Practical Estimates of Rock Block Unconfined Strength

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Background Info

- A **Rock Mass** is an assemblage of **Rock Blocks** which are separated by **Discontinuities**

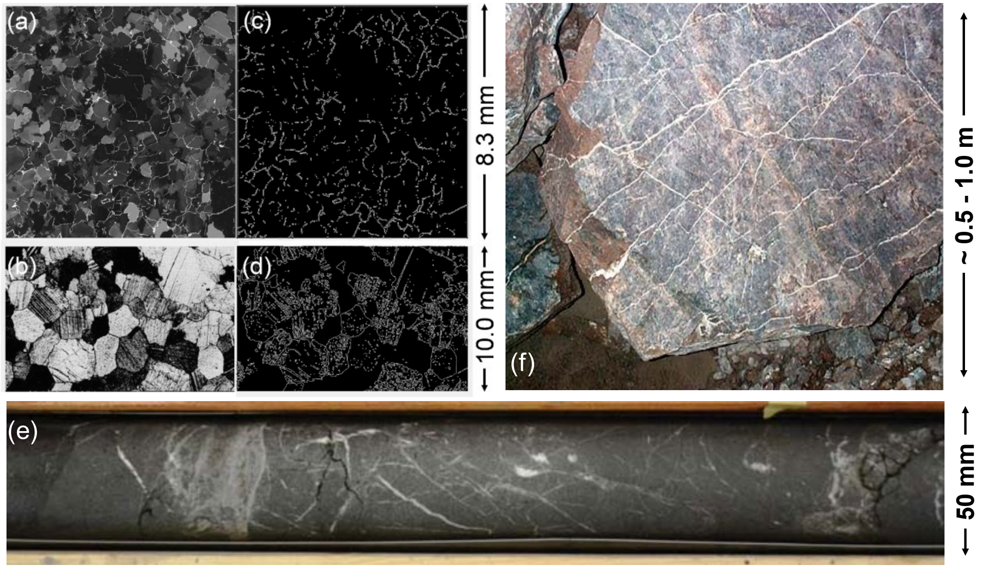
- The rock mass behaviour and the associated rock-support interactions depend on:
  - properties of the rock blocks
  - properties & structural pattern of joints
  - in-situ stress conditions

- For massive to moderately fractured rock masses in high stress environments the role of the **Rock Blocks** is important because:
  - pre-existing discontinuities are locked
  - brittle damage dominates the failure processes
  - or combined stress-structure failure mode

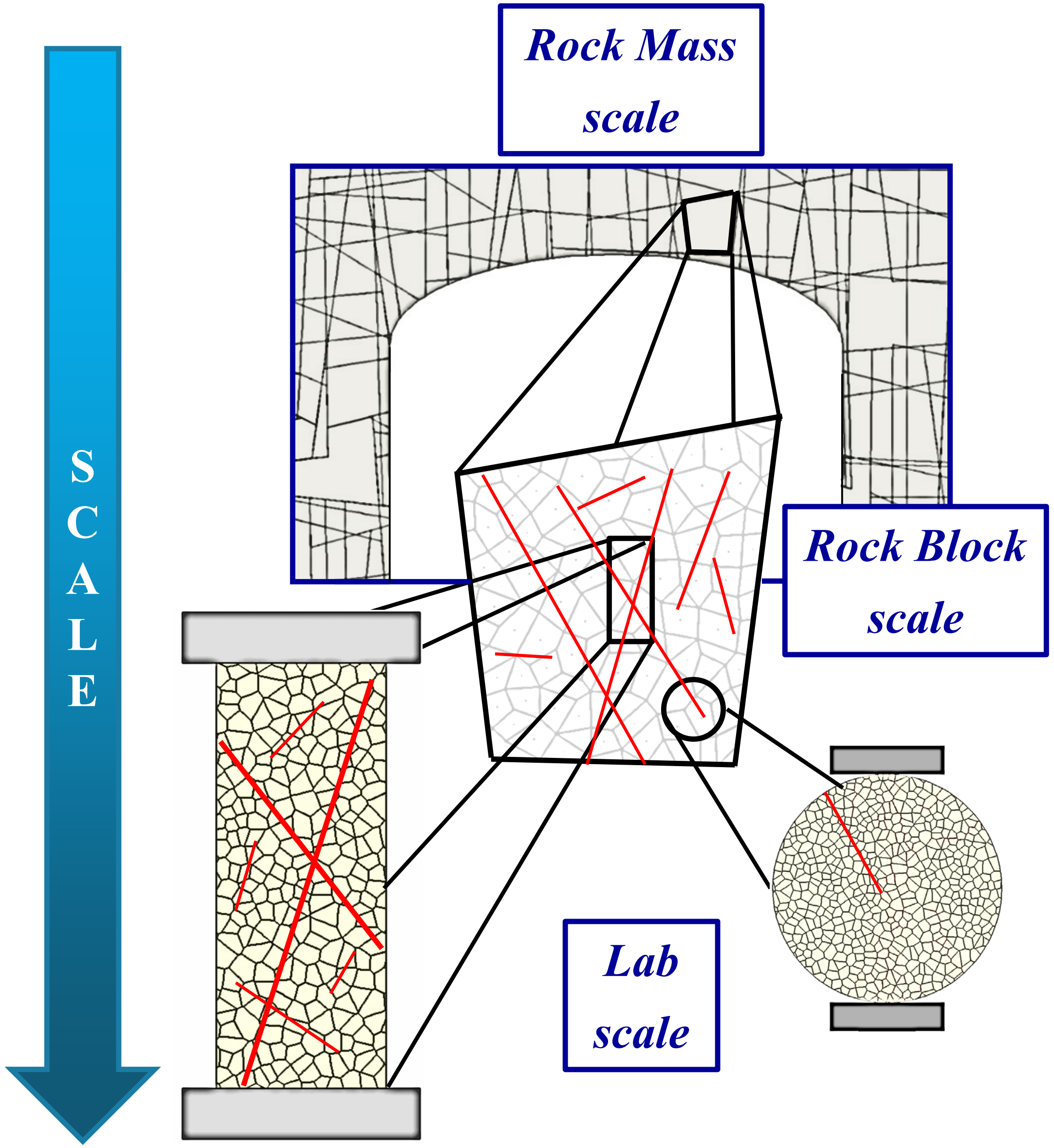
Background Info

Rock blocks:

- are volumes of unjointed rock material
- their properties are influenced by scale effects and the presence of micro- and meso-scale structural defects



- such defects impact significantly their mechanical behaviour and it is therefore critical to account for their weakening effects



UCS Scale Effects

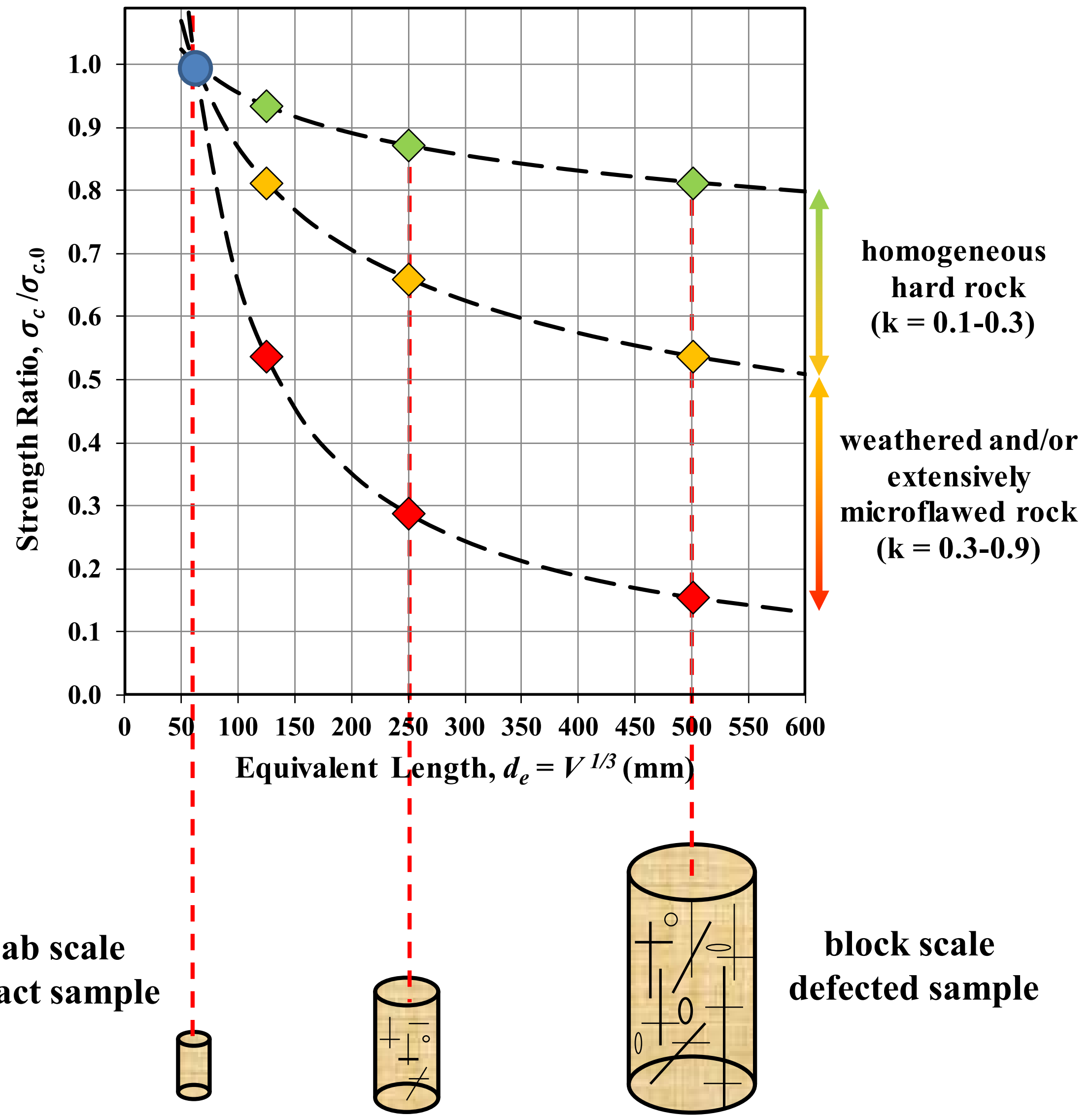
known knowns

The **Unconfined** Compressive **Strength** (UCS) **decreases** with increasing **scale** due to an increased **heterogeneity** as a function of block volume

known unknowns

as defect intensity increases and/or defect strength decreases then rock block strength decreases

…only limited options are available for estimating the UCS of rock blocks based on qualitative descriptions (e.g. GSI) or quantitative measurements (e.g. MRMR)



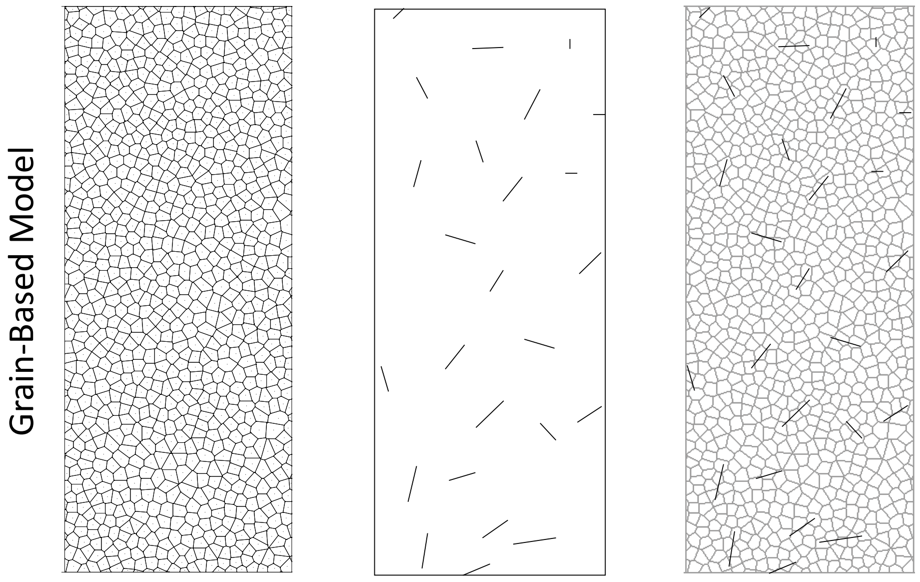
Current Work

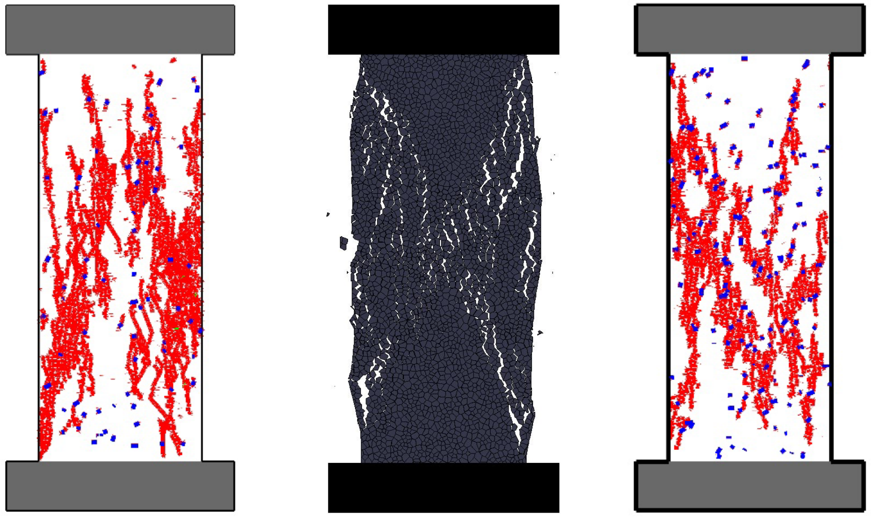
- A scaling study was performed: **UDEC** Grain-Boundary Models (GBM) & **FracMan** micro-Discrete Fracture Networks (DFNs)

- The Synthetic Rock Blocks (SRB) can capture both the crack evolution processes and the effect of pre-existing defects

- A series of unconfined compression tests were run on samples of varying sizes and defect geometries/strengths

a) to better understand the **strength reduction** of rock blocks as a function of scale, defect geometry and defect strength
b) to develop a **practical tool** for quantifying the **unconfined strength** of **defected rock blocks**





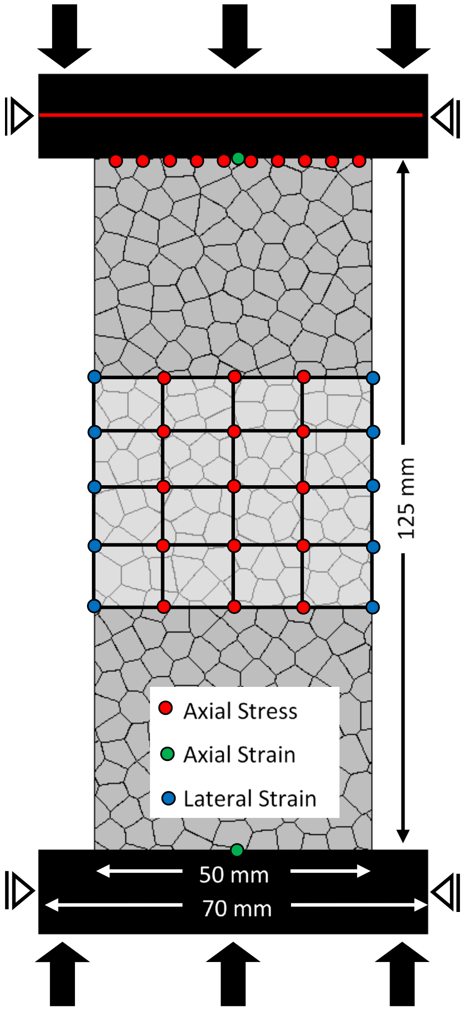
Approach

1. Calibrate **lab-scale (intact)** GBM against a set of target macro-properties (UCS = 50MPa)

2. Calibrate the micro-properties of **large-scale non-defected** samples to express **only** the effect of **size**

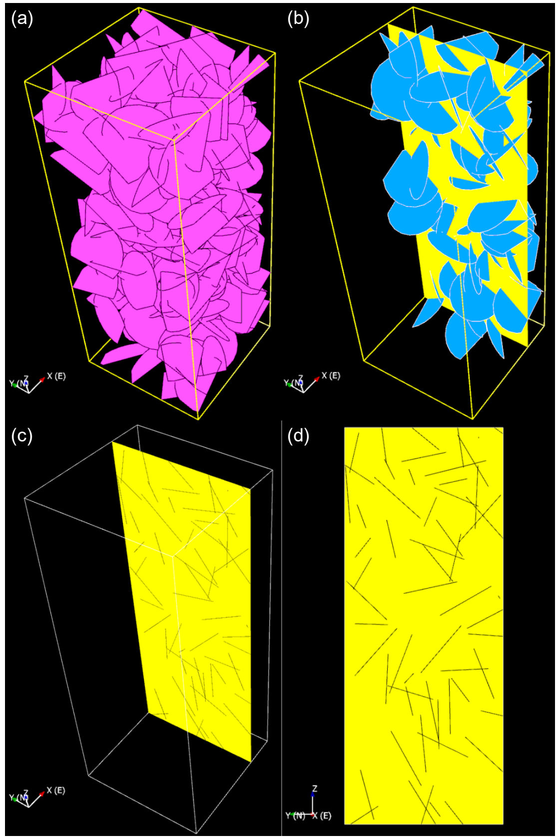
3. Run UCS tests on **large-scale defected samples** under progressively increased defect intensities (frequency & persistence) and defect strength

4. Refine existing empirical approaches and develop a methodology for estimating the UCS of blocks



GBM UDEC UCS tests

3D μDFN generated in Fracman

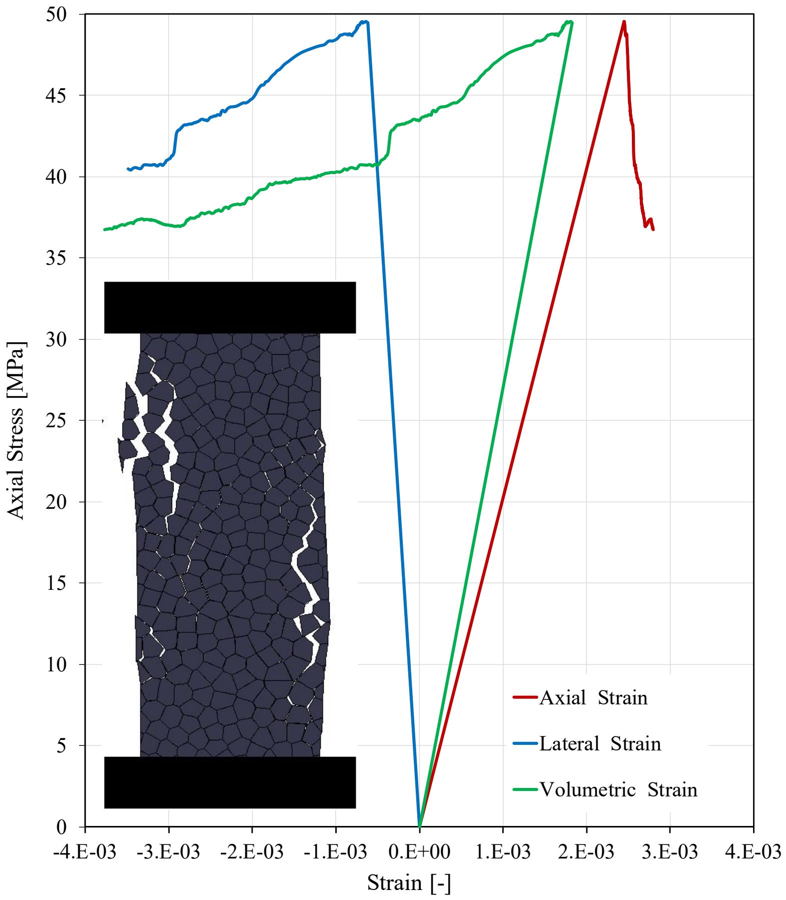


Lab-scale intact GBM Calibration

Target macro-properties

Properties		Units	Values
Target macro-mechanical properties			
UCS	σ_i	MPa	50
Modulus ratio	MR	–	400
Young's modulus	E_i	GPa	20
Poisson's ratio	v_i	–	0.25
HB constants	m_i	–	15
	s	–	1
	a	–	0.5
Secant slope	N_φ	–	6.8
Cohesion	c	MPa	9.6
Friction angle	φ	[°]	48.1
Tensile strength	σ_t	MPa	3.3

UDEC UCS test

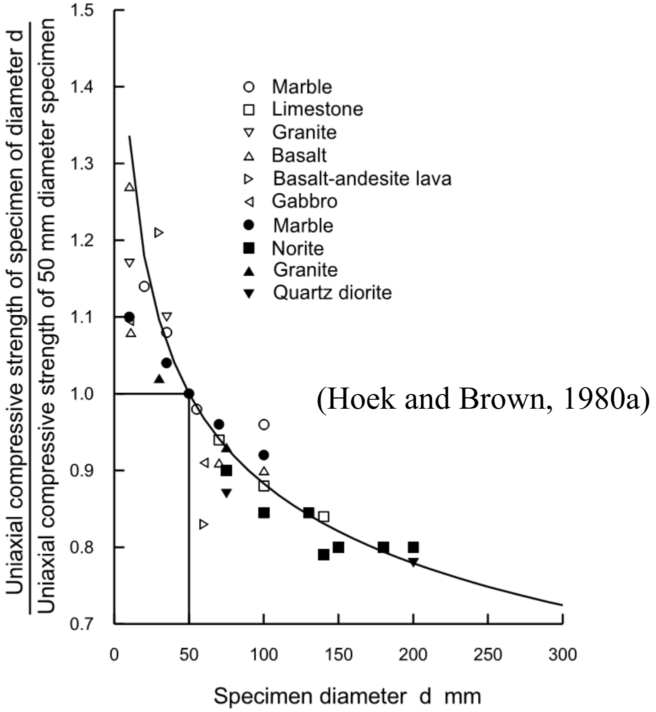


Calibrated micro-properties

Properties		Units	Values
Calibrated SRB micro-mechanical properties			
Grain Young's modulus	E_m	GPa	26.0
Grain Poisson's ratio	v_m	–	0.25
Contact normal stiffness	k_n	GPa/m	15,600
Contact shear stiffness	k_s	GPa/m	14,040
Contact stiffness ratio	k_s/k_n	–	0.9
Contact cohesion	c_m	MPa	11.5
Contact friction angle	φ_m	[°]	48.1
Contact tensile strength	t_m	MPa	3.3
Residual cohesion	c_{mr}	MPa	0.0
Residual friction angle	φ_{mr}	[°]	25
Residual tensile strength	t_{mr}	MPa	0.0

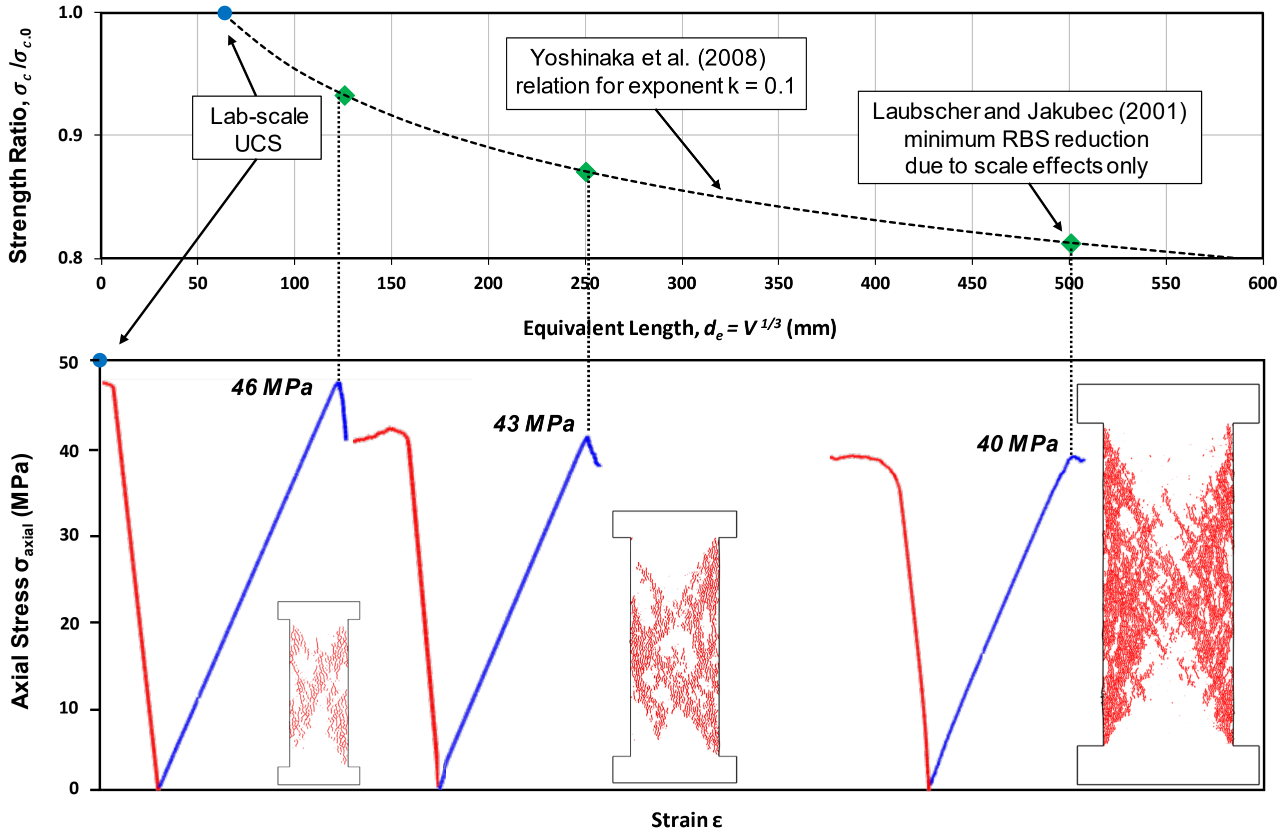
Block-scale non-defected GBM Calibration

The micro-properties of three **non-defected** GBM large samples were **re-calibrated** to capture the expected size-dependant strength of homogenous rock blocks (i.e. 80% of UCS)



(Hoek and Brown, 1980a)

50 x 125 mm



100 x 250 mm

200 x 500 mm

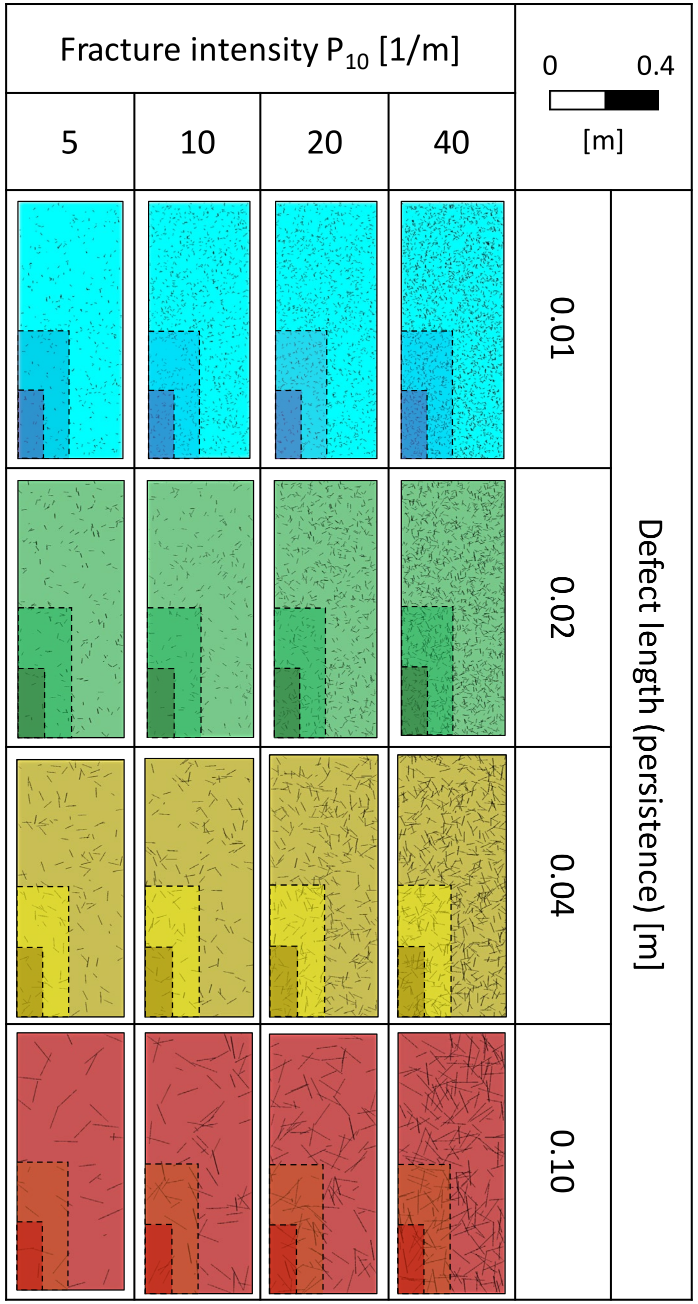
400 x 1000 mm

Block-scale defected UCS tests

- Several μDFN geometries were embedded into the large scale UDEC GBMs
- A series of unconfined compression tests were run on samples of varying sizes and defect geometries/strengths
  - P_{10} = 5, 10, 20, 40 [defects/meter]
  - Persistence = 0.01, 0.02, 0.04, 0.1 [m]
  - Case 1: ‘**open**’ defects (strength purely frictional, zero cohesion & tensile strength)
  - Case 2: ‘**healed**’ defects (cohesion and tensile strength were increased by 50% & 100% in respect to the baseline intact rock GBM strength)

Table 3 Matrix of modelling scenarios considered to generate SRB models

Width (mm)	Height (mm)	Area (mm^2)	Volume (mm^3)	d_e (mm)	No of blocks (–)	P_{10} cases (defects/m)				Persistence cases (m)			
50	125	6.25E+03	2.5E+05	63	300	–				–			
100	250	2.50E+04	2.0E+06	125	1100	5	10	20	40	0.01	0.02	0.04	0.10
200	500	1.00E+05	1.6E+07	250	4100								
400	1000	4.00E+05	1.3E+08	501	16,200								
Case 1						√	√	√	√	√	√	√	√
Case 2						√	√	√	√	√	–	√	–



Case 1 - “open” defects:

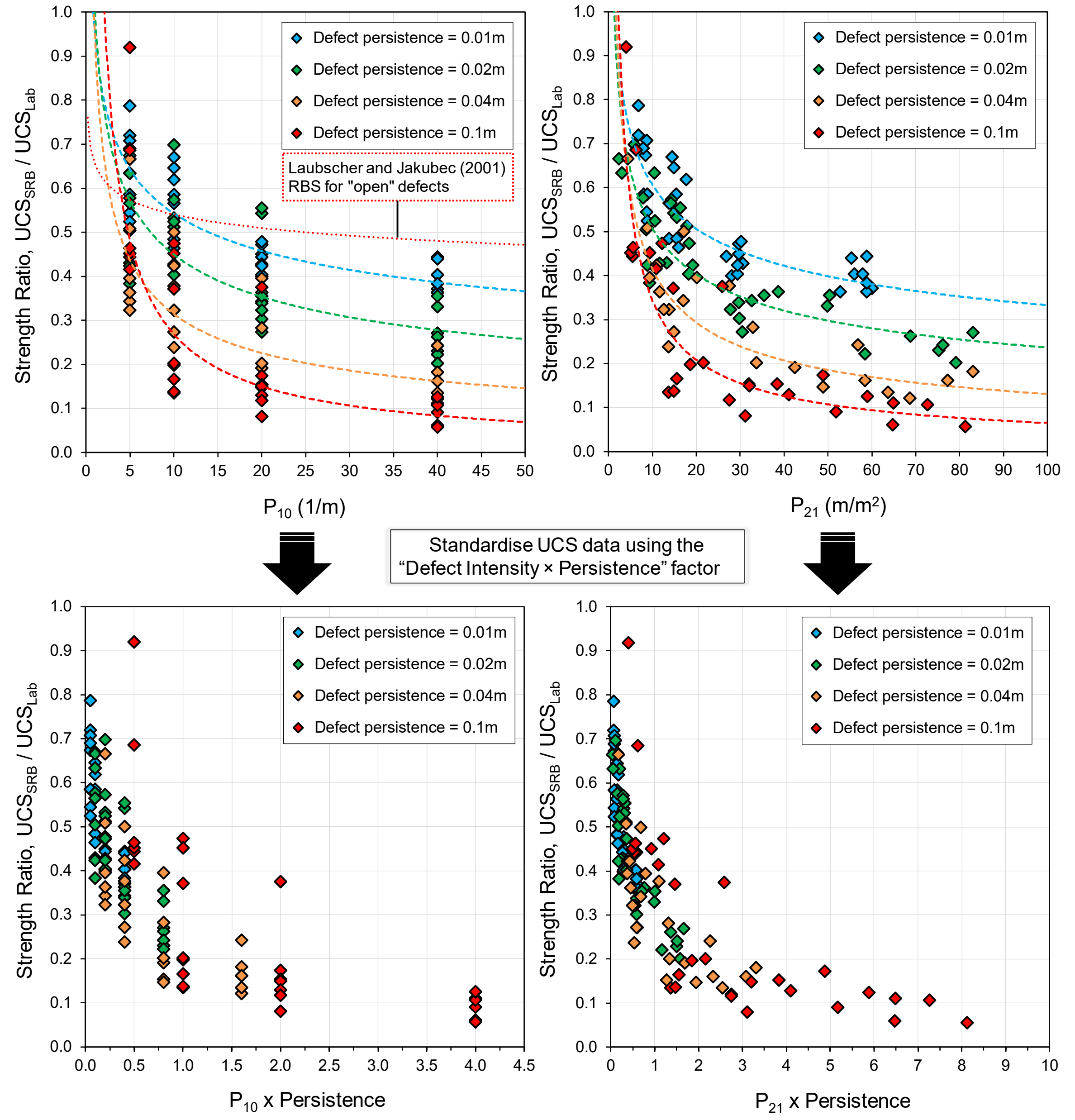
- Rock block UCS strength is strongly influenced by the presence of pre-existing open defects

- there is a systematic and progressive strength reduction as defect intensity and persistence increase

- the decay of strength follows a power-law trend and beyond a certain defect intensity the strength approaches a horizontal asymptote (i.e. REV)

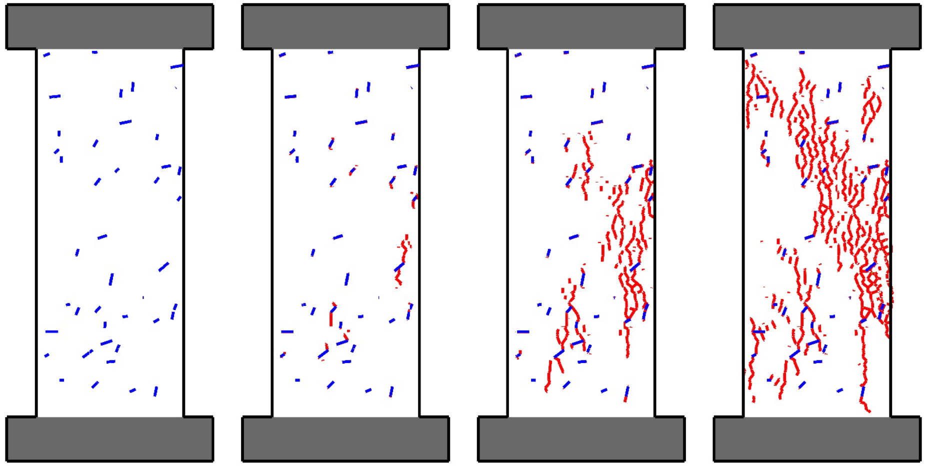
- the rate of strength reduction increases as defect persistence increase

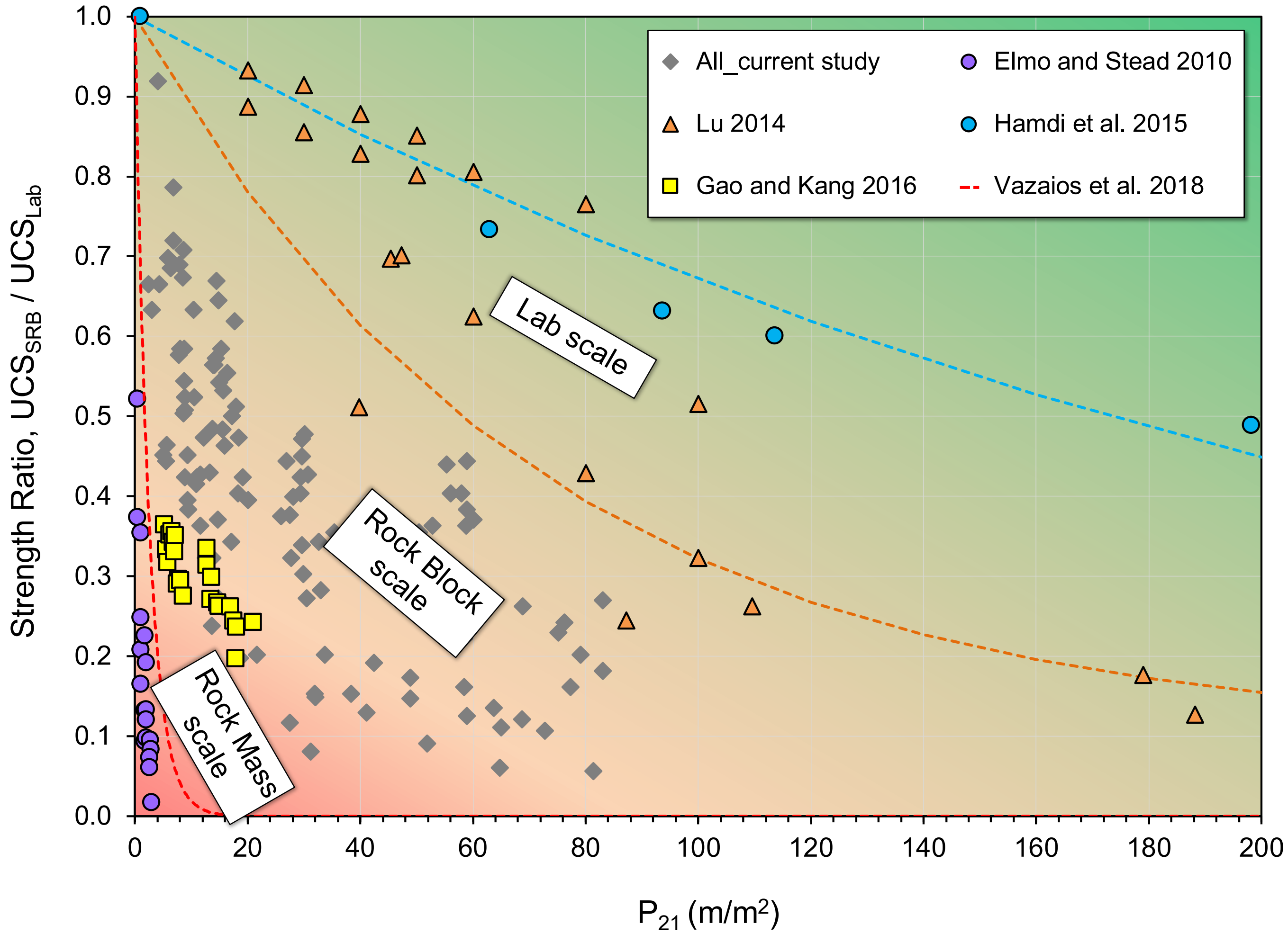
- when the defect intensity is combined with the defect persistence (i.e. Defect Intensity × Persistence = **DIP factor**), a very good clustering is observed in the data set



Case 1 - “open” defects:

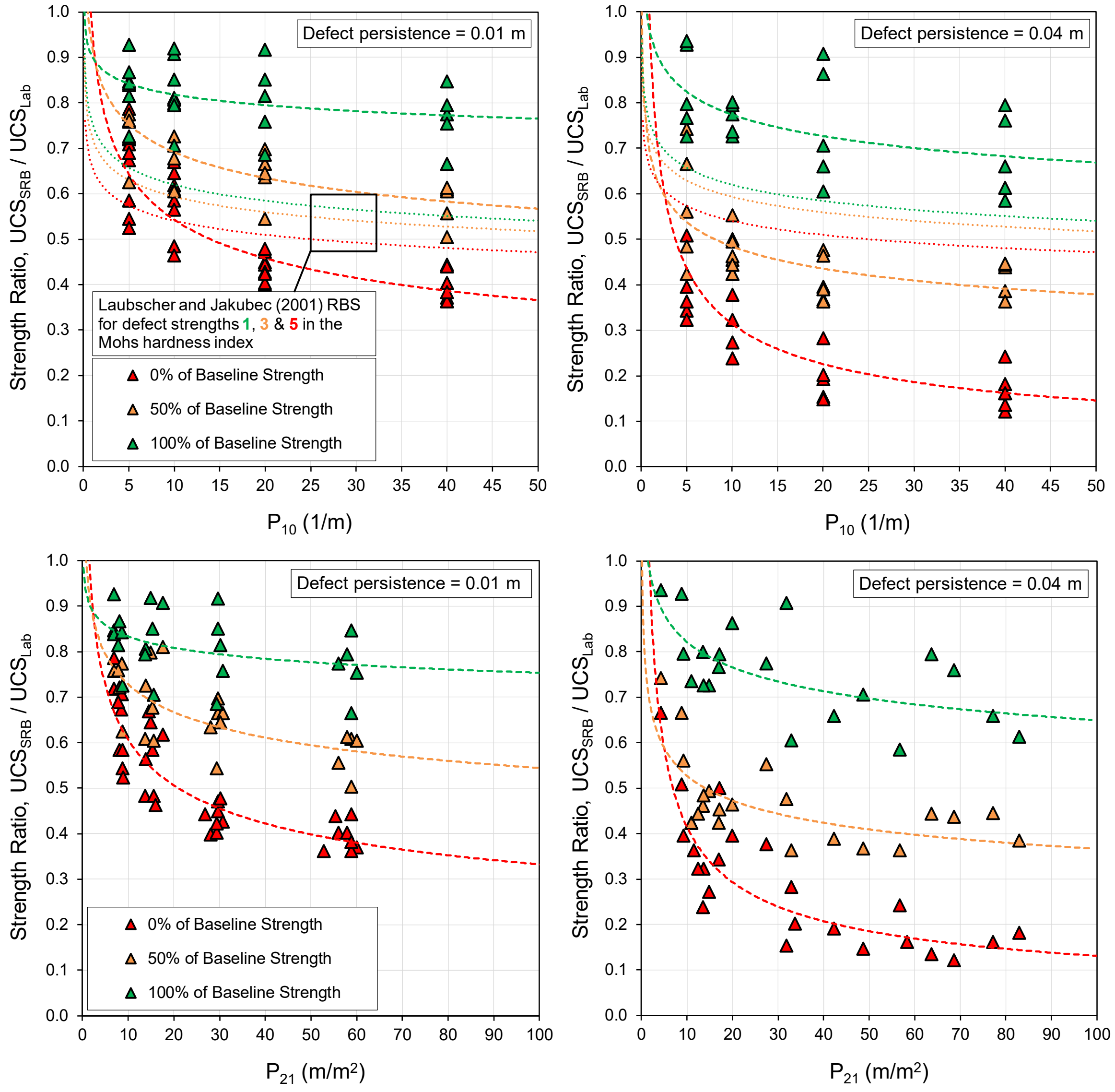
- The results from the current study were plotted together with results from other numerical investigations
- All studies show a systematic strength reduction with increasing defect intensity but the shape and rate of strength loss clearly depends on the scale of the sample under investigation (i.e. intact-block-mass scale)





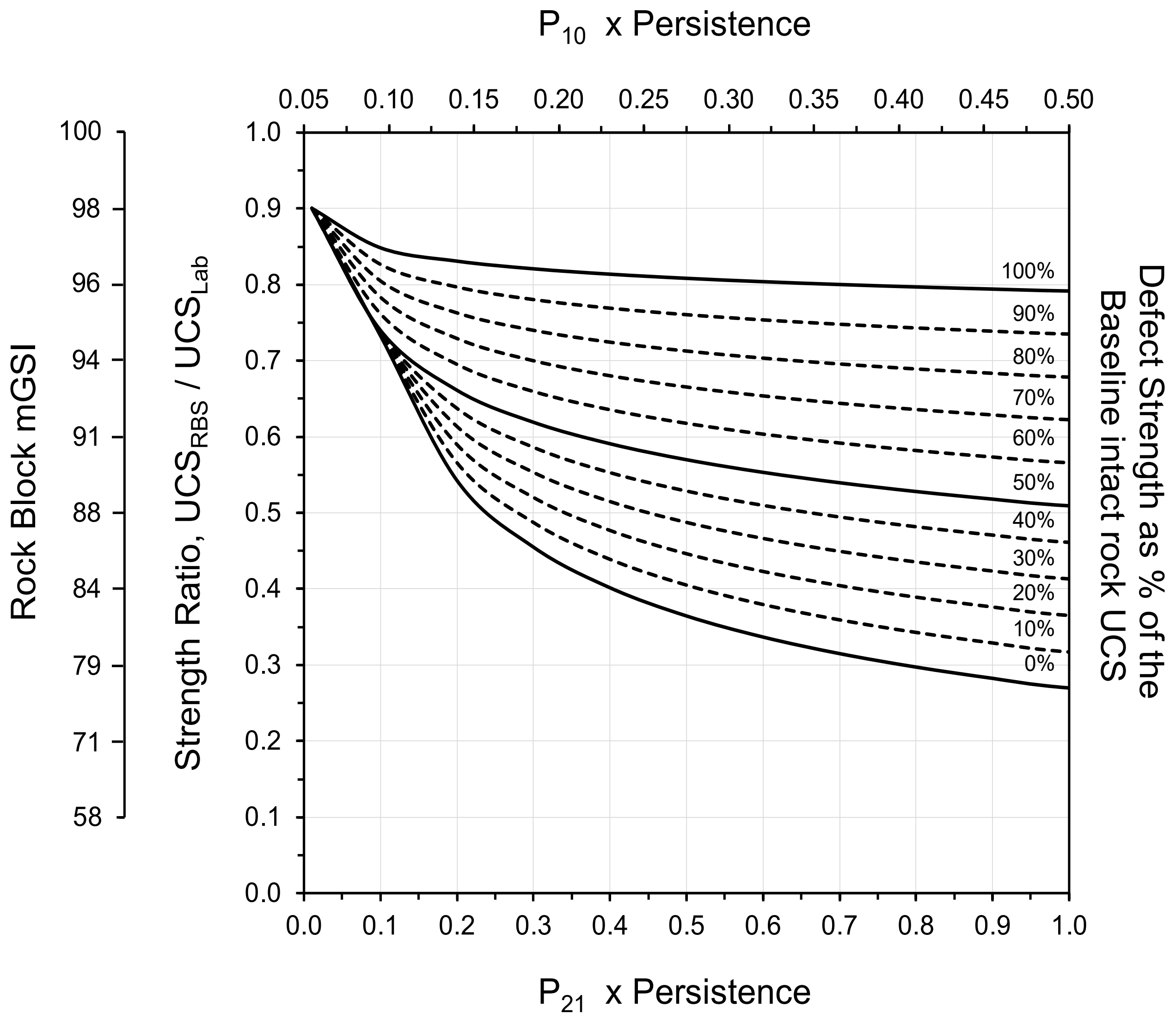
Case 2 - “healed” defects:

- the defects were strengthened by 50% and 100% in respect the surrounding grain contact-to-contact strength
- The progressive increase in defect strength from 0% to 100% improves significantly the UCS of the samples as the defects become “invisible” within the GBM matrix
- a systematic strength improvement is achieved as defect strength increases from 0% to 100%
- The strength of defects overrides the effect of persistence as defect strength increases. For the 100% defect strength case the effect of persistence has disappeared



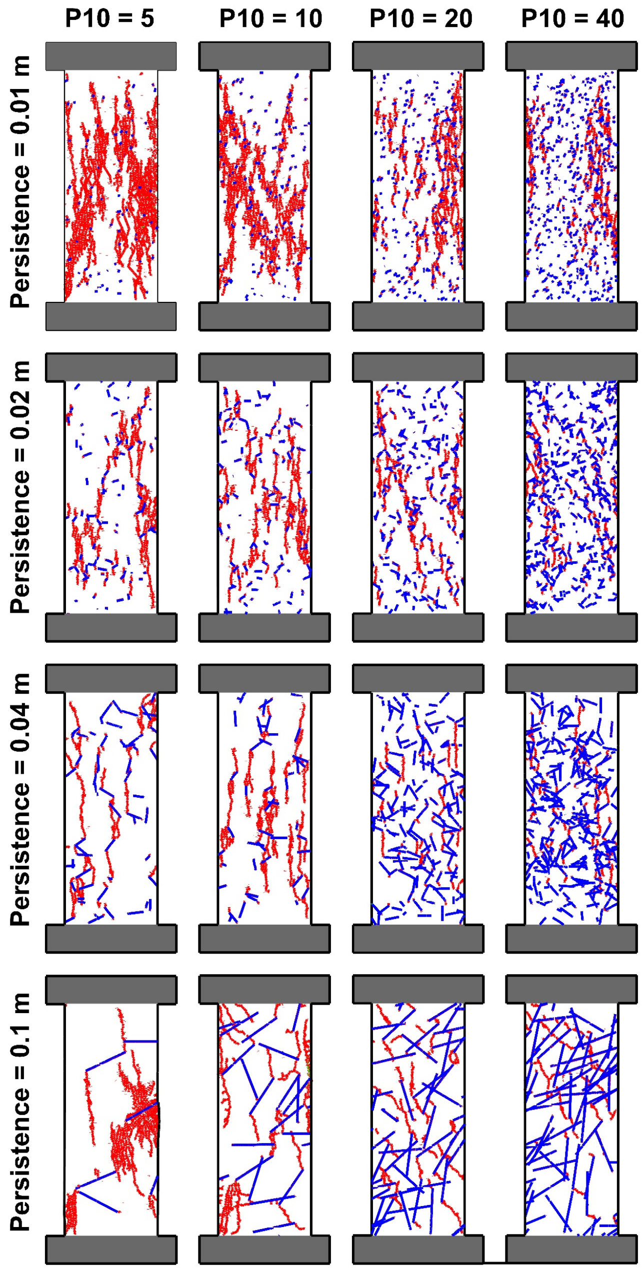
Rock Block Strength Quantification

- The systematic strength reduction/improvement with defect intensity, persistence and strength allowed to standardise the data
- Refined approaches for estimating the UCS of defected blocks are proposed in the form of strength reduction envelopes
- The combination of these charts with the mGSI-strength relationship (Stavrou and Murphy, 2018) allowed to quantify the mGSI in terms of specimen size and defect geometry-condition
- <u>Limitations</u>: the study reflects the results of 2D simulations (i.e. strength is under-estimated)



Summary

- the behaviour of rock blocks is a significant factor controlling the rock mass behaviour (i.e. deformations, failure modes, fragmentation, stand-up time, etc.)
- especially when the design relies on discontinuum analysis where blocks are simulated explicitly, then the adopted block properties influence the specification of reinforcement/support solutions and construction stages.
- a series of simulated UCS tests were performed to develop a methodology for estimating the strength of rock blocks considering the influence of scale and pre-existing defect
- charts for assessing the UCS of blocks are proposed considering scale effects and the geometry/condition of the defects (needs improvement for 3D effects)
- the study demonstrates the strong potential of using synthetic rock mass modelling techniques to develop quantitative guidelines



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