FIFTH INTERNATIONAL ITASCA SYMPOSIUM ON APPLIED NUMERICAL MODELING IN GEOMECHANICS — 2020

FLAC3D-PFC3D Coupled Simulation of Triaxial Hopkinson Bar

Wanrui Hu & Dr. Qianbing Zhang
Monash University, Australia

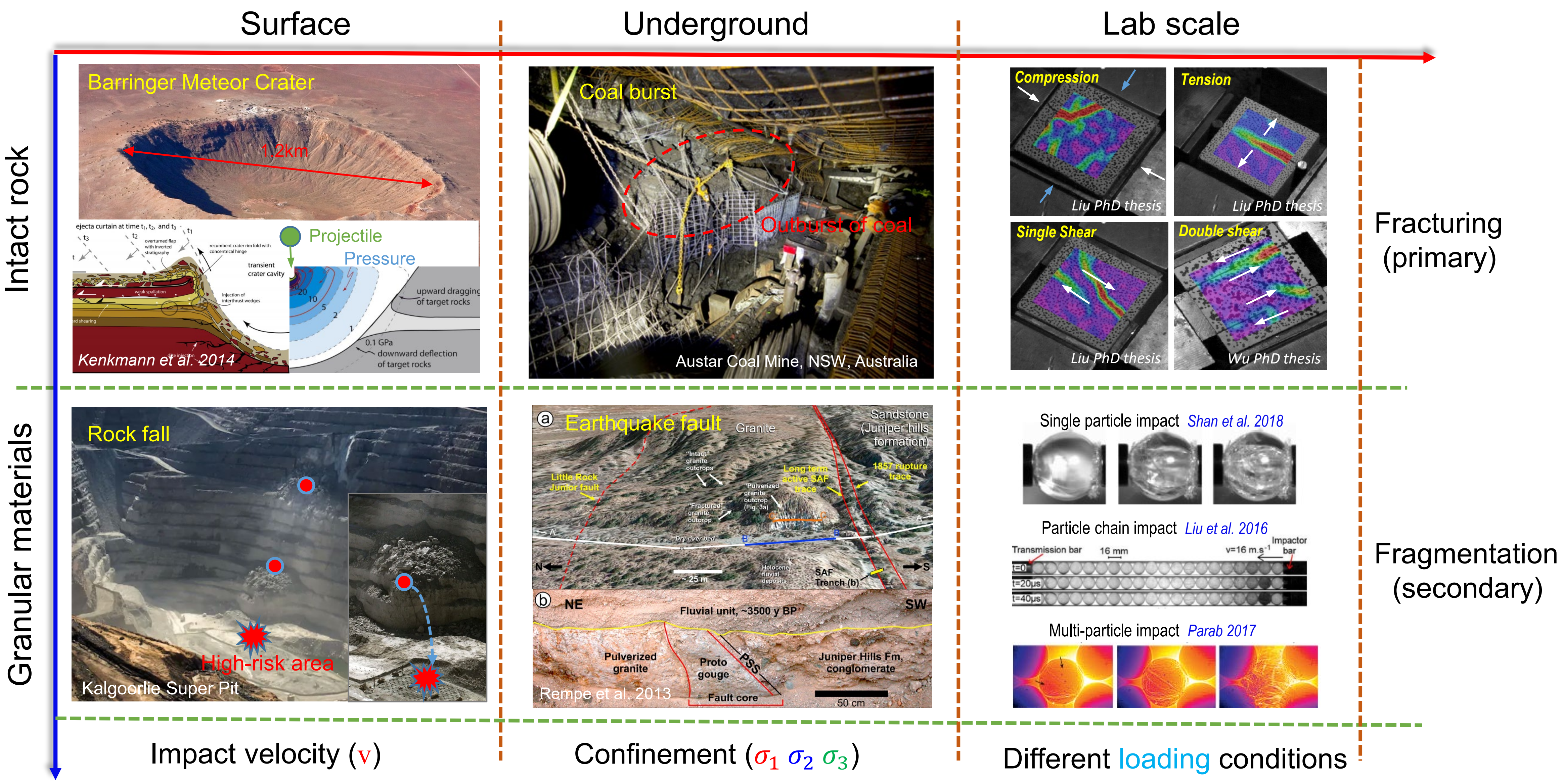
Dr. David O. Potyondy
Itasca Consulting Group Inc., USA

Wanrui Hu is a PhD candidate in the Department of Civil Engineering, Monash University in Australia. He received both his Master and Bachelor degrees from Wuhan University in China. His research topic is dynamic fracturing and fragmentation of brittle materials. He is currently focusing on dynamic compression and shear behavior of rock under multiaxial loading using a coupled continuum-discrete modelling method.

OUTLINE

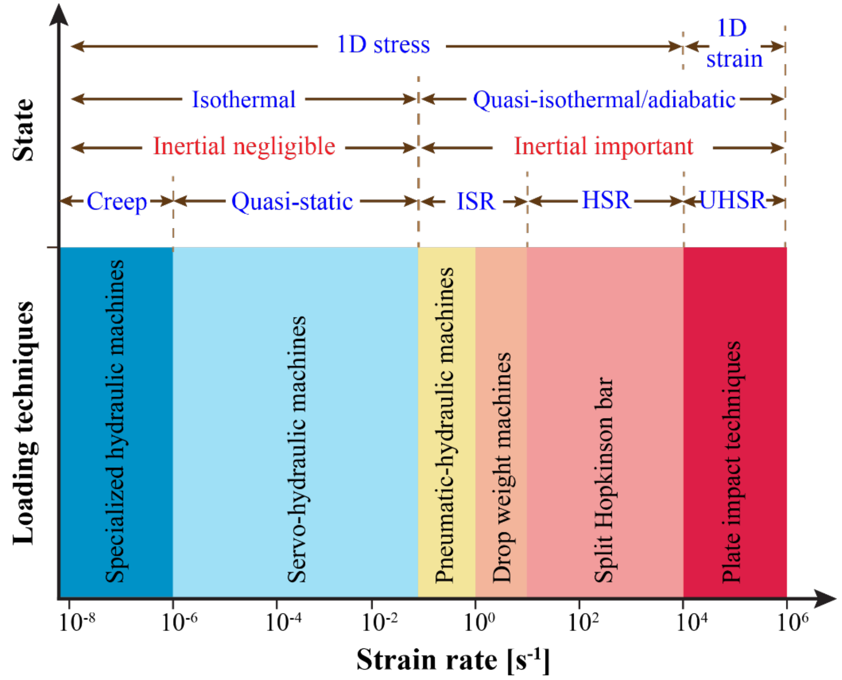
- Introduction
  - Dynamic loading resources
  - Experimental and numerical methods
- 3D Triaxial Hopkinson Bar
- Numerical Modelling
- Summary and Future Study

Natural and Human-induced Hazards: Confinement and Impact

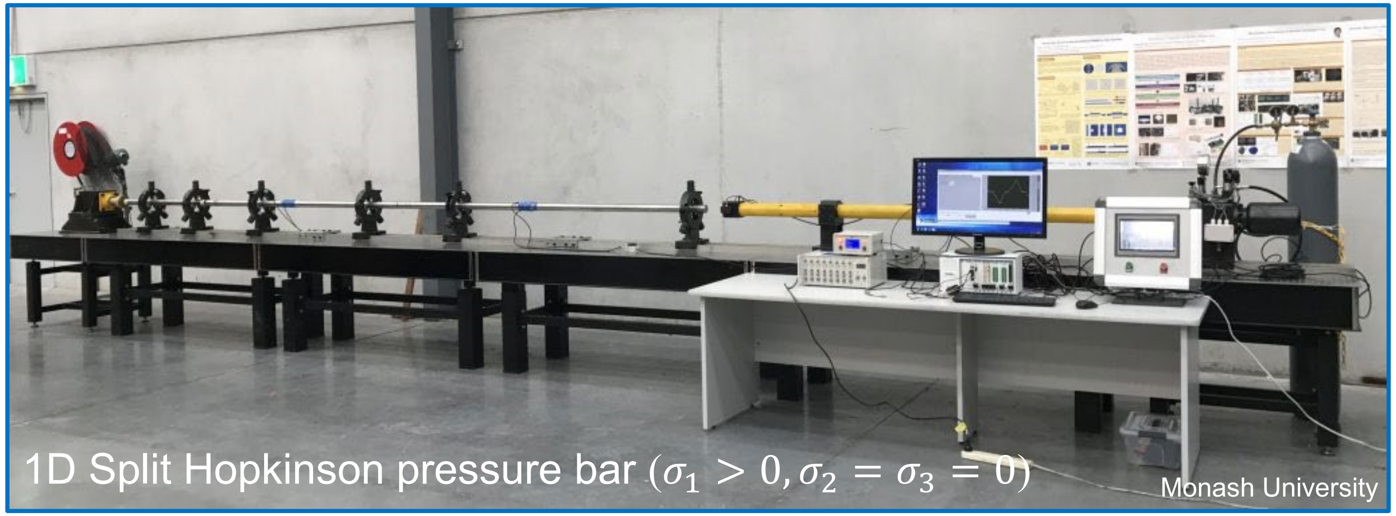


Dynamic Experimental Techniques

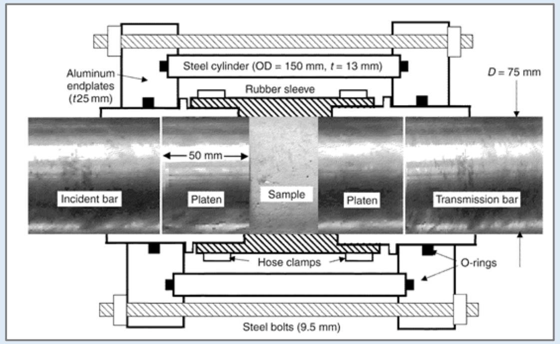
- Pneumatic-hydraulic Machines
- Drop Weight Machines
- **Split Hopkinson Bar**
- Plate Impact Techniques



Zhang et al. 2019, *AREPS*



Conventional confining boundary
$(\sigma_1 > \sigma_2 = \sigma_3)$



Nemat-Nasser et al. 2000

Multiaxial loading boundary
$(\sigma_1 > \sigma_2 > \sigma_3)$

Monash University

Numerical Modelling Methods

❑ Continuum-based methods

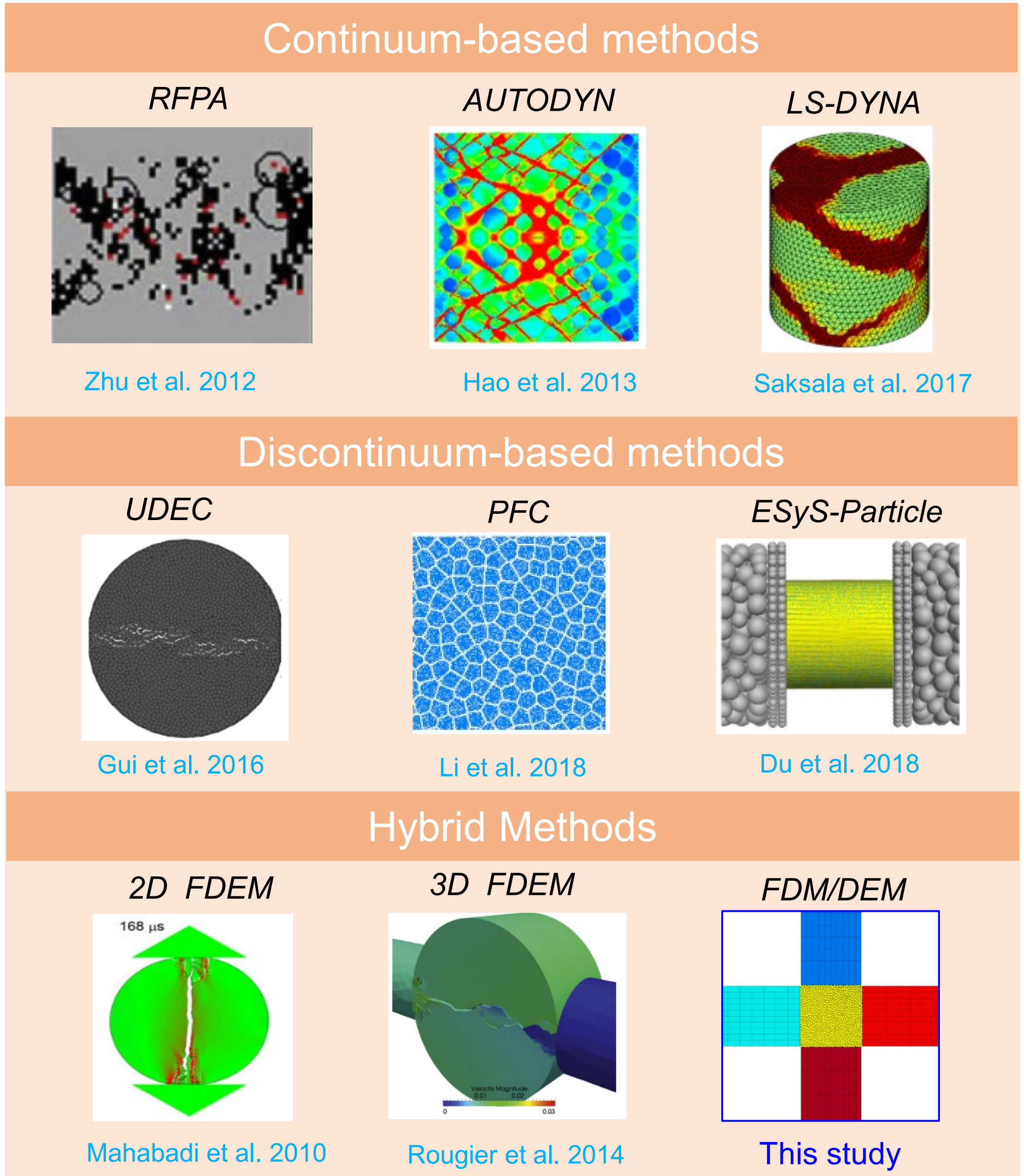
- RFPA, AUTODYN, LS-DYNA
- Incorporation of rate-dependent constitutive models
- Phenomenological representation of failure

❑ Discontinuum-based methods

- UDEC, PFC, ESyS-Particle
- Explicitly modelling of fractures formed by microcracks
- Limited scale
- Insufficient strain rate effects

❑ Hybrid Methods

- FDEM, FDM/DEM
- Computational efficiency
- Fracture and fragmentation
- Stress wave propagation



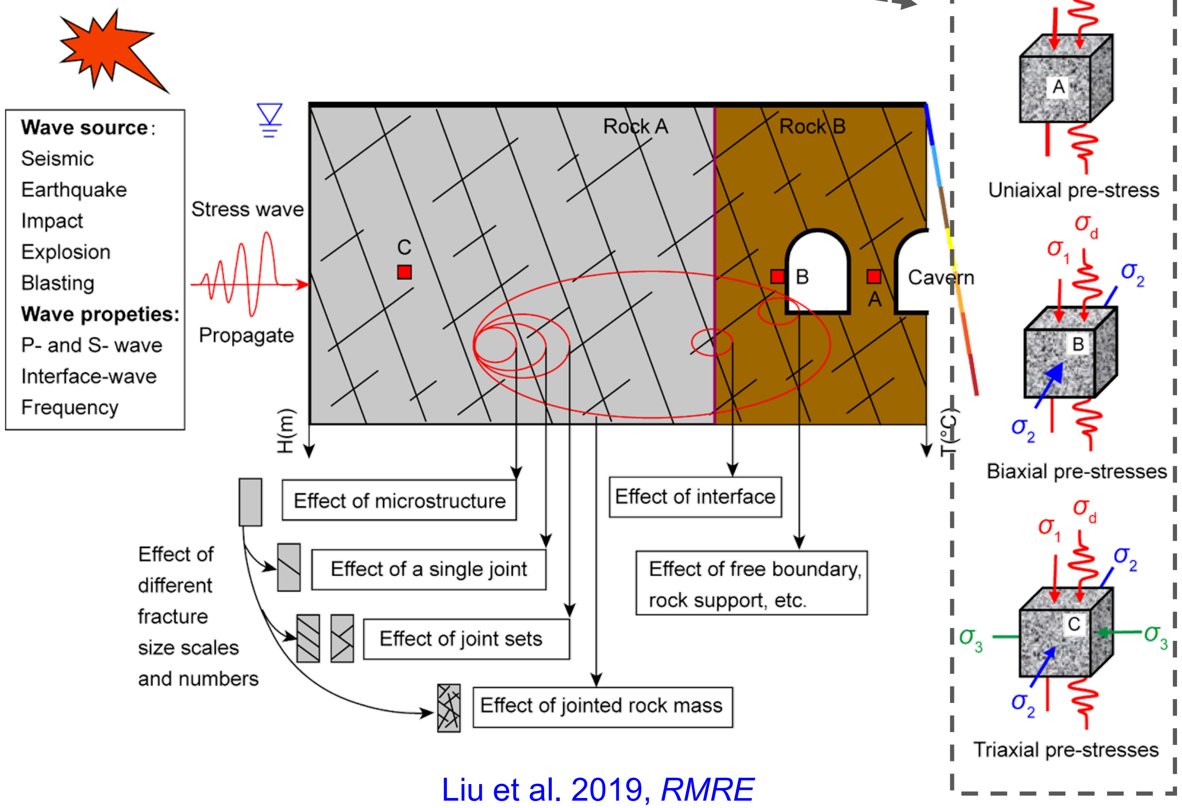
MONASH University

OUTLINE

- Introduction
- 3D Triaxial Hopkinson Bar
  - Components and Capabilities
  - High-Speed Imaging and Micro-CT Scan
- Numerical Modelling
- Summary and Future Study

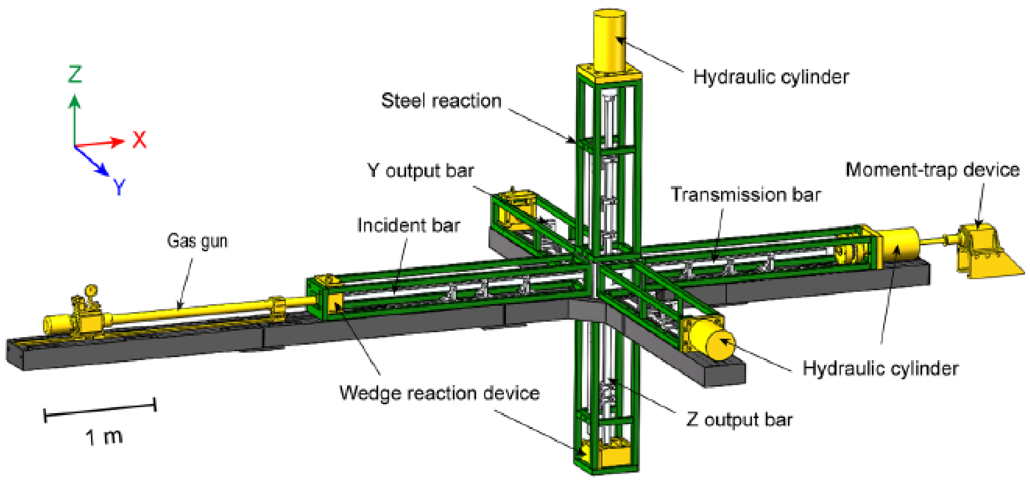
Dynamic Behaviours under Multiaxial Loading

Rock dynamic problems in underground engineering: multiaxial loading



Liu et al. 2019, *RMRE*

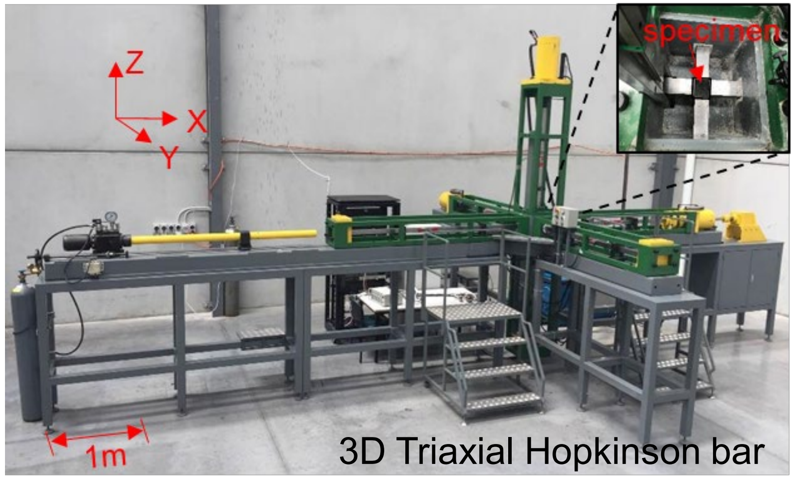
- Impact velocity up to 50 m/s
- Specimen size from 50 mm
- Triaxial quasi-static loads up to 100 MPa

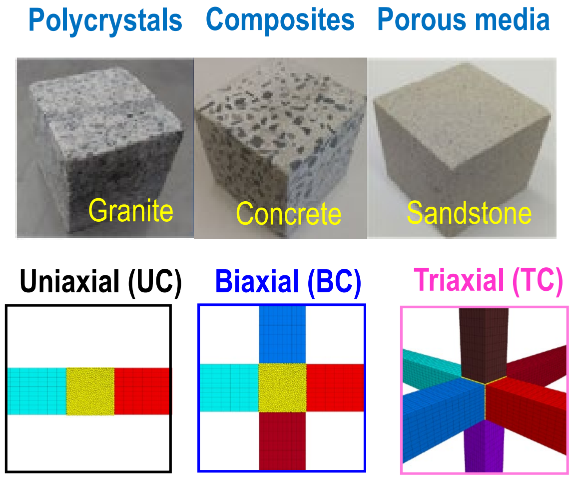


Schematic of 3D Triaxial Hopkinson bar

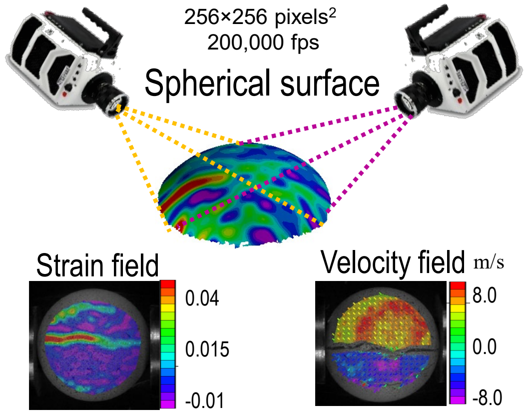
3D Triaxial Hopkinson bar at Monash University

Dynamic Behaviours under Multiaxial Loading





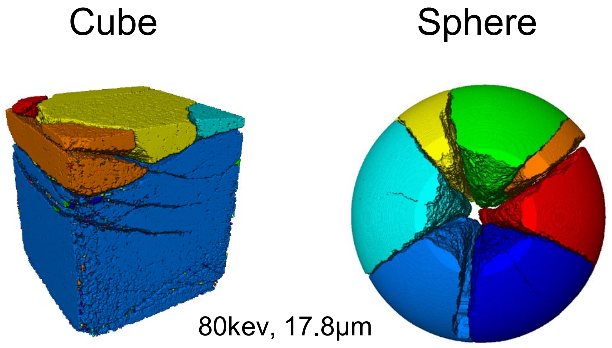
Surface (3D DIC)



- kinetic energy of the flying fragments

$$E_k = \frac{1}{2}mv^2 + \frac{1}{2}Iw^2$$

Internal (X-ray CT)

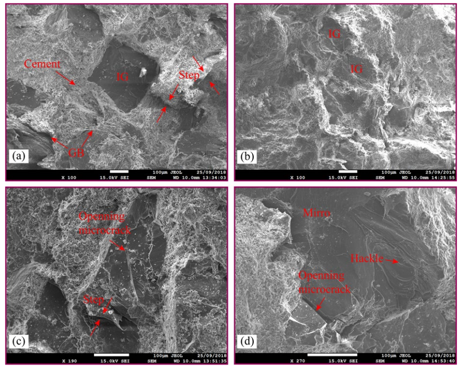


- Fracture surface energy

$$E_s = W_{In.} - W_{Re.} - W_{Tr.} - E_k$$

$$G = E_s/A$$

Micro scale (SEM)



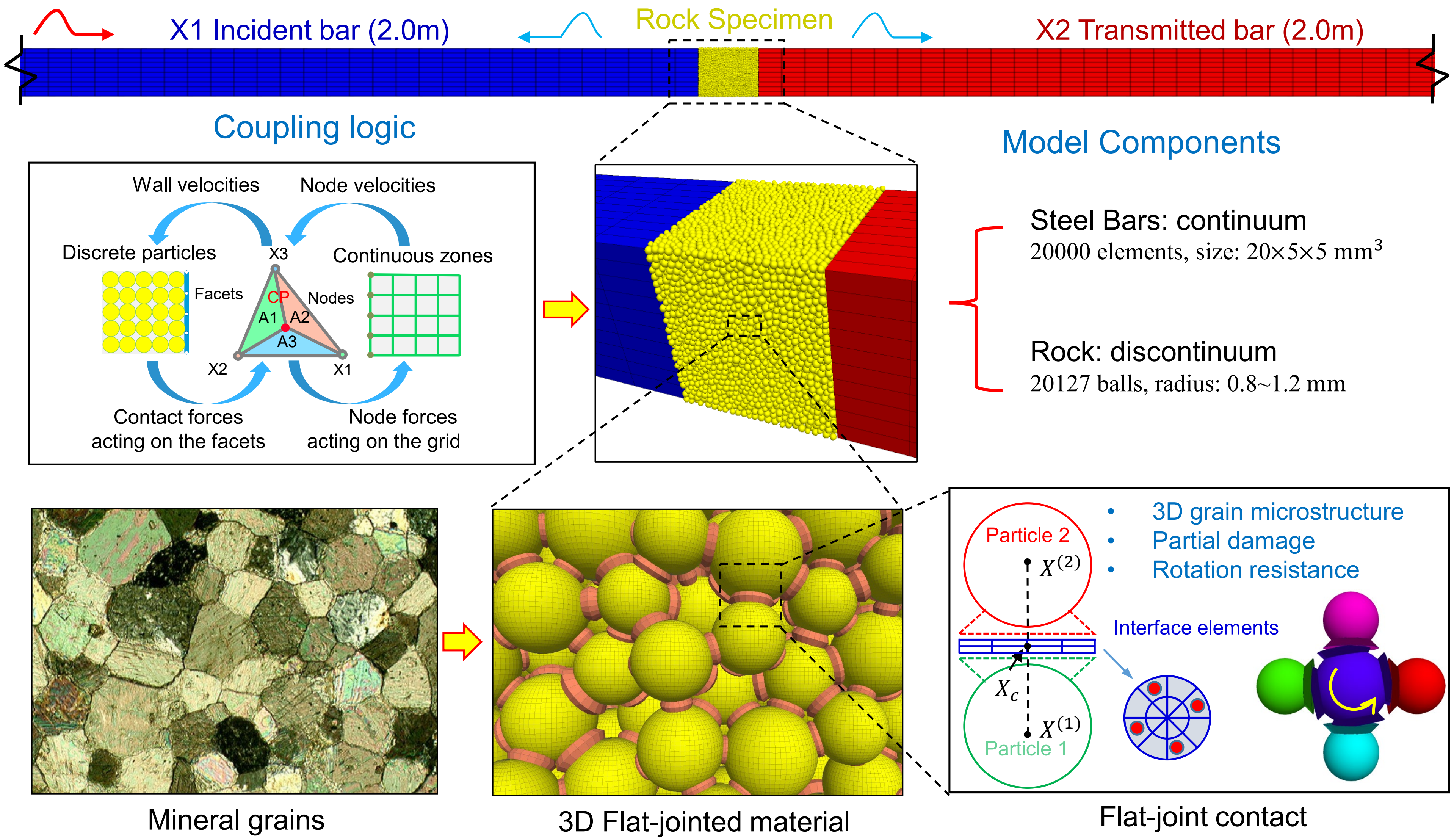
- Microstructure
- Failure mechanism

MONASH University

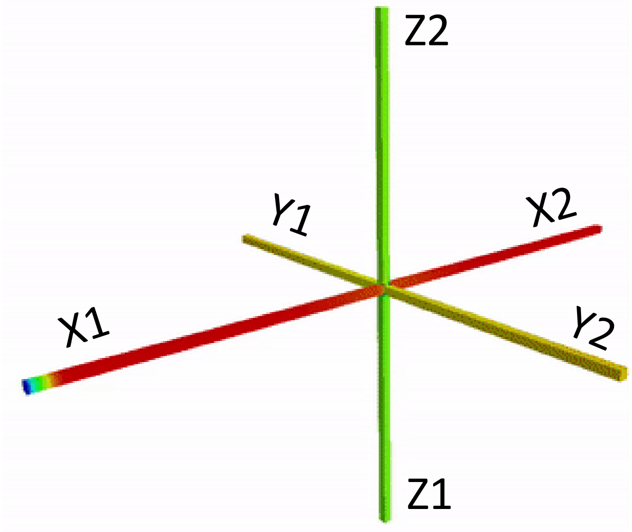
OUTLINE

- Introduction
- 3D Triaxial Hopkinson Bar
- Numerical Modelling
  - A coupled continuum-discrete method
  - Flat-jointed model
  - Verification and comparison
- Summary and Future Study

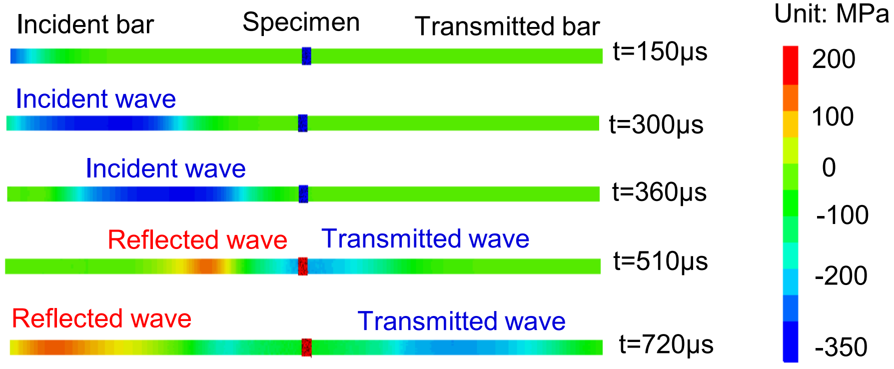
A Coupled Continuum-discrete Model for 3D SHPB



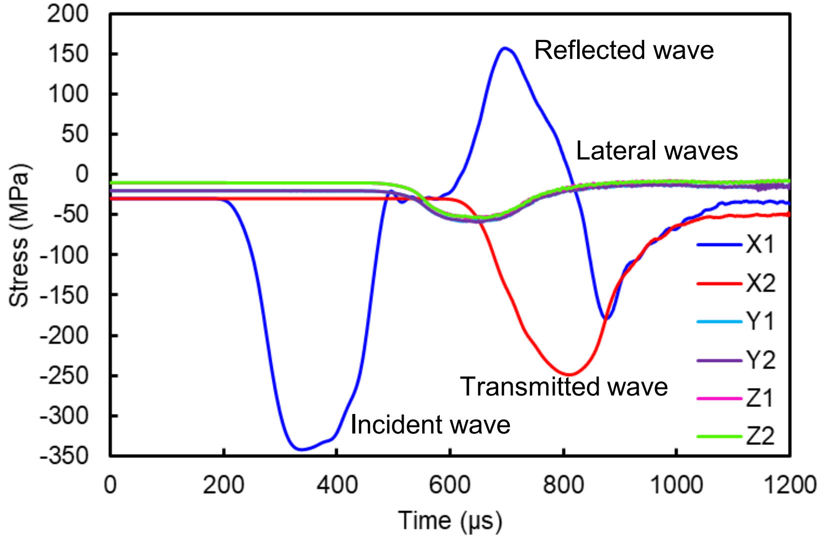
Verification and Comparison



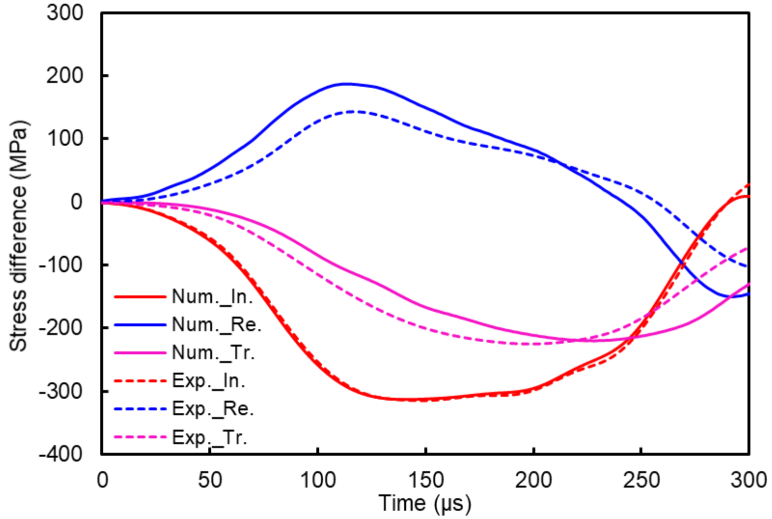
Wave propagation in X direction

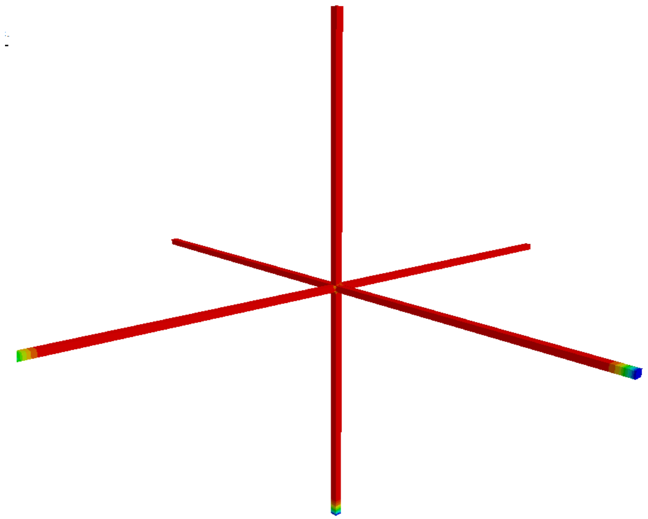


Stress-time history



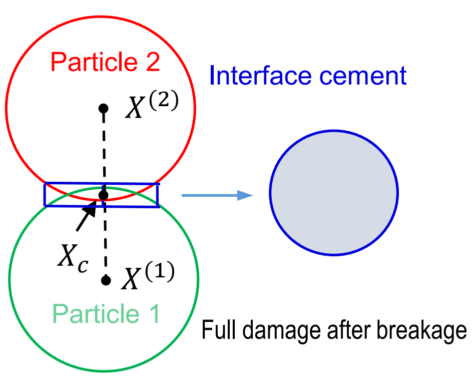
Comparison in X direction



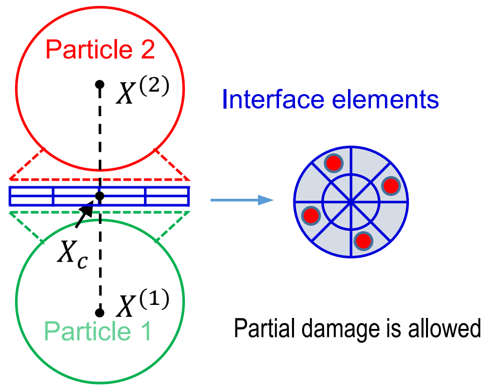


Impact from multiple directions

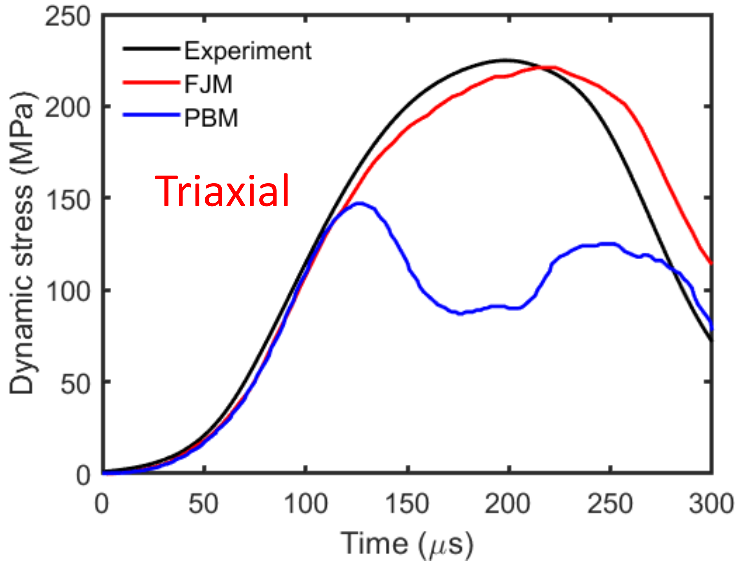
Damage Pattern



Parallel-bonded model (PBM)

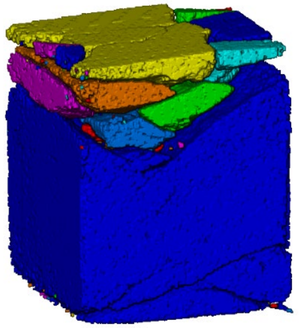


Flat-jointed model (FJM)



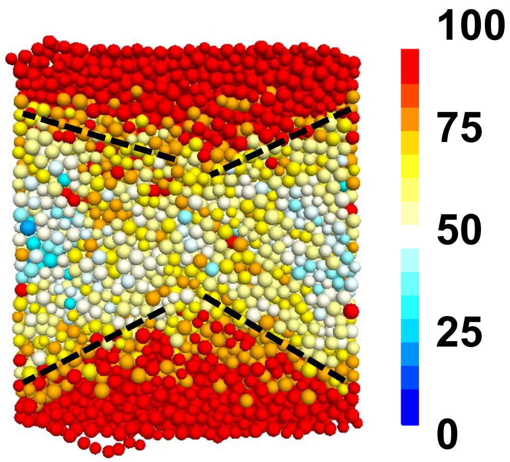
CT slice

3D fragments

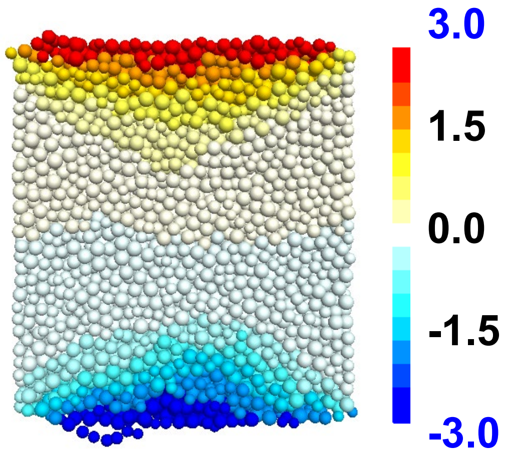


$$\text{Damage ratio} = \frac{\text{Broken contact elements}}{\text{All contact elements}} \times 100\%$$

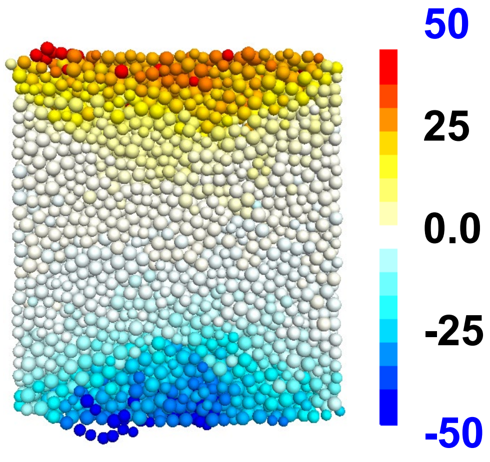
Damage ratio (%)



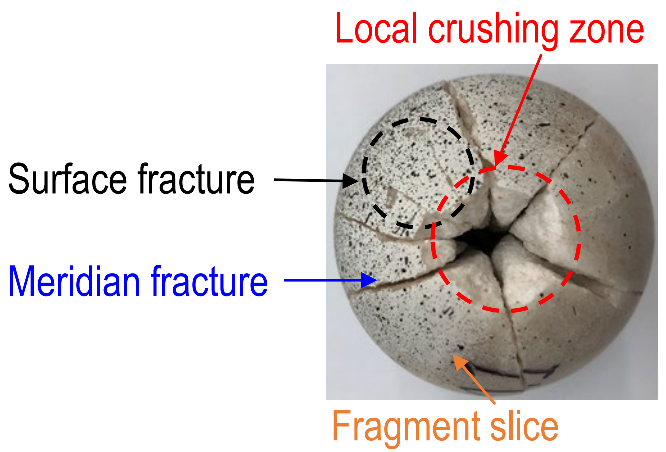
Z displacement (mm)



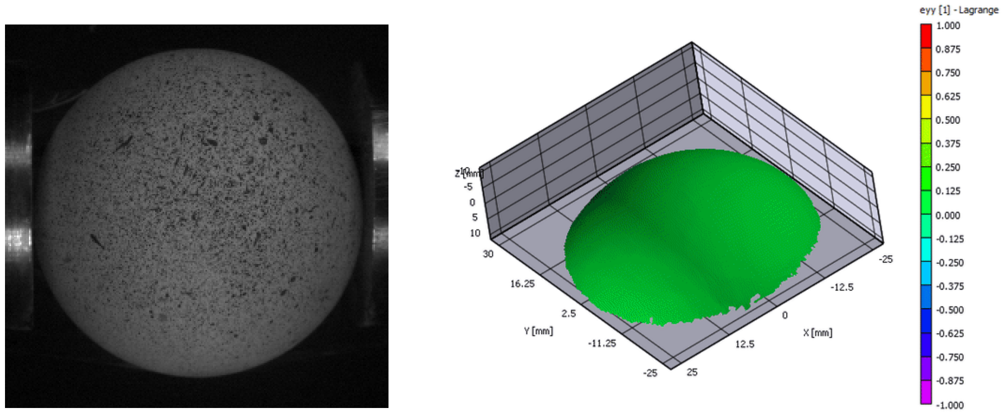
Z velocity (mm)



Double Impact on Rock Spheres

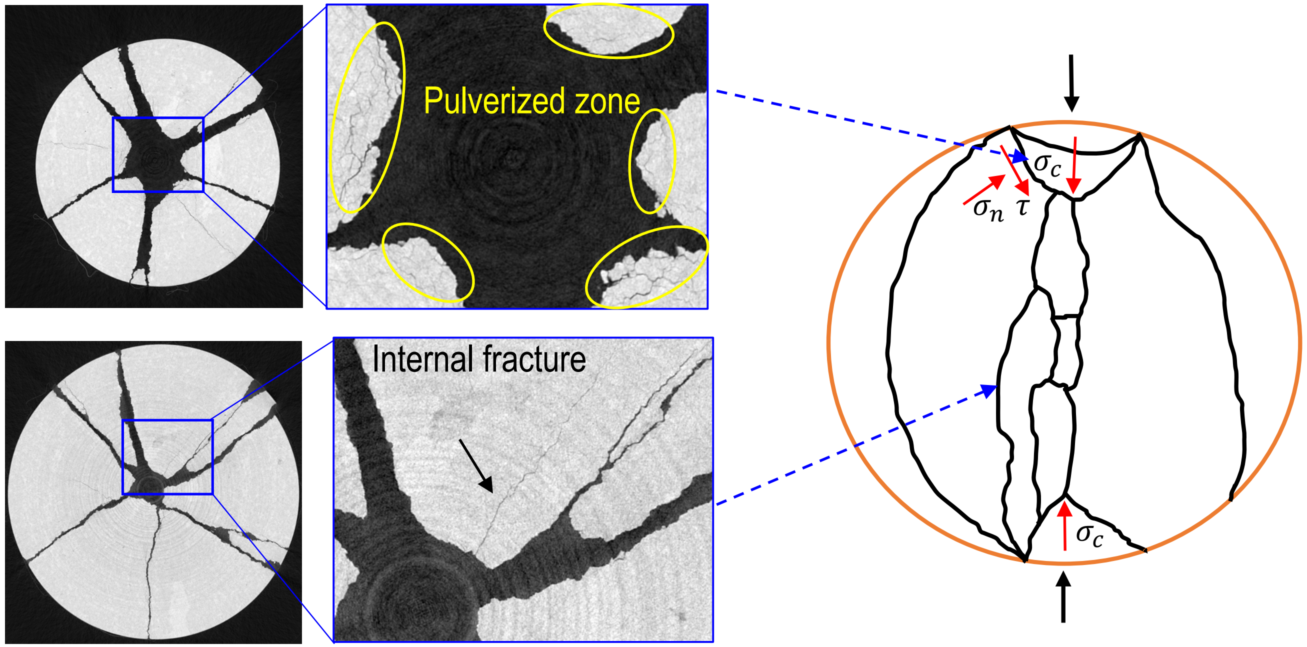


❖ High speed cameras and DIC techniques

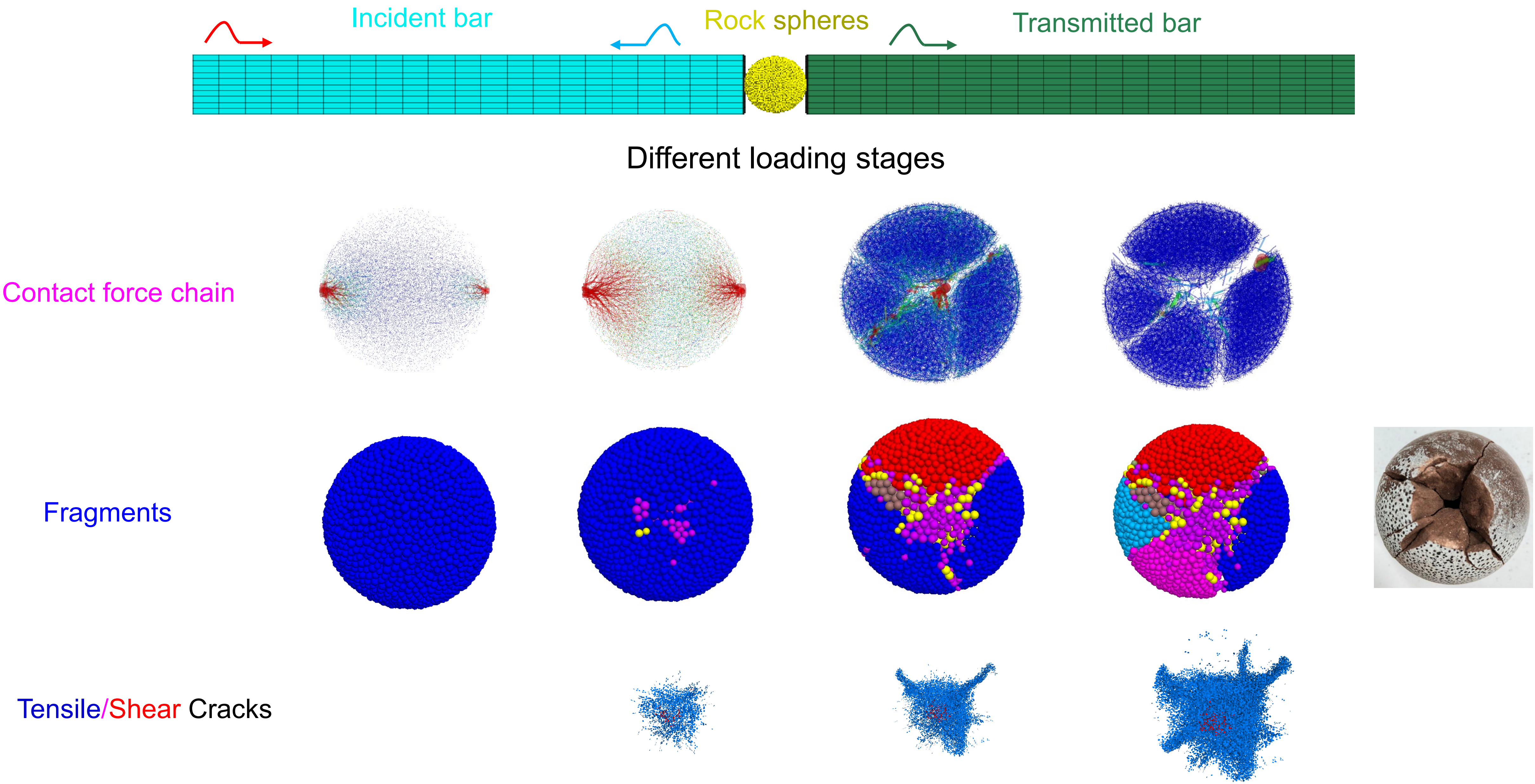


Marble - impact velocity = 9.17m/s

❖ CT slices characterizing fracture and damage



Numerical Modelling of Double Impact Test on Sandstone



Summary and Future Studies

❑ Summary

- The coupled continuum-discrete method can be used to simulate the triaxial Hopkinson bar
- Consideration of rock microstructure represented by 3D FJM contributes to an enhanced dynamic strength
- Similar V-shaped and orange-slice failure pattern of cubic and spherical rock can be observed

❑ Future Studies

- Dynamic constitutive relationship under true triaxial loading condition
- Dynamic fragmentation models considering rock heterogeneity
- Application in prediction of blasting and crushing during mining operations