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Conceptual Design of Disposal of Bauxite Tailings
Conceptos de Diseño para la Disposición de los Desechos de Bauxita

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SYNOPSIS

Fine grained tailings created in the washing process of bauxite ore from the Trombetas mine had temporarily been discharged into an adjacent river.

Due to environmental concern alternative long-term tailings disposal methods have been pursued. Two alternatives have been studied and include the construction of a conventional dam to permanently store the tailings and a in-mine disposal of the tailings.

Compressibility and permeability behaviour of the tailings have been measured both in the field and in the laboratory and enabled computer simulations to prove the second alternative as feasible.

The in-mine disposal process have been chosen due to its environmental and economical advantages.

INTRODUCTION

The washing process of the bauxite ore from the Trombetas mine creates a fine-grained tailings.

From the beginning of the mining operation a long term solution have been pursued and several alternatives have been studied; in the meantime tailings were disposed at an adjacent river and lake system.

The existance of this deposition area offered an excelent possibility of performing in situ tests which could confirm the compressibility and permeability properties determined in the laboratory.

In a previous paper (Carrier, D.W. et al, 85) the authors have presented the basic concepts which would be pursued in the disposal plan; more laboratory work and the decision to go ahead with the in-mine disposal of tailings, which proved itself economically feasible, are discussed in the present paper.

TAILINGS DISPOSAL METHODS

When seeking for alternative long term disposal methods two conceptual alternatives have been studied: the construction of a conventional dam to permanently store the tailings in any of the valleys adjacent to the washing plant or and in-mine disposal method.

In the conventional dam scenario, the washing plant could remain where it is now operating or be moved to the mine and the necessary storage capacity would be found in nearby valleys.

The dam, if only one adjacent valley was to be used, could be constructed in a series of stages over a period of thirty years to a height of 70 meters to store approximately one billion cubic meters of tailings.

There are many disavantages associated with the conventional tailings disposal alternative : (a) a large area, covering several hundred hectares, cannot be reclaimed until many years after mining has ceased and may never be returned to an usefull function; (b) although the probability of a dam failure is very small, the potential ecological damage would be enormous if tailings were to flow down the valley.

Because of these reasons the owner has pursued the in-mine disposal of tailings as an alternative.

The investigation presented in this paper was collected in the process of determining its technical and economical feasibility.

IN MINE DISPOSAL SCENARIO

The in-mine disposal system would require the washing plant to be moved to the mine plateau. The tailings would initially be pumped to a small, permanent thickening pond. As the tailings settle and consolidate to a sufficiently high solids content, minimising the volume of material to be pumped to greater distances, it would be dredged to cells within the mined out area.

Clear water from the thickening pond can be recycled to the washing plant.

The dikes in the periphery of the thickening pond and of the mine cells will be constructed by reshaping the overburden piles left by the mining operation with the draglines.

The design and construction of these dikes poses no special concern as the stored tailings have a beneficial sealing effect of the pond and cells. The reshaping of the overburden piles will flatten its outside slopes and increase their stability safety factor.

After two years the tailings will consolidate and desiccate sufficiently so that reclamation can begin.

Reclamation will consist of levelling the exposed overburden and reforesting it with natural species. The entire operation will be continuous as thickening of the tailings in the initial pond is continous.

Sufficient surge capacity will be provided in the thickening pond in order that disposal in it can continue even if the dredge is not operating.

The in-mine disposal alternative has several advantages over the conventional dam: (a) the in-mine disposal has proven itself cheaper; (b) the ground surface at the mine will be reclaimed close to the original grade; (c) the tailings are used beneficially in reclamation rather than being left unreclaimed in a large reservoir.

GEOTECHNICAL PROPERTIES OF THE TAILINGS

Filling of the mine cells with thickened tailings has been analyzed using a numerical model based on a family of finite strain,one dimensional consolidation computer programs (Somogyi, F.80; Carrier, D.W. et al 83). Classic Terzaghi theory, which assumes infinitesimal strain, linear consolidation, does not apply in the case of consolidation of very compressible slurries. Instead, it is essential that finite strain, non-linear consolidation theory be used. The programs require the following input:

- Compressibility of sediment
- Permeability of sediment
- Initial void ratio of sediment
- Filling rate of dry solids
- Filling period
- Boundary drainage conditions

The compressibility and permeability were determined in the laboratory using a specially constructed stress controlled slurry consolidometer. The compressibility of the sample is determined by plotting the void ratio at the end of each loading increment versus the applied stress, as is generally done in the conventional oedometer test. The permeability of the sample is both calculated from time-deformation measurements, and directly measured using constant head test. During the constant head tests, the externally applied load is adjusted to compensate for the effects of the seepage force.

The testing proceedure has been described elsewhere (Carrier, D.W. et al 83).The compressibility relationship and the permeability relationship is shown in Figure 1. Field compressibility data from testing in the existing disposal site and of a test pit are also shown; the in situ testing techniques have been presented by Bromwell, L.G. et al 79, it can be seen that the field data confirm the laboratory compressibility. Centrifuge laboratory tests were also performed (Schofield, A. 80).

In this technique, a physical model of a disposal area is "spun" in a geotechnical centrifuge, such that the tailings are subjected to 50 to 100 times the earth's gravity force. The scaling laws are such that the ratio of the physical dimension of the prototype to the model is equal to the gravity ratio. The time for consolidation is proportional to the square of the gravity ratio. Hence, the entire design life of a disposal area can be accurately modelled in the laboratory in a matter of hours.

One centrifuge test was performed on a representative sample of the tailings in order to verify the compressibility and permeability relationships. The initial

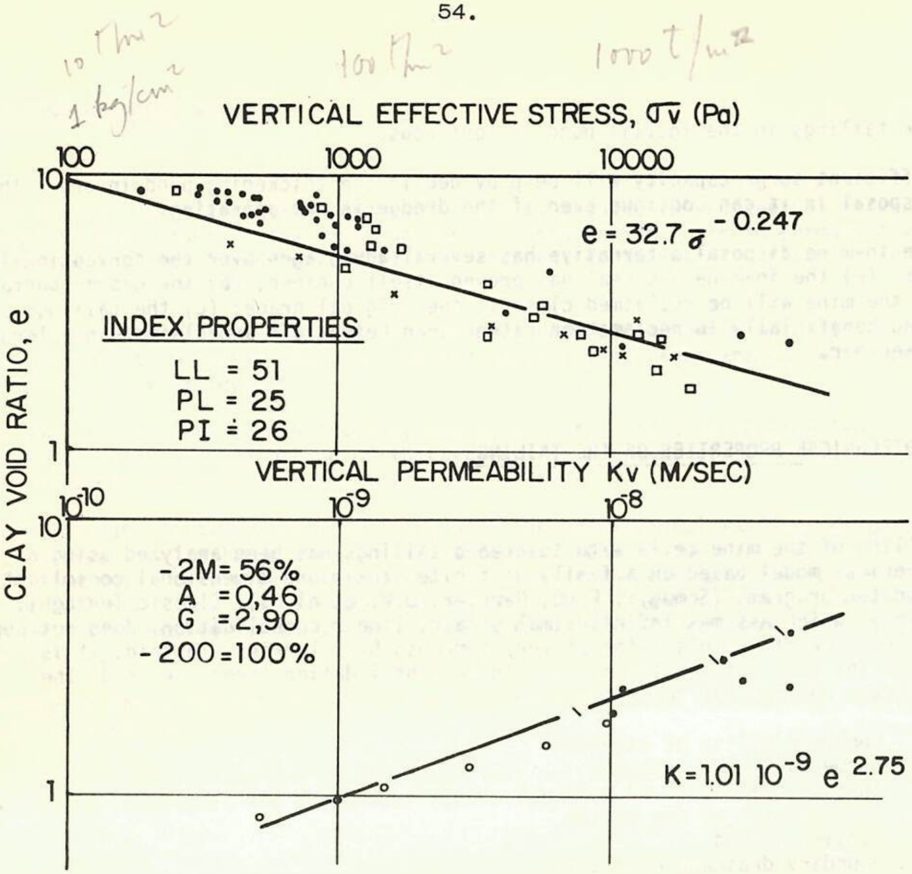

FIG.1 - GEOTECHNICAL PROPERTIES

solids content and height are approximately the same as those in the test pit. The results of the centrifuge test are shown in figure 2, along with a computer simulation of the test using the laboratory measured compressibility and permeability. As can be seen, the numerical model accurately predicts the results of the centrifuge test. Hence, the centrifuge test verifies the compressibility and permeability relationships.

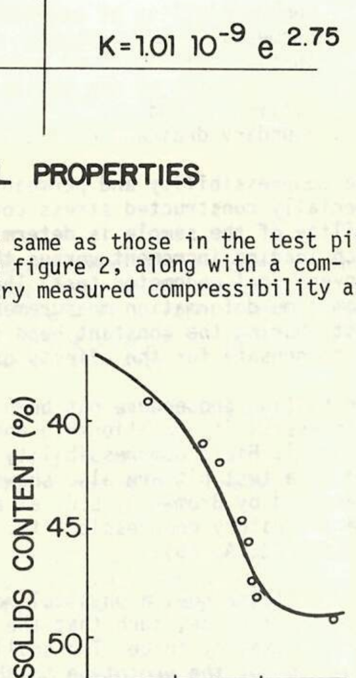

FIG.2 - TROMBETAS CENTRIFUGE TEST.

TEST PIT

In order to further investigate consolidation of the tailings in the mine cells, a test pit of dimensions and geometry similar to that of the mine cells was constructed. The test pit was located near the Carana cofferdam and was filled with thickened tailings pumped from the Carana River.

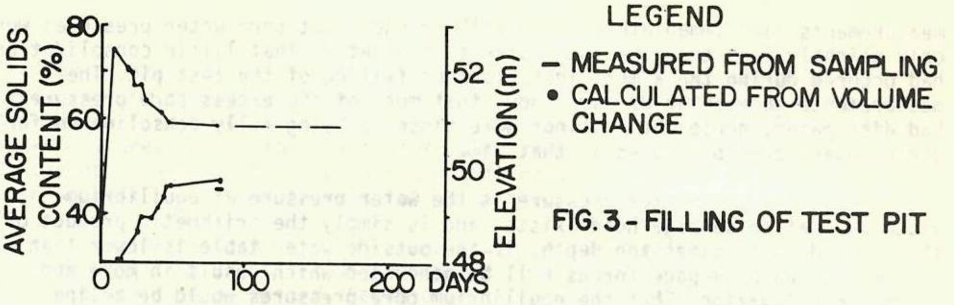

FIG. 3 - FILLING OF TEST PIT

Figure 3 shows how the elevation of the tailings surface has varied with time. It can be seen that the pit was filled very quickly to a maximum depth of 4 meters and then allowed to undergo quiescent consolidation. Essentially full consolidation was achieved within 100 days. Figure 3 also shows how the average solids content of the tailings varied with time; the measured average solids content after 87 days is also shown and is very close to the estimated value.

Samples of the tailings with depth were taken with a special piston tube sampler (Bromwell, L.G. et al 79) immediately after the pit was filled and again 87 days later when full consolidation was being approached. Samples were recovered at each test location at the tailings surface, and 0.5 meters depth increments thereafter to the bottom of the pit. The samples were tested in the laboratory for solids content.

Pore water pressure measurements in the tailings and below the bottom of the pit were made in conjunction with sampling in the pit. These measurements were made using an electrical pore pressure probe (Bromwell, L.G. et al 79). The piston tube samples of the tailings were taken immediately adjacent to the pore pressure probe locations at the same depths. As can be seen in Figure 4 the

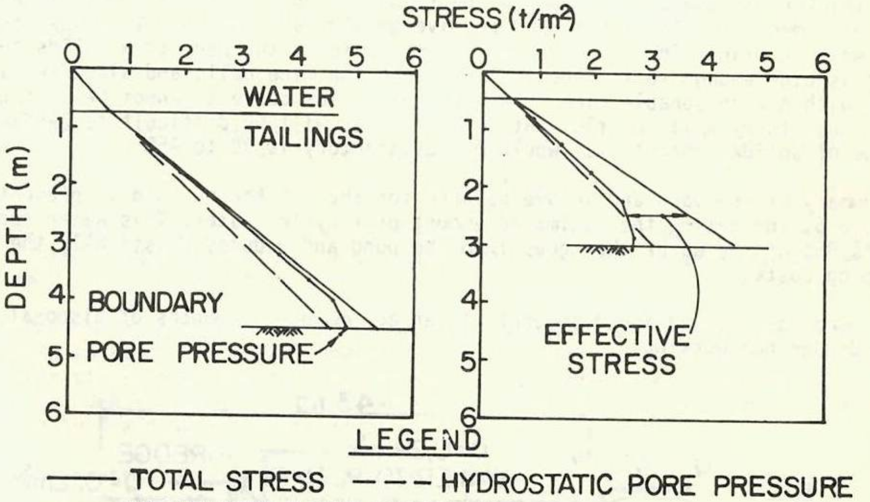

FIG. 4 - PORE WATER PRESSURE DATA IN TEST PIT.

measurements made immediately after filling show that pore water pressures were only slightly less than the total stress, indicating that little consolidation had occured during the almost instantaneous filling of the test pit. The measurements made after 87 days show, that most of the excess pore pressures had dissipated, hence the tailings were close to being fully consolidated for the boundary pore pressures at that time.

The hydrostatic pore water pressure is the water pressure at equilibrium assuming that no seepage head exists, and is simply the arithmetic product of the water density times the depth. If the outside water table is lower than inside, downward seepage forces will be generated which result in more and faster consolidation. Then the equilibrium pore pressures would be a line starting at the phreatic surface and ending at the boundary pore pressure. However, for self-weight consolidation, the line is not linear but is curved, because more head loss occurs in the denser tailings near the bottom of the deposit. The difference between the measured pore pressure and the equilibrium pore pressure is the excess pore pressure.

The boundary pore pressures measured in the test pit are conservative when compared with the mine cells where the seepage head at any time will be equal to the average depth of tailings.

This behaviour have been taken into consideration in the computer simulations by allowing for the proper drainage boundaries.

THICKENING POND DESIGN

The design of the thickening pond, as well as of the mine cells, followed the proceedures discussed by Carrier, D.W. et al, 1982, making use of the computer programs specially written to develop design guidelines.

The thickening pond will be located near the washing plant, possibly on previously reclaimed land. The pond would receive dilute tailings (6-12% solids) from the washing plant. The tailings must consolidate in the pond to a solids content that is high enough to fit the tailings into the mine cells and allow reclamation within a reasonable time. However, the solids content cannot be so high that the slurry will not flow satisfactorily or will be difficult to handle. The range of solids content that would be satisfactory is 30 to 45%.

A summary of the mass and volume balance for the thickening pond is presented in Figure 5, indicating the estimated amount of recycled water. This water represents 85% of the water that goes into the pond and reduces drastically the pumping costs.

The pond has been designed so that it can accommodate 6 months of disposal with the dredge not working.

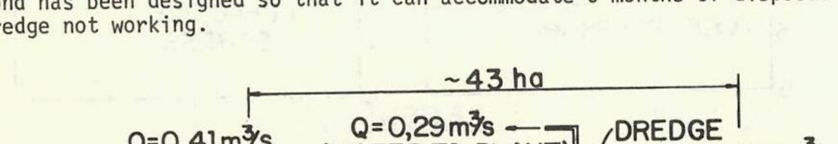

FIG.5 - TAILINGS THICKENING POND

MINE CELL DESIGN

The mining process consists of clearing the forest ahead of the mine and stripping and stockpiling the topsoil. An average thickness of 8 meters of overburden is removed with a large dragline and cast in piles in the adjacent mined out area. Using this technique, overburden from the first cut must be discarded elsewhere. Next, an average thickness of 5 meters of ore is removed with shovels, and then the next cut is started.

In the in-mine disposal system, dikes would be constructed within the mined-out area by utilizing the piles of overburden to form cells in which thickened tailings would be deposited. Because of the nature of the thickened tailings,it would not be necessary to construct the dike as a conventional dam, as high quality compaction control and internal drains would not be required. The dikes would be constructed by simply shaping the overburden piles. Each cell would contain a mass of tailings produced from an equivalent area. Hence, all of the tailings would be returned to the mine.

The geometry of a typical cell is shown in Figure 6 and is based on an average overburden thickness of 8 meters, an average ore thickness of 5 meters, and the slope of the overburden piles of 1 vertical to 1.5 horizontal.

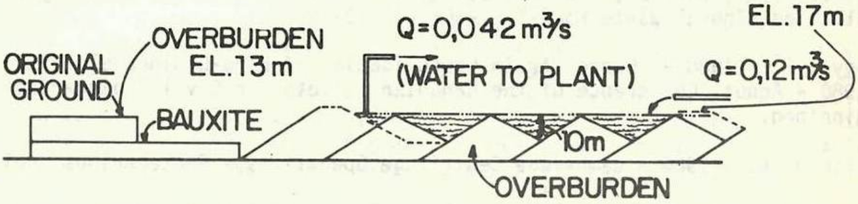

FIG. 6 - MINE CELL DESIGN

RECLAMATION

After depositing the tailings back into the mine, the next major concern is reclamation of the mine cells. Reclamation will consist of leveling the overburden peaks, possibly spreading stockpiled topsoil, and then reforesting.

The estimatives show that from the mined area only 63.5% will be used as mine cell for tailings deposition. This means that 36.5% of the area can be reclaimed immediately after mining with the knowledge already gained at the site.

In order to level the overburden, the tailings must have sufficient shear strength to allow ligth bull dozers to traffic over the mine cells. The undrained shear strength of the tailings at 62% solids content was measured to be 0.5 t/m2. Densification of the tailings will continue as the phreatic surface is lowered by drainage and desiccation occurs.

Some desiccation must occur before reclamation can begin; it is estimated that after two dry seasons the mine cells can be reclaimed.

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