Stability Analysis of Geology Structures Controlled Tunnel Profiles

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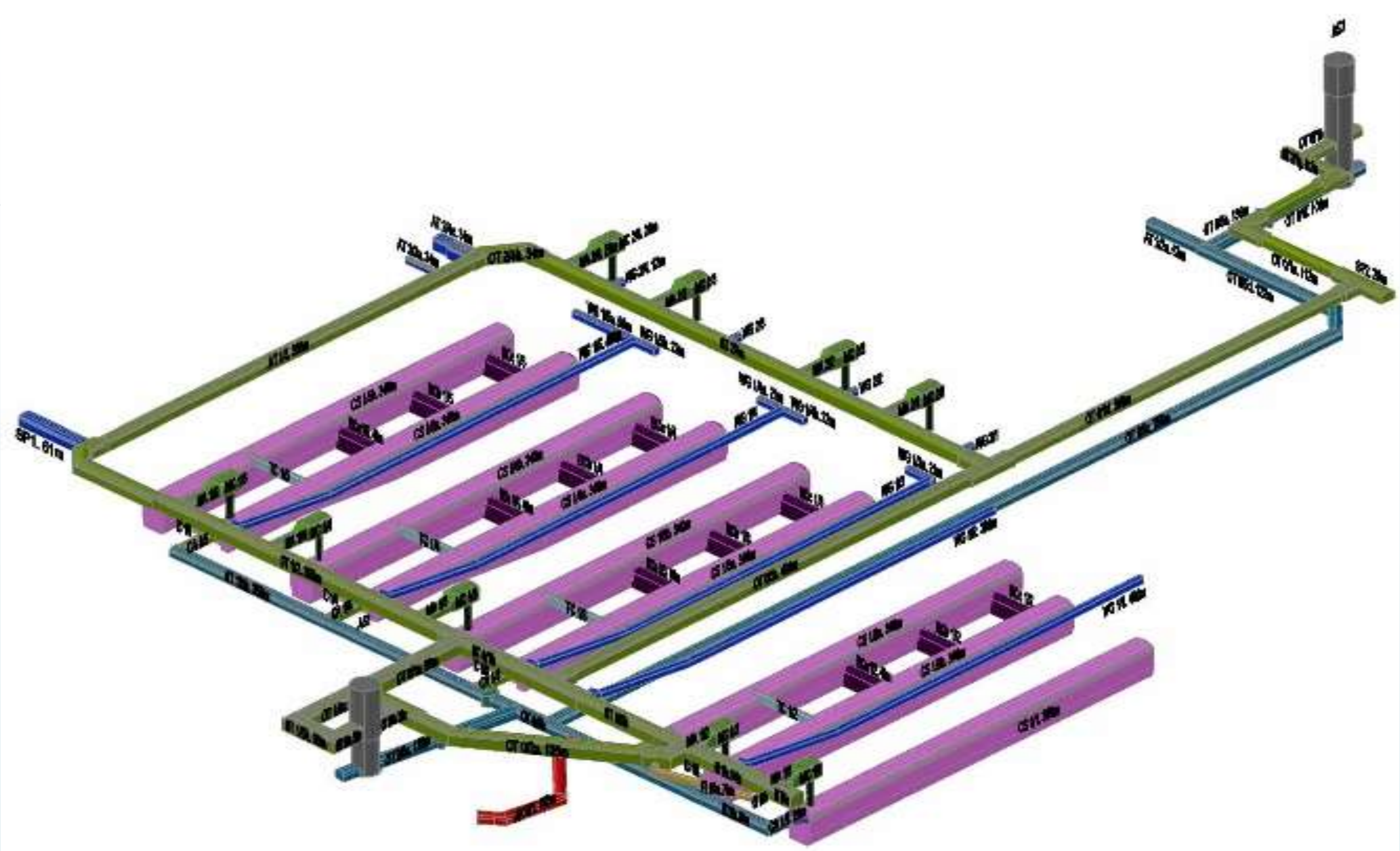
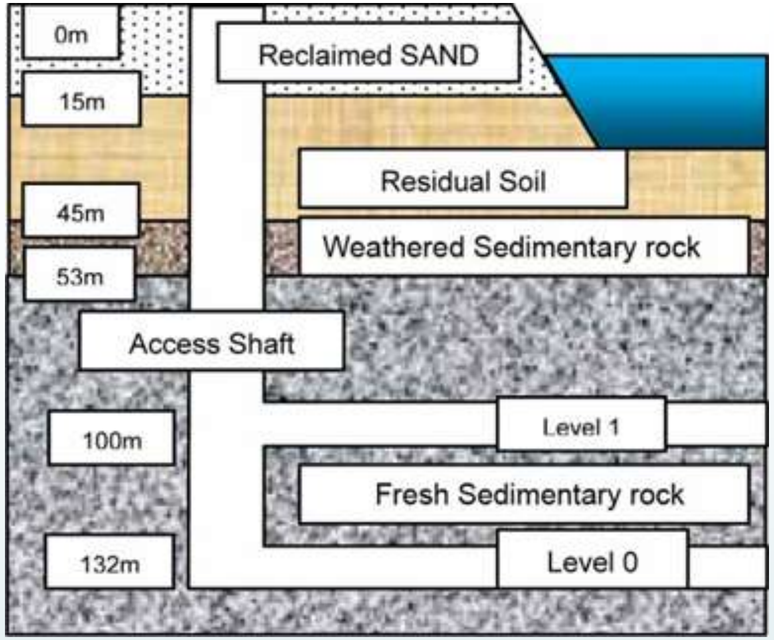
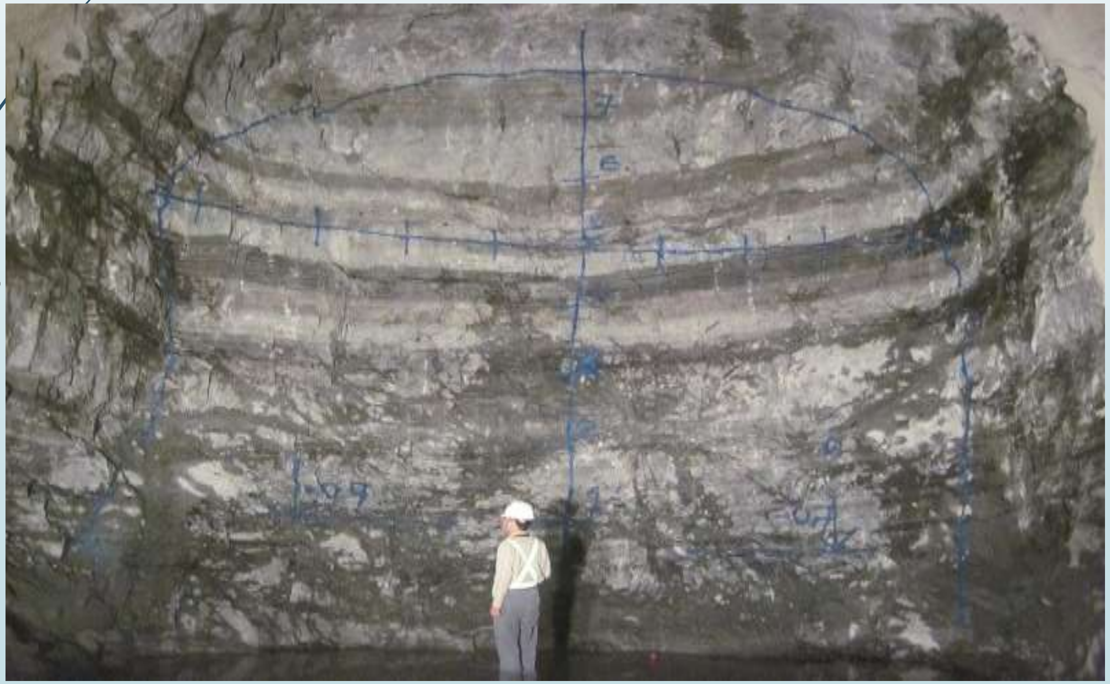
Location of Jurong Rock Cavern Project, Singapore



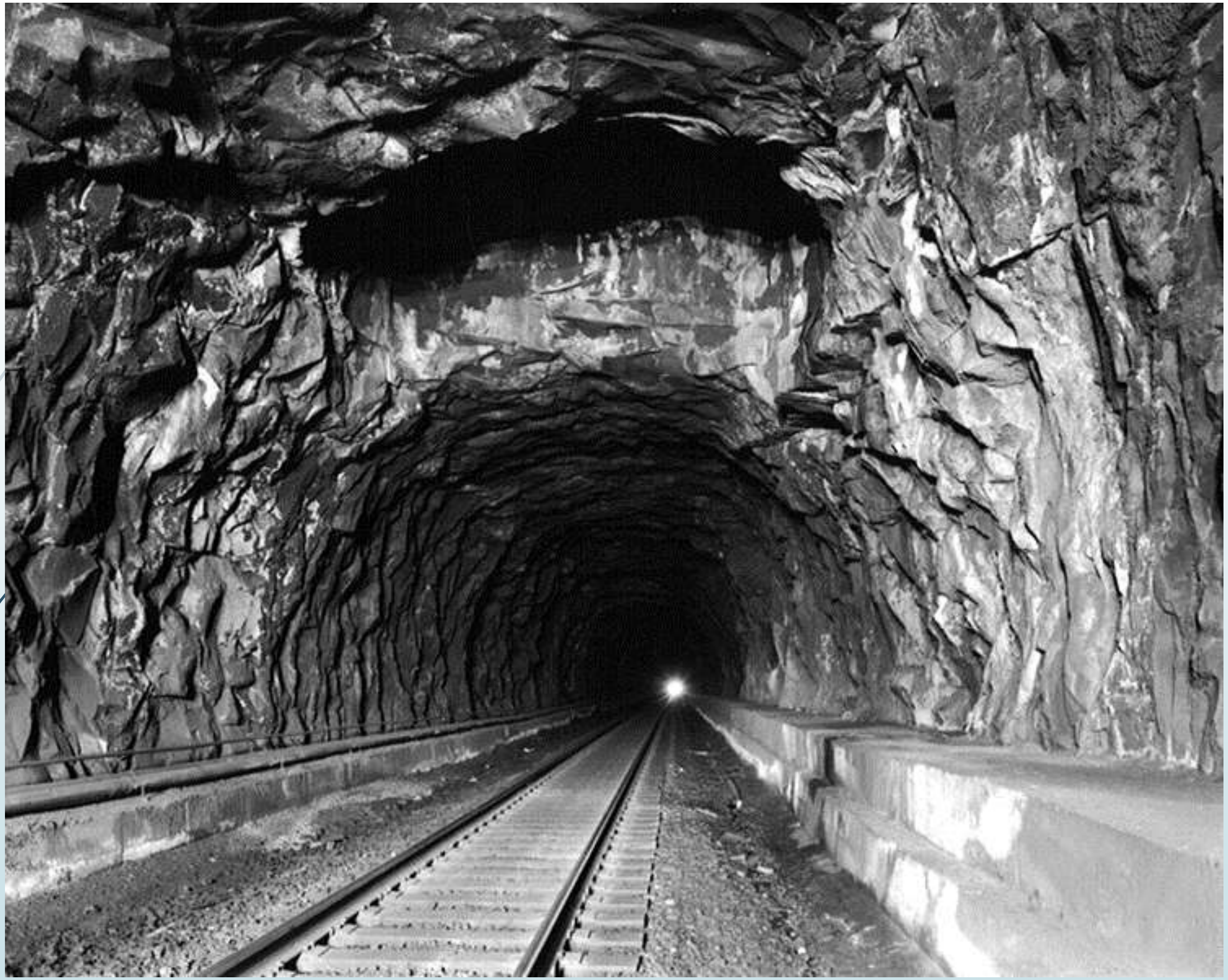
Birds eye view of Jurong Rock Cavern Project, Singapore

Geology of JRC project showing sub-horizontal bedded structures of Ayer Chawan Facies



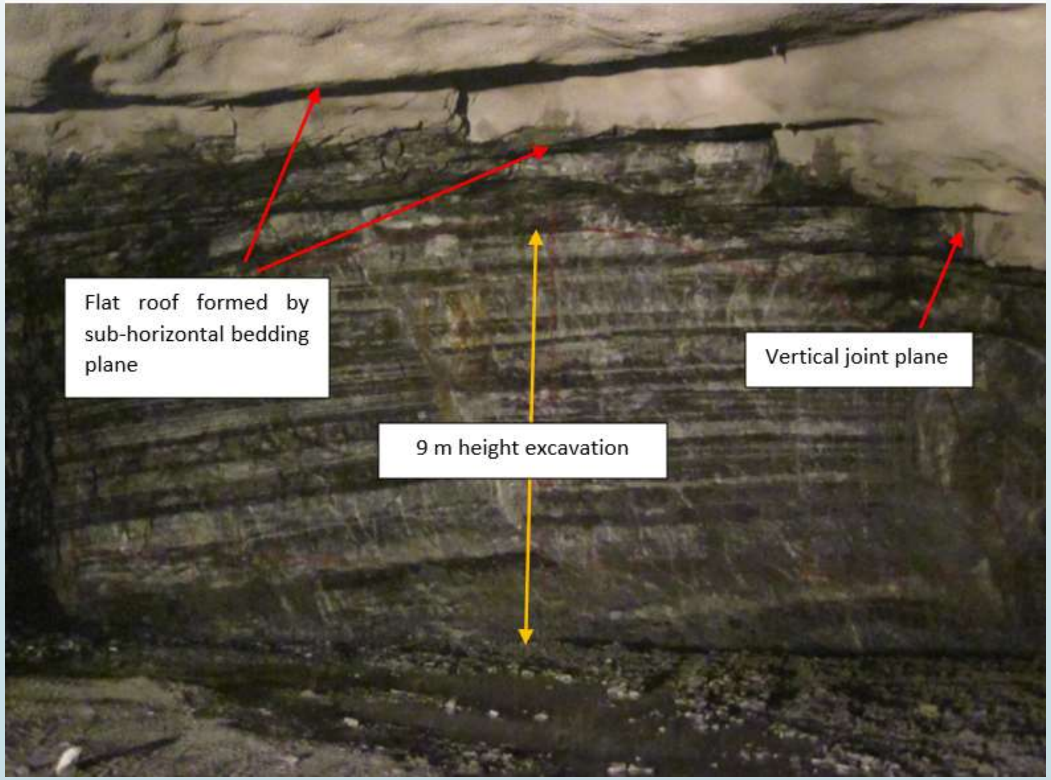


Mudstone interbedded with pyroclastic rock (Lithic Tuff) and sandstone

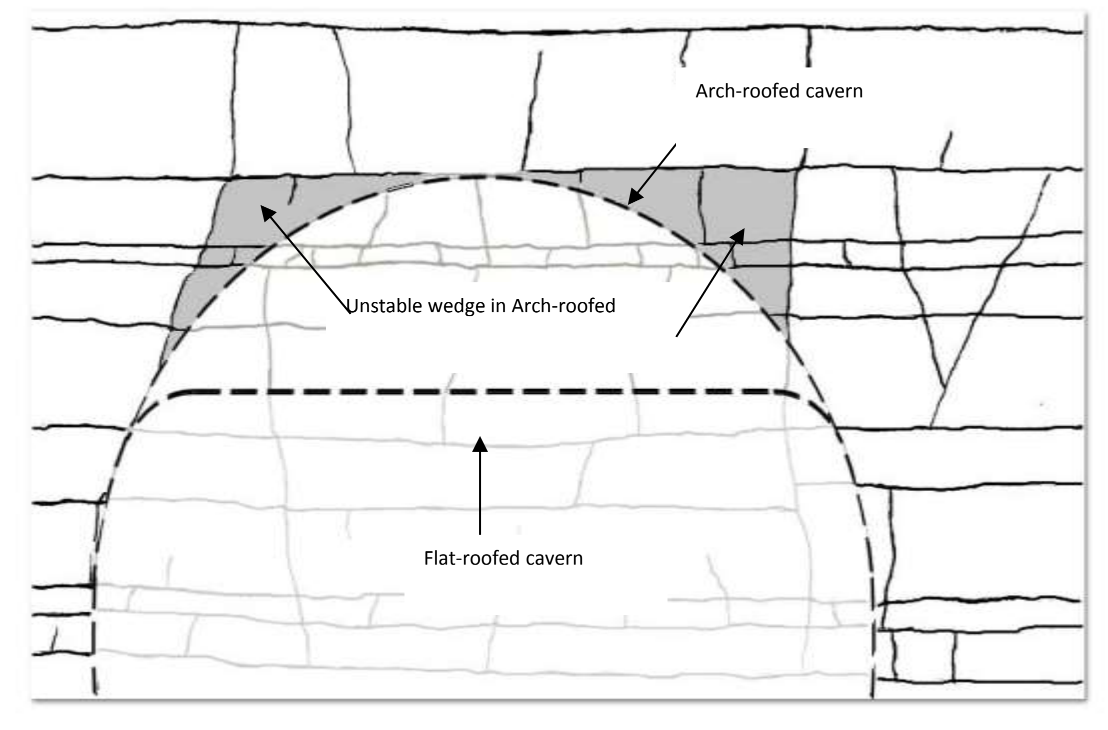


Bergen hill tunnel: source – Google images : horse shoe shaped tunnel

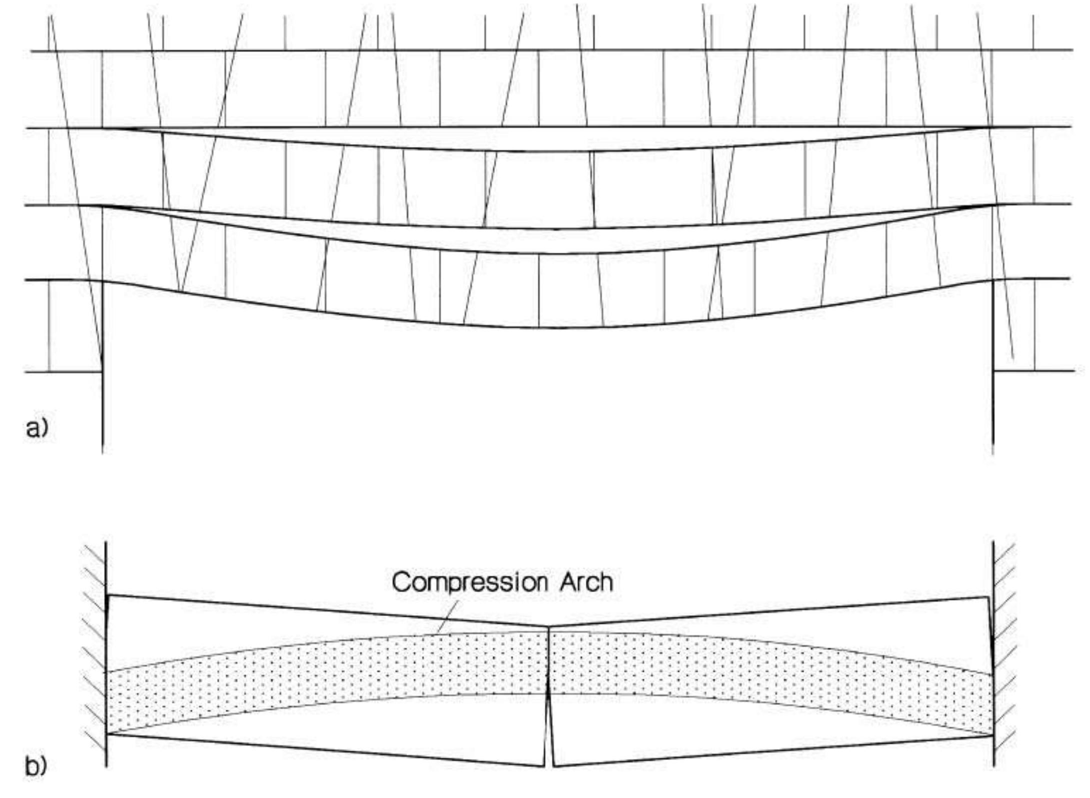
- Traditionally circular, arch and horse shoe shaped tunnel profiles are designed
- Smooth stress distribution after excavation for better stability condition



Flat-roofed tunnels / caverns in JRC project were excavated in sub-horizontal bedded sedimentary, Ayer Chawan facies of Jurong Formation



The shaded rock mass became unstable in arch-shaped roof cavern excavated in horizontal bedded rocks with vertical joints (Pells, Crockford and Diederichs)

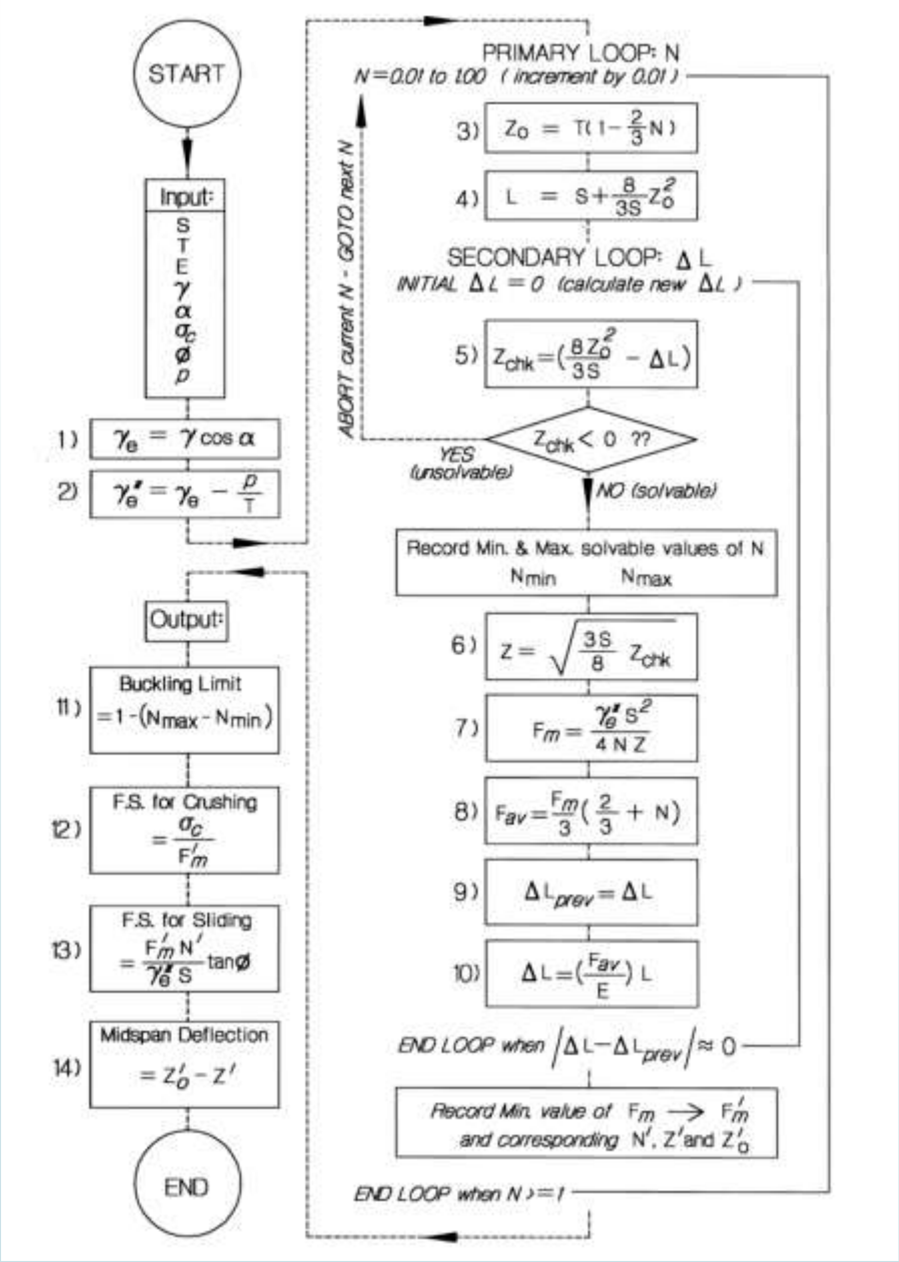


a. Vertical and horizontal jointed rock mass dissociated and deflects in the crown of an excavation

b. A compression arch forms to prevent the deflection of two discrete blocks (a Voussoir beam analogue)

(Diederichs & Kaiser)

- Left - Flow chart for the determination of stability and deflection of a Voussoir beam (Diederichs & Kaiser, 1999)
- Right – Stability analysis results of **storage cavern** following L flow chart
- Individual bed thickness = 0.4m
- Dip angle of bed = 10 degree
- Cavern span, s = 20 m
- Unit weight, r = 27 kN/m^3
- UCS, σ = 164.5 MPa



At the available lowest N value = 0.4,

F.S (crushing) = 3.42

F.S (sliding) = 6.58

Displacement (mid-span deflection/bed thickness) ratio = 36.8%.

Buckling limit, (1 – N) = 0.6.

The above displacement ratio and buckling limit are close to the collapse limit proposed by Diederichs & Kaiser.

Caverns are stable after tunnel supports (80 mm thick shotcrete with 5 m long rock bolts) were applied

Analytical approach

Intact Rock Properties in Phase^2 Analysis

General Intact Rock Properties				
Young's modulus	65000 MPa		Material Type	Plastic
Poisson's ratio	0.3		Dilation Angle	0
Failure Criterion	Mohr-Coulomb		Residual Friction Angle	32.4 deg
Tensile strength	0 MPa		Residual Cohesion	8.4 MPa
Peak Friction angle	10.3 deg		Initial Element Loading	Field Stress
Peak Cohesion	68.6 MPa			

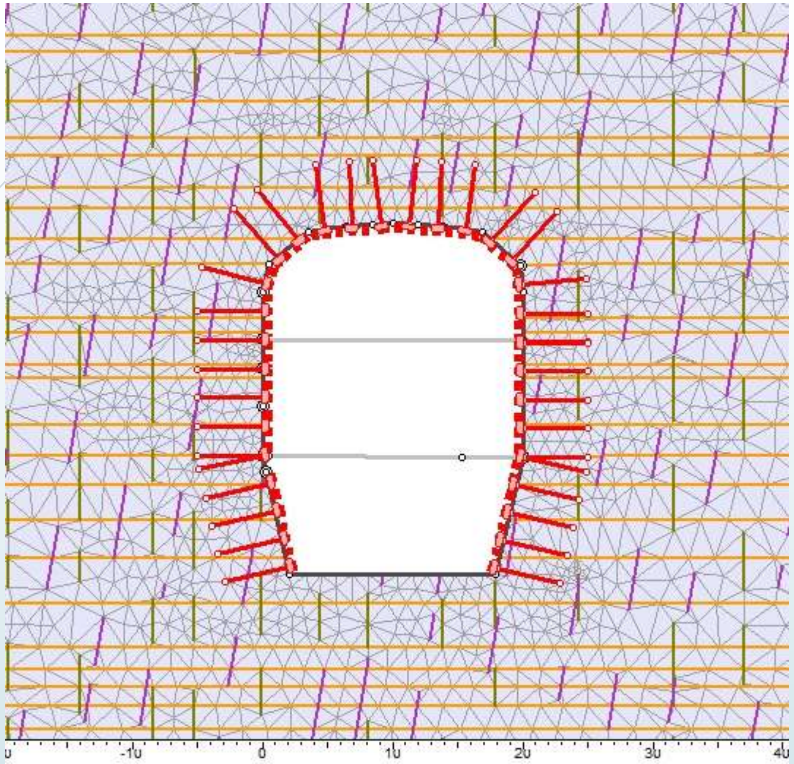
General Joints Properties			
Properties	Joint Set 1 (Bedding plane)	Joint Set 2	Joint Set 3
Normal stiffness (MPa/m)	10000	10000	10000
Shear stiffness (MPa/m)	1000	1000	1000
Cohesion (MPa)	0.3	0.2	0.2
Friction (degree)	30	30	30
Initial joint deformation	Allowed		
Slip criteria	Mohr-Coulomb		
Tensile strength (MPa)	0		

Tunnel Support properties

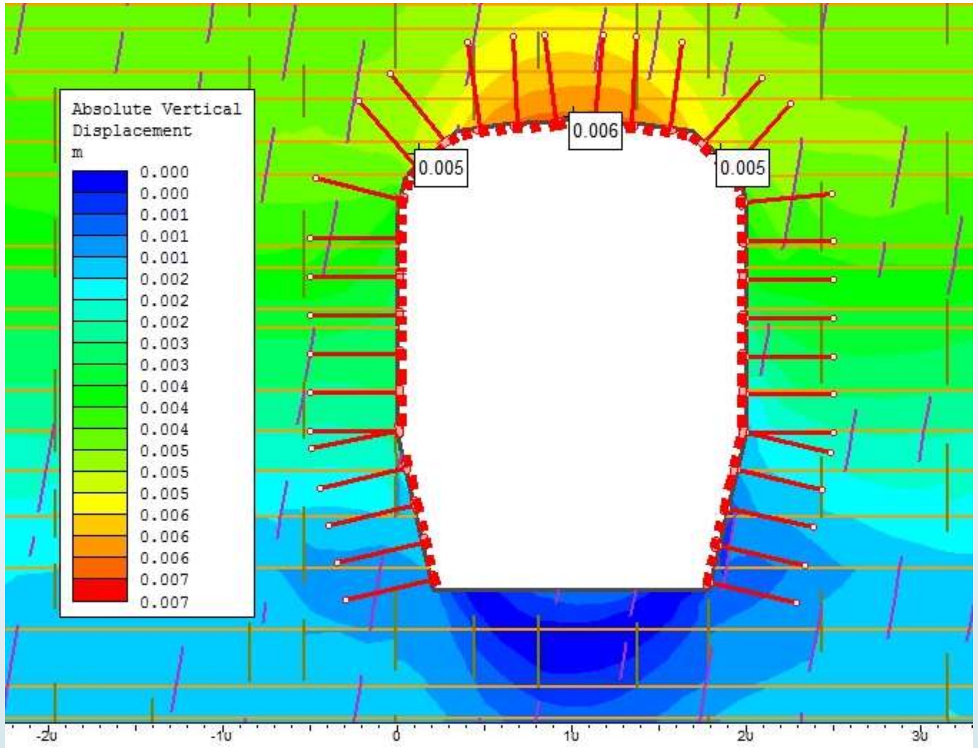
Shotcrete Properties				
Liner Type	Formulation	Thickness	Young's Modulus	Poisson's ratio
Standard Beam	Timoshenko	0.08m	20000 MPa	0.15

GFRP Rock Bolt Properties (Glass Fibre Reinforced Polymer Bolts)			
Bolt Type	Plain Strand Cable	Water : cement	0.3
Borehole diameter	44mm	Out-of-plane spacing	2.2m
Cable diameter	22mm	Face Plate	Attached
Young's modulus	50000 MPa	Allow joints to shear Bolt	Yes
Cable Peak strength	0.35 MN		

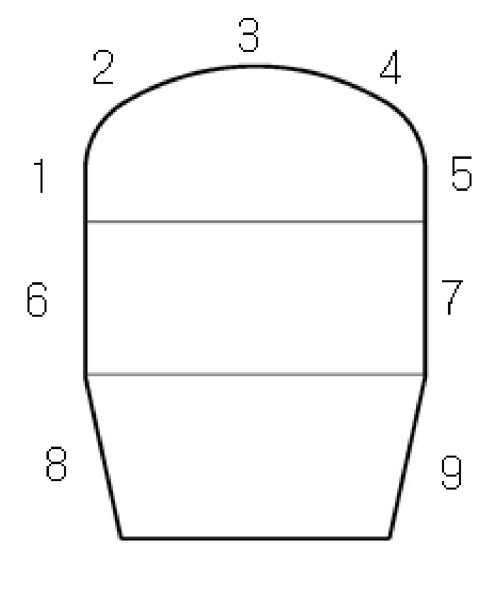
Phase² FEM analysis of storage cavern with staged excavations and tunnel support application



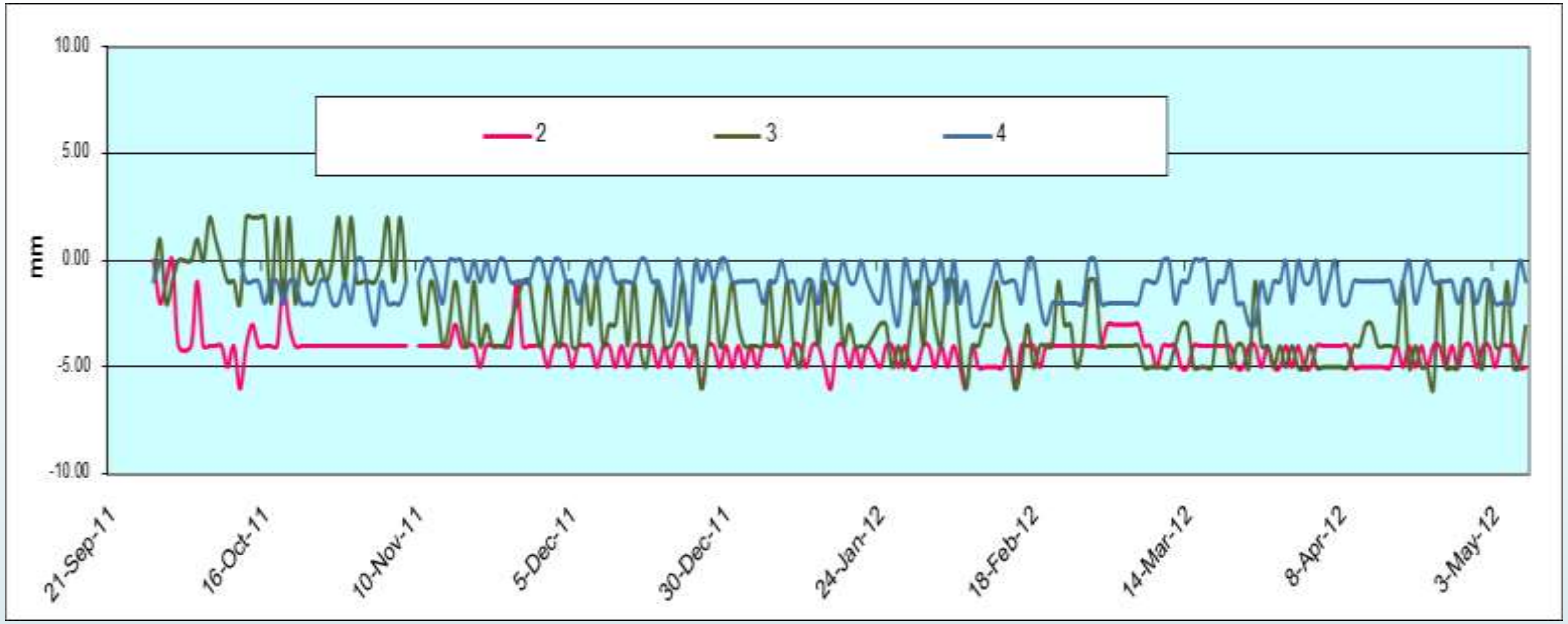
2 D model of storage cavern (20 m W, 340 m L, 27 m H)



Calculated vertical displacements (meter) at cavern crown after final excavation and tunnel support (80 mm thick shotcrete with 5 m long GFRP bolts at 2.2 m spacing)



Location of convergent monitoring points for displacement monitoring inside cavern



Vertical displacement monitoring results

Vertical displacement monitoring results are comparable with those obtained by Phase^2 analysis

CONCLUSIONS

Two main controlling factors for stability of compression arch (Voussoir beam)

1. Sufficient horizontal stress and
2. Sufficient layer thickness

In Jurong Rock Cavern Project

1. $S_H : S_h ; S_v = 2.2 : 1.8 : 1.0$ (high horizontal stress ratio)
2. Individual sedimentary layers are of 0.35 m minimum thickness


Thank you...