Widening of Existing Bridge Abutments – A Geotechnical Approach
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Agenda

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2. The Project
3. Site Geology
4. Design Challenges
5. Design Options
6. Adopted Design Approach
7. Overview of Adopted Design Methodology
8. Construction Methodology, Interface Challenges and Lessons Learnt
1. Overview

- Widening of existing infrastructure is not yet routine
- Requires a different thought process to designing new infrastructure.
- Design codes change over time which often change acceptable factors of safety.
- Challenging when upgrading infrastructure 30 or so years later.
- Presentation presents challenges, options considered and final solution adopted for a bridge abutment widening.
  - Compliant with Scope of Works and Technical Criteria (SWTC).
  - Enabled widened abutment to wrap around the existing spill through with minimal excavation.
2. The Project

- Upgrade of a section of a major Australian Motorway.
- Current four-lane motorway is a critical transport corridor for more than 75,000 vehicles each day. Upgrade includes:
  - Widening of over 10 km of the motorway from four to six lanes
  - Modifications to road interchanges including extended on- and off-ramps; construction of off-road cycle / pedestrian facilities; widening of more than five existing bridges; deconstruction and reconstruction of three existing bridges and construction of two new structures.
- Presentation focuses in detail on a particular bridge constructed around 1985 and forms part of the southbound widening of a major interchange. The approach adopted at this bridge spill through was adopted for all bridge widenings.
3. Site Geology

• Pleistocene age alluvial plane materials (comprising sand, silt, clay and gravel).
• To the east of the Bridge site Holocene age undifferentiated coastal plains sediments (comprising clay and sand) is shown to be present.
• These more recent deposits are underlain by residual soil and a deeply weathered rock profile from the Tertiary age Petrie Formation (comprising sandstone, siltstone, mudstone, and basalt).
• Boreholes indicate occasional fill overlying up to 5m of alluvium overlying 3 to 5m of residual soil overlying extremely weathered rock.
• Variable weathering profile across the bridge with several boreholes encountering residual soil layers or extremely weathered rock underlying a stronger upper basalt cap.
• Groundwater monitoring wells were not installed, however, given the vicinity of the bridge site to a creek and wetlands, groundwater levels were taken to be at ground level.
4. Design Challenges

- No one in the team had previously designed a spill through widening for an existing bridge abutment
- Existing batter slope of 1v:1h
- As-builts indicated existing spill though comprised Select Fill with a Terrafix interlocking concrete block facing. No details on what the Select Fill was comprised of or any other form of ground treatment
- Exemplified importance of good As-built dwgs for safety in design as well as enabling future works and ensuring future works are cost effective
- No Highway Authority standard details for 1v:1h batter slopes as these are no longer allowed to be designed (only 1v:1.5h)
- 1v:1h slopes in Select Fill do not generally stand up unaided in the long term
4. Design Challenges

- No sign of bulging, distress or repair
- Absence of physical repair, remediation work or records
- Therefore existing spill through was assumed to be stable in its current state.
- Construction sequencing meant that piles were constructed from headstock level
  - Piling platforms constructed out of rockfill at widened spill through locations
  - Rockfill would form the permanent spill through widenings and trimmed to match spill through geometry.
- Every spill through abutment had a different geometry and had to be designed separately, no one size fits all solution.
4. Design Challenges

Figure 1: Widening of the Bridge, Abutment A and B Spill Throughs
4. Design Challenges

Figure 2 Section 5.A.1

Figure 3 Section 5.B.1
4. Design Challenges

Figure 4 Section 5.B.4
5. Design Options for 1v:1h to 1v:1.5h

- 4 options considered:
  
  Option 1. Reinforced concrete facing and shear key.
  
  - Reinforced concrete facing acting as slope stability measure
  - Wraps around existing abutment
  - Shear key connection with concrete facing embedded 1.5m below ground level with 1m of dig out and replace in front of toe
5. Design Options for 1v:1h to 1v:1.5h

- Option 1
5. Design Options for 1v:1h to 1v:1.5h

• 4 options considered:
  Option 2: Reinforced concrete facing as per Option 1 except:
  - Geogrid is placed between layers of rockfill
  - A shear key isn’t required
5. Design Options for 1v:1h to 1v:1.5h

- Option 2
5. Design Options for 1v:1h to 1v:1.5h

- Option 2 Cont’d
5. Design Options for 1v:1h to 1v:1.5h

- 4 options considered:
  - Option 3: Reinforced concrete facing and a mechanical anchor
    - As per Option 1 but with a mechanical anchor to increase slope stability
    - Anchor would be located immediately below headstock level
    - Shear key not required
5. Design Options for 1v:1h to 1v:1.5h

- Option 3
5. Design Options for 1v:1h to 1v:1.5h

- 4 options considered:
  - Option 4: Soil nails with a shotcrete facing
    - Discounted due to difficulty of installing soil nails through rockfill.
5. Design Options for 1v:1h to 1v:1.5h

• **Preferred Option**
  Options 1 and 2 were worked up into sketches and cross section to ensure the options worked in 3D with the abutment geometry
  - Option 1: selected by Contractor due to ease of construction
  - Option 1 put forward to Highway Authority for approval based on the Adopted Design Approach discussed in the next few slides.

• For 1v:1.5h to 1v:2h the std Highway Authority spill through detail was applied.
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

- Step change to design approach required
  - No details on existing Select Fill – std Highway Authority parameters assumed
  - Global FoS of 1.1 to 1.4 for existing spill throughs in the long term condition.
  - Existing spill through’s visually stable,
    - Therefore only needed to ensure new widened section was stable and met SWTC (FoS of 1.3 and 1.5 in short and long term).
  - New widened section wraps around existing
  - No need for temporary works or lane closures
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

- Using adopted design approach:
  - Where new spill through in influence of existing, designed to match FoS of existing (std FoS of 1.3 adopted for existing for short and long term)
  - Outside zone of influence of existing spill through, FoS of 1.3 and 1.5 for short and long term adopted as required by SWTC.
  - Approach accepted by Highways Authority as compliant with the SWTC
  - Approach was adopted for all spill through abutments on the project where the existing spill through is at 1v:1h.
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

- **Figure 5 Section 5.B.1**: Slope stability analysis through existing section (refer Tables 1 to 4)
- **Figure 6 Section 5.B.1**: Slope stability analysis through widened section (refer Tables 1 to 4)
- (Note the widened section is within the zone of influence of the existing spill through. Slip circle goes below shear key)
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

Section 5.A.2 – New Widening Spill-through: Long Term Condition – Circular Slip

Figure 7: Slope Stability analysis through widened section
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

Table 1: Representative Sections: Zone of Influence and Factors of Safety

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Influence Zone</th>
<th>Analysed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.A.1</td>
<td>Raising to full height at 1V:1H</td>
<td>Inside influence zone</td>
<td>Yes</td>
</tr>
<tr>
<td>5.A.2</td>
<td>Widening and transition from 1V:1H to 1V:1.5H</td>
<td>Outside influence zone</td>
<td>Yes</td>
</tr>
<tr>
<td>5.A.3</td>
<td>Widening and transition from 1V:1.5H to 1V:2H</td>
<td>Outside influence zone</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Slope Angle</th>
<th>Undrained</th>
<th>Drained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Circular</td>
<td>Widened$^\dagger$ Circular</td>
<td>Widened$^\dagger$ Non-Circular</td>
</tr>
<tr>
<td>5.A.1</td>
<td>1V:1H</td>
<td>1.20</td>
<td>1.83 (1.70)</td>
</tr>
<tr>
<td>5.A.2</td>
<td>1V:1.2H</td>
<td>N/A</td>
<td>1.83 (1.73)$^2$</td>
</tr>
</tbody>
</table>
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

Table 2: Representative Sections: Zone of Influence and Factors of Safety

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Influence Zone</th>
<th>Analysed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.B.1</td>
<td>raising to full height at 1V:1H</td>
<td>Inside influence zone</td>
<td>Yes</td>
</tr>
<tr>
<td>5.B.2</td>
<td>widening and transition from 1V:1H to 1V:1.5H</td>
<td>Inside influence zone</td>
<td>No</td>
</tr>
<tr>
<td>5.B.3</td>
<td>widening and transition from 1V:1H to 1V:1.5H</td>
<td>Inside influence zone</td>
<td>No</td>
</tr>
<tr>
<td>5.B.4</td>
<td>widening and transition from 1V:1.5H to 1V:2H</td>
<td>Inside influence zone</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Slope Angle</th>
<th>Undrained</th>
<th>Drained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Existing Circular</td>
<td>Widened Circular</td>
</tr>
<tr>
<td>5.B.1</td>
<td>1V:1H</td>
<td>1.47</td>
<td>1.40 (1.31)</td>
</tr>
<tr>
<td>5.B.4</td>
<td>1V:2H</td>
<td>1.44</td>
<td>1.40 (1.29)</td>
</tr>
</tbody>
</table>
6. Adopted Design Approach for 1v:1h to 1v:1.5h Wrap Round

- Approach applied from 1v:1h at interface with existing to 1v:1.5h as spill through approached interface with adjoining embankment
- For section 1v:1.5h to 1v:2h the std Highway Authority spill through detail was applied.
7. Overview of Adopted Design Methodology

- Geotechnical model was developed based on latest exploratory hole information.
- Existing spill through and new widened spill throughs modelled using standard parameters for engineered fill and rockfill as specified by Highways Authority.
- Slope stability for existing and widened sections undertaken using Slope W.
- Short term (unplanned excavation case) and long term stability checks against sliding and overturning for the reinforced concrete facing were undertaken using GEO5 for the critical section.
- Bending moments and shear forces in the reinforced concrete facing were calculated using Plaxis (soft soil model) for input into structural design of the facing.
  - Soft soil model allowed pore water dissipation and can decouple interface RC facing from soil behind it.
7. Overview of Adopted Design Methodology

- Bending moments generated were minimal resulting in a facing thickness of 160mm (only 10mm thicker than the standard detail for the 1v:1.5h batter slope.)
7. Overview of Adopted Design Methodology

Typical BR05 Plaxis Model (Plane Strain)

10kPa for construction
20kPa for long term

Widening:
Rock fill (phi=40)

Existing embankment:
General fill (c’=5kPa, phi=30)

CH-st
CH-f
R6
7. Overview of Adopted Design Methodology

Stage 00: In situ condition

Stage 01: Existing embankment (drained)

Stage 02: Placement of rock fill (30 days) + 10kPa surcharge (undrained)

Stage 03: Installation of RC walls – End of construction (10 days) (undrained)

Stage 04: Long term condition + 20kPa surcharge (drained)
7. Overview of Adopted Design Methodology

Stage 04: Long term condition (drained) – Lateral soil displacement

Output Version 2015.0.18717.12095

Total displacements $u_x$

Maximum value = $1.756 \times 10^{-3}$ m (Element 2012 at Node 19058)
Minimum value = $-0.01054$ m (Element 1930 at Node 7443)

PLAXIS

Abut B Section 5.B.1

Date: 30/08/2016
8. Construction Methodology, Interface Challenges and Lessons Learnt

- Construction Methodology: Safety in Design
  - Design considered construction methodology critical to excavation of a 1.5m deep shear key and potential risk of encountering soft marine clay in excavation.
  - Original intention: shear key installed ahead of piling platform construction; piling platform then trimmed to form widened spill through abutments
  - 1.5m deep trenches constructed in 2m long slots open for a limited period at interface with existing spill through
  - 2m by 1.5m sections ideally precast so can be dropped into excavation to minimise length of time trench was left unsupported.
8. Construction Methodology, Interface Challenges and Lessons Learnt

- Interface Challenges and Lessons Learnt
  - Stage 1: Construct piling platforms over footprint of widened spill through to enable bridge piles to be installed
  - Temp works team both on design and construction did not consider construction of shear key as it was part of the permanent works
  - Piling platform constructed before the shear key, so shear key had to be constructed once spill through abutments were in place.
  - Original construction personnel who had been part of design phase & with whom construction methodology had been developed were no longer on the project.
    - Construction challenges around excavating a 1.5m deep trench immediately below a rockfill temp works piling platform had been not been considered.
    - Shear key could not be precast due to lead in time required which had not been allowed for in the programme.
8. Construction Methodology, Interface Challenges and Lessons Learnt

- Interface Challenges and Lessons Learnt Cont’d
  - Shear key constructed by site structural engineers
    - Majority of details shown on earthworks dwgs
    - Despite cross referencing between structural and earthworks dwgs, details on earthworks dwgs missed until clarified by the Construction Phase Services Team (CPS)
  - For future – a separate note in a highlighted box to ensure construction sequencing and location of certain details are not inadvertently missed out.
  - Soft marine was encountered, limited trench size and proactive observation process with site spotters prevented trench collapse.
    - Temp shoring and cement stabilised sand used to infill trench at risk of collapse.
    - Trench backfilled with cement stabilised sand and allowed to cure for 24 hrs prior to re-excavation of trench.
8. Construction Methodology, Interface Challenges and Lessons Learnt

- Interface Challenges and Lessons Learnt Cont’d
  - D & C process highlights need to have integrated design which includes both temporary and permanent works.
  - Design and subsequent construction of temp works should not be carried out in isolation of the permanent works.
  - Unless temporary works are deconstructed similar to the permanent works, good quality construction records should be kept for temporary works for future reference.
8. Construction Methodology, Interface Challenges and Lessons Learnt
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Questions?