IoQ Webinar:
Rock Products Extraction from Cavern
10 September 2021 (Fri)
1. Needs and Benefits of Rock Cavern Development in HK
2. Rock Cavern Development in HK
3. Rock Cavern Design & Construction
4. Possible Rock Products from Rock Cavern
1. Needs and Benefits of Rock Cavern Development in HK
Needs of Rock Cavern Development in HK

- < 25% of HK land developed.
- > 80% land underlain by hard and massive igneous rocks
- Favourable for rock caverns development (source of land supply)
Benefits of Rock Cavern Development in HK

- Rock cavern can release **surface land** to serve a medium to **long-term HK land supply**
- Rock cavern easier secure **public acceptance** for **Not In My Back Yard (NIMBY)** land uses
- Rock caverns are better in **security** for some land uses

- **Temperature steady** rock caverns can provide an ideal environment some good storage such as wines with less electricity consumption.

- **Excavated materials** from cavern can be re-used as rock products.
2. Cavern Development in HK
History of Rock Cavern Development in Hong Kong

1980

1985: MTR Station (Tai Koo)

1985: MTR Station (Sai Wan Ho)

1985:

1990

1995

1997: Explosives Depot (Kau Shat Wan)

1997: Island West Transfer Station

1997: Stanley Sewage Treatment Works

1997:

2000

2005

2005: Explosives Depot (MTR WIL)

2010

2010: Western Service Reservoir (HKU)

2014: MTR Station (HKU)

2015

2015: MTR Station (Sai Ying Pun)

2016: MTR Station (Admiralty)

MTR Station (Lei Tung)

MTR Station (Ho Man Tin)

2016:

2020

2020:

1980:

1985:

1990:

1995:

2000:

2005:

2010:

2015:

2020:
Current Rock Cavern Projects in Hong Kong

• Relocation of Sha Tin Sewage Treatment Works into Caverns
• TKO-LT Tunnel - Semi-Cavern for Ventilation Building
Upcoming Rock Cavern Projects in Hong Kong

1. Anderson Road Quarry (ARQ) Joint Cavern Development (PWCL + AC)
2. Underground Quarrying at Lam Tei
3. Diamond Hill Services Reservoirs Cavern
4. Tai Sheung Tok Transfer Station Cavern Sai Kung STW Cavern
5. Sham Tseng STW Cavern
6. Tuen Mun Water Treatment Works Cavern
7. Lam Tei Service Reservoirs Cavern
8. Yau Tong Fresh Water and Saltwater Service Reservoirs Caverns
9. Tsuen Wan No. 2 Fresh Water Service Reservoir Cavern
3.1 Rock Cavern Design
Cavern VS Tunnel

- Caverns vs Tunnels – similar design principles
- Caverns vs Tunnels – different physical dimensions & applications
- Caverns – larger cross sections & specific usage
- Tunnels – small cross sections & connectivity
- HK largest-span caverns – Shatin Sewage Treatment Works Cavern (32m Span & 33m Heights)
- The world largest-span cavern – Gjøvik Olympic Cavern Hall in Norway - 61 m span & 25 m high
Cavern Design Approach:
Basis of Cavern Design includes:
(a) rock as a structural material (stability)
(b) rock mass is not a perfectly homogenous and impermeable medium (ground water inflow)

Cavern Design Considerations:
• **Stability** – cave-in, rockfall and failure of structural supports
• **Serviceability** – cavern deformation, amount of groundwater seepage and movements tolerated by sensitive receivers
• **Service Life** - Support elements be durable and robust
• **Health and Safety** – safe to construct, operate and maintain
Cavern Location and Orientation

- **Minimum Rock Cover (0.5D)** – sufficient to give adequate self-supporting.
- **Weakness Zones** – amount of rock supports required & construction difficulties
- **Discontinuities** – Orientation with respect to excavation axis - influence on its stability & amount of overbreak.
- **Groundwater** – groundwater table & changes of hydrogeological condition
- **In-situ Stress Conditions** – Gravitationally induced stresses, tectonic stresses, and residual stresses
Main parameters determining cavern size / shape / spacing between caverns:

- **Roof Arch** – roof arch height = 1/5 cavern span
- **Wall Height** – vertical to suit excavation method & maximises usable space
- **Rock Pillar** – pillar widths = 0.5 to 1 x full Span or Height of Cavern
- **Vertical Separation** – should NOT less than span / height of adjacent caverns
- **Cavern Junctions & Adit Connections** – junctions often result in stress concentration / intruding corners leading to cavern instability
Geological Model, Ground Model & Design Models

• 3-step process for engineering geological input into cavern developments - geological, ground and design models.

  • **Geological model**: considerations of the materials, geomorphology, structure, groundwater and stress conditions of the ground.

  • **Ground model**: builds on the geological model and embeds the range of engineering parameters, ground and hydrogeological conditions into the design.

  • **Design Models**: is concerned primarily with assessment of the ground response to proposed works.
Design Model – Rock Support vs Rock Reinforcement

Rock is a structural element
Self-stand by “rock arching”
(Part of solution NOT problem)

Loosened rock is supported
by cast-in-situ reinforced
concrete lining

Rock is a loading

Typical Highway / Railway Tunnel
(Rock Support Approach)

Rock bolts as reinforcement

Shotcrete as safety measure between
rock bolts

Rock Cavern
(Rock Reinforcement Approach)
Rock Reinforcement Approach (RRA)

- **Permanent systematic rock bolts** – Rock arch reinforced by permanent systematic rock bolts as primarily support
- **Permanent spot rock bolts** – Stabilize individual rock blocks/wedges
- **Permanent sprayed concrete** – Stabilize falling rock pieces between systematic bolts

**Design Procedure:**
1) Deriving from **NGI Q-system** for the respective sizes / ESR of caverns
2) Estimating parameters and material properties for design
3) Checking of the initial support by **reinforced rock arch theory**, amend the permanent support as necessary
4) Verifying the design by **numerical analyses** and confirm the support requirement.
Design Model – NGI Q-system & Rock Support Chart

- First developed by Barton et al. (1974) and updated by Grimstad & Barton (1993)
- Continuously updated by Norwegian Geotechnical Institute (latest version is 2015) with more than 2,000 case histories from underground openings and the advancement in construction technology
- Empirical support requirements (e.g. shotcrete thickness & systematic rock bolt spacing) can be obtained for a given cavern size (+ ESR) and rock mass quality


\[
Q = \frac{RQD}{J_s} \times J_w \times SRF
\]

Some Site Records:
- RQD (Rock quality Designation) = 60 - 100
- \(J_s\) (Joint set number) = 6 / 9 / 12
- \(J_r\) (Joint roughness number) = 1.5
- \(J_a\) (Joint alteration number) = 1.5 / 2 / 6
- \(J_w\) (Joint water parameter) = 1
- SRF (Stress Reduction Factor) = 5 / 2.5 / 1

RQD = 110 – 2.5J, (for \(J_s\), between 4 and 44) - Palmström (2005)

where \(J_s\) is the number of joints per m³
Design Model – Numerical Analyses

- Empirical methods / Analytical solutions – Verification of Design by Numerical Analyses
- Can model a continuum with material properties suitable for the rockmass, or discontinuum with joints

- Need to model different excavation sequences as they can give different critical cases results
Design of Rock Bolts

- Systematic bolting to reinforce the overall stability
- Spot bolting to secure individual loosened blocks
- Typical diameter: 20 to 32 mm
- Typical length of 2 to 6 m
- Common type: Fully grouted, (temporary) expansion shell at end
- Design life 100 years
- Double corrosion protection – Galvanized with epoxy coating

Lang (1961) and later re-modelled by Hoek (2007)

\[ L = 2 + \frac{0.15B}{ESR} \]  

where 
- \( L \) = bolt length (in m) 
- \( B \) = cavern span for roof support (use cavern height, \( H \), for wall support) (in m) 
- ESR = excavation support ratio, representing the safety requirement for the use of the cavern space (Barton & Grimstad, 2014; NGI, 2015).
Design of Shotcrete/Sprayed Concrete

- Thin layer (75 to 200 mm) along the uneven excavated profile
- Does not act as an arch, and does not support loads via compression or bending
- Failure modes of shotcrete in the RRA are very hypothetical
- Compression or tension cannot develop within the shotcrete
- Six Potential Failure Modes:
Design of Waterproofing Elements

• Details of Waterproofing Elements
  ➢ Cast-in-situ Lining – Sheet Waterproofing Membrane
  ➢ Sprayed Concrete – Drainage Strips
3.2 Rock Cavern Construction
Rock Cavern Construction – The Drill-and-Blast Method

The Drill-and-Blast cycle

- Pre-Excavation Grouting
- Probing
- Inspection and Testing
- Support Installation
- Mapping and Surveying
- Mucking Out and Scaling
- Drilling
- Explosives Delivery
- Charging
- Evacuation and Detonation
- Ventilation
- Check of Misfire
- Support Installation
- Inspection and Testing
- Probing
- Mapping and Surveying
- Mucking Out and Scaling
- Drilling
- Explosives Delivery
- Charging
- Evacuation and Detonation
- Ventilation
- Check of Misfire
Drilling

Computerised drilling jumbos

Inclination
Probing ahead

Checking of Drilled Materials
Pre-Excavation Grouting (PEG)

Drill Probe Holes
Measure Water Ingress

< Trigger Value?
Yes
No Grouting

No

< Trigger Value?
Yes
Stop Grouting

Pressure Monitoring
Explosives Delivery

Explosives Delivery from Mines

Loading of Explosives

Checking of Explosives

Contractor’s Delivery Truck to Tunnel
The D&B Cycle – Explosives

Detonators
- Electric
- Non-electric
- Electronic

Detonating Cord

Explosives
- Cartridge
- Bulk Emulsion
- ANFO

Booster
The D&B Cycle – Explosive Charging
Monitoring

Vibration Monitoring Instrument

AOP Monitoring Instrument
Evacuation & Detonation

Close Blast Door

Ventilation & Check of Misfire

Warning Signals

Blasted Rock Fragments
Mucking Out and Scaling

Scaling

Mucking Out
Rock Mass Geological Mapping

- Slightly Decomposed Granite
- Highly Decomposed Granite
- Moderately Decomposed Granite
Rock Dowel/Bolt

Length increase with excavation span. Long bolts may be very heavy if steel, and there needs to be sufficient space in the top heading to insert the bolts into holes that should be perpendicular to the profile. Can be a problem in wide span excavations that use low height top heading.
Expandable Friction Rock Dowel
Hollow Bolts with Expansion Shell

1. Anchor nut
2. Dome – shaping grouted adapter
3. Polyethylene sleeve
4. Bolt plate
5. Rebar rock bolt
6. Expansion shell
The D&B Cycle – (8) Self-drilling Anchor
Support Installation – Shotcrete

Compared with steel mesh reinforcements, fiber-reinforced shotcrete also has other benefits, such as:

• a greater **homogeneity of the support structure**
• a **more efficient rock section profile**
• offering **simpler application logistics**
• fibers help **reduce rebound** and improve **compaction**
4. Rock Products from Cavern
Possible Re-use of High Quality Rock Materials from Cavern

- Excavated rock materials from caverns will compose high quality granite or volcanic.
- These rock can be processed to produce different types of rock products including:
  - concrete, asphalt, crushed rock fines, drainage filter materials, paving stone, pipe bedding, railway ballast, road sub-base, armour rock, rock fill, etc.
- Comprehensive, effective and environmentally-friendly solution will be developed to maximize the re-use & efficient handling
5. Summary
Summary

• Rock Cavern development can offer multi-fold benefits:
  ➢ Innovative approach for land supply
  ➢ Support sustainable community development & enhance living quality
  ➢ Improve environment taking advantage of caverns as natural barriers
  ➢ Minimize the visual impacts and remove incompatibility with surrounding area

• Significant amount of high-quality rock from caverns – re-use and handling of these excavated rock materials are being developed
Thank you