Deep Excavation in Hong Kong – Design and Construction Control

Jack Pappin, John Endicott & John Clark
(James Sze)

Content of the Presentation

• Part I – Design Considerations
• Part II – Numerical Modelling
• Part III – Observational Method
Part I – DESIGN CONSIDERATIONS

Design Codes and Guides

• CIRIA 104
• BS 8002
• DD ENV
• BD 42/00
• Piling handbook
• CIRIA R185
• CIRIA C517
• CIRIA SP95
• GEOGUIDE 1 2nd Ed.
• GCO Publication No. 1/90
**Conventional Retaining System Design Approach**

Figure 29, GCO 1/90 (Navfac, 1982b)

**CIRIA Report C580 Design**

- Aim - holistic, consistently reliable & economic ELS design
- Limit states design
- Maintain simplicity over different uncertainties – adopt partial factor of safety on soil strength only
Use of C580 in Hong Kong

- Review Group set up by Geotechnical Engineering Office in 2004
- Promulgated by BD/GEO in early 2005
- alternative to global factor of safety approach in GCO Publication No. 1/90
- review in 2 years before long-term implementation

Simplified Flowchart of C580 Design Approach (SSI)

ULS Analysis
- Moderately conservative parameters
- Apply partial factors
- Unplanned excavation (0.5m or 0.1H)
- Unfactored surcharge load
- Worst credible groundwater level

- BM, SF & prop loads (ULS)
- Toe-in requirement

SLS Analysis
- Most probable parameters
- Unfactored
- Unfactored surcharge load
- Most unfavorable groundwater level under normal circumstances

- BM, SF & prop loads (SLS) x LF
- Lateral wall deflection

BM, SF & prop loads envelope (structural design)
Conventional vs C580 Design Approach - Example

Sensitivity analyses – Wall Bending Moment

-2000 -1000  0  1000  2000
0  1  2  3  4  5
-600 -400 -200 0  200  400  600

-20 -15 -10 -5  0  5
-20 -15 -10 -5  0  5

Max. bending moment (kNm/m)  Ultimate Bending moment (kNm/m)

ULS (+ve)  ULS (-ve)  SLS x 1.4 (+ve)  SLS x 1.4 (-ve)

Soil side  Excavation side

Depth of embedment (m)

Level (mPD)

-6.0mPD Dig Level

C580 toe level

Conventional toe level
Sensitivity analyses – Wall Shear Force

Max. shear force (kN/m)

Depth of embedment (m)

ULS  SLS x 1.4

Ultimate Shear force (kN/m)

Soil side

Excavation side

-6.0mPD Dig Level

C580 toe level

Conventional toe level

Sensitivity analyses – Strut Force & Wall Deflection

Max. strut force (kN/m)

Depth of embedment (m)

ULS - S1  ULS - S2

SLS - S1 x 1.4  SLS - S2 x 1.4

Horizontal Wall deflection (mm)

ULS - S1  ULS - S2

SLS - S1 x 1.4  SLS - S2 x 1.4

Conventional

C580 - SLS

ULS - S1

ULS - S2

SLS - S1 x 1.4

SLS - S2 x 1.4

Conventional - SLS
Control of Groundwater at Passive Zone

- Alluvium
- CDV
- Rock

Pump well

E.g. KCRC Spurline Kwu Tung Station

Buildability

- Difficult in constructing
- Unrealistic movement criteria
**Buildable Design**

- Easy and fast construction
- Less risks
- Safer working environment
- Could be more cost effective

E.g. KCRC Tsuen Wan West Station

**Over-excavation**

Unworkable sequence vs Opportunistic contractor
Optimization of ELS Design at Kowloon Bay

Development at Sheung Shing Street, KLN
Bottom-up with Raking Strut Option

Settlement measured at Chater Station in mid 70s

Unrealistic Movement Criteria - Diaphragm Wall

Settlement measured at Chater Station in mid 70s
How about Sheetpile Wall Installation?

Installation may attribute a substantial part of induced movements

Sheet piling – Giken (Silent) piling

E.g. East Rail TSTE Mody Road Subway, CLP Cable Tunnel TWS access shaft
Conclusions of Part I

- C580 design approach would result in consistently reliable design.
- Shortest Toe-in might not be most economic.
- Buildability - one of key factors for successful execution of ELS works.
- Get Contractor’s involvement at earlier stage if possible.

Part II – NUMERICAL MODELLING
Numerical Modelling

- Earth pressure
  Coulomb 1776

- Applied Pressure Diagram
  Terzaghi & Peck 1948
Numerical Modelling

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  Coulomb 1776
- Applied Pressure Diagram
  Terzaghi & Peck 1948
- Beam on Springs
  1976
- Finite Elements/Differences
  1986
Numerical Modelling

- Earth pressure Coulomb 1776
- Applied Pressure Diagram Terzaghi & Peck 1948
- Beam on Springs 1976
- Finite Elements/Differences 1986
- Bricks on Strings Simpson 1992
- 3D Applications in practice 2002 - 2005
Layout Plan of Extension to the Tsim Sha Tsui Station Concourse

Typical Cross Section showing Ground Conditions and the Proposed Works
View of the 3D FLAC Model Developed showing the Lateral Wall Deflections along the length of the Excavation

Plan view from FLAC 3D Model Showing the Displacement of the Tunnel Linings along the length of the Excavation
Wall Deflections and Tunnel Deformations from FLAC 3D at a Section about 40 m from the southern end
Monitoring of Tunnel Convergence – Downtrack Tunnel

Measured Deformation of Excavation Lateral Support Wall
• 3-D modelling can be useful for complex geometries

• Often variations in ground conditions or construction procedure render sophisticated constitutive models redundant
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• KIS = Keep It Simple

• 3-D modelling can be useful for complex geometries

• Often variations in ground conditions or construction procedure render sophisticated constitutive models redundant

• KIS = Keep It Simple
  • Less likely to get a plausible result based on wrong reasons
  • Easy to check for approval
  • Easy to compare with monitoring results
  • Easy to back analyse
Part III - USE OF OBSERVATIONS MADE DURING EXCAVATION

What Constitutes a Well Performing Excavation?

- Common Objectives of Client and Contractor
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  - totally safe against collapse
  - adequate protection to nearby structures and roads etc.
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**Protective Factors**
What Constitutes a Well Performing Excavation?

• Common Objectives of Client and Contractor
  Protective Factors
  • totally safe against collapse
  • adequate protection to nearby structures and roads etc.
  • makes provisions for a safe working environment

  • permits reasonably rapid progress of work

• Cost as low as possible after considering the above
What Constitutes a Well Performing Excavation?

• Common Objectives of Client and Contractor
  
  **Protective Factors**
  • totally safe against collapse
  • adequate protection to nearby structures and roads etc.
  • makes provisions for a safe working environment

  **Commercial Factors**
  • permits reasonably rapid progress of work
  • cost as low as possible after considering the above

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Dominating Factor...

**Ground Conditions Uncertainty**

• The state-of-the-art in modern geotechnics gives us...
  • increasingly powerful design tools
  • easy access to information on the outcome of many past projects
• But still views diverge on the correct balance between protective and commercial aspects.
  • variance between analytical tools
  • significance of disturbance to field samples
  • use of average values or more conservative
  • whether soil properties may change during the excavation process

The Only Sure Way is the Observational Way

The Observational Method in ground engineering is the continuous review and refinement of a design based on observations of field behaviour
Examples

• Tseung Kwan O Station
  • observational method was used to justify omission of a layer of props and a buried prop at later stages of the project
  • otherwise it seems that use of observational design is the exception in Hong Kong
Why Use Observational Design?

**Direct Alteration of Soil Properties**

- Heating / Dessication due to Jet Grout Hydration

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**Why isn’t OM used for every excavation?**

- time lag between measurement and reporting and interpretation
- reliability of reported measurements
- authority approval for change in sequence of work
Web Based Real Time Reporting

Instruments (e.g., strain gauges on struts)

Dataloggers with solar panel

Users connected over the Internet

Server

Instrument Reliability

Average Load vs. Time Plot for LC-10590-5

- Average Load
- Action (1795kN)
- Alert (1395kN)
- Average Temperature

Temperatures (deg C)
Authority Approvals Strategy

• Submit two designs for approval
  • Design A – Adopts "moderately conservative" parameters agreeable to the authority (i.e. normal practice)
  • Design B – Targets more favourable parameters
    • Proponent (probably the contractor) decides how much better performance is expected to be... could be "most probable" or even more optimistic

• Identify a Test Stage in the Excavation
  • Up to the test stage, A and B follow the same path, but diverge thereafter
  • Identify test conditions to verify that more favourable parameters are safe
  • At design approval stage, the authority approves only the test conditions, not the target parameters

![Diagram](image)
Issues to Address in adopting the Observational Method

- Most critical is to avoid a delay of say one month waiting for consent after submission of a report on reaching the test stage, therefore...
  - make consistently up-to-date archive of observations available to the authority and the supervising engineer
  - build a simple control framework into the web based real time reporting system so that compliance with test stage conditions can be instantly verified
  - adopt a “self-regulation” process whereby the Supervising Engineer (RSE) certifies the compliance with the test stage conditions

Summary

- Limit State Design
  - for consistency and economy

- Buildability
  - most problems are the result of buildability not being properly considered in the design, the leanest solution may not be the best

- Sophisticated 3D modeling
  - invaluable for unusual, complex analysis, esp. for effects on existing sensitive structures, but requires specialist expertise in its application

- Observational Method
  - viable tool for reducing cost and improving safety that can and should be integrated into existing procedures for authority control
Thank you