Rock Investigation Planning for Rock Cavern Development

SRMEG-GEOSS Workshop on Geology of Singapore

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Site Investigation – The Most Important 1st Step to Reduce Project Risks

- Underground caverns are excavated through natural geoenvironment - soil/rock and surrounded by groundwater, with a need for special considerations to deal with risks related to Geologic Complexity and Uncertainty.
- Geologic risks are due to "non-transparent" earth – inherent spatial and property variability with enormous range.
- Geology is unpredictable – a hazard without site investigation; and will always present a risk unless adequately understood.

Site Investigation – The Most Important 1st Step to Reduce Project Risks

- For underground projects, the geologic risk during construction is the major risk of projects, and also often causes contractual dispute between contractor and client. Although geotechnical baseline report is a solution for reducing the dispute, sufficient site investigations is the best solution.
- You pay for site investigation whether you have one or not.
- The less the SI works, the higher the project risk.
- Common Mistakes:
  - Insufficient SI.
  - Improper SI.
  - Measurement errors.
  - Mis-interpretation.

SI Program Planning – Program in Phases

- Plan SI program for need by different design levels.
- Control budget in steps – spend the same money but maximize "geology gain".
- Typical SI phases according to purposes and levels of detailing
  1. Desk study (geologic map, literature, existing SI report) and surface geologic mapping (rock exposure) for project planning / preliminary feasibility,
  2. Broad SI for feasibility / concept design,
  3. Zoomed down SI for basic design,
  4. Supplementary SI for detailed design or during construction.

SI Techniques/Methods Available

- **Site visits and renaissance, surface geologic mapping**
- **Surface geophysical survey**
  - Seismic reflection
  - Seismic refraction
  - Electric resistivity
- **Exploratory borehole**
  - Vertical borehole
  - Inclined borehole
  - Horizontal directional drilling (HDD)
- **Downhole in-situ measurement**
  - Dilatometer test
  - In-situ stress measurement
- **Downhole geophysical logging**
  - Seismic logging
  - Electric resistivity logging
  - Acoustic imaging by tele-viewer
  - Video logging by optic viewer
  - Borehole radar
- **Cross-hole geophysical tomography**
- **Hydrogeologic testing**
  - Packer test
  - Lugeon test
  - Short/long duration test
  - Pumping test
- **Lab testing**
  - Petrological analysis
  - Mechanical rock test

Choose Suitable SI Methods

- General Principles
  - **No single method is the best.**
  - **Complementary methods reduce uncertainty.**
  - **Different methods as cross check.**
  - **Boreholes are direct & reliable; geophysical survey is indirect info and always accompanied with boreholes.**
  - **Remember critical SI items required specially by cavern usage, i.e. hydrogeologic testing & interaction test of rock materials with oil products are critical for oil storage cavern.**

Choose Suitable SI Methods in Each Phase

- **Project planning / pre-feasibility**
  - Desk study on literature and existing SI reports, site visits and renaissance, surface geologic mapping of rock exposures. If yes, no need to spend money for subsurface exploration,
  - If there is neither much literature and nor rock exposures, a few boreholes shall be planned.
- **Feasibility / concept design**
  - Main purpose is for macro view of site
  - More surface geophysical survey to have better coverage of site
  - Some vertical boreholes & downhole logging to obtain rock cores and verify geophysical results
  - Some lab tests – rock properties
- **Detailed concept design / basic design**
  - Main purpose is for micro view of site
  - More boreholes at critical area or suspected weakness zones
  - Cross-hole tomography at critical area or suspected weakness zones
  - More In situ testing & lab testing
- **Detailed design / construction**
  - Supplementary SI as per concerns and missing information

If a special need by cavern usage, you shall add in at feasibility stage.

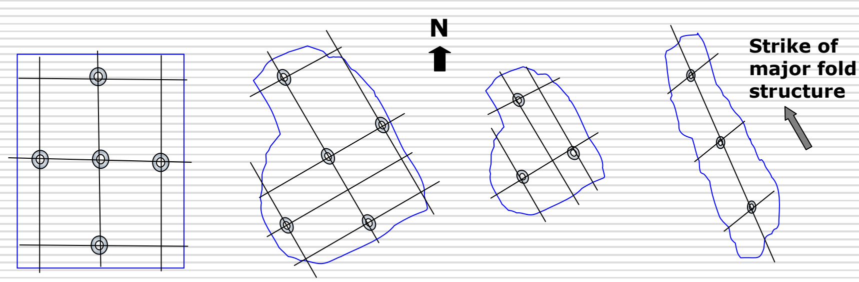
SI Layout Planning – General Principle

- Boreholes distribute evenly to cover the whole site
- Boreholes at the junction of intersected geophysical lines
- Boreholes distribute in different rock formations
- Supplementary boreholes at suspected fault/weakness to verify and cover the "worst" rock conditions

- Geophysical lines cut through boreholes for correlation
- Geophysical lines distribute evenly to cover the whole site
- Geophysical lines are grouped into two perpendicular for 3D interpretation
- One group must be alined perpendicular to overall strike of major formations or across the suspected fault/weakness zones (if any)

- Site is covered by an INTEGRATED Hole+Line NET.
- 1D Linear Drilling + 2D Geophysical Profiling = 3D Geologic Image

SI Layout Planning – Typical Layout at Feasibility/Concept Design Stage



Ideal Case

Layout according to actual strike of major formation and site boundary

SI Layout Planning

- Downhole geophysical logging in all the boreholes and for the whole borehole – fully use the boreholes.
- In-situ stress measurement in borehole at center of site, but not at toe of hill or bottom of valley to avoid influence of topography.
- In-situ stress measurement at the borehole with the best rock quality.
- Dilatometer tests at different rock quality to cover the range from “the best” to “the worst” conditions.
- Hydrogeologic tests at different fractured rock section to cover the range from “the best” to “the worst” conditions.

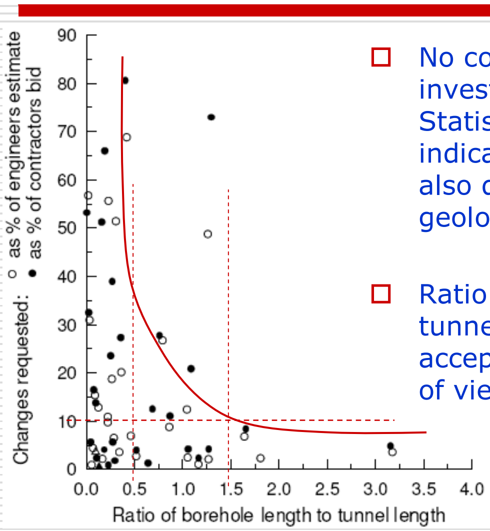
SI Layout Planning

- Detailed SI boreholes and geophysical lines zoomed down and focused on the “critical” or “interested” or “suspected” locations for basic design or detailed design.
- Supplementary SI boreholes for missing info or special issue of concerns during detailed design or construction.

SI Quantity & Cost Planning – Factors to be Considered

- **Comprehensive Considerations on Many Factors:**
  - Purpose of the investigation (planning stage, feasibility study, concept design, basic design, detailed design…)
  - Usage of faculties – oil storage or warehouse with specific need for geologic information
  - Size and extent of site / facilities – storage cavern or transportation tunnel
  - Complexity of geology, expected subsurface material and groundwater
  - Depth range
  - Site conditions (topography, access, etc)
  - Environmental constrains & impacts
  - Availability of equipments, technology and specialists in local market
  - Time required

SI Quantity & Budget Planning – ratio of borehole length to tunnel length



- No code to follow for rock investigation deep boreholes. Statistics on project cases give indicative figure for reference. It also depends on complexity of geology
- Ratio of borehole length to tunnel length of 0.5-1.5 seems acceptable from contractual point of view

Source: Hoek & Palmeiri, 1998

SI Quantity & Budget Planning – Borehole & Line Spacing

- **Spacing of boreholes**
  - For 1km tunnel, borehole (BH) length > 500m
  - Individual BH depth = 100m; a total of 5 BHs; the spacing < 200m.
  - Cavern is a cluster not linear, the spacing can be 2-4 times (<400-800m), depending on complexity of geology.
  - Minimum 3 boreholes at one site.
  - Intense at the "critical" or "interested" or "suspected" locations for basic design or detailed design.
  - Notes:
    - Singapore BCA Advisory note for buildings (>10 storey): soil investigation shallow borehole density shall be not less than 300 m^2/BH, meaning average 18-20m spacing.
    - BS5930 – a spacing for 10 to 30m between points of exploration for soil investigation; minimum 3 exploration points each site.

- **Spacing of geophysical lines**
  - Usually, geophysical line spacing not less than borehole spacing, because geophysical lines always cuts through boreholes.
  - Intense at the "critical" or "interested" or "suspected" locations for basic design or detailed design.

SI Quantity & Budget Planning – Borehole & Geophysical Detective Depth

- **Drilling depth of boreholes**
  - Vertical boreholes 100 – 150m in depth; inclined borehole 150-200m in drilling length.

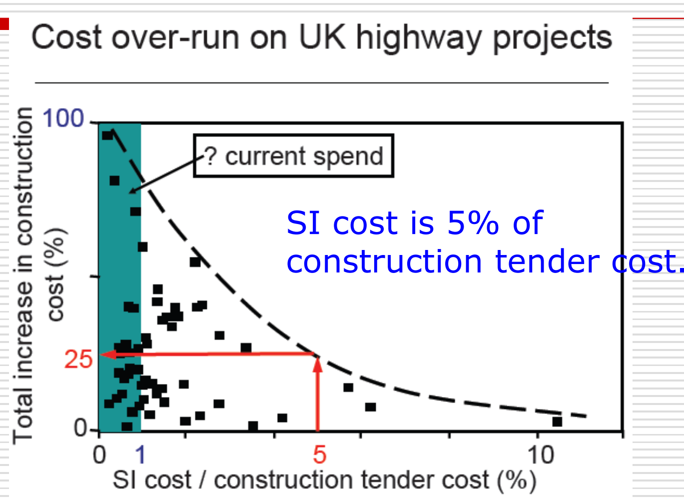
- **Detective depth of geophysical survey**
  - Usually, geophysical line spacing follow borehole depth, because geophysical lines always be verified & calibrated by boreholes.

- **There is sometimes a need for deeper borehole as required by usage purpose, i.e. LPG storage cavern**.

SI Budget Planning

- Norwegian tunnelling recommendations: SI cost is 2-10% of excavation cost for road tunnels; 5-15% for subsea tunnels
- Singapore rock cavern projects: about 1-1.5% of rock excavation cost.

Soft Ground Project SI



Source: TRL Project Report 60

Prof Clayton, 2008

Typical Rates for Major SI Works

- Seismic refraction: $15k-20k/km
- Seismic reflection: $20k-$25k/km
- Electrical resistivity: $15k-20K/km
- Crosshole seismic tomorgraphy: $20k-$25k / section (150 m deep boreholes)
- Diamond core drilling: $200-400/m increasing $50/m every 50m-depth interval
- Soil boring: $25-$60/m.
- Rate for inclined borehole is 1.5 times for vertical borehole
- Borehole logging: $100-200/m per test
- In-situ stress measurements: $100-150 k/borehole (4 points)
- Rock mechanics lab tests: $50-$500/test

Description of Typical SI Techniques/Methods

Typical SI Techniques/Methods

- **Site visits and renaissance, surface geologic mapping of rock exposures**
- **Surface geophysical survey**
  - Seismic reflection
  - Seismic refraction
  - Electric resistivity
- **Exploratory borehole**
  - Vertical borehole
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  - Pumping test
- **Lab testing**
  - Petrological analysis
  - Mechanical rock test

Desk Studies and Surface Geologic Mapping

- Acquire literature, air / satellite photographs.
- Local geological map, database / existing SI reports.
- Site visits and renaissance to confirm data and identify areas where engineering difficulties may exist and areas for focused investigation.
- Surface geologic mapping of rock exposures.

Surface Mapping at Rock Slope

- **Manual scan-line mapping on rock outcrop, rock joint measurement….**
- **Automatic rock mapping technique**
  - 3D images allow detailed acquisition of large areas serving as basis for further assessments. The 3D assessment software allows to gain geometrical measurements , to perform geological mapping , and to provide the basis for geotechnical analysis .
  - From large distances (5 - 1.500 m) are geometrically acquired and combined with high resolution image information.

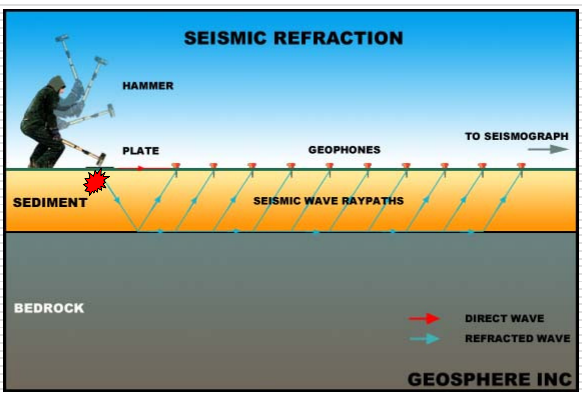
Geophysical Survey – 2D profiling

- Objectives
  - Broad coverage of investigated site
  - Cross-section subsurface profiling
  - Overburden thickness and rock head elevation
  - Weathering zone thickness
  - Geologic strata & settings
  - Major faults & weakness zones
  - Seismic velocity of rock layers, implying bedrock quality

Geophysical Survey – 2D profiling

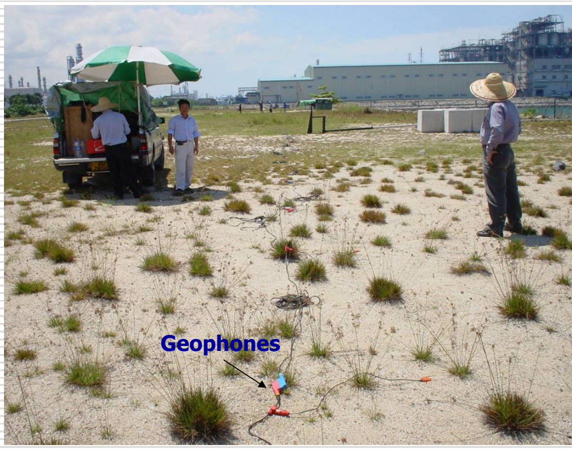
- Methods
  - Seismic refraction
  - Seismic reflection
  - Electrical resistivity
- Coupled seismic reflection (good vertical resolution) and electrical resistivity (good horizontal resolution) strongly recommended

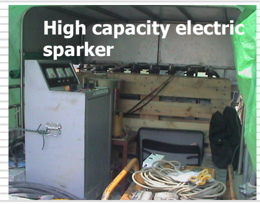
Seismic Refraction Method

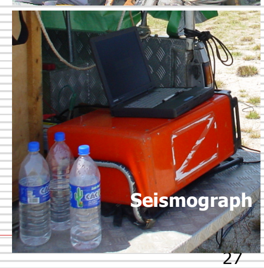


When a seismic wave crosses an interface between layers of two different velocities, the wave is **refracted**. Assumes increasing layer velocity.

Land Seismic Refraction Survey



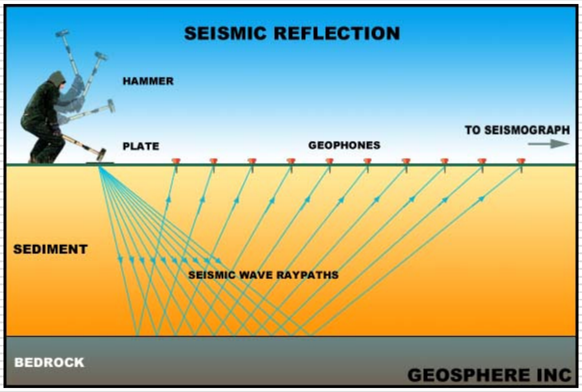


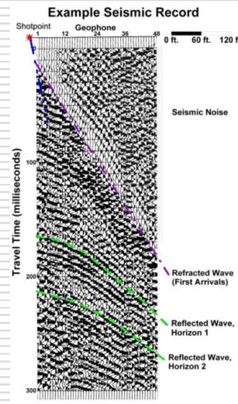


Seismic Refraction Method

- Advantages
  - Detection of geological layers/features
  - Determination of seismic velocities
  - Velocities relate to rock mass quality
- Disadvantages
  - Increasing velocity with depth assumed
  - Significant velocity contrast between layers
  - Large energy source required, i.e. blasting wave
  - Limited depth.

Seismic Reflection Method





By measuring the arrival time at successive surface locations we can produce a **profile**.

Seismic Reflection

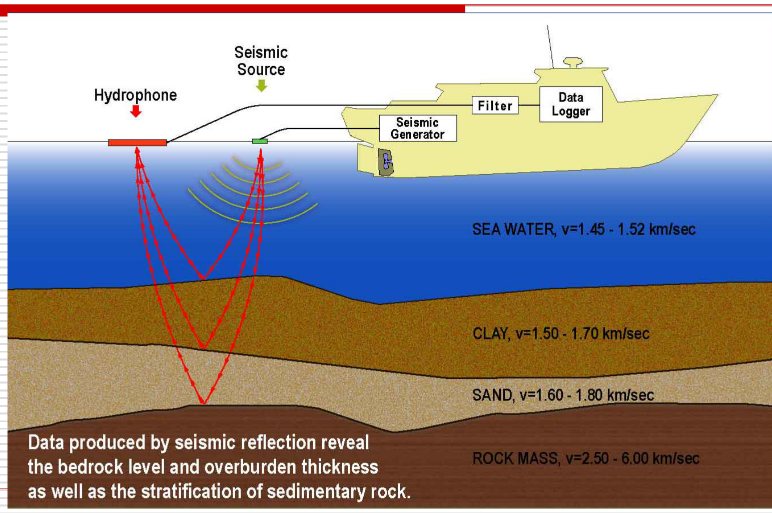
- Advantages
  - No matter how the seismic speed varies with layers
  - More easily interpreted in term of complex geology
  - The subsurface can be directly imaged from the acquired observation
  - Less energy source required
  - Information on larger depth
- Disadvantages
  - Many source and receivers must be used, reflection seismic observation can be expensive to acquire
  - No direct determination of seismic velocities of rock layers

Land Seismic Reflection Survey at Jurong Island

- 8000V high capacity electric sparker as wave source
- 80m penetration depth
- 3m geophone spacing
- 24 channels
- A total of 10km

Geophone spread out

Marine Seismic Reflection Survey

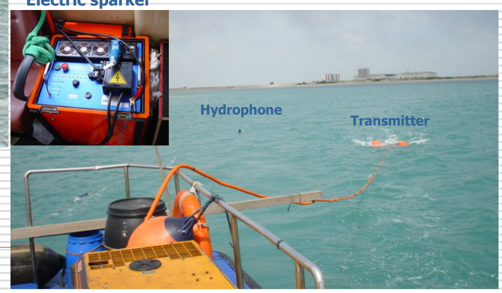


Marine Seismic Reflection Survey at Jurong Island

GPS navigation

- Electric sparker (0.05-1 kHz) as wave source
- Penetration depth 100-150m
- GPS navigation
- A total of 30km

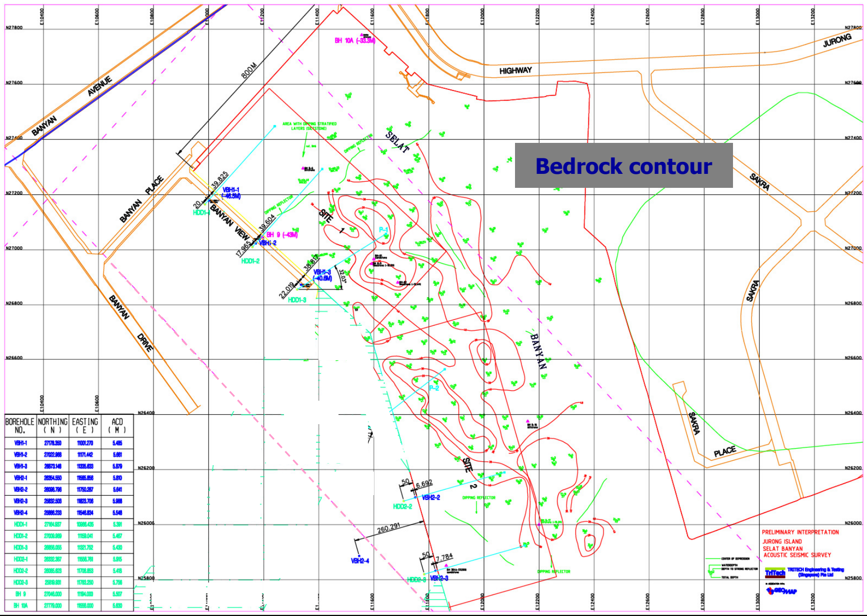
Electric sparker



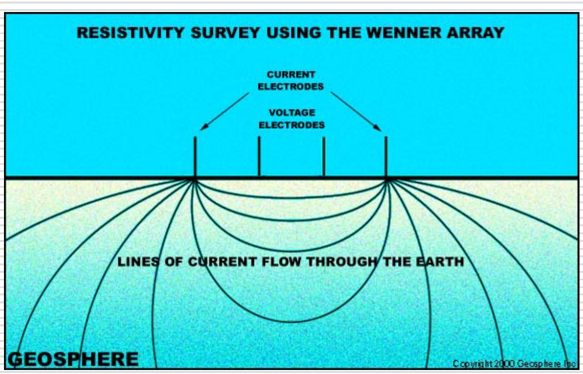
Marine Seismic Reflection Survey at Jurong Island

Seismograph real-time printing

Rock Surface Contour Obtained from Reflection Survey



Electrical Resitivity Survey Method



Electrical conductivity (resistivity) can also be measured by applying a current directly into the ground through a pair of electrodes. Have good horizontal resolution.

Electrical Resitivity Survey Method - Restriction

- Depth of penetration is limited.
- Interpretation limited to simple geologic structures
- Masking by near surface resistivity variations

Exploratory Borehole – 1D linear drilling

- Vertical borehole
  - Certify/calibrate geophysical results – rock layering & variation with depth.
  - Obtain rock cores for lab tests (properties).
  - Obtain rock cores for rock mass quality assessment and distribution with depth.
  - Obtain non-vertical joint information.

Intersecting 2D-Geophysical Profiling + 1D Linear Drilling = 3D net and Geologic Model

Rock Cores (Siltstone) Obtained from Wireline Diamond Coring at Jurong Island

Very good quality siltstone, 90m below ground surface

Rock Cores (Granite) Obtained from Wireline Diamond Coring at Mandai

Inclined borehole – supplementary to vertical

- Inclined borehole – supplementary to vertical
  - Inclination up to 45 degree from vertical.
  - Obtain vertical joint information.
  - Verify fault / weakness zones obtained from geophysical profiling.
  - Able to have core orientation measurement to obtain rock joint dip/dip angles, and joint set classification.
  - Certify/calibrate geophysical results – rock
  - Obtain rock cores for lab tests (properties).
  - Obtain rock cores for rock mass quality assessment and distribution with depth.

Inclined borehole Drilling

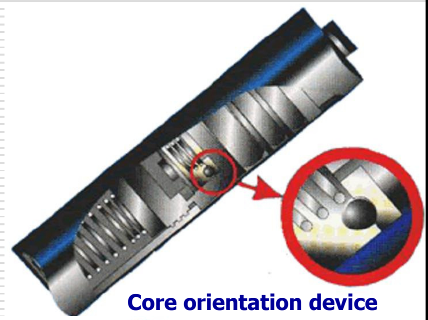
Core Orientation in Inclined Drilling

- Mark desired orientation of rock cores in borehole
- Allow for logging orientaion of rock frcatures and layers based on core orientation
- Use Ball Mark Mechanism:

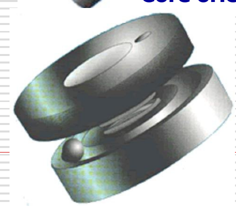
  Locking ring in open position is adjusted to the desired direction of rock core

  The orientation device is connected to core barrel

  When activated, locking ring is compressed to lock indicator ball into place at desired orientation in borehole



Core orientation device



Ball marker

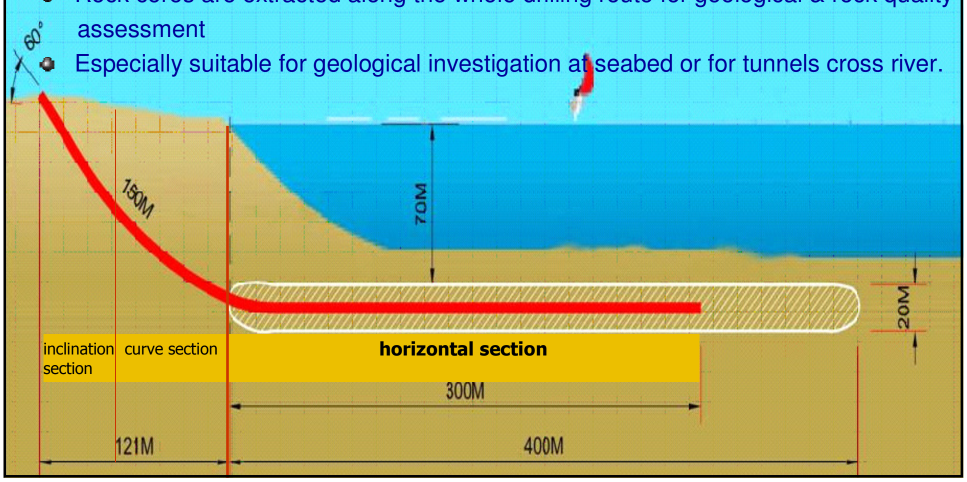
Core Orientation in Inclined Drilling

Core orientation device attached to wireline core barrel

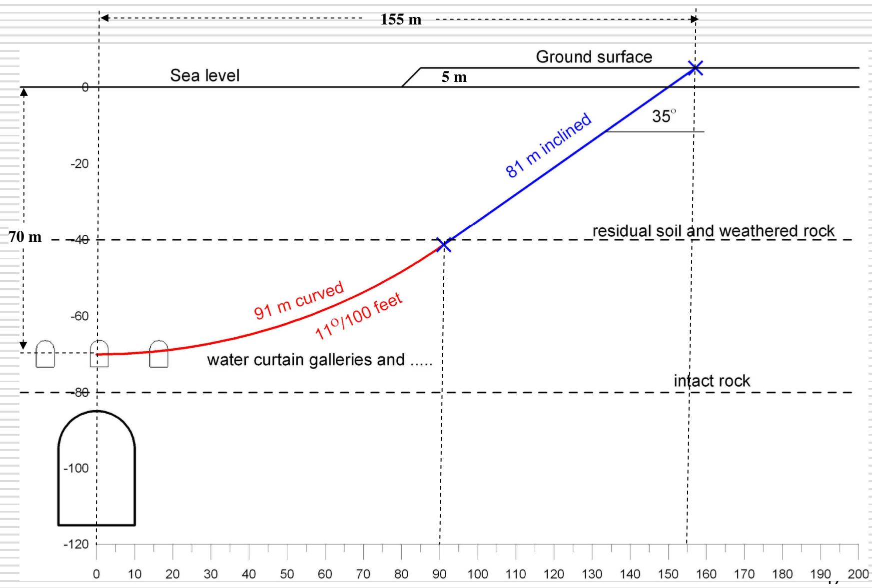
Core Orientation in Inclined Drilling

Horizontal Directional Drilling (HDD)

- Borehole drilling is accurately controllable & steerable according to predetermined trajectory ----- The State-Of-The-Art drilling technique in the world
- Drilling in inclination, then curve and finally horizontal direction is feasible
- Rock cores are extracted along the whole drilling route for geological & rock quality assessment
- Especially suitable for geological investigation at seabed or for tunnels cross river.



HDD Trajectory Design Principle

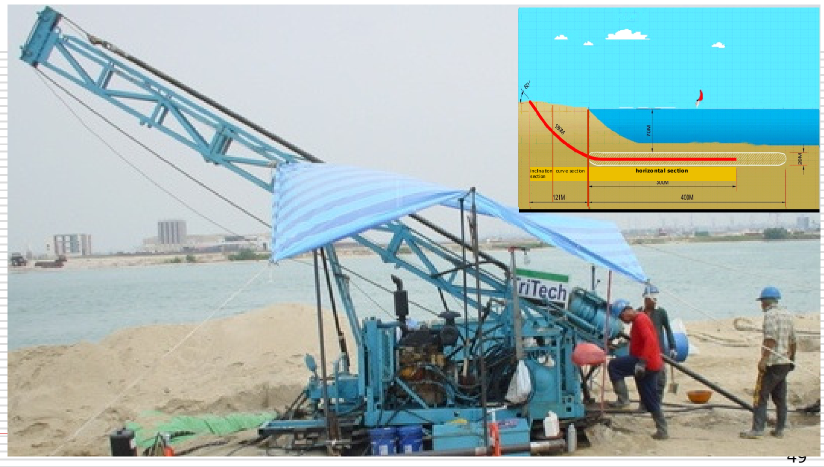


Horizontal Directional Drilling (HDD) – Curved Drilling

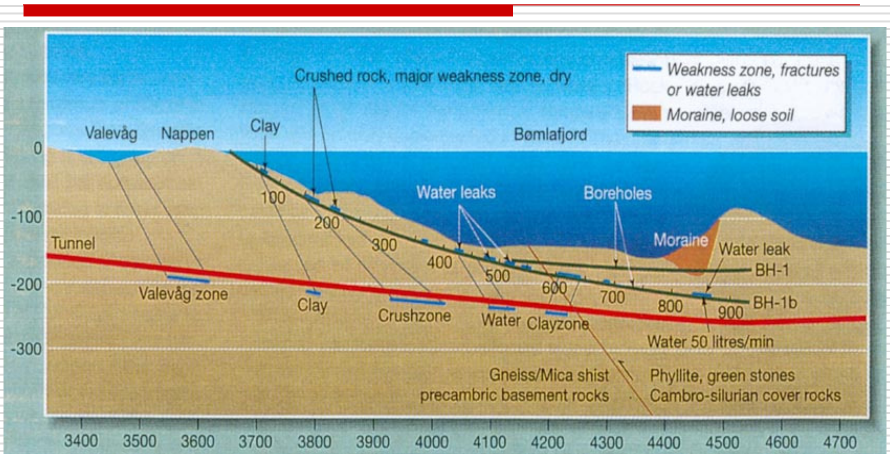
- Exactly drilling along cavern/tunnel route to obtain exact info along tunnel route
- Obtain vertical joint information
- Able to have core orientation measurement to identify rock joint system
- Verify fault / weakness zones obtained from geophysical profiling
- Certify/calibrate geophysical results
- Obtain rock cores for lab tests (properties)
- Obtain rock cores for rock mass quality assessment and distribution with depth

HDD Drilling ay Jurong Island for Oil Storage Caverns under Seabed

- HDD drill up to 500m/borehole
- 6 holes, a total of 2,400m



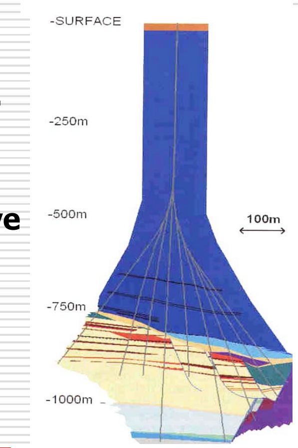
HDD Drilling in Norway for Subsea Tunnel



- **Subsea tunnel at Bømlafjord, Norway**
- **HDD drill 930m**

HDD Advantages over Traditional Drilling Methods

- **Underground target-orientated drilling, especially suitable for geological investigation at seabed or for tunnels cross river**
- **Core samples are extracted along whole drilling route, even in the curve**
- **Multiple repetitive deviations can be done**

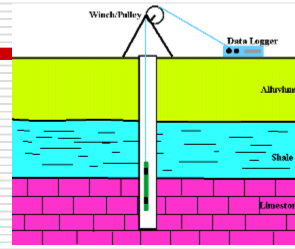


Downhole Geophysical Logging

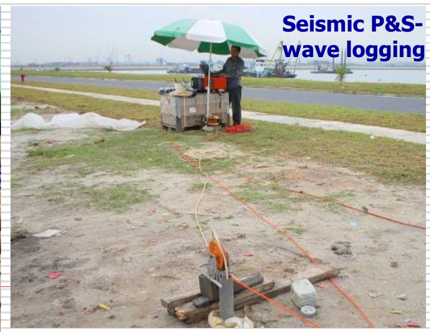
- **Objectives**
  - Provide parameters for geophysical survey interpretation.
  - Obtain statistics rock joint/fracture system.
  - Borehole surrounding profiling.
  - Verify faults / weakness zones.
  - Verify bedrock quality.
- **Types**
  - Caliper logging
  - Temperature logging
  - Gamma ray or spectra Gamma ray logging
  - Spontaneous polarization logging
  - Seismic P&S wave logging
  - Electric resistivity logging
  - Acoustic imaging of borehole wall with tele-viewer
  - Video logging of borehole wall with optical viewer
  - Borehole radar imaging

Geophysical Logging

- Caliper and P & S-wave logging
- Objective -- measure P & S-wave velocity in rock layers
- 6 boreholes
- 0.5m sensor spacing



Caliper logging device



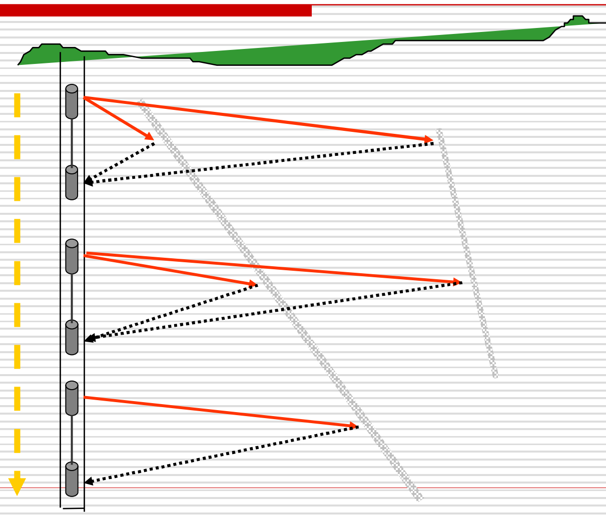
Seismic P&S-wave logging

Borehole Geophysical Logging

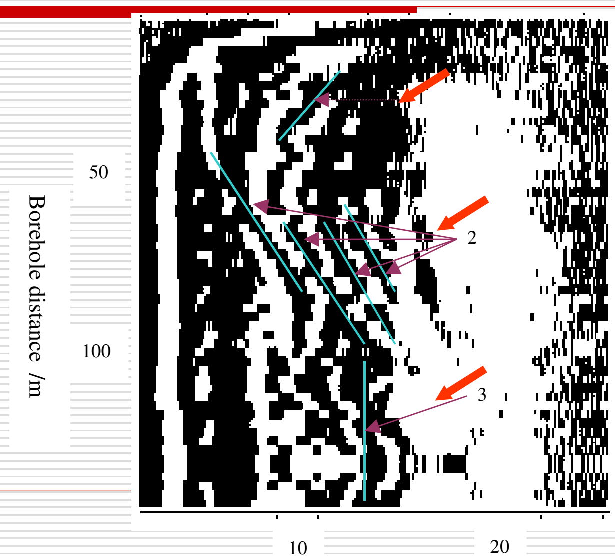
Lower down logging sensor

Data Logger

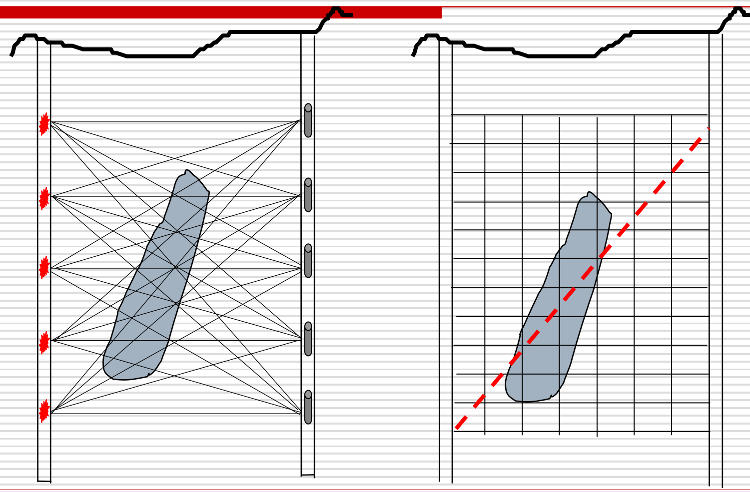
Borehole Radar Image



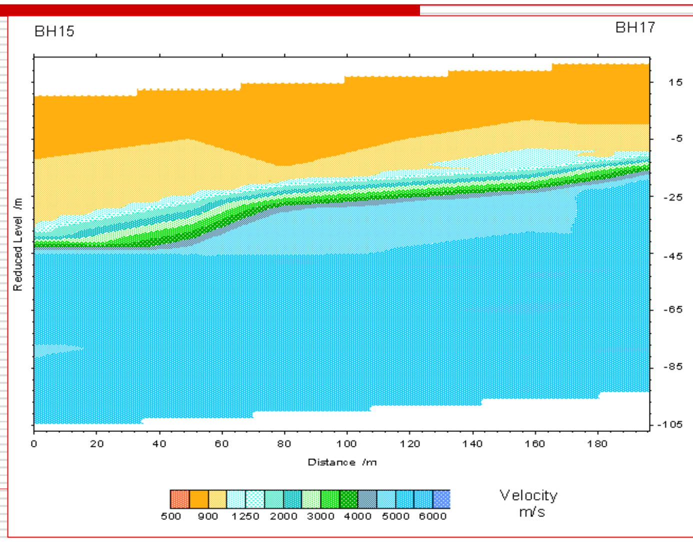
Borehole Radar Imaging



Cross-hole Geophysical Tomography

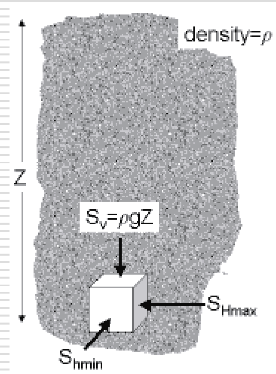


Cross-hole Geophysical Tomography



Downhole In-Situ Measurement

- Dilatometer test to measure in-situ E-modulus of rock mass
- In situ stress measurement to obtain tectonic stress – horizontal or vertical stress is dominant ?
  - Hydraulic fracturing method in borehole prior to cavern excavation
  - 3D overcoring method in tunnel during excavation (better option).



Natural in-situ stress at depth

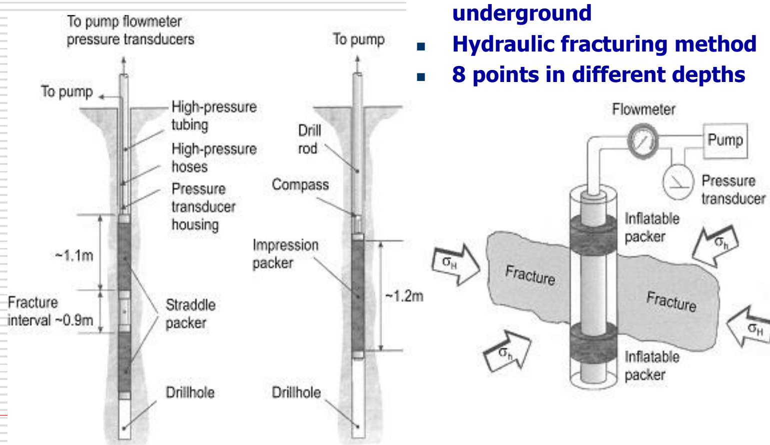
Dilatometer Test

- Objective: to measure deformation behavior & E-modulus of in situ rock mass.
- Method: Widening a borehole section by compressed air expansion packer.
- Test depth: down to 400m.

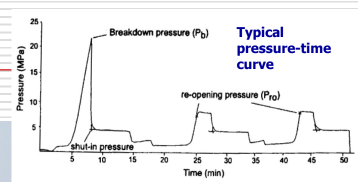
Installation of dilatometer probe

Hydraulic Fracturing Method

- Objective -- measure original state of natural stress underground
- Hydraulic fracturing method
- 8 points in different depths



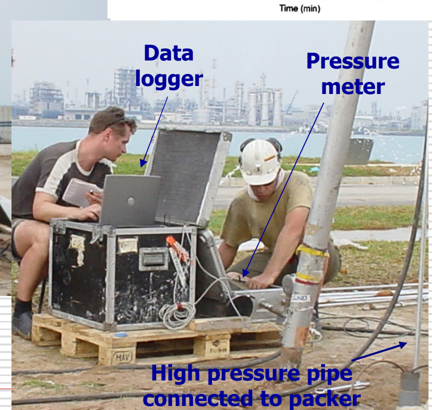
In Situ Stress Measurement at Jurong Island



Typical pressure-time curve

Pump

Winch



Data logger

Pressure meter

High pressure pipe connected to packer in borehole

Hydrogeologic Test

- Methods vs Objectives
  - Observation well for groundwater level
  - Rising/falling head permeability test for overall permeability
  - Double packer test for permeability at selected rock sections
  - Lugeon test for permeability
  - Short duration test for permeability
  - Long duration test for permeability
  - Pumping test for aquifer water flow and permeability.
  - Groundwater chemical tests.
  - Test of Radon in groundwater – high concentration of Radon may be a hint for faulted zones or highly permeable rock layer.

Laboratory Test

- **Method *vs* Objectives**
  - Petrography analysis for mineral components and rock naming
  - Physical properties of rock material (density, gravity, porosity, etc)
  - Chemical test of rock materials (PH, Sulphate, Chloride content) for potential chemical erosion.
  - Hardness & abrasion of rocks for drillability.
  - Expansive reactivity of aggregate for expansionability
  - Unconfined swelling index of rocks
  - Point load (strength - point load index)
  - Uniaxial/triaxial compression (strength, E-modulus and Poisson's ratio)
  - Brazil tensile (strength)
  - Rock joint direct shear (cohesion and frictional angle)
  - X-ray defraction analysis for detecting clays included in rock joints.

  - The test results characterize rock parameters and form the basis for rock mass classification, and stability numeric modeling.

Intact Rock Properties (Granite)

Properties	Range	Average
Density (g/cm^3)	2.62 ~ 2.67	2.65
Uniaxial compressive strength (MPa)	108.09 ~ 224.89	163.83
Young's modulus (GPa)	37.10 ~ 111.25	65.87
Poisson's ratio	0.14 ~ 0.35	0.24
Cohesion (MPa)	—	24.51
Internal friction angle (^{o})	—	59.02
Point load index	5.6 ~ 16.1	8.7
Brazil tensile strength (MPa)	8.46 ~ 14.30	11.71
Three-point tensile strength (MPa)	13.25 ~ 27.30	19.94

History of

Previous Site Investigations, Feasibility Studies, Actual Rock Cavern Projects in Singapore

History - Previous Site Investigations & Feasibility Studies

Stage 1 (1990-1994) -

- Feasibility Study of Rock Cavern Construction in the Bukit Timah Granite, Sponsored by NSTB, Studied By NTU, 1990-1994
- Site Characterization of Bukit Timah Granite for Rock Cavern Construction, Invested by LEO (DSTA) of MINDEF, Studied by NTU and Singapore Technologies Construction (Pte) Ltd, 1995-1997
- An Investigation of Hot Spring at Sembawang, Invested by Faser and Neave (Singapore), Studied By Zhao Jian and Chen CN, 1994

Stage 2 (1995-1998) -

- Feasibility Study of Rock Cavern Construction in the Jurong Formation, Sponsored by NSTB, Studied By NTU & PWD, 1995-1998

Stage 3 – (1997-2000) -

- Feasibility Study of Underground Science City (USC) at Kent Ridge, Sponsored by NSTB, Studied By NTU & PWD, 1997-2000

History - Previous Site Investigations & Feasibility Studies

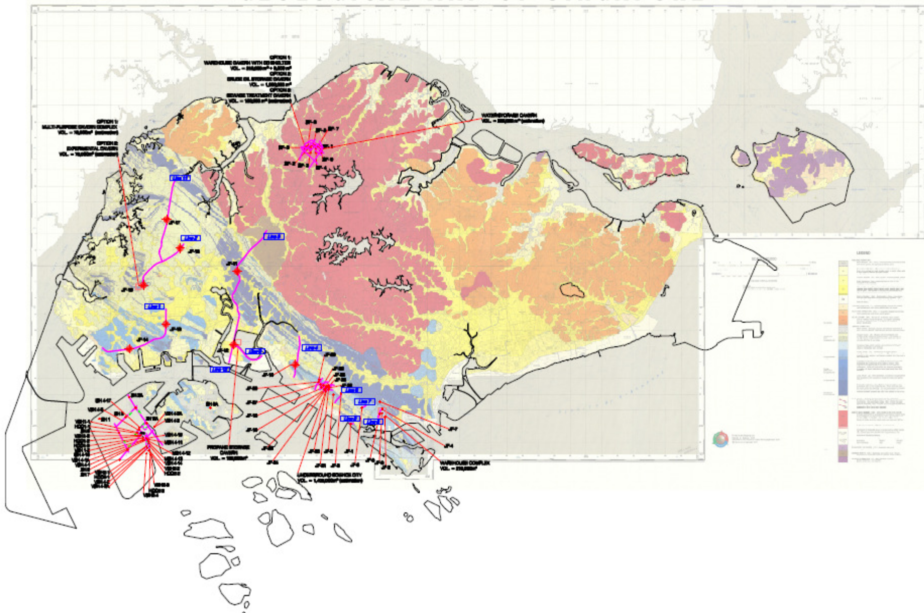
Stage 4 (2001-2007) -

- Feasibility Study of hydrocarbon storage caverns at Jurong Island, studied by JTC & NTU, 2001-2002.
- Detailed feasibility & design of hydrocarbon storage caverns at Banyan Basin, studied by Geostock & Jurong Consultants, 2004-2007.
- Construction of hydrocarbon storage caverns at Banyan Basin, invested by JTC, 2007-2013.

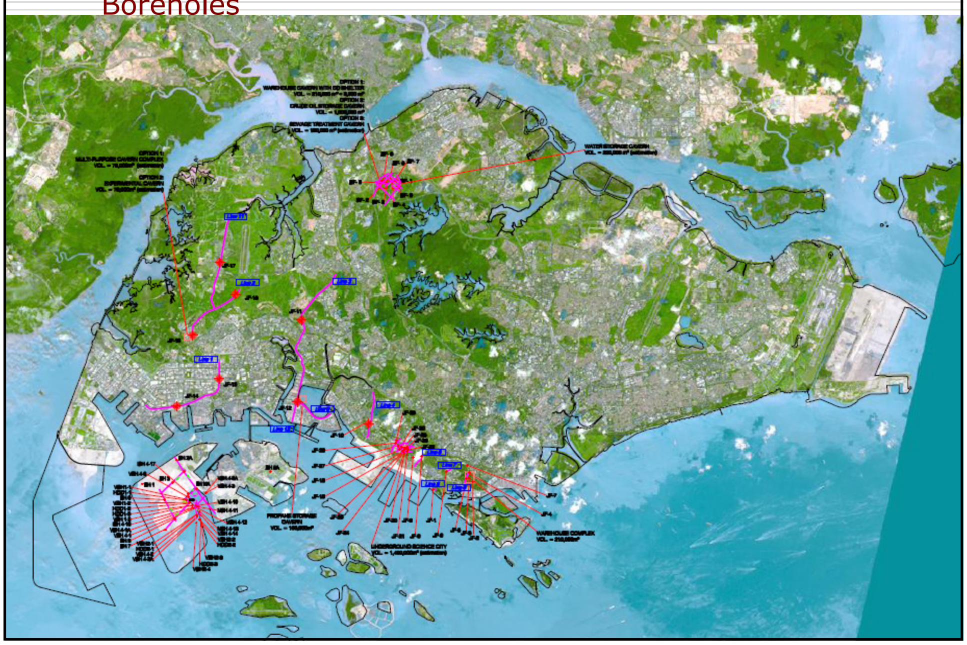
Stage 5 (Recent Development) -

- Underground rock cavern usage (URC) feasibility study, studied by Sintef-Tritech-Multiconsult (STM) Consortium, 2008-2009.
- Feasibility study (detailed conceptual design) for underground science city (USC) at Kent Ridge, under tendering by JTC, 2009.
- Geological investigation and ground characterization at Tanjong Kling and Jurong Hill (for feasibility study of underground warehouse), under tendering by JTC, 2009.

Layout of Previous Site Investigation – Seismic Lines and Deep Boreholes



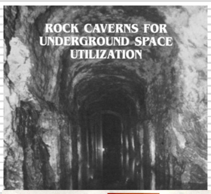
Layout of Previous Site Investigation – Seismic Lines and Deep Boreholes

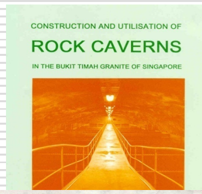


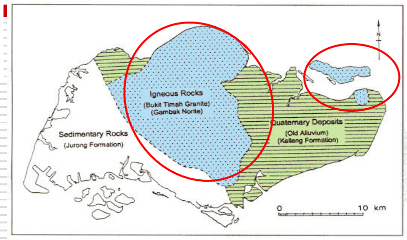
History - Previous Site Investigations & Feasibility Studies

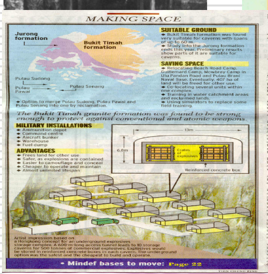
Stage 1: 1990~1994,

NTU-PWD studied the Bukit Timah Granite Formation and reported that cavern development in granite rocks are technically feasible and economically viable.








MAKING SPACE


MOVE TO CARVE CAVERNS

Ammo may be stored underground

By DOMINIC NATHAN


Mindef goes underground

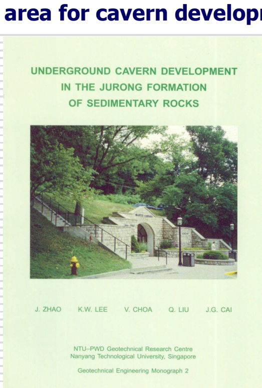
Construction of ammunition storage complex deep under disused quarry in Mandai has started

UNDERGROUND AMMUNITION DEPOT

History - Previous Site Investigations & Feasibility Studies

Stage 2: 1995~1998

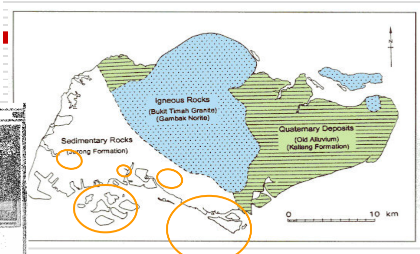
NTU-PWD studied Jurong Formation, identified potential locations in Jurong area for cavern development.

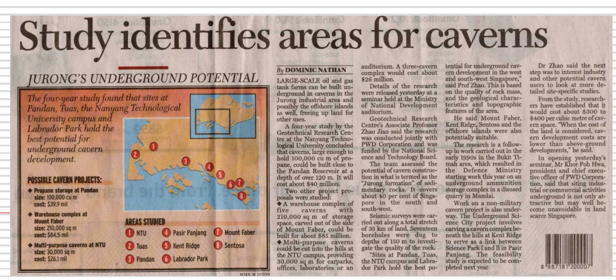



Underground caverns offer space to expand

Bukit Timah, Jurong areas studied for suitable sites

Variety of uses for underground caverns




Study identifies areas for caverns

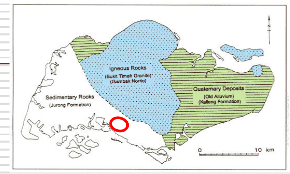
JURONG'S UNDERGROUND POTENTIAL

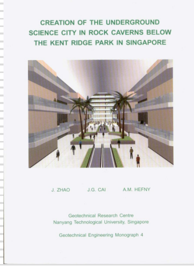
By DOMINIC NATHAN

History - Previous Site Investigations & Feasibility Studies

Stage 3: 1997-2000

NTU-PWD studied the feasibility of Underground Science City at Kent Ridge




CREATION OF THE UNDERGROUND SCIENCE CITY IN ROCK CAVERNS BELOW THE KENT RIDGE PARK IN SINGAPORE

J. ZHAO J.G. CAI A.M. HEFNY

Geotechnical Research Centre
Nanyang Technological University, Singapore

Geotechnical Engineering Monograph 4

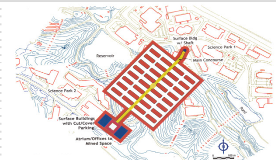

The Straits Times

It will be biggest subterranean complex in region if project is approved

Underground caverns near Science Park?

Going under

Caverns can also be built in:

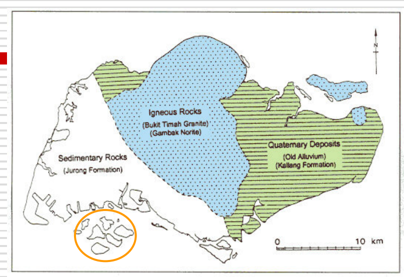


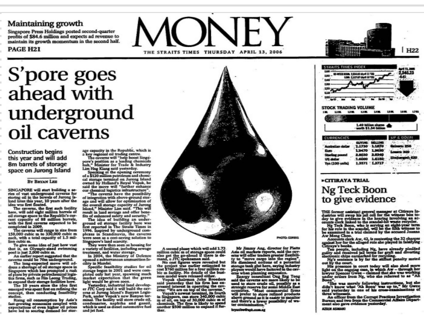
History - Previous Site Investigations & Feasibility Studies

Stage 4: 2001-2007

JTC-NTU studied the feasibility of hydrocarbon storage caverns at Jurong Island (2001~2002)

JTC studied the feasibility, design and construction of Jurong Rock Cavern for hydrocarbon storage at Banyan Basin (2004~2007)



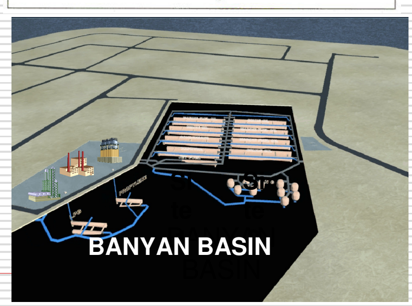

MONEY

THE STRAITS TIMES THURSDAY APRIL 13, 2006

Maintaining growth

S'pore goes ahead with underground oil caverns

Ng Teck Boon to give evidence



History - Previous Site Investigations & Feasibility Studies

Stage 4: 2001-2007

Construction of Jurong Rock Cavern for hydrocarbon storage at Banyan Basin, invested by JTC, 2007-2013. Media Report on 29 Oct 2009

Jurong Rock Cavern ready by 2013

Work on underground oil storage facility to start by year's end; phase 1 to cost $890m

By Jessica Cheam

PHASE 1 of Jurong Rock Cavern, the first underground oil storage facility to be built in South-east Asia, will finally begin construction by year's end and cost about $890 million.

The first storage caverns will be ready by the first half of 2013, said JTC Corporation during a briefing yesterday.

JTC has awarded the building contract to South Korea's Hyundai Engineering and Construction – over the only other bidder, fellow South Korean firm SK Engineering and Construction.

The tender was called in late 2007 but the complexity and design of the project led to delays, said a JTC spokesman.

Its cost has also risen, above the $700 million expected earlier.

Japanese firm Sato-Kogyo has already built two access shafts and start-up galleries in the initial phase for the storage caverns, work that has cost about $50 million.

The media yesterday visited part of the rock cavern under the seabed of the Banyan Basin via an access shaft that went as deep as 132m below ground level.

Workers will use a technique that drills and blasts sedimentary rock to build the cavern, which will be used to store liquid hydrocarbons such as crude oil, condensate, naphtha and gas oil.

The first phase consists of 8km of tunnels and five caverns.

Together, they will contain nine storage galleries, each about nine storeys high and big enough to accommodate the water from more than 64 Olympic-sized swimming pools.

The Jurong Rock Cavern will free up about 60ha of usable land above ground, which is highly sought after by investors on Jurong Island.

This land can now be used for higher value-added manufacturing activities, said JTC's spokesman.

The Government is also considering building offshore sites to cater to Jurong Island's storage needs.

"The cavern will provide strategic storage for better fuel security and it also gives Singapore a competitive advantage to attract more investors," said the spokesman.

Hyundai Engineering won the contract due to its experience in building similar projects in South Korea and Taiwan, said JTC.

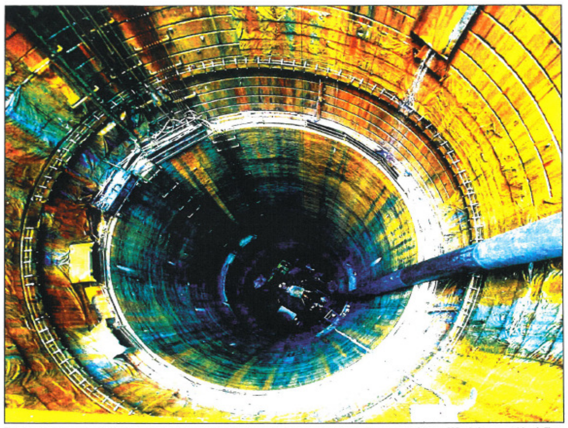
The contractor is also working on other projects here, such as phases 3 and 4 of the Pasir Panjang Terminal and the One Shenton Way residential development.

jcheam@sph.com.sg

BETTER FUEL SECURITY

"The cavern will provide strategic storage for better fuel security and it also gives Singapore a competitive advantage to attract more investors."

JTC's spokesman

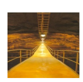


This access shaft to the Jurong Rock Cavern, South-east Asia's first underground oil storage facility, goes as deep as 132m below ground level. The first phase consists of 8km of tunnels and five caverns. ST PHOTO: CHEW SENG KIM

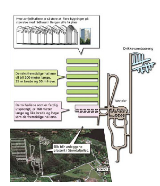
Potential Nine Rock Cavern Usages

Stage 5: 2008-2009 Underground rock cavern usage (URC) feasibility study, studied by Sintef-Tritech-Multiconsult (STM) Consortium, 2008-2009

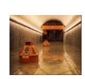
1. **Generic R&D facilities – Lead Agency JTC**
2. **Warehousing and storage & port logistics – Lead Agency JTC**  **A**

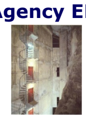


3. **Water reclamation plants – Lead Agency PUB**
4. **Reservoirs – Lead Agency PUB**



5. **Incineration plants – Lead Agency NEA**
6. **Landfills – Lead Agency NEA**





7. **Power station and electrical substations – Lead Agency EMA**
8. **Airport logistics – Lead Agency CAAS**
9. **Data centre – Lead Agency IDA, JTC & DSTA**

History - Previous Site Investigations & Feasibility Studies

Stage 5: 2008 - 2009

Underground rock cavern usage (URC) feasibility study, studied by Sintef-Tritech-Multiconsult (STM) Consortium, 2008-2009

Media Report on 14 May 2008

Down in the cavern

POTENTIAL UNDERGROUND ROCK CAVERN USES	LEAD AGENCIES
Power stations and electrical substations	Energy Market Authority
Incineration plants	National Environment Agency
Water reclamation plants	Public Utilities Board
Landfills	National Environment Agency
Reservoirs	Public Utilities Board
Warehousing and storage	JTC & Defence Science and Technology Agency (DSTA)
Port logistics	Maritime and Port Authority of Singapore
Airport logistics	Civil Aviation Authority of Singapore
Data centre	Infocomm Development Authority of Singapore, JTC and DSTA
Wafer fab plants and R&D labs	JTC

Source: JTC Tender

An underground reservoir?

Govt tender to study feasibility of more facilities in rock caverns

ANSLEY NG
ansley@mediacorp.com.sg

LAND-SCARCE Singapore is already storing some of its military munitions in this way. And work is underway on similar storage facilities for crude oil and oil products.

Now, the Government wants to look at building power stations, warehouses, incineration plants, airport logistics centres and reservoirs – all below ground.

Industrial landlord Jurong Town Corporation (JTC) last Friday called a tender for a "underground rock cavern usage feasibility study" to see how subterranean grottos could be used to maximise land use. Among other things, the winning consultant will have to study the costs and the use of underground caverns in other countries. It will also advise JTC on the possible environmental and health issues, such as pollution, radiation and damage to existing buildings and infrastructure.

Last July, TODAY broke the story of how government agencies including the JTC were exploring the feasibility of creating caverns for living.

Professor Zhao Jian, who led early feasibility studies on cavern development in Singapore, had said then that the potential for space underground was "almost limitless" and was "particularly useful for any facilities that are not desirable at surface level, for example, sewage treatment plants".

The study now up for tender will look merely at feasibility and not sites, a JTC spokeswoman told the *Business Times*.

However, potential sites could be areas with deposits of igneous rock, such as granite, in the central, northern and northeastern areas of the island.

A 1995 paper by Nanyang Technological University researchers including Prof Zhao, in the Quarterly Journal of Engineering Geology, concluded that the Bukit Timah granite – which forms one-third of the surface area of Singapore – had good potential for underground cavern construction.

The tender closes June 6, and the consultant is expected to work with the Civil Aviation Authority of Singapore and the Energy Market Authority, among others.

OTHER CAVERN PROJECTS:

- In March, the Ministry of Defence opened caverns under the disused Mandai Quarry to store ammunition such as bullets, bombs and missiles. The warehouse caverns – each about the size of six basketball courts – were blasted out of solid granite underneath the quarry, freeing up surface land the size of Pasir Ris town.
- The JTC is constructing the $2-billion Jurong Rock Cavern beneath Jurong Island, for use by petrochemical companies. The first caverns under Phase 1 should begin operations in 2010.
- A plan in the late 1990s to construct a Science City, a mixed-use commercial project, under Science Park 2 was derailed by cost factors.

Recommendations for Future Geologic Investigations

Site Investigations and Geologic Data Base

Scheme 1 – Islandwide broad Site Investigation for a master plan of underground space development in Singapore
Boreholes down to depth 100-150m, associated with seismic survey and lab tests;
followed by pre-feasibility study for quick and preliminary assessment of geology, bedrock depth, RQD and rock mass quality.

Scheme 2 – Zoom into the identified cavern locations with strategic considerations for industrial usages
Further comprehensive site investigations and detailed feasibility study are recommended to achieve the following purposes:

① **Topographic features and geometry**
② **Overburden thickness, bedrock depth and rock strata/layer**
③ **Weathering grade and thickness**
④ **Soil & rock material classification and properties**
⑤ **Major fold and fault structures**
⑥ **Rock joint sets and grouping**
⑦ **Groundwater and permeability**
⑧ **In situ stress condition**

Followed by systematic geologic investigations, a global geologic data base shall be established and shared for underground master planning & project planning in Singapore.

Thank You !