STATE OF NEW MEXICO
BEFORE THE WATER QUALITY CONTROL COMMISSION

In the Matter of:	)	
PROPOSED AMENDMENT TO 20.6.2 NMAC (Copper Rule)	)	No. WQCC 12-01(R)

EXHIBIT SCOTT – D-13

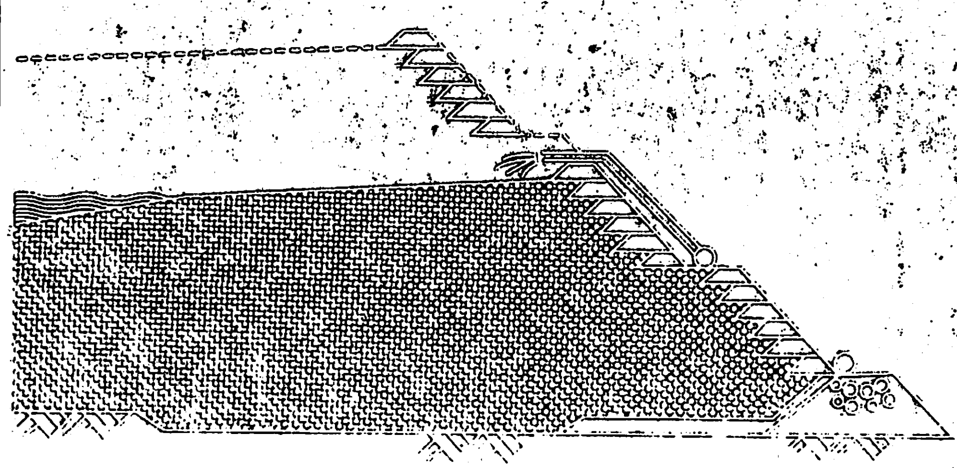
A GUIDE TO TAILINGS DAMS AND IMPOUNDMENTS

Design, construction, use and rehabilitation

GUIDE DES BARRAGES ET RETENUES DE STÉRILES

Conception, construction, exploitation et réhabilitation

Bulletin 106



3. DESIGN CONSIDERATIONS

3.1. GENERAL

This Chapter considers the design of dams and does not extend to the design of the whole impoundment, although the two are interrelated in many ways. The design should take into consideration the expected long life of the structure, including periods when the maintenance and monitoring systems are unlikely still to be present.

As stated in Chapter 2, the dams may be built on almost any site, from a wide variety of materials including borrowed fill, waste overburden/various wastes from industry, waste rockfill, the tailings themselves and various combinations. Whatever the combination of types of fill that are used, for safety and minimum maintenance, dams must be designed, as are all embankment dams, to sound geotechnical principles.

An advantage inherent in the design and construction of tailings dams that is seldom afforded to designers of water retaining embankment dams is that most are built slowly and it is possible to use a design-as-you-go approach. Initial mining or industrial programmes frequently change so initial designs of dams usually have to be modified as construction proceeds. Often the original planned maximum height of the dam will be exceeded as the requirement for increasing storage volume continues.

3.2. DESIGN AND CONSTRUCTION RECOMMENDATIONS

Legislation controlling water reservoirs in Britain requires design and supervision of construction to be the responsibility of one competent engineer. The competence of an engineer wishing to take this responsibility is assessed by a severe professional review. Successful candidates are appointed for a five year period, before being required to renew their application. In addition, the operation of dams has to be supervised continuously by competent engineers specially chosen for this task.

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Although there is no legislation in the world that has such strict provisions, there is much to be said for its application to tailings dams. It is in the interests of the owner to employ a competent engineer for the design of his tailings dams and to ensure that their construction is satisfactorily supervised.

3.3. SITE INVESTIGATION

The choice of site is usually controlled by the position and type of industry or mine the impoundment is to serve. The topography will control the positions and possible maximum required heights for retaining dams. Environmental considerations relating to the tailings impoundment will be revealed through a systematic environmental base line study. Site investigation for geotechnical purposes will also have to be extensive. A typical sequence of events [e.g. see Clayton et al (1982)] might be as follows:

a) Preliminary desk study. This should include study of contoured maps showing dwellings, installations and streams; geological maps showing strata and underground workings; any existing borehole information and/or well records; information on hydrology and seismicity.

b) Possible air photograph interpretation, particularly if contoured maps are not available, for the purpose of identifying spring lines, unstable areas (landslides), dissolution features etc.

c) Obtain information on water usage and climate.

d) Site walkover survey to investigate and confirm features noted from the desk study and air photography interpretation.

e) Preliminary subsurface exploration. Standpipe piezometers installed and sealed into completed boreholes to record water table and to enable water samples to be taken for chemical analysis.

f) Soil classification by description and sample testing.

g) Detailed subsurface exploration with sampling and field tests. Standpipe piezometers should be installed in exploratory boreholes downstream of the dam area. The designer may require some to be installed under the dam area that can be converted to remote reading. Piezometers can be used to measure permeability.

h) Laboratory testing of undisturbed and bulk samples.

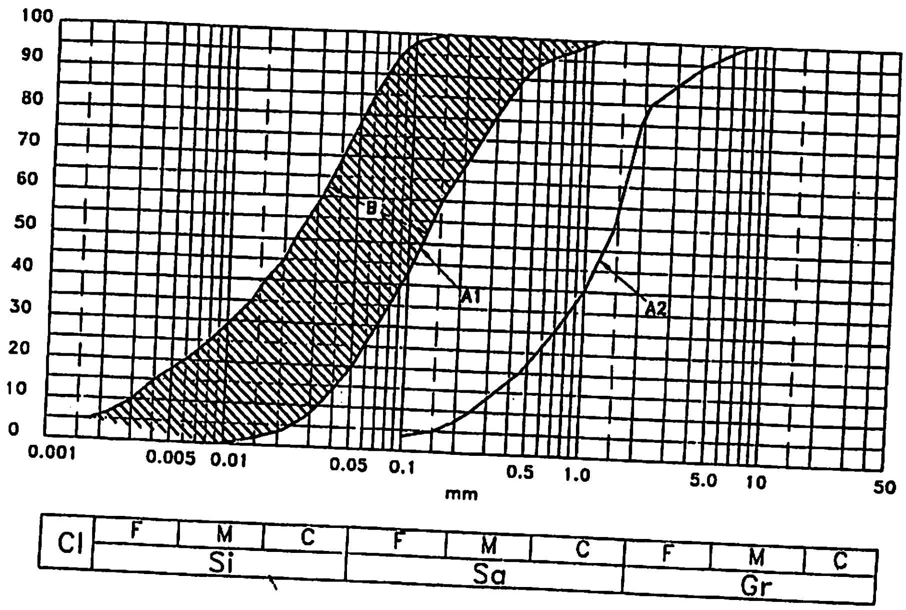
i) Evaluation of data.

The interpretation of borehole findings, to produce a three dimensional model of the ground, can be computer assisted by a suitable software programme.

The results would be used during the design stage for the impoundment and dams. During the early stage of construction, the geotechnical engineer responsible for site investigation would liaise closely with the design engineer and exanieur de projet et examinera le sol décapé et les excavations pour constater toute différences éventuelles par rapport aux conditions établies à partir des reconnaissances.

3.4. MATÉRIAUX MIS EN DÉPÔT

Les matériaux devant être stockés peuvent comprendre des solutions chimiques, parfois chaudes (voir chapitre 4.1.2), et d'autres liquides, bien que les stériles dont il est question dans le présent Guide soient acheminés sous forme de boue, la nature du matériau étant donc généralement limitée aux éléments solides transportables économiquement dans l'eau. La Fig. 19 présente des courbes granulométriques caractéristiques de stériles mis en dépôt, la dimension maximale de particule se situant dans la catégorie « sable moyen à grossier ».



On doit cependant noter que, lors de la mise au point des dispositions de mise en dépôt de stériles, il arrive qu'on ne porte pas une attention suffisante au choix du site, aux caractéristiques des matériaux de construction et aux conditions de fondation ; le projeteur sera souvent obligé de rechercher la solution la plus économique, compatible avec les conditions de sécurité et d'environnement, en utilisant les matériaux, la topographie et le climat existants.

Une grande partie des stériles devant être mis en décharge provient d'exploitations minières et du traitement de roches relativement inaltérées. Dans les mines d'or, de cuivre, d'étain, de plomb, de zinc et d'argent, les stériles qui globalement représentent une très grande proportion de la production mondiale de stériles rentrent généralement dans cette catégorie. Les stériles provenant de ces exploitations

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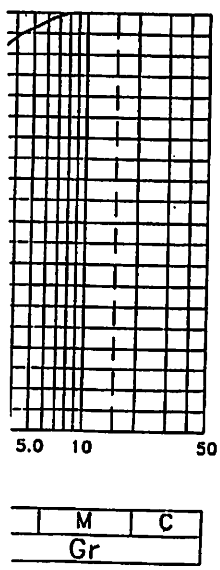

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mine stripped ground and excavations to record any variations from the conditions predicted by the site investigation.

3.4. MATERIAL FOR DISPOSAL

The materials to be stored can include chemical solutions which may be hot (see section 4.1.2) and other liquids, although the main tailings product under consideration in this Guide is delivered as a slurry and the nature of the material is thus generally limited to particulate solids which are economically transported in water. A typical particle size distribution of tailings normally requiring disposal is shown on Fig.19, with maximum particle size in the medium to coarse sand classification.

Fig. 19

Particle size distribution curves for tailings

Courbes granulométriques de stériles

Cl - Clay	*Cl - Argile*
Si - Silt	*Si - Silt*
Sa - Sand	*Sa - Sable*
Gr - Gravel	*Gr - Gravier*
F - Fine	*F - Fin*
M - Medium	*M - Moyen*
C - Coarse	*C - Grossier*
A1 - Normal upper limit	*A1 - Limite supérieure normale*
A2 - Exceptional upper limit	*A2 - Limite supérieure exceptionnelle*
B - Normal envelope	*B - Enveloppe normale*

It must be noted, however, that in the development of a tailings disposal sche me, the luxury of choice of site, construction materials and foundation condition may not be present; the designer will frequently be required to prepare a schem to produce the most cost effective solution commenserate with safety and envi ronmental conditions, using only the materials, topography and climate availabl

A large proportion of tailings products for disposal result from the mining an processing of relatively unweathered rock. Tailings from gold, copper, primary ti lead, zinc and silver mining, which collectively constitute a dominant proportio of the total world production of tailings, are normally in this category. The tot product from these operations has a reasonably consistent grading curve shape an

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normally lies within the envelope shown, the coarseness or fineness of the particular product being related to the degree of grinding applied in the plant mill. It may be noted that the finer fractions of the product lie in the silt size category, rather than the clay size, giving to the product the principal characteristics of a silt. The particles from unweathered rock after grinding are generally angular to sub-angular in shape.

Where the host rock of the mineral is more extensively weathered, as for example in the capping material of porphyritic deposits, a larger proportion of the fines may be composed of clay particles, i.e. smaller than 0.002 mm. If the clay proportion is high the material, on deposition, may exhibit clay-like properties, which may dominate the material behaviour. Finely ground material from more weathered rock may contain a higher proportion of sub-rounded to sub-angular particles but the surfaces of the particles may be pitted and irregular.

Where minerals are extracted from alluvial or beach deposits, there may be no grinding involved and the particle size distribution will be governed by that of the host material. The coarser particles may be rounded and the finer particles may be clay or silt, according to the origin of the material. In general the upper bound of the particle size distribution curve will follow that shown in the diagram but in some mining activities, such as the exploitation of secondary tin deposits, considerably larger particles are included in the material processed in the plant and the resulting tailings may have a coarser upper bound.

In some extraction processes the material may be sorted and discharged to waste as separate tailings fractions. This is particularly common where the host material is weathered or composed of secondary deposits and sorting is used to remove the fine silt and clay materials, the mineral being extracted only from the coarser particles. The fine discard is then often described as "slime" and the coarser discard as "tailings". (In many metalliferous mines, however, the term "slime" is used to describe the total tailings product.) Alternatively the sorting of the product may take place after the extraction process for the derivation of a product which may be useful to the mining operation, such as the coarse fraction for underground stope filling.

The tailings product from mining and quarrying operations is generally composed of natural rock and soil particles and the properties of the material may in many respects conform with the principles of soil mechanics. Where the waste material emanates from a manufacturing process, however, its composition may be quite different. It may, for example, not be particulate in the normal sense and its behaviour may follow correspondingly different patterns. Whereas the properties of mining tailings may be predicted with reasonable accuracy from a knowledge of the geological, mineralogical and processing background, those from manufacturing processes may need to be determined from scratch. Pulverised fuel ash (pfa) that results from burning powered coal in power stations, generally lies in the silt size range, but usually exibits a lower range of particle densities and contains some cenospheres which are lighter than water. These particles, also of silt size,

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are hollow spheres of glass like material formed in the intense heat of the furnaces, and in demand by many industries as non irritant powders and fillers. Cenospheres may cause particular design and operational problems, as described later.

The particle density of tailings particles is controlled by the nature of the host rock in the case of mining operations. For the great majority of operations the bulk of the material is derived from quartz and felspars and the particle density of the particles lies in the range 2.60 to 2.70. Where mining economics or the limitations of extraction technology dictate that only a proportion of the mineral is extracted, the particle density of the resulting tailings reflect the presence of the mineral. For example, in the tailings from iron and coal mining operations, the aggregate particle density may be respectively greater than 4.0 and less than 2.0. The particle density of tailings from manufacturing operations may again vary widely and will need to be determined specifically for each operation.

The fluid phase of the tailings product for disposal is normally water derived from inland sources, although sea water is occasionally used. In a few, usually small scale, manufacturing processes other fluids may be part of or comprise the fluid medium. The nature and amount of dissolved solids in the water, determining its properties, will be controlled by its source and the extraction process used. These properties, together with the effect of its continued contact with the solid phase of the tailings, are important factors in the planning of the measures to prevent environmental pollution. The pH of the water may vary from being very acid, as may be experienced while mining organic alluvial deposits with a natural pH of 4 or less, to very alkaline, as may result from the addition of lime during or after the extraction process to give a pH of 10 or more.

The ratio of water to solids may vary according to the mining method, extraction process and the planned water budget for the project. In alluvial mining projects the percentage of solids may be 10% or less by weight of the total slurry; where the ore is mined dry and the flotation process is used for extraction, commonly employed in gold and copper mining operations, the solids content of the tailings may be in the region of 25%; where a thickener is used to recover a proportion of the water before the tailings are sent for disposal, the slurry may have a solids content of 50 to 55%; where a specially designed high performance thickener is used deliberately to increase the density of the tailings, the solids content may be as high as 60% or more. The ratio of solids to water has a profound effect on the methods which may be used for disposal of the tailings.

Production rates of tailings clearly vary with the size of the mining operation. For example, a small gold mining operation may produce less than 100 tons/day, whilst the largest copper mines may produce over 150 000 tpd.The principles of construction are similar for the full range of production rates, with similar attention having to be paid to safety, economy and the avoidance of pollution, but the methods adopted may vary to accord with the scale of the operation.

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3.5. PROPERTIES OF PARTICULATE MATERIALS - BASIC CONCEPTS

The shear strength of a particulate material depends mainly on the force holding the particles together. The ease with which a dry sand on the surface can be shovelled and moved belies the very considerable shear strength it possesses at depth, where it is confined and subject to forces caused by the weight of overlying material.

The value of the angle of shearing resistance in terms of effective stresses (ϕ') depends on grain shape, the way the grains are packed together (measured in terms of relative density), and the force pressing them together. This force, per unit area of the particulate material, is referred to as the effective stress (σ'), because it is effective in determining strength and deformations, and is defined as the total stress applied to the material (σ), less the pore pressure (u), ie.

$$\sigma' = \sigma - u \quad \text{et} \quad \tau = (\sigma - u) \text{ tang } \phi'$$

From this it can be seen that pore pressure plays a vital role in the potential shear strength (τ) that can be developed.

The influence of grain shape and relative density must be determined for the particular tailings of concern from series of tests.

With a high enough density, when the grains are closely packed together, shearing strains force them apart so that the material expands. In undrained conditions, such as may occur in the saturated parts of embankments, this creates a fall of pore pressure, thereby increasing σ' and hence shear strength τ.

An opposite condition can occur with low density, when the grains are very loosely packed. Particles of the finer fraction from tailings, settling under water, can land so gently on the lower particles that they build up a very open structure. Subsequent consolidation under the increasing weight of added material reduces pore space to some extent, but the delicate, open nature of the structure persists. Shearing strains dislodge the contacts between particles, allowing them to move into pore spaces, so causing contraction or, if undrained, a rise of pore pressure u. This rise reduces σ' and hence the shear strength τ. The critical density of Casagrande (1936) gives the inbetween situation, when shear strains cause no change.

In a body of low density tailings, the pore pressure during shearing may rise to equal σ, so reducing τ to zero. This situation is called liquefaction: the mass behaves as a dense liquid and if it is free to flow (dam breach) it can exert considerable force on any object in its path. It is because of this that a release of tailings can cause so much more damage than a corresponding release of water.

The shearing strains produced by seismic shocks in loose tailings can cause liquefaction and the shearing strains along a potential slip surface can result in considerable loss of shear strength which must be taken into consideration when assessing dam stability. Stability analyses are discussed in Appendix A.

3.6. FOUNDATION CONSIDERATIONS

Stability may be controlled by considerations of pore water pressures or foundation conditions in cases where the natural ground that will be covered by the dam has strength characteristics that are inferior to those of the dam construction materials. This applies particularly to clayey foundation soils. The existing undrained foundation strength may be sufficient for a certain height of dam, but the increase of strength caused by consolidation under the increasing weight of the tailings dam may be insufficient to maintain stability as dam height increases. The predicted rate of construction of the dam, i.e. the rate of loading of the foundation especially if clay, must be compared with its predicted rate of consolidation. Usually rates of construction are slow enough to give time for sufficient consolidation of relatively thin layers, but with thick layers of fat clay, consideration may have to be given to accelerating their rate of consolidation by use of vertical drains, installed during foundation preparation. Stability analysis involving a deep seated slip surface passing through a thick clay layer should consider the risk of progressive failure (Potts et al 1990) if the clay exhibits brittle behaviour. A geological assessment may indicate the probability of existing slip surfaces, left by old landslips, glacial action or downslope creep. Design would have to allow for only the lowest residual strength on such surfaces. The shearing stresses induced in the clay can be reduced by reducing the angle of the downstream slope of the dam and stability can be improved by the use (if available materials exist) of a heavy rockfill starter dam keyed deep into the foundation clay layer to form a heavy toe.

The strength parameters for foundations on clay should be determined from in situ tests or laboratory tests on undisturbed samples taken from the whole depth of the strata. There may be variations with depth and it may be convenient to divide the foundation into several layers, each allocated specific strength and consolidation characteristics. Lowest values of residual strength should be determined for use where pre-formed slip surfaces are expected to be present. The position of the most critical potential slip surface is likely to be controlled by the characteristics of the clay foundation, combined with the predicted pore pressures.

The prediction of pore pressure in a clay foundation is very difficult. The developed pore pressures are controlled by rates of loading, consolidation characteristics, permeabilities in horizontal and vertical directions, position of drainage layers and the pore pressure transmitted from the overlying tailings impoundment

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and dam. While it is essential to make predictions of expected pore pressure to enable design for the proposed tailings dam to evolve, the actual pore pressures developed must be measured during construction to check on the accuracy of the predicted values and to enable modifications to be made to the initial design to ensure safety and a satisfactory behaviour for the tailings dam and impoundment. Instrumentation to measure pore pressures, etc. are discussed in detail by Dunnicliff (1988).

Sandy soil and ground containing layers of sand or sandy-gravel can be of benefit by improving drainage from the base of an embankment and from the impounded tailings. When dense, this type of soil provides a strong foundation. If, however, the drained leachate from the tailings is slightly toxic, it may be necessary to collect horizontal flows into filter wells, spaced so as to trap all the leachate, or build cut-off walls in the ground to intercept the horizontal flow and bring it up into a downstream collecting ditch or small reservoir, to be pumped back up on to the impoundment or directly to the processing plant.

When there are great depths of gravel or the underlying rock is very fissured or karstic, vertical cut-offs or filter wells may not be sufficient to prevent the pollution of ground water by draining leachate. If the degree of toxicity produced in the ground water is unacceptable, it will be necessary to form an impervious layer over the whole area to be covered by the impoundment. (see Section 4.3.2.).

3.7. EARTHQUAKE CONSIDERATIONS

The designer of a tailings dam will wish to take into consideration a) the level of seismic activity that may occur at the site, b) the ability of the proposed tailings dam to survive predicted shock induced loadings, c) the proposed siting of the impoundment relative to areas of habitation and d) the existance of a local emergency plan. Bulletin No.98 (1995) 'Tailings Dams and Seismicity' deals with these problems and gives the current state-of-the-art on the subject.

3.8. THE DESIGN OF DAMS CONSTRUCTED MAINLY FROM TAILINGS

In situations where the storage lagoon has to be situated some distance from the source of the tailings it may be more economic to construct as much of the dam as possible from hydraulically transported tailings, even though there may be a surplus of waste fills at the mine or production plant, to avoid haulage costs.

The suitability of tailings as a construction material depends on the type of rock from which they were derived, the degree of grinding required for extraction of the metals and the effects of chemical treatment used in the extraction process.

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Annexe A.

As described in Section 3.4, particle sizes found in mine tailings usually lie between 2 mm and 0.0005 mm, i.e. they have the sizes of sand or fine sand, silt and some clay. The mechanical properties of the tailings are affected by the sizes, distribution of sizes and on the shape of the particles. Those tailings which will form fill with the greatest potential strength and greatest ability to drain (the most suitable for dam construction) are those with the larger sizes: sand, fine sand and coarse silt.

A problem frequently facing the designer of a new project is that of knowing the likely properties of the tailings that are to be produced. His initial design may be based on the properties of similar tailings produced from similar processes elsewhere. Nevertheless, as has already been mentioned, the relatively slow rate of construction of tailings dams provides the opportunity for changes to be made to the original design concept during development, to ensure the most suitable construction.

3.9. DAMS CONSTRUCTED BY THE UPSTREAM METHOD.

3.9.1. The beach

The use of a beach is the traditional way for obtaining the coarsest fraction from the tailings for dam building. In theory the tailings slurry released at the top of the beach spreads out as a uniform thin sheet which flows down the beach at such a rate that the sand sizes settle out over the first part of the beach, the coarse silt over the second part and only the fine silt and clay are carried beyond the lower end into the liquid pool of the impoundment. In practice, the deltaic movement of the slurry, discharged from the pipe spigots, produces a complex pattern, conforming largely to this theoretical principle but carrying some coarser material into the body of the impoundment producing eventually a highly stratified deposit not dissimilar to a compressed leaf like structure. In this way the solid particles build up the beach and raise its level, while the transportation water, still carrying the finest particles flows into the body of the impoundment. As it progresses slowly over the length of the impoundment the fines settle sufficiently to leave a pool of relatively clear water at the far end of the impoundment. This may still contain dispersive and other chemicals and can, with advantage be pumped back to the processing plant for reuse. The sedimentation of the fines under water produces the slimes, a mass of low density material with a very loose structure. Abadjiev (1985a) and Blight (1987) have considered beach formation in detail.

As the particle size decreases from the downstream slope with the distance upstream, so the permeability decreases. This has the effect of lowering and altering the shape of the phreatic surface in the embankment from that which it would have had if the material had been of a homogenous permeability. This effect improves stability and helps to explain the stability of many of the early upstream types of dams. It is an aspect fully discussed in Bulletin No.97 (1994) 'Tailings Dams: Design of Drainage', Appendix A.

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3.9.2. Strength parameters

As a further generalisation, the values of the shear strength parameters may be expected to decrease with reduction of particle size and reduction of density. The strength parameters for a coarse sand forming the outer face of a dam will be the highest in value of all the constituent materials partly because of the presence of larger particles and partly because of greater density, which may have been improved by mechanical compaction. Strength parameters tend to decrease with distance into the body of the impoundment due to the reduction in particle size and the lower densities often found distant from the point of deposition.

Improving density is an important aspect both in improving stability and enabling more waste to be stored in a given volume. Resistance to earthquake would be greatly enhanced if density could be increased above the critical value. Klohn et al (1981) and Mitchell (1981) have discussed the use of explosives to improve the density of loose tailings. While it would be valuable to improve the density of tailings forming a dam constructed by the upstream method, explosives could damage the drainage system, resulting in an adverse effect. For the body of the impoundment, however, it could be advantageous in giving increased weight of storage and reduced risk of liquefaction.

Prior to construction, an assessment can be made of the value for ϕ' for the various grain size fractions of the whole tailings from laboratory tests. These should be determined from samples prepared at varying relative densities to define a range of ϕ' values for relative densities of, say, 20% to 80%. At the initial design stage, estimates can be made of the expected extent of zones of materials of various grain sizes and of their relative densities. Methods for estimating the physical characteristics of deposited tailings have been given by Abadjiev (1985a).

Stability during the first stages of construction is unlikely to be critical. In situ tests can be carried out to determine the actual densities and grain sizes found in the lower part of the dam, and to obtain a further assessment of strength parameters. Piston samplers may be used to obtain relatively undisturbed samples for laboratory testing from boreholes kept full of a drilling mud of density slightly greater than that of the slimes. Further analysis at this stage may show the need for slight alterations to the initial design and adjustments made to the methods of construction (considered in Chapter 4) to achieve the required results.

3.9.3. Pore pressures and drainage

Adequate and effective control of water is imperative to the safety of dams built by the upstream method. The majority of the failures of these type of dams has been due to water, causing erosion or undesirable pore pressures.

Control is required to prevent the water pool from encroaching upon the beach. If the outflow is restricted by failure of a decant system, or inflow increases excessively due to failure of a diversion system or as a result of an exceptional

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flood, the dam may fail as a result of rising water level and excessive seepage before the crest is itself overtopped.

The phreatic surface, which remote from the embankment, is at pond level, should be contained within the body of the dam, to avoid the instability that can be caused should it reach the downstream slope and begin exit erosion. In the past, low dams have been built without special drainage measures and when on dry, permeable ground, have been successful. But on ground of low permeability or if the need has arisen to raise the dam above its original design height, the phreatic surface may rise and intersect the downstream slope. In these circumstances pore water will begin to drain from the face of the slope and effective stresses may be sufficiently reduced to allow small rotational slips to develop. These cut back into regions of ever higher pore pressures, so that larger, deeper slips occur and immediate remedial action of applying layers of filter drainage material and toe weighting may become necessary to avoid progressive, serious failure. It is very important that the design of new dams, if constructed using upstream methods, should incorporate adequate drainage measures.

Drainage, built into the tailings during construction, is essential to the stability of dams built by the upstream method. Careful design is required to produce a fully effective scheme, and the greatest care is needed during construction to prevent faults and blinding from occurring. Effective drainage should be viewed as cheap insurance, because it is very difficult to do some form of remediation in the latter stages in the life of the dam.

The design of suitable drainage is dealt with in greater detail in Bulletin No.97, 'Tailings dams: design of drainage', which also discusses the design of filters.

Weakness can be caused by allowing the slimes to accumulate immediately upstream of the starter dam during the early stages of construction. In general this material has a lower value of ϕ' than the coarser fraction used for dam construction and tends to develop positive pore pressures under shearing strains. In this position, shown by A in Fig. A.2, it can be on the path of a deep seated slip surface as the dam approaches full height. It also considerably reduces the resistance of the dam to seismic forces. The use of an extended drained toe for the starter dam, as advocated by Bulletin No.97, can avoid this situation. Clearly the greater the extent of compacted, well drained coarser material along the path of any potential slip surface, the more stable the dam will be under any circumstances.

In summary, it can be said that good upstream constuction requires:

- tailings containing an adequate fraction of coarse sizes
- starter dam with an extended toe

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- the incorporation of good drainage
- use of a beach of considerable width

3.10. DAMS CONSTRUCTED BY THE "PADDOCK" METHOD (SEE SECTION 2.2.2 F_3)

This method of construction is suitable for tailings containing no coarse fraction, to form impoundments of moderate size, and has been used extensively at gold mines in South Africa. It is well suited to a dry climate with high rates of evaporation and relatively flat sites. It is not necessary to separate grain size fractions so neither beach nor cyclone are required. Gold mine tailings tend to be of a fairly uniform silt size: the ore is crushed and ground to this size to obtain the maximum extraction of gold. Strength in the dam is developed by pore water suction as the transportation water evaporates from the thin layers of slurry exposed in the flat paddocks. Tailings containing a coarser fraction may cause horizontal layering that can conduct water from the impoundment and lead to piping, as occurred at Bafokeng, described by Jennings (1979). Because consolidation is influenced by drying, drainage layers within the fill can be a disadvantage and may carry water into the otherwise dry fill.

In order to keep the phreatic surface some distance away from the downstream face, a wide filter drainage blanket should be placed on the foundation surface, before dam construction begins. The filter requires the most careful design to prevent it becoming clogged by the fine tailings. This aspect of design is fully covered by Bulletin No.97 (1994) 'Tailings Dams: Design of Drainage'.

Most of the earlier dams built by this method in South Africa did not have filter drainage blankets and relied on the very low water table and permeability of the natural ground to provide downward drainage. Environmental considerations in those times did not require measures to be taken to prevent the drainage of pore water into the ground.

The outer slopes of paddock dams require protection against water and wind erosion. Gullying can be reduced by providing berms, with relatively steep slopes between them. A safe average slope of say 1 on 2 can be constructed with berms typically every 10 m vertical height, with slopes of 1 on 1 between them. The berms should have an inward slope of about 1 on 60 with a lined gutter along the inner edge connected to a piped drainage system.

Additional protection is required to prevent wind erosion and erosion by rainfall, that tends to block the gutters, which require regular cleaning. The establishment of vegetation cover is the best solution but this is not always feasible during construction, and temporary measures, such as chemical spraying to provide light cementing may be considered.