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**DEVELOPMENT OF TWO AND THREE-DIMENSIONAL METHOD OF FRAGMENTS TO
ANALYSE DRAINAGE BEHAVIOR IN HYDRAULIC FILL STOPES**

Thesis submitted by

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in September 2007

**for the degree of Doctor of Philosophy
in the School of Engineering
James Cook University**

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Acknowledgements

The author wishes to thank,

My family – Dad, Mum, Tegan, Rudd, Shauna, Briony, Kirralee and Lachlan. Thankyou for being there through the good times and the bad, for sharing my laughter, tears, frustrations and achievements. I feel blessed to have the family that I have, and want to thank each and every one of them for always being there.

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**This work is dedicated to my wonderful family – Dad,
Mum, Tegan, Rudd, Shauna, Briony, Kirralee and
Lachlan**

Abstract

The extraction and processing of most mineral ores, result in the generation of large volumes of finer residue or tailings. The safe disposal of such material is of prime environmental, safety and economical concern to the management of mining operations. In underground metaliferous mining operations, where backfilling of mining voids is necessary, one option is to fill these voids with a tailings-based engineered product. In cases where the fill is placed as a slurry and the fill contains free water, permeable barricades are generally constructed to contain the fill within the mining void whilst providing a suitable means for the drainage water to escape from the fill. Recent barricade failures, resulting from poor drainage, have led to an immediate need for an increased understanding of the pore pressure developments and flow rates throughout the filling operation. This thesis presents simple analytical solutions, based on the ‘method of fragments,’ for estimating discharge and maximum pore pressure for two and three-dimensional hydraulically filled stopes. Shape factors were developed to account for the inherent individuality associated with stope and drain geometry. The influence of scaling on discharge and pore pressure measurements is also investigated. The proposed solutions are verified against solutions derived from a finite difference program and physical modelling of a scaled mine stope and results showed excellent agreement. Using these analytical solutions developed for flow through three-dimensional hydraulic fill stopes, a user-friendly EXCEL model was developed to accurately and efficiently model the drainage behaviour in three-dimensional stopes. The model simulates the complete filling and draining of the stopes and was verified using the finite difference software FLAC^{3D}. The variation and sensitivity in drainage behaviour and pore water pressure measurements with, the variation in geometry, fill properties and filling-cycles of a three-dimensional hydraulic fill stope was also investigated.

List of Publications

Journals

Rankine, K.S. and Sivakugan N. (2007) "Application of Method of Fragments in Three-Dimensional Hydraulic Fill Stopes." *Journal of the Geotechnical Division ASCE, Under Review 3rd draft*

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Refereed Conference Proceedings

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Rankine, K.S. and Sivakugan, N. (2005). "A 2-D numerical study of the effects of anisotropy, ancillary drains and geometry on flow through hydraulic fill mine stopes," *Proceedings of the 16th ISSMGE*, Osaka, Vol.2, 955-958

Rankine, K.J., Sivakugan, N. and Rankine, K.S. (2004). Laboratory tests for mine fills and barricade bricks, *Proceedings of 9th ANZ Conference on Geomechanics*, Auckland, 1, pp. 218–224

Rankine, K.J., Rankine, K.S., and Sivakugan, N. (2003). "Three-dimensional drainage modelling of hydraulic fill mines," *Proc. 12th Asian Regional Conf. on Soil Mech. and Geotech. Engineering*, Eds. CF Leung, KK Phoon, YK Chow, CI Teh and KY Yong, 937-940.

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List of Symbols

A = cross-sectional area

a = air content

B = stope width

C = Hazen's constant

C_{slurry} = percent solids of slurry

C_u = coefficient of uniformity

C_v = viscosity coefficient

C_0 = Terzaghi (1925) shape factor

C_2 = Kozeny-Carman (1938) shape factor

C_3 = Taylor (1948) shape factor

C_4 = Samarasinghe (1982) constant

C_5 = Amer and Awad (via Das, 2002) constant

c' = effective cohesion stress

D = drain height

D_r = relative density

D_s = effective particle diameter

D_5 = the grain size for which 5% of the particles are finer

D_{10} = the grain size for which 10% of the particles are finer; effective grain size

D_{30} = the grain size for which 30% of the particles are finer

D_{50} = the grain size for which 50% of the particles are finer

D_{60} = the grain size for which 60% of the particles are finer

E_1, E_2 = material property constants, Carrier et al. (1983)

e = void ratio

e_{max} = maximum void ratio

e_{min} = minimum void ratio

F = drain width

Fr = Froude number

f = soil fabric

G = equivalent drain height

G_s = Specific gravity

g = acceleration due to gravity

H = height
H_w = height of water
h_i = head loss in ith fragment
h_L = head loss
Δh = change in head between two points
i = hydraulic gradient
i_{entry} = entry hydraulic gradient
i_{exit} = exit hydraulic gradient
J = fill height increase per hour
K₀ = horizontal pressure coefficient (assumed to be 0.5)
k = permeability
k_{0.85} = permeability at void ratio of 0.85
k_e = effective permeability
k_{equiv} = equivalent permeability for a layered system
k_h = permeability in the horizontal direction
k_v = permeability in the vertical direction
L = length
L_a = length of ancillary drain
m = soil compressibility
m_s = mass of solids
m_w = mass of water
N_d = number of equipotential drops
N_f = number of flow channels
n = porosity
n_{eff} = effective porosity
P_b = pressure exerted by the bulkhead on the fill
Q = discharge
q = discharge per unit length
Re = Reynold's number
R_s = solids filling rate
S = saturation
S_s = specific surface area of grains

S_v = grain surface per unit volume
 s = shape factor
 T = temperature
 t = time
 u = pore water pressure
 u_{\max} = maximum pore water pressure
 v = discharge velocity
 V_{drained} = volume of water that has drained
 V_f = volume of fill
 V_{free} = total free water that is drainable
 V_{in} = volume of water entering stope
 V_{out} = volume of water draining from the stope
 V_{residual} = volume of residual water
 V_s = volume of solids
 $V_{\text{to-drain}}$ = volume of water that is yet to drain
 V_v = volume of voids
 V_w = volume of water
 W = stope thickness
 w = water content
 w_{res} = residual water content
 w_{sat} = saturated water content
 w_{slurry} = water content of hydraulic fill slurry
 X = drain length
 α_{2D} = fraction of the head loss within fragment 2 for a two-dimensional stope that takes place in the horizontal segment of the largest stream line
 α_{3D} = fraction of the head loss within fragment 2 for a three-dimensional stope that takes place in the horizontal segment of the largest stream line
 Δh = change in head between two points
 Φ = two-dimensional form factor for i^{th} fragment
 Γ_i = three-dimensional form factor for i^{th} fragment
 γ_t = total bulk unit weight of fill
 γ_w = unit weight of water

η = dynamic viscosity

ϕ = effective frictional stress

κ = intrinsic permeability

μ = water viscosity

μ_T = water viscosity at T degrees Celsius

μ_{10} = water viscosity at 10 degrees Celsius

ρ_d = dry density

ρ_s = soil grain density

ρ_w = density of water

σ_h = horizontal/ barricade pressure

σ'_h = effective horizontal pressure

σ'_v = effective vertical pressure

τ_w = shear strength of rock-fill interface

ω = fluid surface tension