Synthetic Rock Mass modeling for determination of geomechanical properties reservoir rock masses

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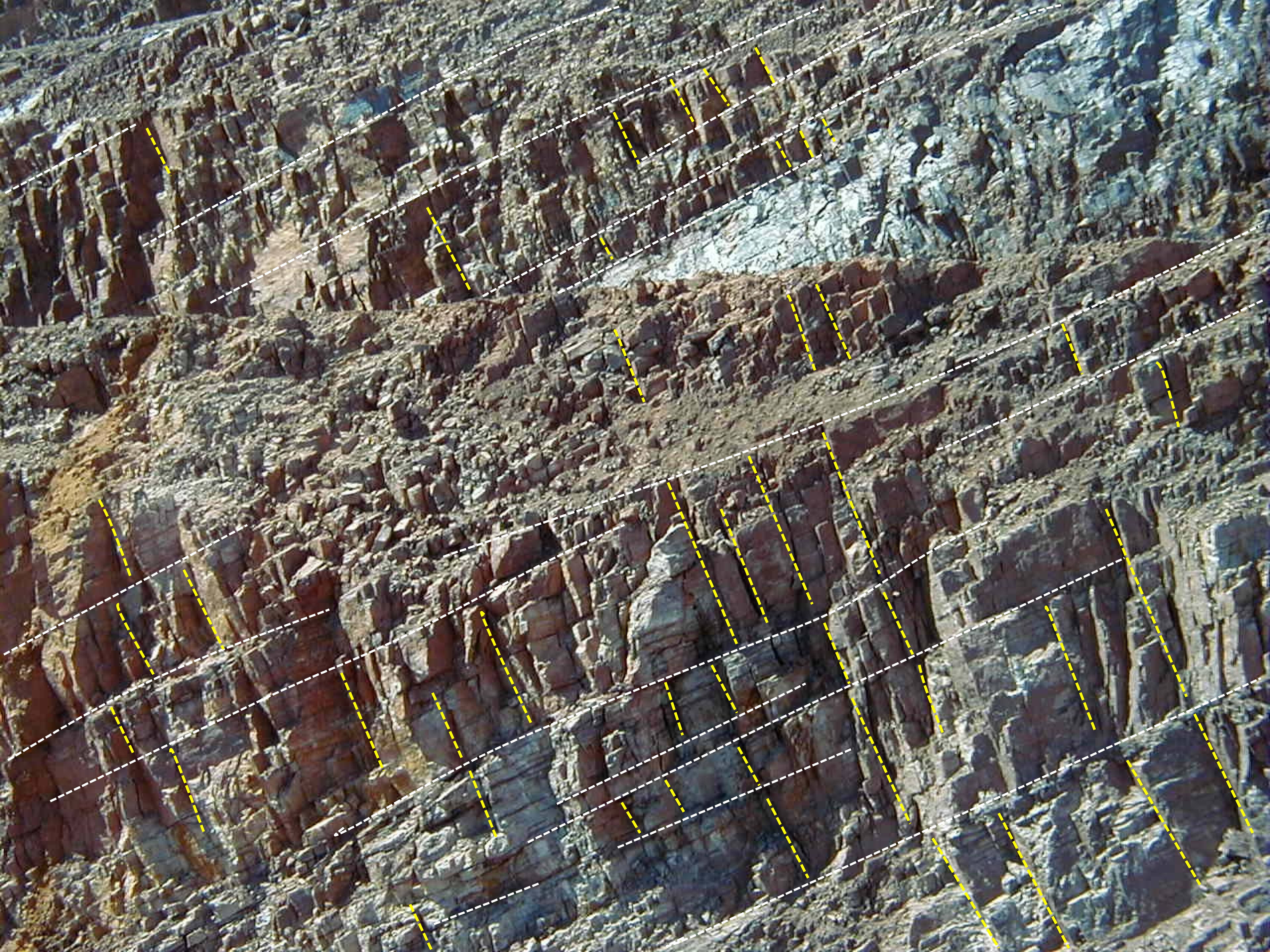
Outline:

- Rock *mass* heterogeneity and scale effects

- DEM/Synthetic Rock Mass modeling approach

- Example – Effect on reservoir compaction

- Discussion of on-going work



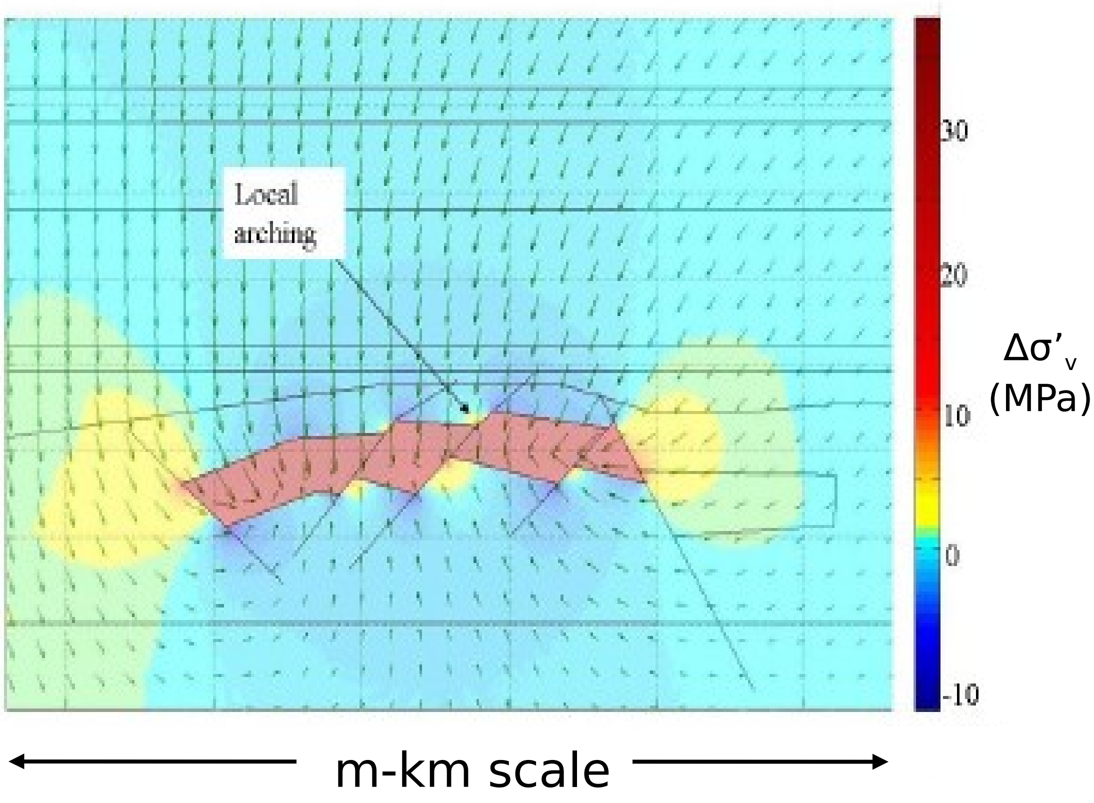
Rock mass heterogeneity

Image: Helge Langeland/Statoil Archive

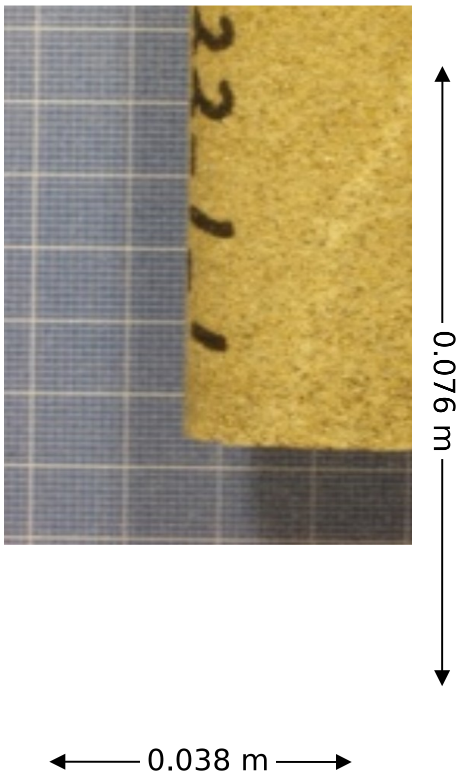
Rock mass heterogeneity

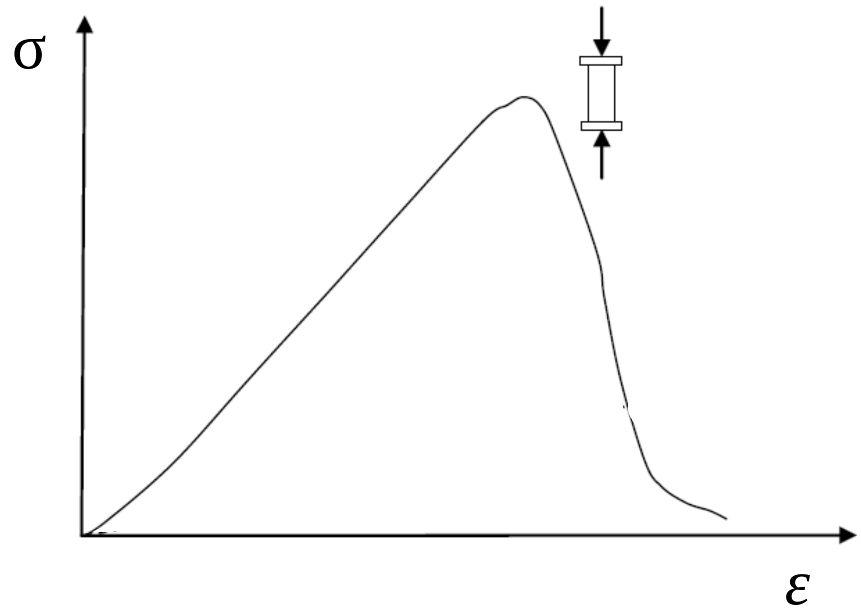
-*MDEM* simulation of stress changes due to depletion at the Elgin-Franklin reservoir (North Sea, UK sector)

- Alassi et al. (2010)



Rock mass heterogeneity

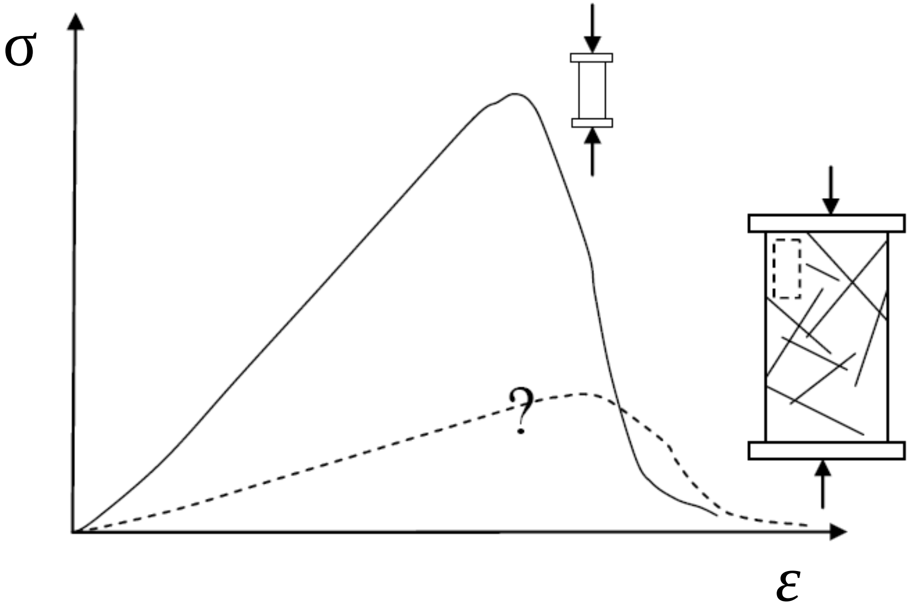




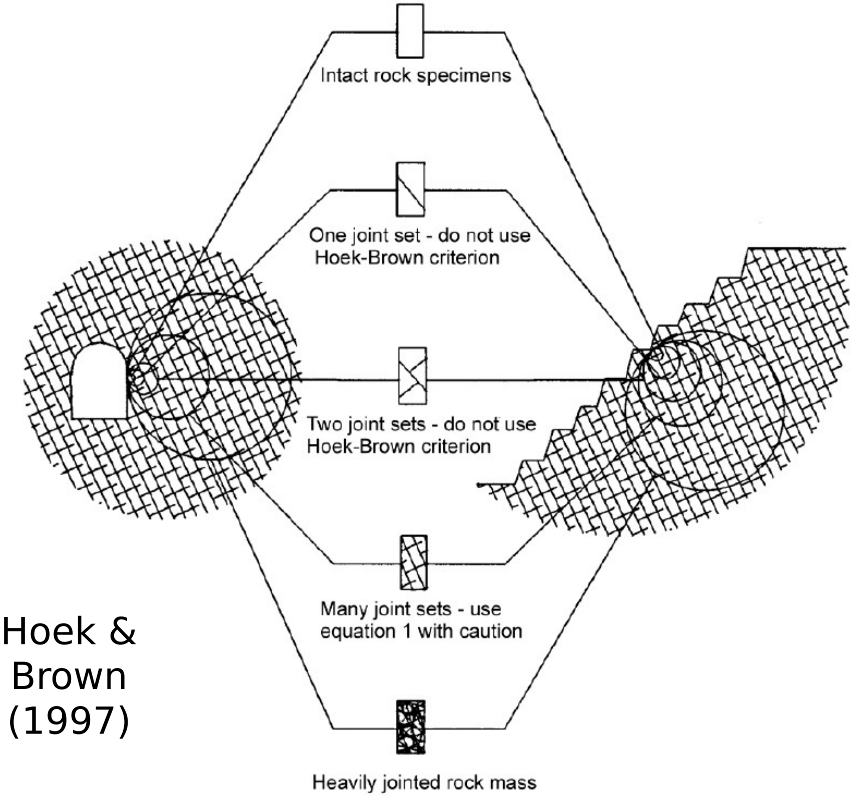
Rock mass heterogeneity – scale effects

Intact laboratory sample

Reservoir rock *mass*



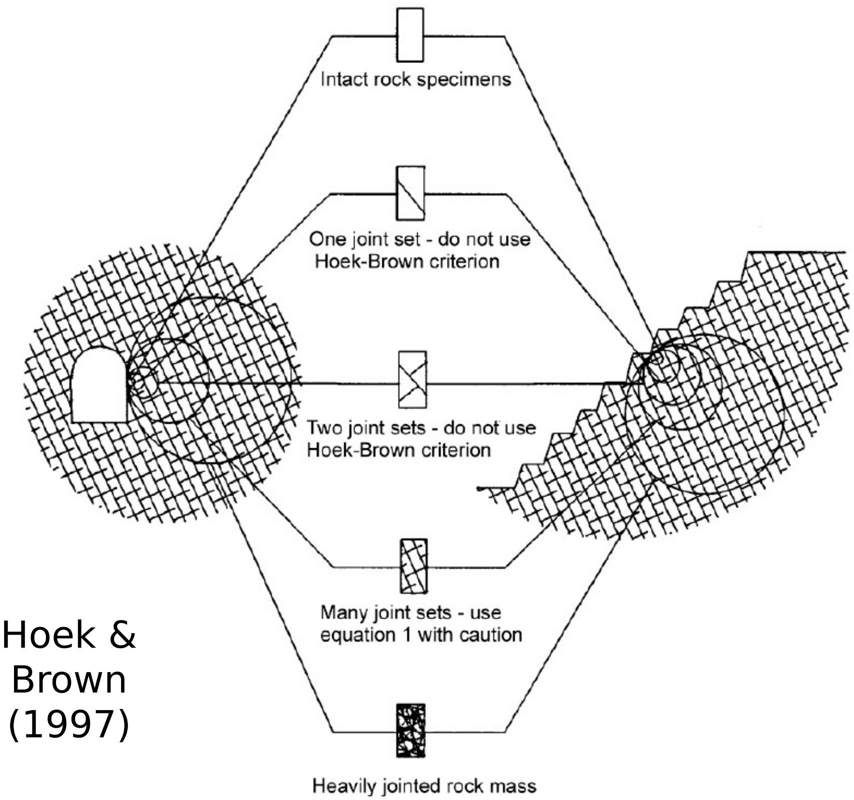
Rock mass heterogeneity – scale effects



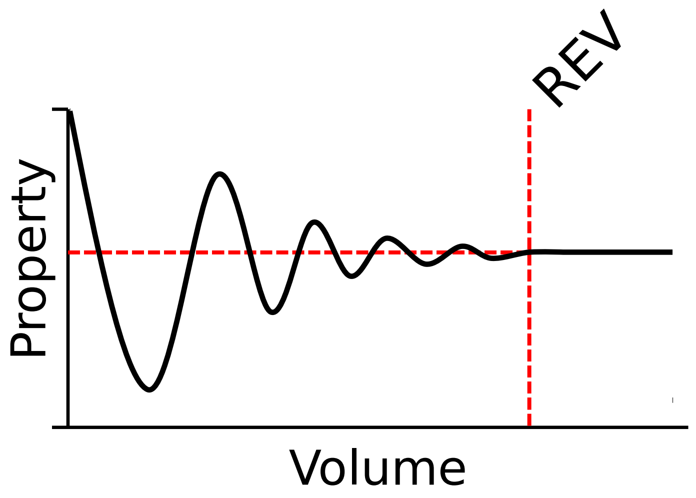
Hoek & Brown (1997)

Decreasing strength/stiffness

Rock mass heterogeneity – scale effects



Hoek & Brown (1997)



REV – Representative Elementary Volume

Rock mass heterogeneity – scale effects

- Discontinuities are commonly present in rock units

- Discontinuities have significant effects on the geomechanical parameters of the rock mass

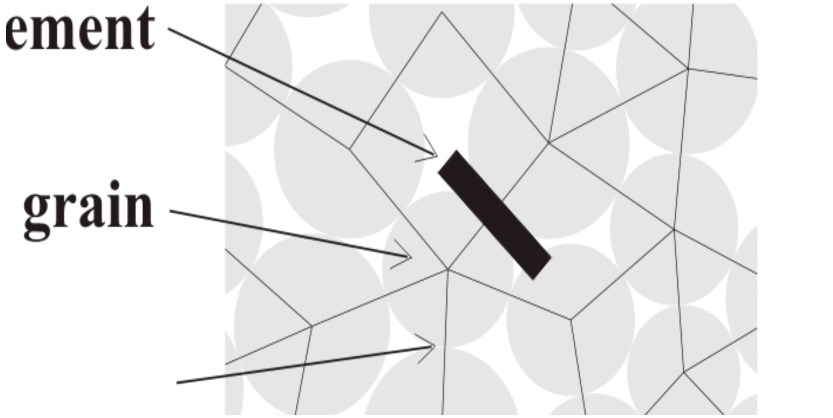
- Rock mass might be treated as a equivalent continuum at the REV

- These effects should be accounted for in

Discrete element modeling (DEM) and the Synthetic Rock Mass approach

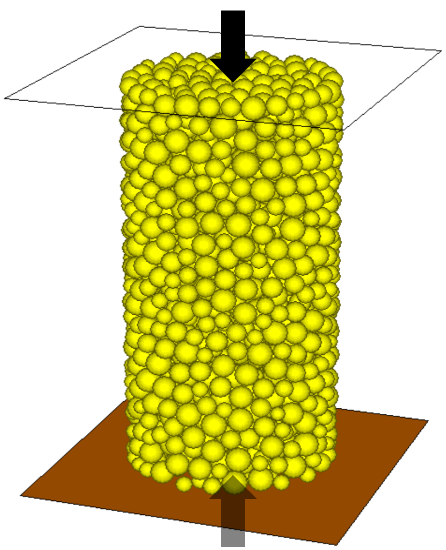
- Numerical tool for analysis of geomaterials and particulate systems

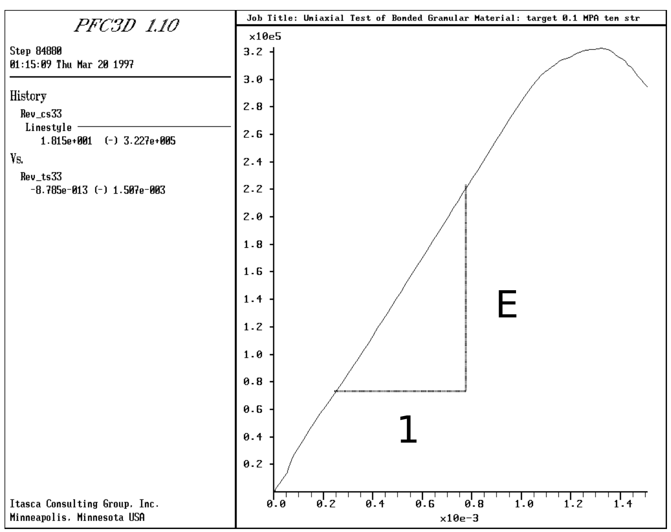
- Bonded particle assemblies simulate the geomechanical behavior of rock



Discrete element modeling (DEM) and the Synthetic Rock Mass approach

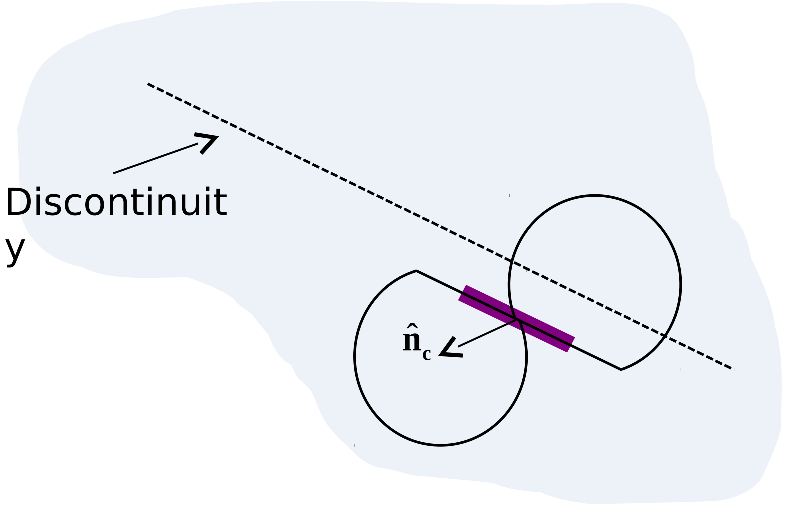
- Microproperties of bonds calibrated so that the macroresponse of the particle assembly matches that of the material in question

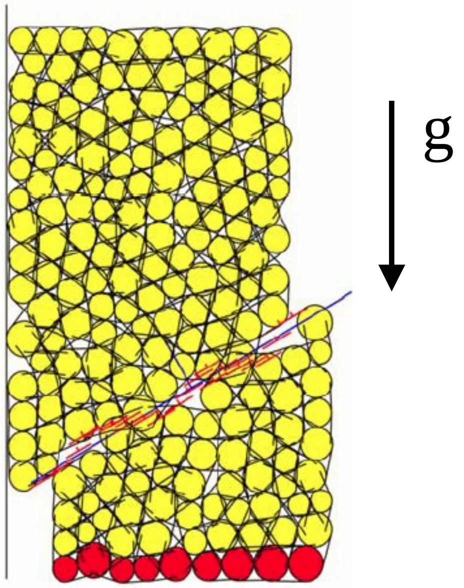




Discrete element modeling (DEM) and the Synthetic Rock Mass approach

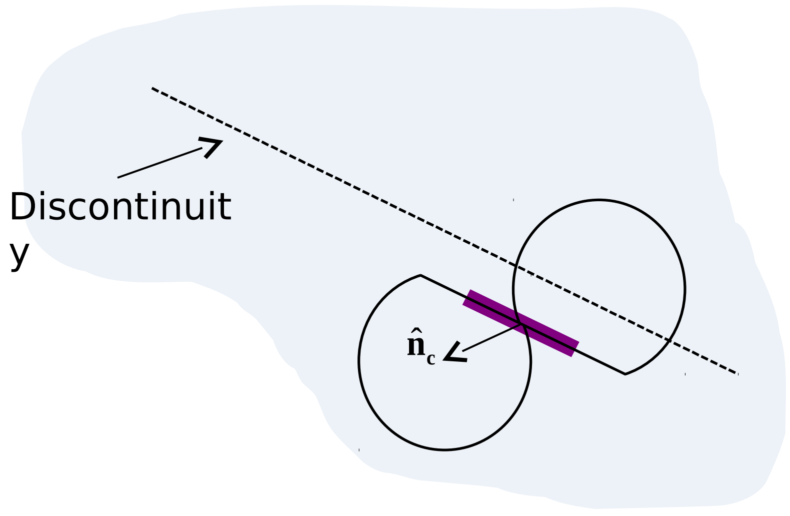
- Smooth Joint contact model - Representation of rock mass discontinuities (smooth interface)

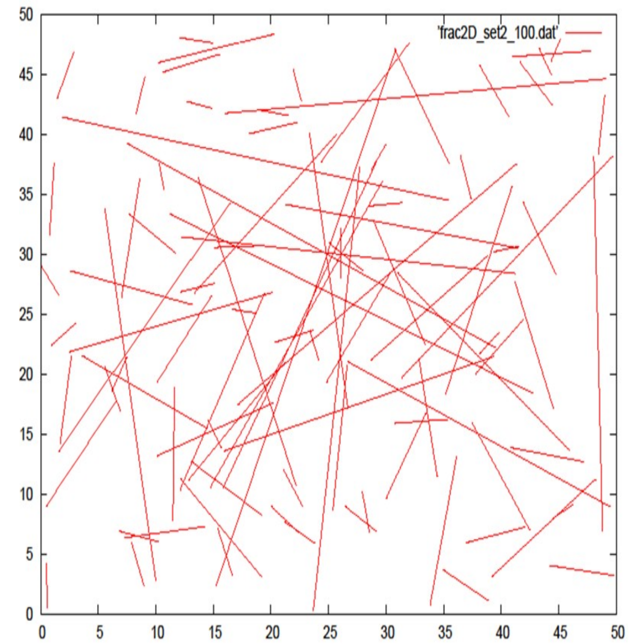




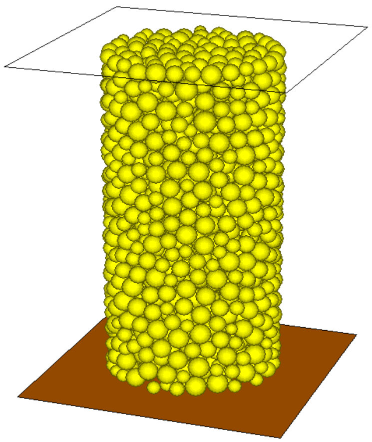
Discrete element modeling (DEM) and the Synthetic Rock Mass approach

- Discrete fracture network (DFN)



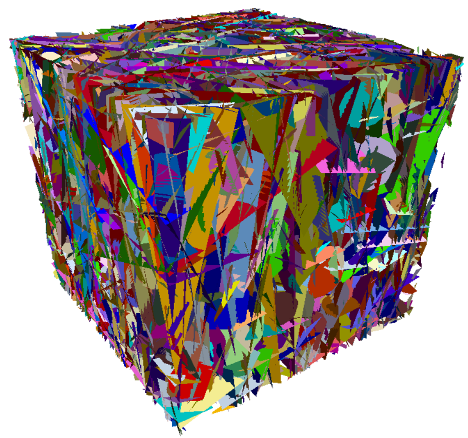


Discrete element modeling (DEM) and the Synthetic Rock Mass approach



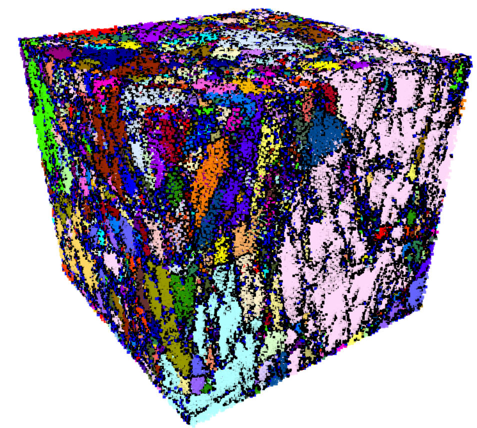
Intact rock representation

+



DFN

=



SRM

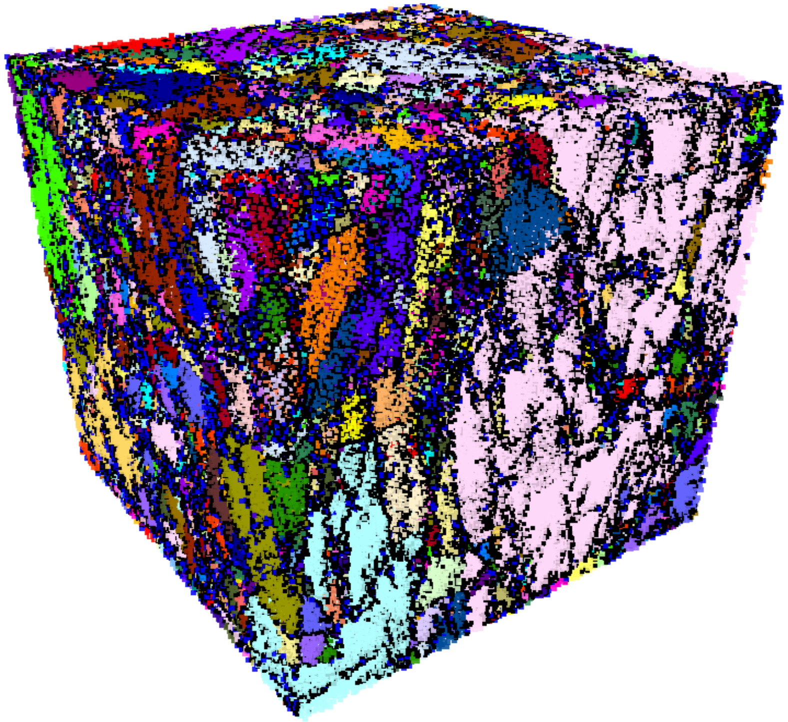
Discrete element modeling (DEM) and the Synthetic Rock Mass approach

- Run pseudo-laboratory tests

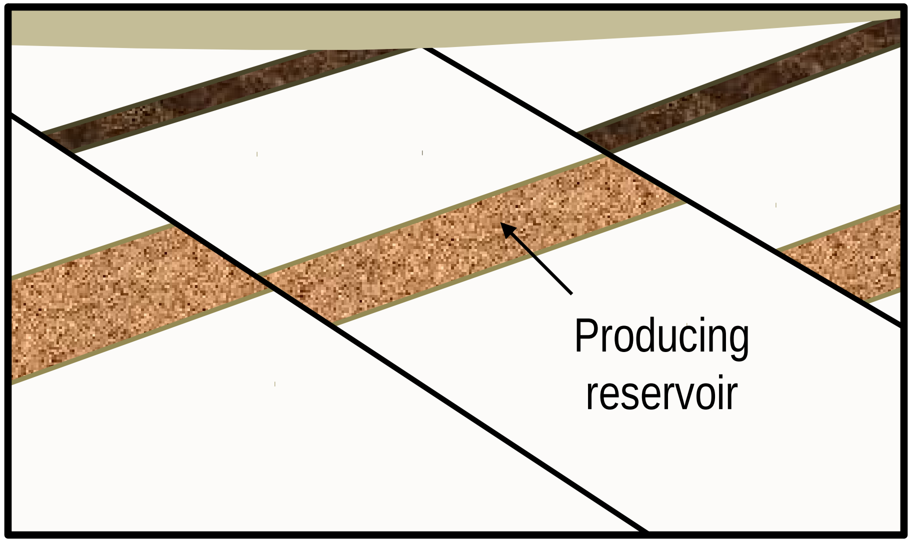
- Determine REV of rock mass in question

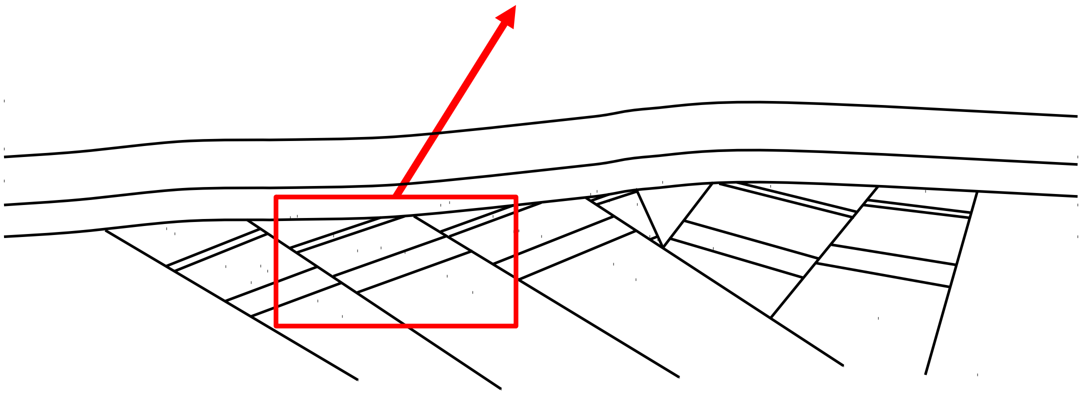
- Determine geo-mechanical parameters

- Observe changes in post-peak behavior



Example – Effect on reservoir compaction



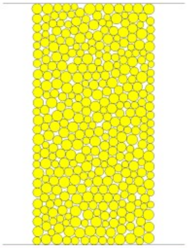


Arbitrary reservoir, 2.5 km depth

Example – Effect on reservoir compaction

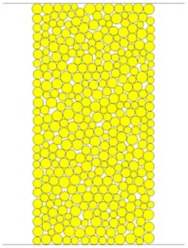
	Laboratory
Size (m)	0.038 × 0.076
Particles	--
Particle radii (m)	--
UCS (MPa)	14.7
E (GPa)	4.2
ν	0.28
φ	35°

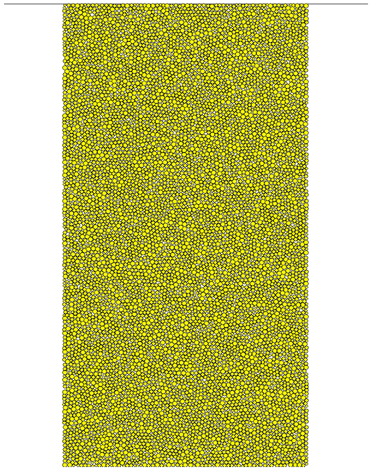
Example – Effect on reservoir compaction



	Laboratory	PFC^{2D} calibration
Size (m)	0.038 × 0.076	0.1 × 0.2
Particles	--	367
Particle radii (m)	--	3e-3 – 4.98e-3
UCS (MPa)	14.7	14.7
E (GPa)	4.2	4.2
ν	0.28	0.28
φ	35°	27.4°

Example – Effect on reservoir compaction



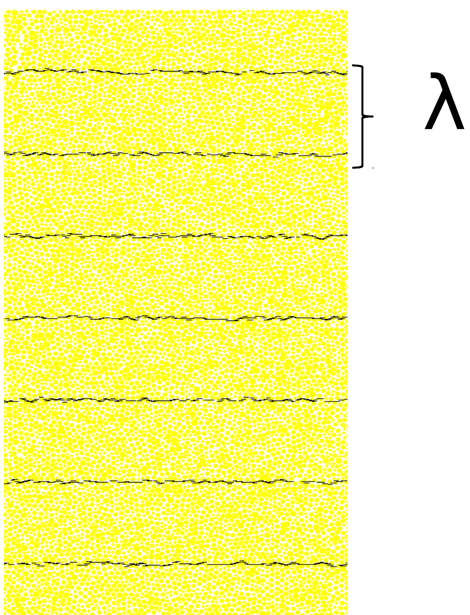


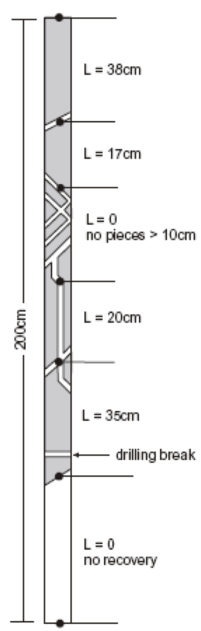
	Laboratory	PFC^{2D} calibration	Large-scale
Size (m)	0.038 × 0.076	0.1 × 0.2	0.5 × 1
Particles	--	367	9197
Particle radii (m)	--	3e-3 – 4.98e-3	3e-3 – 4.98e-3
UCS (MPa)	14.7	14.7	17.7
E (GPa)	4.2	4.2	4.4
ν	0.28	0.28	0.28
φ	35°	27.4°	24°

Example – Effect on reservoir compaction

Example – Effect on reservoir compaction

- Vertical spacing – λ





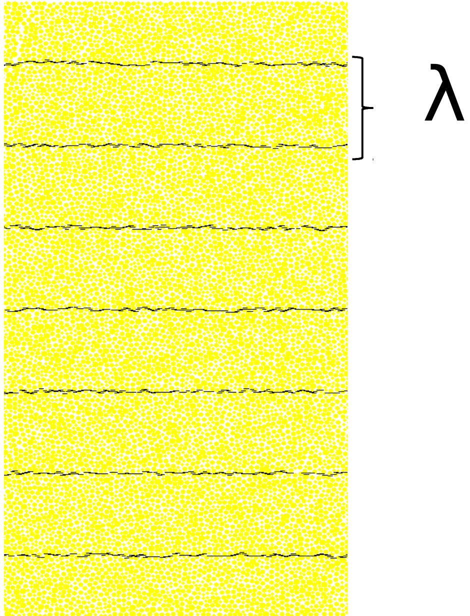
Palmstrom (2005)

$$\text{RQD} = \frac{\Sigma \text{ length of core pieces} > 10 \text{ cm}}{\text{Total length of core}}$$

Example – Effect on reservoir compaction

- Vertical spacing – λ

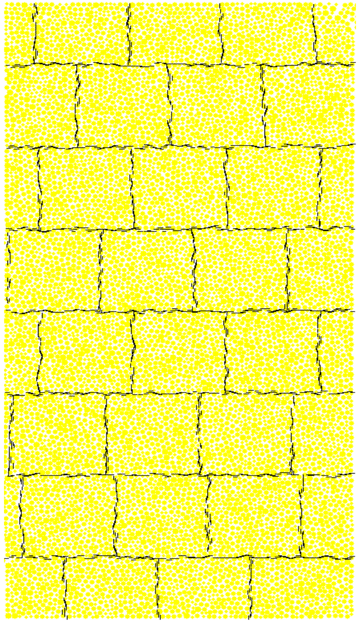
$$RQD = 100e^{-0.1\lambda}(0.1\lambda + 1)$$ Priest and Hudson (1975)



RQD Range (%)	Qualitative description	Selected RQD	Equivalent spacing (m)
0-25	Very poor	12.5	0.028
25-50	Poor	37.5	0.047
50-75	Fair	62.5	0.077
75-90	Good	82.5	0.133
90-100	Excellent	95	0.282

Example – Effect on reservoir compaction

- Horizontal spacing
  Fracture Spacing Index (FSI) Narr and Suppe (1991)

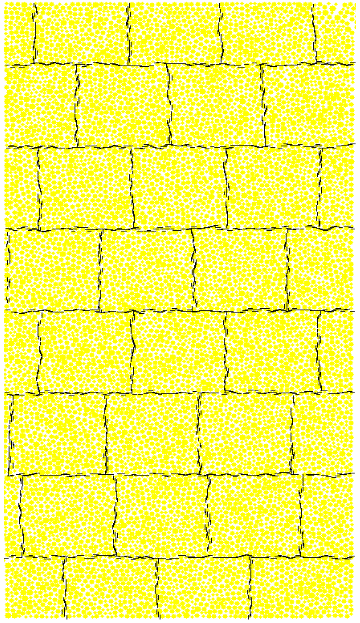


- FSI = 1.3 (Range 0.5-1.5)

- FSI = 0.5, 1, 1.5 to create DFNs

Example – Effect on reservoir compaction

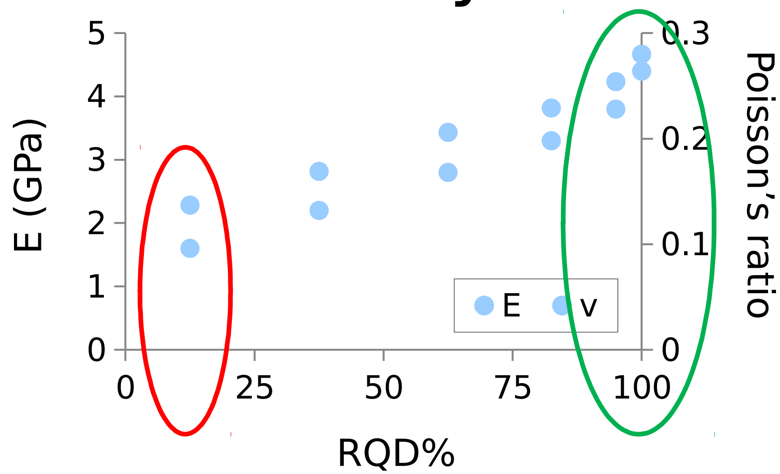
- Horizontal spacing
  Fracture Spacing Index (FSI) Narr and Suppe (1991)

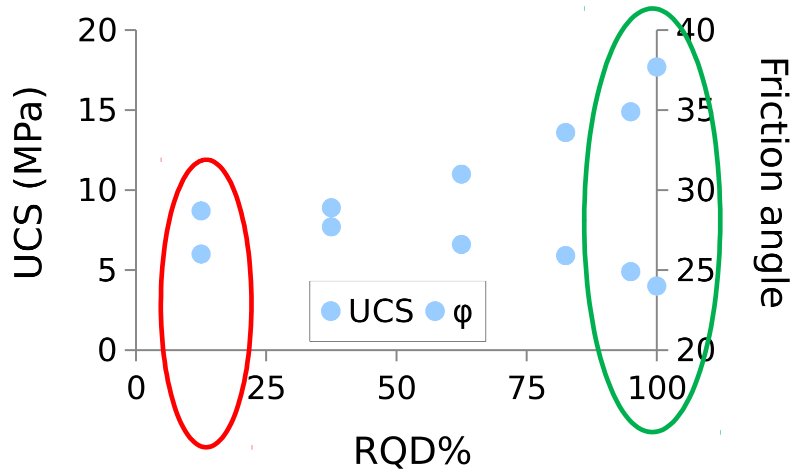


- Discontinuity properties:
  - k_N = 100 GPa/m
  - k_S = 50 GPa/m
  - μ = 0.6
  - cohesion = dilation = 0

Example – Effect on reservoir compaction

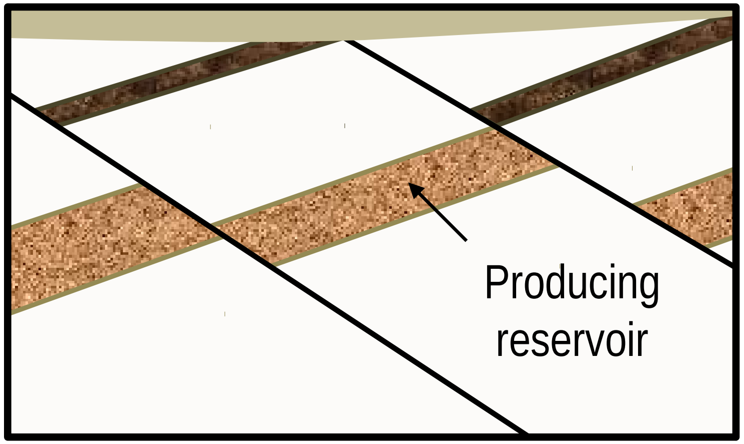
- Laboratory results (FSI = 1):

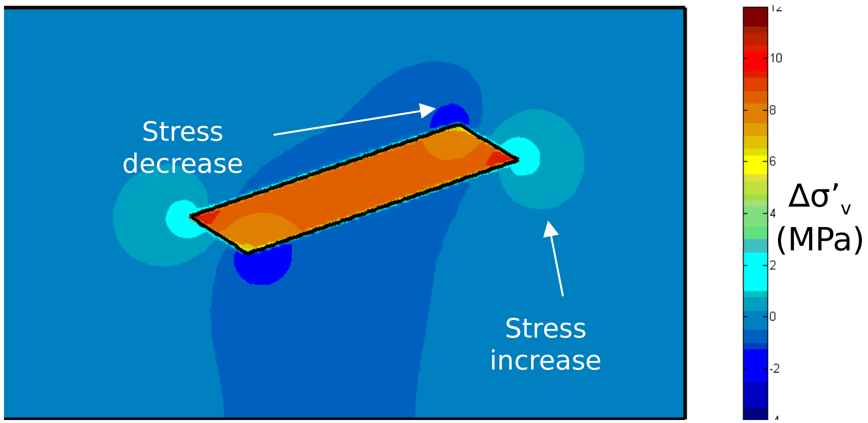




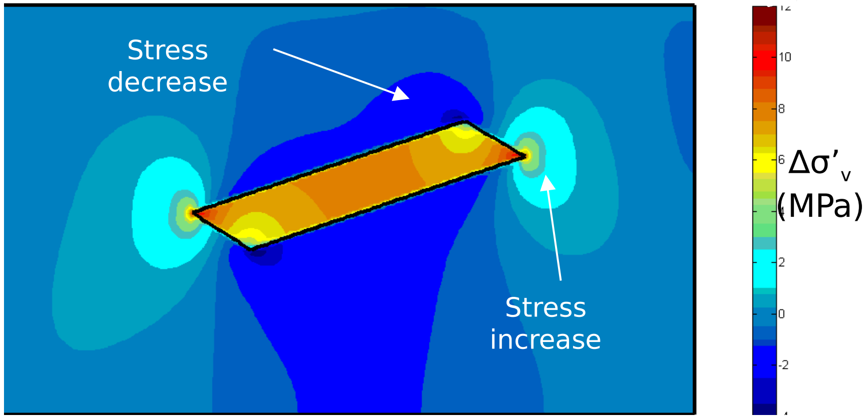
- Decreasing strength/stiffness with decreasing rock mass quality
- Best case (RQD = 100%)
- Worst case (RQD = 12.5%)

Example – Effect on reservoir compaction





Best case (RQD = 100%)



Worst case (RQD = 12.5%, FSI = 1.0)

- *MDEM*,10 MPa depletion

- Stress arching

Example – Effect on reservoir compaction

- Limitations to example presented:

    - 2D

    - REV not considered

    - Discontinuity properties

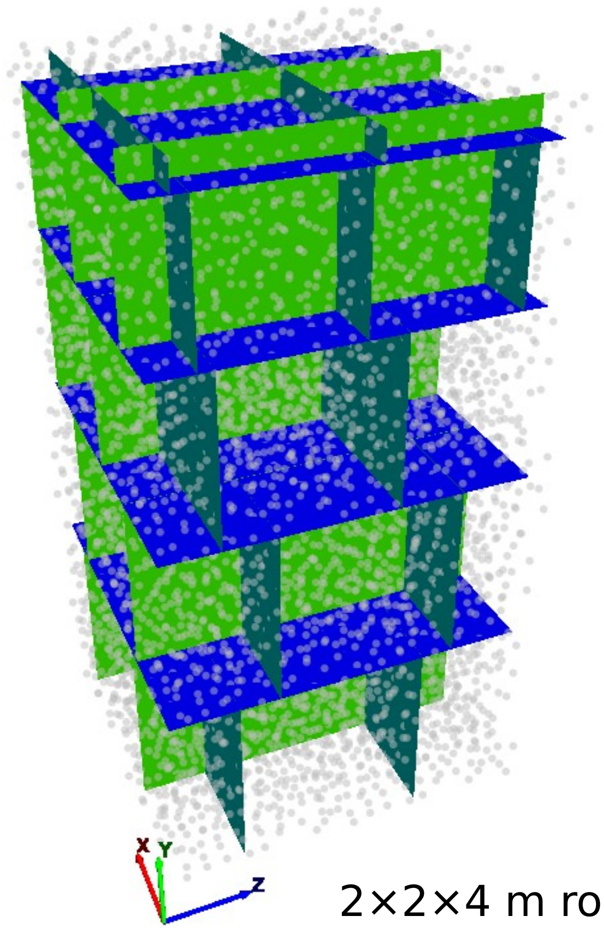
    - Idealized fracture network

On-going work

- 3D

- Determine REV

- Discontinuity property calibration



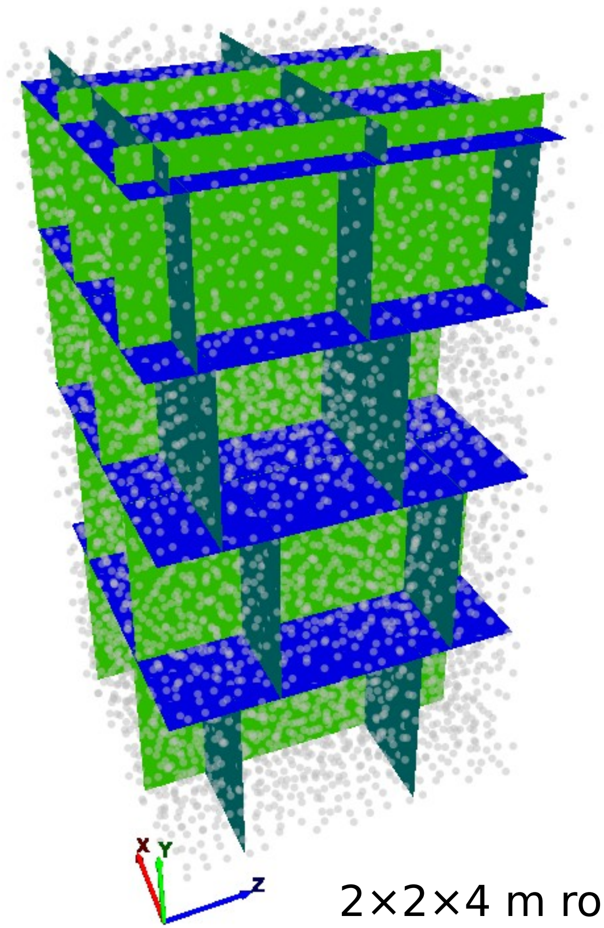
2×2×4 m rock mass

On-going work

- Key questions:

1) How is REV dependent o
variations in bed height an
fracture spacing?

2) Degree of change in
geomechanical parameters
at REV?



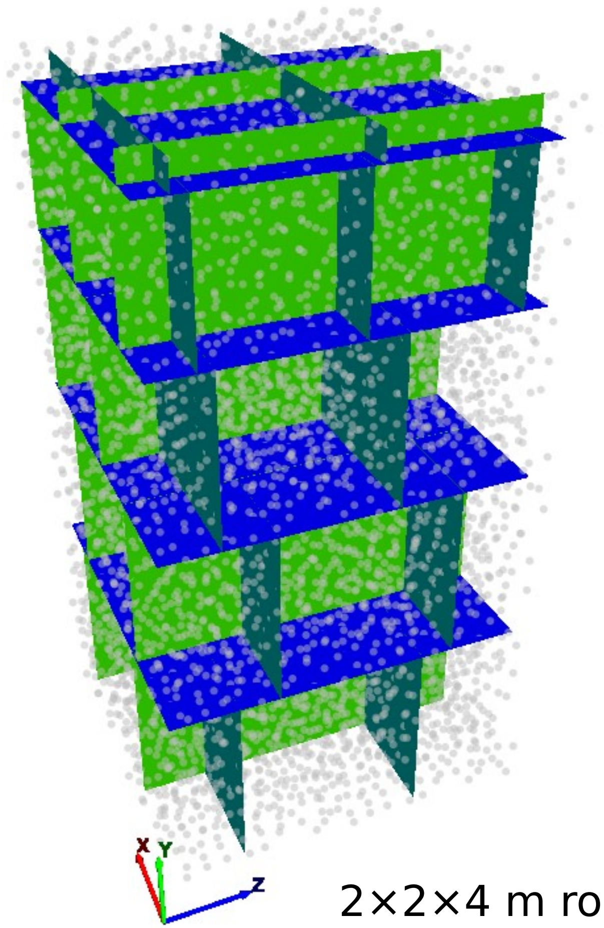
2×2×4 m rock mass

3) How do the results match with analytical solutions?

On-going work

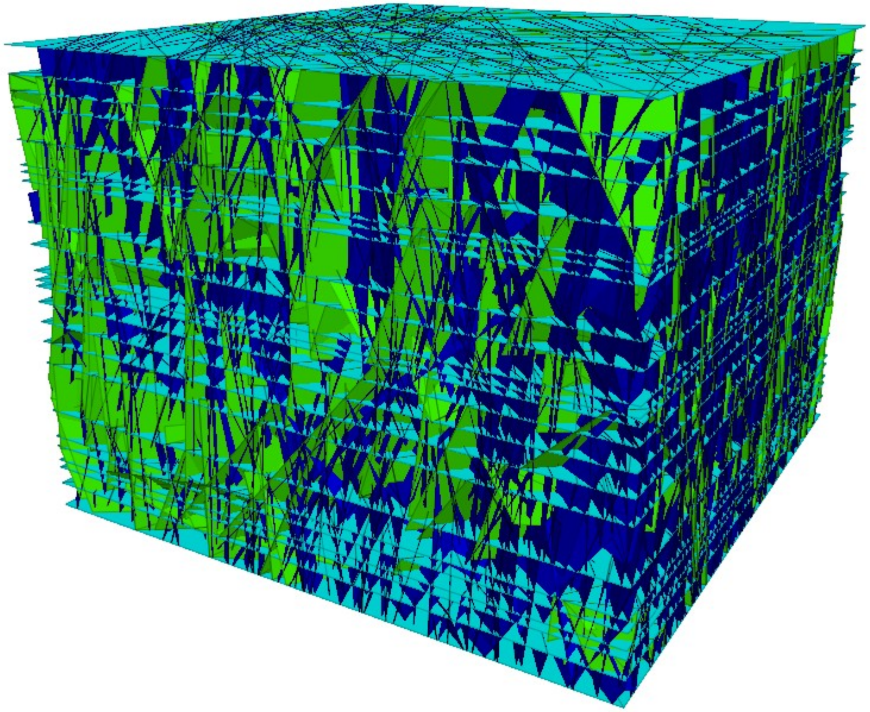
- Key questions:

4) Post-peak behavior



2×2×4 m rock mass

Thank you!



Acknowledgements

- ROSE project partners

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