Dubai Metro – Project outline

Red & Green lines under construction
● Red Line – Opened Sept 2009
● Green Line – Opening 2011

Other lines to follow:
● Purple line
  – Airport express
● Blue line
  – Along Emirates Road

Dubai Metro will be:
● Driverless
● Fully-automated
● Longest in the world
Dubai Metro – Project outline

Red line
- 52 km route
- 42 km viaduct
- 22 overground stations
- 5.5 km tunnels
- 4 underground stations
- 2 depots
Dubai Metro – Project outline

Green line
- 24 km route
- 16 km viaduct
- 12 overground stations
- 7.0 km tunnels
- 8 underground stations
- 1 depot
Dubai Metro – Project organisation

Client
Government of Dubai
Roads & Transport Authority

Engineer
Systra Parsons

Contractor
Mitsubishi Corporation / Mitsubishi Heavy Industries
Kajima – Obayashi – Yapi Merkezi

Designer
Atkins
Dubai Metro – Geological Setting
Dubai Metro – Geological Setting

Recent
- Unit 1: Dune Sands & Sabkha Deposits

Pleistocene (2 million years)
- Unit 2a(i): Marine Sands, weakly cemented
- Unit 2a(ii): Marine Calcarenite, very weak to weak
- Unit 2b: Aeolian Gypsiferous Sandstone, very weak to weak

Mio-Pliocene – Barzaman Formation (20 million years)
- Unit 3: Conglomerates, mudstones and siltstones (Wash from Hazar Mountains)
Dubai Metro – Geological Setting
Dubai Metro – Geological Investigation
Dubai Metro Ground Investigation

Red Line: Over 1200 boreholes and CPTs

Green Line: Over 600 boreholes and CPTs
Dubai Metro – Ground Investigation

Cable Percussion Boring & Cone Penetration Testing
- Sands and Weakly Cemented Sands

Rotary Coring
- Sandstone, Calcisilitite, Conglomerate

In situ testing
- SPT
- In situ permeability

Laboratory Testing
- Moisture Content, PSD, Sulphate, pH on soils
- Point Load, Unconfined Compressive Strength on Rock
Dubai Metro – Ground Investigation

Unit 2a(i)

Unit 2a(ii)
Dubai Metro – Ground Investigation

Unit 2b

Unit 3
Dubai Metro – Derivation of Design Parameters
Dubai Metro – Derivation of Design Parameters

• Design parameters derived by Atkins Dubai and agreed with the Engineer in Dubai

• Atkins Dubai produce a Ground Report and Pile Length Report

• No opportunity to re-negotiate design parameters

• Design parameters in soil and rock derived from SPT- N value and Unconfined Compressive Strength (UCS) respectively
Dubai Metro – Derivation of Design Parameters

• $\Phi_{\text{soil}}$ from SPT N-value after Peck, Hanson and Thorburn
• $\Phi_{\text{rock}}$ from triaxial test results
• $c'_{\text{rock}}$ from $c' = \frac{\text{UCS}_{\text{mass}}(1-\sin \Phi)}{2 \cos \Phi}$

• $E'_{\text{soil}} = 2.3N_60$ MPa
• $E'_{\text{rock}} = 215 \times \text{UCS}^{0.5}$

• $f_{s(\text{soil})} = 1.6N + 6$ kPa after Decourt (1995)
• $f_{s(\text{rock})} = 02.5$ or $0.35 \times (\text{UCS}_{\text{design}})^{0.5}$ after Zhang & Einstein (1998)
• $f_{b(\text{rock})} = 2.5 \times (\text{UCS}_{\text{design}})^{0.5}$
### Typical Design Parameters

<table>
<thead>
<tr>
<th></th>
<th><strong>v</strong></th>
<th><strong>γ_b (Mg/m³)</strong></th>
<th><strong>c’ (kN/m²)</strong></th>
<th><strong>φ (°)</strong></th>
<th><strong>f_s (kN/m²)</strong></th>
<th><strong>E_{sv}’ (kN/m²)</strong></th>
<th><strong>E_{sh}’ (kN/m²)</strong></th>
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<tbody>
<tr>
<td><strong>Soil</strong></td>
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<td>1.9</td>
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<td>30</td>
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<td>36</td>
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<td>69</td>
<td>48</td>
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<td><strong>Rock</strong></td>
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Dubai Metro – Viaduct Substructure Design
Dubai Metro – Viaduct Substructure Design

Viaduct arrangement

- Precast segmental construction
  - Single spans of 20m to 36m
  - Twin spans of either 44m+44m or 40m+40m made continuous after deck erection
  - 3-span continuous structures made by balanced cantilever method with main spans of 66m to 74m
  - 3-span or 4-span continuous structures of 30m to 36m through elevated stations
Dubai Metro – Viaduct Substructure Design

Pile design

- Single central piers typically 2.2m to 2.8m diameter
- Twin-pile groups, typically 1.6m to 1.8m diameter, used to span over existing services
- 4-pile groups, typically 1.6m to 1.8m diameter, for more heavily loaded internal piers of continuous spans

- Piles up to 40 metres long

- Lengths determined from critical SLS or ULS cases
  - Based on skin friction safety factors of 2.5 and 1.5 respectively
  - End bearing ignored
Pile Design (continued)

- Designed for durability in aggressive environment
  - Addition of waterproofing membrane to protect against chloride attack
  - Pile cover of 120mm to protect against sulphate attack

- Horizontal ground acceleration coefficient of 0.12g (ULS only)

- Centrifugal loading (plan curvature down to 300m)

- Self-weight of deck on curved sections of deck

- Wind

- Collision loads

- Rail-structure interaction
Dubai Metro – Viaduct Substructure Design

Pile Analysis

- Load effects for reinforcement design generated by analysis using REPUTE program and verified using PLAXIS, PIGLET & L-PILE
Pile Testing

- 3no piles tested
- Showed 2 x calculated ultimate skin friction and 50% calculated end bearing
- Recommended $0.35 \times (\text{UCS}_{\text{design}})^{0.5}$ for polymer supported pile shaft and $0.25 \times (\text{UCS}_{\text{design}})^{0.5}$ for bentonite supported pile shaft as minimum values
- Recommended $Q_{\text{allow}} = Q_s + Q_b / 2.5$
## Dubai Metro – Viaduct Substructure Design

### Pile Testing (continued)

<table>
<thead>
<tr>
<th>Pile No.</th>
<th>Diameter (m)</th>
<th>Length (m)</th>
<th>Design SWL (kN)</th>
<th>Maximum Test Load (kN)</th>
<th>Settlement at SWL (mm)</th>
<th>Settlement at Max Load (mm)</th>
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<td>OP1</td>
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Dubai Metro – Union Square Station
Dubai Metro – Union Square Station

• First Underground Station to be constructed
• On-line junction of Red and Green Lines
• Internal dimensions 50m x 250m
• Open aspect with few internal columns (25 metre span with internal columns)
• Drive shaft for all Red and Green Line tunnel drives
Dubai Metro – Union Square Station

Design Considerations

- Wall depth to -44.6mDMD to provide satisfactory FoS against flotation and reduce water ingress during construction (Tender design had grout plug)
- Base slab design to counteract uplift from 22 metres of water, 2.5 metres thick (tension barrettes)
- Wall design for high moments from large spans of slabs, 1200mm thick to optimise reinforcement density (reverse moment from uplift of base slab)
- Wall design to BS8110 and BS8007 (Reinforcement controlled by 0.2mm crack width requirement)
Dubai Metro – Union Square Station

Panel Arrangement – Eastern End of Station Box
Typical sections through box
Dubai Metro – Union Square Station

Design analysis

- Wall reinforcement design after CIRIA C580 using PLAXIS
- Flotation design using I. Struct. E. Guidelines for Basement design
- Settlement Analysis using approach after CIRIA C580
Typical Panel Detail
Dubai Metro – Substructure design

Seismic analysis

- Nearest fault line is 120 km from UAE – Zargos fault line
- Cautious approach because of use for evacuation – “essential” to AASHTO
- AASHTO defined seismic response spectrum used with $A = 0.12g$
  - Site coefficient dependent on bearing type used
Dubai Metro – Substructure design

Column and pile design

- Once rules established, 1400+ unique foundations designed in 9 months
- Strict control procedures between design team & setting-out team
- Optimisation / automation process developed throughout
  - Process of seismic analysis and section checking automated by linked macros
  - Enabled peak output of 100 foundations to be designed per week