Underground mining flows: an application of kinematic and plasticity models

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Outline

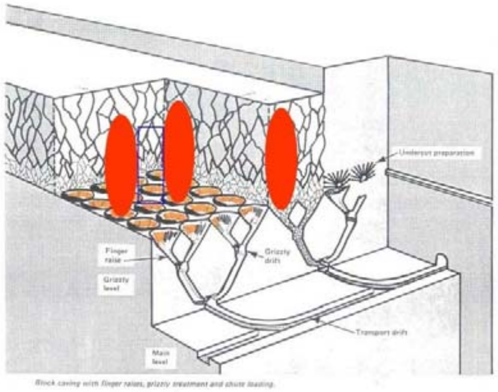
1. Introduction
2. Modeling
3. Comparing model to experimental data
    a. Janelid and Kvapil
    b. Peters and Power
    c. R. Castro
4. Conclusions

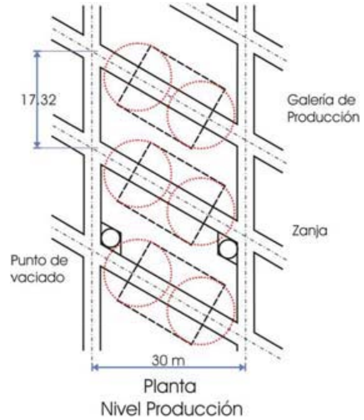
Outline

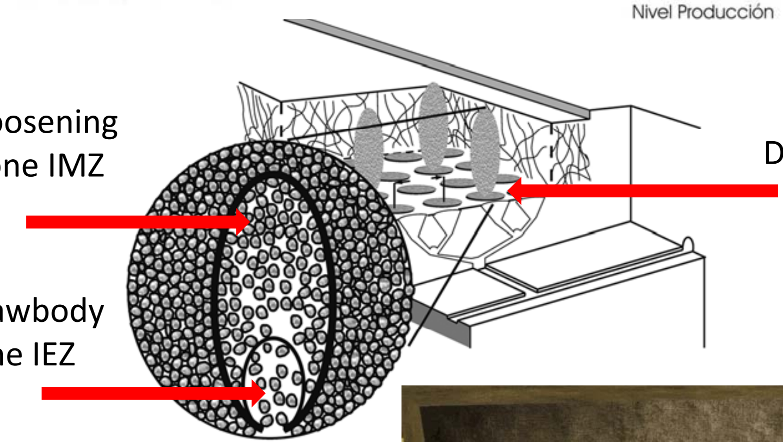
1. Introduction
2. Granular flows
    a. General overview
    b. Basic questions
3. Underground mining
    a. Introduction
    b. Modeling
    c. Summary
4. In progress and Future work

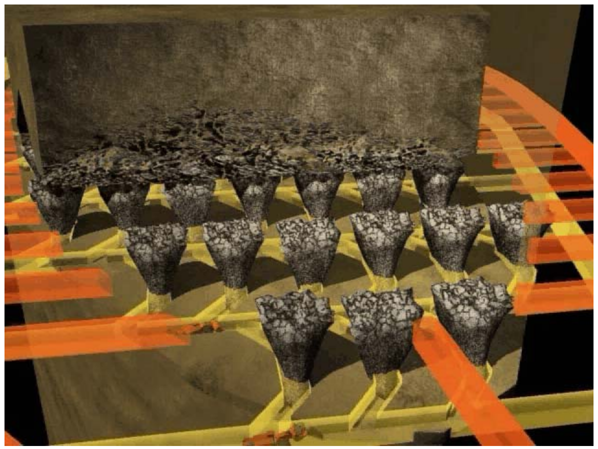
Underground mining
Block caving method

- Characteristics
  - Low cost operation.
  - Applicable in weak ore.
  - Other techniques are unsafe.
- Conditions
  - Massive ore bodies.
  - Large dimensions.
  - Fracture into manageable size block.
- Some numbers
  - Material 1000M Ton.
  - Cost US$ 1000M.
  - Profit US$ 6000M.









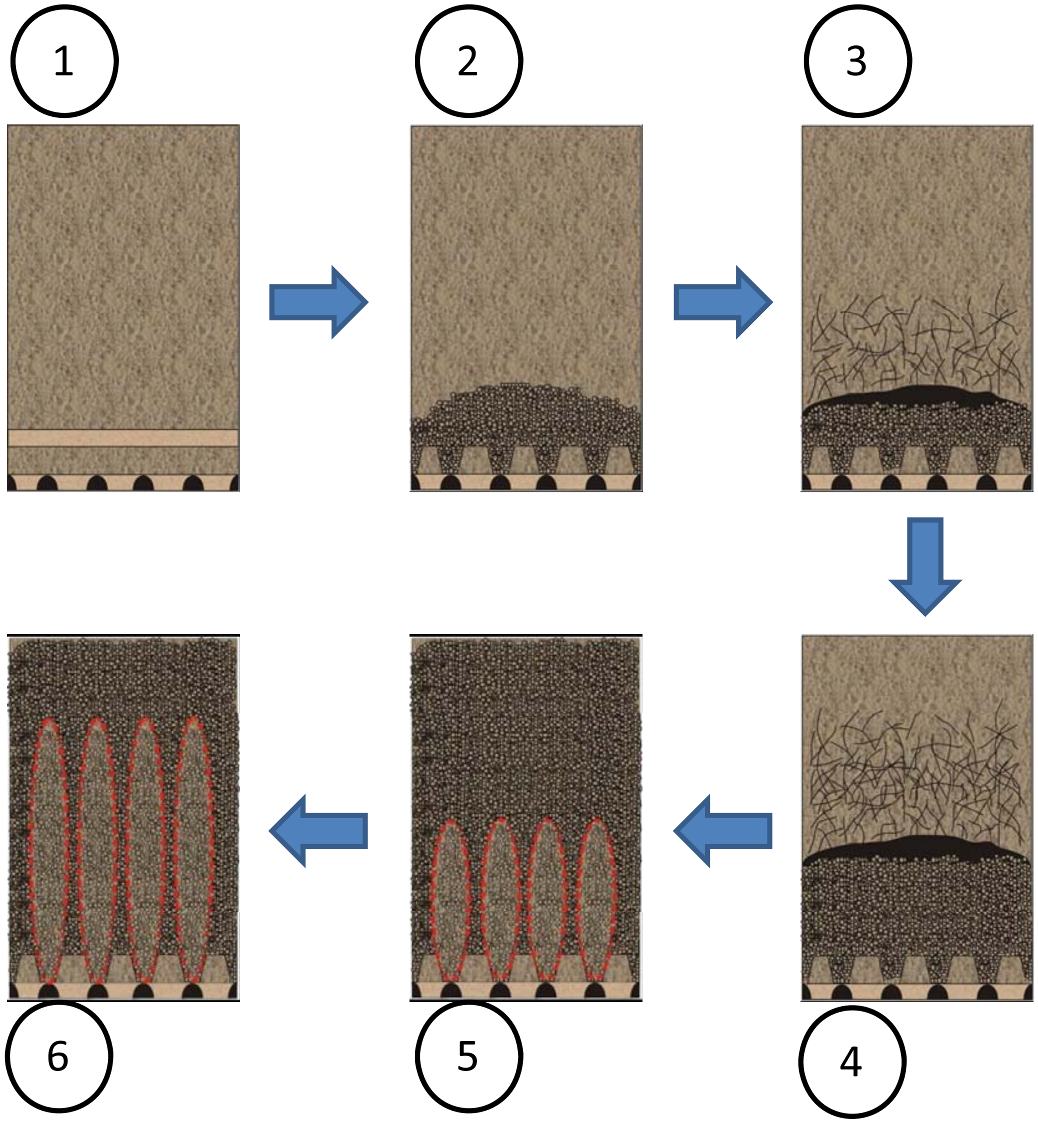
Courtesy of C. Fuentes

"On drawbody shapes: From-Bergmark to kinematic model." F. Melo et al, Int J Rock Mech Mining Sci, 44, 1 (2007), 77-86.

"Kinematic model for quasi static granular displacements in block caving: dilatancy effects on drawbody shapes." F. Melo et al, to be appear in Int J Rock Mech Mining Sci.

Standard procedure

1. Initial stage: cut hoppers.
2. Fracture initiation.
3. Common view: as material is extracted fracture front propagates, critical cavity diameter for propagation.
4. Extraction speed: too fast might form unstables cavities.
5. Fracture reach the top after 30% of material has been extracted.
6. Questions: How to avoid extraction of dilution material at the top?, How drawbodies evolve and interact?, How to optimize the drawbody size?.



All the above questions are connected to the granular flow inside the mine.

2. Modeling

Kinematic model

Plasticity model

Simple idea:
Quasi static flow

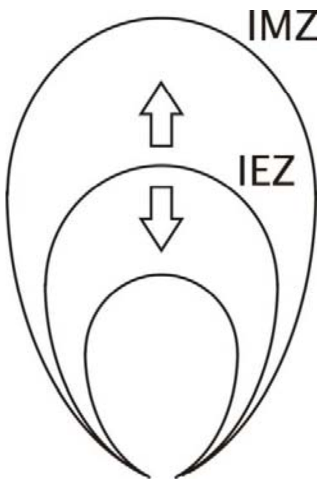
Diffusive model (Kinematic model, Nedderman and Tüzun, Powder technol. **22**, 243, 1979), Flat bottomed hoppers.

$$u = -D_P \frac{\partial v}{\partial x} \qquad \frac{\partial v}{\partial y} = D_P \frac{\partial^2 v}{\partial y^2}$$

$$2\pi D_P \exp\left(\frac{r_1^2}{4D_P z_1}\right)\left(z_1^2 - z_2^2\right) = Qt$$

$$\frac{dr}{dt} = -v_0 \frac{r_D^2}{r^2} \cos\left(\frac{\pi\theta}{2\theta_G}\right)$$

$$r^2 - r_D^2 = 3\cos\left(\frac{\pi\theta}{2\theta_G}\right) Qt$$



$$t_{dilation\_front} = \left(\frac{\Delta\rho}{\rho}\right) t_{particles}$$

3. Comparing model to experimental data
    a. Janelid and Kvapil

Janelid and Kvapil estimation

Kvapil Ellipsoidal theory.

Assuming same eccentricity and loosening factor 1.066.

$$\Rightarrow \left(\frac{H_{IMZ}}{H_{IEZ}}\right) \sim 2.5$$

KM2D

$$\left(\frac{H_{IMZ}}{H_{IEZ}}\right) \sim \left(\frac{\rho}{\Delta\rho}\right)^{2/3} \sim 6.1$$

KM3D

$$\left(\frac{H_{IMZ}}{H_{IEZ}}\right) \sim \left(\frac{\rho}{\Delta\rho}\right)^{1/2} \sim 4$$

PM3D

$$\left(\frac{H_{IMZ}}{H_{IEZ}}\right) \sim \left(\frac{\rho}{\Delta\rho}\right)^{1/3} \sim 2.5$$

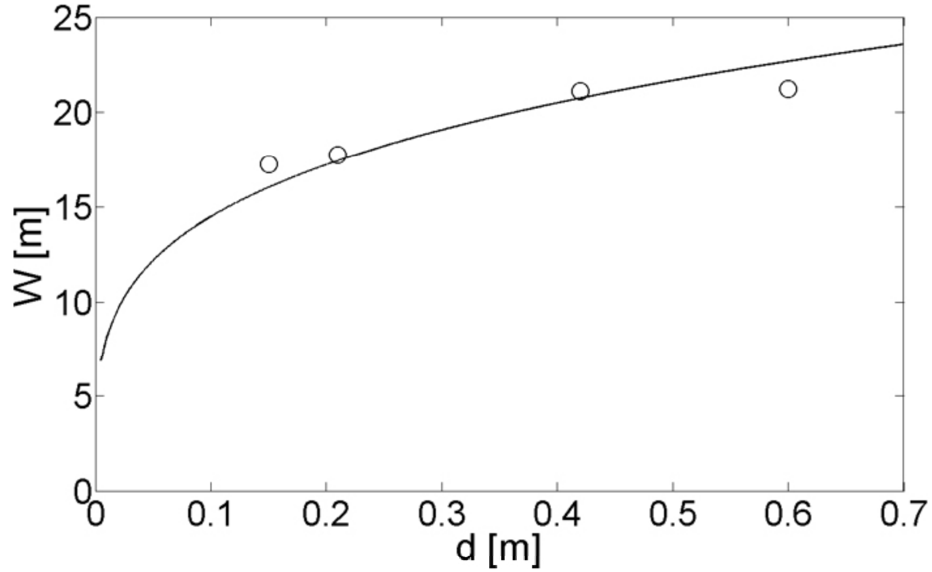
3. Comparing model to experimental data

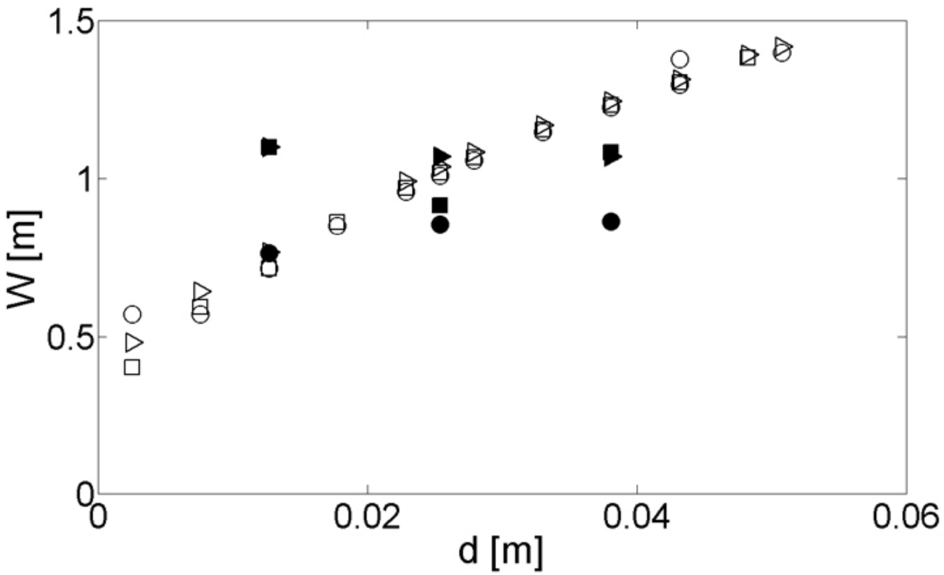
   b. Peters and Power

Peters and Power

Rock size effect

Power – KM3D





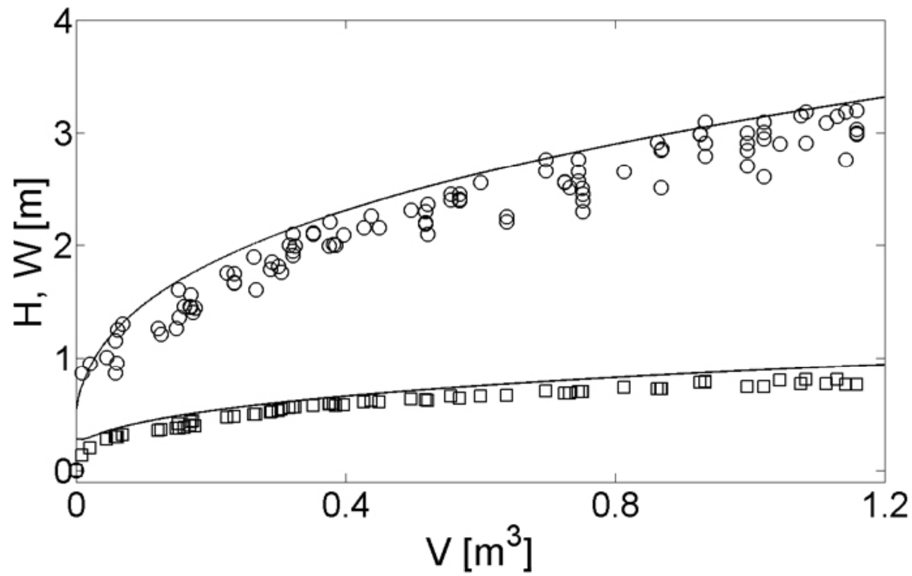
Peters - KM2D

3. Comparing model to experimental data

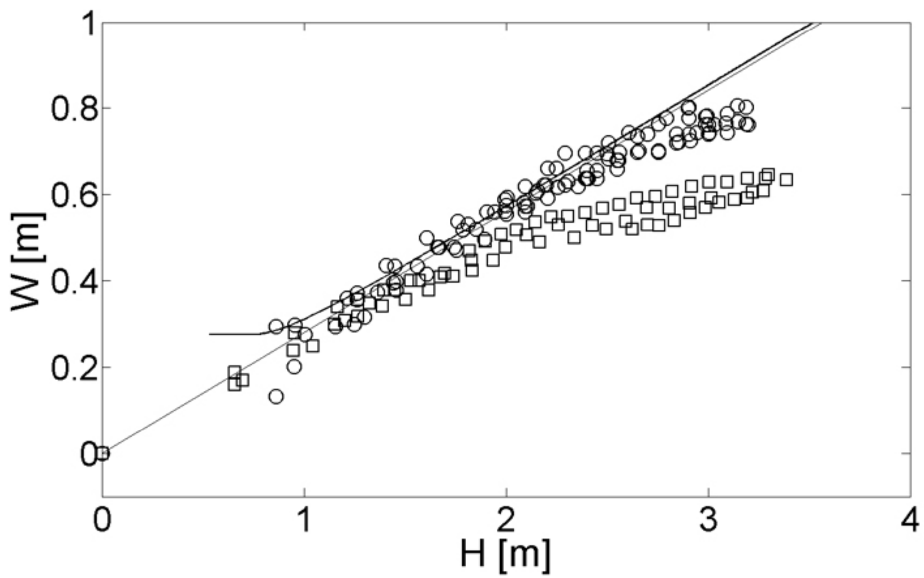
   c. R. Castro

Castro

Height and Width
of IMZ and IEZ



Plasticity 3D



Peters - KM2D

4. Conclusions

Conclusions

- Dilation allows to Kinematic model describes IMZ shape.
- According to Kinematic and Plasticity models IMZ to IEZ heights ratio depends on internal density changes.
- Peters and Power data are consistent with Kinematic model.
- Main Castro data are fairly well fitted with only one parameter, angle of repose.
- Kinematic and Plasticity models capture the overall behavior observed in experiments.
- Both models have a good chance to reproduce behavior found in mines.