應用地質技師公會2021年度聯合會員(代表)大會

二十一世紀應用地質的回顧與展望

闕河淵 Ho-Yen Chuay
BSc MSc PhD FICE PE

27 March 2021

宜蘭礁溪晨曦

1979 — 2020 專業經歷

- 南安技師事務所主持技師 1990 - 2013
- 台北市議會第六屆議員 1989 - 1994
- 台北市政府捷運工程局副局長 1994 - 1998
- 台北市應用地質技師公會第二屆理事長 1998 - 2001

1999 九二一集集大地震

2010 地質法立法

- 財團法人陽光社會福利基金會董事/董事長/監察人 1998 — 迄今
- Mott MacDonald Ltd – Project Manager/Managing Director – Taiwan 2001 - 2013
- CAF – Project Manager/Consultant, Kaohsiung LRT 2014 - 2015
- MMC-Gamuda JV Director, Kuala Lumpur MRT Line 2 2017-2020

簡報大綱

- 何謂應用地質?
- 地質災害 Geological hazards
- 地質資源 Geological resources
- 工程地質專業以外
- 挑戰與機會
- 結語
- Q & A

Definition

- **Applied Geology: The application of geologic principles to all manner of works and natural conditions that could or would affect health, safety and welfare**
- **Engineering Geology: The application of geologic sciences to engineering practice to assure that geologic conditions affecting the location, design and construction of engineering works are recognized and adequately provided for.**
- **Applied Geology**

  - Ore Deposit Geology + Engineering Geology + Environmental Geology (or Urban Geology) + Hydrogeology

  - Ground Engineering (used in Europe, equivalent to Engineering Geology)

應用地質技師之角色

- 地質
- 應用地質
- 工程地質
- 大地工程
- 土木工程

地質工作者與人類文明演進息息相關

James H. Williams 2016

US Geological Survey

- 自然資源開發、掠奪：煤、鐵、石油、天然氣
- 大型公共建設：公路、鐵路、運河、水庫
- 地質災害防治 ：地震、山崩、火山噴發、地盤下陷、地下水汙染
- Military geology

Development of Engineering Geology

- 1882 O. Mohr: Mohr′ s Circle
- 1925 Karl Terzaghi: Soil Mechanics – Theory of consolidation

- 197_ Q. Zaruba & V. Mencl: Engineering Geology
- 1974 P.B. Attewell & I.W. Farmer: Principles of Engineering Geology
- 1974 E. Hoek & J.W. Bray: Rock Slope Engineering
- 1980 E. Hoek & E.T. Brown: Underground Excavations in Rock

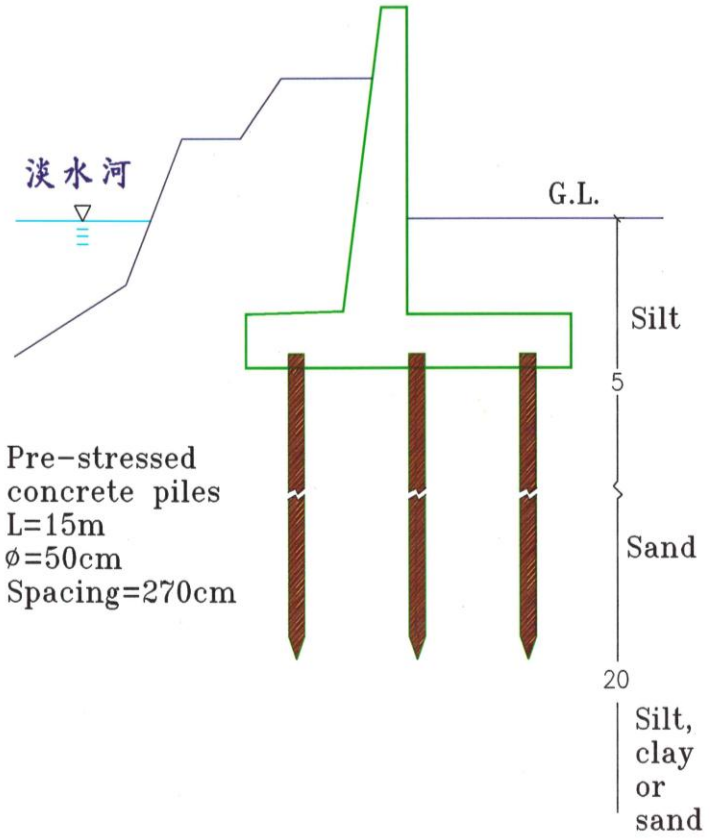
- Instrumentation & Monitoring (Observational approach)

1980-90

- **Geological mapping in Sha′ ar Descent Highway Project, Saudi Arabia**
  - **Slope stability**
  - **NATM in tunneling**
- 南迴鐵路中央隧道地質調查(地形測量、鑽探、震測、岩心試驗)
  - 建立 [工程地質模型]
  - 硬頁岩（低度變質）單壓強度：取決於泥縫之方位
- 翡翠水庫
- 明湖、明潭抽蓄發電：**Load cell**、**Convergency meter**、 **Extensometer**
- 台北捷運系統

Geophysical exploration

社子島防潮堤加高工程



地質災害 Geological Hazards

- 與邊坡穩定有關
  - 順向坡
  - 山崩
  - 礦渣堆：台北南港山系
- 土石流

地質災害 Geological Hazards

- 與活動斷層有關
  - 活動周期及規模
  - 斷層帶與禁限建之關係
  - 震動及液化

地質災害 Geological Hazards

- 與火山噴發有關
- 與地下水汙染有關：加油站油槽、高雄捷運前鎮段
- 與方解石(石灰岩、大理石)有關
  - Karstic limestone

地質災害 Geological Hazards

- 英國水壩建設計畫：豎井底部工人窒息命案

  命案現場：頁岩 + 石灰岩 + 地下水 + 通風設備 + 樓梯

  誰是兇手?

$$2FeS_2 + 7O_2 + 2H_2O > 2FeSO_4 + 2H_2SO_4$$

$$H_2SO_4 + CaCO_3 + 2H_2O > CaSO_4 \cdot 2H_2O + H_2O + CO_2$$

- Hazard associated with ???

  兇手 ! 共犯 ! 凶器 !

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地質災害 Geological Hazards

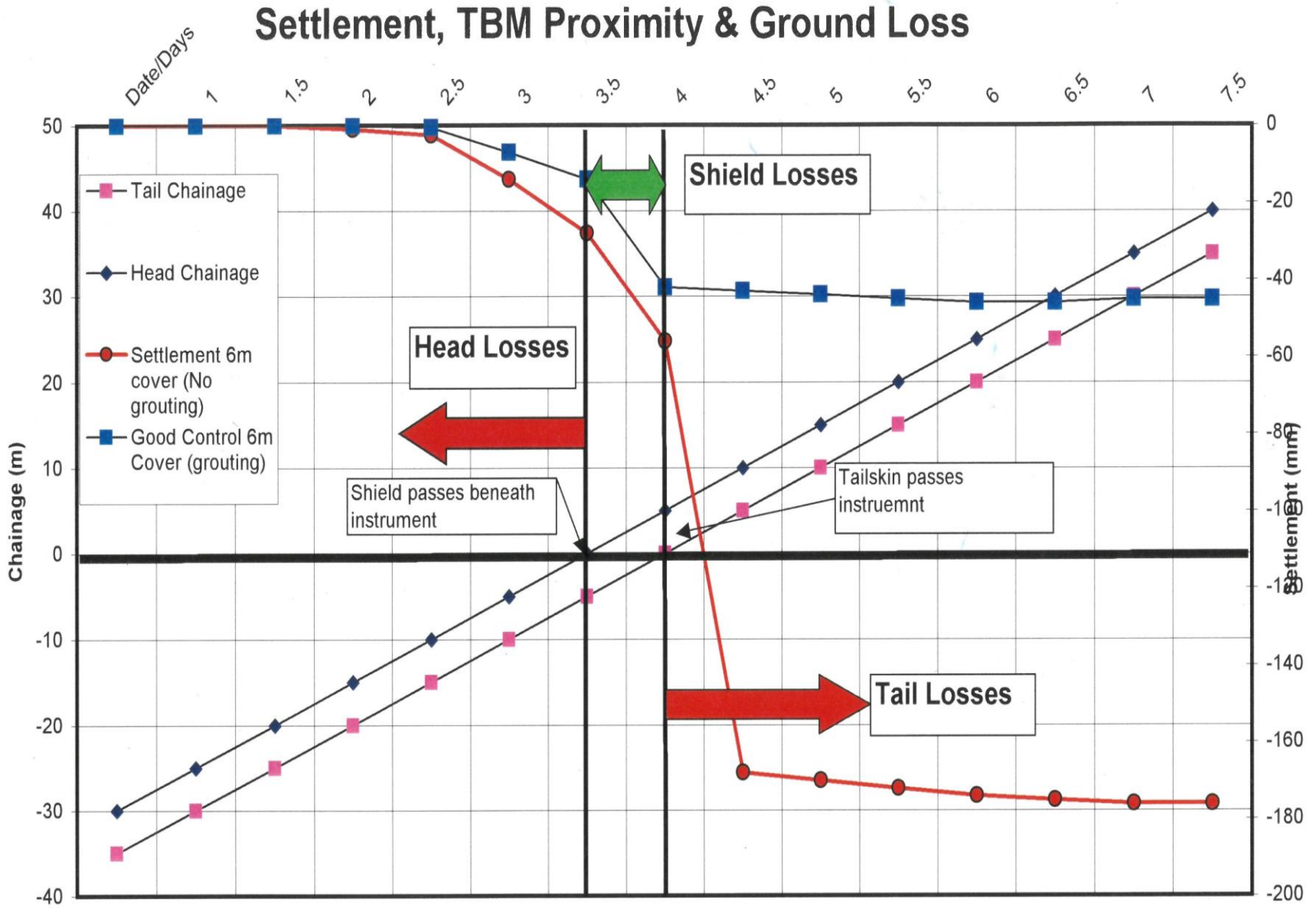
- **Ground subsidence induced by coal mining**
- **Ground subsidence induced by groundwater pumping**
- Settlement induced by tunneling in soil
  - Impact on buildings/structures
  - Impact on utilities

地質災害 Geological Hazards

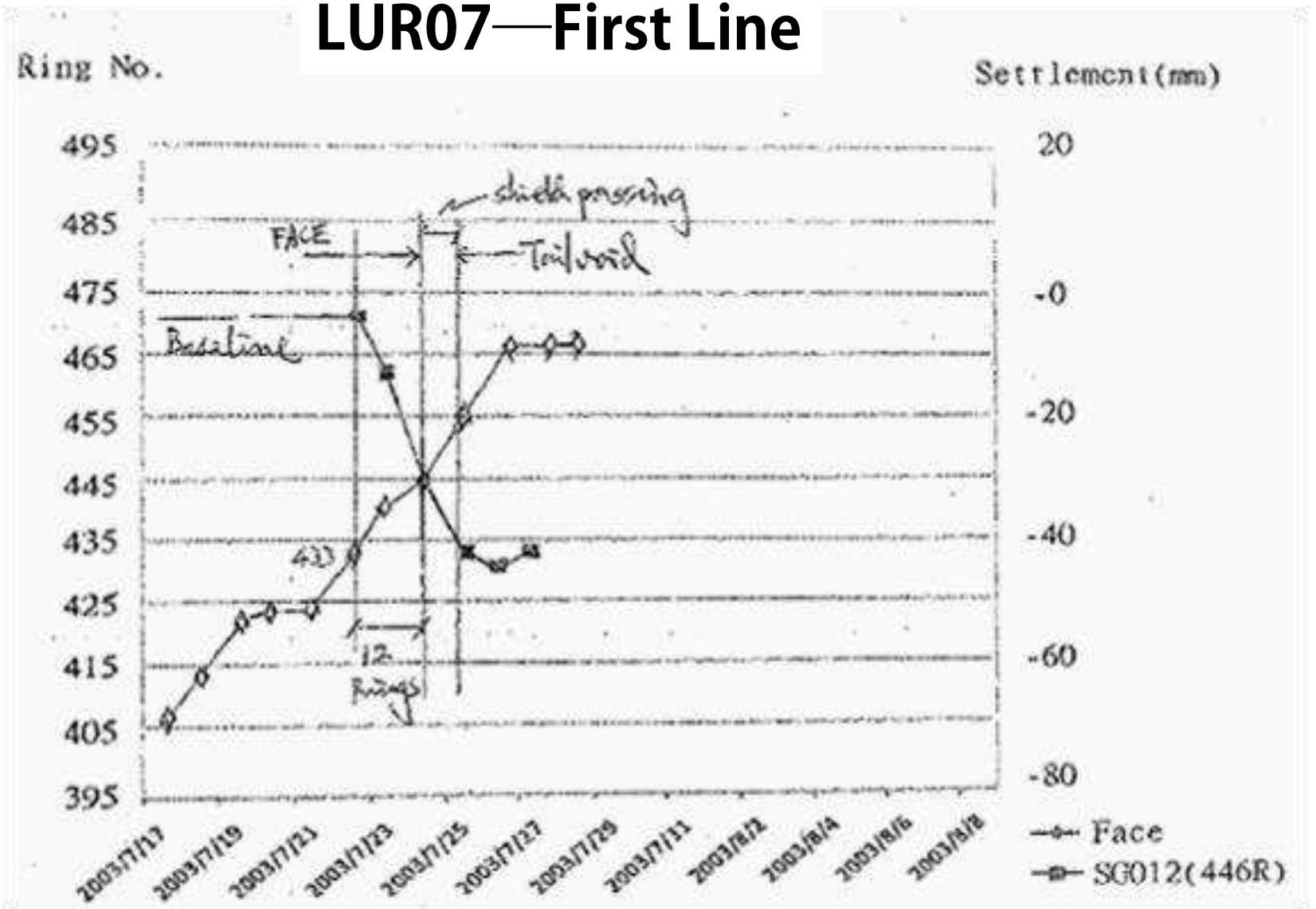
- Ground subsidence induced by coal mining

- Ground subsidence induced by groundwater pumping

- **Settlement induced by tunneling in soil**
  - **Impact on buildings/structures**
  - **Impact on utilities**


Settlement, TBM Proximity & Ground Loss
Date/Days
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
Chainage (m)
Settlement (mm)
Tail Chainage
Head Chainage
Settlement 6m cover (No grouting)
Good Control 6m Cover (grouting)
Shield Losses
Head Losses
Tail Losses
Shield passes beneath instrument
Tailskin passes instruemnt

LUR07—First Line



土壤隧道引起的沉陷
Settlement induced by tunneling in soil

- **Settlement curve defined by 3 parameters**
  - **Ground loss volume, v (constant vs depth)**
  - **Inflection point, i**
  - **Maximum settlement, w**

Assumption: Volume change = 0

Settlement trough

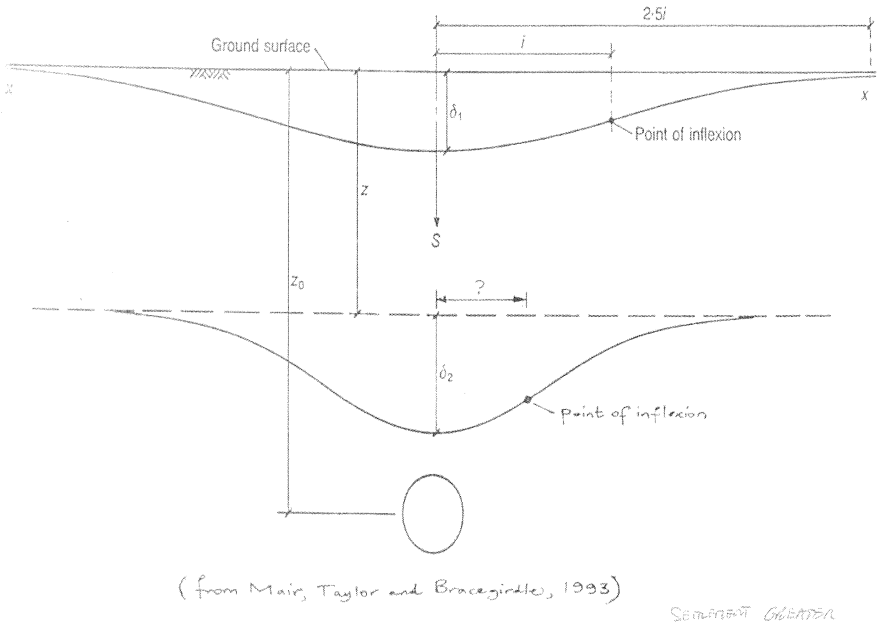
$$V = W(max) \exp - (x/i)^2$$

$$= W(max) \cdot 2.5i$$

$$i = (D/2)\,(Z/D)^m \text{ or}$$

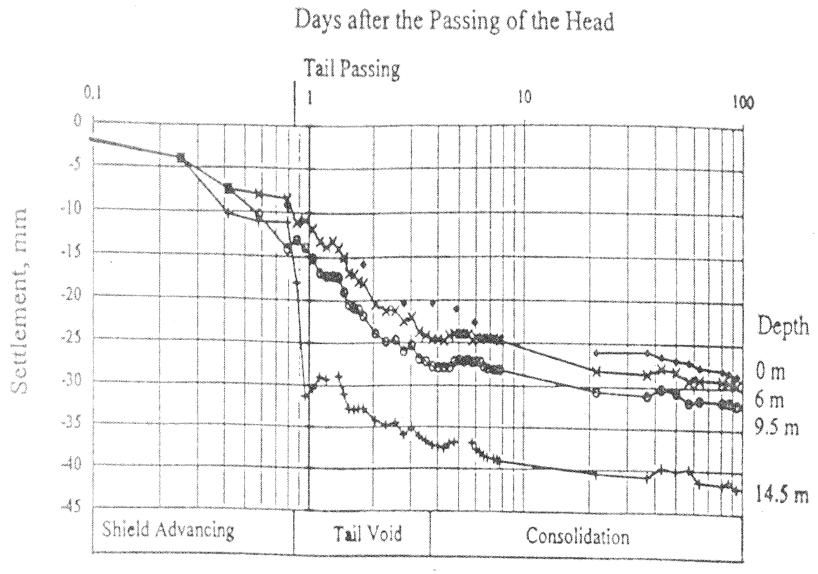
$$i = K\,Z$$

Settlement troughs at depth



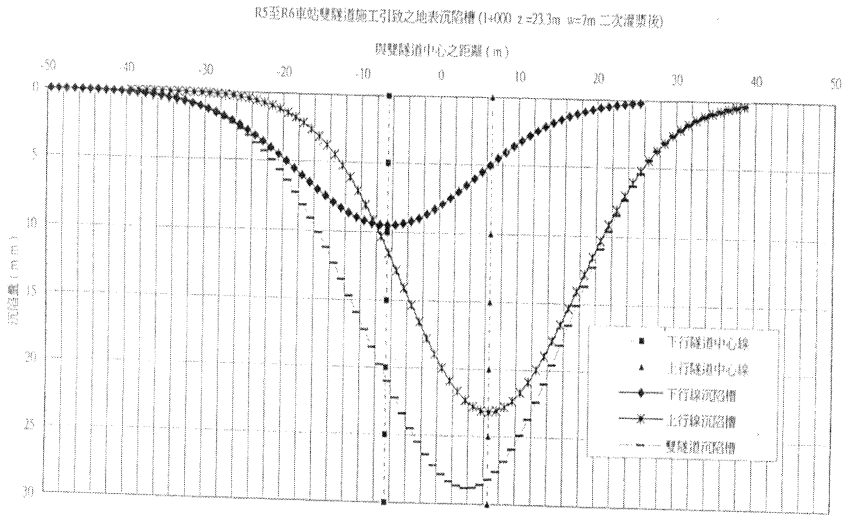
(from Mair, Taylor and Bracegirdle, 1993)

Surface and subsurface settlement profiles – (UNITED KINGDOM National Report: Taylor)



Development of settlement above EPB tunnel in Taipei (Moh et al, 1996)

Superimposition of settlement troughs



附圖 21　R5 至 R6 車站雙隧道施工引致之地表沉陷槽 (1+000 z =23.3m w=7m 二次灌漿後)

STACKED TUNNELS

Building/Utility safety assessment

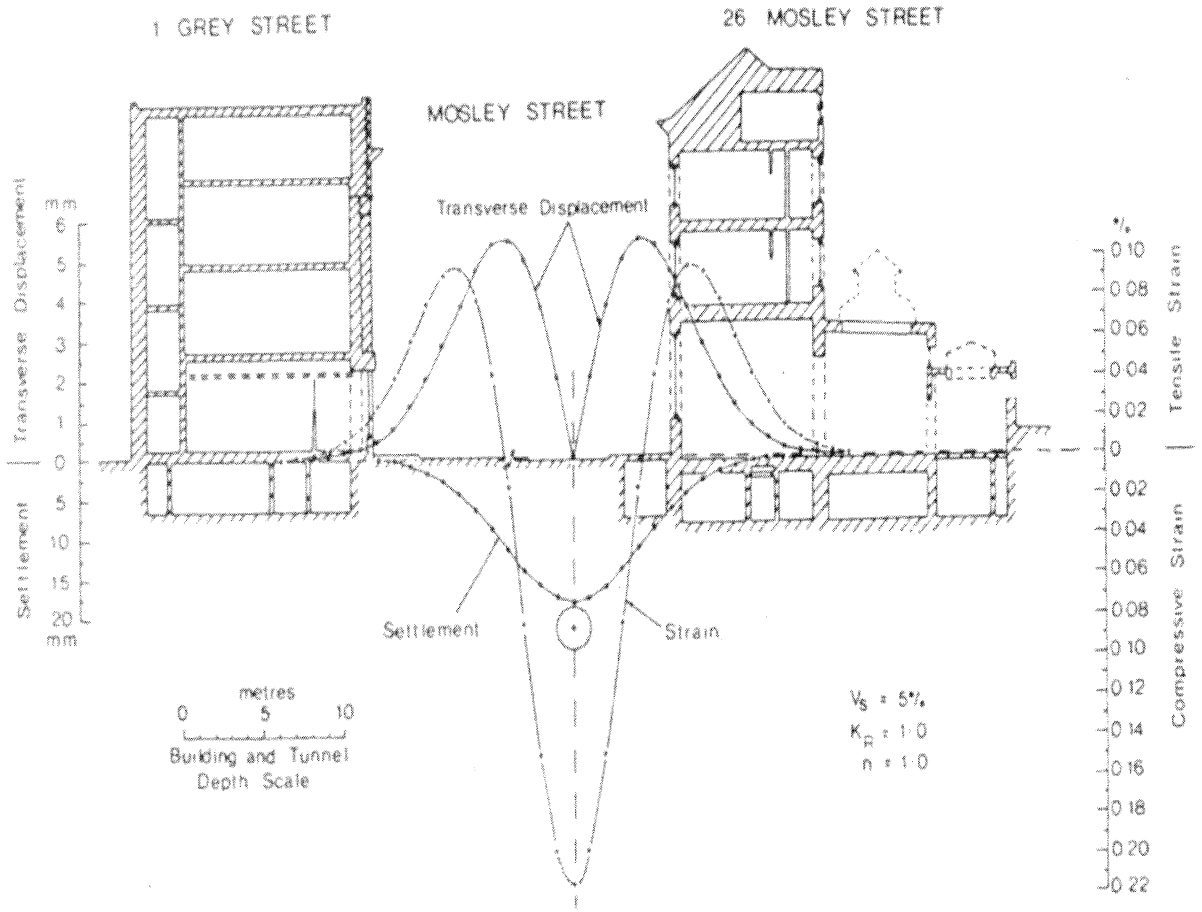


Figure 6.44 Prediction of ground deformation transverse to the centre line of a tunnel driven in soil beneath a major street in Newcastle upon Tyne (Section *C* on Figure 6.48).

Effect of consolidation

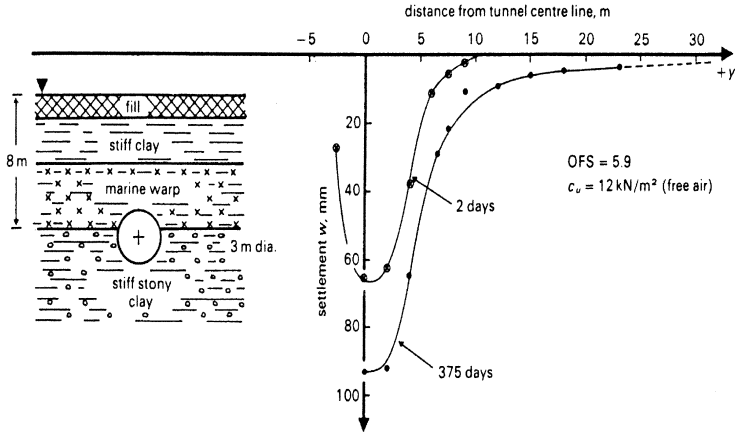


Figure 6.15 Transverse surface settlement distribution: Grimsby Array A (after Glossop, 1980; Glossop and O'Reilly, 1982).

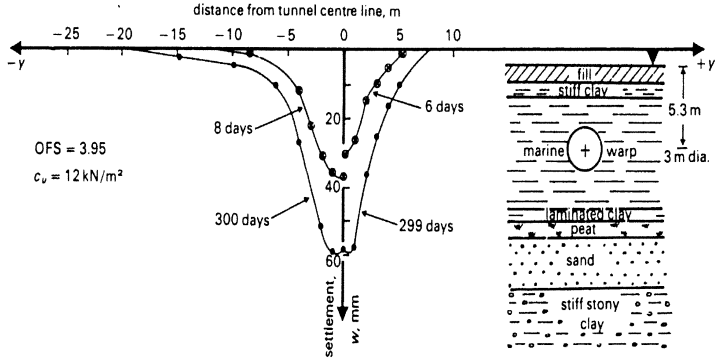
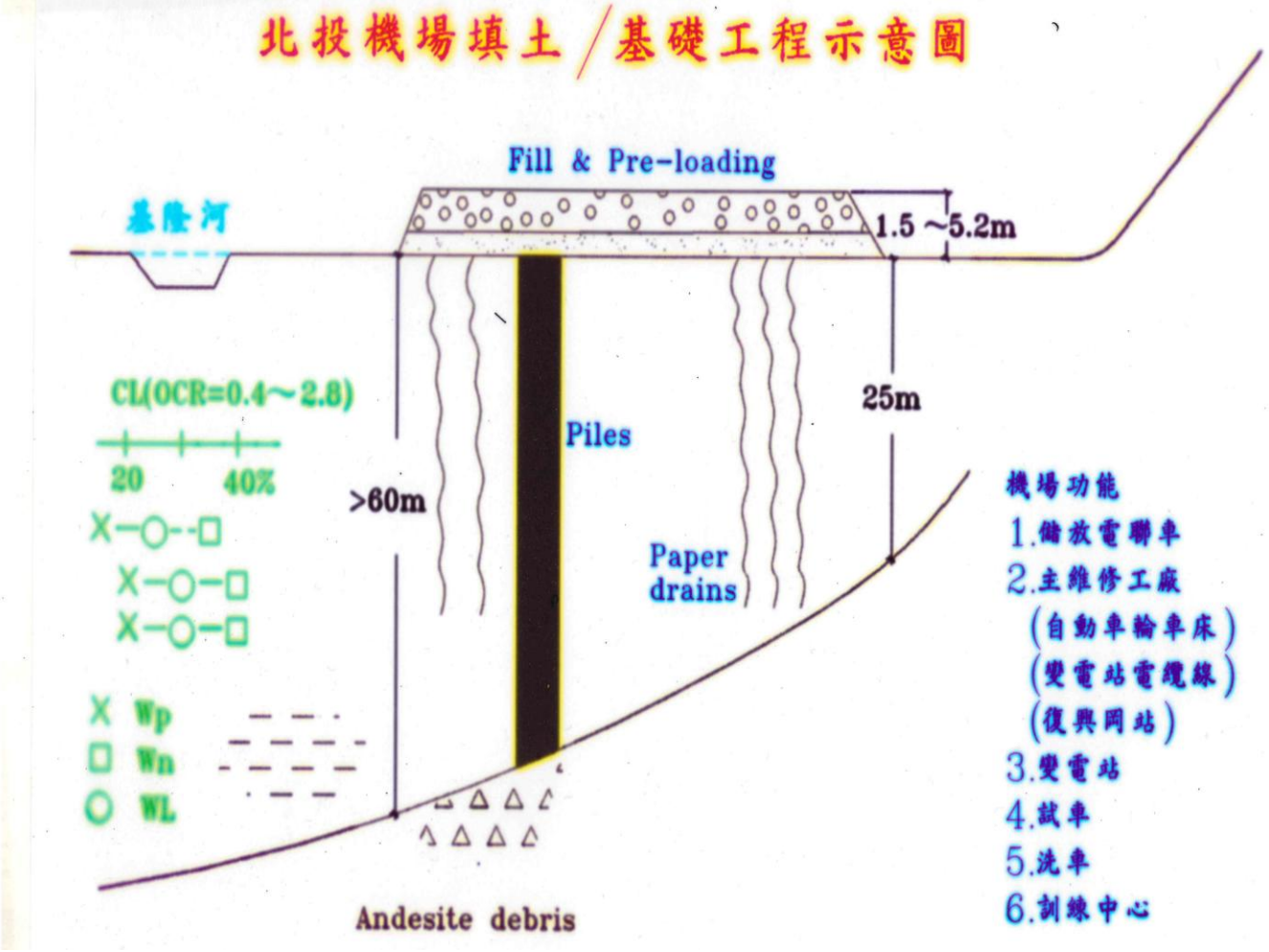


Figure 6.16 Transverse surface settlement distributions: Grimsby Array B1 (after Glossop, 1980; Glossop and O'Reilly, 1982).

地質災害 Geological Hazards

- 與黏土相關
  - 壓密Consolidation:
    - 台北捷運北投機廠(paper drain)
    - 高雄輕軌第一期(stone column) - 台鐵高雄港站
  - 膨脹Swelling:
    - Panama Canal (Mudrock)
    - London Clay (Heavily over-consolidated clay)
    - 翡翠水庫拱壩(層間泥縫)
    - 新莊機廠(斷層泥)
  - 殘留強度Residual strength:
    - 國道三號/台灣高鐵寶山段

台北捷運北投機廠地盤改良



地質災害 Geological Hazards

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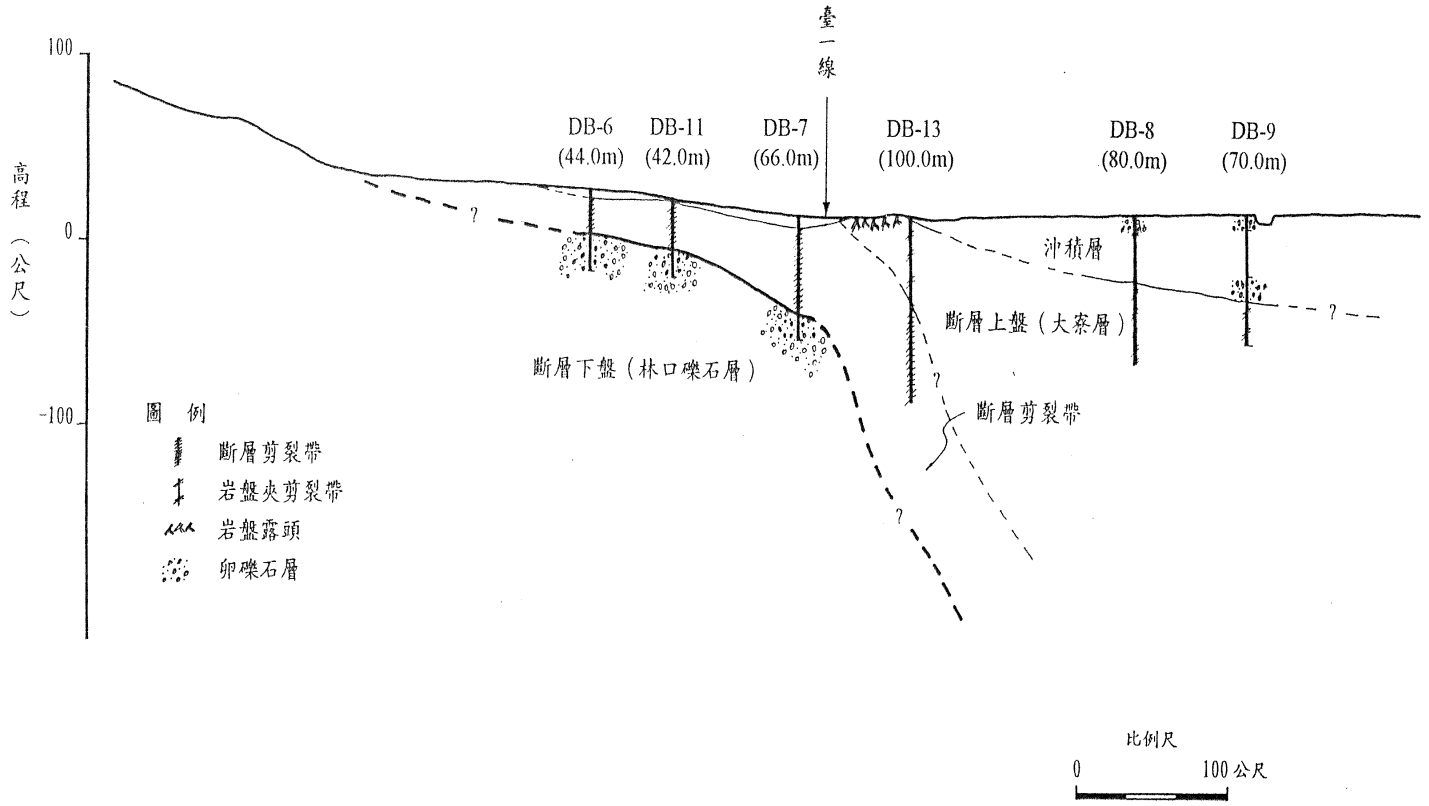
    - 新莊機廠(斷層泥)
  - 殘留強度Residual strength:
    - 國道三號/台灣高鐵寶山段

台北捷運系統新莊機廠斷層帶



圖三　新莊斷層地質剖面圖（A—A′）

Swelling of mudrocks

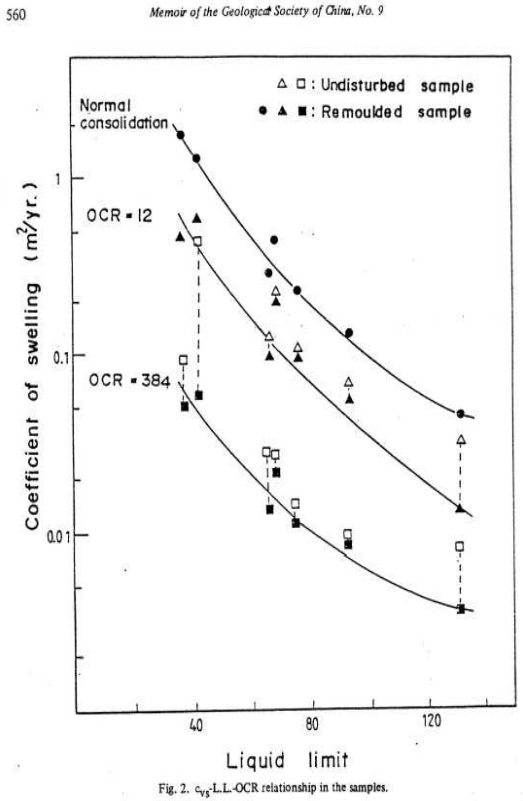


Fig. 2. c_{vs}-L.L.-OCR relationship in the samples.

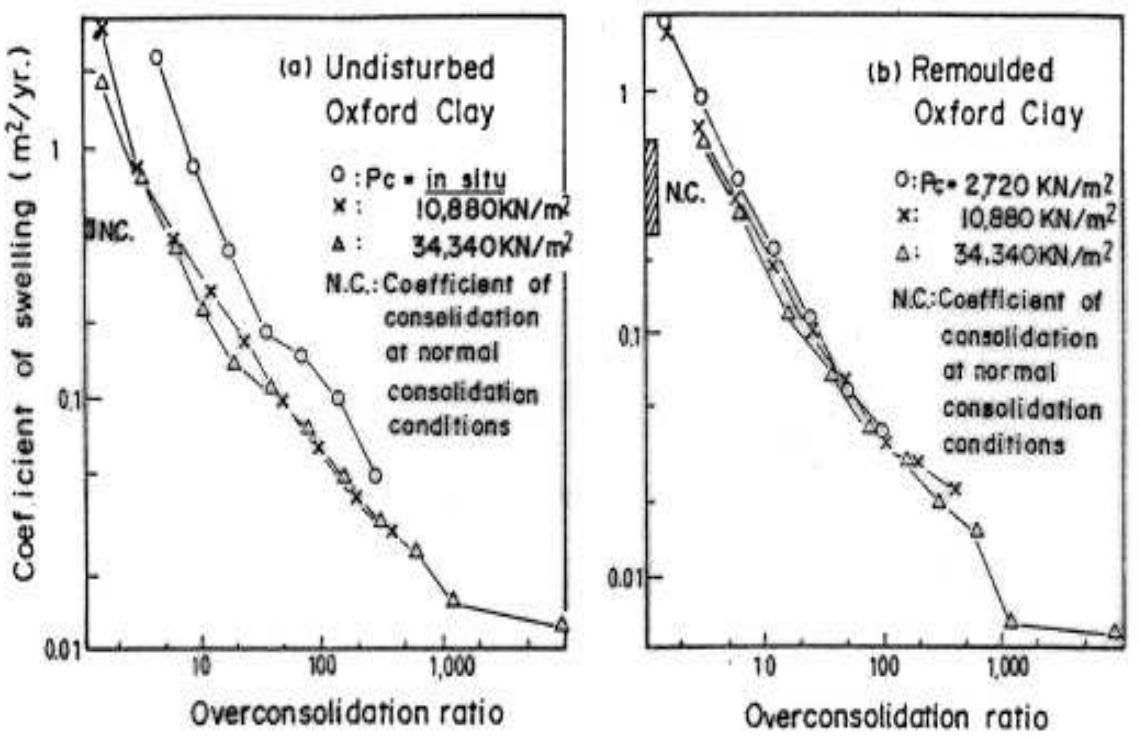
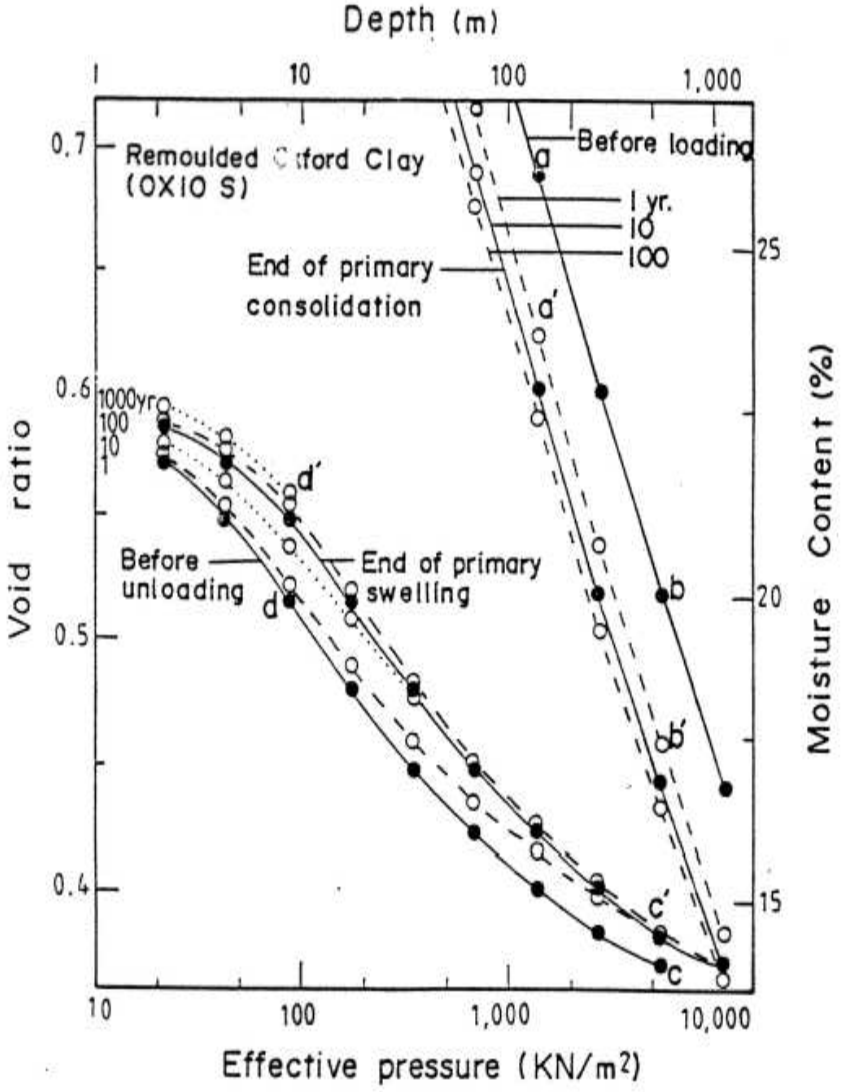


Fig. 1. Relationship between coefficient of swelling and overconsolidation ratio in Oxford Clay (0X10).


Depth (m)
1
10
100
1,000
Remoulded Clifford Clay
(OX10 S)
Before loading
1 yr.
10
100
End of primary
consolidation
1000yr
100
10
1
Before
unloading
End of primary
swelling
Void ratio
0.7
0.6
0.5
0.4
Moisture Content (%)
25
20
15
10
100
1,000
10,000
Effective pressure (KN/m2)

地質災害 Geological Hazards

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  - 壓密Consolidation:
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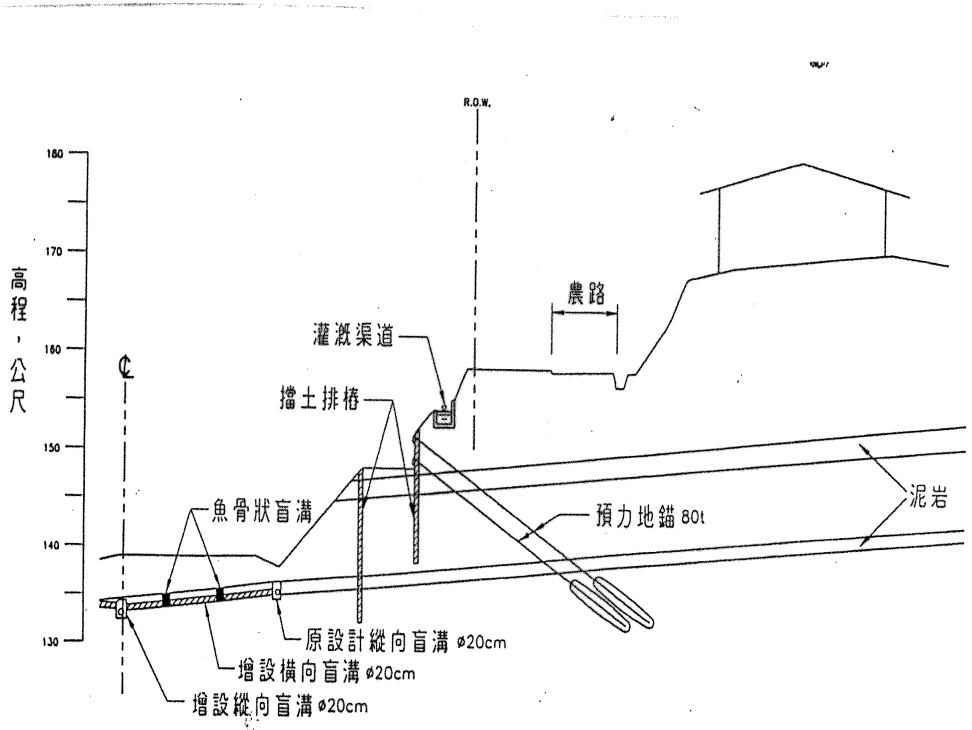
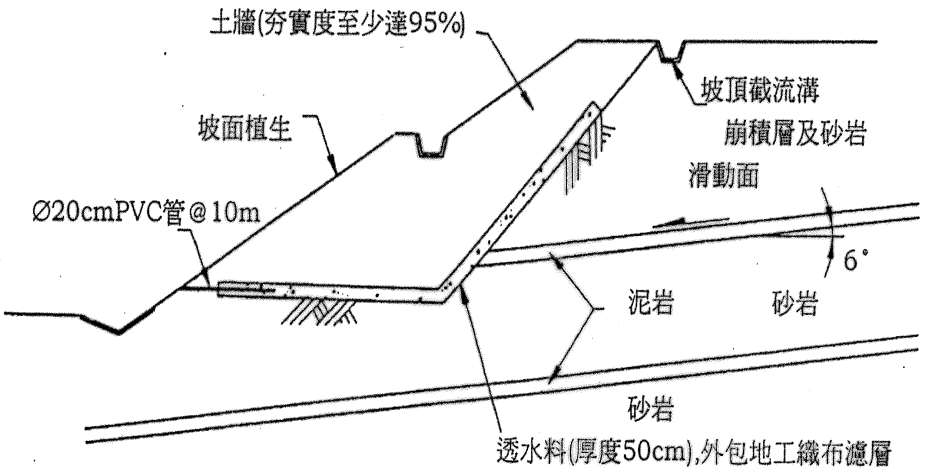
    - 翡翠水庫拱壩(層間泥縫)
    - 新莊機廠(斷層泥)
  - 殘留強度Residual strength:
    - 國道三號/台灣高鐵寶山段

Residual strength of mudrock

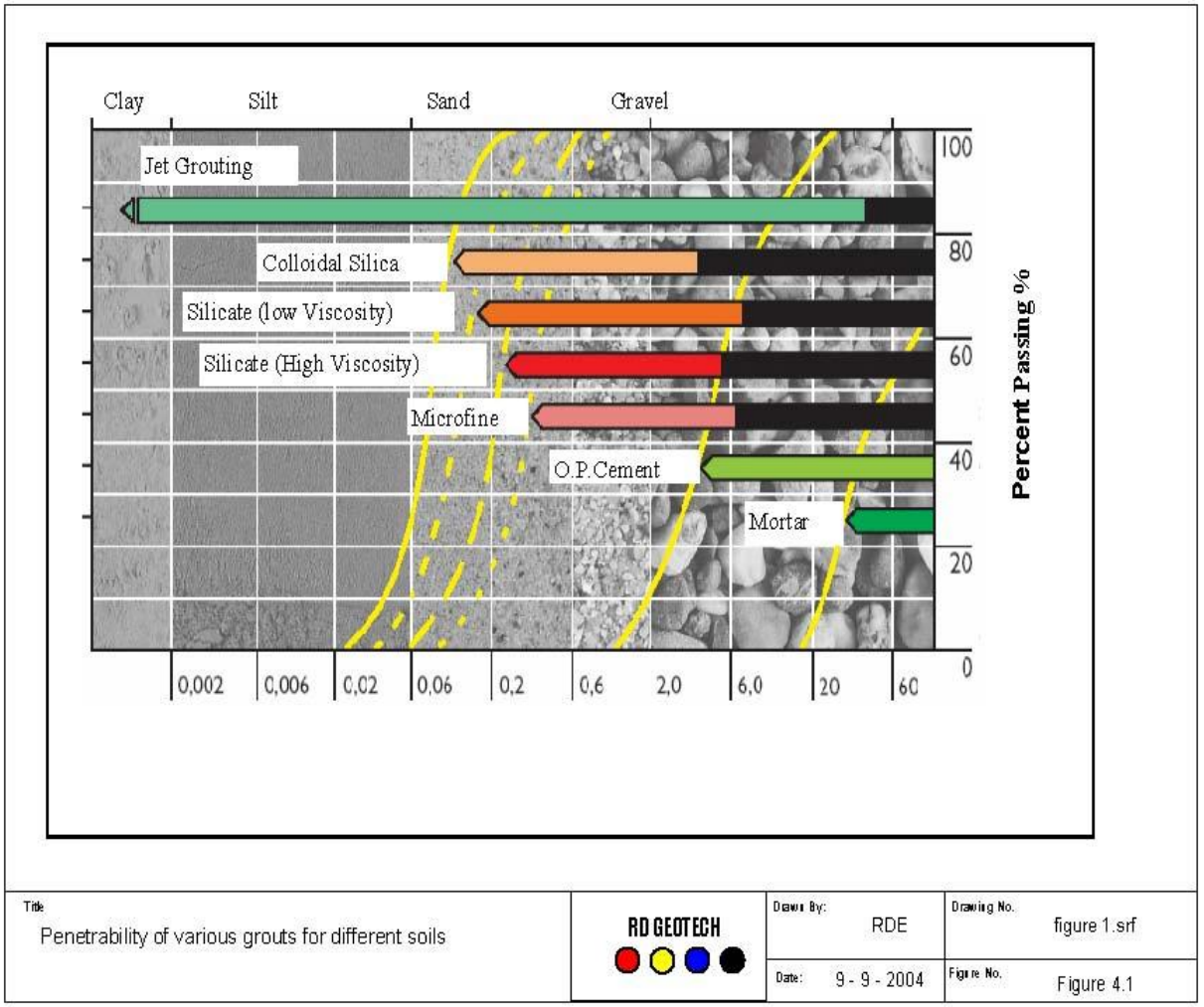


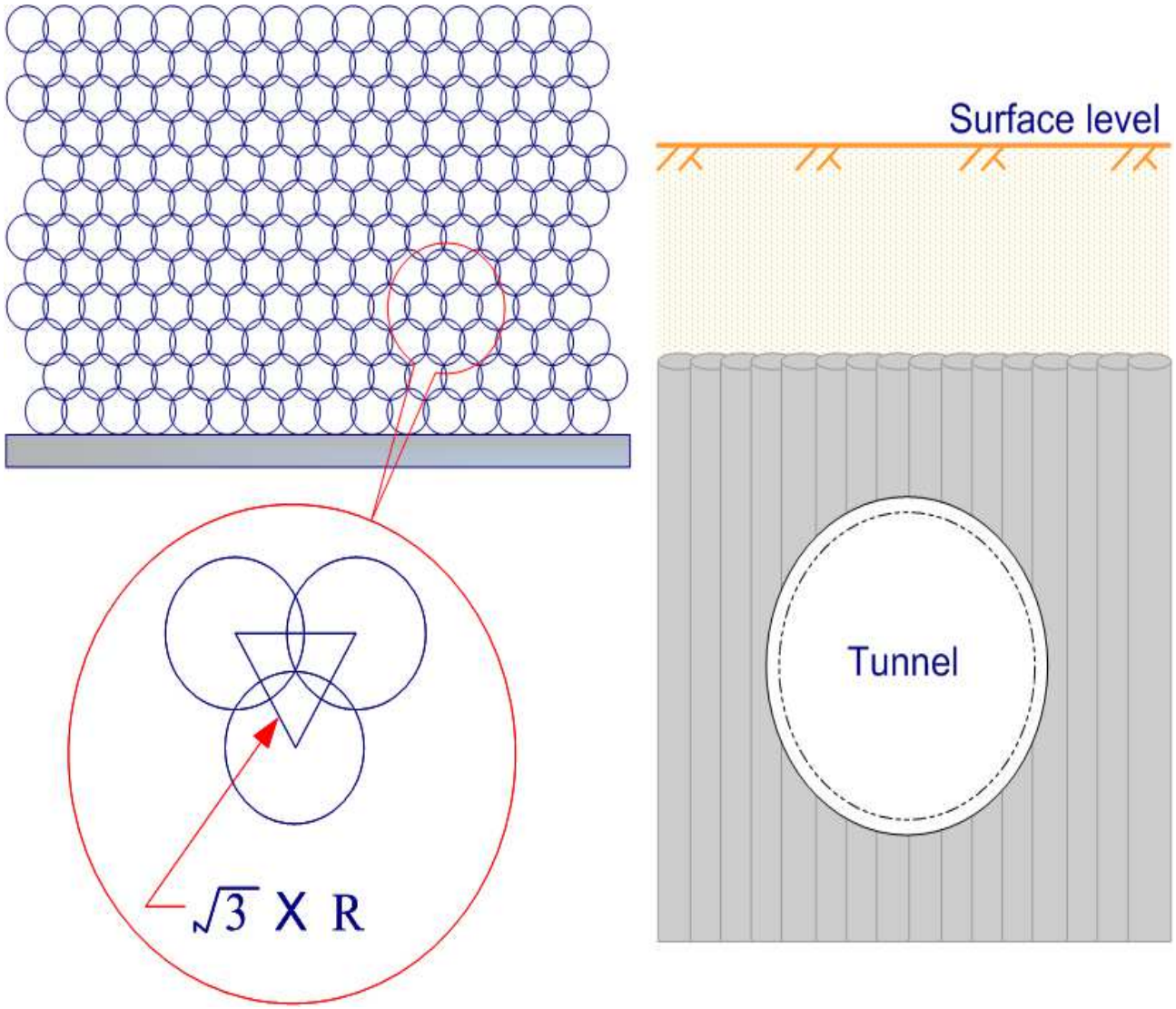
圖四　案例二整治措施剖面示意圖



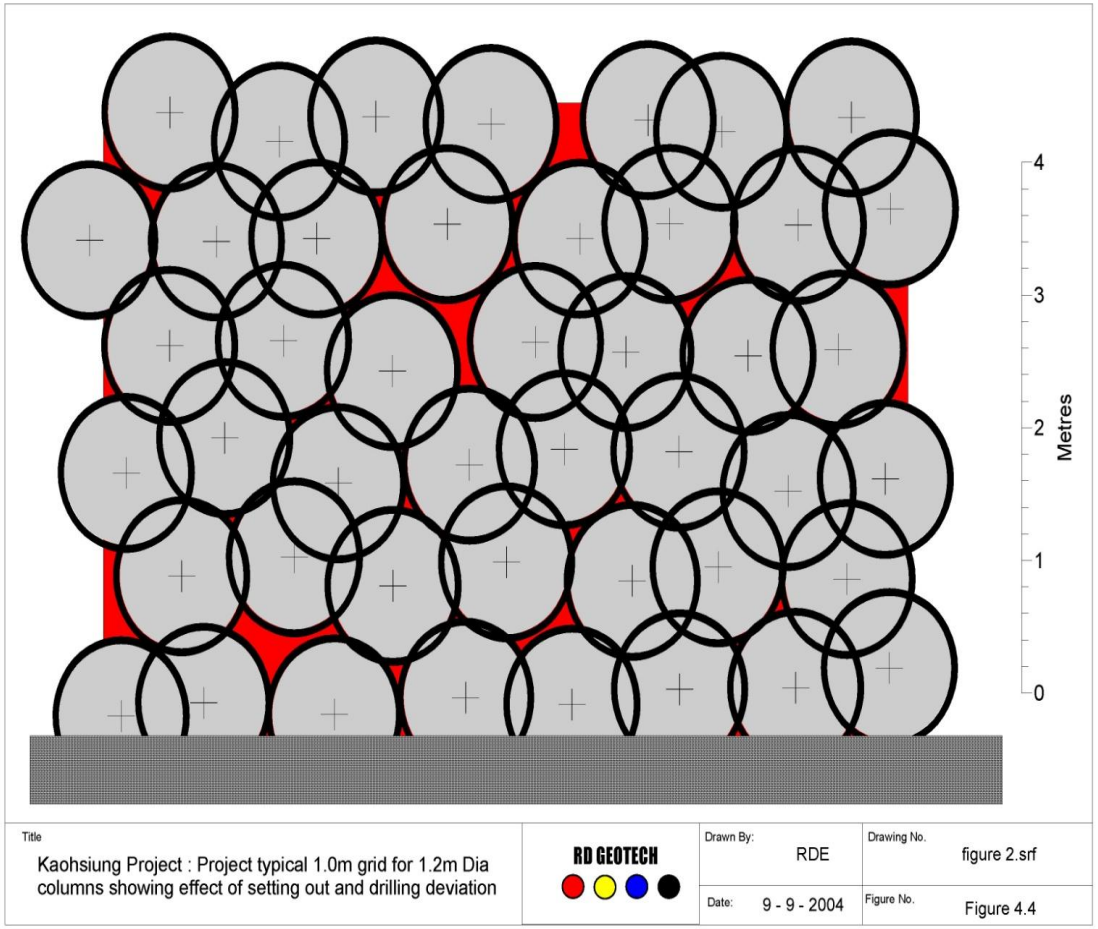
圖五　案例三土牆剖面示意圖(王建元與顏東利，1996)

地盤改良 Ground Improvement

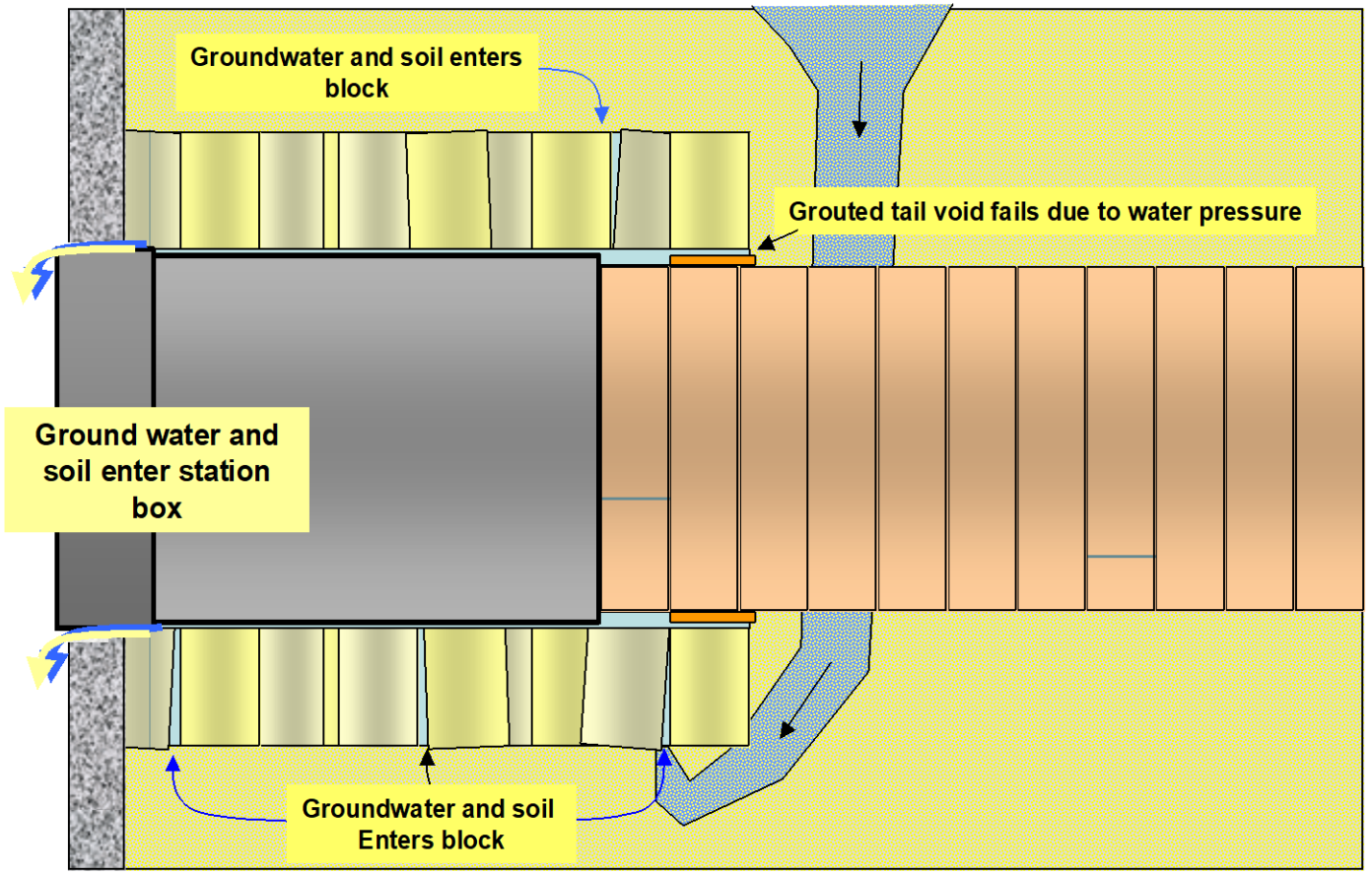



Surface level
Tunnel
√3 X R

Jet Grouted Piles in Deeper Ground



ACTUAL TBM ARRIVAL



Mott MacDonald

0 2 4 6 8 10 12 14 16 18 20

RD GEOTECH

地質資源 Geological Resources

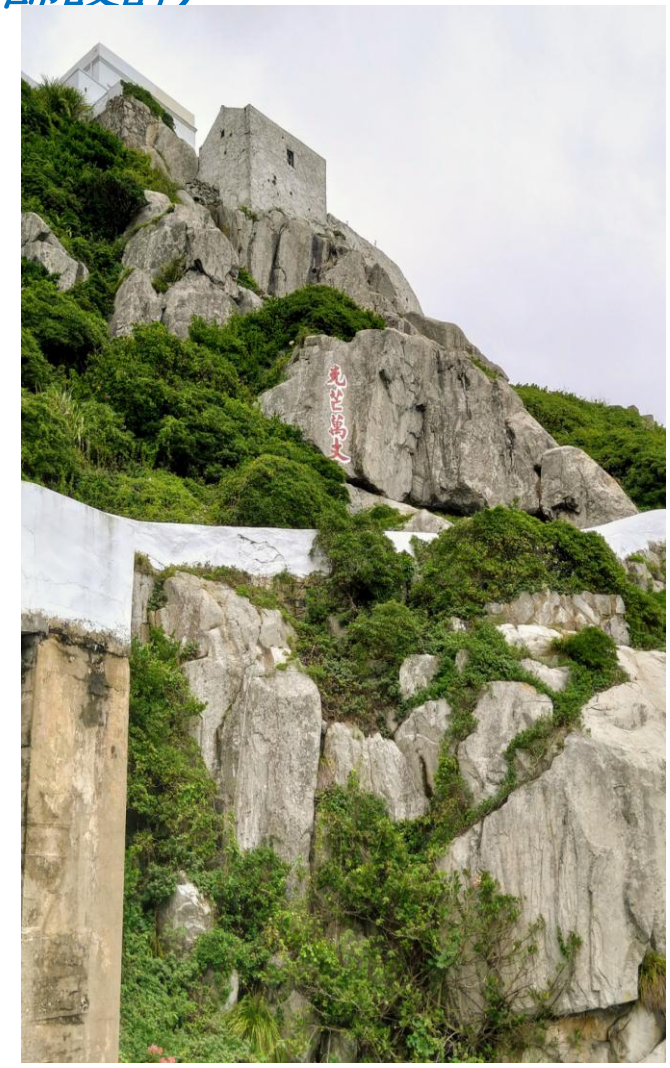
- 礦床：金屬(金、銅)、非金屬(石灰岩、大理石、白雲石)
- 寶石：貓眼石、台灣玉、文石、藍寶石
- 石油及天然氣
- 地下水
- 溫泉
- 地熱發電
- 骨材
- 地質景觀：柱狀玄武岩、太魯閣、東北角海岸、恆春珊瑚

南港砂岩 NanGang

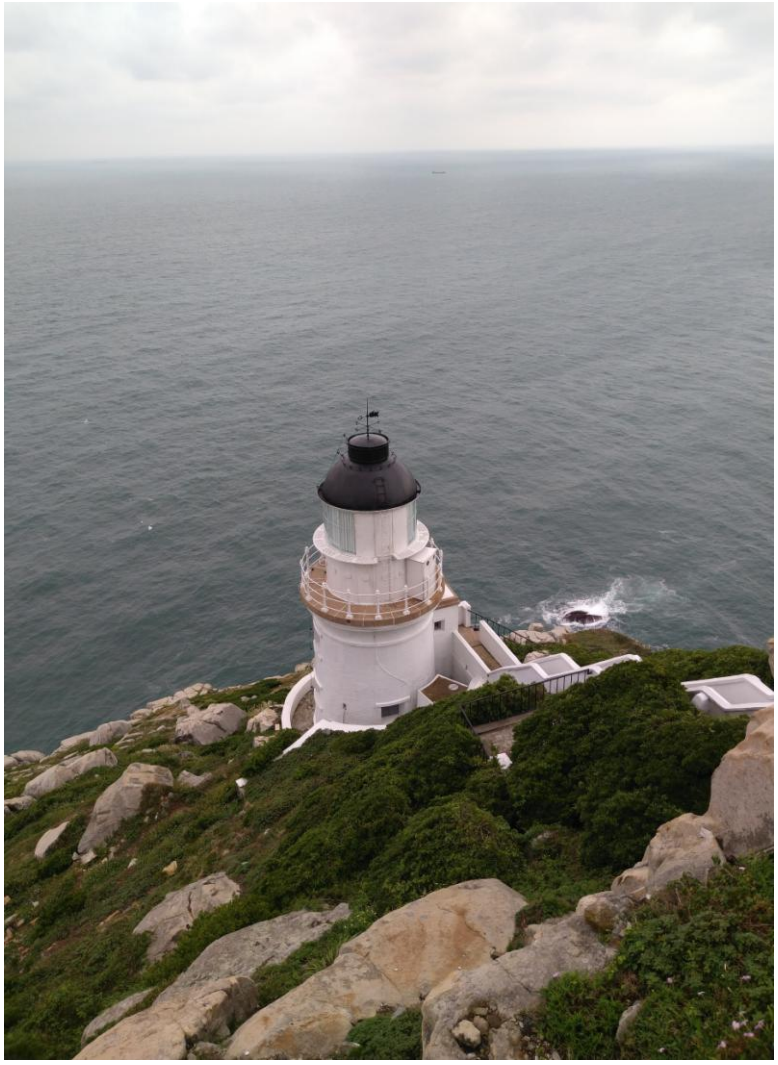
Sandstone

東引閃長岩
Diorite at Mazhu

師設計)



東引燈塔
(建於清朝，英國建築



工程地質專業以外

- QA: Quality Assurance 品質保證
- VE: Value Engineering 價值工程
  - 台北捷運後續路網：VE-1997/8 百億瘦身減肥運動
- IV&V: Independent Verification and Validation 獨立驗證與認證
- Risk Assessment and Management 風險評估與管理
  - Construction safety 施工安全
  - Operational safety 營運安全

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Major Accidental Events in Taiwan and Overseas

1994(April) TRTS-CH221: Excessive ground subsidence during segment replacement in the interface of bored tunnel and vent shaft

1994 (Oct) Heathrow Express Rail Link: Collapse of a NATM tunnel

1994(Nov) TRTS-CN252: Ground loss induced by piping in deep excavation of an underground station

1995(April) TRTS-CN261: Ground loss during TBM-launching

1995(July) TRTS-CN262: Excessive ground loss during TBM-docking

TANEEB Suei-shan Tunnel : Series of accident during TBM & NATM tunnelling

2002(Aug,Nov) THSRC-Hu-ko Tunnel: Ground loss during NATM tunnelling

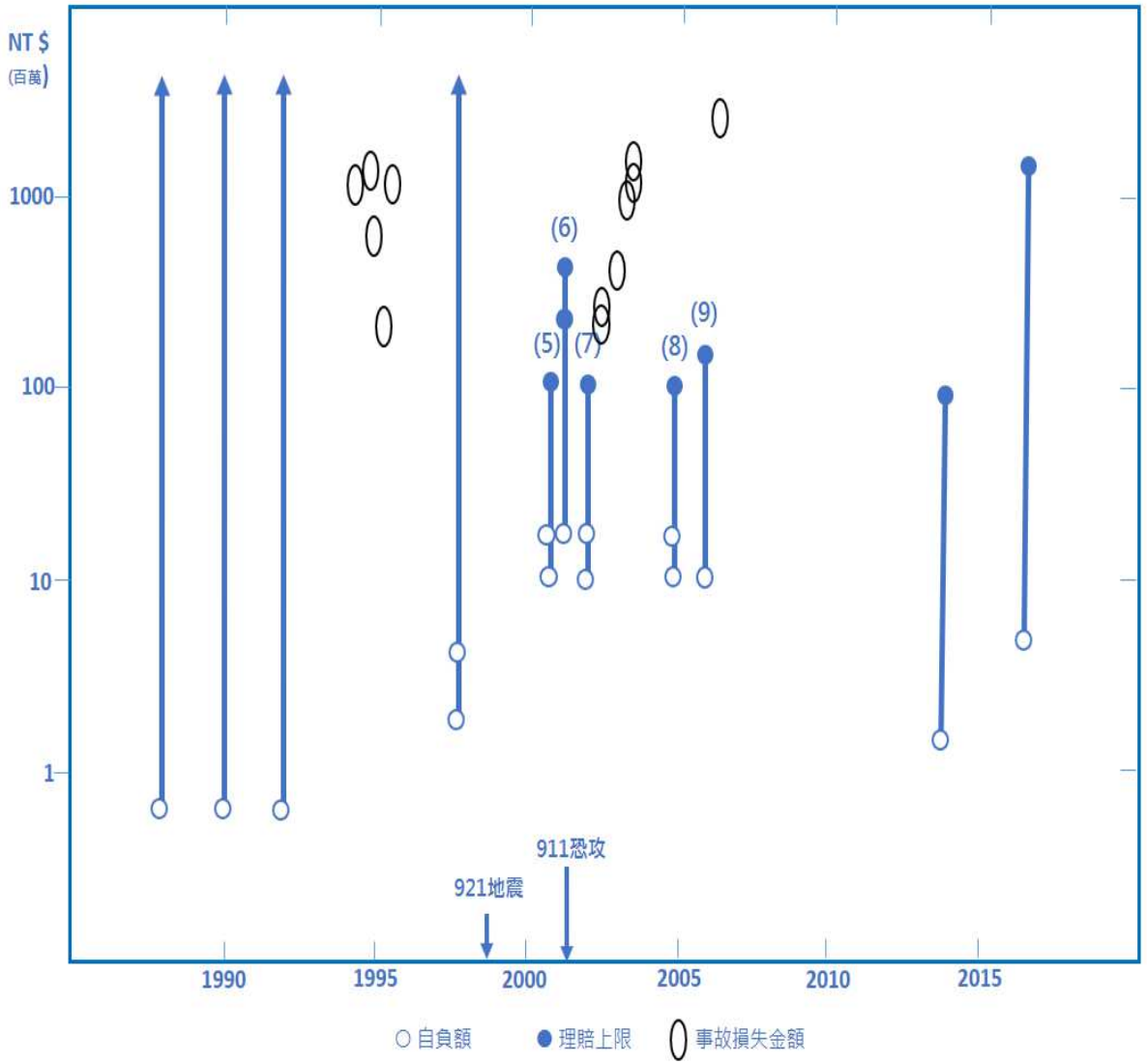
2003(Feb) TRTS-CD266: Ground loss during TBM-docking

2003(May) KRTC-LUO04: Excessive ground loss during TBM-docking

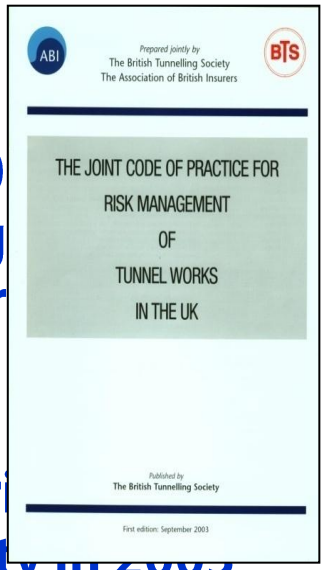
Major Accidental Events in Taiwan and Overseas

2003(July)	Shanghai Metro 4: Tunnel collapse during the excavation of a cross-passage
2003(Aug)	KRTC-O01: Ground loss induced by piping due to defective diaphram wall during the excavation of an underground station
2003(Aug)	TRTS-CK570C: Flooding due to a gap btwn the river bank and a pump station
2004(April)	Singapore LTA-MRT Circle Line: Collapse of 33m deep excavation of a cut-and-cover tunnel
2005 (Dec)	KRTC-LUO09: Excessive ground subsidence during the excavation of a sump inside a cross-passage
2007(Jan)	Sao Paulo Metro-Linea 4: Collapse of a NATM tunnel
2008(Nov)	Hanzho Metro – Line 1: Collapse of 16 m deep excavation

地下工程保險和重大施工意外之統計資料



Joint Code of Practice for Risk Management of Tunnel Works in the UK



- Discussion at ICE, London in July, 200
  the "JCoP for the procurement, Desig
  Construction of Tunnels and Undergr
  Structures in the United Kingdom"

- Jointly produced by Association of Bri
  Insurers and British Tunnelling Society in 2003

- Pre-requisite for insurance

International Standard

ISO 3100:2009 Risk Management

- **Principles and Guidelines, supported by "Practice standard for project risk management" 2009 published by Project Management Institute**

Kuala Lumpur MRT Line 2 Project

- **Design & Build Contract by MMC-Gamuda JV**
- **Underground section**

  Length: 13.5 km

  No of stations: 11

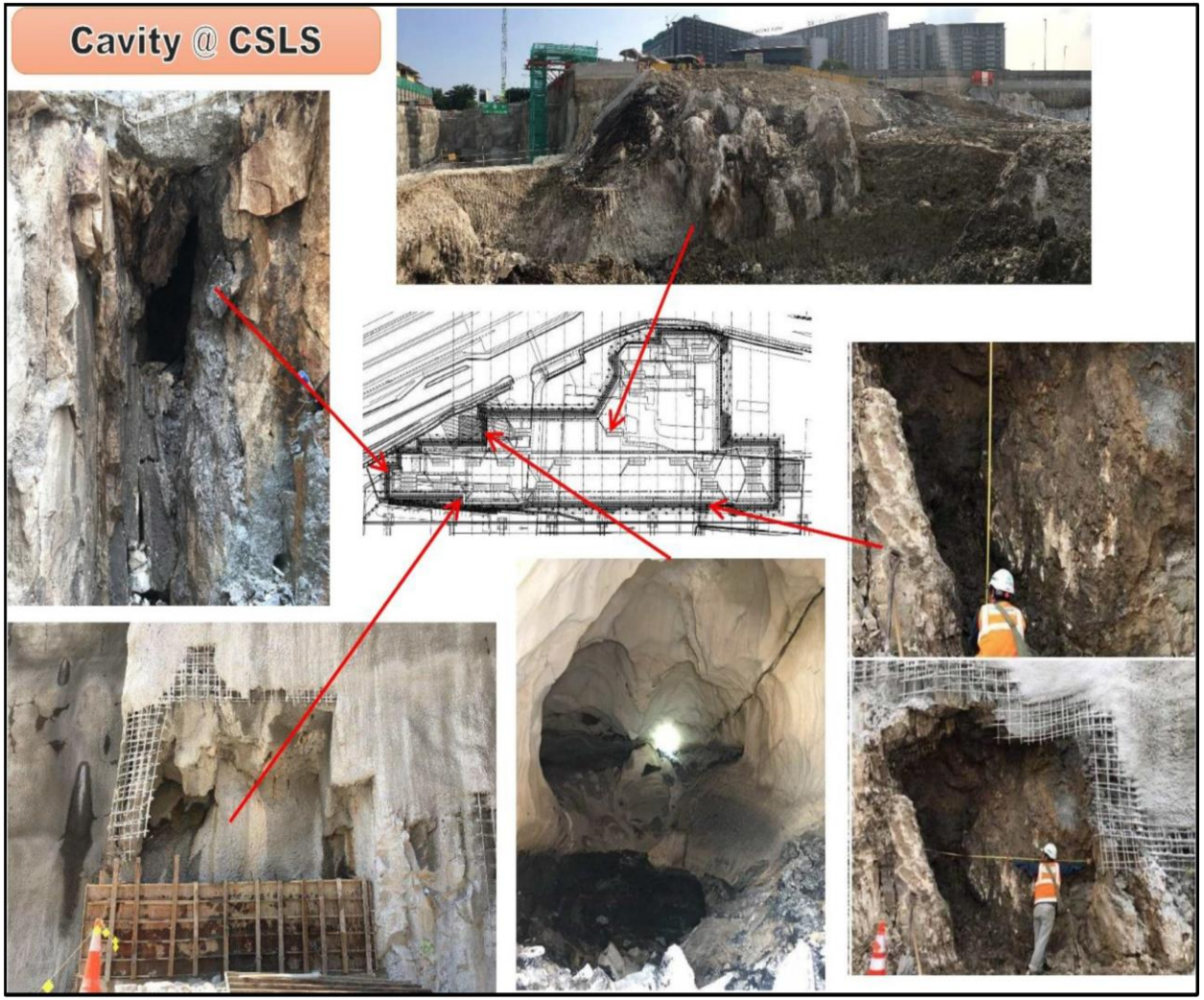
  No of crossover: 1

  No of shafts/portals: 8

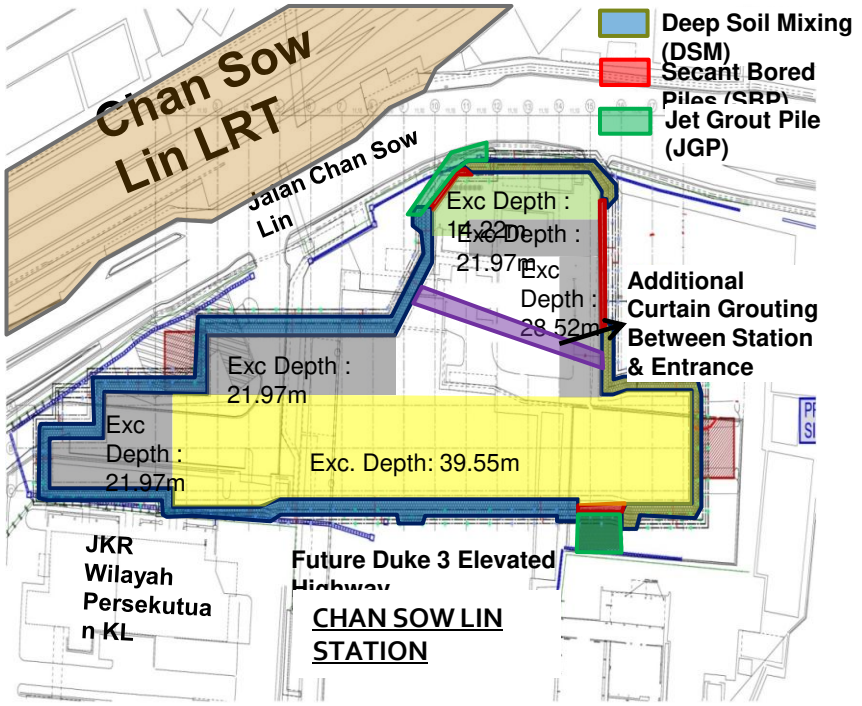
  No of TBMs: 12

FEATURES ALREADY EXPOSED in Chan Sow Lin excavation.

Multiple caves and cavities were unearthed during excavation. Extreme Karst condition exhibit very variable combination of black organic material infills to highly weathered rock.



Geological Conditions

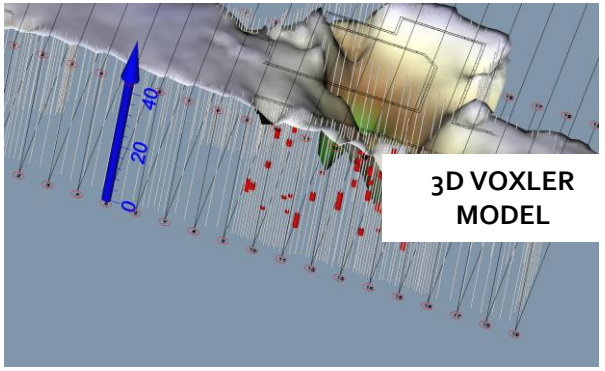


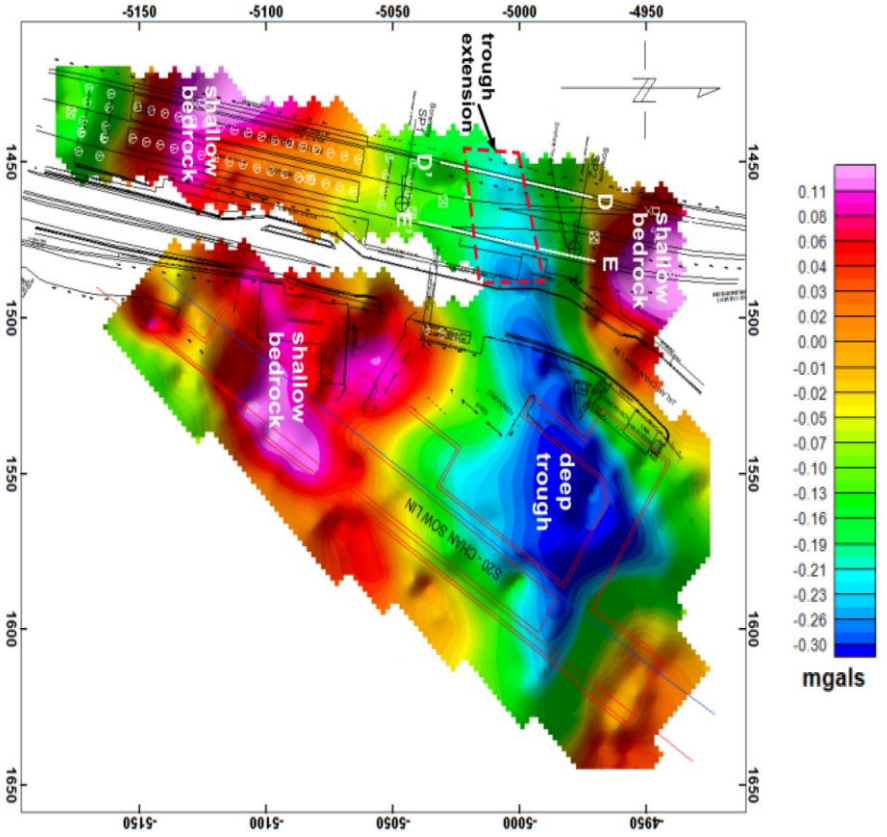
Ground Investigation:

1. Soil Investigation
2. Drilled Holes for Curtain Grouting Surrounding Station Perimeter (2m to 4m spacing c/c)
3. Bored Pile Drilled Hole
4. Microgravity Survey
5. Borehole Televiewer
6. Rock Mapping on Rock Face

Geological Conditions

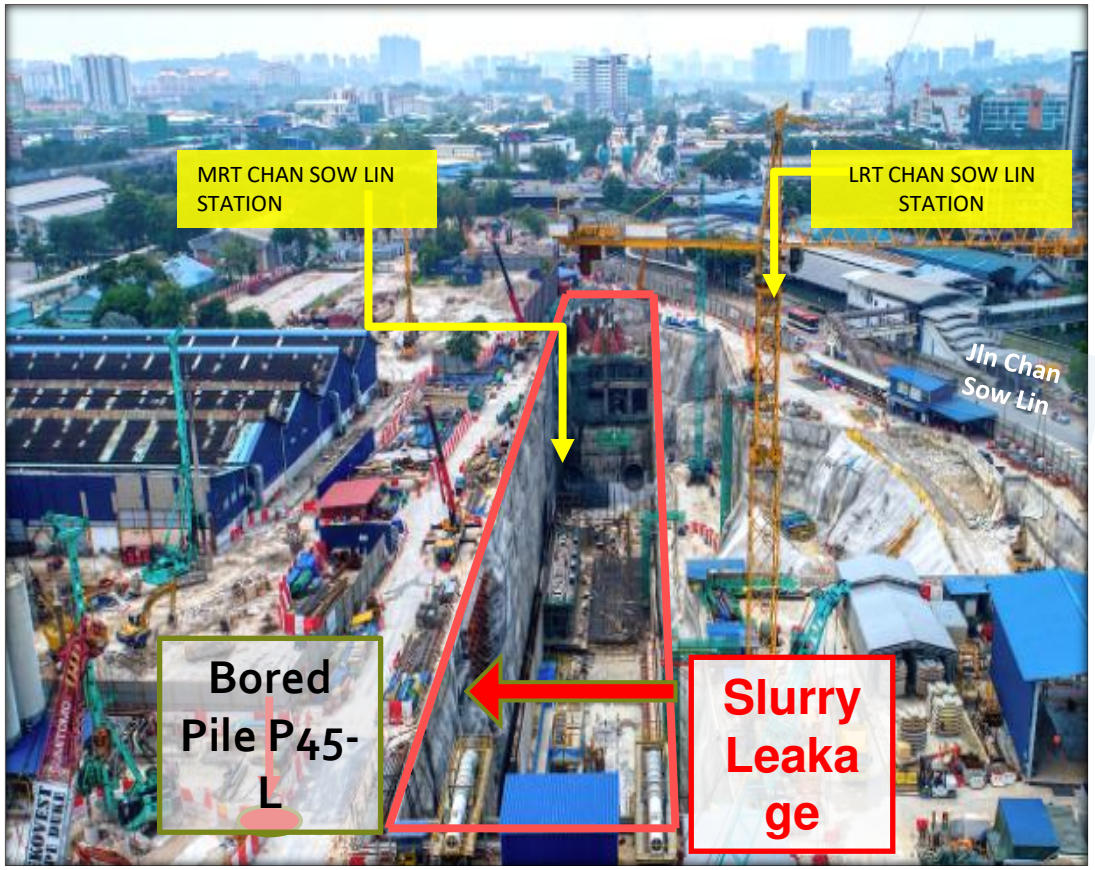
Deep valley cutting across Chan Sow Lin Station footprint shown by microgravity survey (in blue) and SI data/piling record/grouting record





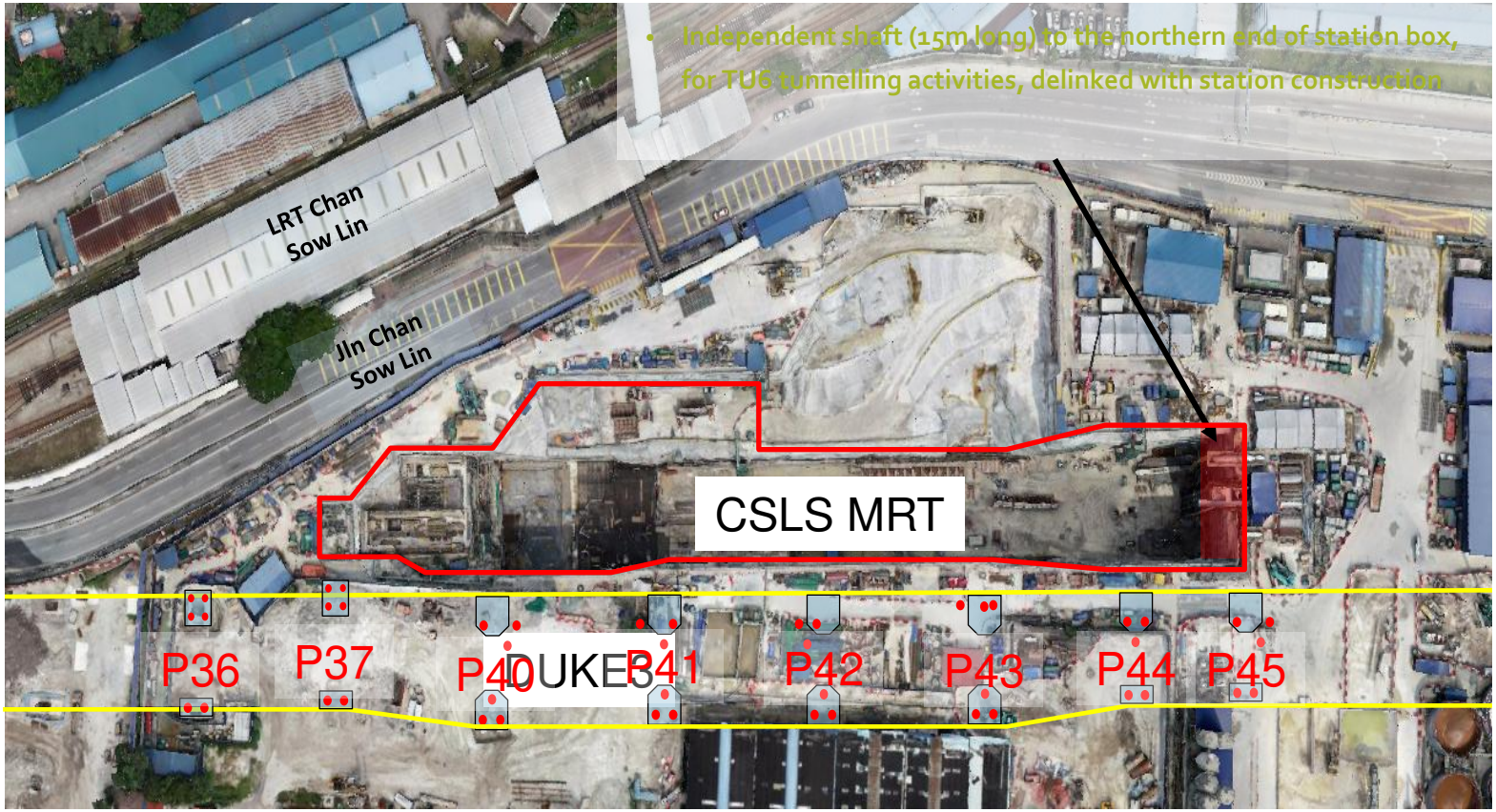
Microgravity Survey & Voxler Rockhead Model

Site Plan



Station Information	
Length	**200 m**
Width	**21.6 m**
Depth	**40 m**
Entrance	**3 nos**
Linkway to LRT	**1 nos**
No. of Floors	**5**

Station Configuration



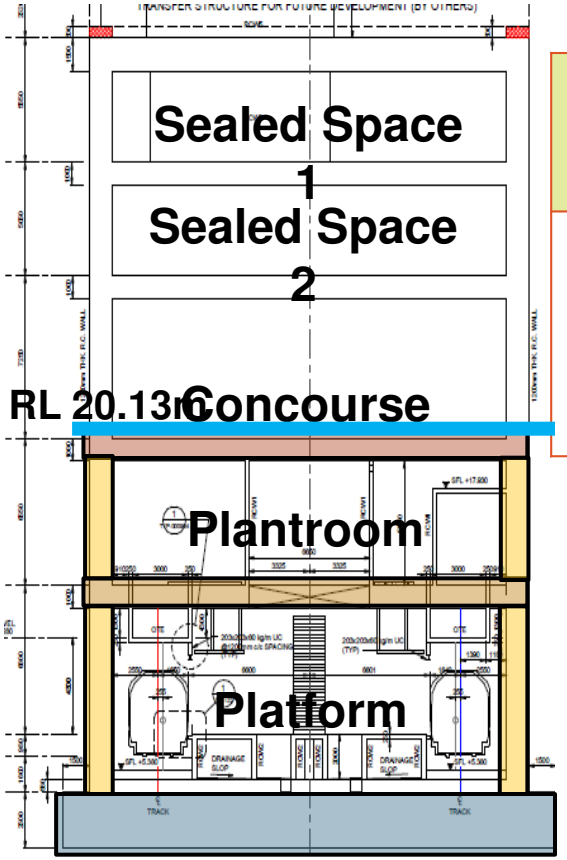
- Independent shaft (15m long) to the northern end of station box, for TUS tunnelling activities, delinked with station construction

Example of What Could Go Wrong

Example of localized rock slip due to unforeseen rock joint behind exposed rock face.

Despite extensive soil investigation and geophysics work were carried out, the risk is still unpredictable in karstic limestone.

Mitigation Measure



CSLS Box
Cross Section

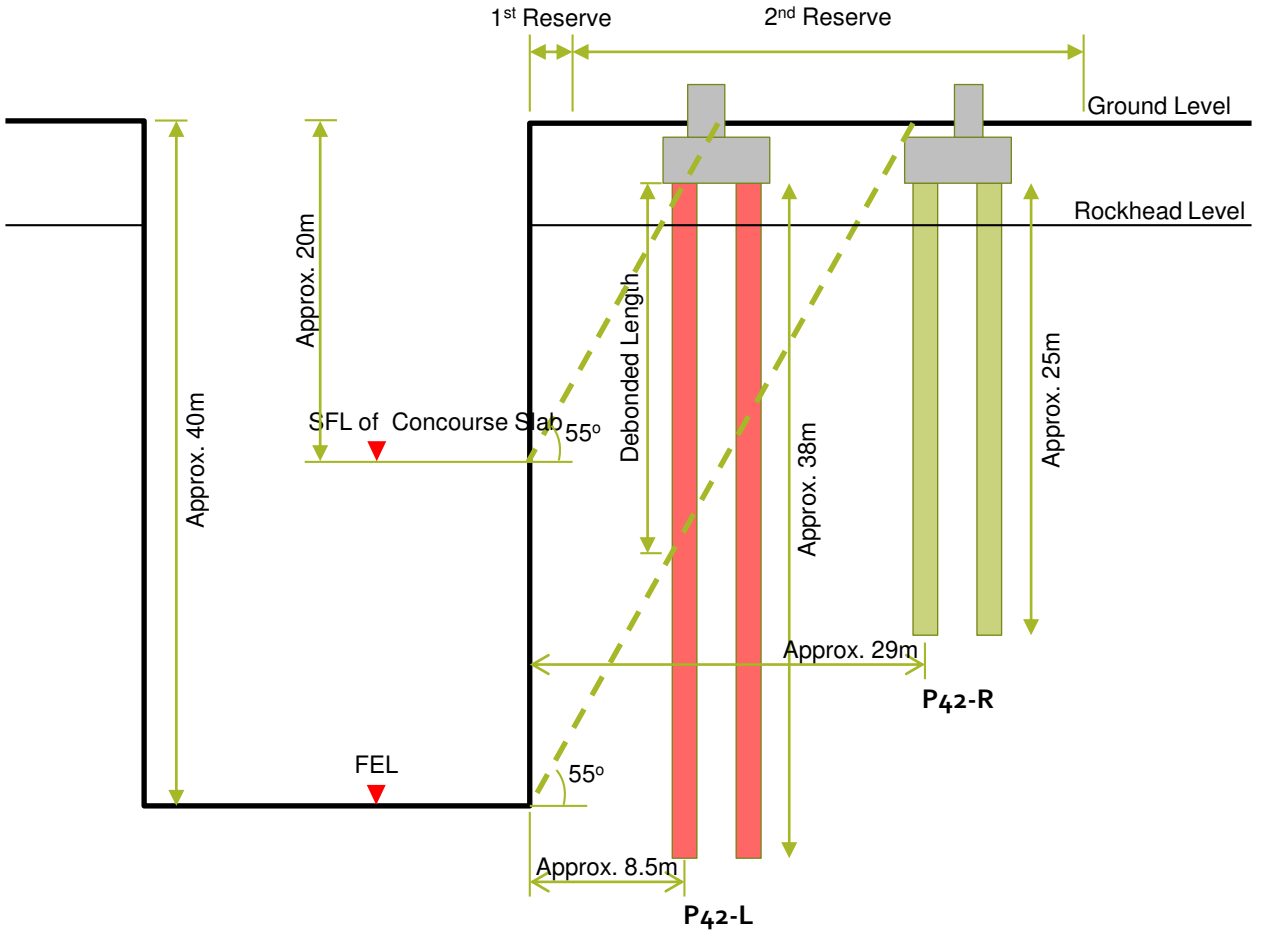
Proposed 2 Level Structural Completion of Station Box

Structural Completion until Concourse Level Slab Level

Note:

1) After the completion of concourse slab, the remaining rock face height is still approx. 20m.

Mitigation Measure



挑戰與機會 (一)

- 巴黎協定 2015 >>> 碳中和 Carbon Neutral 2050-70

  >>> 綠色能源 Green Energy (20% - 2025)

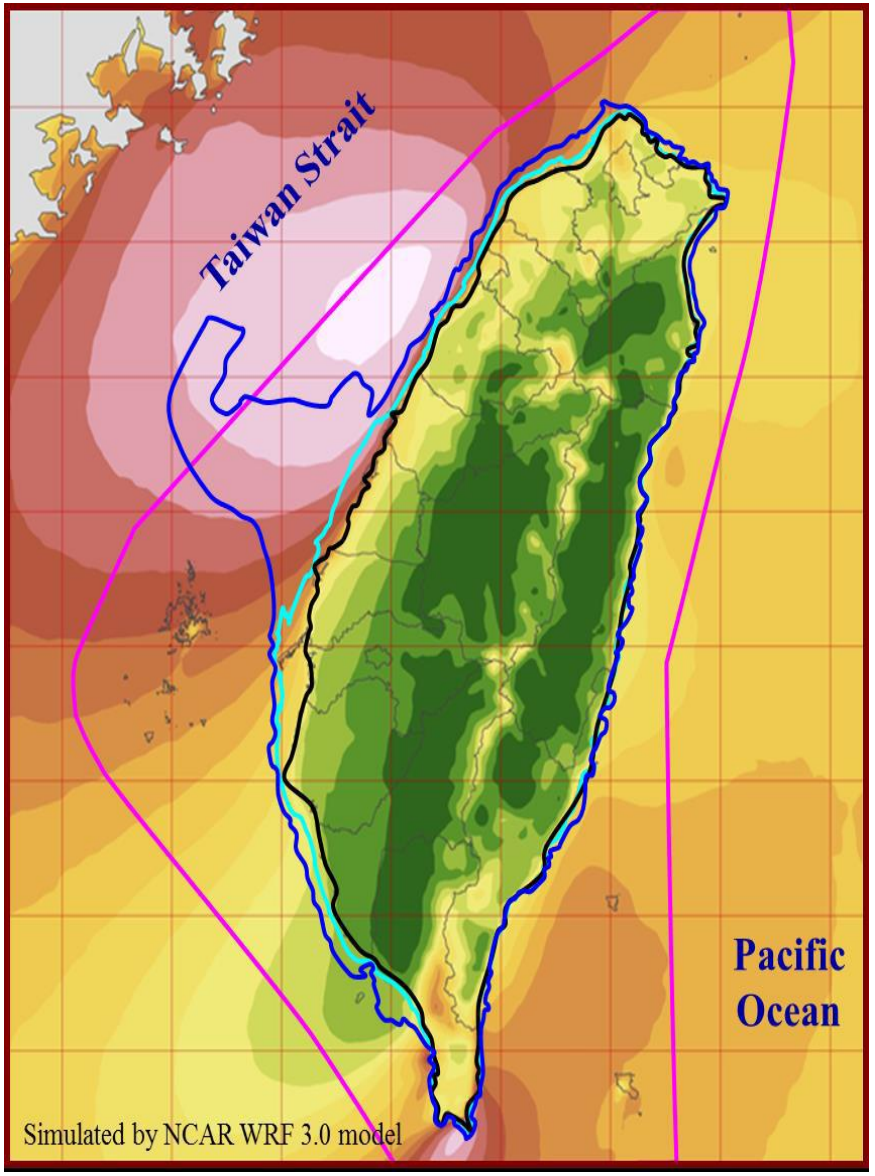
  - 1972 台灣大學海洋研究所 [九連號] 海洋調查研究

  - 2019 離岸風力發電 Offshore wind farm：新台幣兆元以上規模

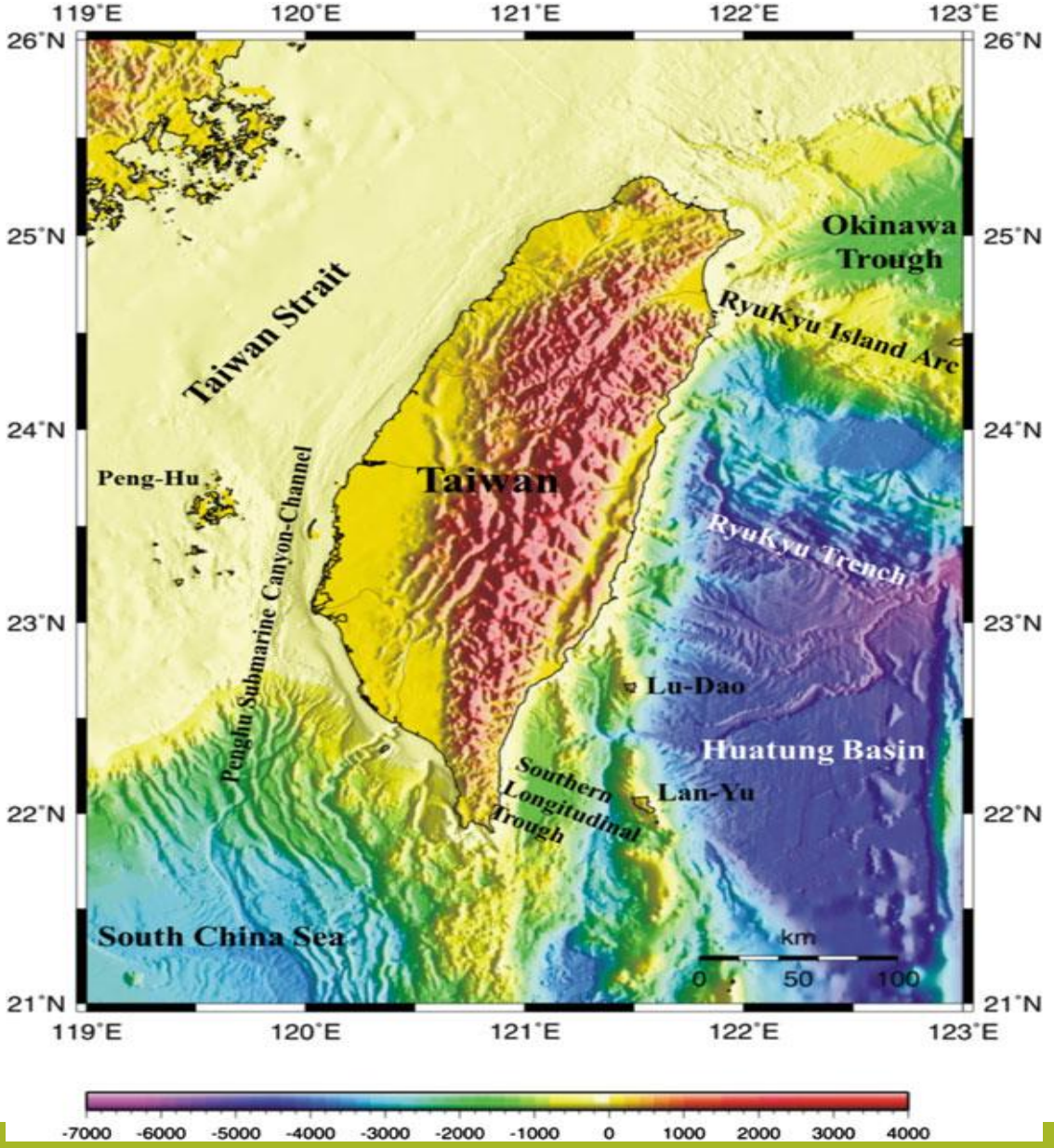
  - Kuroshio Power Plant: 台灣大學講座教授陳發林 2013

  - EIA (Environmental Impact Assessment) 環境影響評估

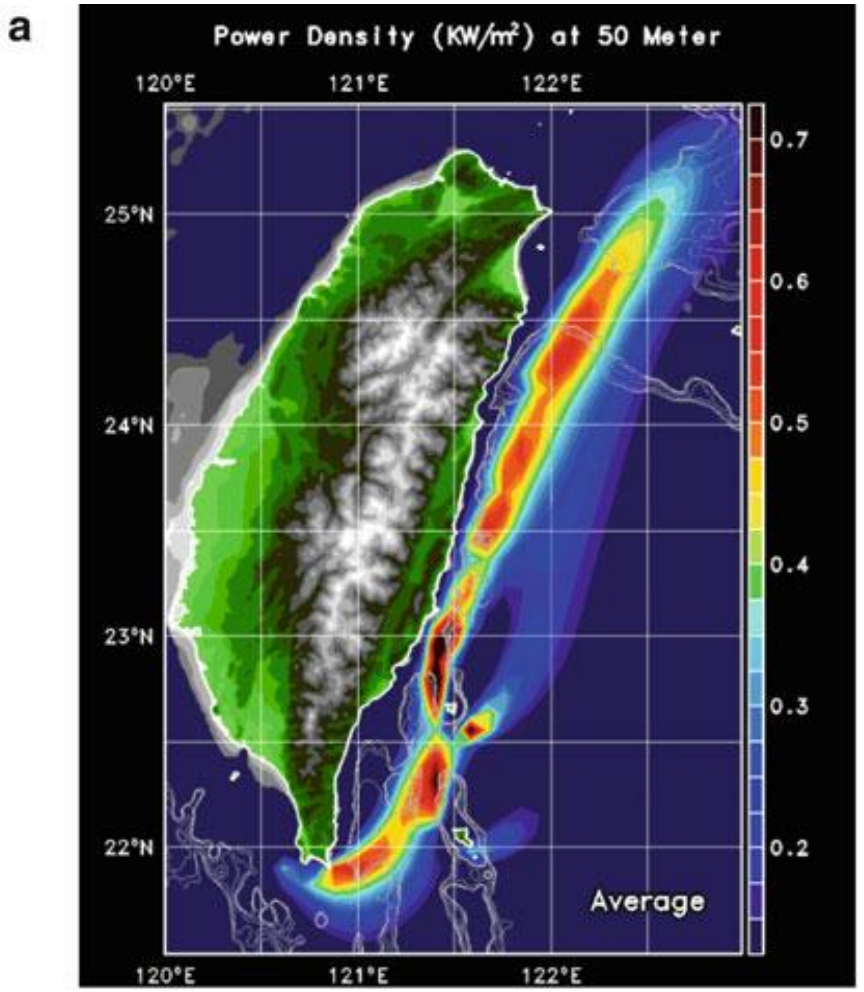
台灣海峽風場

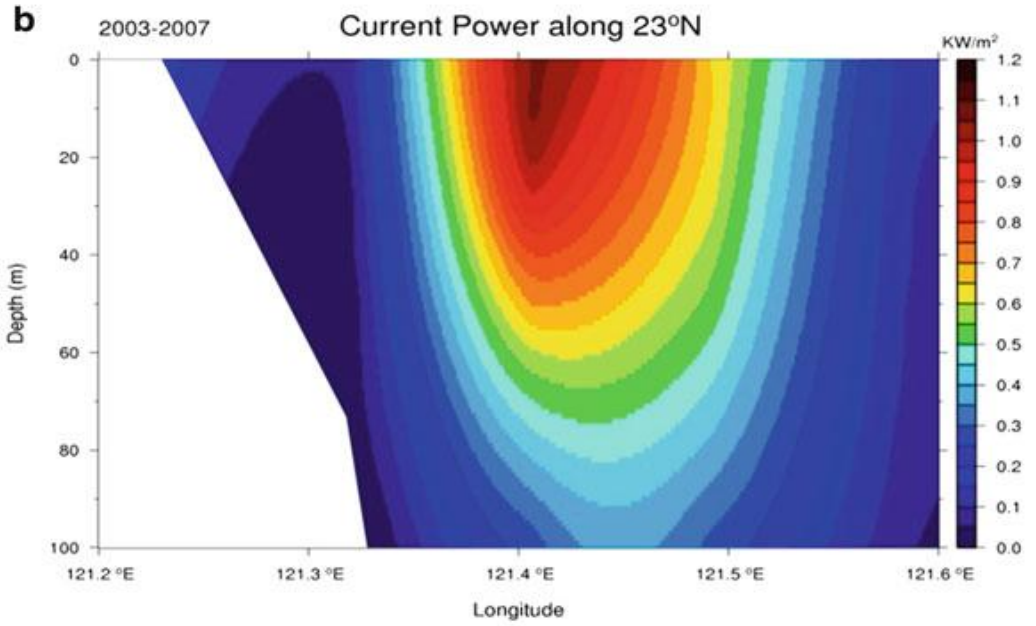


最佳風場 vs 第一級場址

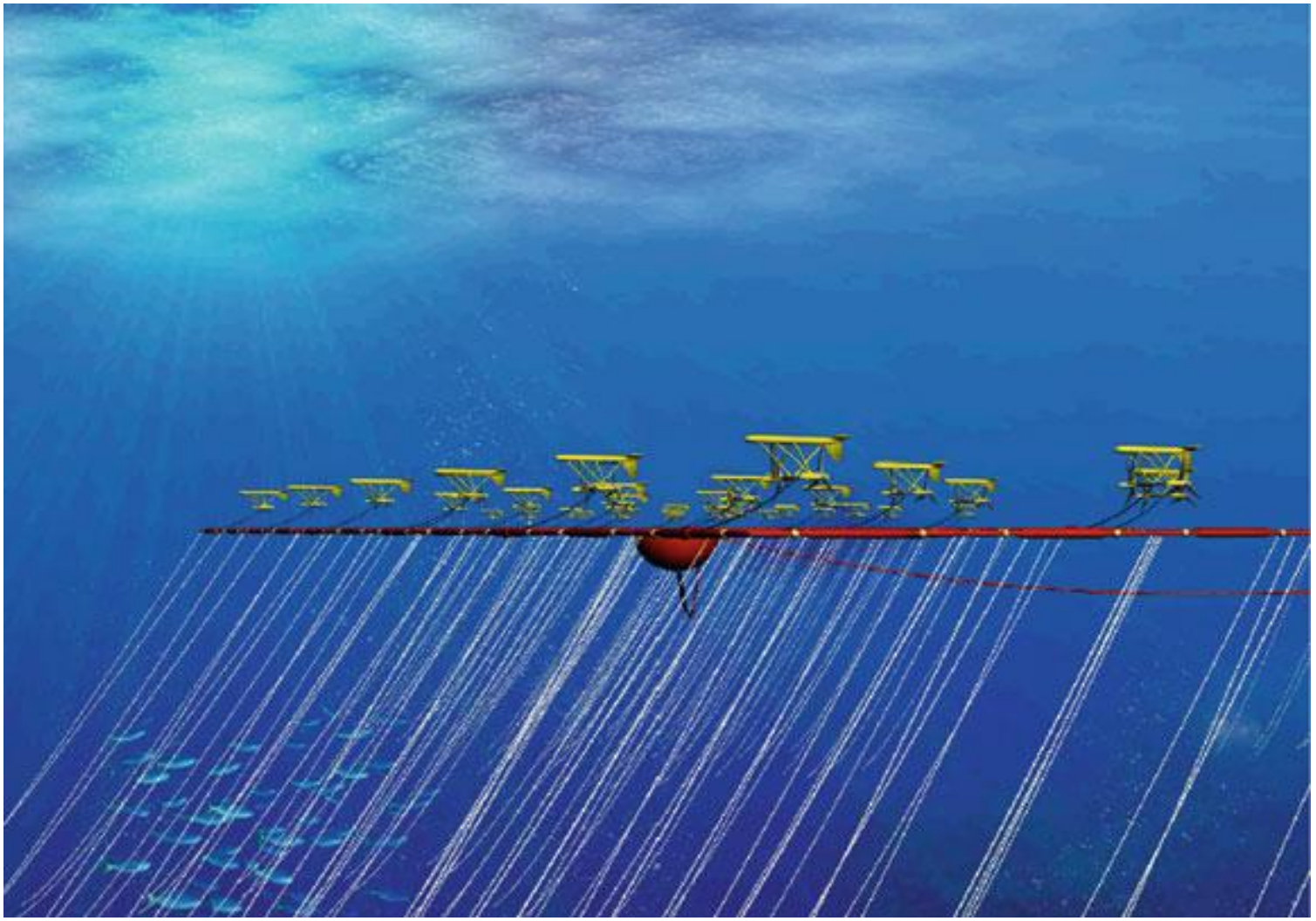


黑潮 Kuroshio

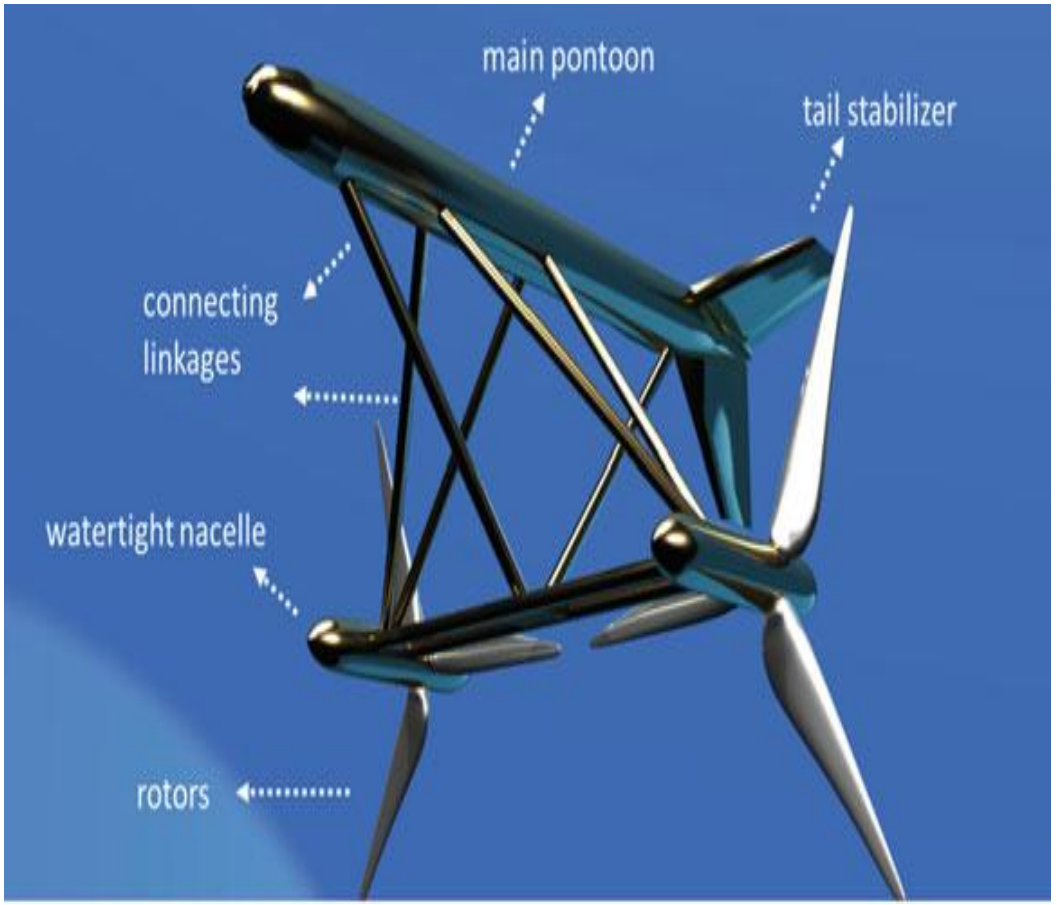

a
Power Density (KW/m²) at 50 Meter
120°E
121°E
122°E
25°N
24°N
23°N
22°N
0.7
0.6
0.5
0.4
0.3
0.2
Average


b
2003-2007
Current Power along 23°N
KW/m²
Depth (m)
0
20
40
60
80
100
121.2 °E
121.3 °E
121.4 °E
121.5 °E
121.6 °E
Longitude
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

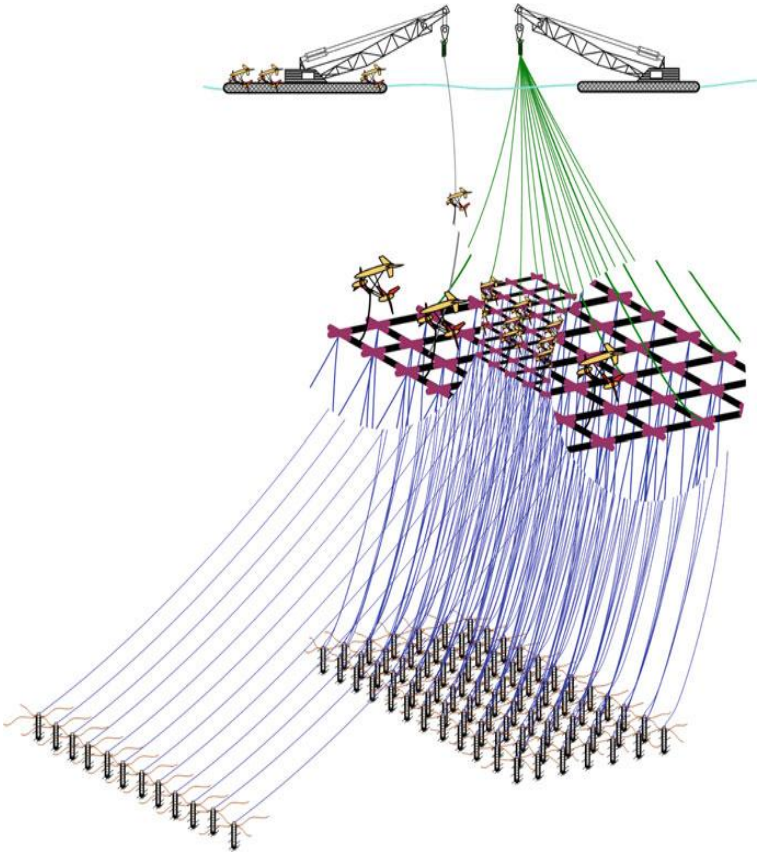
黑潮電廠 Kuroshio Power (Pilot) Plant (Chen 2013)



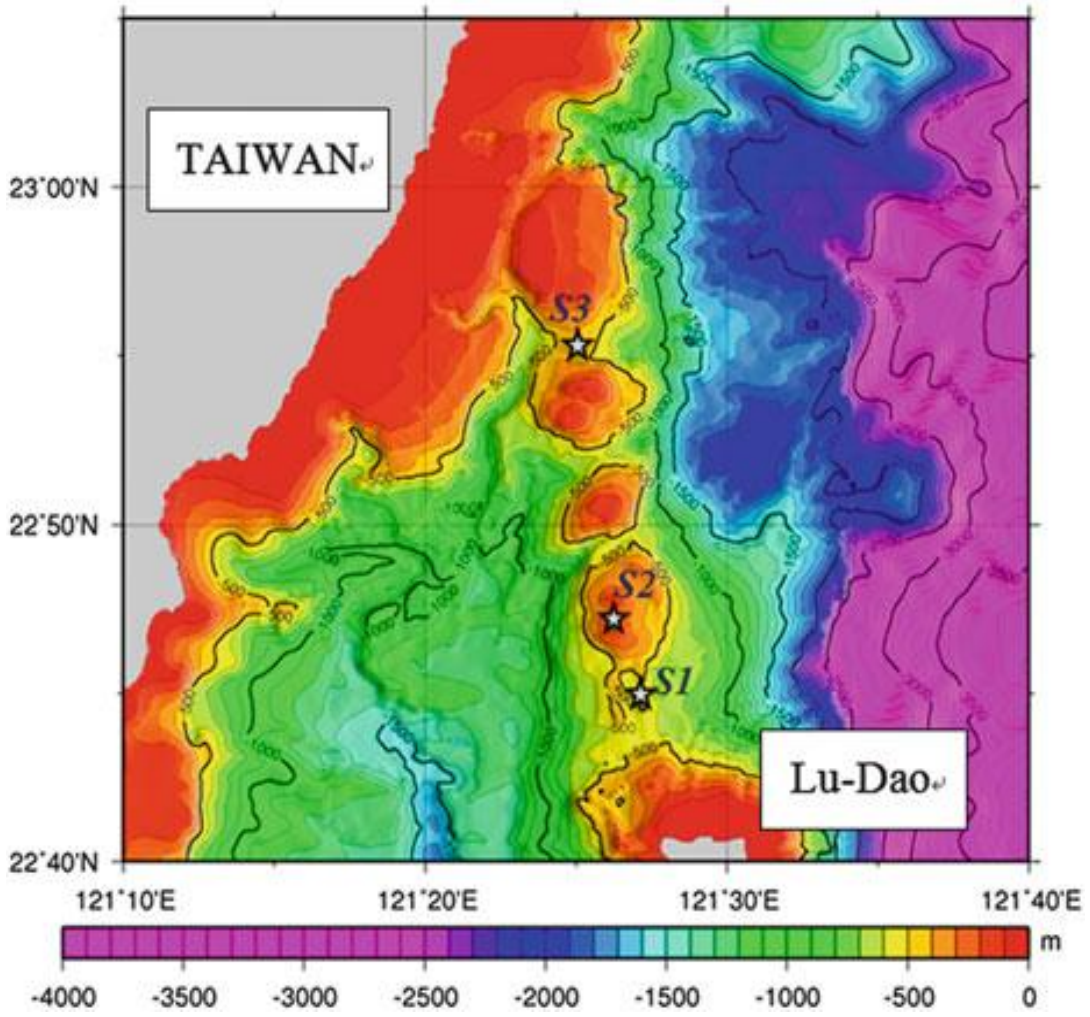
Kuroshio Power Plant - Turbine



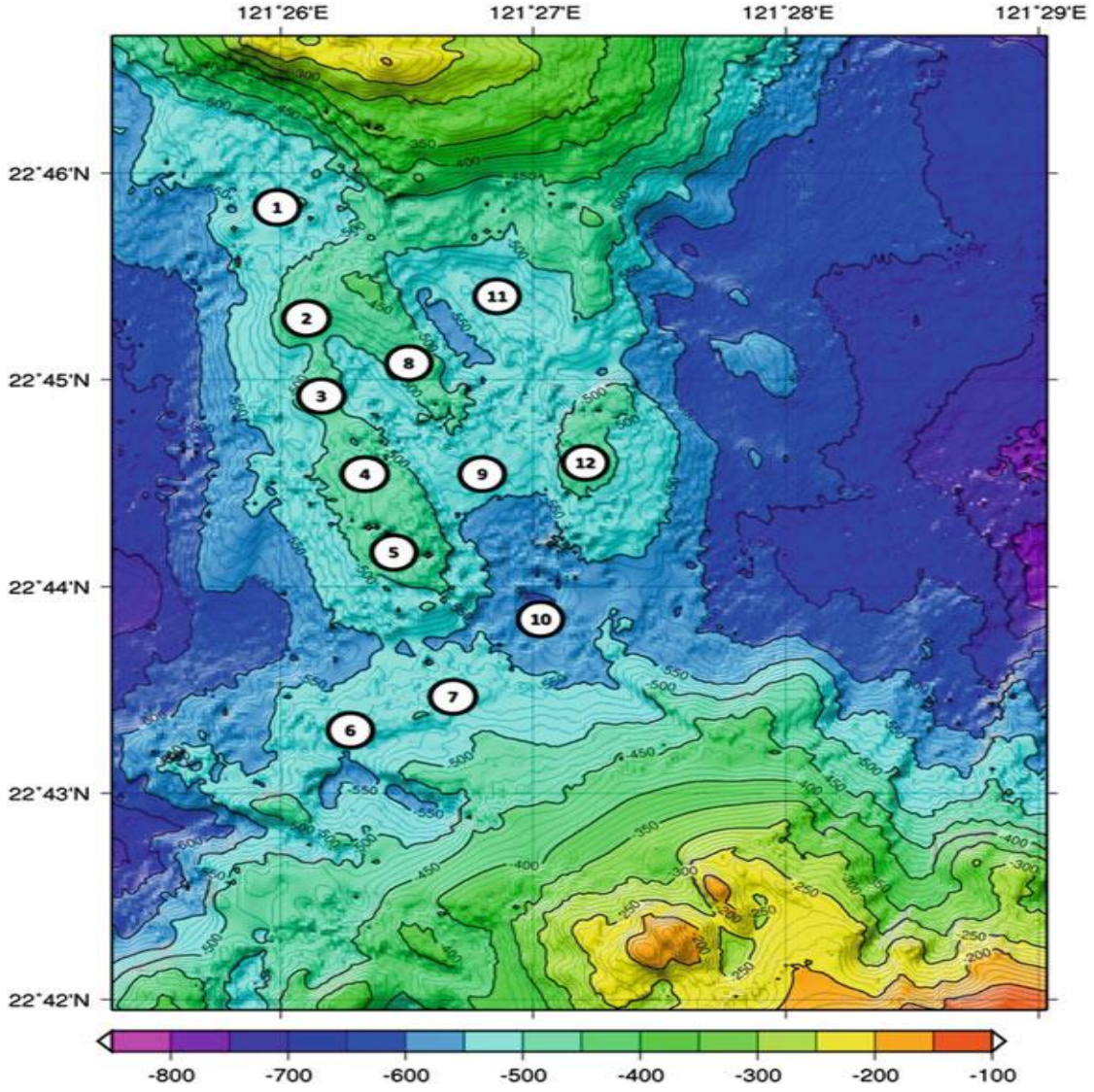
Kuroshio Power Plant - Construction



Kuroshio Power Plant - 綠島與本島之間海底地形



Kuroshio Power Plant - 優先廠址



海事工程 Maritime Engineering

- **Site characteristics: Sediments, Landslide at seabed, Faults, etc.**
- **Site investigation: Morphology, Geology, Hydrology, Ecology, etc.**
- **Tools of site investigation: Ships, Geophysical exploration, Sampling**
- **Design & Construction: Anchoring, Structures and Installation of turbines**
- **Operations & Maintenance: Monitoring of the environment**

大投資 > 高風險 > 高報酬

挑戰與機會(二)

- 巴黎協定 >>> 綠色能源 >>> 碳中和 2050 - 70
  - 離岸風力發電 Offshore wind farm (Floating type)：新台幣兆元以上規模
  - 黑潮電廠 Kuroshio power plant: NTU Lecture Professor Falin Chen 2013
- 氣候變遷 >>> 極端氣候 (暖化、嚴寒、暴雨、乾旱、颱風)
- 暴雨 >> 山崩、土石流
  -水資源
  -海平面上升

挑戰與機會(三)

- 數位化、科技化：**1981 IBM-5150 PC >>> Wintel**
  - **GIS/BIM (Building Information Model)**
  - 無人機掃描、測量 **(Drone scanning/survey)**
  - 機器人 (Robotics)：**Sampling/Anchoring at seabed (>50m deep)**
  - 遙控 (Remote control)：**e.g. Automatic TBM operation**
  - **地球物理探勘 (Geophysical exploration)**

  - - - - -

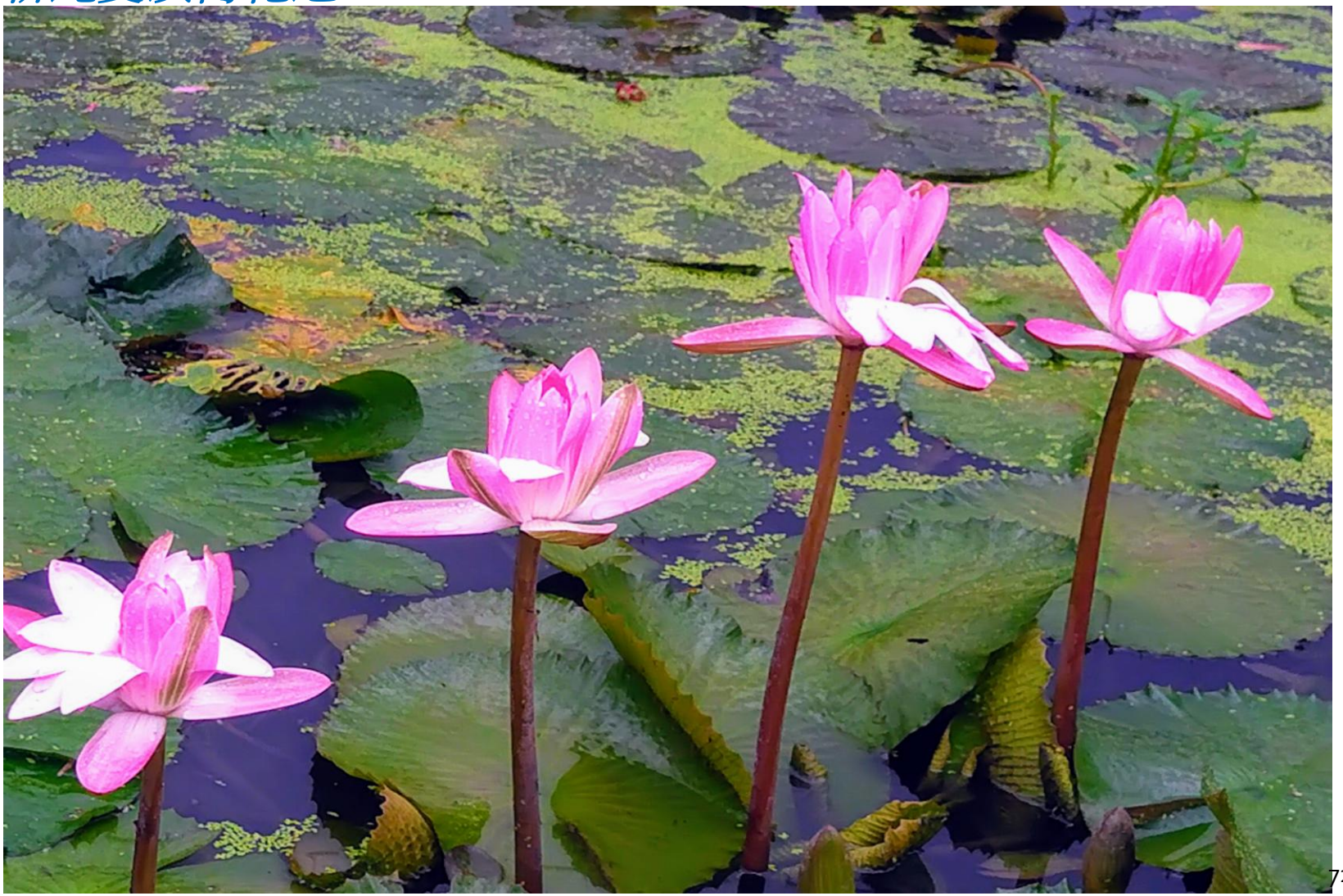
Digital scanning

結語

- 應用地質技師在台灣之角色
  - 以地質災害之防治為首要任務
  - 加強地質資源之調查及利用
- 地質技師與工程師之關係
  - 服務範圍不限於工程地質
  - 技術與管理並重

Q&A

新北雙溪荷花池



廣告時間

大地情懷：捷運、地質、陽光三重奏 - 闕河淵回憶錄