Kinematic model and drawbody in underground mining process

F. Vivanco[1], C. Fuentes[2], V. Apablaza[2] & , F. Melo[1]

[1]Universidad de Santiago de Chile, CIMAT

[2]IM2, Codelco, Chile

Outline

- Goal:

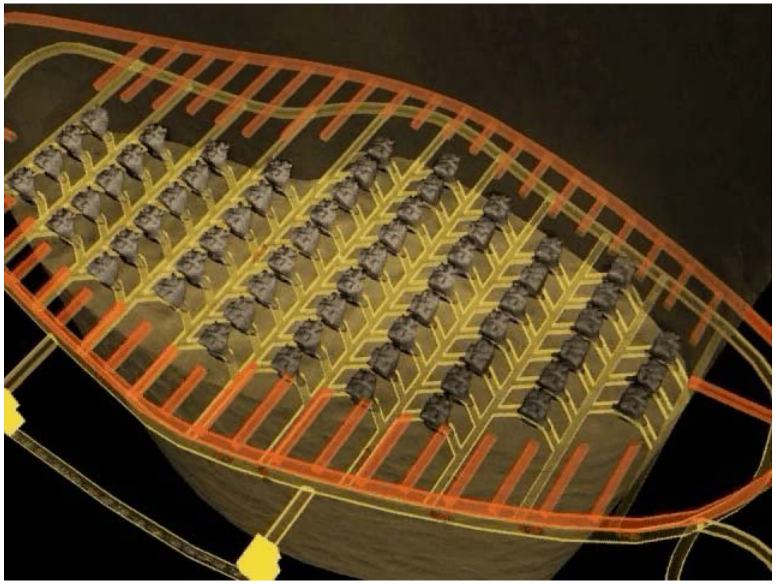
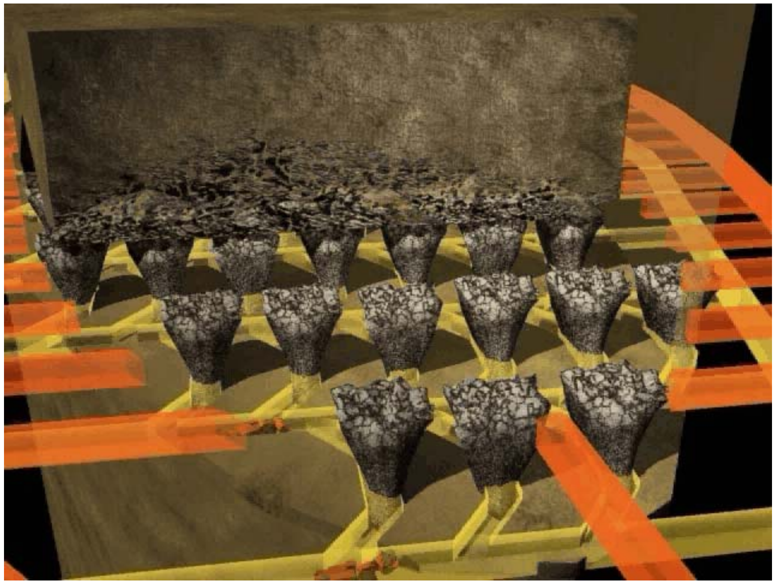
  Develop a simple tool to help in optimizing ore recovery reducing dilution in underground mines.

- Approach:

  Kinematic model, laboratory scale experiment validation.

Underground mining - block caving

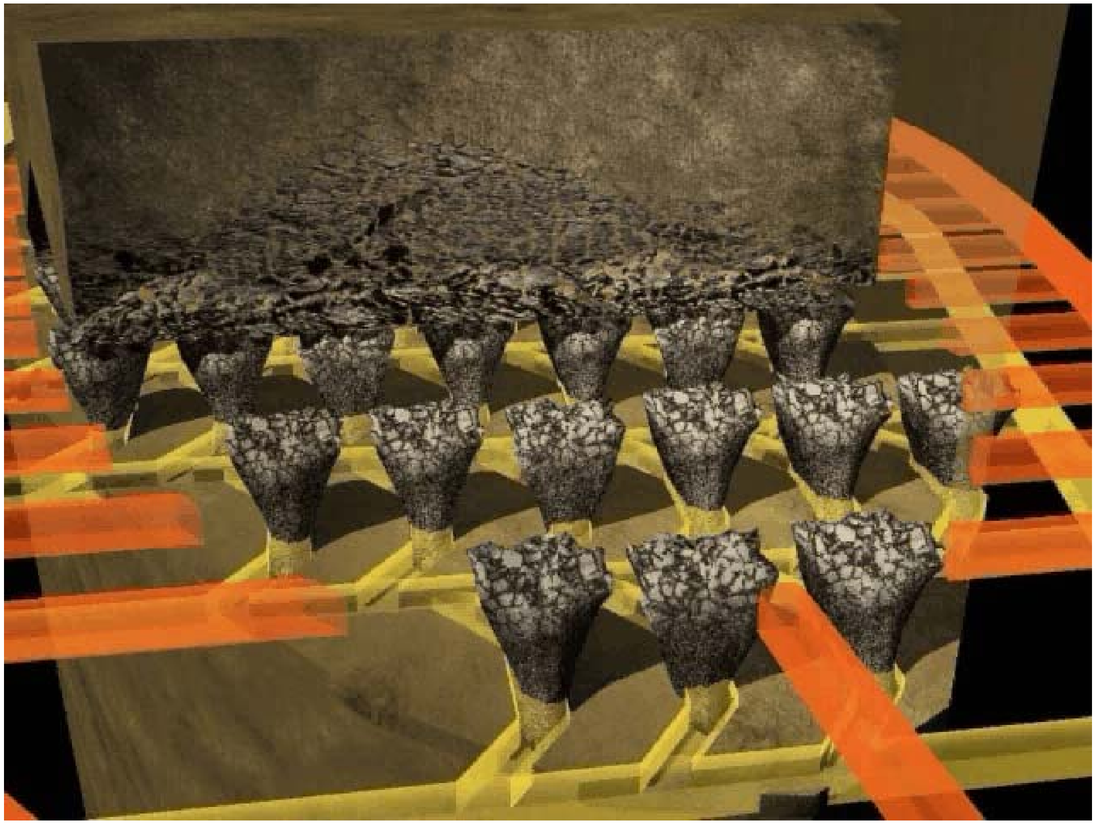
- Large scale production. Low cost method applicable in weak ore, unsafe to mine with other techniques (1000M ton., cost US$ 1000M, profit US$ 6000M).
- Conditions. Massive ore bodies, large dimensions, rock mass breaking into manageable size block.

Block caving

- Description. Gravity+rock stresses fracturing rock mass. Minimal drilling and blasting.
- Problems. Lots pre-ore recovery, ore dilution[1,2] extraction, surface disturbance.

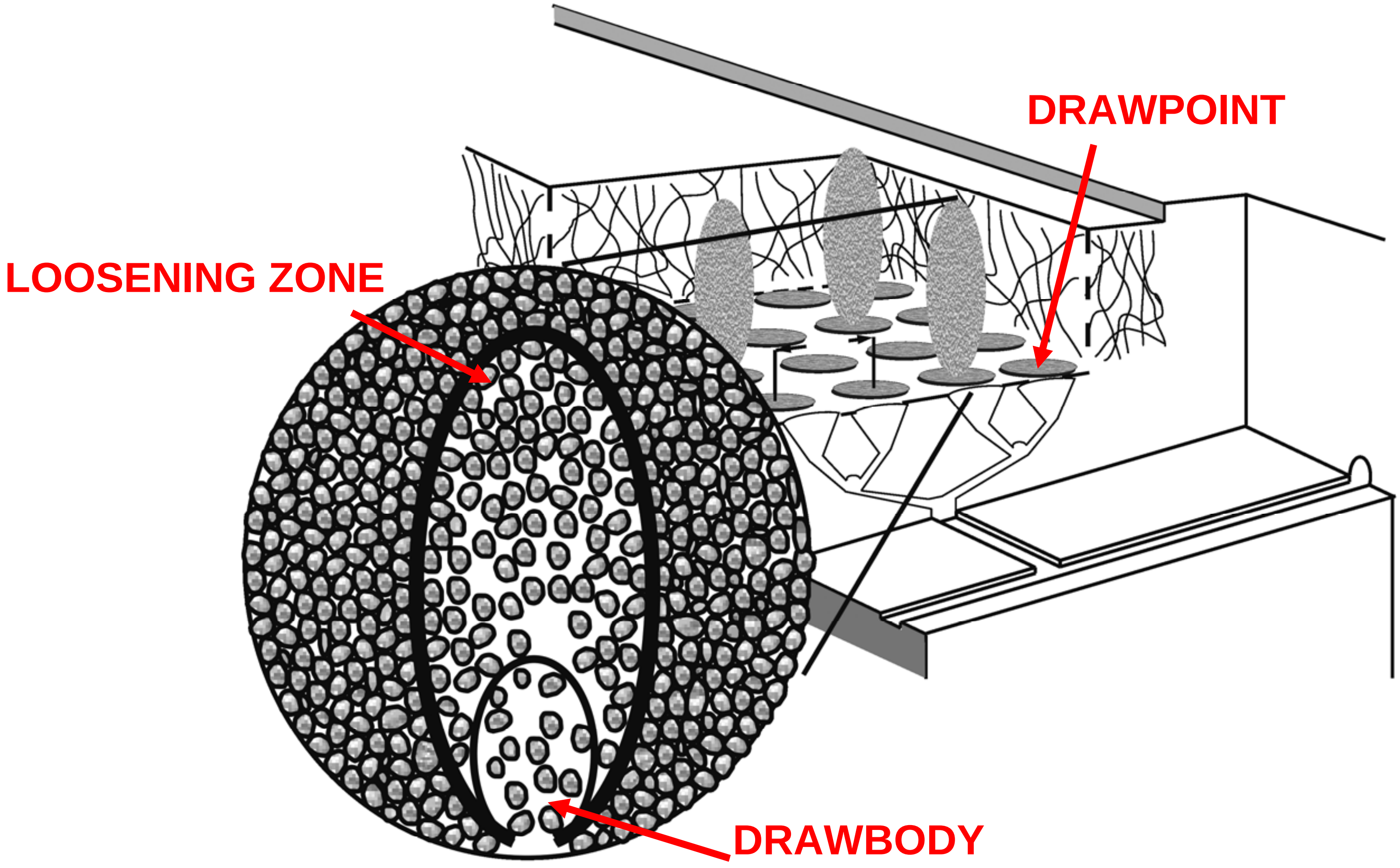
Block design and operation optimization



Courtesy of C. Fuentes

[1]tonnes waste rock mined/tonnes ore mined
[2]tonnes waste rock mined/tonnes ore+waste mined

Concepts

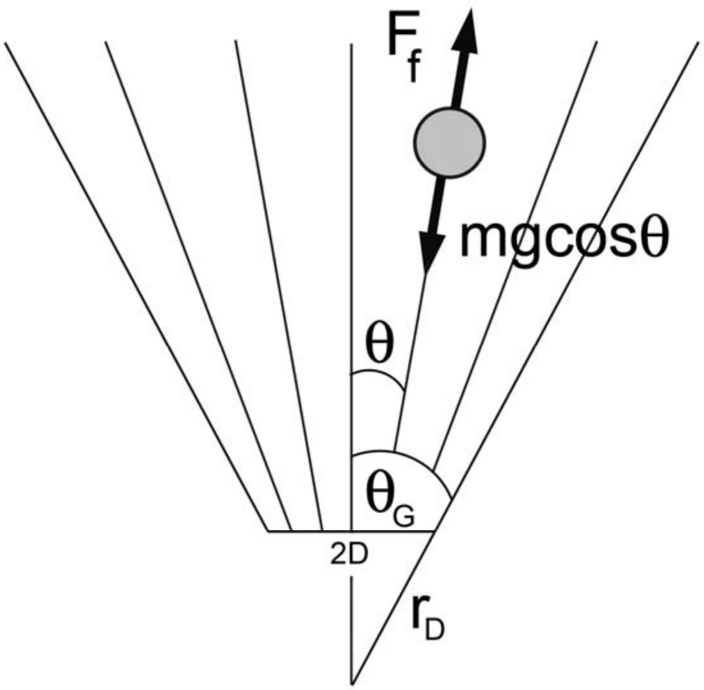


Drawbody models

- Bergmark-Roos

$$r(\theta,t) = r_0(\theta) - \frac{1}{2}a_r(\theta)t^2$$

$$\rho = \rho_0 \frac{r_0^{\;2}}{r^2}$$



Drawbody models

- Plasticity[1]

$$v_r = -\frac{v_0 r_D{}^2}{r^2} f(\theta)$$

$$\rho = \rho_0$$

[1]Velocity distribution is obtained from stress distribution in static material

Drawbody volume

- Bergmark-Roos

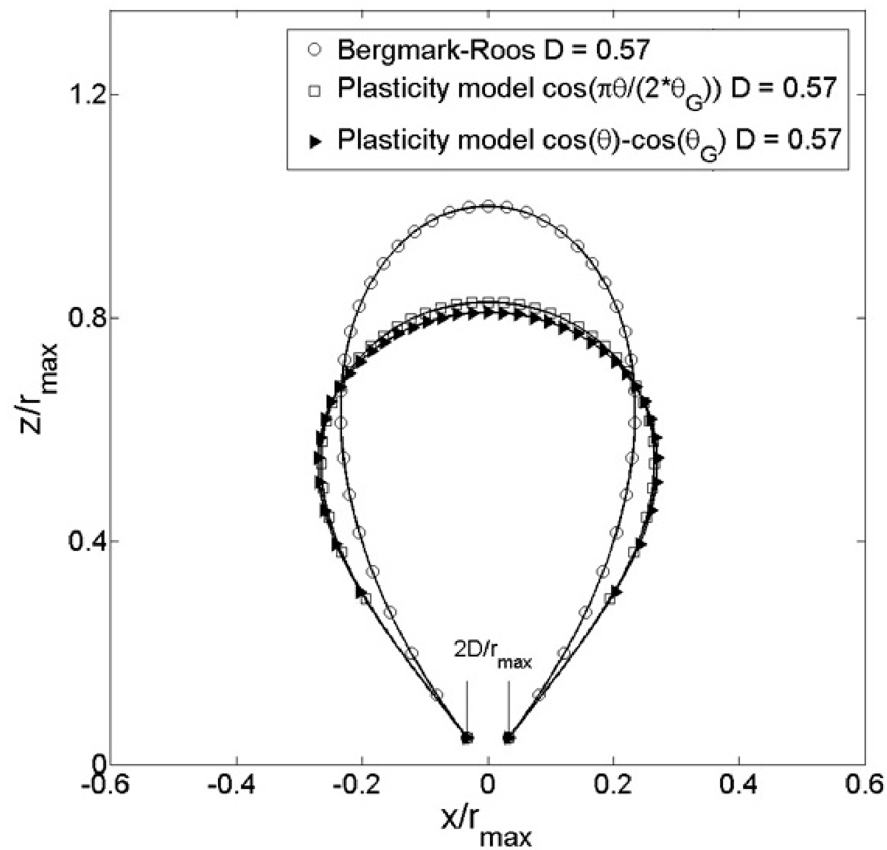
$$\Omega_0 = \frac{\pi}{6}(1-\cos\theta_G)\left[r_{\max}^3 - r_D^3 + r_{\max}^2 r_D + r_{\max} r_D^2\right]$$

$$\xrightarrow[r_{\max} >> r_D]{} \Omega_0 = \frac{\pi}{6}(1-\cos\theta_G) r_{\max}^3$$

- Plasticity

$$\Omega_0 = \frac{\pi}{3}(r_{\max}^3 - r_D^3)\left[\frac{\cos^2\theta_G - 2\cos\theta_G + 1}{1-\cos\theta_G}\right]$$

$$\Omega_0 = \frac{2\pi}{3}\left[\frac{r_{\max}^3 - r_D^3}{(\pi/2\theta_G)^2 - 1}\right]\left[\frac{\pi}{2\theta_G}\sin\theta_G - 1\right]$$



Kinematic model

Nedderman and Tüzun, Powder Technol. **22**, 243 (1979)

$$v_x = -D_P \frac{\partial v_y}{\partial x} \Rightarrow \frac{\partial v_y}{\partial y} = D_P \frac{\partial^2 v_y}{\partial x^2}$$

$$\frac{\partial v_z}{\partial z} = D_P \left[\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial v_z}{\partial r} \right) \right]$$

- Velocity distribution in rectangular hopper.
- Stationary conditions.
- Loose packing state.
- Dilation when dense packing systems start to flow.

Single drawpoint extraction

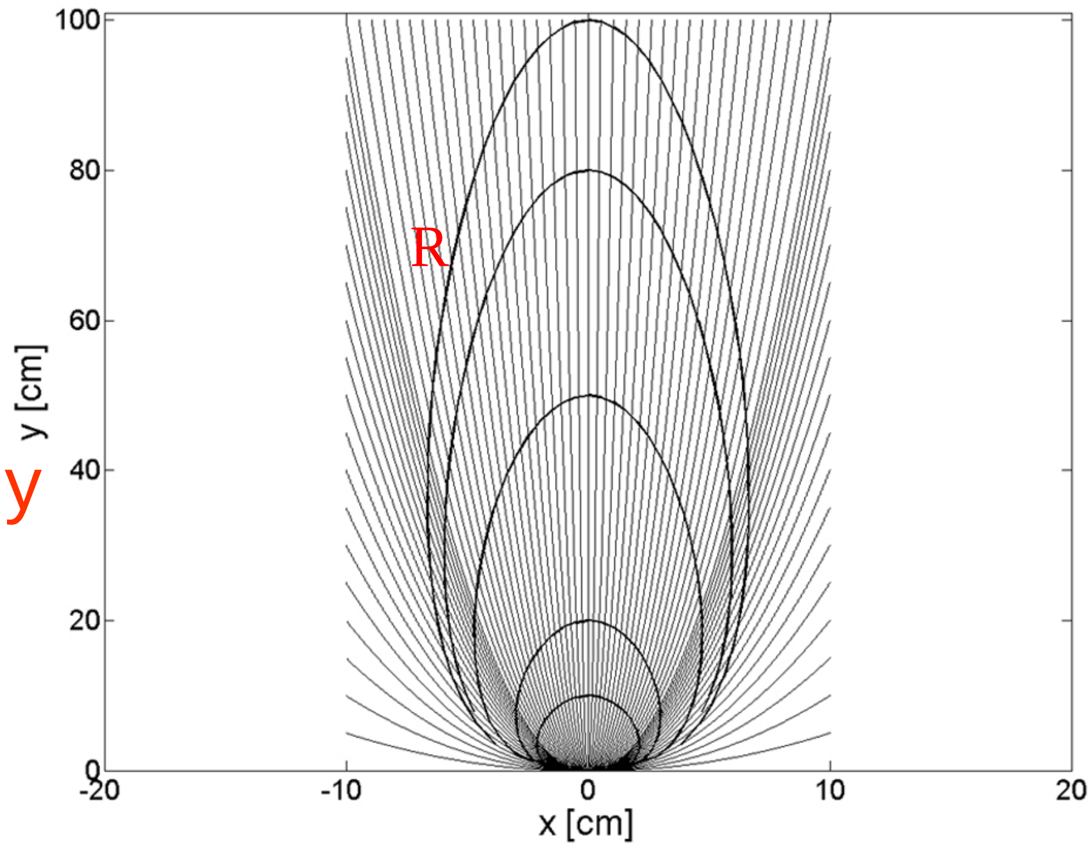
- Particles streamline

$$\frac{dx}{dt} = f(x, y, D, Q)$$

$$\frac{dy}{dt} = g(x, y, D, Q)$$

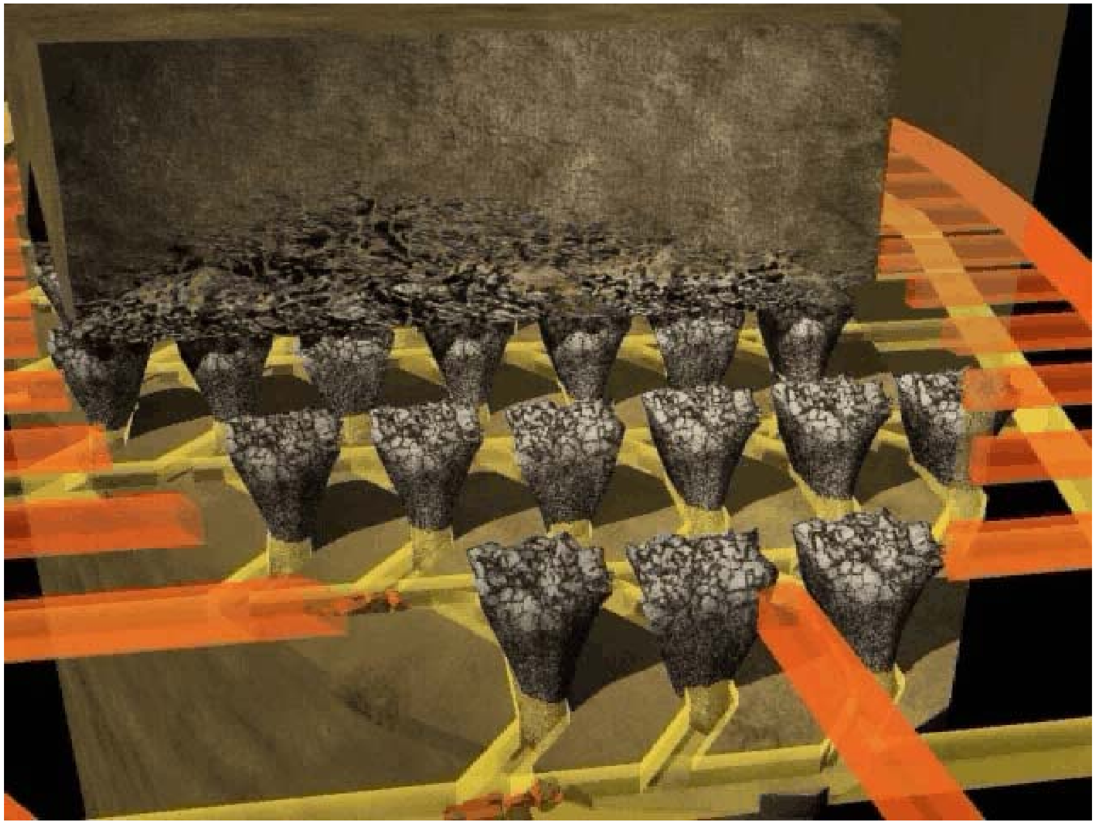
- Condition for drawbody

$$R(x_0, y_0, D) = Qt$$



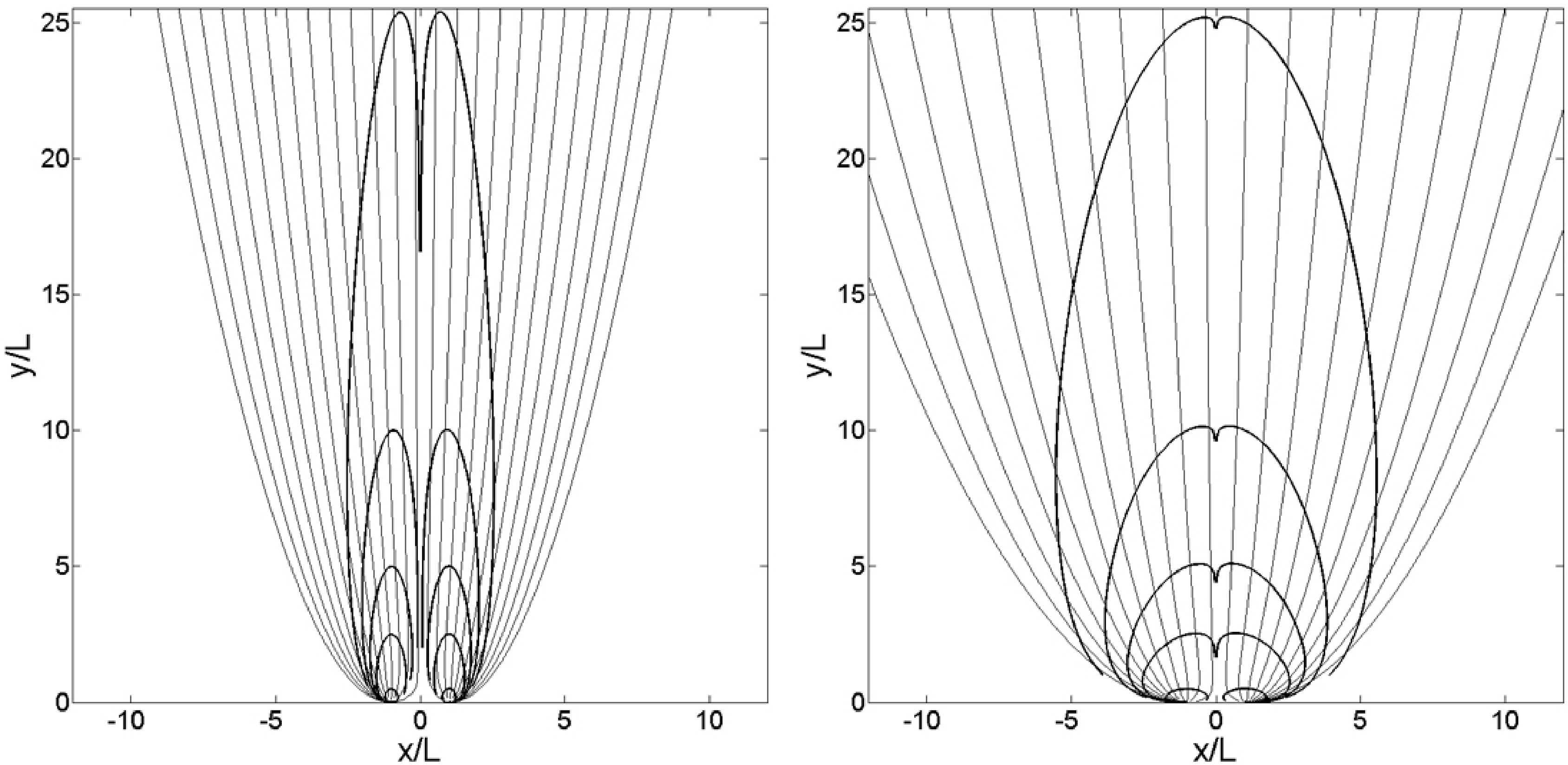
Drawpoints interaction

- Extraction: simultaneous or alternating
- Open question: How drawpoint interact?
- Drawpoints distribution is based on common belief.
- Description simplified by linearity of kinematic model.



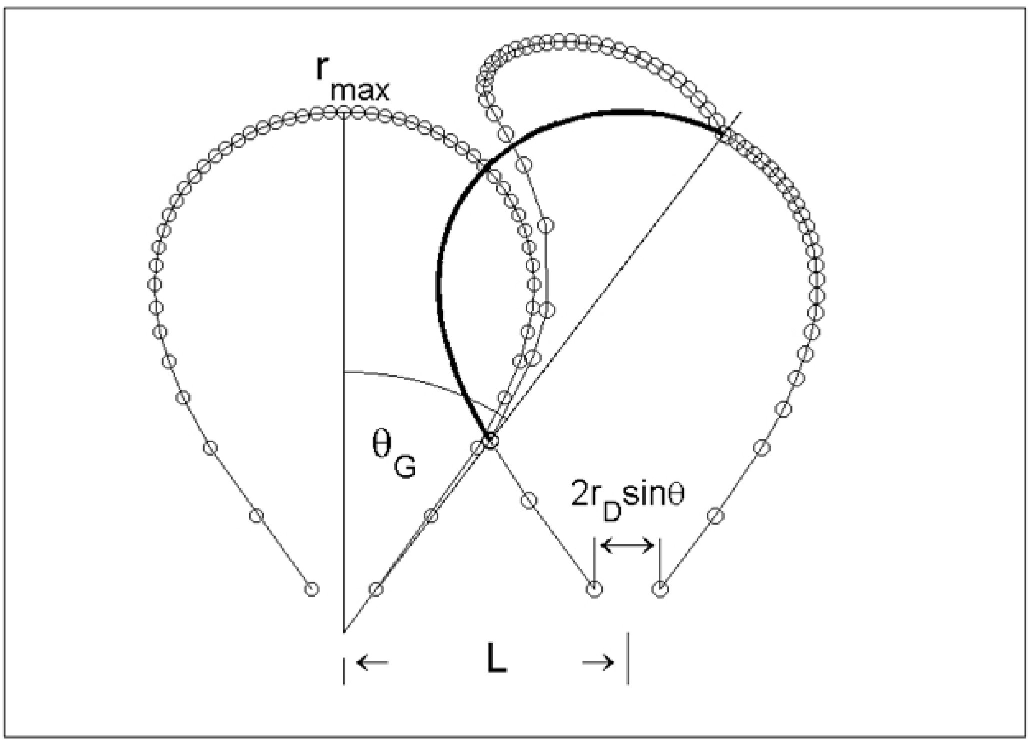
Drawpoints interaction

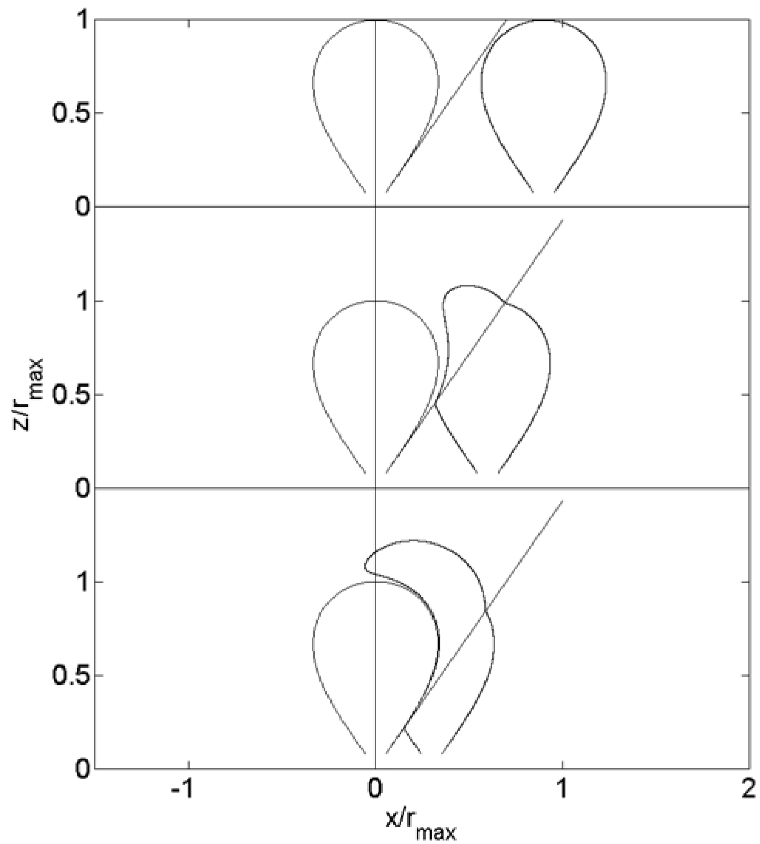
- Simultaneous extraction $\vec{v} = \sum_{\vec{L}_i} \vec{v}_{Q_{0i}}(\vec{x} - \vec{L}_i)$



Drawpoints interaction

- Alternating extraction



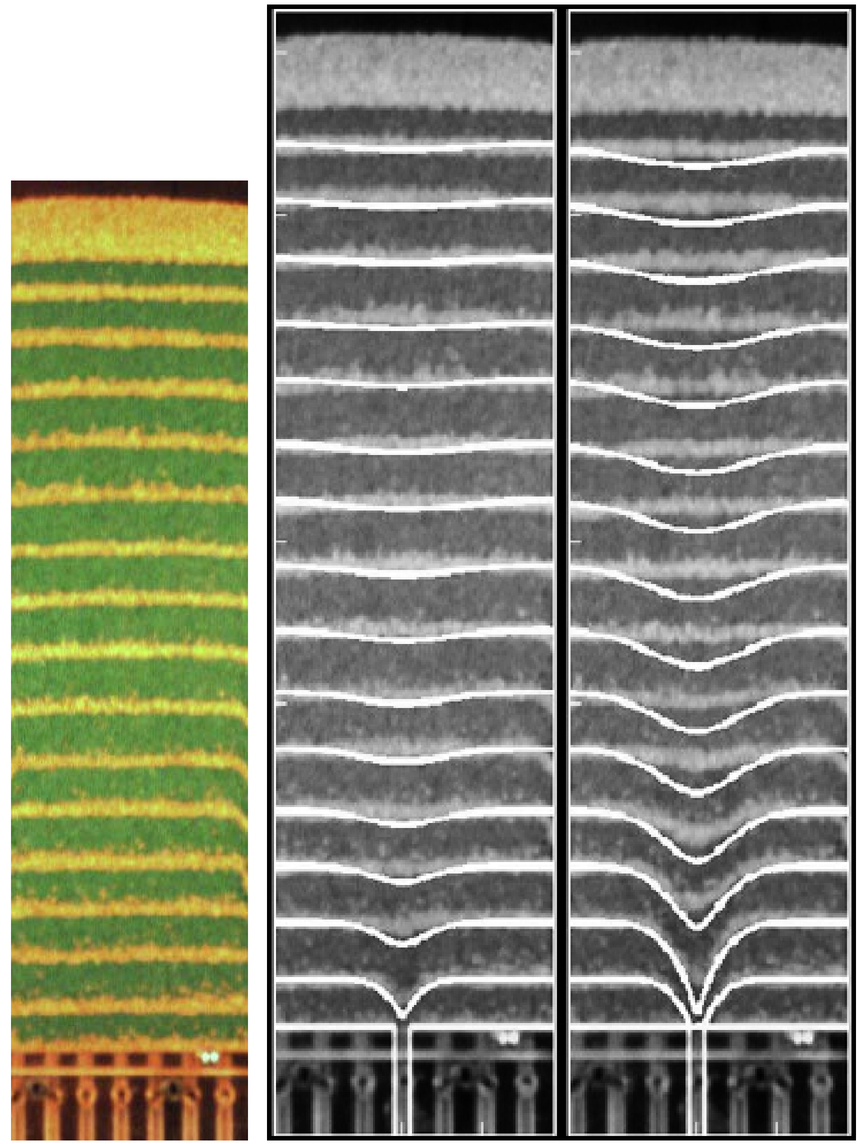


Experiment & model

- Pure kinematic model

- Good agreement close to the aperture.
- Theoretical prediction fails at higher vertical positions.
- Area of deflection is equal to extracted material (constant density hypothesis.) Not fulfilled in experiments.
- Dilatancy effect must be considered.

F. Melo et al, to be published in IJRMMS (2006).

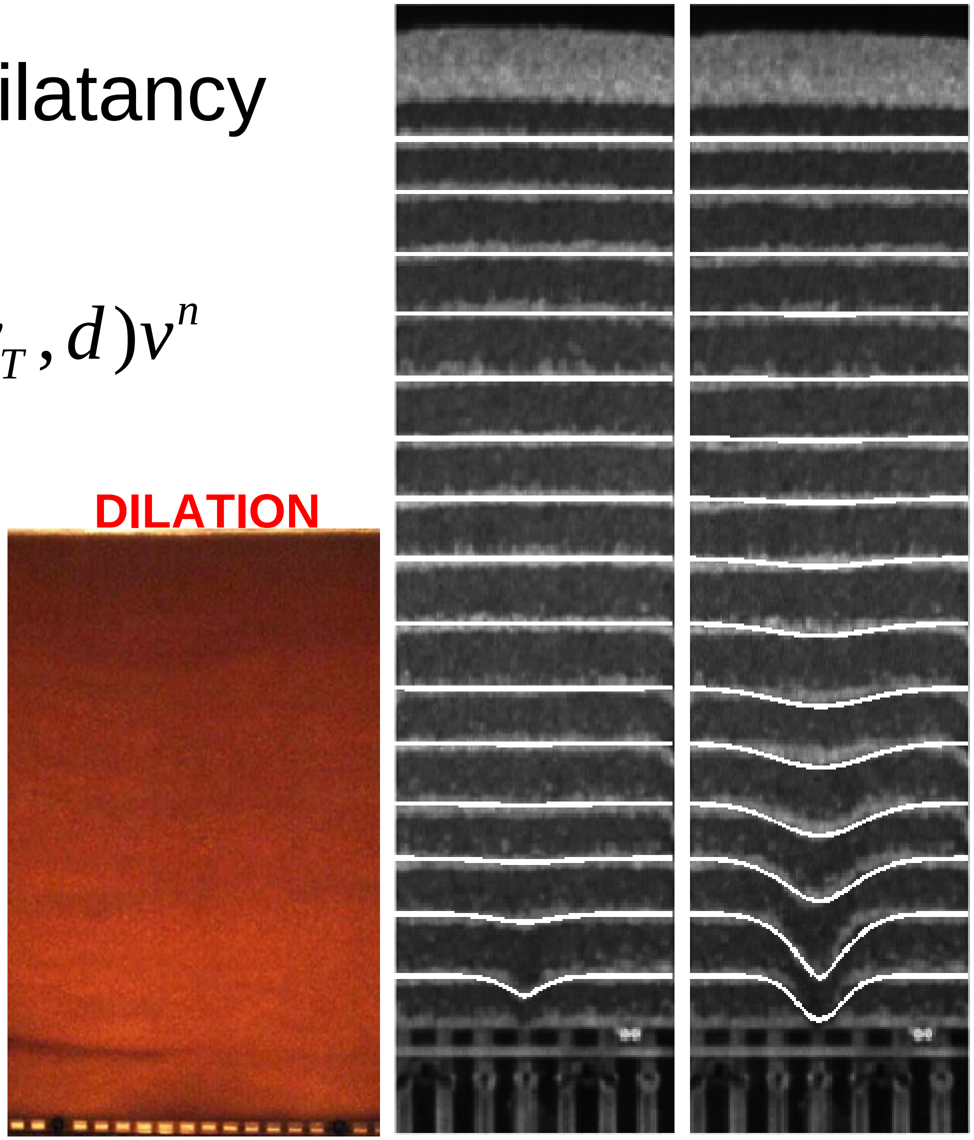


Experiment & model

- Kinematic model + dilatancy

$$\frac{\partial v^n}{\partial y} = D(v_T)\frac{\partial^2 v^n}{\partial x^2} + f(v_T, d)v^n$$

$$f(v_T, d) = -\alpha_0 \exp\left(-\frac{|v_T|}{d}\right)\frac{v^n}{d}$$

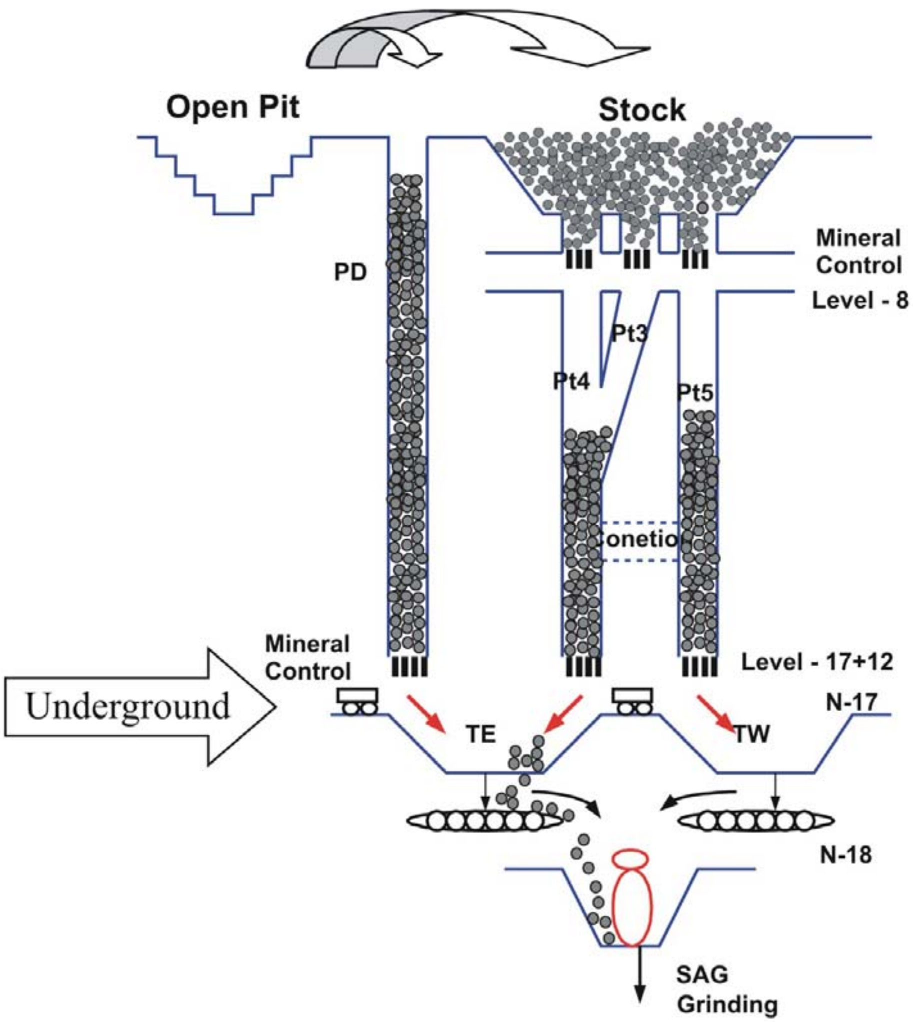


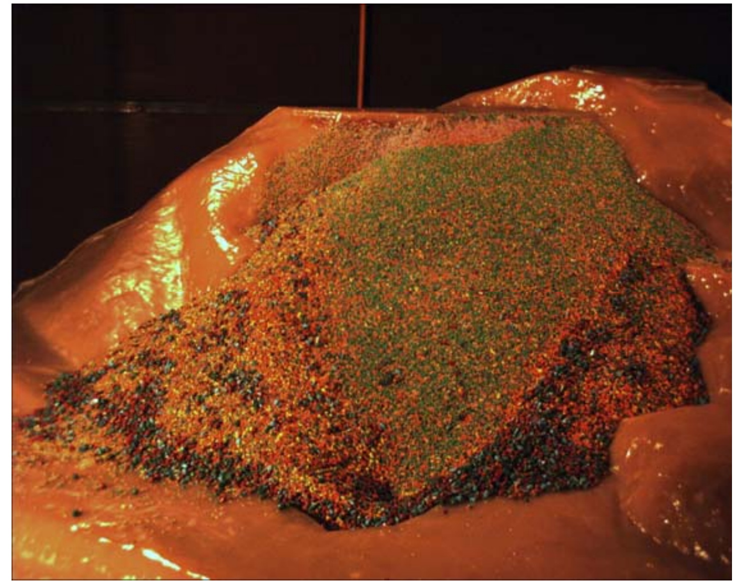
Summary

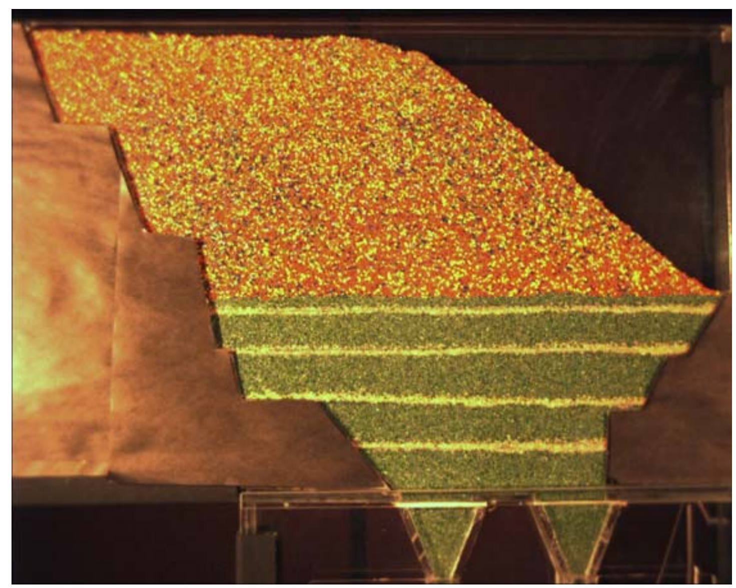
- Model in use (B-R) presents unphysical increase of density.
- More physical models, Kinematic and plasticity, are suitable to describe drawbody and loosening shape.
- Simple kinematic model captures characteristics found in single drawpoint extraction.
- Interactions of drawpoint can be described by kinematic model.
- Divergence between kinematic model and experiments can be surpassed introducing a dilatancy term.
- Kinematic model can be used as a simple tool to optimize draw spacing and draw strategy in underground mining.
- We believe even in the worst case it is enough to characterize a single drawpoint experimentally and use linear superposition to get insights on flows interactions.

Ongoing research

- Lab. scale ore stock experiment.







C. Fuentes, G.Bravo & D. Opazo

Ongoing research

- Full scale ore stock experiment.

- 1100M ton. Stock capacity
- 500K ton. Production, 3 months duration.
- Local measure accessibility