Proceedings of the 14th Annual British Columbia Mine Reclamation Symposium in Cranbrook, BC, 1990.
The Technical and Research Committee on Reclamation

Some Research Aspects on Australian Waste Disposal

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Abstract

Rock wast densities achieved in the construction of the embankments are a function of the manner in which the rock is placed and compacted. Just dumping the rock achieves low densities varying from 0.9 to 1.2 t/m^3. This results in large deformations in the subsequent behaviour of the waste dump. Because of the anisotropies induced in the rock dump from both the placement and compaction techniques these deformations instigate major load arching characteristics of the embankment loads. The anisotropic rotational effects redistribute the embankment loads on to the valley abutments. The formation of the valley sheet joints generally occur in the regions where the embankment loads are arched onto the valley abutments. Of consequence these aspects of anisotropy, arching and valley sheet joints, require careful consideration.

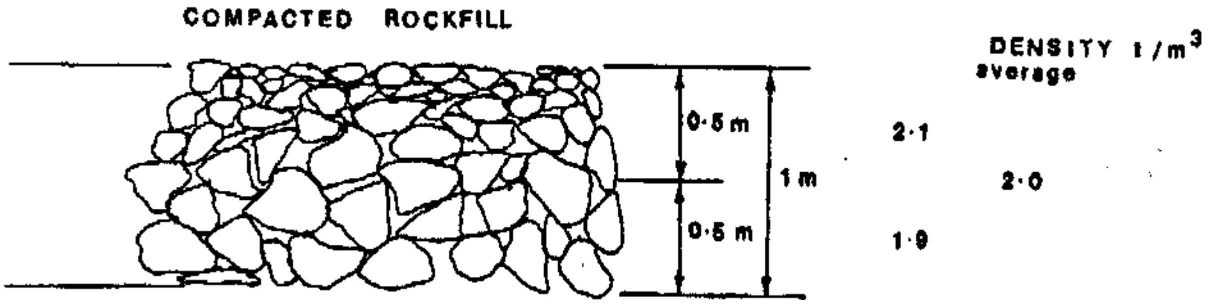

FIG.3

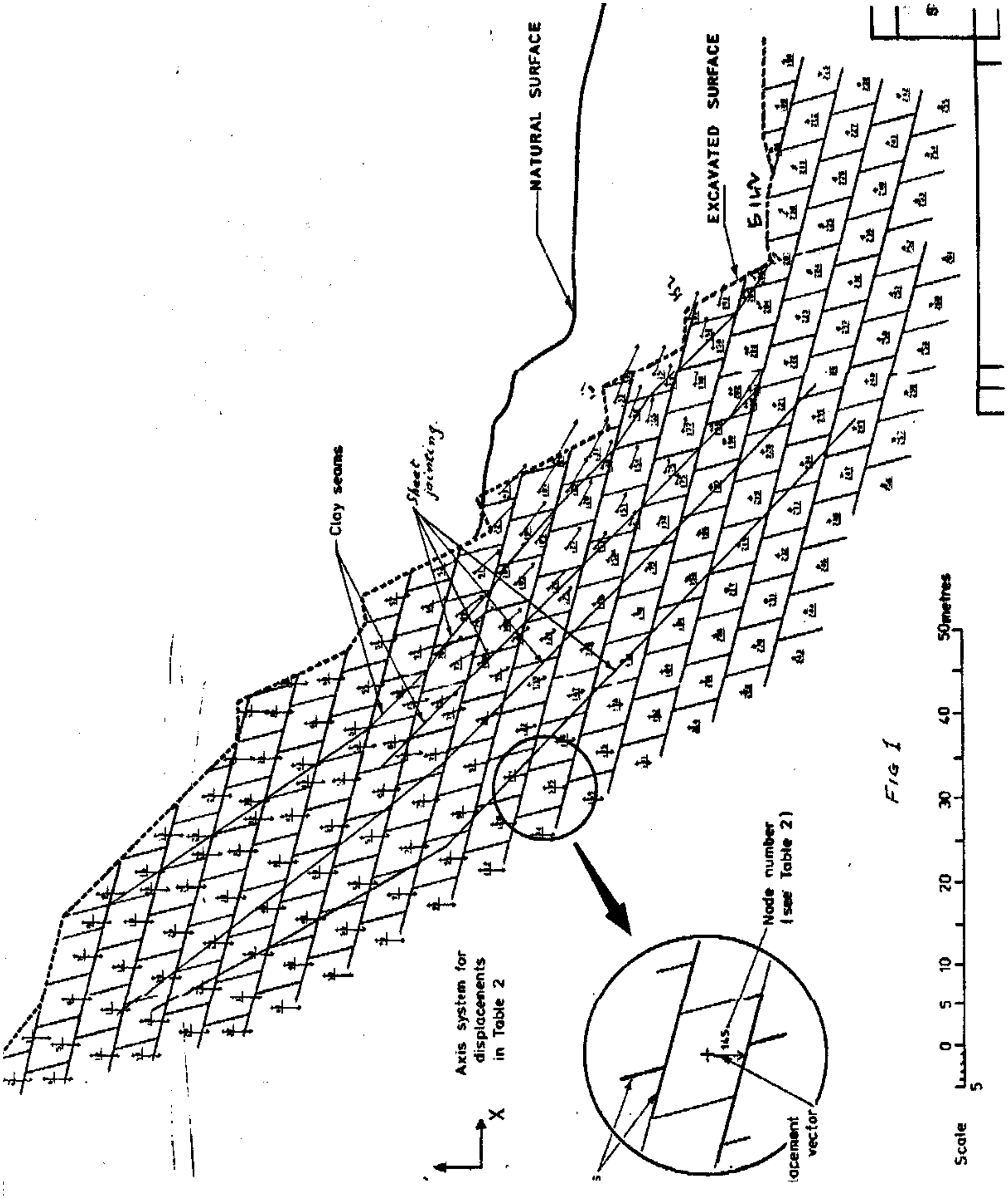
NATURAL SURFACE
EXCAVATED SURFACE
Clay seams
Sheet jointing
Axis system for displacements in Table 2
X
Node number (see Table 2)
lacement vector
145
Scale
5
0
5
10
20
30
40
50metres

Fig 1

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SOME RESEARCH ASPECTS IN AUSTRALIAN WASTE DISPOSAL

by BRIAN A CHAPPELL

Introduction

Because of the variety of mine waste material and the various construction techniques available there are a variety or solutions available in storing and stabilising this waste, in most if not all instances water is associated with this mine waste. For example disposal of gangue or surface stripping material requires consideration of surface water that passes through or over the waste dump, while in slurry disposal, the water and suspended tailings require consideration. In doing this, a retaining structure generally in the form of an embankment is initially constructed, and is made up of different materials such as rock, earth, clay, geofabrics, steel, and concrete. This results in a composite structure that deforms and distributes stresses as if it were a composite material.

Design of the retaining embankment in the first instance must take cognizance of the overall requirement as to whether the associated mine water (both surface and subsurface) is to be allowed off the mine site or be completely retained. With these aspects in mind the embankment besides being stable must retain the tailings and, if required, allow the different sources of water to pass through or over the embankment. Nevertheless, the major factor incorporating the waste disposal's overall performance is that of stability. As the embankment heights are increased the stability criteria change as the stress distributions are more mechanistic in that geometric rotations due to anisotropy become more prevalent. In addition, as the requirements, both operational and environmental, become more stringent, the need to determine cost effective solutions rely on the deforitiational response and stress distribution evaluations. This becomes even more important when the composite and anisotropic nature of the embankment is called on to meet the ever increasing size (height) and permeability requirements.

In order to determine or evaluate the embankment's deformations and stress distributions with consequent redistributions, the embankment's deformational moduli are required. Different material placement and compaction techniques induce different material densities and, more importantly, generate anisotropic material characteristics. With the inclusion of different materials such as steel reinforcement and geofrabics to meet specific functions, anisotropic characteristics are accentuated.

If the embankment is located in a relatively narrow valley and as the anisotropic embankment load increases (heightened), the existent and increasing stresses arch onto the abutments, Pig 1. The composite material and associated anisotropies increase these arching effects over and above what would occur if the embankment material where isotropic, Chappell 1987. This results, in the main, with the gravity loads not being imposed on the foundation but on the abutments. At the embankment face (downstream) the abutment forces are skewed downstream and this imposes considerable shear forces on the abutments. Because of valley formation load relief, sheet joints, Fig 2, are formed and are prone to shear force slip (Viont dam failure).

General Attributes of Dumped Rocks

Rock fill dams constructed from the 1850's on (French Lake Dam, California) were generally built by dumping rock from various heights and sluicing. The resultant average density of these rock embankments was approximately 0.9 t/m^3 but were restricted to heights of 60m. This low density led to subsequent rock mass differential settlements that cracked the ridged wator retaining diaphragms such as concrete. Of consequence, deformable earth fill embankments were used. From the 1960's on the method of rock placement improved in that the rock was placed in 0.9 to 3m layers, and vibrating smooth wheeled rollers (weighing up to I0t and performing 3 to 6 passes) were used to compact the rock. The average rock mass densities achieved 1.9 to 2.2 t/m^3 , Fig 3 and 4. These higher densities reduced relative deformations and enabled the rock mass embankment heights to reach 300m without excessive deformations.

Besides the improvements of rock mass densities resulting from rock placement and compaction, the rock mass stiffness (deformational moduli) also improve. For example, the rock mass's pseudo Young's modulus increase from 10 MPa to 90 MPa. If some rock grading is introduced or reinforcement incorporated into the rock mass these moduli increase significantly. In addition by placing the rock in layers and compacting it, an anisotropy is induced into the rock mass. For example, the rock mass laid out and compacted as shown in Fig 3 gives vertical and horizontal (pseudo Young's Moduli) moduli of 50 and 150 MPa respectively.

In summary, the important factors that improve rock embankment behaviour are the placement and compaction techniques and the incorporation of reinforcement such as steel rods, geofabrics or grouting. This improvement is defined in terms of the increases in the rock mass's moduli and reduction in subsequent and continuing deformations.

Increase in Embankment Height but not Rock Embankment Densities

If the rock mass is loose, that is it is pushed over an edge from heights without any compaction, the resultant rock mass densities are again low, generally less than 1.5 t/m^3. The result is that the potential for large differential deformations is again prevalent especially between the rock placed over the central valley and that placed over the abutments. These differential deformations induce considerable load redistributions with the abutments receiving a disproportionate share of the loading caused by, in the main, arching (Chappell 1987). This coupled with the shears generated from the retained waste imposed on the sheet jointing makes the assessment of valley abutment stability as important as the foundation's stability evaluations.

In large rock mass flows observed in regions such as Papua New Guinea (Hindenberg escarpment Ok Tedi) rock sizes up to 300 to 600t are readily moved considerable distances. These large boulders accumulate as talus or scree at the toe of the escarpment and form large dumped embankments. With the advent of an earth tremor these large boulders travel considerable distances down the the valley without the help of water. The loose condition of the talus seems to make it susceptible to flow initiated from a medium sized earth quake coupled with the potential energy attributes pertaining to the surrounding topography. Of consequence, it is important to improve the rock embankment's characteristics to a standard where the deformational response and consequent load redistributions are minimal. To assess this behaviour the rock embankment's anisotrooic characteristics need to be defined and measured so that the stress distribution and redistributions can be evaluated»

Anisotropic Rock Mass Properties

With the availability of computers and the various codes, the deformational response and consequent stress distributions with redistributions are readily predictable if the associated embankment characterisation is possible. As stated above, evidence is available (Jennings 1979, Cooke 1984) showing that Placement and compaction techniques readily impose anisotropic characteristics on the resultant rock embankment. Even if the embankment is constructed in 30m lifts, anisotropy is still an important part of the rock mass's resultant anisotropy. For example, if the embankment is 450m high there are 15 layers where for each layer the bottom has a modulus approximately 10 to 15MPa and the top (because of trafficking and particle degradation) have vertical and horizontal moduli equal to 50 MPa and 150 MPa respectively. The embankment is both composite and anisotropic.

In addition, there are the anisotropic flow characteristics. When saturated, these anisotropic flow chatacteristics have a large effect on the rock mass's deformational characteristics and consequent stability characteristics.

If the equilibrium and compatibility constraints for a deforming anisotropic material loaded by gravity (σy stress) are considered, induced horizontal loads ($\sigma x = K\sigma y$) are generated resulting in horizontal shear stresses between the composite material layers, Fig 5. This horizontal shear stress is coupled to the differences in the inverse shear moduli values (shear compliances) in the horizontal and vertical directions, Chappell 1990. This shear compliance difference results in a geometrical rotation that redistributes the applied and/or gravity loads. The mechnaism that does this is the geometric rotation equal to the differences in the directional shear compliances and results in the arching of the applied loads, namely the gravity load σy.

The normal compliance (1/Ey) considering a two dimensional anisotopic rock mass, Fig 5, is (Chappell 1990):

$$\frac{1}{E_y} = \frac{m^4}{E_u} + \frac{\ell^4}{E_L} + \ell^2 m^2 \left\{\frac{1}{G_u} + \frac{1}{G_L} - \frac{2\nu_u}{E_u}\right\} + \frac{\sigma_x}{\sigma_y}\ell^2 m^2 \left\{\left(\frac{1}{E_u} + \frac{1}{E_L} - \frac{1}{G_u} - \frac{1}{G_L}\right) - \left(\frac{\nu_u \ell^4}{E_u} + \frac{\nu_L m^4}{E_L}\right)\right\}$$
$$+ \frac{\tau_{xy}}{\sigma_y}\frac{\ell m}{2}\left\{\frac{1+\ell^2}{G_u} - \frac{1+m^2}{G_L}\right\} + \frac{\tau_{yx}}{\sigma_y}\frac{\ell m}{2}\left\{\frac{\ell^2}{G_L} - \frac{m^2}{G_u}\right\} \text{-------}(1)$$

where $\ell = \cos\theta$ and $m = \sin\theta$

If $\frac{\tau_{xy}}{\sigma_y}$ is considered negligible relative to $\frac{\tau_{yx}}{\sigma_y}$ and stresses except for $\frac{\tau_{yx}}{\sigma_y}$ as constant and then if the orientation of the anisotropies are also constant then:

$$\frac{1}{E_y} = C + \left(\frac{\ell^2}{G_L} - \frac{m^2}{G_u}\right)\frac{\ell m}{2}\frac{\tau_{yx}}{\sigma_y}$$

If the effective normal stresses σ_y on plane is

$$\sigma_y = (\gamma_t - \gamma_w)\, h$$

where γ_t is the bulk density and γ_w is the water density and h is the depth below the surface.

$$\tau_{yx} = \sigma_y \tan\phi = (\gamma_t - \gamma_w)\, h \tan\phi$$

where ϕ is the induced angle of shear.

Substitution of these latter relations in Eqn 1 gives:

$$\frac{1}{E_y} = C + \left(\frac{l^2}{G_L} - \frac{m^2}{G_u}\right)\frac{lm}{2}\tan\phi$$

This means that as the angle of friction increases to ϕ_{max}, where slip along the joint occurs, there is a mechanical rotation due to the shear compliance difference between $1/G_L$ and $1/G_u$.

As the load increases ϕ increases, the induced transverse stress σ_x increases to ϕ_{max} which is the friction angle at which relative slip occurs and there is a further redistribution of stress. This latter stress redistribution accentuates the arching mechanism instigated by the initial differences in shear compliance.

The important result is that anisotropy increases arching both before and after the mechanism of slip occurs.

Anisotropies in the fluid flow regime increases the pore pressures (and gradients) in the finer material and accentuate both the arching mechanisms. Namely arching due the difference in the directional shear compliances and then relative slip.

Conclusion

Stability of an embankment is a function of the material from which it is constructed and the manner with which it is placed. These material characteristics then control how the embankment deforms as the loads are applied. In turn the deformations distribute and redistribute the initial and increasing loads.

The manner in which the rock is placed and then compacted control the rock mass densities achieved and consequently its potential for deformation. By placing the rock in layers and then compacting, two distinct anisotropies are induced into the rock embankment material. While placing the material, especially from a height greater than 5m, the falling rock segregates resulting in a rock coarse at the bottom and relatively finer at the top. On the other hand, while compacting the rock, the particles break down at and near the compacting surface resulting in a more dense rock at and near the compaction surface. Besides the density differences causing a layering effect (anisotropy) to the resultant embankment, the deforinational moduli in the vertical and horizontal directions of these resultant rock density layers are different. Generally, the horizontal moduli are from three to ten times stiffer than the vertical moduli.

Besides the deformational moduli being anisotropic so are the permeabilities. The deformational anisotropies, however, effect the load redistribution while the permeabilities, in the main effect the rock mass's strength characteristics.

The deformational anisotropies introduce a geometrical rotation (before slip rotation effects occur) into the deforming rock embankment. This rotation arches the existent and any increasing loads onto the abutments provided by the valley that encloses the valley fill rock embankment, in the formation of the valley, imposed vertical rock loads are generally relieved while horizontal loads increase. The result of this is that sheet joints occur in the valley abutments. These joints and associated imposed arching loads coining from the rock waste, especially at the down stream end, require careful consideration.

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