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Underground Pumped Hydro Energy Storage Project (UPHES SRG)
Stakeholder Reference Group

MINUTES: Meeting 4

Date	14/04/2022	
Time	4.00pm – 5:05pm	
Venue	Online due to COVID-19 precautions	
Independent Chair	Abigail Goldberg	Chair and Director, GoldbergBlaise
Invitees	Ms Robyn Charlton Mr Ray Robinson Mr Trevor James	Newstan-Awaba CCC & Lake Macquarie Sustainable Neighbourhoods Alliance Myuna CCC Mandalong CCC & Mandalong MCA
Observers	Mr Tim Couchman Mr Anthony Margett Mr Ryan Skinner	ARENA DPE - Mine Safety NSW Emerging Energy Program (observer)
In attendance	Mr Matthew Fellowes	Banpu Energy Australia
Apologies	Mr Peter Leven Mr Glenn Bunny Mr James McDonough	Awabakal & GuriNgai Pty. Ltd Lake Macquarie City Council DPE - Energy, Resources and Industry

Agenda item		Action
1.0	**Welcome** The Chair welcomed participants and advised apologies.	
	Declaration of interests No new interests were advised.	

2.0	**Overview of project progress**
	An update of project progress was provided by Matt Fellowes, who addressed:
	Summary of conclusion of Stage 1 Research Program – technical viability:
	• Overview of project progress:
	  ○ Re-cap of modelling mechanics and test program
	  ○ Reservoir modelling behavior – water
	  ○ Water transfer implications for goaf gases.
	• Summary of outcomes:
	  ○ The modelling indicated that the underground coal mine goafs could only support a viable 8 hour generation with complimentary pump out cycle if very low goaf loading of circa 3MPa and less exists. This loading environment would unlikely support a financially viable development.
	  ○ As such only partial extraction areas or deeper mines with strong geological sequences that can span and shield the goaf rock piles from load will offer viable options	

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A marginal 8 hour cycle was modelled for a sub-critical panel layout. For the base case, 37% of water was needed to initially fill the lower reservoir (dead storage) to prevent cavitation during the pump-out cycle. This represented the loss of 10% net head for the modelled scenario.
The mass transfer of water as modelled induced unmanageable goaf gas atmosphere outcomes for most mines.
Only non-gassy mines with very low propensity to spontaneous combustion could be considered
Leakage rates through seals are too high
Small ventilation shafts to the surface as proposed by other countries were not considered viable
The high leakage rates will lead to significant oxygen ingress during pump out cycles. For goaf's with high methane contents, these goaf atmospheres would eventually pass through the explosive range. This would be an unacceptable outcome.
The gas modelling analysis was considered adequate for this stage of the research and produced conclusive outcomes, albeit for a generic set of base models. Bespoke details of a mines layout, specific emission & gas mixture, ventilation arrangements including coal seam contours and using complex multi-phase modelling would be needed if a project progressed.

Overall, the research indicates that the pumped hydro model under consideration in Australian conditions is not viable, and not worth progressing, at this stage.

The PPt presentation from the meeting is attached to the draft Minutes and will be posted online with the final Minutes.
Next steps:

Research findings to be reported to BANPU Board on 22 April 2022
Discussions to follow with funding agencies
Communication to SRG regarding next steps anticipated in May
Knowledge-sharing report still to be prepared – target is June.

Participants discussed:

Whether Newstan or Mandalong mines had greater potential. Discussion indicated that neither had viable potential until after 2030 and by then it is unlikely that extra 8hr duration pumped hydro will be needed.
Competing energy storage technologies including the rise of large utility scale chemical batteries, which are proving to be highly capable of supporting the renewables transition and cost effective at longer durations.
The complexities of the trial, professionalism of the approach, and objectivity of the researchers.

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<td>Other business
No other business was raised.</td>
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4.0	**Roadmap for meetings going forward** The roadmap for meetings going forward is dependent on whether the BANPU Board and funding agencies consider the trial to be worth progressing. SRG members are expected to be advised of next steps in May 2022.	
5.0	**Thanks and close** The Chair closed the meeting with thanks to participants and stakeholders, as well as the research team, at 5:05pm.	

Underground Pumped Hydro Energy Storage (UPHES)
Stakeholder Reference Group
Meeting 4 – 14 April 2022

Project Proudly Funded by:

NSW GOVERNMENT | Planning, Industry & Environment

Australian Government
Australian Renewable Energy Agency
ARENA

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The views expressed within this document are those of Banpu Energy Australia and do not necessarily represent views of the other funding partners

Presentation content

Overview of project progress

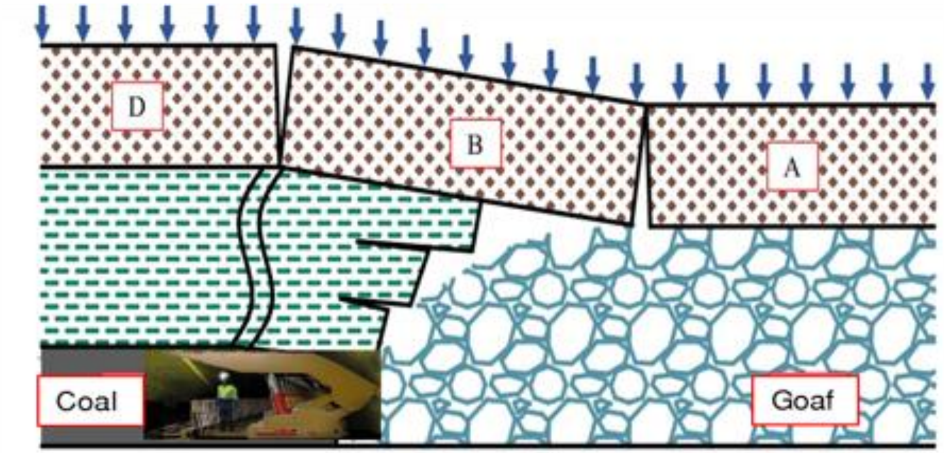
- ❖ Re-cap of flow modelling mechanics & test program
- ❖ Reservoir modelling behaviour – water
- ❖ Water transfer implications for goaf gases
- ❖ Next steps

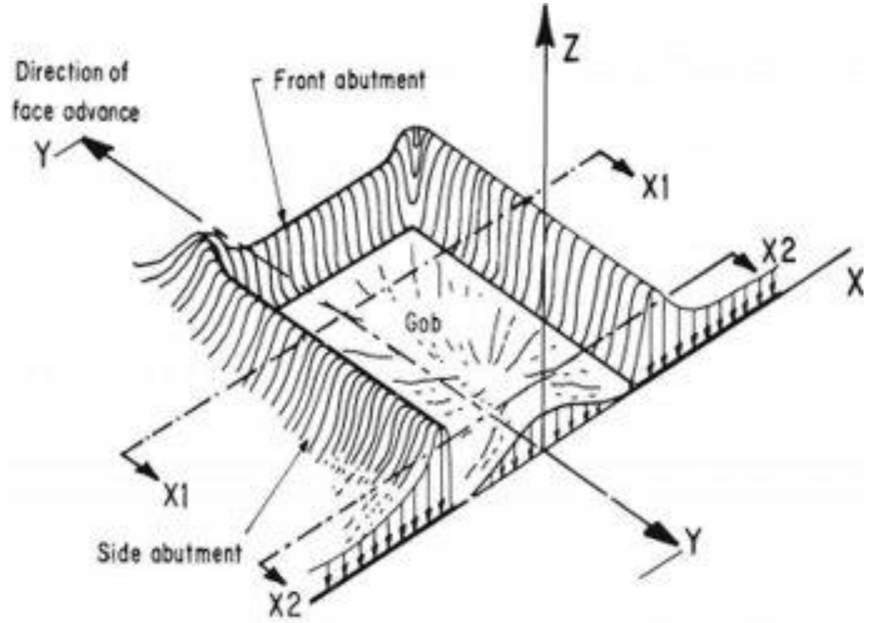
Re-cap of flow modelling mechanics and test program

UPHES SRG Meetings - Presentation content

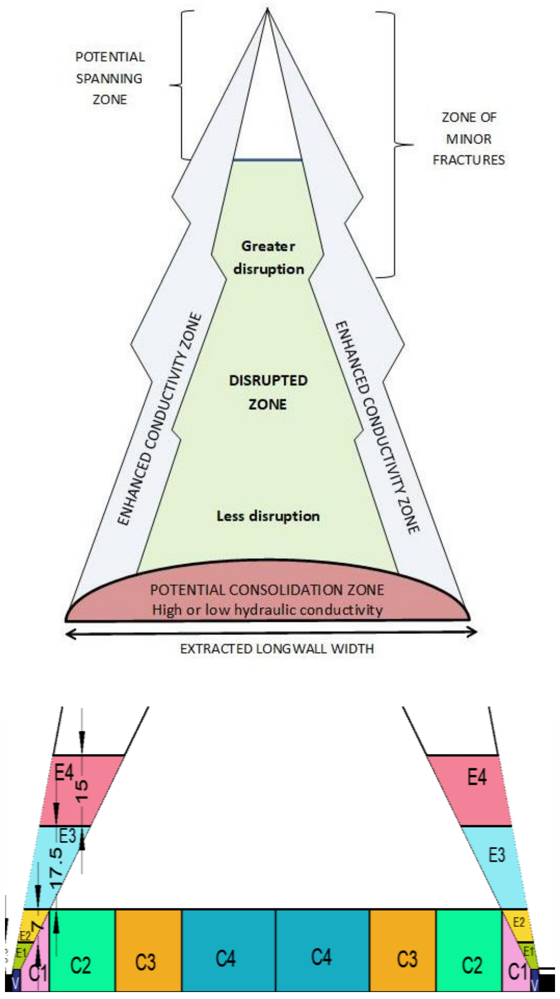
- Meeting 1 – Introduction to the Research Program
- Meeting 2 – Insight into goaf formation and fracture models & early research findings
- Meeting 3 – Large scale test program & relationship between permeability and porosity

UPHES hydro-geology re-cap





Collapse & fracture model



- Mine subsidence and goaf load profiles will vary from mine to mine
- The goaf load profile and hence flow mechanics within any goaf is complex & difficult to verify
- The research has been designed to determine the changes to the rock matrix within the goaf such that the 'hydro-geological flow' behaviour within a given 'goaf reservoir' can be assessed using 3D numerical modelling

Start position - Goaf Consolidation – upto 500m depth

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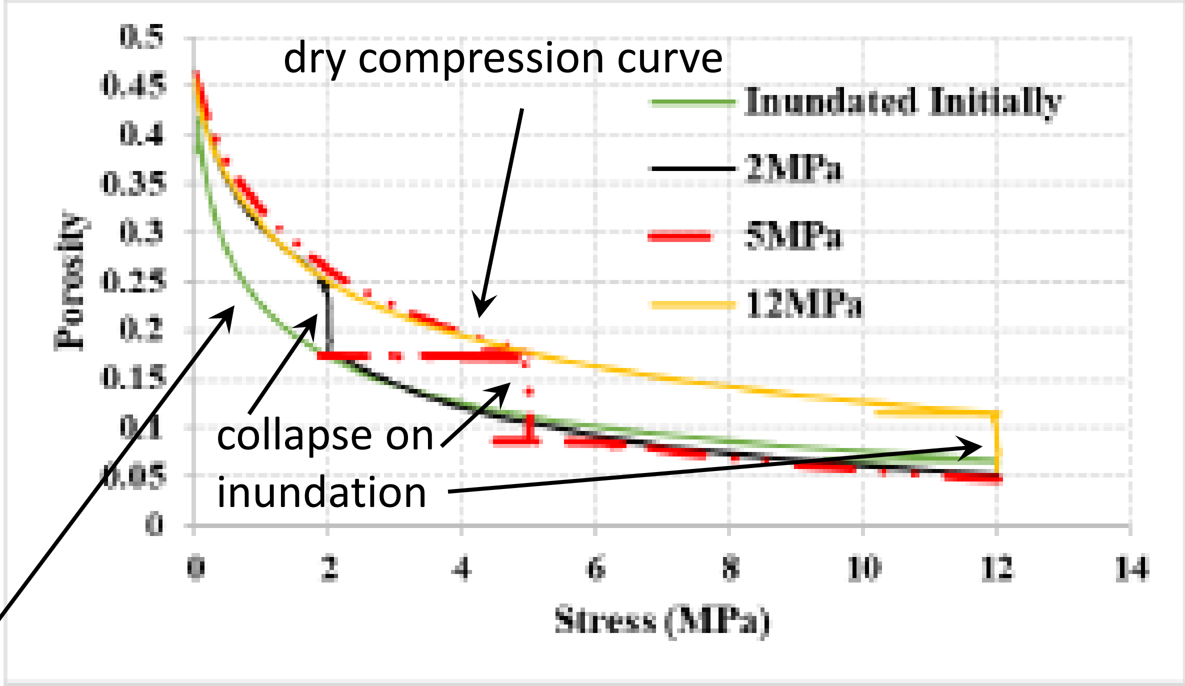
- 300 mm diameter x 250mm high specimens; 4 rock types, 4 stresses.
- Confirmation of expected role of water in decreasing porosity
  - compare yellow (dry) and green (inundated) compression lines

(a) (b)

Figure 6 Typical index test specimen: (a) before the test, (b) after the test (wet and consolidated).



wet compression curve

Permeability testing – lab and scale up

Collapse on saturation tests

- 550 mm diameter tests
- Stresses of 0.25, 1, 2, 3.5 and 5 MPa
- Porosity and permeability vs stress data
- Indicative hydraulic conductivity values from falling head test on collapsed samples

From L-R Saturated induced collapse test before, during and after (using goaf material)

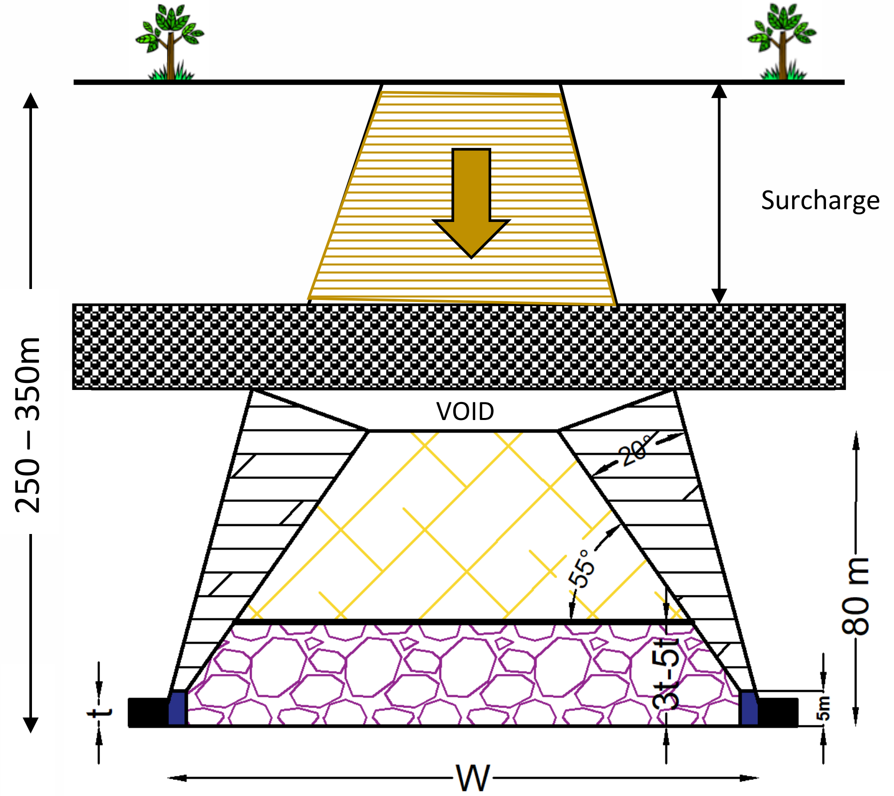
Large scale permeameter

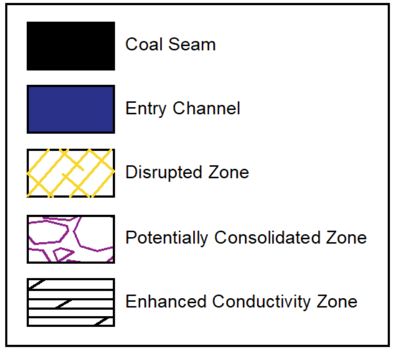
- 2.4m diameter x 2.4m high
- Could take individual rocks ~ 800mm
- Rock size recipe based off digitised UG photo's

Test rig under construction & in operation

Reservoir modelling behaviour - water

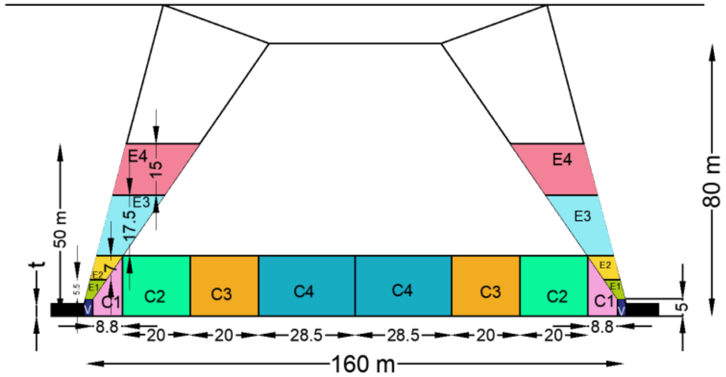
2D Geometry, Subcritical



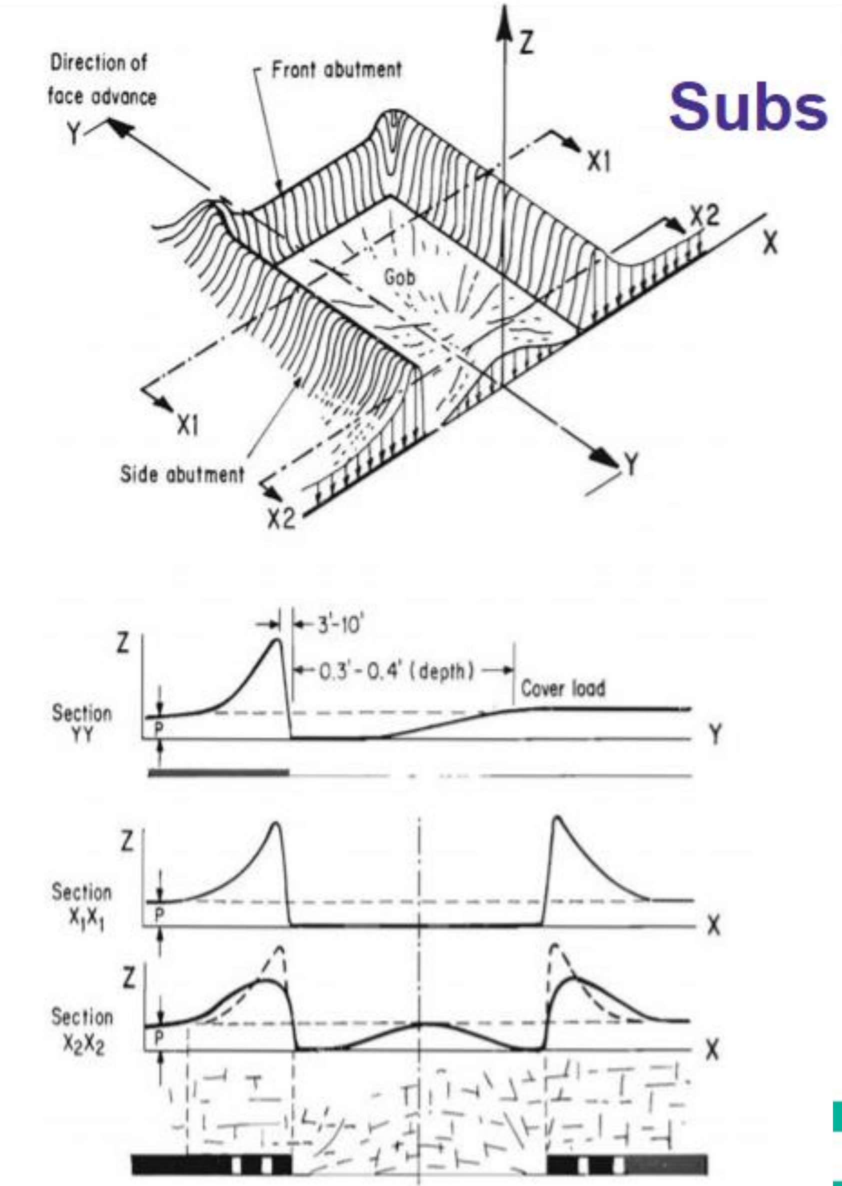


Example mine 250 – 350m deep but goafs behave as though only 80m deep

Geometry is divided to different zones based on the overburden stress distribution and crack density model. Disrupted zone and Enhanced conductivity zones (above 50 m) are considered impermeable and only coloured zones are included in numerical modelling.

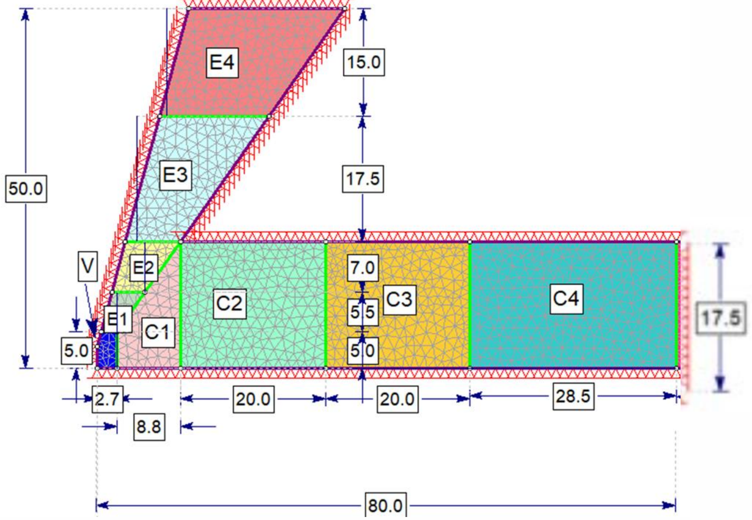


Stress Distribution

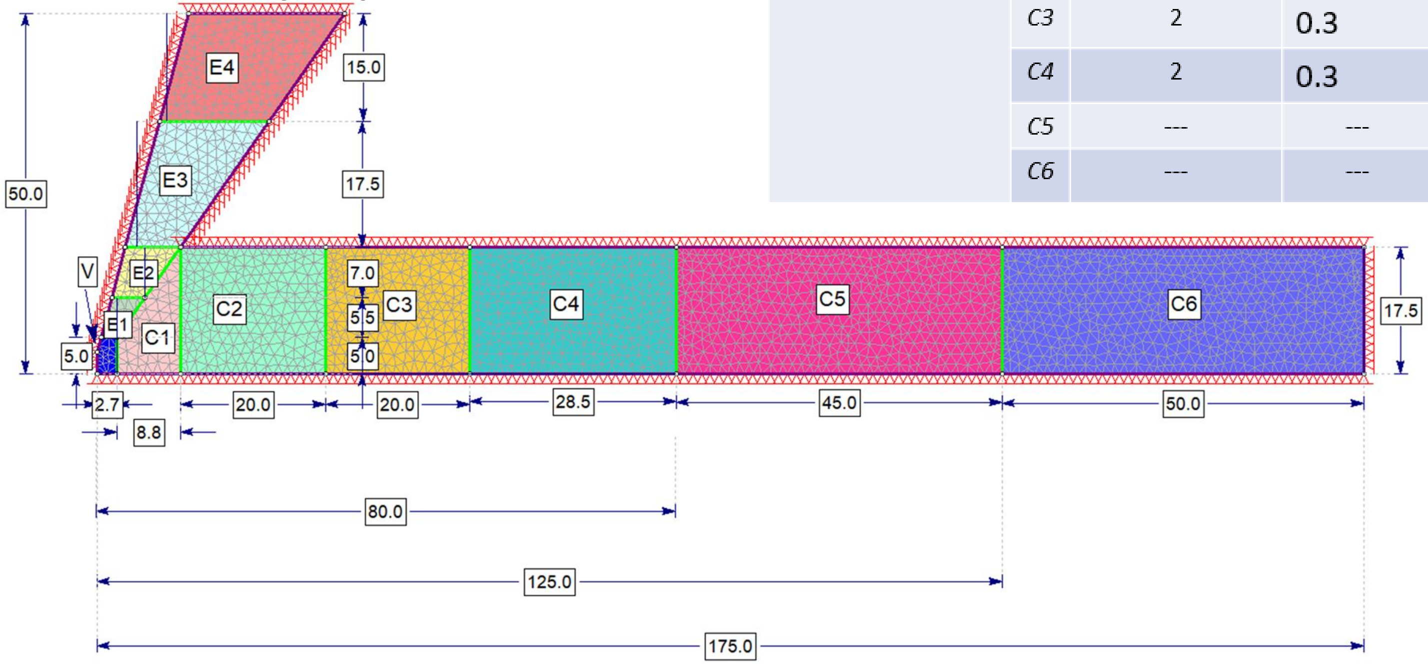


Difference between sub-critical and super-critical extraction

2D Geometry, Subcritical, w=160m



2D Geometry, Supercritical, w=350m

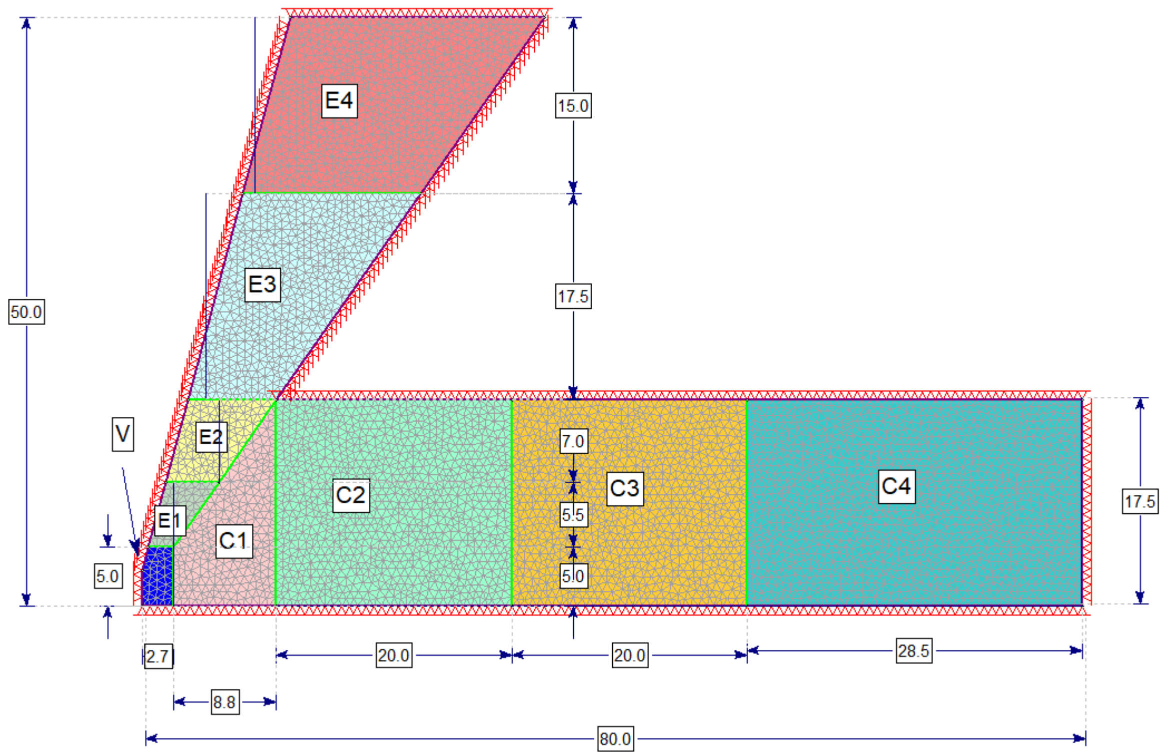


		Subcritical				Supercritical			
Zones		**Stress (MPa)**	**Porosity**	**K (m/s)**	**k (m2) at 20 °C**	**Stress (MPa)**	**Porosity**	**K (m/s)**	**k (m2) at 20 °C**
Entrance Channel	*V*	0.2	0.6	50	2.047E-07	0.2	0.6	50	2.047E-07
ECZ (first layer)	*E1*	---	0.5	10	2.047E-09	---	0.5	10	2.047E-09
ECZ (second layer)	*E2*	---	0.2	10	2.047E-09	---	0.2	10	5.116E-11
ECZ (third layer)	*E3*	---	0.015	1	2.047E-09	---	0.015	1	1.023E-11
ECZ (fourth layer)	*E4*	---	0.006	0.03	5.116E-06	---	0.006	0.03	2.047E-12
Potentially Consolidated Zone	*C1*	0.7	0.42	2	1.023E-06	0.7	0.42	2	1.023E-13
	C2	2	0.3	0.02	1.023E-06	2.1	0.3	0.02	5.116E-06
	C3	2	0.3	0.02	1.023E-07	3.9	0.18	0.0005	1.023E-06
	C4	2	0.3	0.02	3.070E-09	4.5 to 6.2	0.15	0.0001	1.023E-06
	C5	---	---	---		4.5 to 12	0.12	0.00002	1.023E-07
	C6	---	---	---		4.5 to 12	0.08	0.000001	3.070E-09

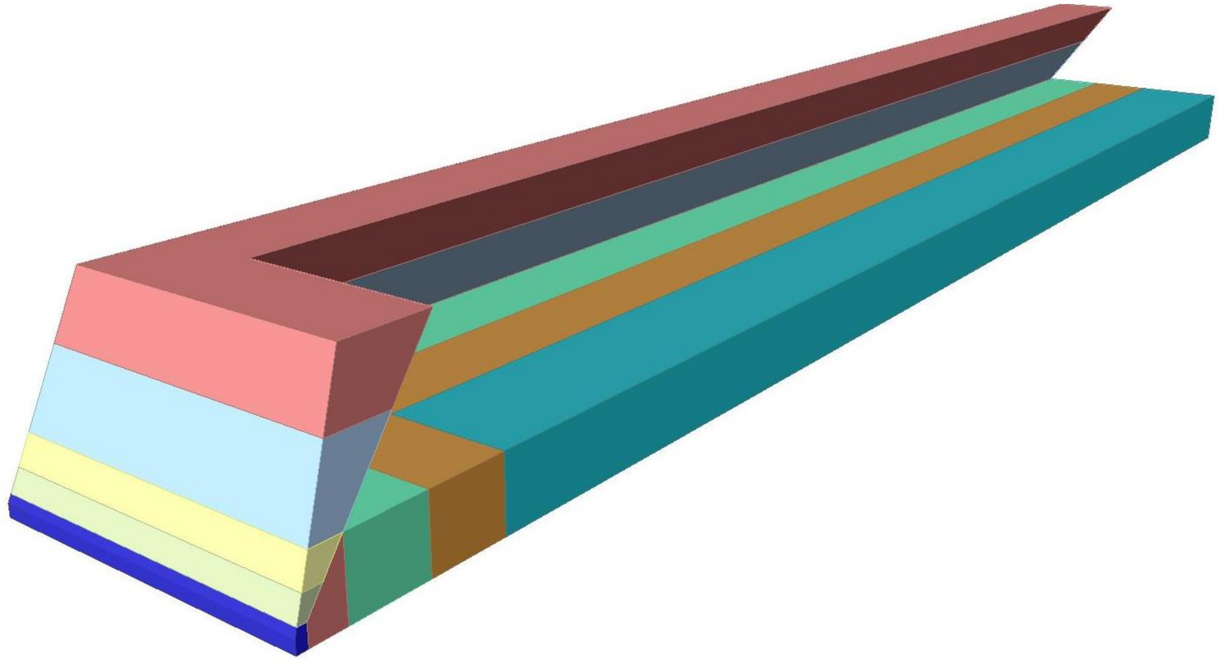
Numerical modelling – Sub-critical

2D geometry of the numerical modelling, Subcritical

Half of the geometry is considered in numerical modelling because of the symmetry.

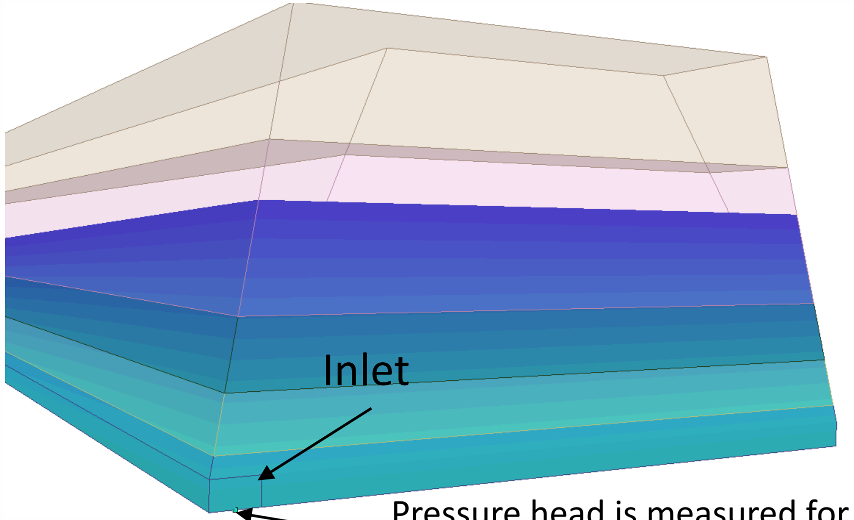


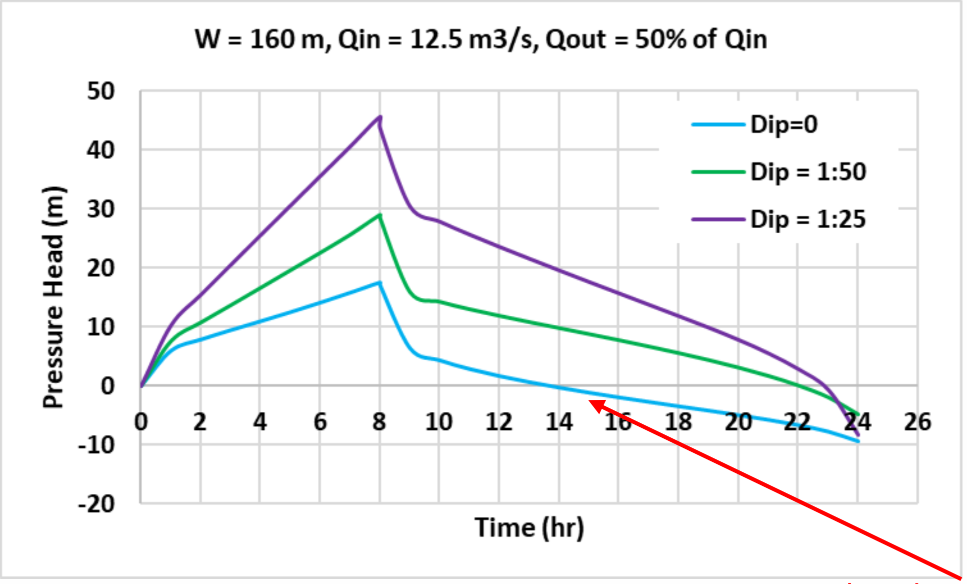
3D geometry, Subcritical – half geometry

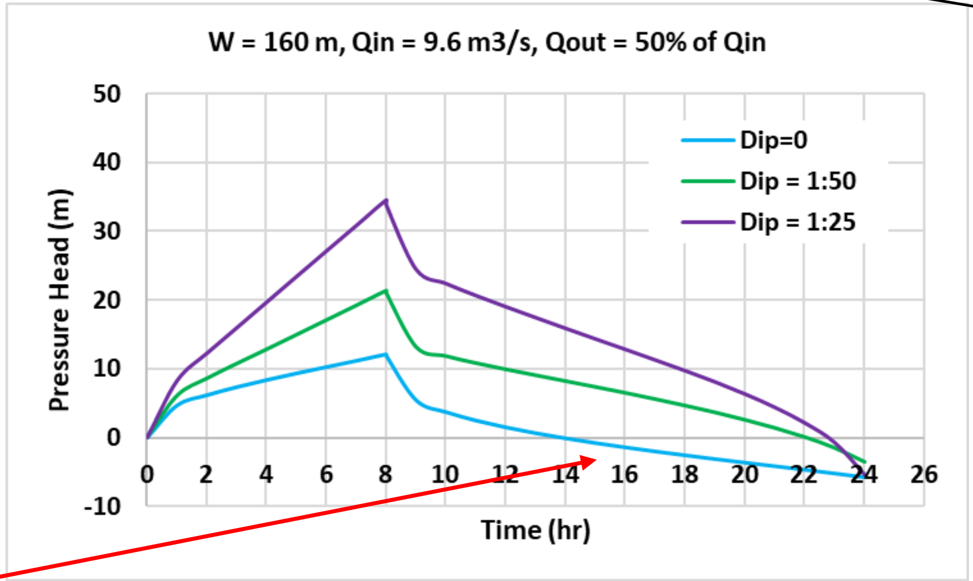


3D preliminary results, Subcritical

Model was set for optimal outcome – water volume flow rate of 25m3/s per panel (60MW) generating and pumping for 8 hours (slower rates also modelled – RHS graph)





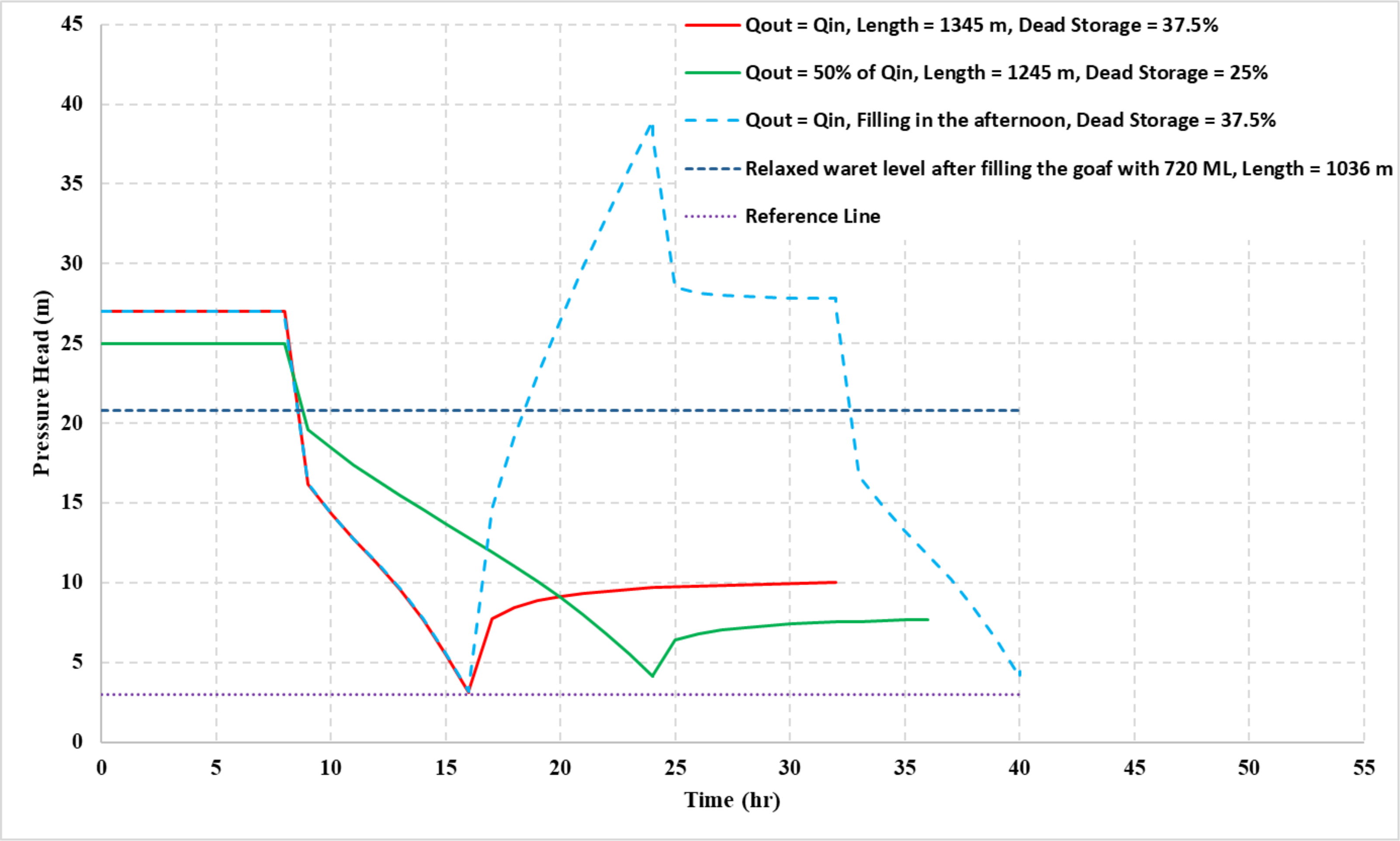


Negative pressure head means that cavity is formed.

Lmax:
Dip=0, L=3000 m
Dip =1.15, L=1058 m
Dip = 2.3, L=970 m

Lmax:
Dip=0, L=3000 m
Dip =1.15, L=815 m
Dip = 2.3, L=750 m

Pumping out scenarios, Subcritical, Dip of 1:50



Duration (D), Real Time (RT)

D (hr)	RT (hr)	Function
8	12 am to 8 am	Relaxing
8	8 am to 4 pm	Pumping out
8	4 pm to 12 am	Filling
8	12 am to 8 am	Relaxing
8	8 am to 4 pm	Pumping out

5 Days cycles, Subcritical, Dip of 1:50

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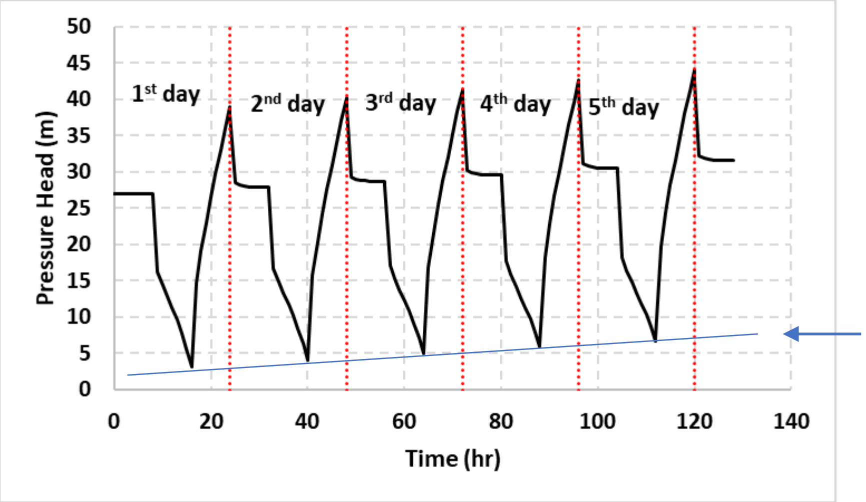
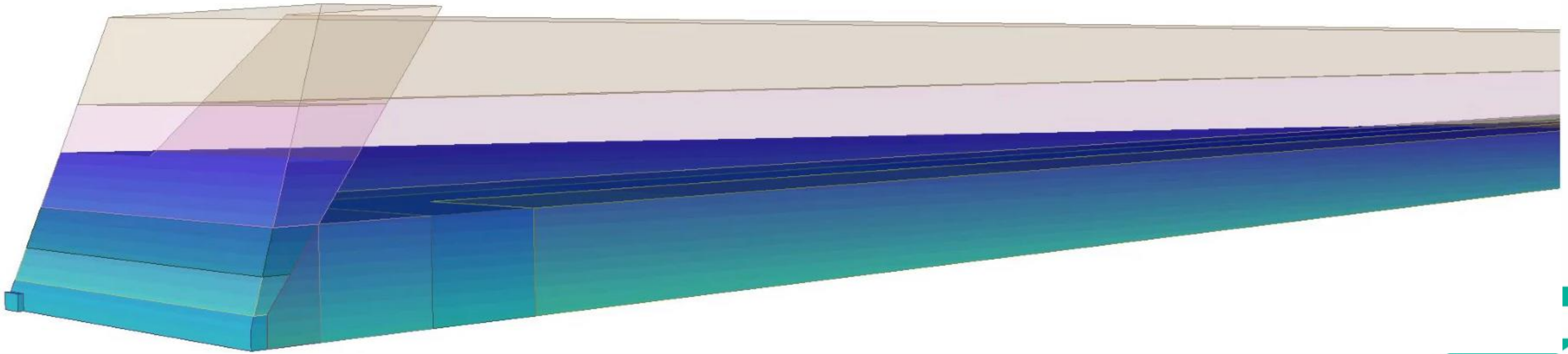
Calculations are based on the coarse mesh, average mesh size 2 to 3 m, 1.9 M finite elements.
Finer mesh is still running, average mesh size 1.5 to 2.5 m, 4.8 M finite elements.

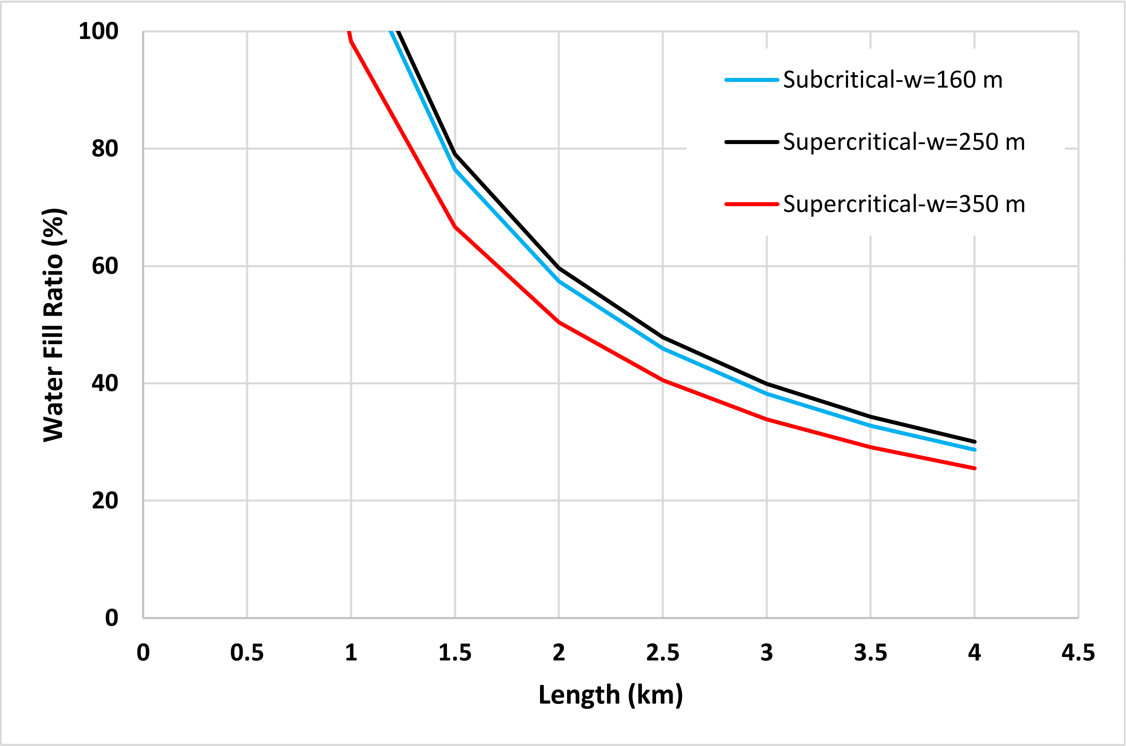


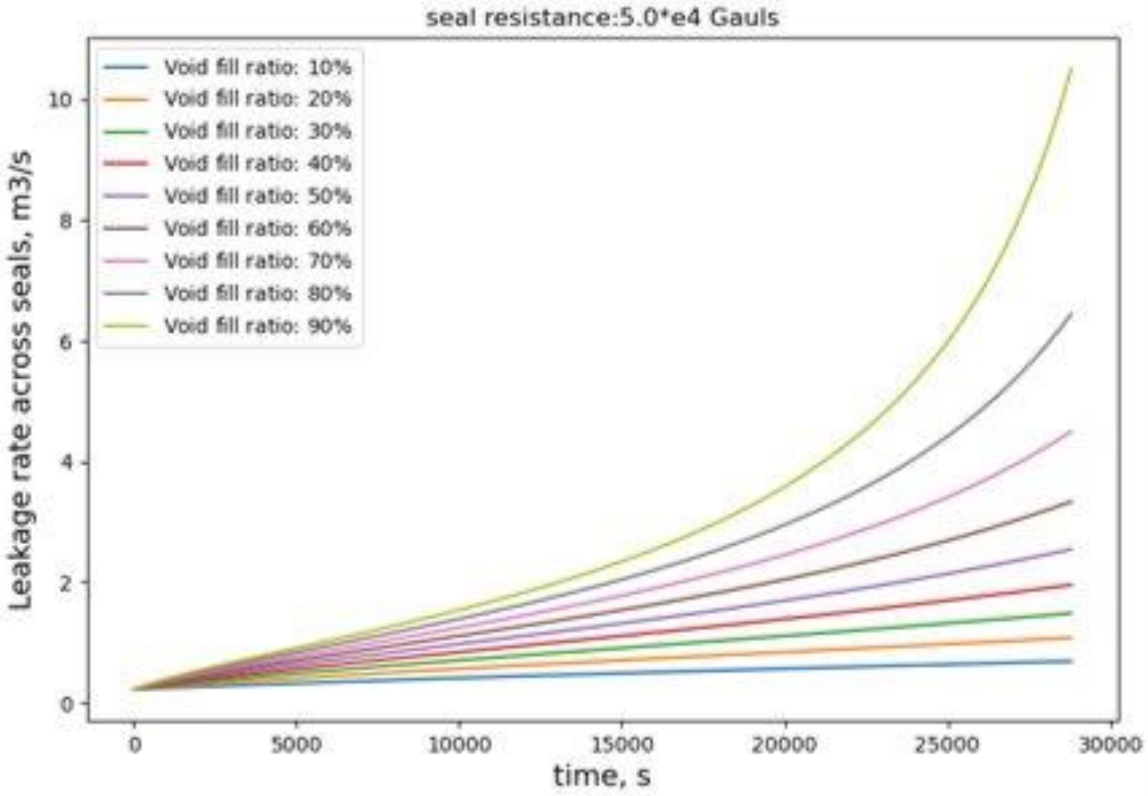
NB: Slight gain in water over 5 day cycle – which can be reset on the weekend



Water transfer implications for goaf gases

Gas pressure and leakage changes





Goaf Gas implications

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- Sealed goaf's were modelled using Universal Gas Laws, with water fill rates matched to the 8 hour generation cycle
- Industry standard final seals were modelled
- Sensitivities were modelled for final seal resistance, specific emissions, atmospheric pressure changes, laminer v turbulent flow, migration to higher voids via fracture networks that water can't occupy and considering different panel lengths including dissipating pressure options to adjacent underground sealed storages

Summary of outcomes

- Only non-gassy mines with very low propensity to spontaneous combustion could be considered
- Leakage rates through seals are too high
- Small ventilation shafts to the surface as proposed by other countries were not considered viable
- The high leakage rates will lead to significant oxygen ingress during pump out cycles. For goaf's with high methane contents, these goaf atmosphere's would eventually pass through the explosive range. This would be an unacceptable outcome.
- The gas modelling analysis was considered adequate for this stage of the research and produced conclusive outcomes, albeit for a generic set of base models. Bespoke details of a mines layout, specific emission & gas mixture, ventilation arrangements including coal seam contours and using complex multi-phase modelling would be needed if a project progressed.

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Future Meetings Roadmap

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Meeting No.	Content
Meeting 5	Findings will be delivered to the Banpu Board of Directors on Friday 22 April Discussions will then be held with the Projects Funding Partners Communication of next Stage (if any) will be sent to all SRG members in May A Knowledge Sharing Report detailing the research outcomes will be compiled