Melbourne Metro
Ground Movement and Land
Stability
Future Development Loading

Presentation to the Inquiry / Advisory Committee by Anthony Bennett

31st August 2016
Ground Movement and Land Stability & Future Development Loading

• Common themes
• Geology

Ground Movement and Land Stability
• Ground movement mechanisms
• Analyses and assessments (Levels 1 to 3)

Future Development Loading
• Analyses for the extent of the Design and Development Overlay
• Assessment of Future Development loadings

Reviews and Summary
Common themes

Existing Building

Ground movement effects from Melbourne Metro

Excavation for Melbourne Metro Construction

Future Building

Loading effects towards Melbourne Metro

Future Loading on Melbourne Metro
Common themes

Geological Long Section - Prior to updated geological information
- More than half the alignment in Melbourne Formation or Basalt
- Soft soil (Coode Island Silt) directly over the alignment at Maribyrnong River, Moonee Ponds Creek, and Yarra River
Ground Movement and Land Stability

Magnitude and shape of settlement is related to:

- Geology (ground mass stiffness)
- Tunnel depth below ground surface
- Tunnel separation
- Excavation / Construction methodology
- Groundwater response
Ground Movement and Land Stability

Tunnelling induced ground movement

- “Volume Loss” transmitted to surface and forms settlement trough
- Occurs partially in advance of the face
- Also applies to cavern excavation, excavated in stages
Ground Movement and Land Stability

Open excavation related ground movement

- Lateral movement with a corresponding vertical movement
Ground Movement and Land Stability

Consolidation Settlement
• Induced by draw down of the groundwater levels
• Effects a consideration in soft soils
  • Western Portal to Arden Station
  • Yarra River Crossing
  • Albert Park & South Melbourne Embayment

Embankment Construction
• Western Portal
Ground Movement and Land Stability

Level 1 assessment

Table 2: Summary of Preliminary Ground Movement Assessment Results for TBM Tunnels

<table>
<thead>
<tr>
<th>Approx. Chainage (m)</th>
<th>Project</th>
<th>Inferred Ground Conditions at Approximate Tunnel Elevation / Tunnel Face</th>
<th>Ke assumed for MF unit</th>
<th>Estimated Maximum Settlement (in mm)</th>
<th>Estimated Maximum Settlement (in mm)</th>
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<tbody>
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<td>0.5%VH</td>
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Combines movements from excavation sources

Potential Zone of Influence

Excavation induced – 5 mm
Consolidation induced – 10 mm
Ground Movement and Land Stability

• Level 1 Assessment
Ground Movement and Land Stability

Level 2 assessment

• Magnitude of settlement and settlement profile (DISTORTION) are key
# Ground Movement and Land Stability

<table>
<thead>
<tr>
<th>Potential Impact</th>
<th>Category of damage and Normal degree of severity**</th>
<th>Description of typical damage*</th>
<th>Limiting tensile strain** %</th>
<th>Broad category grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>0 – Negligible</td>
<td>Hairline cracks less than about 0.1 mm wide.</td>
<td>Less than 0.05</td>
<td></td>
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<tr>
<td>Minor</td>
<td>1 – Very Slight</td>
<td>Fine cracks that are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Close inspection may reveal some cracks in external brickwork or masonry. Typical crack widths up to 1 mm.</td>
<td>0.05 to 0.075</td>
<td>Aesthetic Damage</td>
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<td></td>
<td>2 – Slight</td>
<td>Cracks easily filled. Redecoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weather-tightness. Doors and windows may stick slightly. Typical crack widths up to 5 mm.</td>
<td>0.076 to 0.15</td>
<td></td>
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<tr>
<td>Moderate</td>
<td>3 – Moderate</td>
<td>The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather-tightness often impaired. Typical crack widths are 5–15 mm or several &gt;3 mm.</td>
<td>0.15 to 0.3</td>
<td>Serviceability Damage</td>
</tr>
<tr>
<td>Major</td>
<td>4 – Severe</td>
<td>Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing beams. Service pipes disrupted. Typical crack widths are 15–25 mm, but it also depends on the number of cracks.</td>
<td>Greater than 0.3</td>
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Equivalent system for infrastructure and underground utilities
Ground Movement and Land Stability

For comparison although not directly applicable to settlement from tunnelling “AS 2870 - Residential Slabs and Footings”

<table>
<thead>
<tr>
<th>Characteristic surface movement ($y_s$) (mm)</th>
<th>Site classification</th>
<th>Classification based on Site Reactivity</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>A</td>
<td>Most sand and rock sites with little or no ground movement from moisture changes</td>
</tr>
<tr>
<td>$0 &lt; y_s \leq 20$</td>
<td>S</td>
<td>Slightly reactive clay sites, which may experience only slight ground movement from moisture changes</td>
</tr>
<tr>
<td>$20 &lt; y_s \leq 40$</td>
<td>M</td>
<td>Moderately reactive clay or silt sites, which may experience moderate ground movement from moisture changes</td>
</tr>
<tr>
<td>$40 &lt; y_s \leq 60$</td>
<td>H1</td>
<td>Highly reactive clay sites, which may experience high ground movement from moisture changes</td>
</tr>
</tbody>
</table>

etc.
Ground Movement and Land Stability

<table>
<thead>
<tr>
<th>CLASSIFICATION OF NORMAL SITES BY INTERPRETATION OF FOOTING PERFORMANCE OF EXISTING BUILDINGS (AS 2870-2011) - MASONRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance of walls of existing buildings on lightly stiffened strip footing or slab on ground.</td>
</tr>
<tr>
<td>Damage Category 0 to Category 1</td>
</tr>
<tr>
<td>Damage often Category 1, but rarely Category 2</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>CLASSIFICATION OF DAMAGE WITH REFERENCE TO WALLS (AS 2870-2011)</th>
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<tr>
<td>Description of typical damage and required repair</td>
</tr>
<tr>
<td>Hairline cracks</td>
</tr>
<tr>
<td>Fine cracks that do not need repair</td>
</tr>
<tr>
<td>Cracks noticeable but easily filled. Doors and windows stick slightly</td>
</tr>
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</table>

etc.
Ground Movement and Land Stability

Level 3 Analysis

Figure 9-1 Preliminary model of City Loop tunnels and Melbourne Central Station relative to proposed works
Ground Movement and Land Stability

EPRs set up procedures which:

- Establish the ground model and the ground water model
- Predict ground movement based upon the construction methodology
- Assess the effects on structures
- Assess whether the effects are acceptable
- Prepare mitigations if required
- Establish existing conditions including the current state of structures and the current ground and groundwater movements
- Monitor movements as construction proceeds and compare with predictions
- Instigate corrective actions if monitoring indicates responses outside predictions
- Repair damage caused by excavation
Imagine trying to design for this in 1916
## Future Development Loading

<table>
<thead>
<tr>
<th>Evaluation objective</th>
<th>Key Legislation</th>
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<tbody>
<tr>
<td><strong>Built environment:</strong> To protect and enhance the character, form and function of the public realm and surface structures, having buildings within and adjacent to the project alignment, and particularly in the vicinity of project regard to the existing and evolving urban context.</td>
<td>Planning and Environment Act 1987</td>
</tr>
<tr>
<td><strong>Social, community, land use and business:</strong> To manage the effects on the social fabric of the community in the area of the project, including with regard to land use changes, community cohesion, business functionality and access to services and facilities, especially during the construction phase.</td>
<td>Environment Protection Act 1970 and State Environment Protection Policies Planning and Environment Act 1987 Transport Integration Act 2010</td>
</tr>
</tbody>
</table>
Future Development Loading

1,000 kPa load applied at the surface

Points at various depths for which the ground stress increase is 50 kPa

Line at 10 m depth for reading off stress changes

Increase in ground stress less than 50 kPa

Line at 20 m depth for reading off stress changes

Line at 30 m depth for reading off stress changes

Increase in ground stress between 50 kPa and 100 kPa

Model result at 30 m depth for the distance from the edge of the surface loading to the point where the ground stress increase is only 50 kPa

Derivation of the extent of the DDO
Future Development Loading

Development to be assessed under DDO

- The design of Melbourne Metro will take into account:
  - Existing structures
  - Developments that are approved prior to the DDO taking effect
  - Allowance for an additional loading of 50 kPa for future development (and unloading)
- DDO will require assessment of developments that are proposed after the DDO takes effect, to protect the Melbourne Metro infrastructure from damage
- DDO extent should be reviewed after the construction of Melbourne Metro is complete
Future Development Loading

Matters to be assessed under DDO

• Assessment under DDO will be technically similar to the procedure used for developments near Melbourne Underground Rail Loop (MURL) (City Loop)

• Assessment will consider:
  • Loading and unloading
  • Clearances – avoiding direct contact with Melbourne Metro infrastructure
  • Construction methods – eg avoiding unacceptable vibration
  • Not relying on direct structural support from Melbourne Metro
Future Development Loading

Process for assessment under the DDO

• Pre-application meeting with MMRA (Referral Authority) would be optional but strongly recommended – can include information exchange to assist in preparation of permit application

• Submission of permit application to Council

• If referred to MMRA, MMRA assesses effects of development considering other developments in the area

• MMRA compares with Design Allowances – simple assessment

• If more complex, MMRA conducts first principle’s assessment

• MMRA advises acceptability or mitigation requirements through permit conditions
Reviews and Summary

Submissions & Other Expert Witness Statements

• General concerns about damage from tunnelling
• Specific cases of shallow cover, founding conditions, or structure
• Process of applying the EPR requirements (not a technical area)
• Implications of having DDO applied to property (not a technical area)
Reviews and Summary

Technical Notes

• TN007 – where protective measures may be required
• TN008 – soil and rock bore logs and potential modification of alignment
• TN011 – proposed adit at Franklin Street
• TN023 – additional geological data
• TN024 – revised station cavern construction methodology
• TN053 – further analyses
Reviews and Summary

EES stage
ground model

CBD North

CBD South

Updated
ground model

CBD North

CBD South
Reviews and Summary

EPRs adequately address the matters raised in the submissions and the effects of the updated geological information.

Proposed DDO still applicable under the updated geological information and its extent would not change as a result.

DDO extent should be reviewed after the construction of Melbourne Metro is complete.