THE CONTROL AND DRAINAGE OF WATER IN MINE TAILINGS DAMS

BAUER, G. E.

ABSTRACT : Mining is one of the largest industries in Canada. The costs of controlling water in tailings structures represents a major share of the total cost of tailings disposal. Furthermore, the control and drainage system adopted will have an influence on the stability of the dam and on the pollution potential of the environment. Monitoring of water pressures and water flow within these structures will supply valuable records during construction and for future design considerations.

RESUME : L'industrie minière est la plus importante industrie du Canada. Les coûts de contrôle de l'eau dans les structures faites de déchets miniers représentent la plus importante partie des dépenses totales d'un tel projet. En outre, le contrôle et le système de drainage adoptés auront une influence sur la stabilité du barrage et sur l'éventuelle pollution de l'environnement. La connaissance des pressions interstitielles et de l'écoulement au sein de ces structures fourniront des éléments précieux d'information pendant la construction et pour de futurs projets.

RESUMEN : La industria minera es una de las más importantes de Cánada. Los costos de control del agua en los balses de decantación de rechazos de mina, representan la partida más importante de los gastos totales de tales proyectos. Además, el control y el sistema de drenaje adoptados son fundamentales, en cuanto se refiere a la estabilidad de las presas, y a la eventual polución del medio ambiente. El conocimiento de las presiones intersticiales y del flujo dentro de estas estructuras aporta elementos básicos de información, durante la construcción y para proyectos futuros.

Department of Civil Engineering, Carleton University, Ottawa, Canada.

1. INTRODUCTION

Mining is the largest industry in Canada and the expanding demand for mineral ores has resulted in the production of solid and liquid wastes at an accelerated rate. Solid wastes are usually dumped on waste piles and they can also be used to fill in the mined-out slopes or open pits. In the wet process of extracting minerals considerable quantities of water are added and the resulting waste is leaving the plant in the form of a slurry. This mixture of liquid and solid constituents is generally impounded for sedimentation in tailings dams. The design engineer is faced with the task to design a water-control system which will guaranty an adequate factor of safety for stability at minimum cost.

2. STABILITY OF TAILINGS DAMS

In Canada tailings dams are generally designed using the basic principles from Soil Mechanics, in particular, principles applicable to the design of conventional earth dams. There is, however, a fundamental difference between these two structures. The earth dam will only be subjected to water and seepage forces after the structure has been completed. In contrast the construction of a tailings dam is an ongoing process over the life of the structure and is exposed to water flow right from the start.

Once the strength properties of the tailings material has been established from laboratory and/or field tests, the stability of the dyke can be adequately determined using conventional slope stability analyses, such as proposed by Bishop (1965) or by Morgenstern and Price (1965). Mittal and Morgenstern (1974) concluded from their studies that the shear strength and compressibility of tailings sand were generally comparable or better than natural sands and hence are not a problem in stability considerations of tailings dykes.

Therefore, in the following discussion the attention will be focussed on the other performance requirement: seepage control and the factors affecting seepage control.

3. METHODS TO CONTROL WATER INFLOW

Site Selection

A great degree of control to regulate the amount of runoff which enters the tailings pond can be exercised by proper site selection. A tailings structure located on flat ground has no runoff inflow, whereas a cross-valley dam will experience a maximum volume of runoff inflow. A side-hill dam will have a moderate water inflow due to runoff. In cold and wet climates, inflow from direct precipitation, such as rain and snow, will be high, and the water control system has to be designed to handle these peak volumes. In Canada 50 per cent of the precipitation is lost again by evaporation (Bragg, 1973). During the winter months special precautions have to be taken to ensure that the inlet and outlet areas are kept free from ice to prevent overtopping. The excess free water, that develops primarily from the surface runoff or direct precipitation can be handled by several methods as follows:

(1) The excess free water is allowed to flow over an emergency spillway,

(2) The water is directed around the tailings dams through diversion channels, and,

(3) The excess water flows into the pond area but is removed again through a decant system.

Particular care has to be taken to locate the decant outlets a relatively far distance from the slopes of the dams to avoid erosion and piping. Also, the beds of the diversion channels should be lined to minimize erosion. Spillways are generally relocated as the height of the dam increases.

Water Content of Slurry

The amount of water accompanying the solid particles of the tailings depends on the type of the ore mined and the milling process used. Depending on the thickening procedures, the tailings slurry may contain anywhere from 50 to 85 percent water by weight. For example, the Sherman Mine of Northern Ontario, an open pit iron ore mine, uses 150,000 liters of water per minute. Ten percent, or 15,000 liters per minute is pumped to the tailings pond. The remaining 90 percent is reused in the milling process. This pumped tailings contains 50 to 55 percent solids by weight. In special cases, for example, in tailings from oil shales which have been dried for easier handling, the water content may drop to about 20 percent.

Once the site and type of the tailings structure has been selected, the amount of water inflow from the milling process, the surface runoffs and the frequency at which the peak runoffs will occur can be estimated.

4. METHODS TO CONTROL WATER OUTFLOW

Permeability

The subject of permeability is of paramount importance in the safe and economical design of tailings structures. The quantity of water seeping through the soil pores is directly proportional to the pressure gradient, that is, the difference of the water levels of the pond area and the downstream end, divided by the length of the seepage path. This is expressed by the well known Darcy's law

$$Q = ki\,A \tag{1}$$

where Q = quantity of seepage water
k = coefficient of permeability
i = hydraulic gradient
A = area through which water flows

It is generally agreed that the coefficient of permeability is influenced by the void ratio, grain size distribution and the amount of fines (#200 sieve) of the tailings material.

Figure 1 shows the relationship of the coefficient of permeability to the amount of fines present in the tailings sand. This figure can be used as a first approximation to estimate the volume of water lost through the dyke and/or through the underlying foundation material. Hazen (1892) has established the following empirical relationship between the effective grain size, D_{10}, and the coefficient of permeability, k:

$$k = D_{10}^2 \tag{2}$$

when D_{10} is expressed in millimeters, k will be in cm per second. In Figure 2 this relationship is presented graphically. Superimposed are the test results of different researchers which indicate a close agreement with Hazen's equation. The above discussion holds true only for completely saturated soils, in the case of tailings dams, these soils will be located below the phreatic seepage line. When it becomes necessary to establish the permeability of partially saturated soils above the water table, the engineer can resort to an infiltration test and the coefficient of permeability can be determined by the method proposed by Palubarinova-Kochina (1962).

Density

The density of the sand mass, though less important than the grain size, has an important influence on the permeability. The denser the soil, the smaller the porosity or the void ratio and the smaller will be the corresponding permeability. Cedergreen (1966) reported that for a particular sand permeabilities varied from 1 to 20 times from the loosest to the densest state. For sands of more uniform particle sizes the permeability is influenced to a lesser degree. The placement density of the embankments are controlled to some degree by the method of construction, such as the upstream, downstream or centre-line methods and construction with imported materials. These methods of construction are illustrated in Figure 3.

Embankment Height

The factor of safety against sliding for a dry cohesionless slope is independent of the height of the embankment. Submergence or seeping water will reduce the stability by one half or more. As a general and wise rule the top seepage line (phreatic surface) should be located away from the downstream face of the dyke. The seepage force, which acts in line with the direction of the flowing water, can cause erosion of soil particles where the seeping water exits the embankment. This toe or slope erosion can lead to piping or tunnelling and eventually to collapse of the tailings structure.

Kealy and Bush (1971) have shown the dependency of the factor of safety against failure with regard to the location of the top seepage line. This relationship is shown in Figure 4. Another reason to locate the seepage or flow lines away from the face of the dam is to decrease the potential against liquefaction as reported by Smith (1969).

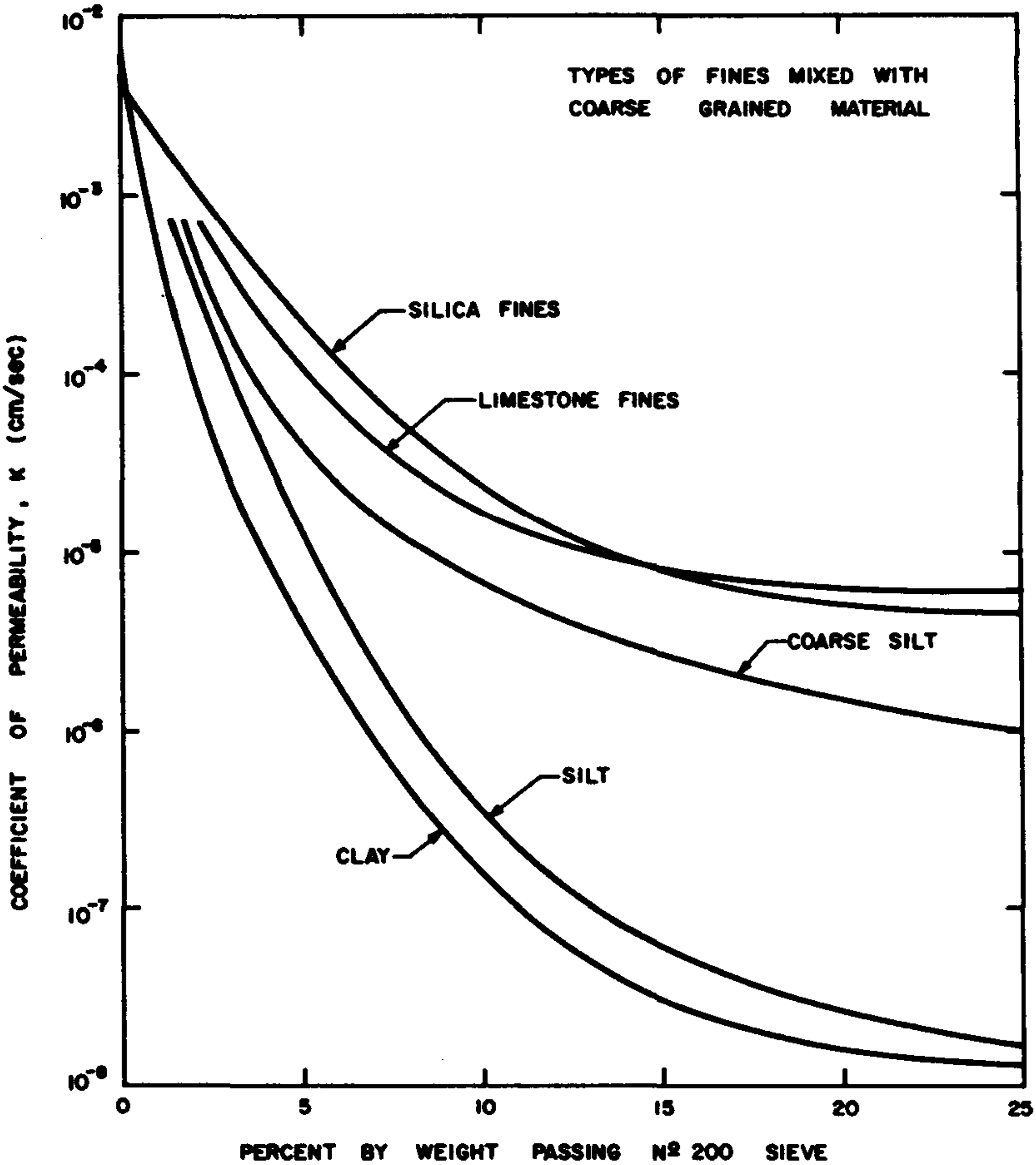


Figure 1. Permeability versus Fines Content

(EMR, 1972)

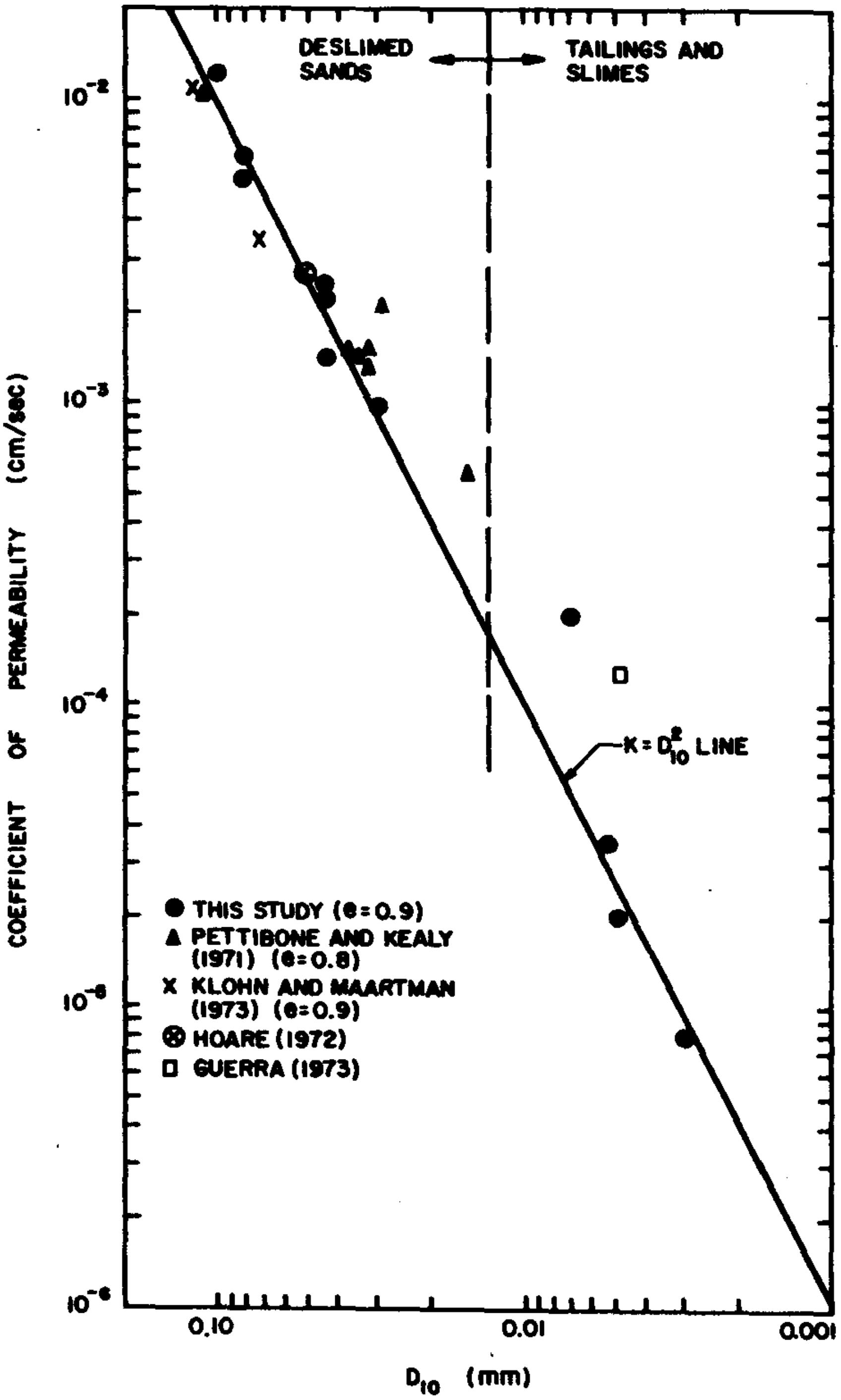
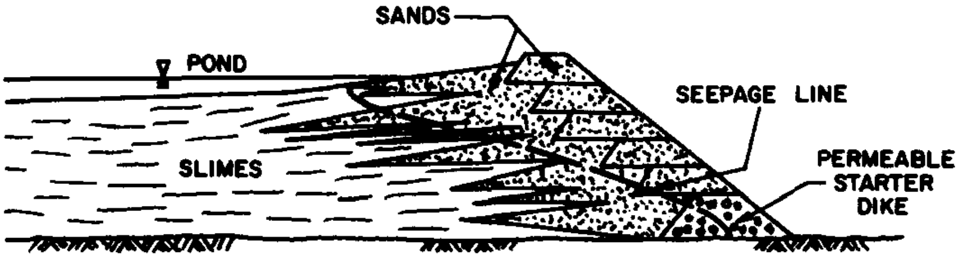
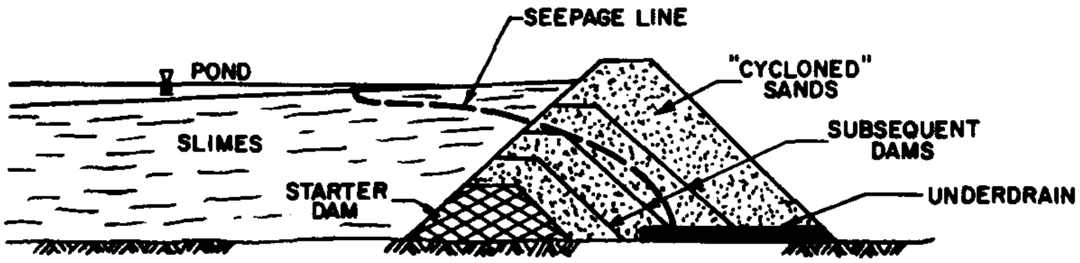


Figure 2. Permeability versus D_{10}

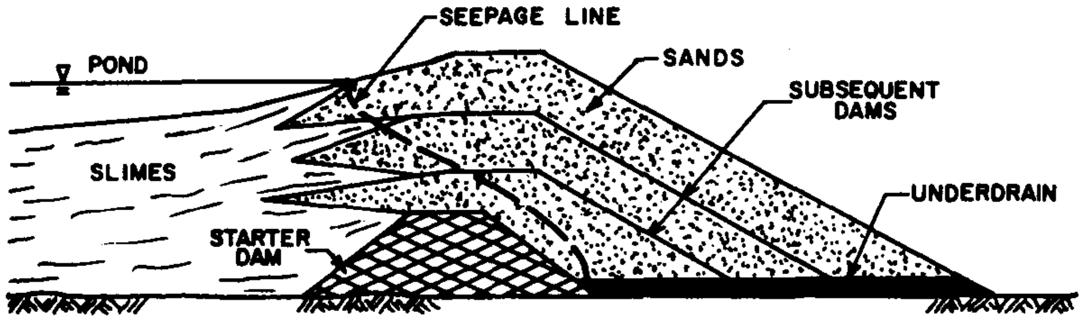
(Mittal and Morgenstern, 1976)



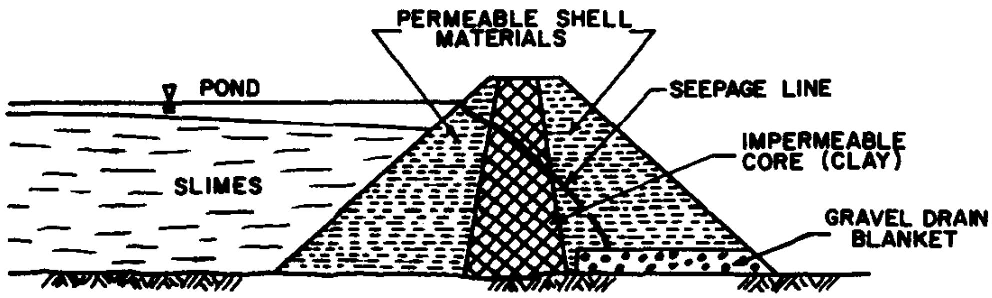
a) Upstream Method



b) Downstream Method



c) Centreline Method



d) Earth Dam Method

Figure 3. Methods of Construction of Tailings Dams

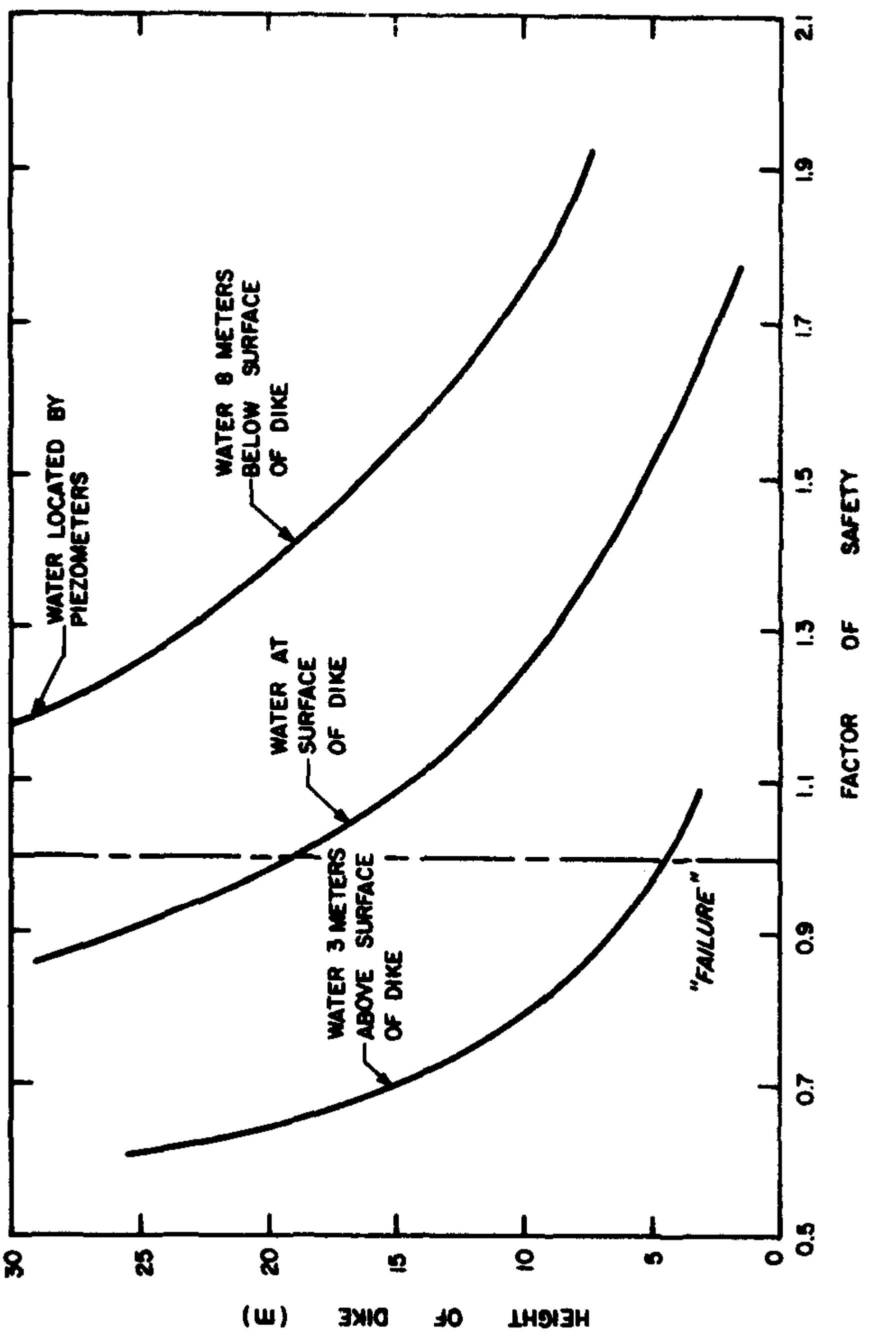


Figure 4. Factor of Safety in relation to Location of Top Seepage Line

(Kealy and Bush, 1971)

Drainage Filters

Filter drains can most effectively be incorporated in the construction of the embankment in order to suppress the seepage lines and to effect better control of the water leaving the structure. The grading or sizing of the filter material is of paramount importance in order that the filter fulfills its two main requirements, (1) the filter material should be course enough to prevent any build-up of hydrostatic pressures and to allow easy passage of water, and (2) the material must be fine enough to prevent washing through or erosion of the tailings sand. These two criteria have been expanded by the Department of Energy, Mines and Resources of Canada (1972) into the following six rules:

1. $\frac{\text{The 50\% size of the filter material}}{\text{The 85\% size of the protected soil}}$ should be less than 5

2. $\frac{\text{The 50\% size of the filter material}}{\text{The 50\% size of the protected soil}}$ should be less than 25

3. The filter material should be smoothly graded; gap graded materials should be avoided.

4. $\frac{\text{The 15\% size of the filter material}}{\text{The 15\% size of the protected soil}}$ should be greater than 5

5. The filter material should not contain more than 5 percent of particles, by weight, finer than the No. 200 sieve, and the fines should be cohesionless.

6. The coefficient of uniformity of the filter material should be equal to or greater than 20.

These requirements are more readily illustrated in Figure 5. The location of the filter drains will dramatically affect the position of the seepage lines as shown in Figure 6. Very seldom is it economically justified to prevent seepage through the tailings dam completely. Reduction of the amount of water through the dyke by grouting, the use of slurry trench walls and cutoff curtains have been used, but if impervious materials, such as clays and silts are readily available at the site, they could be used advantageously to construct an impervious upstream blanket or an impervious core. The application of clay and bentonite to seal tailings ponds has been described by Monea (1977). For environmental considerations, a secondary dam can be constructed downstream of the main tailings dam to impound the outflow from the main dyke. This water can be treated, if necessary, and then returned to the milling plant for reuse.

5. INSTRUMENTATION

Most problems which occur in tailings structures are due to seepage forces and liquefaction. Therefore, as a requirement to a safe performance of the structure it should be made compulsory to monitor the water pressures within and underneath the dam. Installation of simple piezometers to monitor water pressures and reference point to observe horizontal and vertical movements, can provide valuable information during the life of the tailings dam. Hardy (1974)

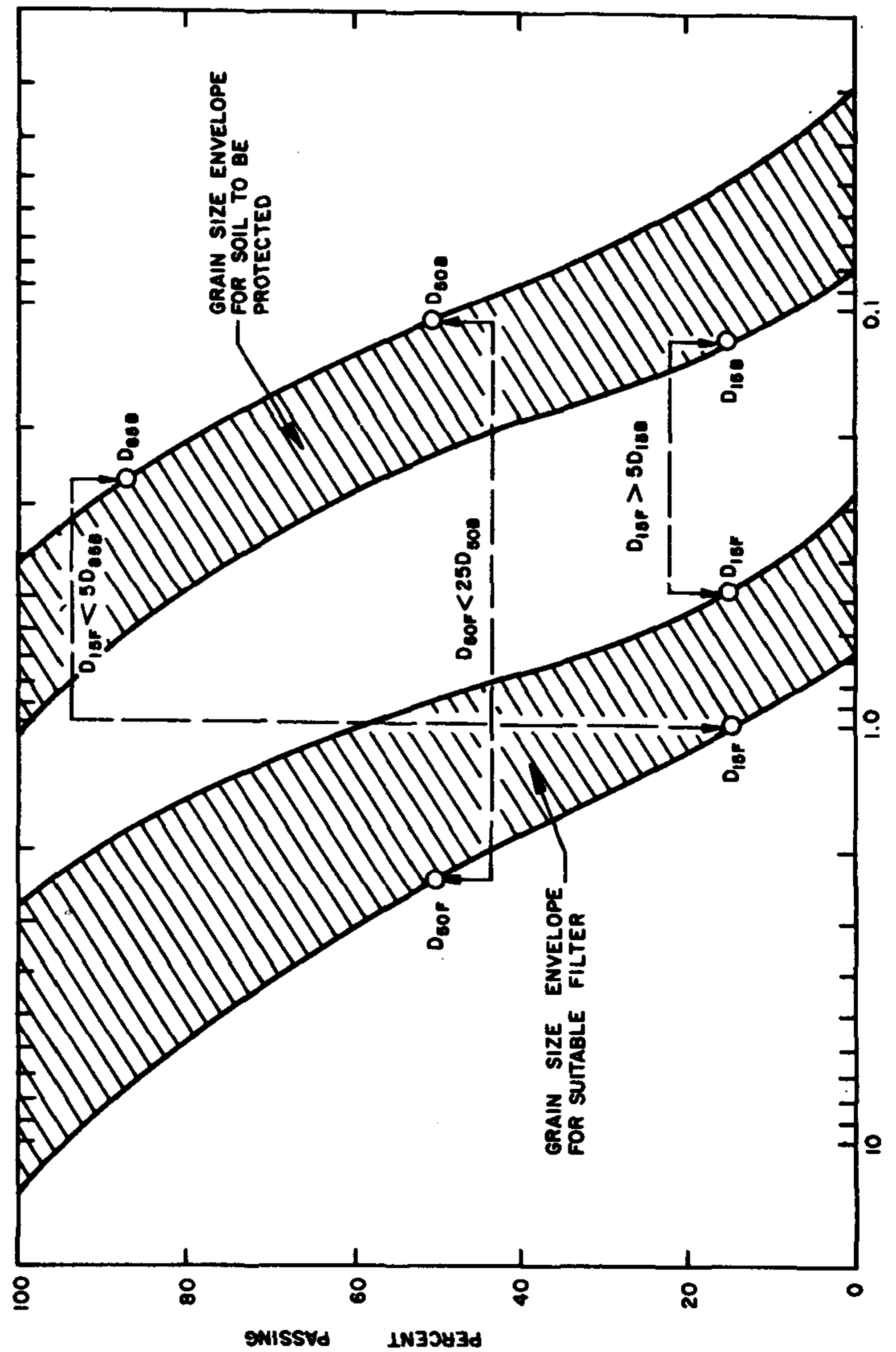
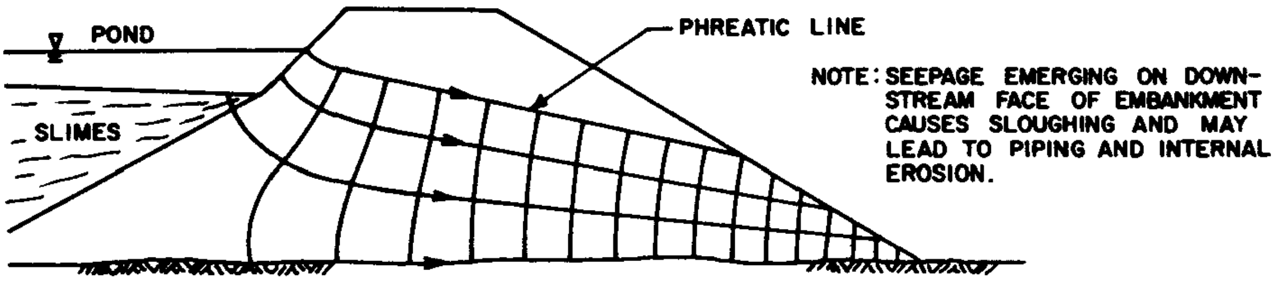
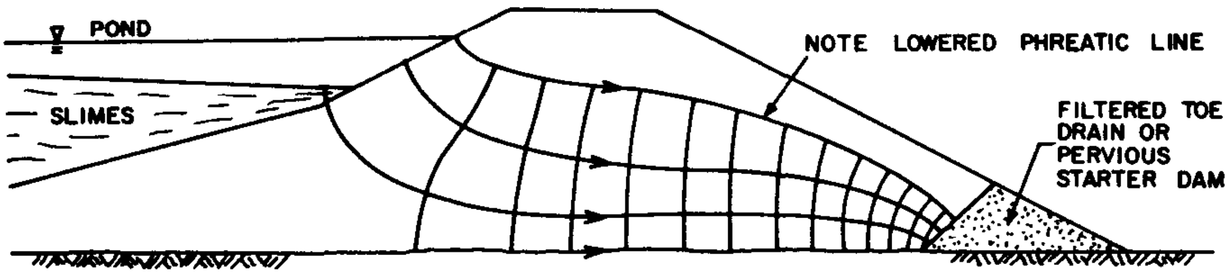


Figure 5. Gradation Requirements for Drainage Filters

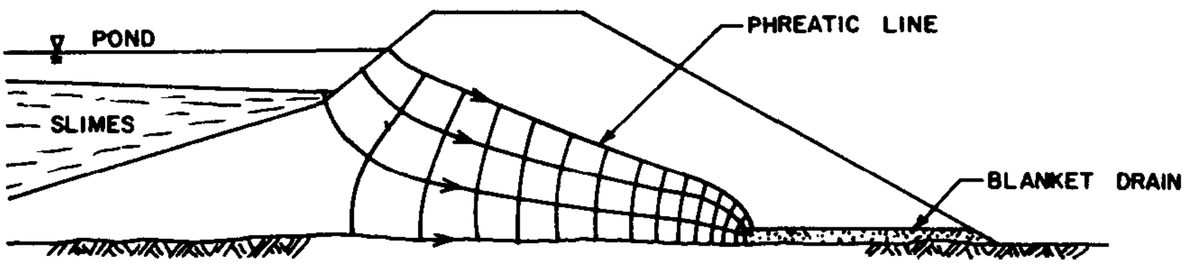
(EMR, 1972)



(a) No Drainage Filter



(b) Toe Drainage



(c) Blanket or Under Drainage

Figure 6. Effect of Drainage Filter on Phreatic Line

reported that 75 piezometers were installed in the 70 m high tailings dam at Great Canadian Oil Sands since its construction was started in 1967 and that they are frequently read in particular before a decision to raise the height of the dyke is made, these monitoring results are reviewed.

In the upstream method of construction some of the material for the successive dykes will be placed over the saturated slimes. This could generate high enough porewater pressures to cause localized failure of the underlying material. The placement of piezometers in the susceptible material could dictate the rate of construction in order to keep the porewater pressures within safe limits.

Since most of the coarser tailings material is quite pervious, simple and inexpensive non-corrosive piezometers, such as the Casagrande type, are quite adequate to monitor the water pressures and seepage quantities. These records could either be used to modify the construction procedures or to help in future design considerations of tailings structures. Also, observation data are frequently used to prove or disprove statements in conflicts or lawsuits.

6. CONCLUSIONS

Proper control of water flowing into and out of tailings dams is absolutely necessary to guaranty the safe performance of these structures. The design engineer has a number of control devices, as discussed in this paper, at his disposal and the decision which ones to use depends on many factors, the two most important ones are cost and concern for the environment.

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