Implementation of Joint Waviness/Roughness into DEM Simulations

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Presentation Outline

- **Introduction**
- **Significance of joint waviness in rock mass behaviour**
- **Joint waviness/roughness implementation algorithm**
- **Numerical simulation of the effect of joint waviness on opening stability**
- **Conclusions**

Introduction

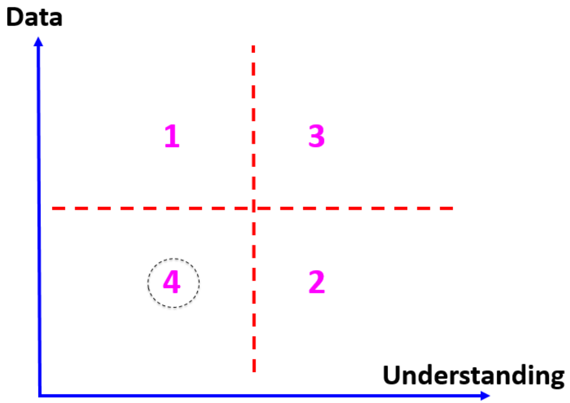
Rock mechanics problems fall into the class of " data limited " problems; one seldom knows enough about a rock mass to model it properly.

It is obvious that data limited problems require a very different analysis approach from that of other applications such as electrical or aerospace engineering. In rock engineering applications the real world is too complex for our understanding and use of numerical techniques are indispensable. Various modelling approaches have been developed and used to model the rock behavior under static and dynamic loading conditions.

Introduction

- **Rock Engineering problems**
  - **Deal with the most complicated engineering material (e.g. fractured rock at Large scales, etc.)**
  - **Has the highest design complexities:**
    - **Rock/joints non-linear behaviour**
    - **Complex loading conditions**
    - **Complicated, large, and deep structures**
    - **Always lack design data !!**

Holling's Classification of Engineering Problems

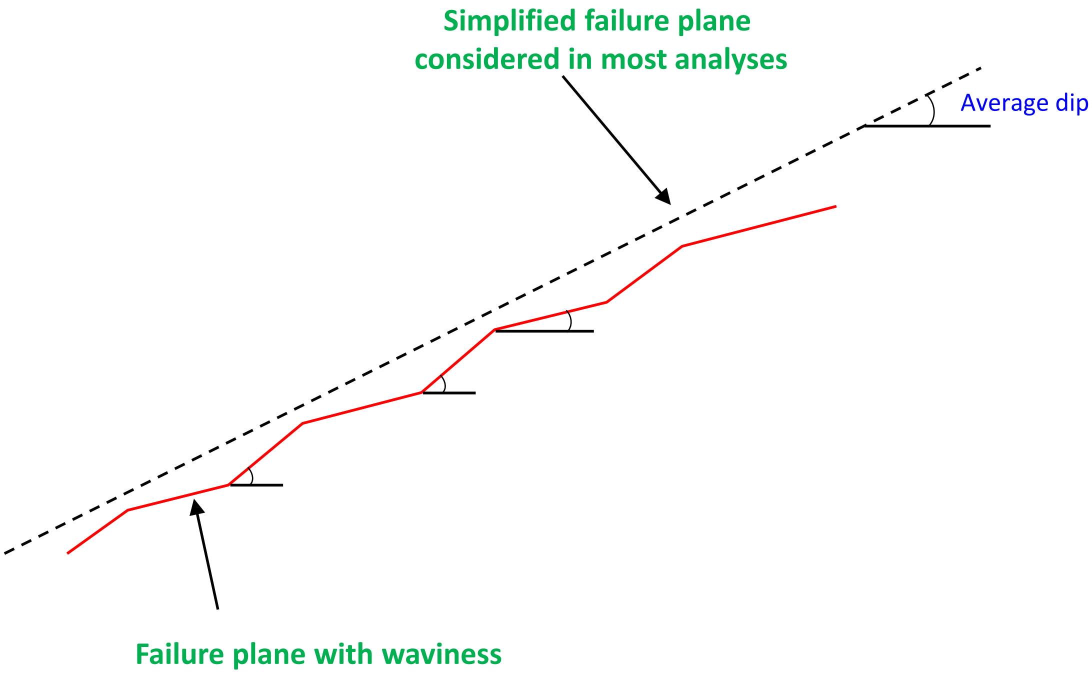


Significance of Joint Waviness in Rock Mass Behaviour

- **The nature of joint surfaces**

  - **The nature of joint surface should be considered in in relation to it waviness and roughness**
  - **Waviness and roughness differ in terms of scale and their effect on shear strength**
  - **Waviness refers to first order asperities and patches and are not likely to shear off during movement**
  - **Roughness refers to 2^{nd} order asperities which shear of upon movement**
  - **Waviness does not affect the joint frictional properties, but affect the apparent dip angle**

Significance of Joint Waviness in Rock Mass Behaviour

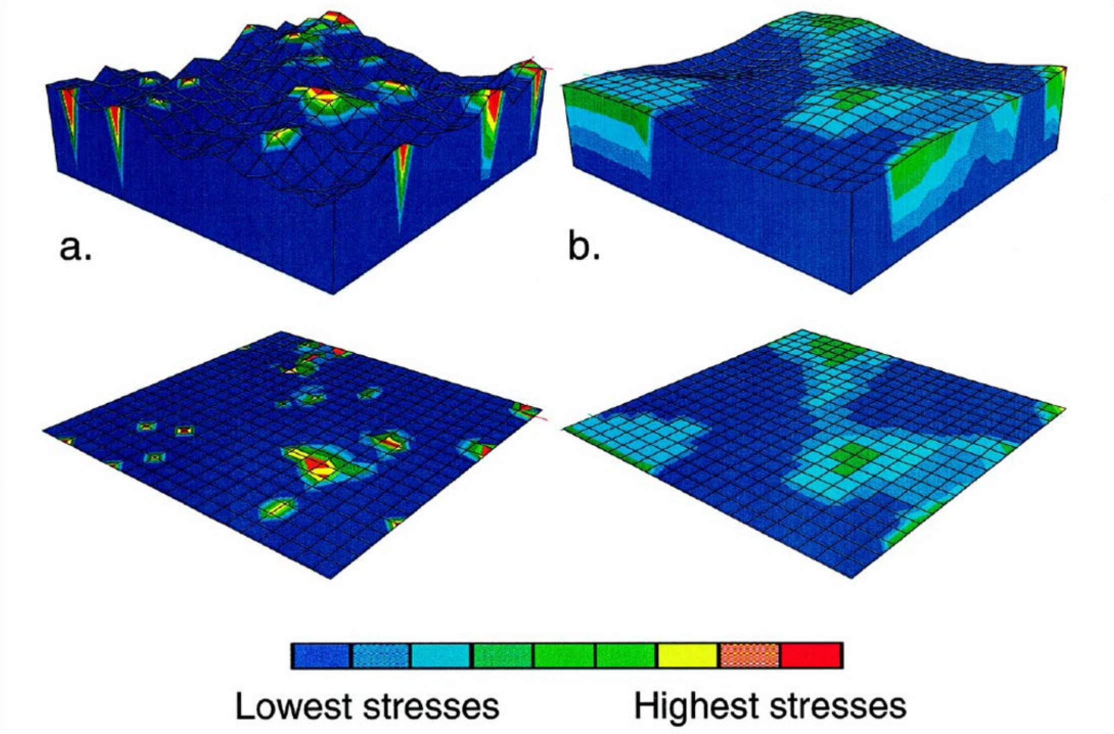


Significance of Joint Waviness in Rock Mass Behaviour

- **In the analysis of jointed rock mass behaviour, a realistic definition of block interfaces has always been a challenge**
- **In all stability analysis methods, block interfaces are assumed to be of hard contacts with no physical roughness and thickness**
- **Implementation of nonlinear joint constitutive models to describe the joint nonlinear behaviour (Bandis et al. 1983, Saeb & Amadei 1992, etc.) ??**
- **This approach is difficult to apply in practice and is not feasible computationally. Also it is very difficult to determine the required input parameters for these nonlinear joint models**
- **The behaviour of a jointed rock mass is mainly controlled by the geometry and orientation of discontinuities**

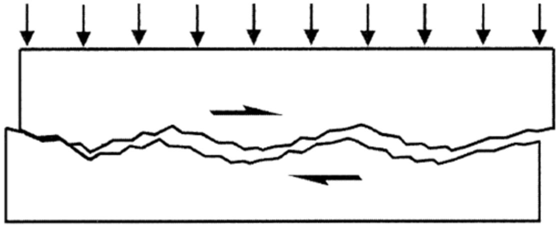
Significance of Joint Waviness in Rock Mass Behaviour

A rough joint surface A smooth joint surface

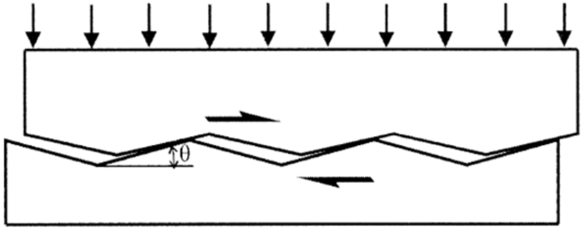


Significance of Joint Waviness in Rock Mass Behaviour

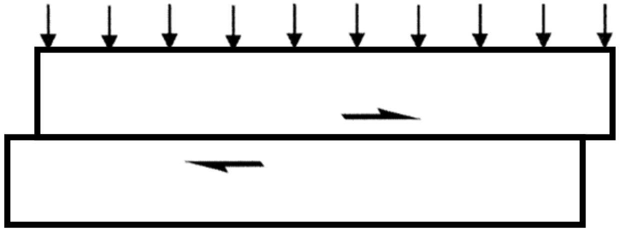
A natural joint surface
(actual field scenario)



An artificial joint surface with
regular asperities (physical modelling)



An artificial joint surface with
no asperities (numerical modelling)

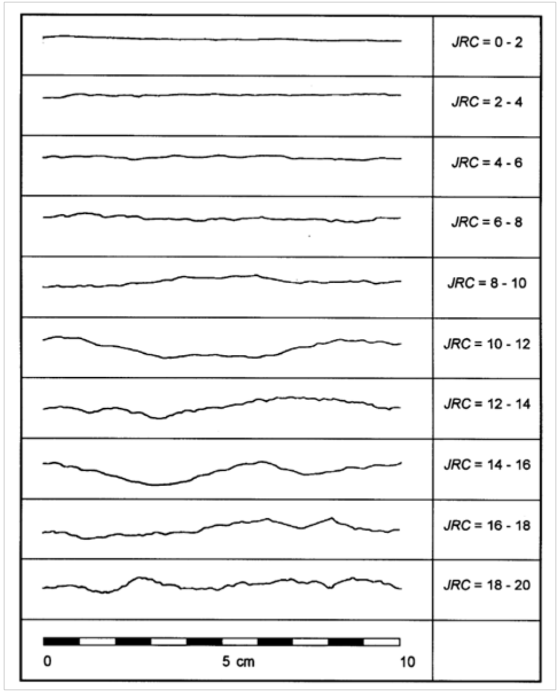


Significance of Joint Waviness in Rock Mass Behaviour

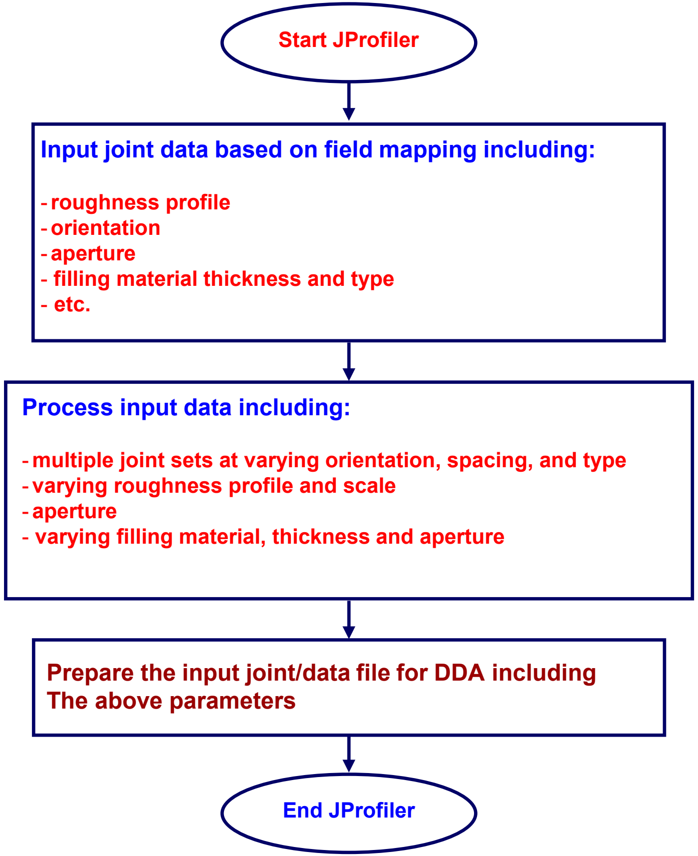
Practical Joint Constitutive Models

(Barton & Choubey, 1973)

$$\tau = \sigma_n \tan\left[JRC.\log_{10}\left(\frac{JCS}{\sigma_n}\right) + \varphi_r \right]$$



Joint Waviness/roughness Implementation Algorithm



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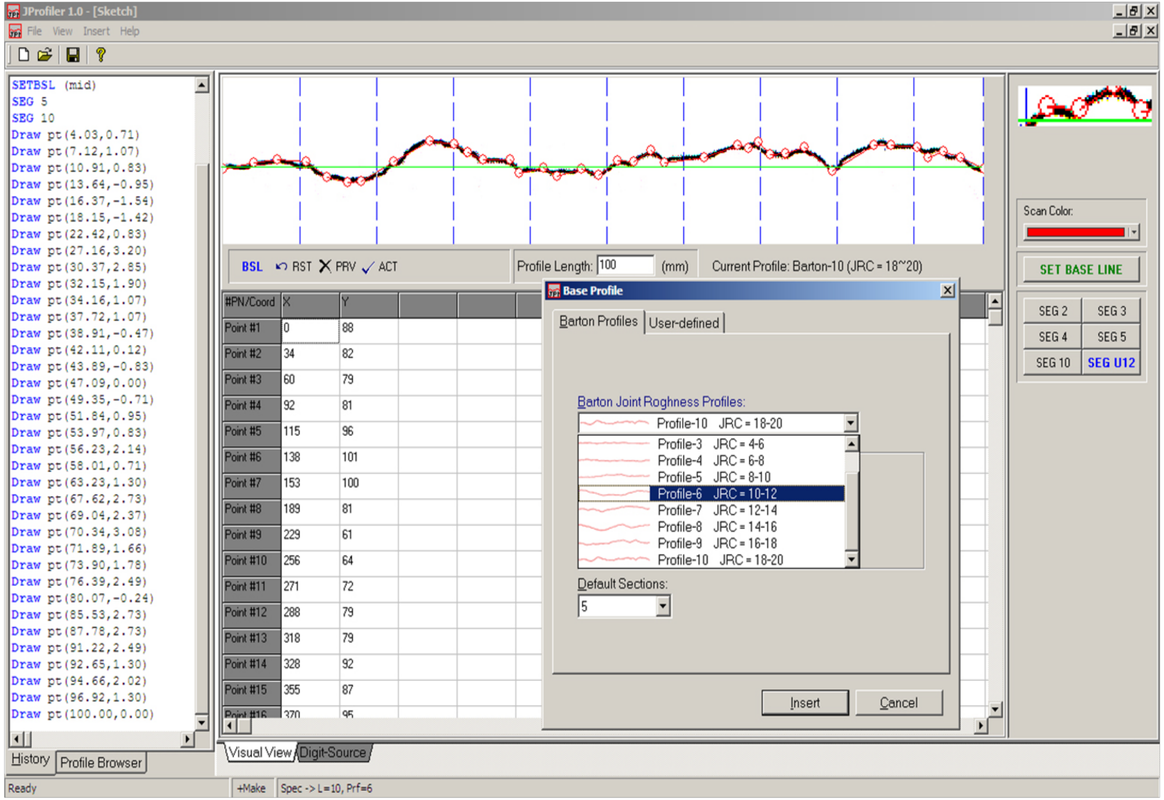
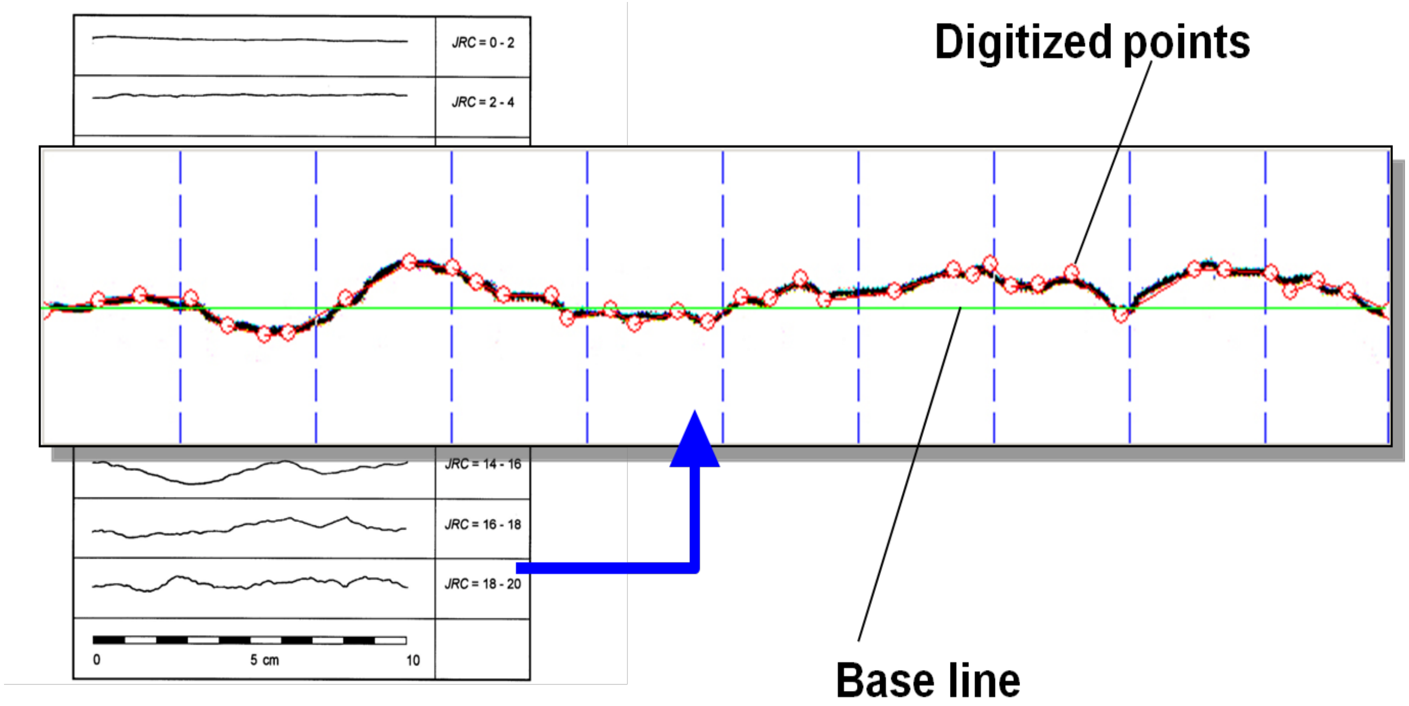
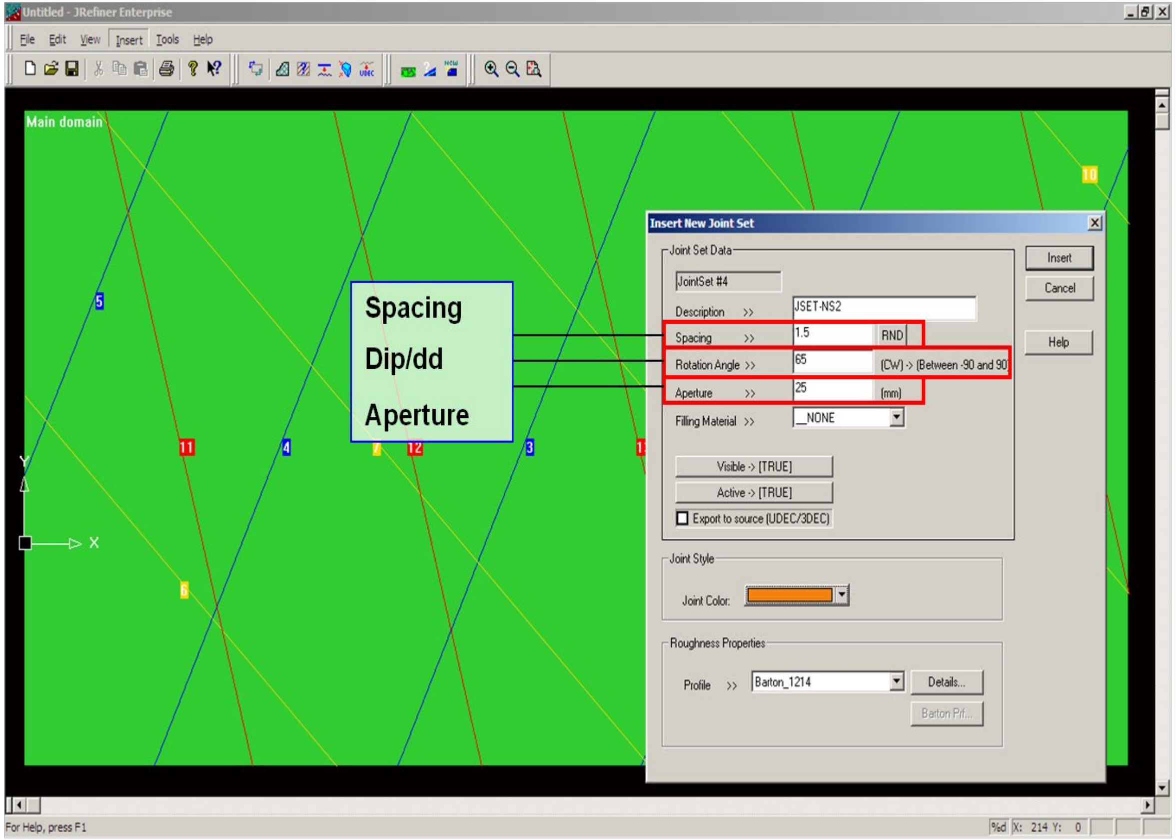


Joint Waviness/roughness Implementation Algorithm

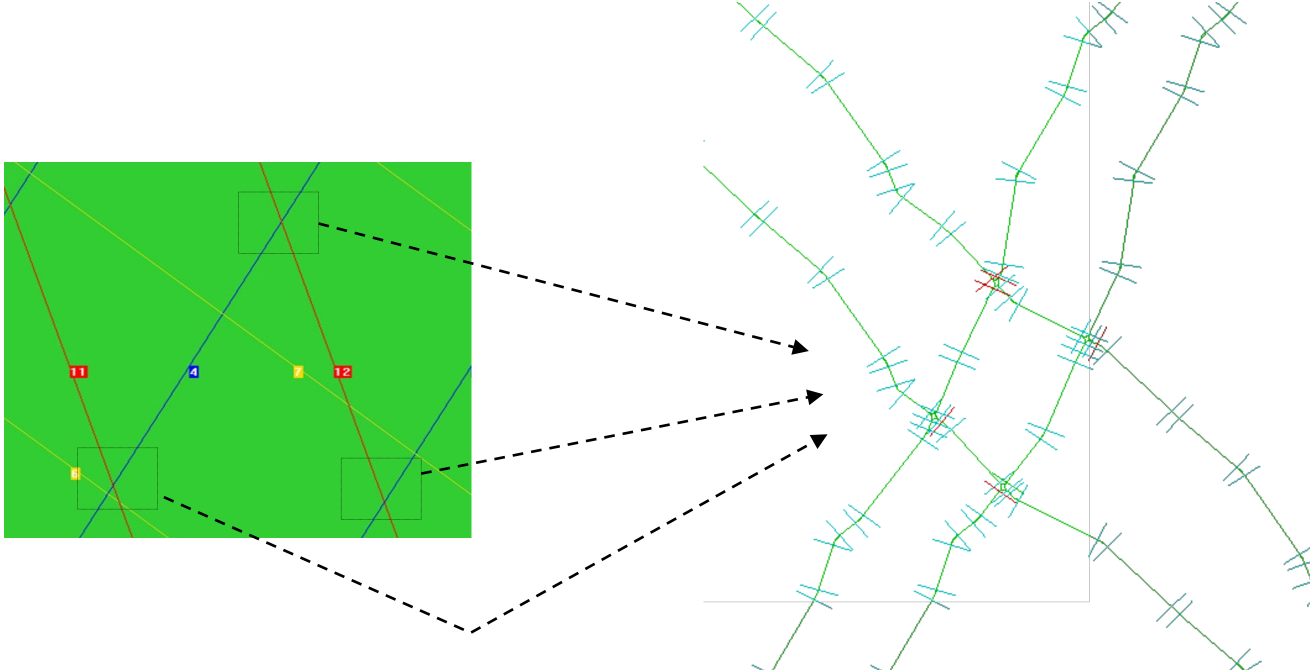


Joint Waviness/roughness Implementation Algorithm



Joint Waviness/roughness Implementation Algorithm

Non-linear joint geometry implemented into a blocky mesh



Discontinuous Deformation Analysis (DDA)

- **Introduced by Shi (1988)**
- **Is an implicit method in which displacements are the unknowns**
- **Mechanical interactions between blocks are simulated by springs or penalties**
- **System of equations are obtained by minimizing the total potential energy of the system**
- **Performs both dynamic and static analysis**

Discontinuous Deformation Analysis (DDA)

- **Equilibrium Equations in DDA**

$$\begin{bmatrix} K_{11} & K_{12} & K_{13} & \cdots & K_{1n} \\ K_{21} & K_{22} & K_{31} & \cdots & K_{2n} \\ K_{31} & K_{32} & K_{33} & \cdots & K_{3n} \\ \vdots & \vdots & \vdots & \ddots & \\ K_{n1} & K_{n2} & K_{n3} & \cdots & K_{nn} \end{bmatrix} \cdot \begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ \vdots \\ D_n \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ \vdots \\ F_n \end{bmatrix}$$

Numerical Simulation of Joint Waviness Effect on Opening Stability

- **A simple geometry cavern was considered in a jointed rock mass**

- **A horse shoe shape cavern of 7 m in span and 8.5 m in height was considered within the modelling domain**

- **The rock mass consisted of two joint sets. The first set was dipping at 60 degree with a spacing of 0.8 m and the second set was horizontal with and average spacing of 3 m. An 11 m rock cover was assumed above the opening**

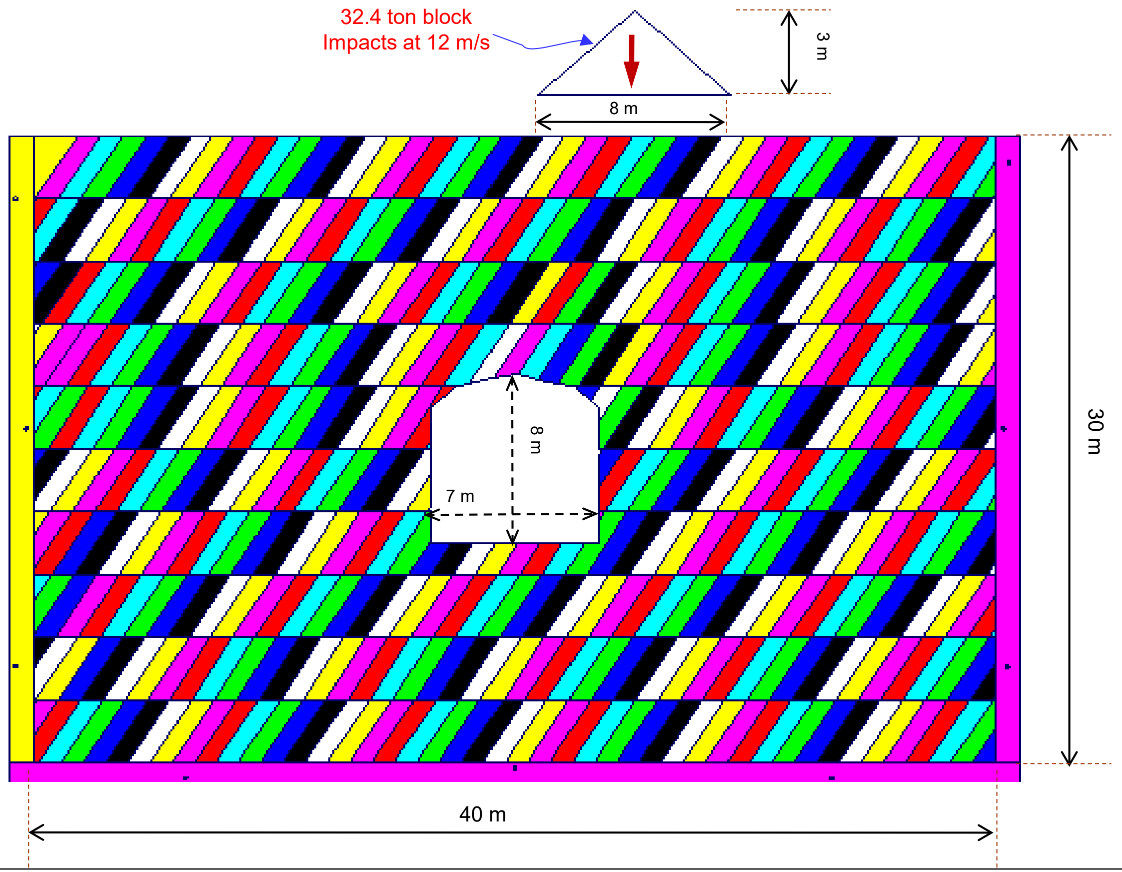
- **Two series of runs were carried out to evaluate the effect of joint roughness**

Numerical Simulation of Joint Waviness Effect on Opening Stability

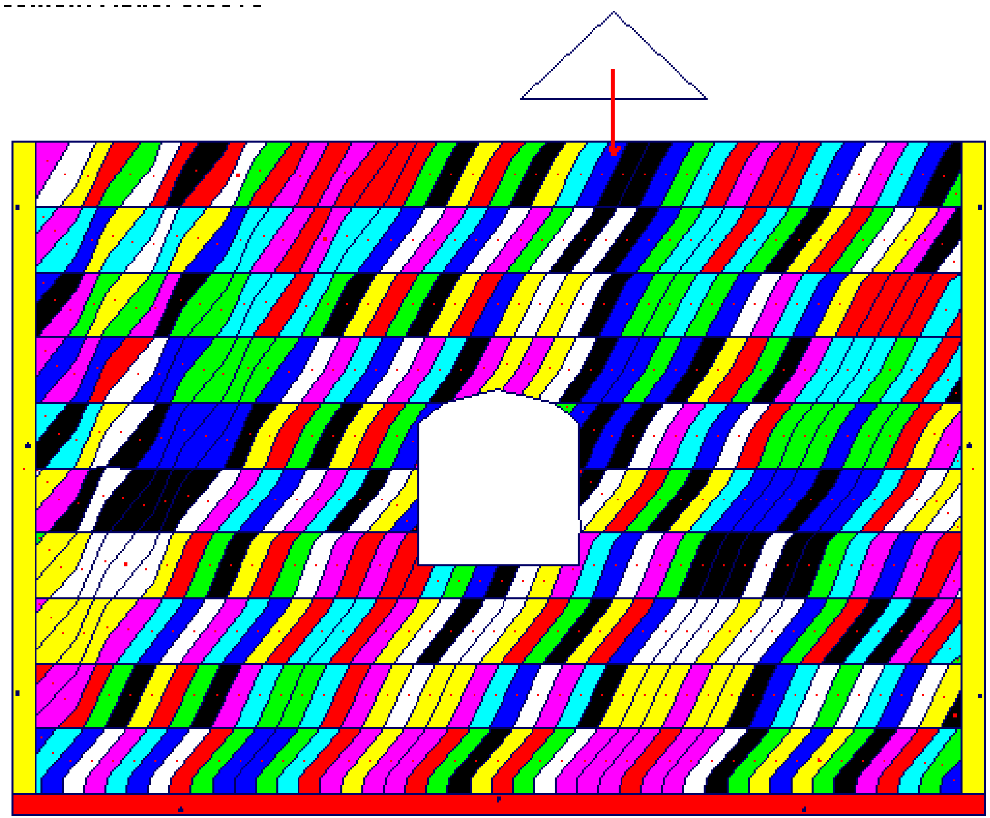
Rock Mass Data

Density (kg/m3)	2700
Modulus of Elasticity (GPa)	50
Poisson's Ratio	0.25
Joint Cohesion (MPa)	0.0
Joint tensile strength (MPa)	0.0
Joint Friction angle (degree)	30

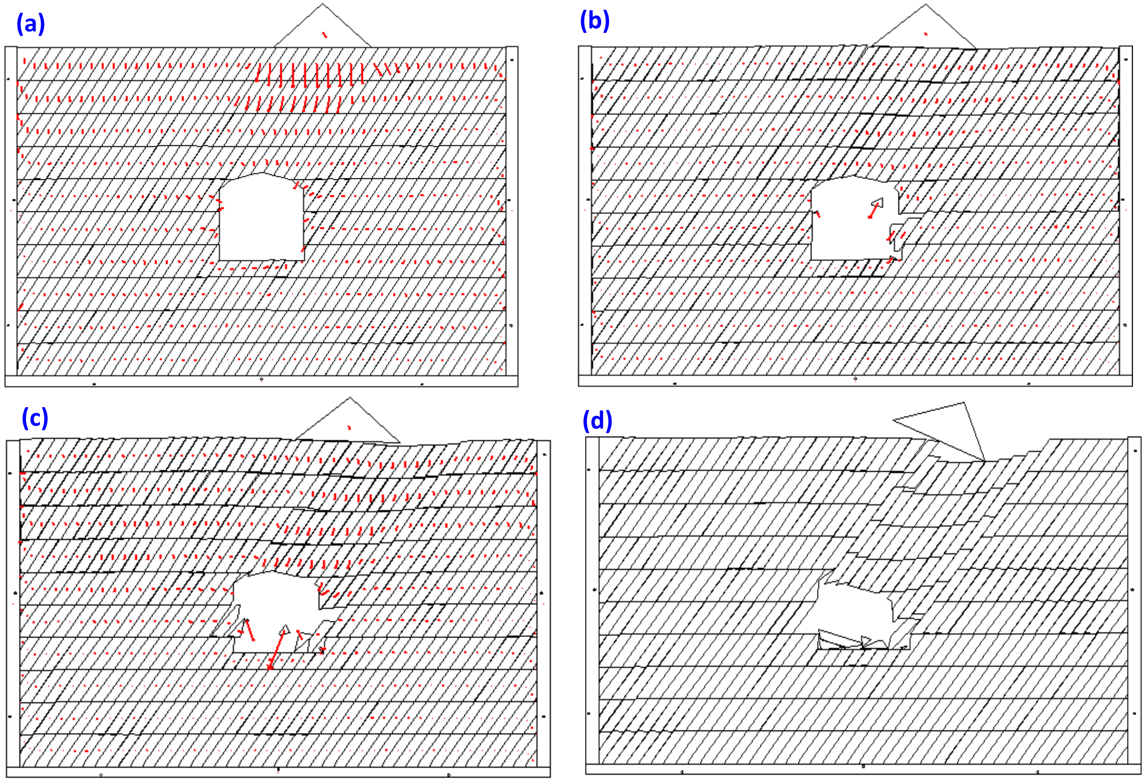
Model I: A blocky DDA Mesh – Planar Joint Geometry



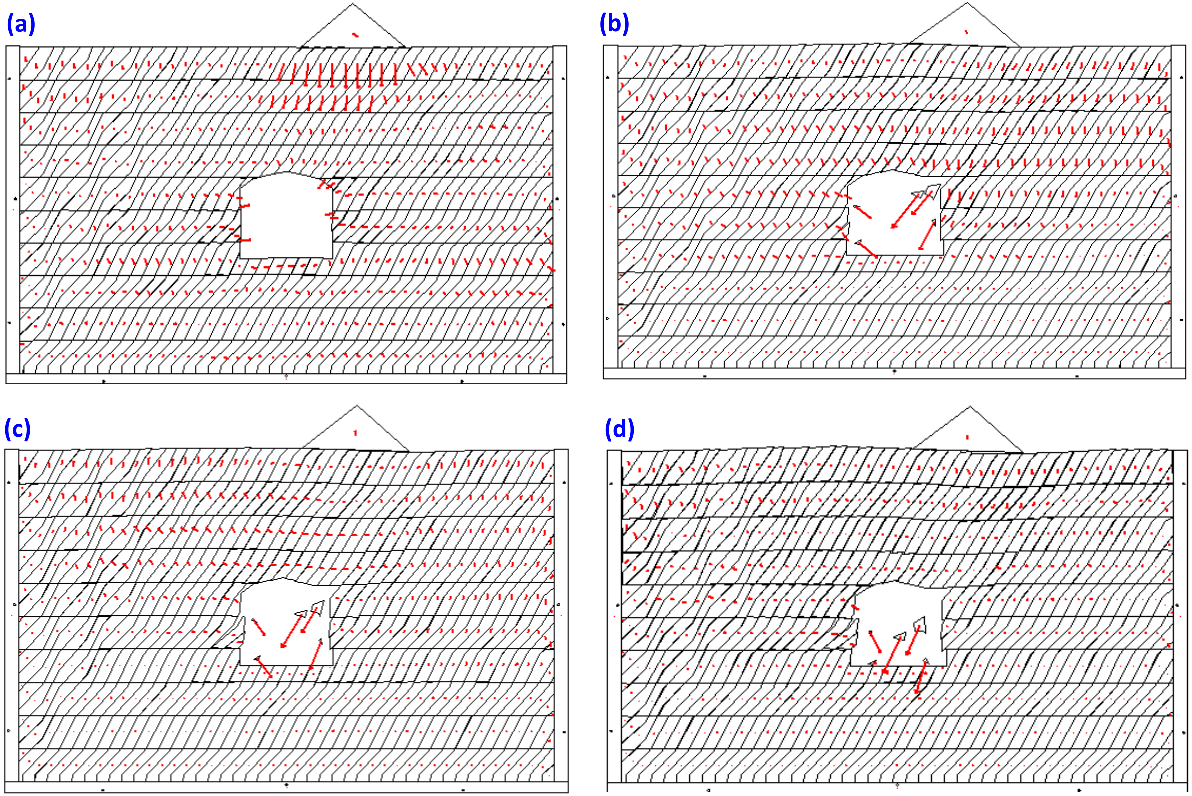
Model II: A blocky DDA Mesh – Wavy Joint Geometry



Model I: Simulation Results – Planar Joint Geometry

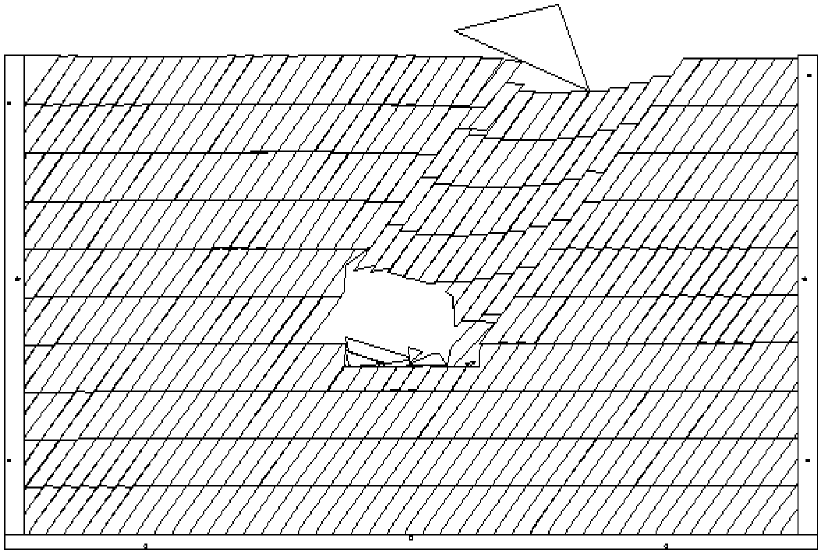


Model II: Simulation Results – Wavy Joint Geometry

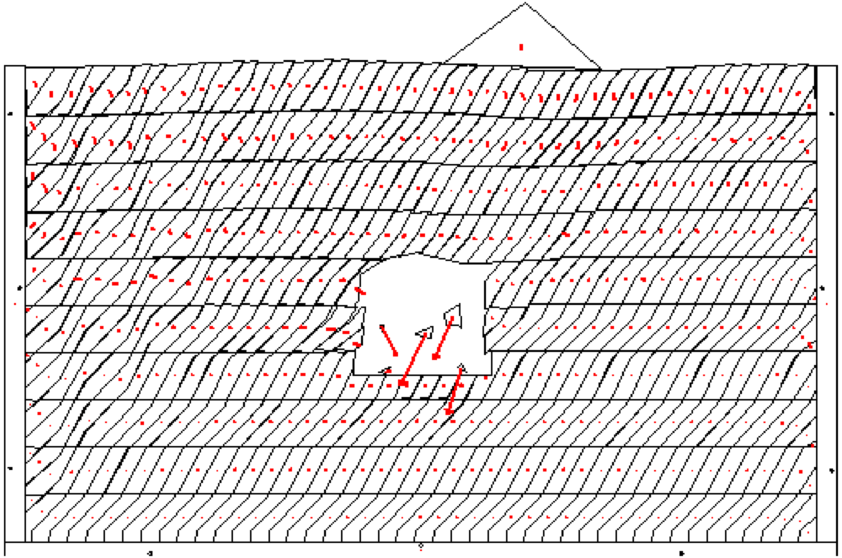


Models I & II Simulation Results

Planar Joint Geometry



Wavy Joint Geometry



Summary & Conclusions

- **An useful algorithm was developed to incorporate the effect of waviness/roughness into modelling in a physically meaningful manner and allow for simulation of geometric aspects of joint non-linearity in discontinuum analysis**

- **The analysis results show that the consideration of a small waviness (at a macro scale) or roughness (in a micro scale) for discontinuities significantly affects the discontinuum modelling results**

- **When considering a wavy/rough discontinuity surface the rock mass behaves in a much stiffer manner and maintains its integrity even under intense dynamic loadings**

- **It should be realized that even sophisticated modelling tools (DDA, DEM, etc.) can produce erroneous and unrealistic results without considering the physical and geometric aspects of discontinuities**