CLC Lecture Series

Uncovering the Underground

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Uncovering the Underground

• Why Underground? – the next frontier for Singapore
• Examples of Underground Projects
• Underground Space Planning
• Tunnel Talking Points
• What’s next for Singapore? – envisioning Singapore 50 years from now
Uncovering the Underground

Tunnelling and Underground Construction Society (Singapore) - TUCSS

Geotechnical Society of Singapore

Spore Rock Mechanics & Engineering Geology

Underground Spaces Unveiled – Planning and Creating the Cities of the Future

Han Admiraal and Antonia Cornaro

Underground Space

Tunnelling and Underground Space Technology

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Uncovering the Underground


Cities without Ground: A Hong Kong Guidebook

Underground – Singapore Next Frontier Exhibition in May 2018 at URA Centre
Why Underground?
Perspective of Singapore

- Finite land (718 km²) and sea (700 km²) space
- Challenging geology – soft clay and rocks
- No typhoon but strong winds ("sumatras")
- No earthquakes but far-field seismic response
- No tsunamis but 40% low land
- Plenty of rain - extreme rainfall events (high intensity, short duration)
- Getting hotter - drought events
- Natural resources – sand, aggregates, water, sun

Geology of Singapore
small island
BIG
NEEDS

Singapore has to cater for more than other cities

Source: URA
Report of the Inter-Ministerial Committee on Sustainable Development (IMCSD)
Launched in April 2009

A LIVELY AND LIVEABLE SINGAPORE:
STRATEGIES FOR SUSTAINABLE GROWTH

One of key strategies – expand land resource:
• Go higher - build taller buildings
• Go wider - more land reclamation
• Go deeper - develop underground spaces
Go Higher!

7 x 48-storey Public Housing project
Since first reclamation works began in 1822, Singapore’s land area has expanded by almost 25% from 580sqkm to 720sqkm [sea space about 700 sqkm]

Depth of water
• Early phases – less than 5m
• Recent phases – up to 30m
• Future phases – up to 45m

Fill materials
• Hill cut from old alluvium
• Hydraulic fill dredged from sea shoals
• Barge transported sand from overseas
• Challenges of fill availability

Areas shaded in pink indicate land reclaimed as of end 2015
Areas in red show possible plans for future reclamation
Go deeper ... **unlimited** underground space

- Southeast Asia’s first underground facility for storing liquid hydrocarbons
- By going deep under seabed, freed up 60 ha of surface land, enough for six petrochemical plants
- 130m beneath the seabed and cavern is as tall as 9-storey building!
Definition of Underground Space – beneath the ground surface

- Jurong Rock Caverns
- Underpasses & Shopping Malls (12m)
- Expressways (8-25m)
- MRT System (15-30m)
- Deep Tunnel Sewerage System (20-55m)
- Singapore Power Cable Tunnel (60m)
- Underground Ammunition Facility
- Utilities (3m)
Examples of Underground Projects

How ahead of the curve is Singapore in terms of Global Underground Space usage?
History of underground cities as refuge from war

8th century BC Derinkuyu Underground City

- Turkey home to >36 underground cities
- Some as deep as 85m
- Derinkuyu deepest; 20,000 population
- Turkey’s Cappadocia region.
- Labyrinthine complex carved in volcanic rocks
- Built to serve as a refuge during wars

14th century Pilsen Historical Underground, Czech Rep

- A 12.5 mile long labyrinth of passageways, cellars and wells built below the city streets
- Cellars once served as storage space for food and barrels of beer (renowned Pilsner Urquell)
- Serve as escape route in case of an attack

[source: History Channel]
Underground Bunkers during Cold War

**Burlington Bunker, Village of Corsham, UK**

- 35-acre underground complex, 30m deep
- built in 1950s for 4000 key govt. personnel in event of a Cold War-era nuclear strike
- series of existing tunnels and stone quarries
- office spaces, cafeterias, medical facilities, telephone exchange, sleeping quarters
- Burlington facility operational until 2004, it was decommissioned and declassified.

**Beijing Underground City (Dixia Cheng)**

- Built in 1960s/70s - threat of nuclear war
- Chinese govt built mammoth fallout shelter beneath Beijing covering 85 sqkm
- Hand-dug site can safeguard 300,000 people
- Consisted of rooms, schools, hospitals, granaries, restaurants, skating rink, 1,000-seat movie theatre and tunnels
- Certain passageways large enough for tanks
- Bunker never put to use, now sealed off
Modern day underground cities

**RESO in Montreal**

Montreal’s Underground City is an elaborate set of over 60 underground complexes that house a number of residential apartments, banks and offices, shops, hotels, and other establishments.

- **500,000** people access the RESO each day
- Spread over **3.6 sq km**

It is a complete city unto itself with universities, museums, entertainment centers, Metro stations, and bus terminals. The RESO is home to about 1600 housing units and is very well lit and ventilated. The RESO is also referred to as the La Ville Souterraine.

Escape the winter cold at RÉSO, Montreal’s complex network of underground passageways, 32 km tunnels, 120 access points

© Phil Roeder
Helsinki, Finland protect its prime near-surface rock resources and developed deep common utility tunnels that limit interference with shallower, people-oriented underground infrastructure.
Underground Storm Water Drainage

Hong Kong West Drainage Tunnel
• intercept storm-water from upper catchment at Mid-Levels and discharge to sea directly.
• Alleviate flooding on Northern Hong Kong Island

Tokyo G-Cans Project
• 6.4 km tunnels, 50m deep connect 5 silos to one massive tank – the Temple
China leading the way in underground rail and urban underground developments

**Xiongnan, Hebei mega city** - above and underground (26m and 40m bgl)
- **1400 sq km area**
- **Shallow** – storage, shopping, parking, entertainment, civil defence
- **Deeper** – water storage and key infrastructure and defence facility

President Xi Jinping
South China Post June 2017

Deepest underground facility - research lab for astro-particle research
UNDERGROUND DEVELOPMENTS IN SINGAPORE

Over the years, underground spaces in Singapore have been developed to house shopping malls, car parks, transport infrastructure, pedestrian links and utility infrastructure. This benchmarking study provides a platform to learn from global best practices so that we can better utilise Singapore’s underground space.

UNDERGROUND INFRASTRUCTURE AND KEY MILESTONES

Rail
Singapore has one of the world’s densest rail networks, coming behind Tokyo. Out of 180km of urban rail, 82km are located below ground. Singapore continues to invest heavily to extend its rail network across the island.

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1987
North-South Line and East-West Line
Singapore’s first MRT line

2003
North EastLine
Singapore’s first fully underground MRT line

2010
Circle Line
Bras Basah Station features the longest escalator in the whole MRT system

Kim Chuan Depot
World’s first underground train depot

Roads
Nearly 10% of Singapore’s expressway network is located below ground, including the KPE, CTE, MCE and the future North-South Corridor.

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1989
Central Expressway
Chin Swee Tunnel and Kampong Java Tunnel are Singapore’s first road tunnels

1996
Woodlands Bus Interchange
Singapore’s first underground bus interchange

2008
Kallang-Paya Lebar Expressway
Southeast Asia’s longest underground road tunnel

2013
Marina Coastal Expressway
Singapore’s widest road tunnel

Caverns
Singapore has two major cavern developments, the Underground Ammunition Facility and the Jurong Rock Caverns which can hold about 1.47 million cubic metres of crude oil and petroleum. There is currently no comprehensive plan to identify potential cavern sites.

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2008
Underground Ammunition Facility
Singapore’s first cavern development

2014
Jurong Rock Caverns Phase 1
Singapore’s deepest underground development

Underground Pedestrian Networks (UPN)
Singapore’s UPN are mostly concentrated in the Central Business District and Orchard Road shopping district. Further plans to extend the networks within the core city areas have already been drawn up.

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2000
CityLink Mall
Singapore’s first underground shopping mall

2013
Marina Bay Link Mall
Expanding Singapore’s underground pedestrian network in the Marina Bay area

Utility tunnels
Singapore has developed the Common Services Tunnel in the Marina Bay area and will study the use of such tunnels for other green field development areas.

Utility plants
Around the world, utility plants have been located underground. Singapore has successfully implemented underground district cooling plants in Marina Bay, with scope to locate more plants underground.

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2008
Labrador-Harbour Cable Tunnel

Deep Tunnel Sewerage System Phase 1

2008 - 2014
Marina Bay Common Services Tunnel
Southeast Asia’s first multi-utility tunnel

[source: URA – ARUP]
Underground rail development

Depth of Bencoolen station 45m
Land Optimization 1 Underground Storage

Underground Ammunition Storage

Results of Technology Development on Underground Storage of Ammunition

- Above Ground: 1000 ha
- Current Underground Storage Standards: 240 ha
- Underground Storage with Technology Development: 100 ha

DSTA Engineers & their R + D Partners Spent $12m & Saved 140 ha of Land

Underground Oil Storage

Aboveground land used for production; underground land used for storage

- Storage in aboveground tanks
- 60 Ha of surface land freed up

- Creating a competitive advantage
- Saving surface land
- Improved security
- Improved health & safety

Jurong Rock Caverns (JRC) Operational 2013

A Storage Chamber Being Readied for Use

[source: Prof PC Lui] [source: JTC - SINTEF InTech Multiconsult]
Land Optimization 2 - High voltage power transmissions cable tunnels

- 35km cable tunnels (50m - 60m deep) - completed tunnelling in April 2017
- No competition for shallow underground space and minimal utilities diversion in future
- 10 hard rock TBMs and EPBMs in 6 contract packages
Land Optimization 3 - The Deep Tunnel Sewerage System (DTSS) saves large areas of land sterilized by Sewage Treatment Plants

- DTSS – a used water underground gravity superhighway to meet long term needs for used water collection, treatment, reclamation and disposal – deep sewers typically 30m – 50m depth and run under roads

- DTSS Phase 1 (2000-2008) – 48km long deep sewer tunnel by TBMs + 60km link sewer by micro-tunnelling/pipe jacking

- DTSS Phase 2 (2013-2025) – 40km long deep sewer tunnel + 60km link sewer
Expanding the Metro (MRT) rail network under LTMP2013

• On-going construction of Thomson-East Coast Line
• New Lines include:
  • 50 km Cross Island Line
  • 20 km Jurong Regional Line
  • Extensions to Circle Line, Downtown Line and North-East Line
• Two cross borders lines:
  • Singapore-Johor Rapid Transit System Link to enhance connectivity between Iskandar Malaysia and Singapore
  • High Speed Rail (HSR) connecting Kuala Lumpur and Singapore (suspended).
Planning and Governance for Sustainable Development

At grade (surface)
- URA Concept Plan (40-50 years)
- Master Plan Committee (MPC) - 5-year review
- Communities Facilities Coordination Committee (CFCC)

Underground
- Underground Master Plan Task Force (UMPTF) led by Ministry of National Development
- Advanced planning and inter-agency coordination of future underground plans
Developing Singapore’s 3D Underground Masterplan

Ensure efficient use of UG space
Synergy with above ground uses
Safeguard vertical accesses
Coordinate efforts from agencies

*For illustrative purposes only

[source: URA]

Geology of Singapore (PWD) 1976
Geology of Singapore updated (DSTA) 2009
Singapore Geology Office (BCA) set up in April 2010

[source: Keifer Chiam, BCA]
Virtual Singapore concept – 3D digital model of the physical city state

- Planning and decision making
- Predictive environmental modelling
- Resource Management
- Disaster Management
- Management of diseases
- Rich data environment for R&D and innovation

Source: National Research Foundation, Prime Minister’s Office Singapore
Tunnel Talking Points
Talking Point 1 - New Legal and Planning Frameworks

- March 2015, Singapore’s Parliament amended two laws to facilitate underground development

- **State Lands Act** amended – surface landowners own underground space up to 30m under the Singapore Height Datum

- **Land Acquisition Act** amended to give state the right to buy out plots of surface land or a specific stratum of subsurface so that the ground underneath it can be accessed

Note: Japan’s Special Measures Act for Public Use of Deep Underground (Act no. 87 of 2000)
Talking Point 2 - Social Dimension

• Quality of life and taboo on living underground
• Behavioural and psychological impact on humans living or working long hours underground
• No different from a person working in basement or in rooms without windows!
• Lund University study – difference in decision-making between people working above ground with daylight against people working in rooms without windows
• Journal of Clinical Sleep Medicine - workers in windowless rooms, or with little daylight exposure, may lose up to 46 minutes of sleep a night.

Cave dwelling complex in Sanmenxia – 3000 ppl live in subterranean city
Talking Point 3 - Technical challenges

- **Urban** Underground Space

- Technical constraints and challenges in underground construction, whether in rock or in soils are not insurmountable.

- Once built difficult to re-develop – design for permanency or high degree of flexibility

- From engineering perspective, **no limit** to how much underground space, including those below seabed could be potentially exploited.

- Limit often lies in the economic and commercial viability of the project.
Talking Point 4 - Construction Cost and Maintenance

• High construction cost (2 - 5 times depending on type of facility, size, depth and geology)

• If land prices rises to an astronomical level as in Tokyo CBD area, it makes commercial sense for land owner to go as deep as 30m below ground (about 8-10 storeys below ground), which is the limit of its ownership.

• Higher cost compensated by savings in façade construction and maintenance, and lower energy consumption (can be 12% or less)

• Must address institutional and economic barriers. For public sector, higher costs offset by value gain in terms of land and better environment. For private sector, issues such as development charge must be addressed.
Talking Point 5 - Risks in Underground Development

• Environmental
  • Seepage of water leading to water drawdown
  • Underground air quality and high humidity
  • Fire risks and evacuation
  • Contamination due to Explosives residues

• Uncertainties due to variable geological and hydro-geological formations.

• Assessing integrity of underground structures

• Insurance and risk assessment
Talking Point 6 - R & D on underground space

- MND/NRF R&D programme on Land & Liveability and Cities of Tomorrow Programme - research and innovation in underground space
- To reduce cost of underground construction by 50% while maintaining or even reducing recurrent and maintenance costs
- Monitoring and surveillance of underground developments to ensure safety of users.

$150 m for Cities of Tomorrow R&D programs
Uncovering the Underground

What’s next for Singapore?

Envisioning Singapore 50 years from now
wish list for better liveability
Envisioning Singapore 50 years from now

- Public mode of transport; car “lite”, shared green AV
- Surface utilities in common services trench
- Road underground connects to major basement carparks
- Underground cities/towns – e.g. from Orchard to Marina Bay to escape heat and rain
- Capsule Transport of Cargo in Pipelines - freight transportation being used Germany, Netherlands and Japan
Envisioning Singapore 50 years from now

- Collect as much of rain water as possible – now only 10%-20%
- Storm water and canals integrated in and underground system
- Heavy industries, treatment plants and environmentally unfavorable (noise, air, odour pollution) installed underground
- Urban Farming
- Everything underground that don’t need light and sky!

[source: Prof PC Lui]
Finally, continue to …… Think Deep

• Think Deep UK (TDUK) is a group of built environment experts committed to creating resilient, sustainable and liveable cities through smart use of underground space

• Think Deep SGP (TD.SGP)?

[source – Think Deep UK]
Thank you