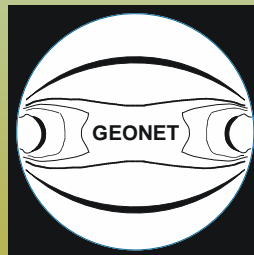


STRESS UNDER STOCKPILES DURING DRAWDOWN

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GEONET *Consulting Group*

August 2008

FLAC/DEM SYMPOSIUM
MINNEAPOLIS 2008

Introduction

- The use of gravity reclaim stockpiles is widespread in the coal industry.
- Design of structural engineering based on linear elasticity.
- Stress conditions in stockpiles governed by frictional properties.
- Mechanics of stockpile systems are generally underestimated at the design stage due to lack of understanding of the complex geomechanical conditions that develop within the stockpile during drawdown.



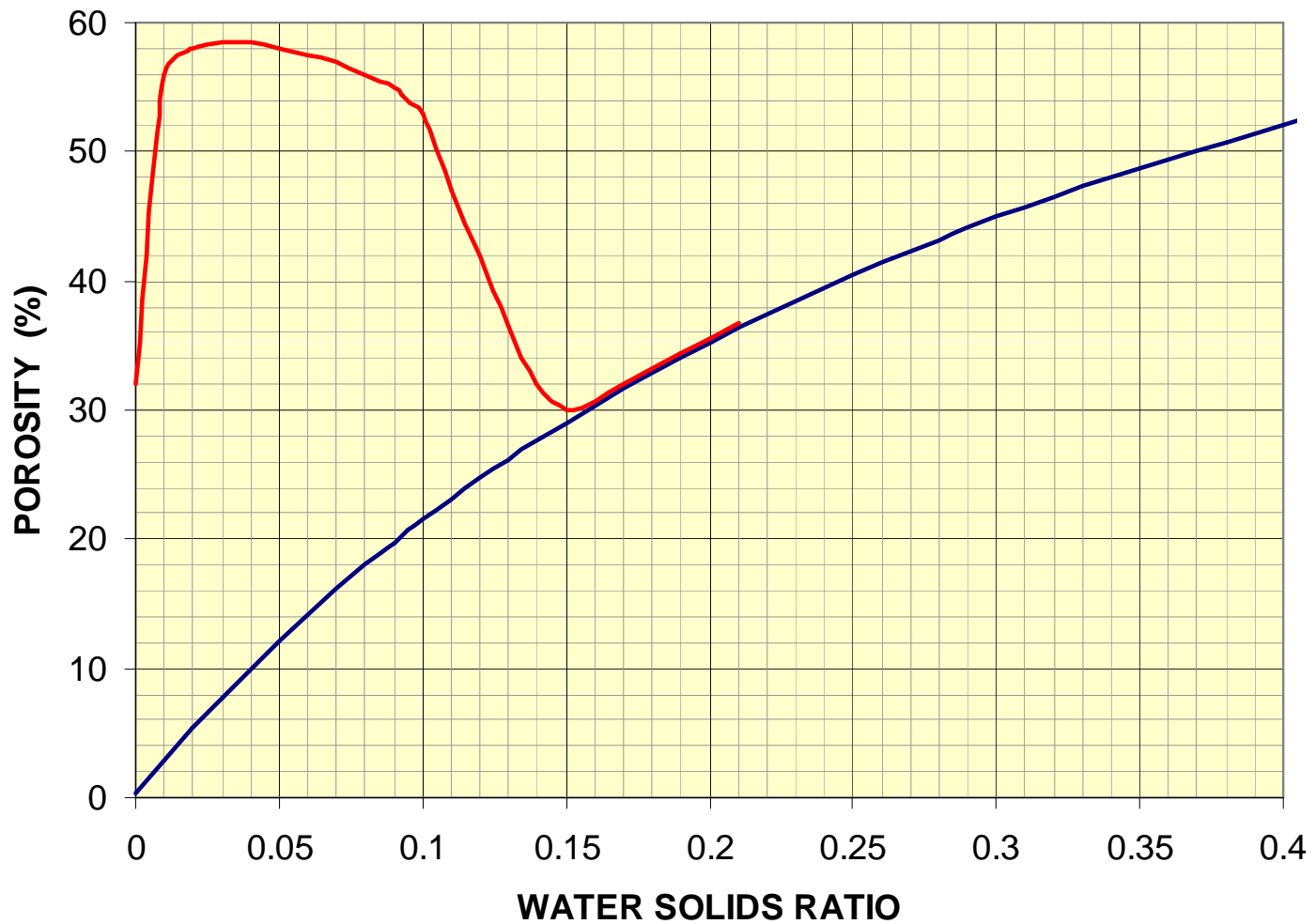
FLAC/DEM SYMPOSIUM
MINNEAPOLIS 2008

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MATERIAL PROPERTIES

- Flow conditions and hence the distribution of stress within a granular stockpile depend on a number of variables:
- Granular, frictional materials
 - Type of material (S.G.)
 - Particle Size Distribution
 - Particle Shape
 - Moisture Content
- Bulk density (porosity)
- Diameter of discharge vent

STOCKPILE PLACEMENT PROPERTIES

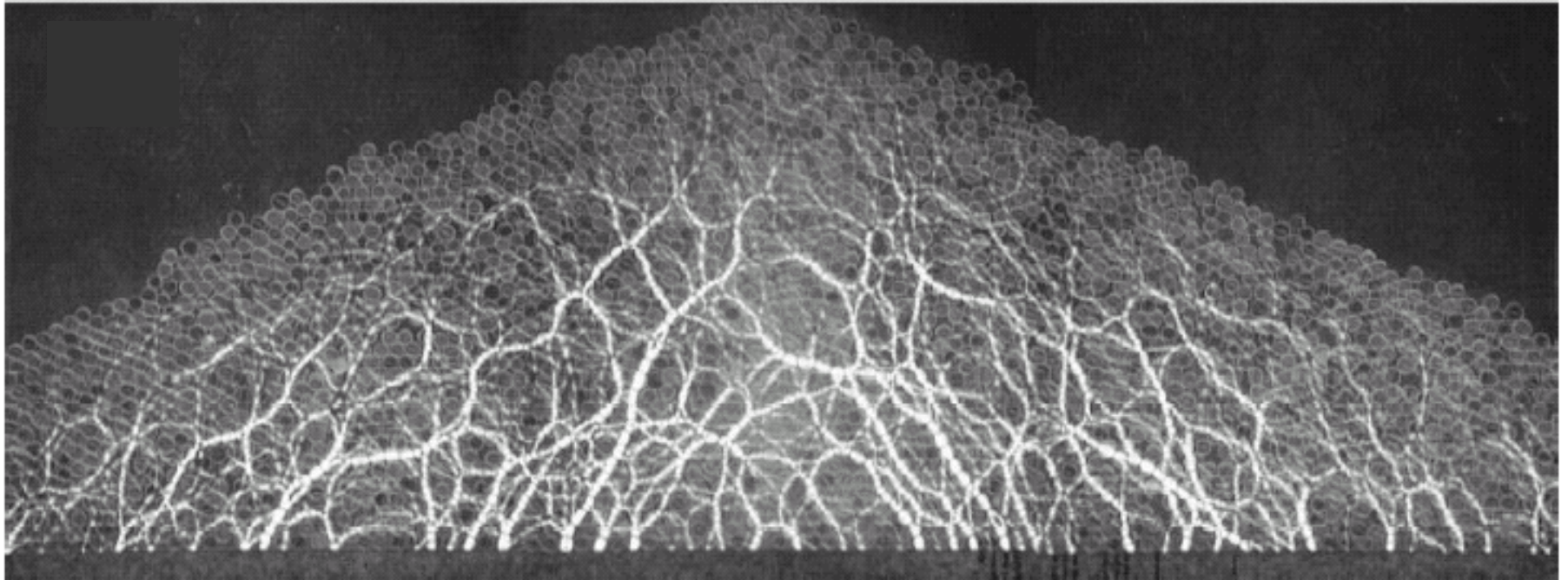


STRESS UNDER STOCKPILES

- Intuitively expect the maximum vertical stress to be directly under the apex
- Stress = Bulk Density x Gravity x Height

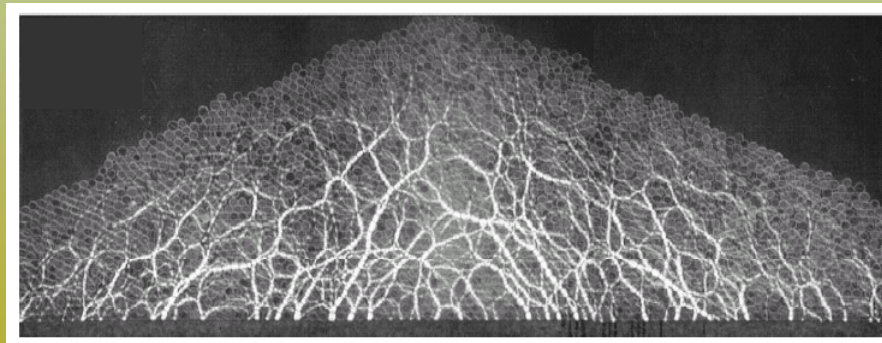
$$\sigma_v = \gamma \cdot g \cdot H$$

- Experimental evidence for:
 - Stress chains



STRESS WITHIN STOCKPILES

- Grains within chains may be under a large stress,
- Grains not in chains may be under no stress at all.
- When the material fails grains rearrange to form new stress chain structures.
- These stress chains are likely to determine where material failure occurs as well as the flow

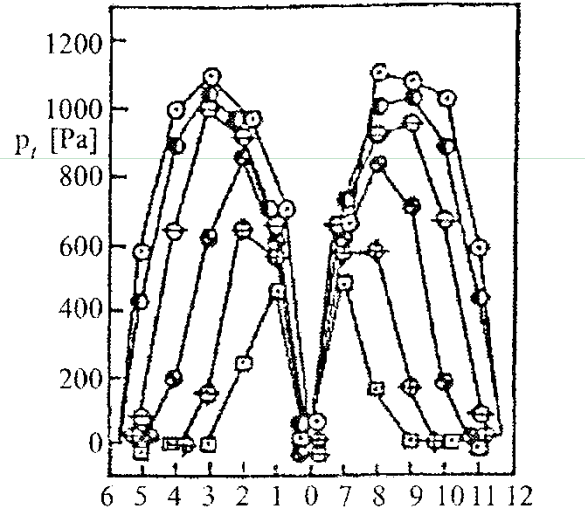
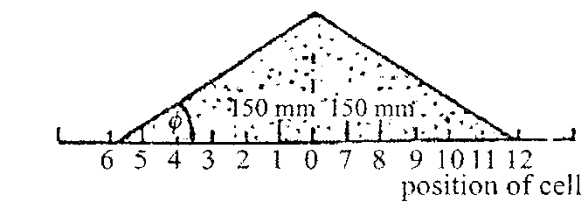


STRESS UNDER STOCKPILES

- Intuitively expect the maximum vertical stress to be directly under the apex
- Stress = Bulk Density x Gravity x Height

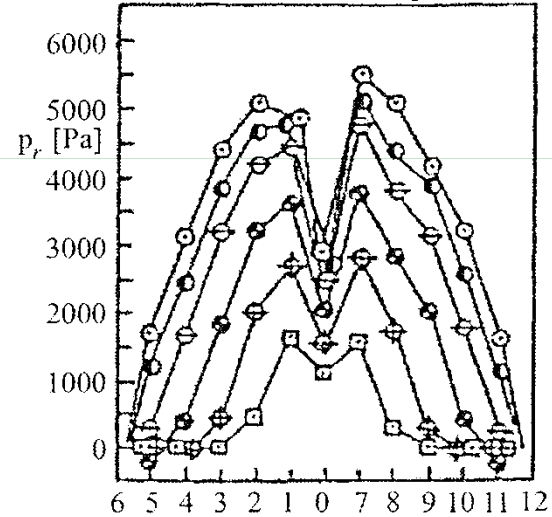
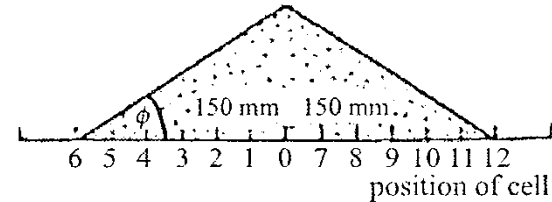
$$\sigma_v = \gamma \cdot g \cdot H$$

- Experimental evidence for:
 - Stress chains
 - Reduction in stress under the apex resulting in a characteristic M-shaped profile



○... h :max ⊕... h :500 mm ⊕... h :300 mm
 ●... h :550 mm ●... h :400 mm □... h :200 mm

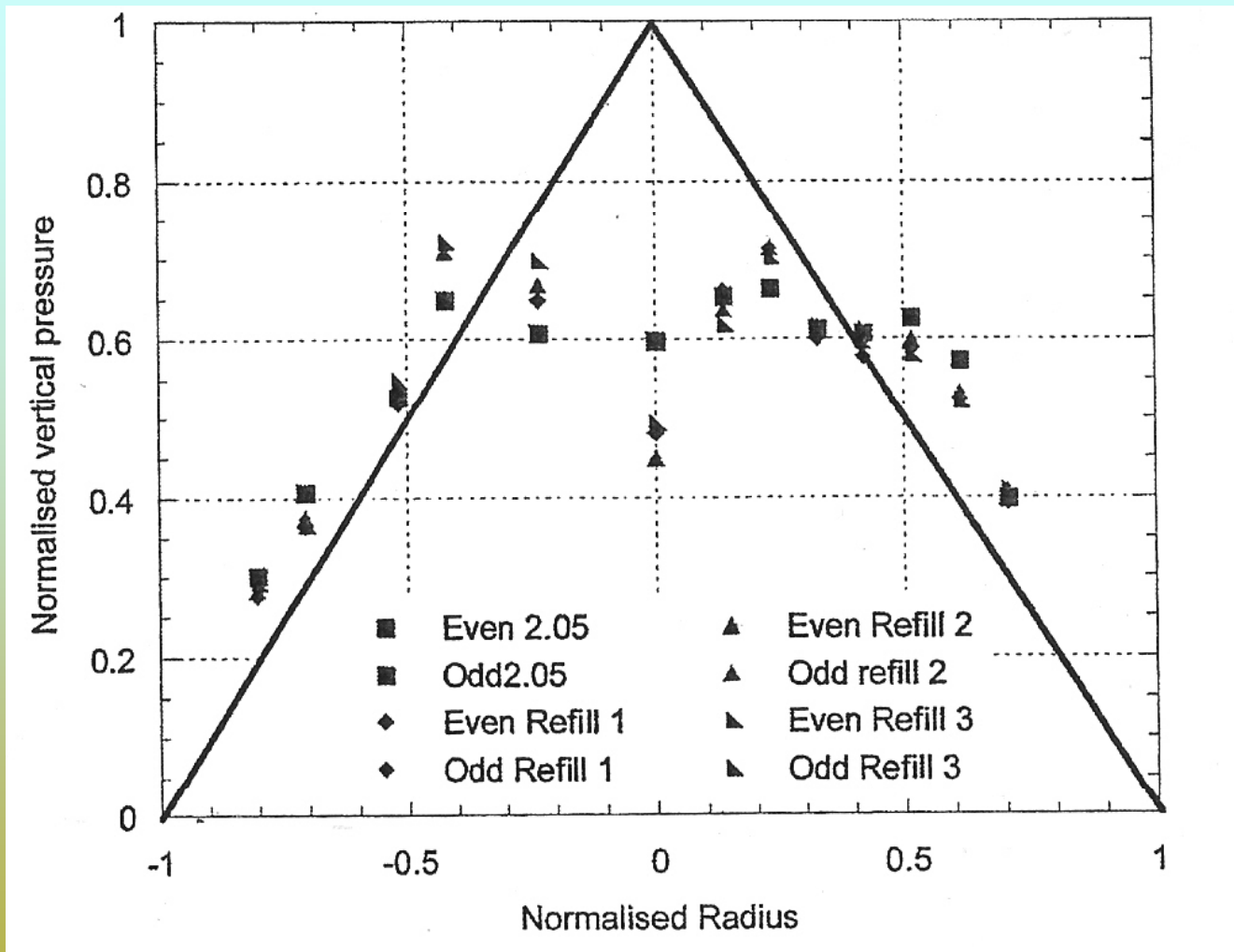
(a)



○... h :max ⊕... h :500 mm ⊕... h :300 mm
 ●... h :550 mm ●... h :400 mm □... h :200 mm

(b)

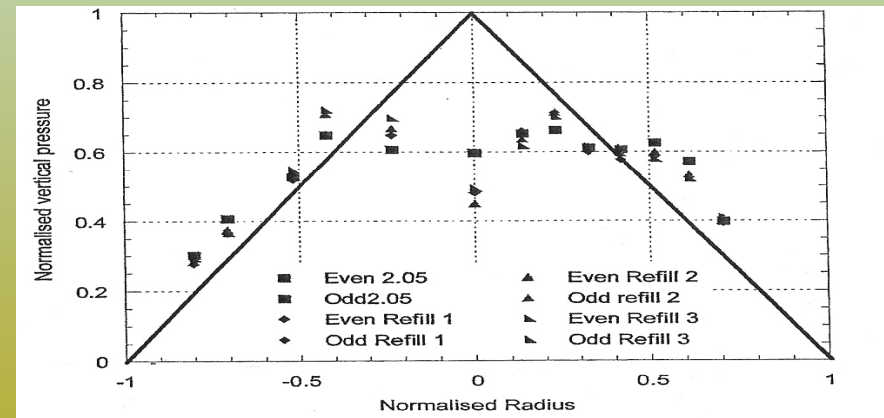
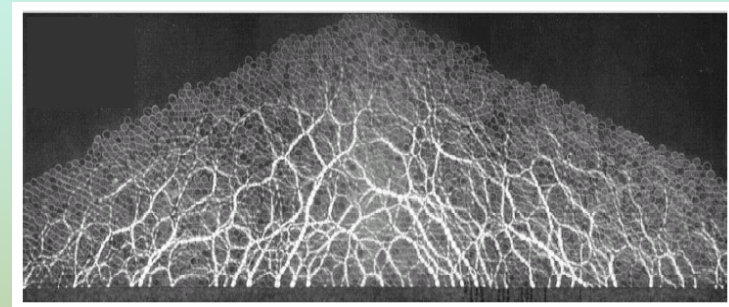
Measured horizontal (a) and vertical (b) force distributions (Smid & Novosad 1981).



Base pressures compared to original fill pressures (McBride 2006).

STRESS UNDER STOCKPILES

- Formation of stress chains
- Stress maxima located at $0.4 \times$ Radius from centre
- Affected by:
 - Emplacement history
 - Physical properties



STRESS UNDER STOCKPILES

- Stress = Bulk Density x Gravity x Height

$$\begin{aligned}\sigma_v &= \gamma \cdot g \cdot H \\ &= 1100 \text{ kgm}^{-3} \times 9.81 \text{ ms}^{-2} \times 17.0 \text{ m} \\ &= 183 \text{ kPa}\end{aligned}$$

- Depending on bulk density and moisture content

$$\text{max } \sigma_v = 240 \text{ kPa}$$

- Additional variations may be introduced by:
 - rainfall infiltration, (refer C.Detournay & R.Hart, 2008)

STRESS UNDER STOCKPILES

$$\begin{aligned}\sigma_v &= \gamma \cdot g \cdot H \\ &= 1100 \times 9.81 \times 17.0 \\ &= 183 \text{ kPa}\end{aligned}$$

- Depending on γ_d and moisture
 $\max \sigma_v = 240 \text{ kPa}$
- Additional variations:
 - rainfall infiltration, and
 - **bulldozers**



STRESS UNDER STOCKPILES



FLAC Models

- FLAC-3D to model stockpile
- FLAC-2D to model reclaim infrastructure

STRESS IN STOCKPILE

FLAC-3D

- Conical geometry with circular draw point
- Fixed base
- Initialise stress according to

$$\sigma_v = \gamma \cdot g \cdot H$$

- Mohr-Coulomb criterion
 - Cohesion = 0
 - Friction = 40°
 - Dilation = 3°

FLAC3D 3.10

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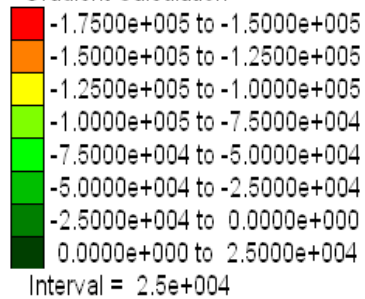
Step 22880 Model Perspective
19:45:22 Thu Apr 24 2008

Center:	Rotation:
X: -2.137e+000	X: 10.000
Y: 2.547e+000	Y: 0.000
Z: 8.002e+000	Z: 50.000
Dist: 1.633e+002	Mag.: 1.95
	Ang.: 22.500

Plane Origin:	Plane Orientation:
X: 1.000e-001	Dip: 90.000
Y: 1.000e-001	DD: 0.000
Z: 1.000e-001	

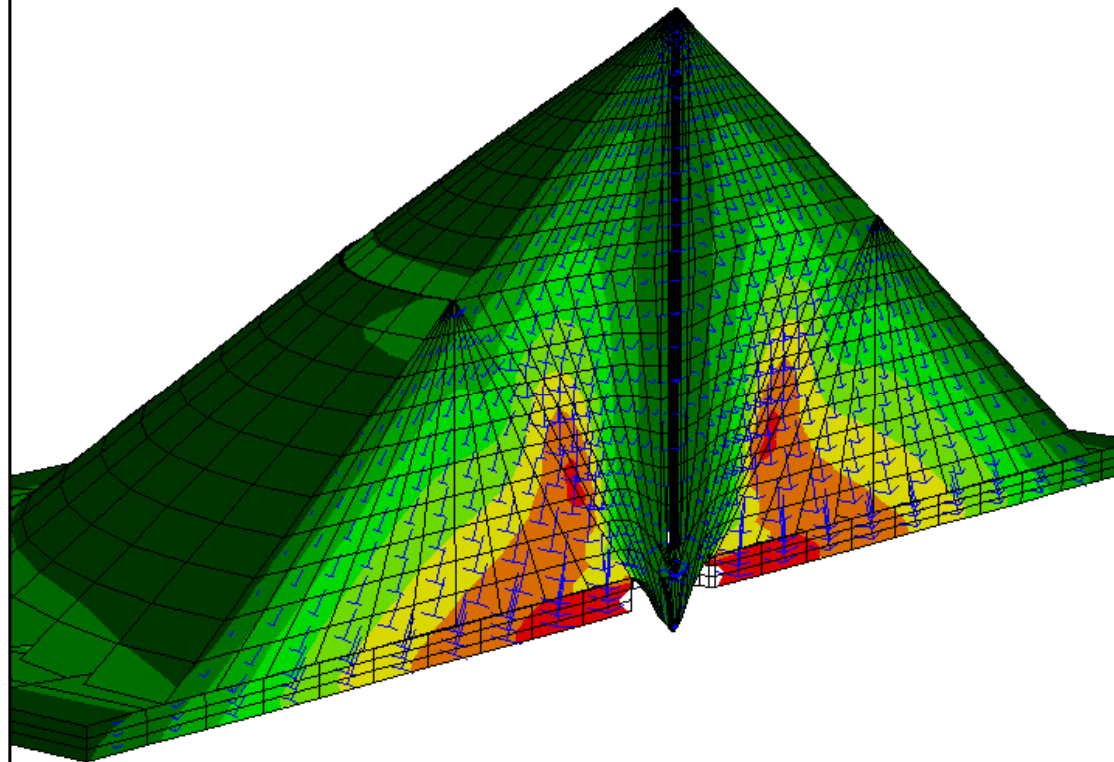
Contour of SZZ

Plane: on behind
Magfac = 1.000e+000
Live mech zones shown
Gradient Calculation



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FLAC3D 2.10

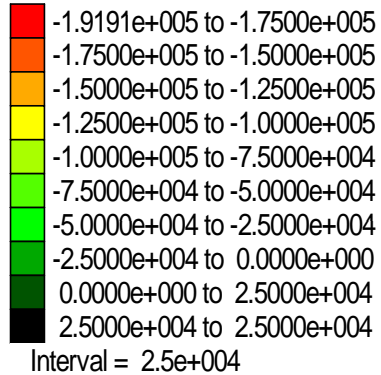
Step 20210 Model Perspective
16:31:51 Sun Jan 16 2005

Center: Rotation:
X: -9.935e-001 X: 10.000
Y: 4.723e+000 Y: 0.000
Z: 5.076e+000 Z: 50.000
Dist: 1.633e+002 Mag.: 1.95
 Ang.: 22.500

Plane Origin: Plane Normal:
X: 0.000e+000 X: 0.000e+000
Y: 0.000e+000 Y: 1.000e+000
Z: 0.000e+000 Z: 6.123e-017

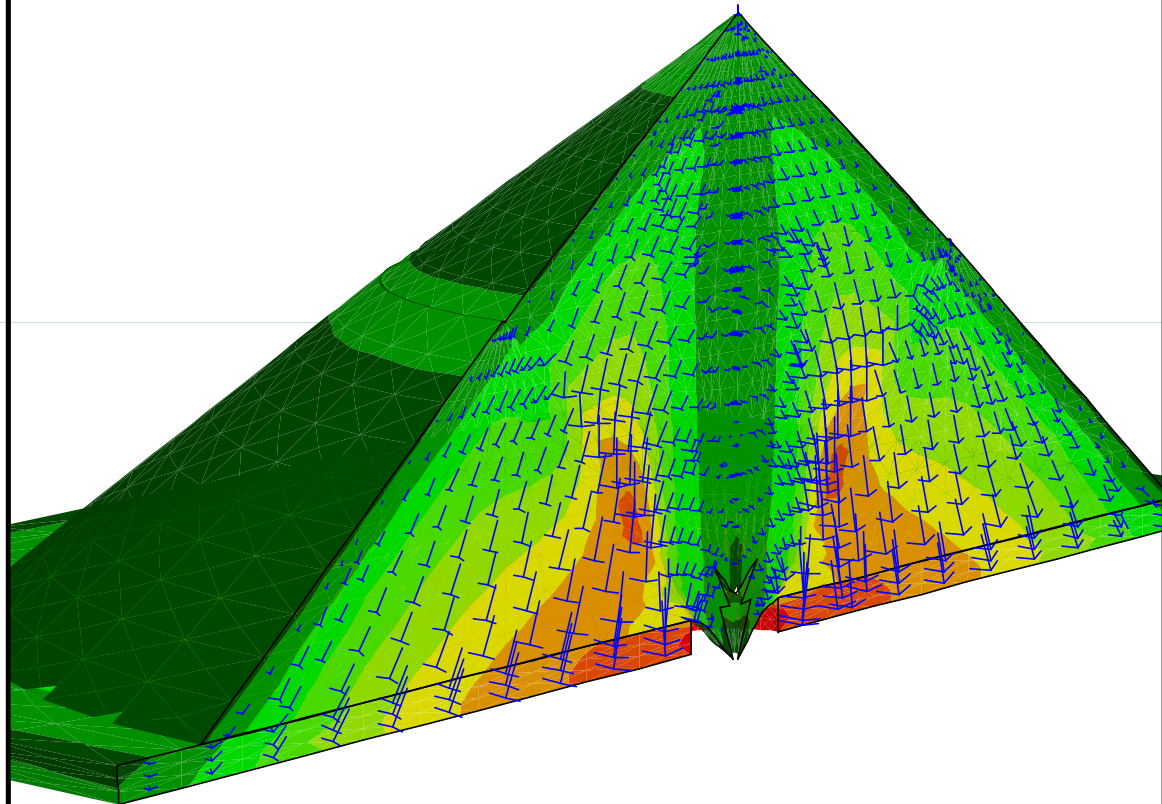
Contour of SZZ

Plane: on behind
Magfac = 1.000e+000
Gradient Calculation



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FLAC3D 2.10

Step 20210 Model Perspective
17:20:10 Sun Jan 16 2005

Center:	Rotation:
X: 3.914e-002	X: 20.000
Y: 6.260e+000	Y: 0.000
Z: 6.045e+000	Z: 40.000
Dist: 1.633e+002	Mag.: 1.56
	Ang.: 22.500

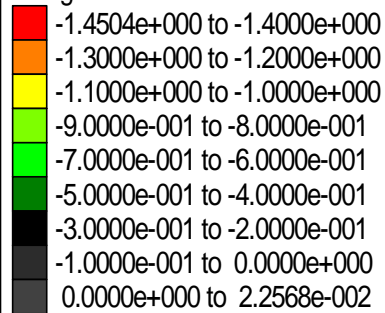
Plane Origin:	Plane Normal:
X: 0.000e+000	X: 0.000e+000
Y: 0.000e+000	Y: 1.000e+000
Z: 0.000e+000	Z: 6.123e-017

Surface

Plane: on behind
Magfac = 1.000e+000

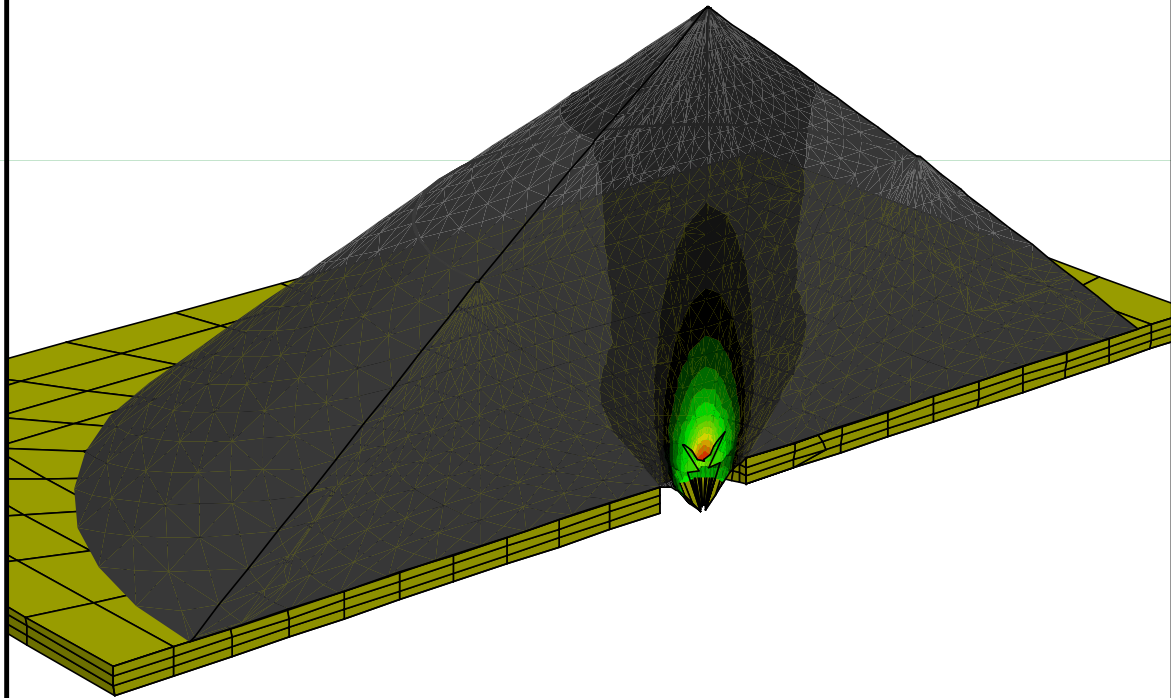
Contour of Z-Displacement

Plane: on behind
Magfac = 1.000e+000



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FLAC3D 3.10

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Step 20000 Model Perspective
21:32:46 Thu Apr 24 2008

Center:	Rotation:
X: 0.000e+000	X: 270.000
Y: 0.000e+000	Y: 0.000
Z: 8.002e+000	Z: 0.000
Dist: 1.633e+002	Mag.: 1.28
	Ang.: 22.500

Plane Origin:	Plane Orientation:
X: 1.000e-001	Dip: 0.000
Y: 1.000e-001	DD: 0.000
Z: 5.000e-001	

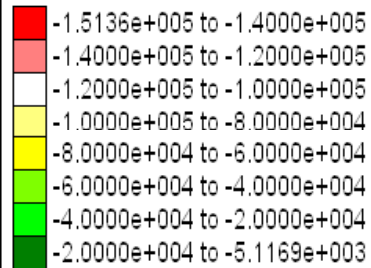
Contour of SZZ

Plane: on

Magfac = 1.000e+000

Live mech zones shown

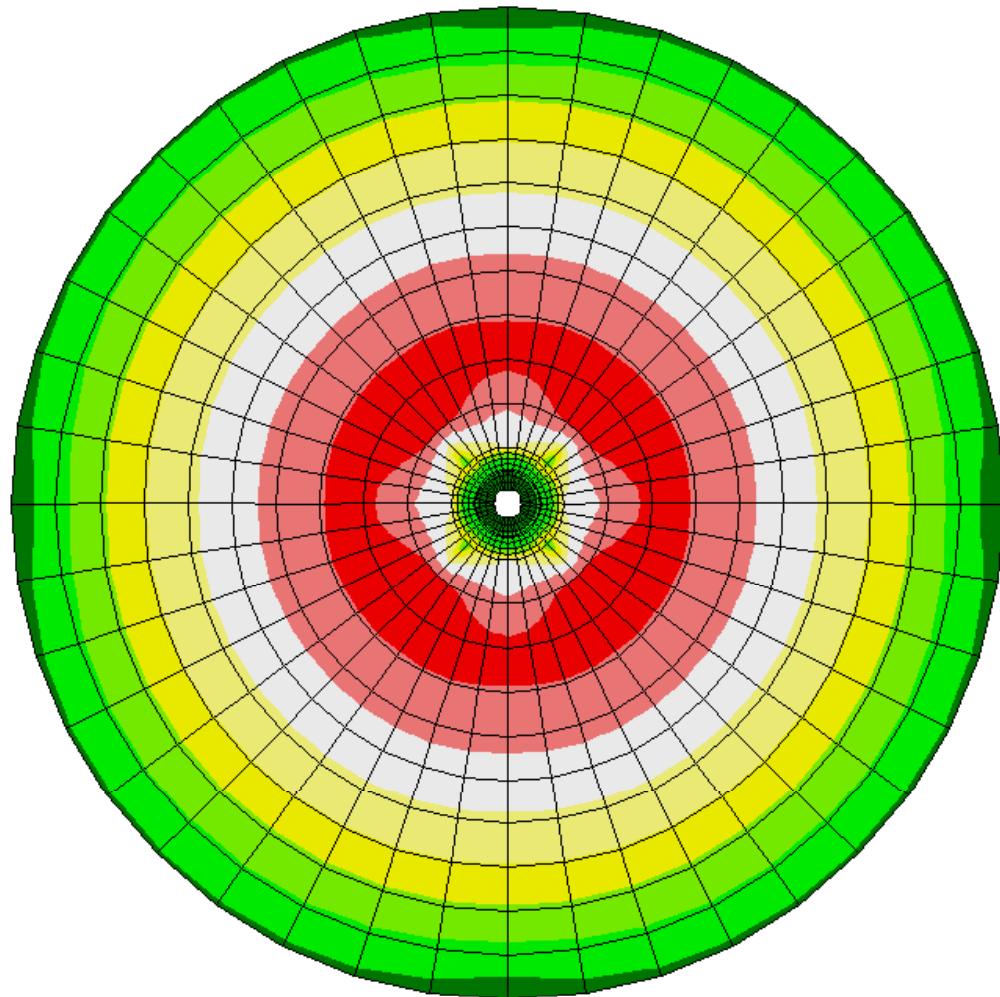
Gradient Calculation



Interval = 2.0e+004

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FLAC3D 3.10

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Step 20000 Model Perspective
23:39:03 Thu Nov 29 2007

Center:	Rotation:
X: 0.000e+000	X: 0.000
Y: 0.000e+000	Y: 0.000
Z: 8.002e+000	Z: 0.000
Dist: 1.633e+002	Mag.: 1.25
	Ang.: 22.500

Plane Origin:	Plane Orientation:
X: 1.000e-001	Dip: 90.000
Y: 1.000e-001	DD: 0.000
Z: 1.000e-001	

Principal Stresses

Plane: on
Magfac = 1.000e+000
Live mech zones shown
Compression

Linestyle

Tension

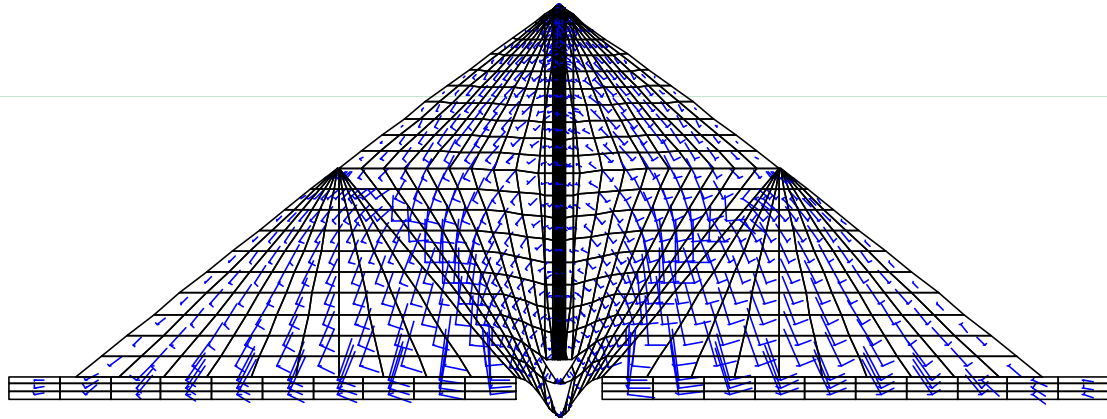
Linestyle

Max Compression = -1.854e+005

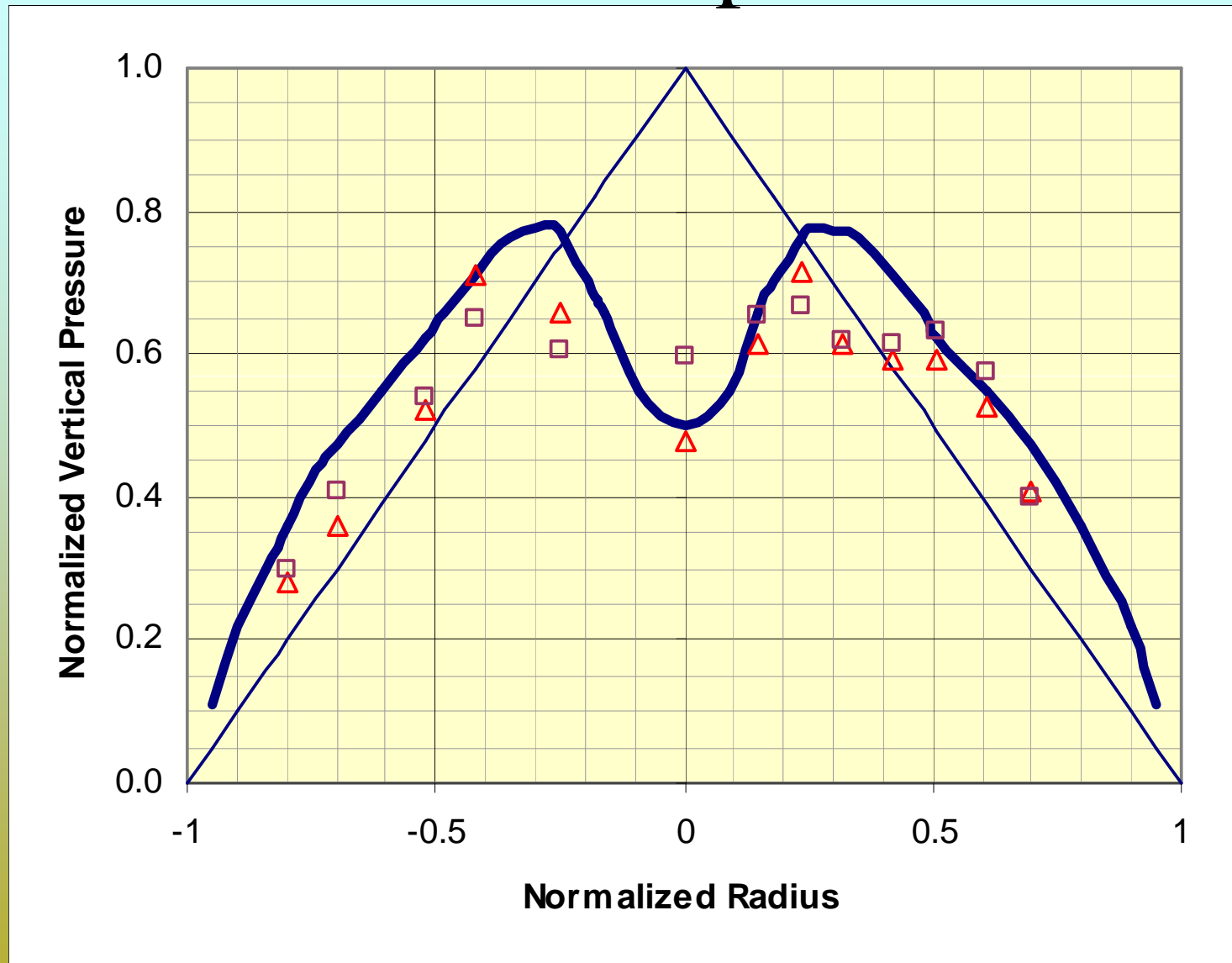
Max Tension = 5.207e+002

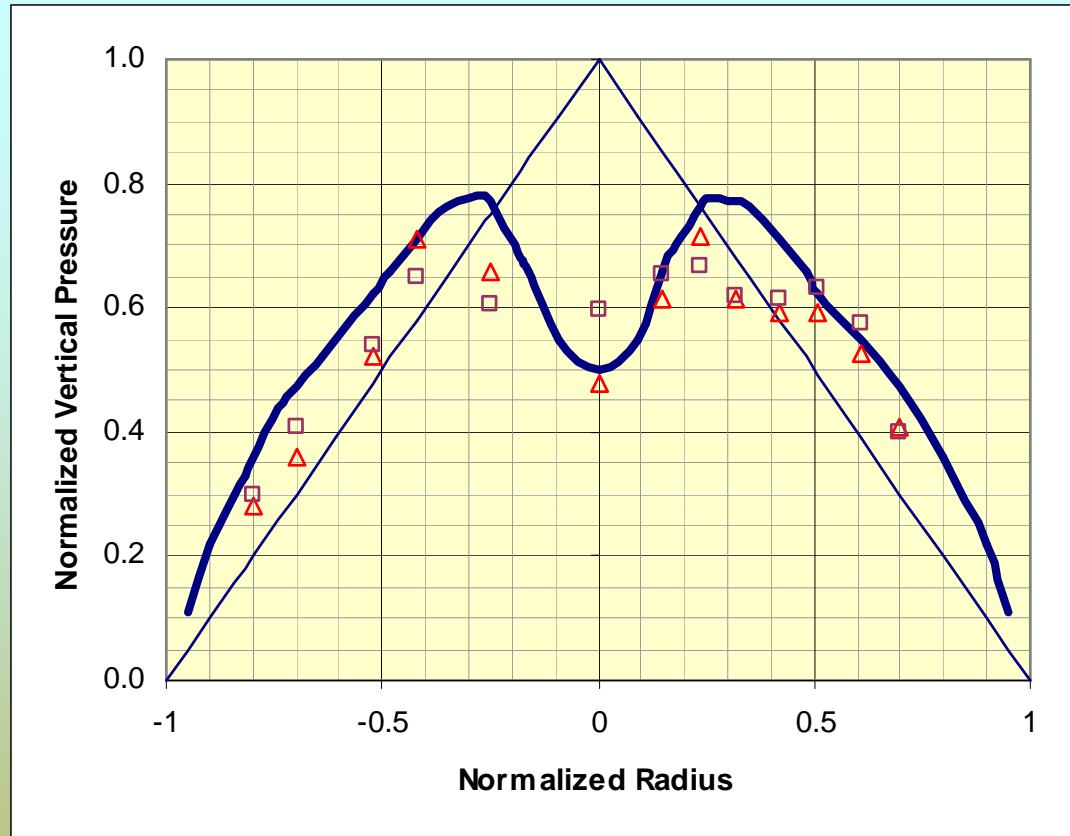
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Job Title: STOCKPILE STRESSES DURING DRAWDOWN



Model vs Experiment

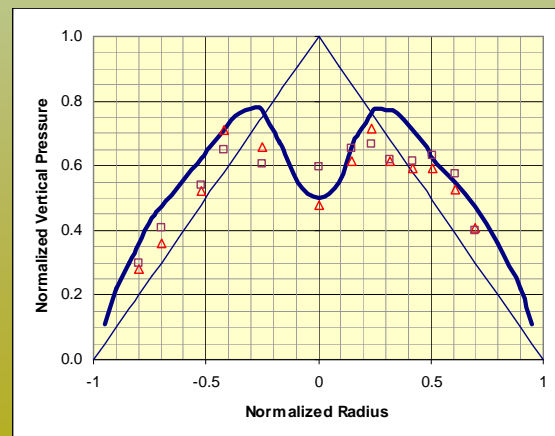




- On the graph the radius normalizing factor is the maximum radius at each height such that for each height measured the max radius is 1.
- The normalizing factor for the vertical pressure is the theoretical maximum pressure for each height measured.

Reasons for Variations Model vs Experiment

- Material (physical) properties of stockpile
 - Particle size
 - Moisture content
 - Bulk Density (porosity)
- Particle segregation during successive fills
- Particle attrition during flow



Conclusions: FLAC-3D

- Stress conditions modeled within a conical coal stockpile similar to those measured in physical experiments
- Formation of the characteristic M-shaped stress profile is accurately reproduced.
- Cannot initialise the stress field as it has to evolve based on:
 - material (physical) properties, and
 - geometry of flow cone within stockpile.

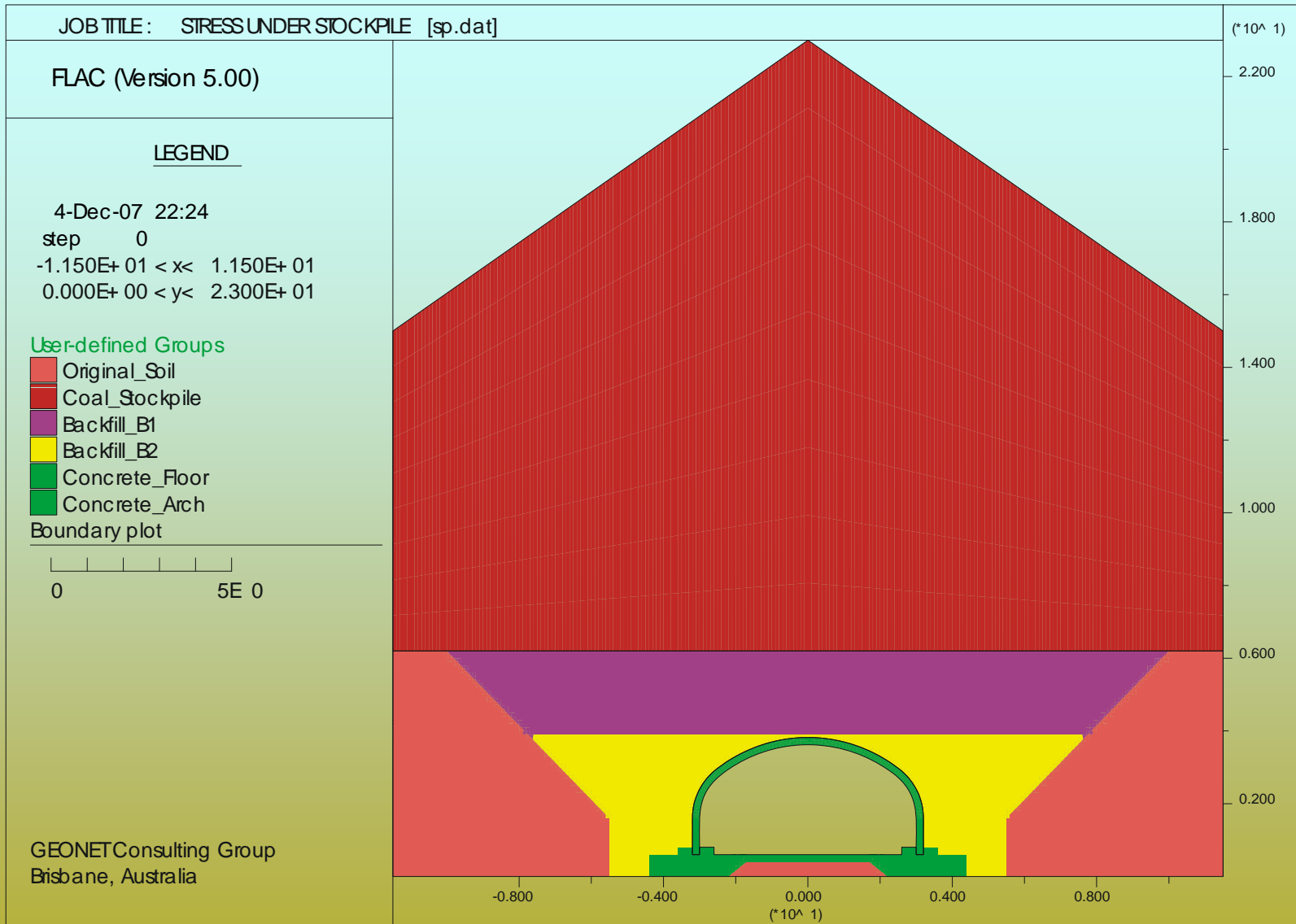
PRACTICAL IMPLICATIONS



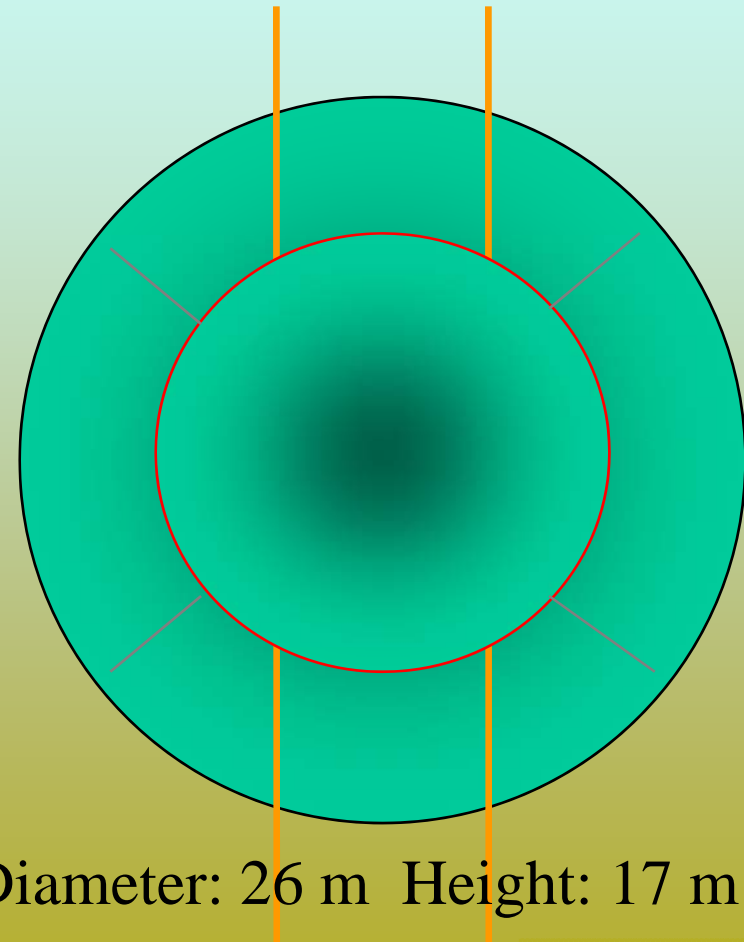
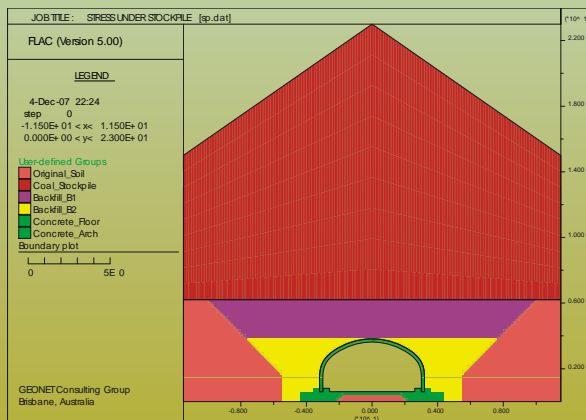
STABILITY OF RECLAIM STRUCTURES FLAC-2D

- Pre-cast concrete arches form tunnel
- Constructed by cut-and-cover method
- Stability of concrete arch depends on stiffness of backfill cover
- Active stockpile above





GEOMETRY OF STOCKPILE RECLAIM FACILITY



Diameter: 26 m Height: 17 m

FLAC (Version 4.00)

LEGEND

18-Jan-05 23:44
step 41000
-4.000E+00 <x< 4.000E+00
-1.000E+00 <y< 7.000E+00

Principal stresses

Max. Value = 4.079E+06

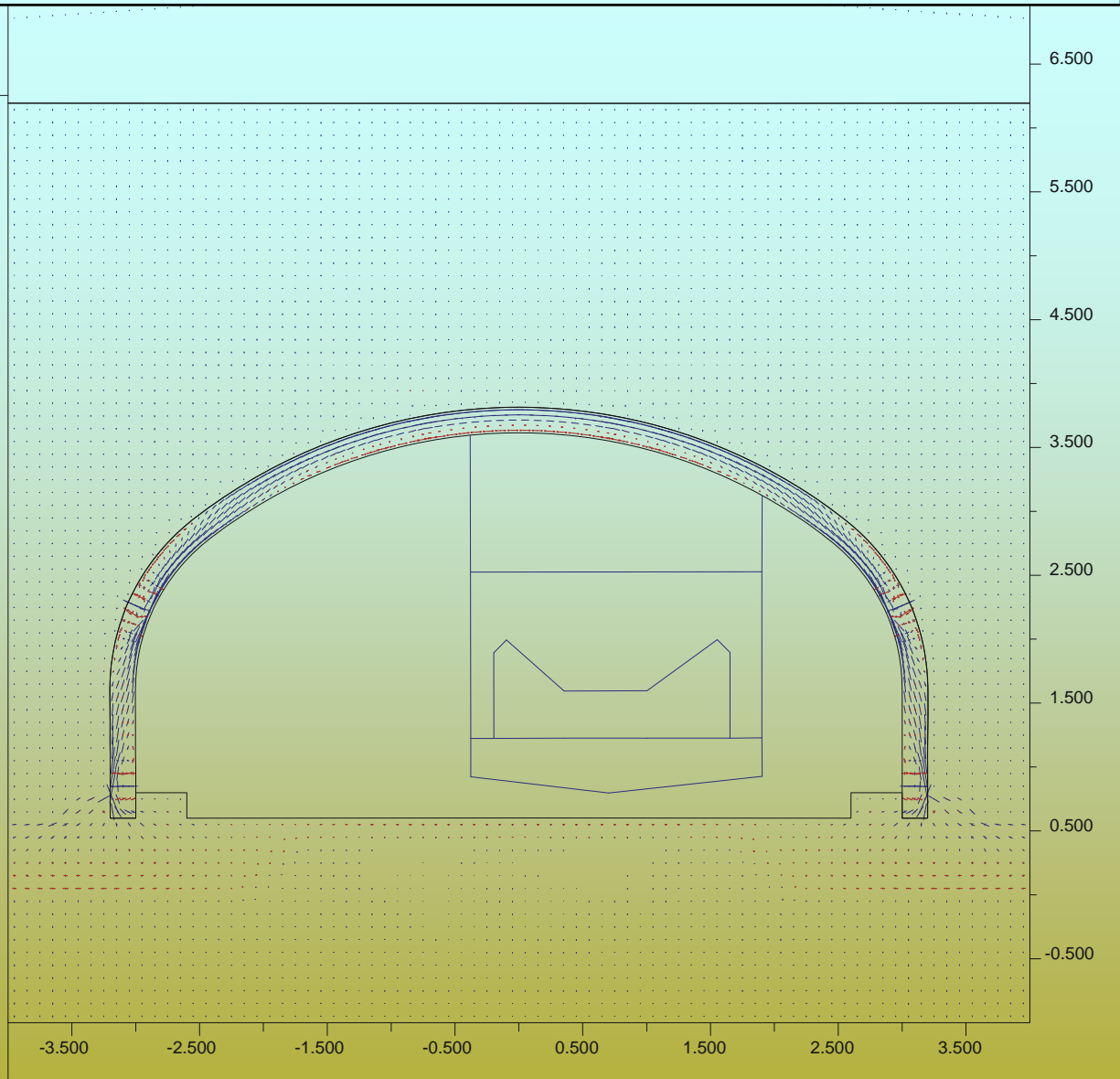
Min. Value = -1.648E+07



Boundary plot



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FLAC (Version 4.00)

LEGEND

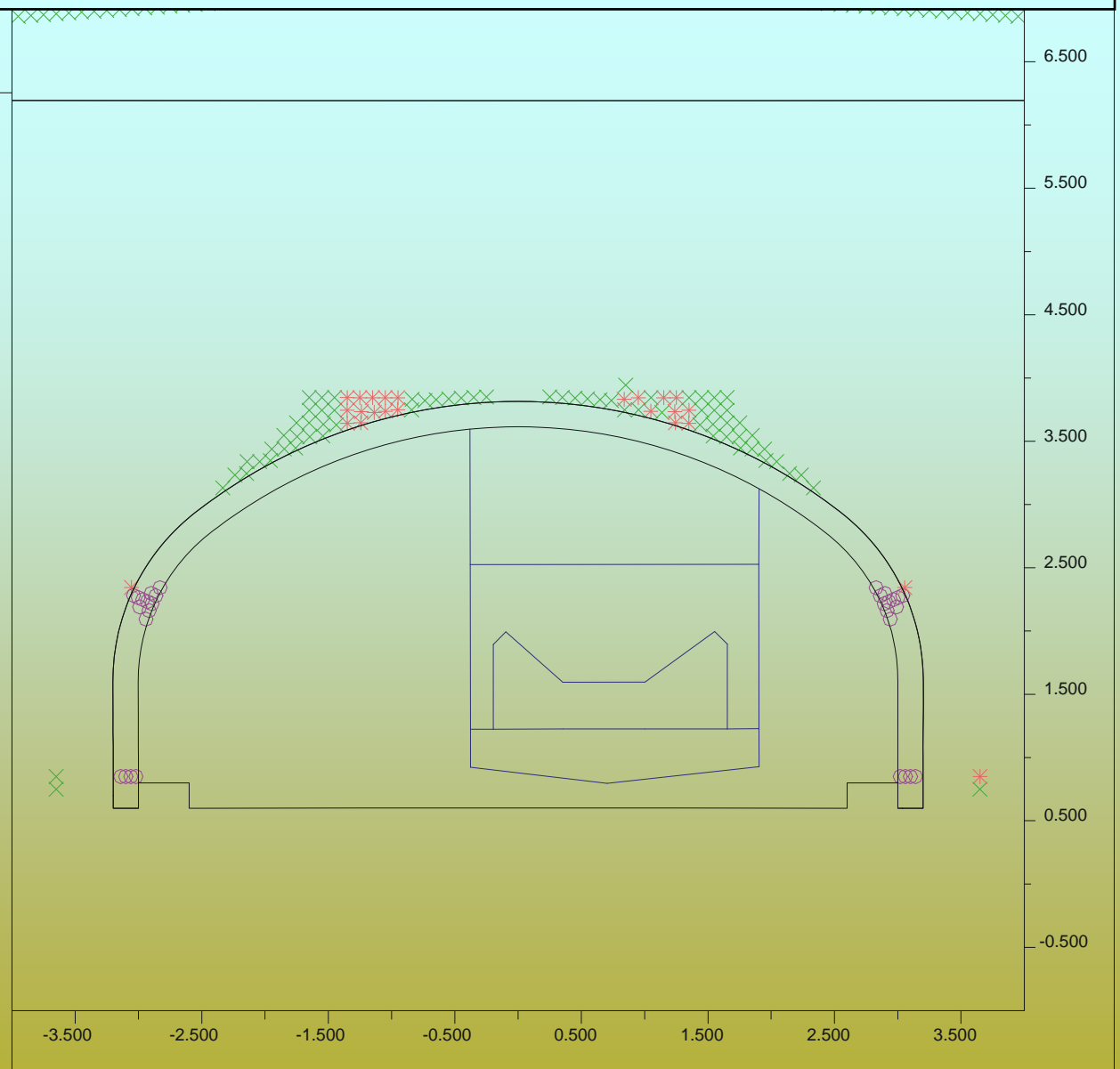
18-Jan-05 23:44
step 41000
-4.000E+00 <x< 4.000E+00
-1.000E+00 <y< 7.000E+00

Plasticity Indicator
* at yield in shear or vol.
X elastic, at yield in past
o at yield in tension

Boundary plot



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Spalling on Face in front of Tension Crack

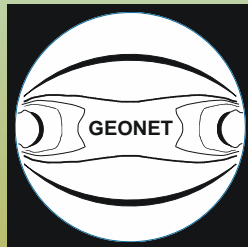


Tension/Shear Crack

CONCLUSIONS

- Maximum stress at the base of stockpile located at 0.3 to 0.4 of the radius from the centerline.
- Second high stress annulus located at one third the height of the stockpile.
- Material converging in draw cone tends to form arch against stationary cone.
- High stress at the base of the stockpile is due to the entire mass of the material in the draw cone being transferred onto the remnant cone.
- Comminution of material in stockpile will occur within the shear annulus formed at the interface between the draw and remnant cones.
- The formation of the annulus of maximum stress at the base of the stockpile suggests that maximum loading conditions would develop on the second and third precast concrete arches from the drawdown chamber in either direction in the drawdown tunnel. The magnitude of load on these concrete arches may be 35% greater than geostatic.

THANK YOU FOR YOUR ATTENTION



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