The requirements for the growth of vegetation, particularly the use of mechanical plant for cultivating and mowing operations, impose limitations on the steepness of the slope. It is suggested that the outer slope should not exceed 18° to allow the reasonable use of mechanical plant. The adoption of a slope angle of 18° for the outer faces would almost eliminate the possibility of slope failures, and dams could be built to virtually unlimited heights at rapid rates of rise even on impervious foundations.

In situ leaching operations appear not to affect the slope angle, although it can be argued that a flatter slope will allow easier access onto the slopes for drilling and pumping operations. If the dam is to be used as a building site in the future, the flatter slopes will make access to the top easier, and it should also be possible to use the slopes for building by benching because the steeper cuts at the back of the benches will still be stable.

DESIGN OF A NEW DAM

If one can assume that a slimes dam is an independent structure, one can consider the ideal site and method of construction. In practice, however, there are other factors that limit the choice of site and construction method. Let us therefore consider the ideal concept and see to what extent it can be affected by other technical considerations.

Site selection

As already mentioned, the ideal site for a normal slimes dam should have permeable foundation soil, but, if there are effluent problems or *in situ* leaching is to be carried out, the foundation should be impermeable. The foundation soil should have adequate strength to prevent foundation failures, which means that it should be at least as strong as the consolidated slimes will be.

The other aspect of site selection is the topography of the site. Generally, a site with a slight slope is preferred so that wall building can be concentrated in one area and a large storage area is gained for a relatively low height of wall. On level sites, all walls have to be built simultaneously and the total storage area is immediately available. On the other hand, steeply sloping sites require rapid rise of wall for a limited gain in storage area, and it is preferable to avoid very rapid rates of rise in the initial stages of building a wall. The dam is usually situated in a low area to take advantage of gravity for moving the slimes from the plant to the dam. This often leads to the dam being sited in a low-lying area next to a stream or vlei, where weak soils may be encountered, and this point must be watched.

Wall construction

If the foundation conditions at the site are not good, the first step in the construction of the dam is the preparation of the site. In badly drained areas, underdrainage must be provided with a rock toe right round the periphery, and any weak foundation spots must be improved. The wall is then built in the normal way with an outer slope of 18° and an inner slope of 30°. While it is still an advantage to allow each successive layer of slime to dry out in the paddocks, the strength analysis has not taken this into account and the only requirement is that the rate of rise should be evenly spread over the whole period; that is, 3 m per year is 0,25 m per month. However, if a period of rapid building is followed by a rest period, the rate of rise may be calculated over the whole period; for example, a rise of 3 m in one month, followed by a rest period of 5 months, is equivalent to a rise of 0,5 m per month, but a rise of 3 m in the last month of a six-month period remains a rate of rise of 3 m per month for that period.

Penstocks and pond

The wider wall area caused by the flattened slope will necessitate moving the penstocks further into the dam, but will be compensated by moving the pond further from the toe and thus reducing seepage flow. The normal recommendation to keep the water level in the pond as low as possible is still valid.

CONCLUSIONS

The recommendations on slimes-dam construction in 1959-60 are still valid and have been proved by practical experience in their application. The requirements for pollution control, vegetation, *in situ* leaching, and possible later use of the dam for building purposes can all be met with minor modifications to existing slimes-dam construction practice. The major change that is likely to occur is the flattening of slopes to allow the use of mechanical plant for vegetating the sides of dams, and this will aid all aspects of dam stability both in use and for later developments. Provided the toe is protected by underdrainage and the foundation has adequate strength, dams at 18° side slope can be built to virtually unlimited heights at a rapid rate of rise.

REFERENCES

1. South Africa, Council for Scientific and Industrial Research. An investigation into the stability of slimes dams with particular reference to the nature of the material of their construction and the nature of their foundation. Pretoria, restricted report, 1959.
2. Donaldson, G. W. Practical observations and the results of research on the stability of slimes dams for the gold mining industry. *J. S. Afr. Inst. Min. Metall.*, vol. 61, no. 3. 1960. pp. 183-199.
3. Blight, G. E. Shear stability of dumps and dams of gold mining waste. *Trans. S. Afr. Instn. Civ. Engrs.*, vol. 11, no. 3. 1969.

SYMPOSIUM ON PELLETS AND GRANULES

During October 1974, the Newcastle branch of the Australasian Institute of Mining and Metallurgy is to hold a symposium on pelletizing and granulation, with particular reference to the iron ore, fertilizer, and cement industries. The symposium will examine the fundamental principles underlying pelletizing and granulation, current international plant practices, and new process developments. The advantages offered by these processes in subsequent industrial operations will also be discussed. Intending delegates and contributors of papers should contact The Conference Secretary, Pellets and Granules Symposium, c/o B.H.P. Central Research Laboratories, Shortland, Newcastle, N.S.W. 2307, Australia.