Tunnelling underneath a heritage-listed building in the heart of Sydney

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- Development of reference DFN
- Development of 3DEC Fracture Networks
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Project Description

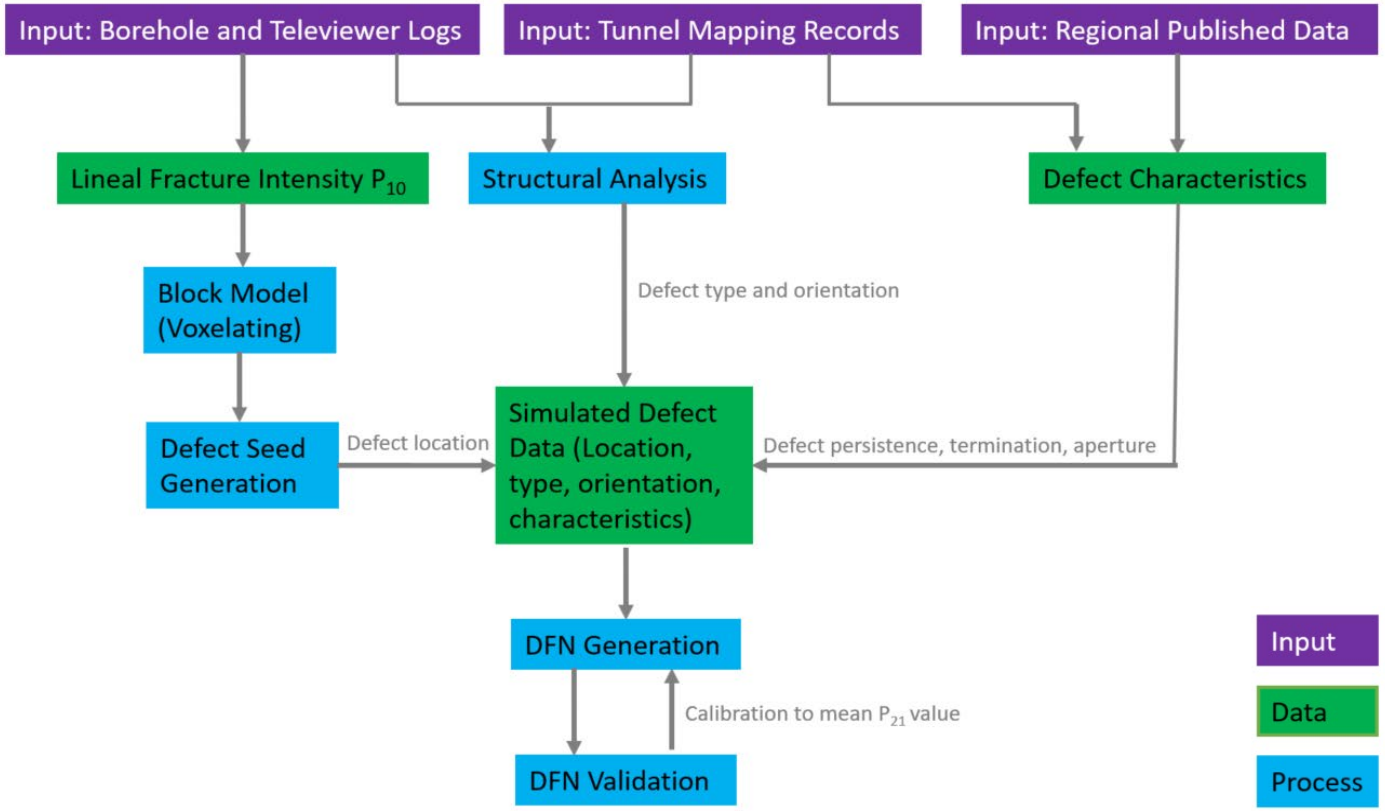
- Tunnel connecting two shafts
  - Length: ~ 65m
- Horse shoe profile
  - Tunnel width: ~ 9m
  - Tunnel height: ~ 6m
- Shallow cover
  - ~ 3.5m cover to pad footings of heritage-listed building
- Pad footings
  - Loads up to 10MN
  - Located centrally above tunnel crown
  - Longitudinal spacing: 5m
- Several underground structures in vicinity

Geologic Conditions

- Hawkesbury Sandstone of the Sydney Basin
  - Coarse-grained quartz sandstone
  - Classified by Pells et al. (1998) into Sandstone Classes (Classes I to V) to group rocks exhibiting similar engineering properties and behaviour.
- Site stratigraphy
  - Upper Layer: 10m Class IV
  - Middle Layer: 15m Class III
  - Bottom Layer: Class II
- Tunnel located ~1m below Class IV to Class III transition
- Major discontinuities
  - Sub-horizontal bedding planes
  - Two orthogonal sub-vertical joint sets (orientated towards NNE and ESE)
- High locked-in tectonic stress horizontal stress

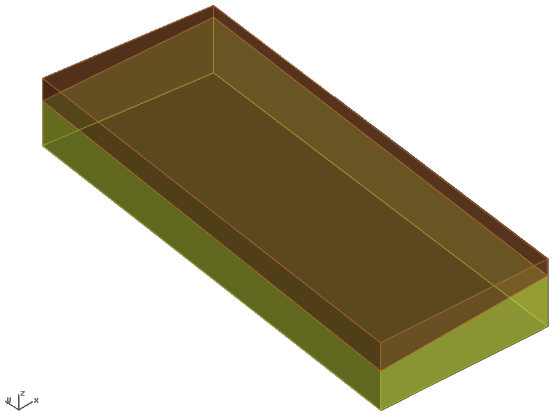
Development of reference DFN

- Discrete Fracture Network
  - Fractures are generated using stochastic processes
- Defect location
  - Voxelization of Model
  - Lineal fracture intensity P_{10} randomly assigned into each voxel
- Defect type and orientation
  - probability of occurrence
- Defect persistence
  - simulated at each fracture seed location

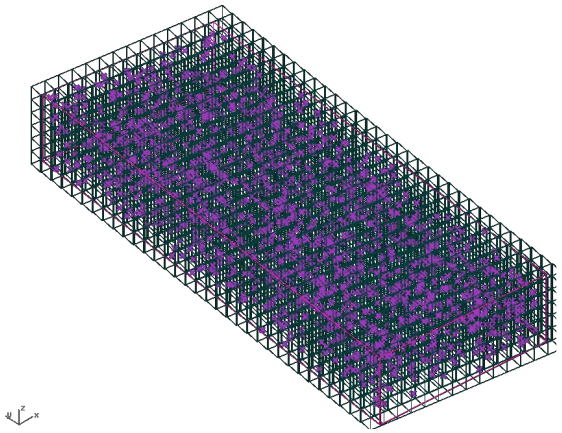


Development of reference DFN

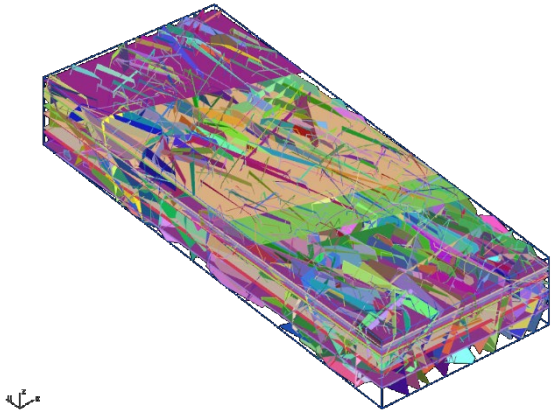
- Input Data Source
  - Borehole Logs
  - Televiewer Logs
  - Tunnel Mapping Records
  - Regional Published Data
- Fracture Types
  - Sub-horizontal bedding
  - Two orthogonal sub-vertical joint sets
  - Random joint set
- Volume of fractured Zone
  - 27.000m^3



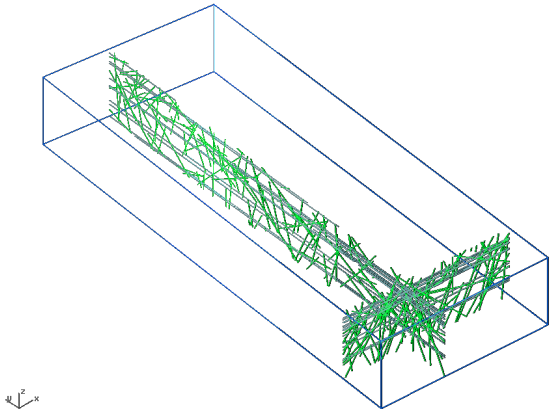
Class IV to Class III transition



Voxelization, assigned seeds



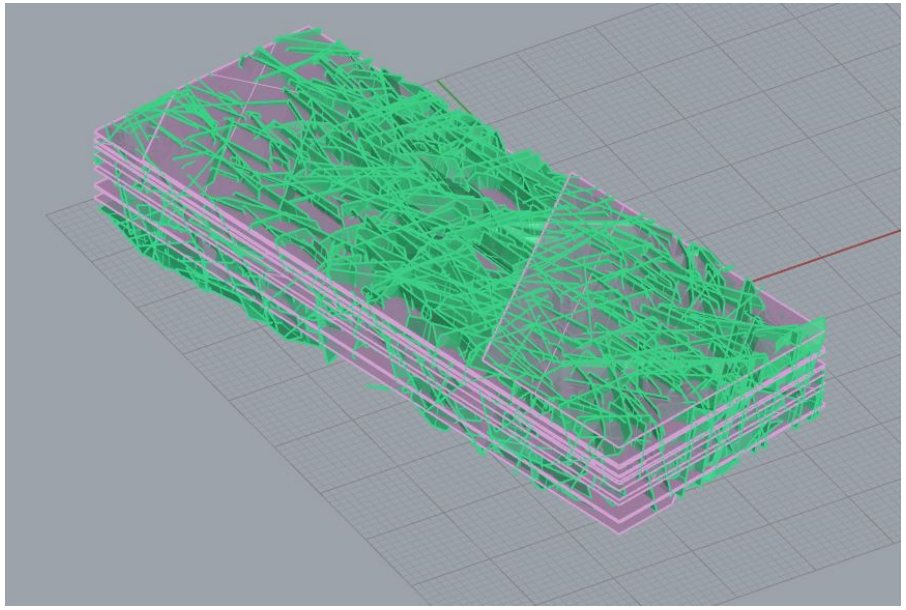
3D DFN



2D Trace Map

Development of reference DFN

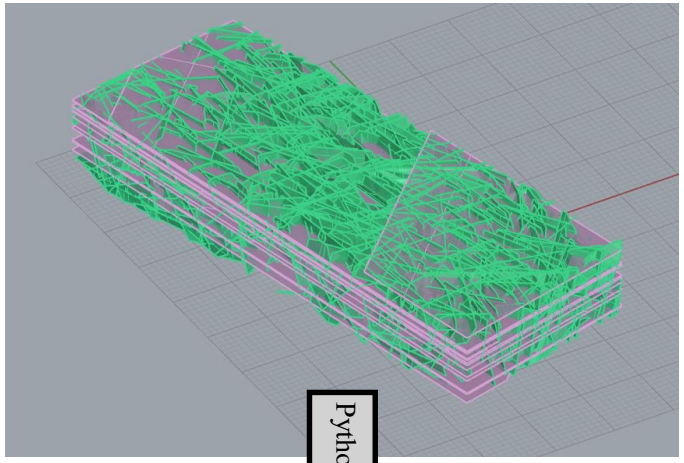
M1: Stochastic DFN



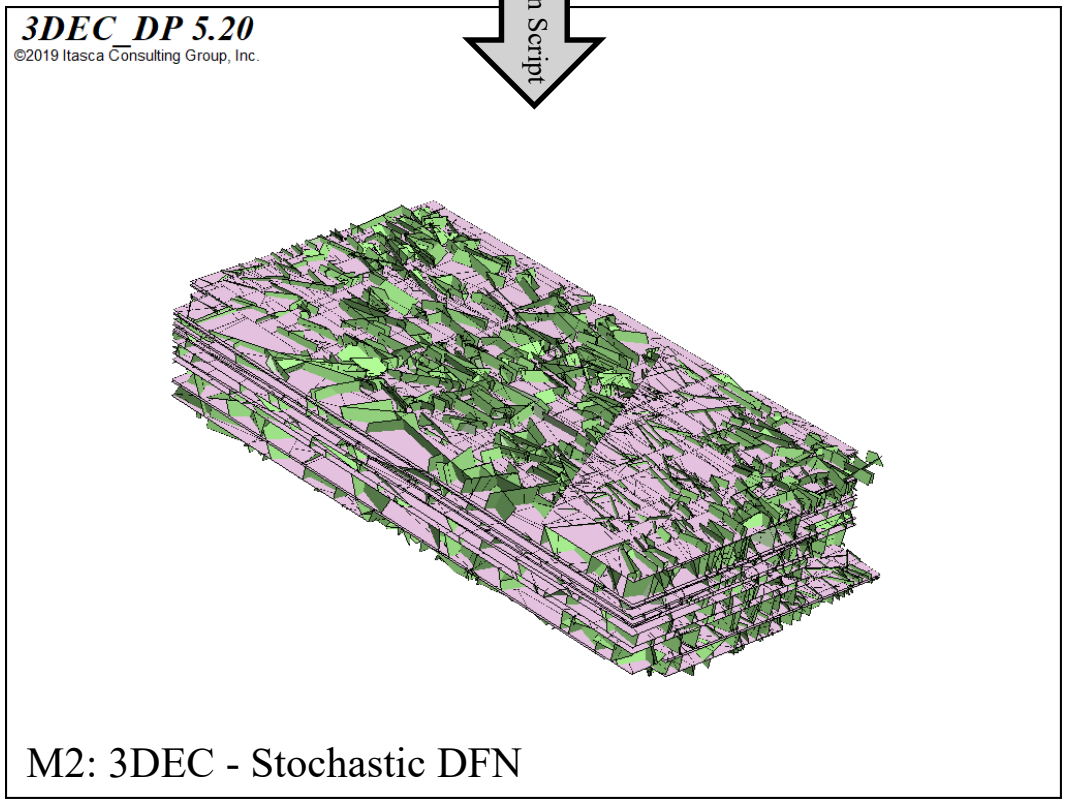
- Validated
  - Comparison of Areal fracture intensity P_{21}
  - Randomly generated cross sections
  - Tunnel mapping records
- Calibration
  - cleaning fracture seeds (remove / add seeds)
  - manipulation of fracture persistence's statistical attributes
- Robustness of DFN
  - Five simulations to ensure model parameter robustness against P_{21} validation

Development of 3DEC Fracture Networks

- Incorporation of ***M1: stochastic DFN***
  - Direct import (*no partial cracks allowed*) – not possible
  - 3DEC in-built *jset dfn* command – not possible
  - Arup developed work flow
- Fracture Network Generation
  - Single *jset* commands for each DFN joint
  - Termination criteria specified by persistence (probability of splitting blocks along the joint path)
- Fracture Network Validation
  - Fisch function for P_{32} – comparison with P_{32} of M1
  - Adjusting fish variable for persistence/probability
  - Export trace map – evaluate P_{21}



Python Script



M2: 3DEC - Stochastic DFN

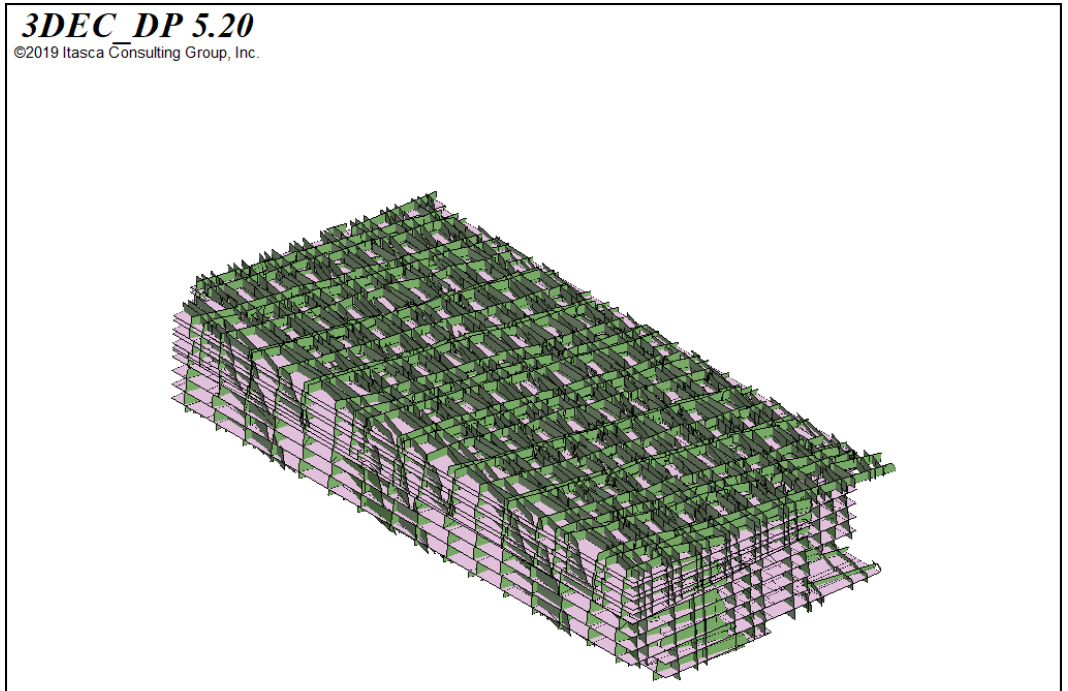
Development of 3DEC Fracture Networks

- Fracture characteristics based on published data
  - Standard deviation for dip and dip direction
  - Comparison of published data vs. DFN approach
  - Sanity check of results

Defect Type	Dip Angle [°]	Dip Direction [°]	Spacing [m]	Trace Lengths [m]
Bedding	0 to 5	160 to 200	1 to 5	>100
Cross Bedding	15 to 30	0 to 45	0.2	<4
Joint 1	70 to 90	100 to 140	2 to 10	H[1]: >10m, V[2]: 30%>10m, 40% 5-10m, 30% <5m
Joint 2	70 to 90	350 to 020	2 to 20	H[1]: >10m, V[2]: 30%>10m, 40% 5-10m, 30% <5m

Notes:
[1] Horizontal direction.
[2] Vertical direction.

After Bertuzzi & Pells, 2002. Class III Sandstone



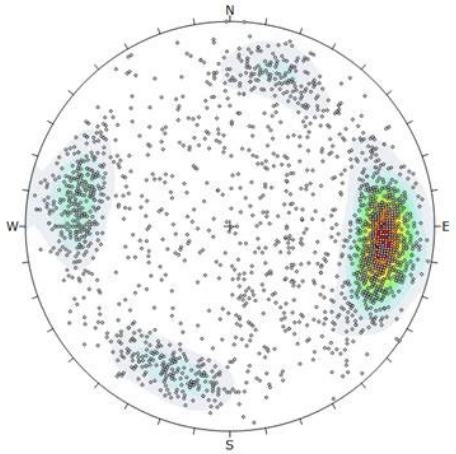
M3: 3DEC - manually generated fractures

Comparison of Fracture Networks

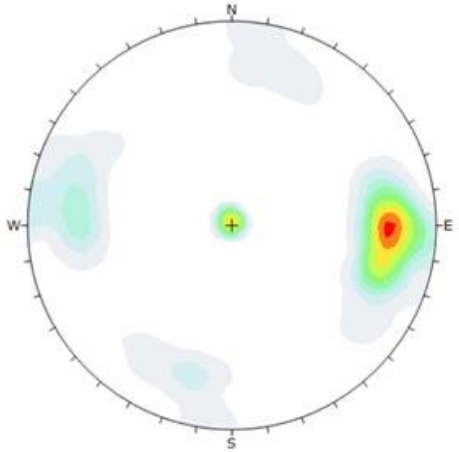
- Fracture Intensity
  - Areal fracture intensity P_{21}
  - Volumetric Fracture Intensity P_{32}
- Stereo plot

Model	Class	No. of sections	P_{21} – east-west	No. of sections	P_{21} – north-south	P_{32}
Tunnel Mapping (adjacent tunnels)	III	17	average: 1.70 (0.92 – 2.90)			-
	IV	26	average: 2.32 (0.72 – 4.39)			-
M1: Stochastic DFN	III	10	1.82	10	1.54	2.06
	IV	10	2.48	10	2.12	2.51
M2: 3DEC – Stochastic DFN	III	7	1.88	3	1.71	1.96
	IV	7	3.1	3	2.76	2.57
M3: 3DEC – manually generated fractures	III	2	1.21	2	1.19	1.39
	IV	2	2.37	2	2.02	2.33

M1: Stochastic DFN

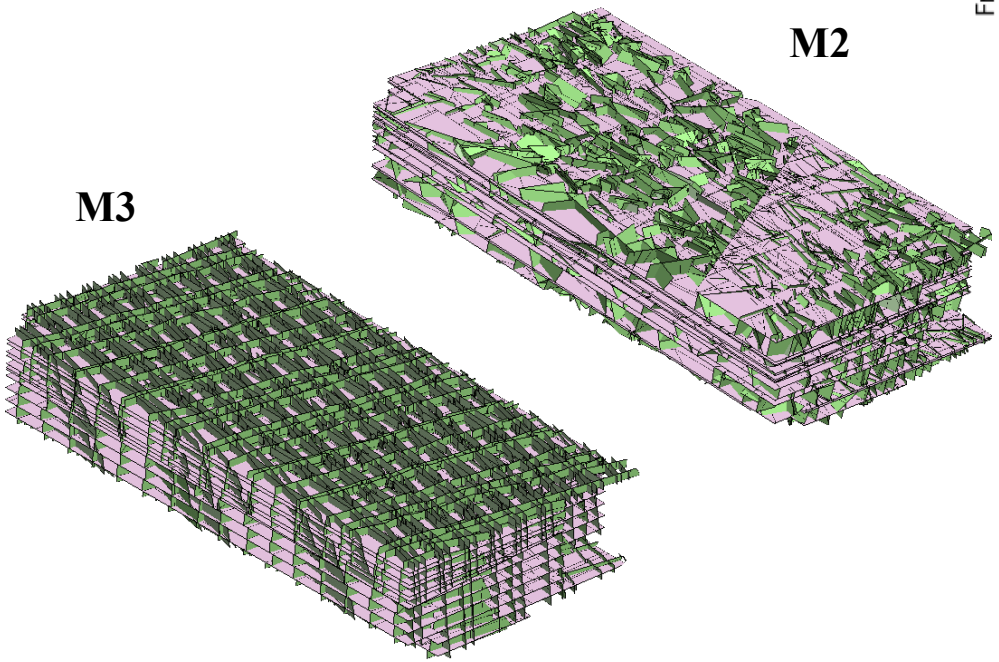


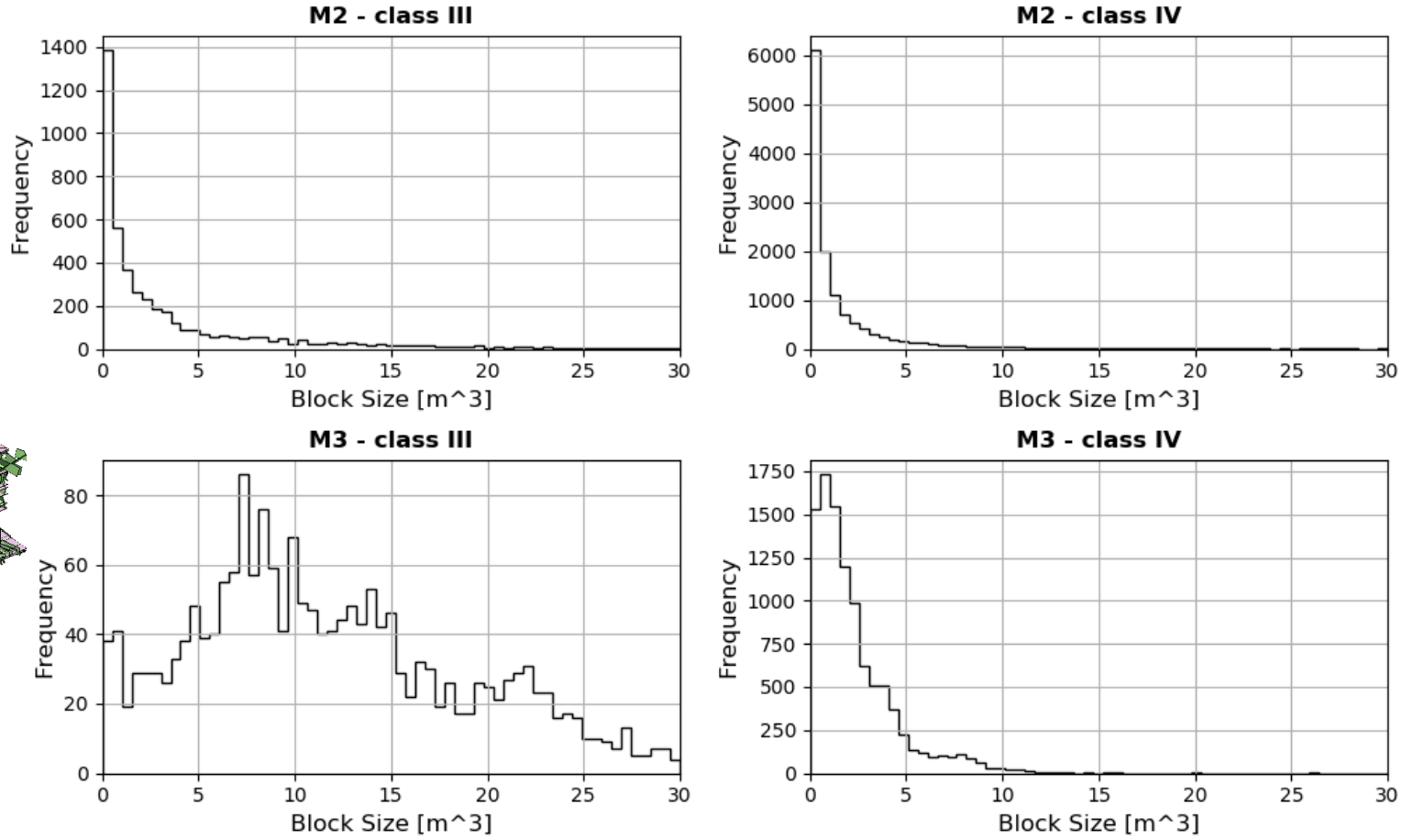
M2: 3DEC - Stochastic DFN



Comparison of Fracture Networks

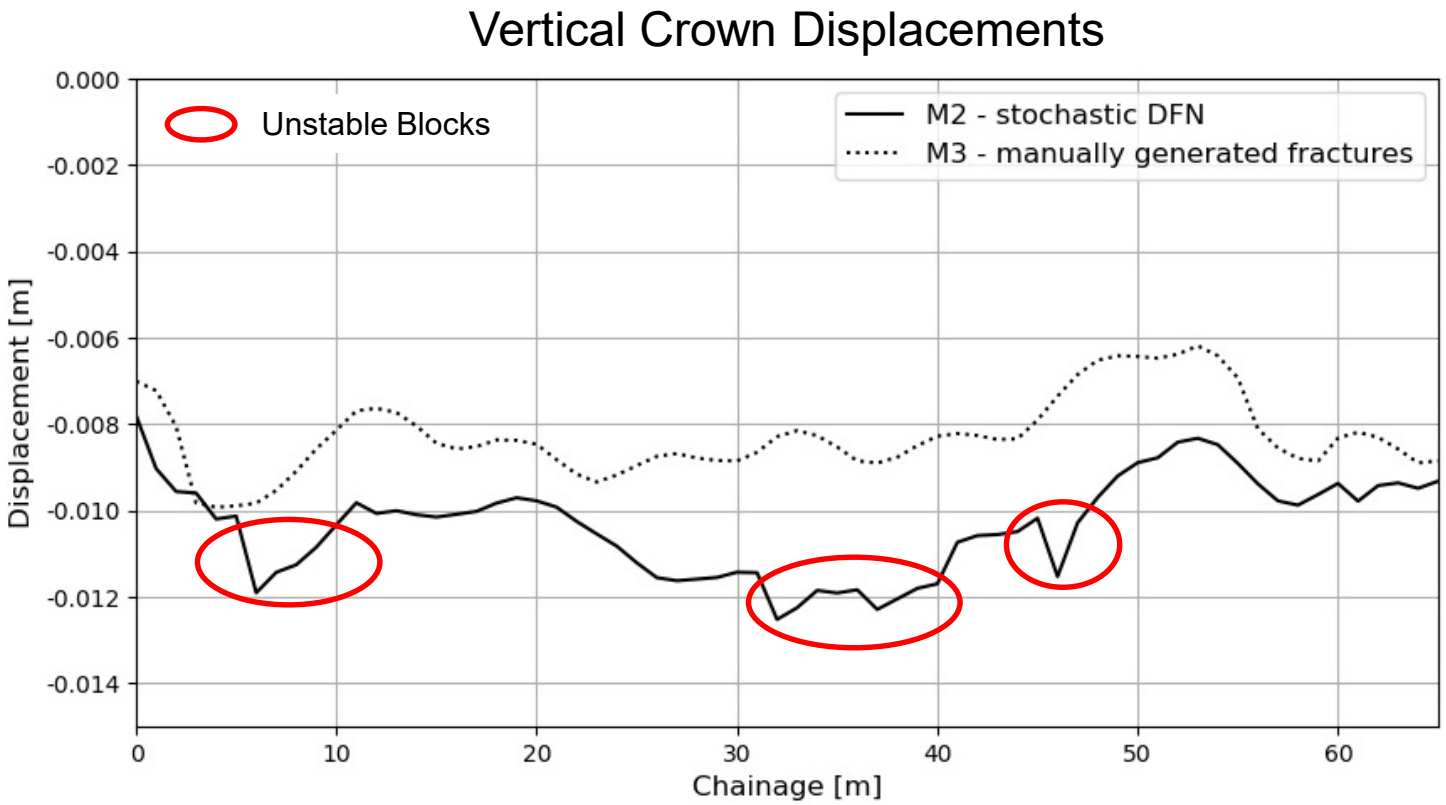
- Comparison of *3DEC – Stochastic DFN* and *3DEC – Manually generated fractures*
- Visual Comparison
- Block Size Histogram
  - Underestimation of small blocks





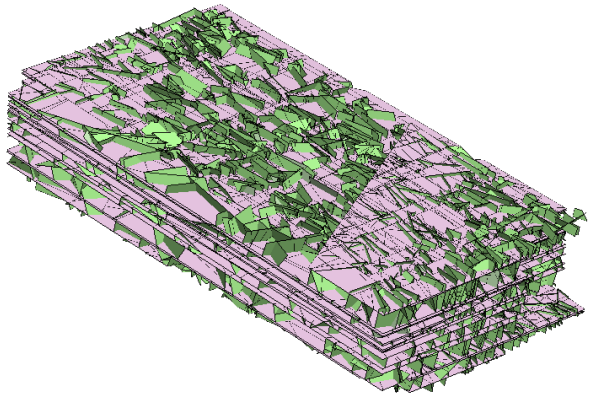
Numerical Analyses – 3DEC

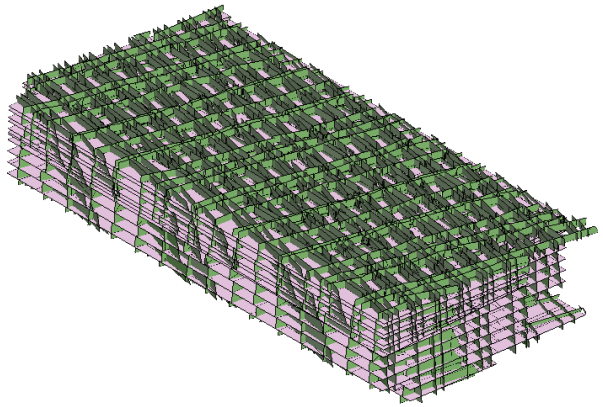
- Similar displacement pattern
- Manually generated Fractures
  - Lower magnitude due to lower fracture intensity
  - No unstable blocks
- Stochastic DFN
  - Potentially unstable blocks



Conclusions

- Incorporation of stochastic generated DFN in 3D numerical analyses
- Large amount of borehole data and tunnel mapping records allowed to calibrate and validate stochastic generated DFN against the site specific
- Manually generated fracture networks result in unrealistic block size distributions
- Fracture networks purely based on literature show too low fracture intensities
- 3DEC input DFN can easily be exchanged for multiple simulations





Glück Auf!

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