Extending the life of a large corrugated steel pipe with a new structural base

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Overview

1. Background
2. Options review
3. Planning
4. Design development
5. Investigations and testing
6. Preconstruction
7. Construction
8. Outcomes and conclusions.
Background
Lorenz Creek culvert

- Corrugated Steel Multiplate Pipe (CSMP)
- Constructed in 1970
- 2 x 4.2 m diameter cells
- Length = 31.6 m
- Fill height = 2.0 m.
# Project evolution

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>L2 Inspection</td>
<td>CS2 – Flaking, surface rust</td>
</tr>
<tr>
<td>2008</td>
<td>L2 inspection</td>
<td>CS4 – Some holes</td>
</tr>
<tr>
<td>2008</td>
<td>L3 inspection</td>
<td>High risk → Full structural liner (reinforced HDPE)</td>
</tr>
<tr>
<td>2009+</td>
<td>L2 inspections</td>
<td>Inspector rating CS3, Engineer’s rating CS4</td>
</tr>
<tr>
<td>2010</td>
<td>Initial estimate</td>
<td>High density polyethylene (HDPE) liner = $1.7m</td>
</tr>
<tr>
<td>2012</td>
<td>Policy directive</td>
<td>HDPE liner no longer approved due to fire risk</td>
</tr>
<tr>
<td>2013</td>
<td>Options review</td>
<td>Structural reinforced concrete base proposed</td>
</tr>
<tr>
<td>2014</td>
<td>Structures review</td>
<td>Structural base supported (with constraints)</td>
</tr>
<tr>
<td>2015</td>
<td>Development</td>
<td>Project developed (constraints modified)</td>
</tr>
<tr>
<td>2015/16</td>
<td>Works</td>
<td>Project completed</td>
</tr>
</tbody>
</table>
The issue – increasing risk
Planning
Options review

Options

1. Non-structural base ($0.3m)
2. Structural base ($0.5-$0.7m)
3. Full structural reline ($1.7m+)
4. Replacement ($2.0m+)

Preferred option

Option 2 - structural base

- Project level
  ▪ Lowest Net Present Value (NPV) (Life cycle cost analysis).
- Network level
  ▪ Optimum asset management benefits.
Concept proposal – structural invert

Basis
- Mitigate immediate risk
- Use residual life in upper 2/3rds
- Utilised by various other road authorities (Caltrans and others).

Key features
- Large internal angle (120°)
- Welded studs
- Sprayed concrete
- Existing voids filled.
Site investigations

Nature, type and extent of damage
Site investigations

Existing geometry

• Diameter
• Shape
• Length
• Base slab
• Height of corrosion
• Residual thickness.
Residual steel thickness

- Thickness gauge (many sites)
- Coupons (selected sites)

Summary of Coupons taken from Culvert
Design thickness = 3/16" = 4.7625

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Span</th>
<th>Section m</th>
<th>Point No</th>
<th>Diameter mm</th>
<th>Thickness Max mm</th>
<th>Min mm</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1-0-1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>19</td>
<td>4.6</td>
<td>3.3</td>
<td>Some heavy pitting evident over part of rear face</td>
</tr>
<tr>
<td>S1-5-6</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>LOST - Dropped on site</td>
</tr>
<tr>
<td>S1-10-2</td>
<td>1</td>
<td>10</td>
<td>2</td>
<td>19</td>
<td>4.5</td>
<td>4</td>
<td>Active corrosion evident on rear face</td>
</tr>
<tr>
<td>S1-15-5</td>
<td>1</td>
<td>15</td>
<td>5</td>
<td>19</td>
<td>4.6</td>
<td>4</td>
<td>Small pit reducing thickness to 4mm. Otherwise generally 4.5mm</td>
</tr>
<tr>
<td>S2-1-1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>19</td>
<td>4</td>
<td>3.1</td>
<td>Rear face appears relatively free of corrosion. Lack of thickness unclear.</td>
</tr>
<tr>
<td>S2-5-6</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>19</td>
<td>4.5</td>
<td>4.5</td>
<td>Rear face appears relatively free of corrosion</td>
</tr>
<tr>
<td>S2-10-2</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>19</td>
<td>4.5</td>
<td>4.5</td>
<td>Rear face shows signs of surface corrosion. No significant pitting</td>
</tr>
<tr>
<td>S2-15-5</td>
<td>2</td>
<td>15</td>
<td>5</td>
<td>19</td>
<td>4.5</td>
<td>4.5</td>
<td>Some surface corrosion evident - minimal loss of thickness</td>
</tr>
</tbody>
</table>

Conclusions
- Adequate for welding
- Good residual life (above corrosion)
Design development
Structural inverts

Design standards

• Corrugated metal culverts (CMCs)
  - designed as flexible pipes to AS/NZS 2566/1:1988.

• Concrete pipes
  - designed as rigid pipes to AS 3725:2007.

• CMC with a structural concrete invert
  - a hybrid with a flexible upper portion and a rigid invert.
  - no structural design standards.
Design philosophy

• Existing corrugated metal culvert is in equilibrium with soil and has a satisfactory past performance
• Critical forces commonly occur during construction
• CMCs rely on hoop compression, bending and plasticity
  • lost with invert corrosion.
• Structural concrete inverts reinstate the hoop compression, bending strength and plasticity.
Design considerations

• 4.2 m diameter twin barrel culvert CMC
• Severe corrosion to invert
• Minimal loss of thickness soil side
• 2 m of fill
• SM1600 loading
• Regional location
• Cost-effective life extension required
• Structural reinforced concrete invert trial.
Design considerations (cont.)

• Sprayed concrete invert
  - Extent of invert corrosion precluded casting concrete invert without formwork
  - Avoid excavation of CMC invert
  - Eccentricity between CMC and structural concrete invert
  - Reinforced concrete invert
  - Fish passage.

• Shear studs
  - Effective structural connection between CMC and concrete invert
  - Cost effective quality – portable equipment and expertise.

• Corrosion protection above new concrete invert.
Structural concept

1. Significant loss of section
2. Insignificant loss of section
3. New sprayed reinforced concrete invert
4. Shear studs (each side)
5. Protective coating (each side)

Upper limit of repair
CMC to invert – Structural connection

Hoop compression

Connection capable of supporting plastic hinge development

Shear studs – shear and tension transfer

Bending in slab from eccentricity
Investigations and trials
Shear stud investigation

Issues

• Can shear studs be welded to the culvert?
  ▪ Multi-plate
  ▪ Wall thickness (3/16” or 4.7 mm)
  ▪ Galvanised

• Will welding compromise durability by removing the galvanising from the soil side?

Trial

• Section of wall of culvert
• 12 mm and 10 mm studs.
Shear stud trial

- 10 mm studs (12 mm too large)
- Remove galvanising before welding – grinding
- Near vertical ribbed surface
  - Valleys not possible
  - Ridge okay with care.
Shear stud trial – outcomes

- Galvanising already lost from rear face
- Studs will remove galvanising
  - 10 mm less severe than 12 mm
- Positioning of stud at centre of rib – centre pop
- Stud welding settings and operator critical
- Quick.
Sprayed concrete

• Critical considerations
  - Durable, structural concrete
  - Mix design
  - Regional supplier
  - Nozzle operator and equipment.

• Two stage approval
  - Mix design
    ▪ Transport and Main Roads’ requirements for structural concrete.
  - Sprayed concrete tests
    ▪ Test panels
    ▪ Sliced and cored.
  - Approval of nozzle operator.
Sprayed concrete trials

- Nozzle operator critical
- Experience required to identify poor technique
- Poor technique results in low concrete strengths, lower density concrete
- Video of operator, saw cuts and cores effective assessment tools
- Two trials conducted
- Seven day and 14 day core strengths lower than expected
- Target concrete densities and 28 day strengths can be achieved with care.
Pipe-invert interface

Issue

• Historical corrosion site
  - Formation of localised corrosion cells.
• Potential to limit remaining life.

Solution

• Trial corrosion protection treatment at interface.
Corrosion protection – interface

Free draining from CMC to concrete

Polymer modified cementitious coating (Intercrete 4840 or equivalent)
Project delivery
Interim treatment

• Need
  ▪ Risk due to developing voids
  ▪ Concept proposal required further investigation and development.

• Purpose
  ▪ Mitigate risk of washout and collapse over the next wet season.

• Adopted treatment
  ▪ Flowable cementitious grout into voids.
Interim treatment

Before grouting

Grouting voids

Grouting voids

Post-grouting

Post-grouting

Grouting at inlet
Environmental

- Development approval (DA)
  - DA Required – Invert raised by > 100 mm.
- Fish passage
  - Roughened surface – As-sprayed preferred, broom finish.
- Inlet/outlet
  - Shape to match natural stream
  - Minimise outlet velocity by limiting slope to natural stream
  - Transport and Main Roads Environmental Officers involved throughout development.
Preconstruction preparation

- Early contractor involvement
- Preconstruction meetings
  - On and off site
  - Site Foreman and Subcontractor.
- Reinforcement geometry
  - Trial bending to shape
  - Trial placement
    - Ability to manipulate on site
    - Need for kink at ends
    - Check influence of existing base
    - Check bar length
    - Determine bar chair sizes.
- Spray concrete trials.
Spray concrete trials

• Purpose
  - Evaluate mix and nozzleman
  - Workforce training
  - Flag potential construction issues.

• Trial Sections
  - Vertical Test Panel
  - Quarter Pipe (50% scale).

• Evaluation
  - Visual observation
  - Videotape/photos
  - Core examination and testing.
Spray trial 1 – Making the panels

Test Panel

Quarter Pipe
Spray trial 1 – Outcomes

- Visual assessment
  - Acceptable.

- Concrete density
  - Acceptable.

- Strength tests
  - Below target strength (40MPa)
  - Approximately 50% cylinder strength.
Spray trial 2

- Concrete strength
  - Exceeded target strength (40MPa)
  - Cylinder strengths -> 60-65MPa.
Construction
Staging the works

- Cells dewatered as needed
  - Stud welding
    - dewatering not required.
  - Placing reinforcement and concrete spraying
    - dewatering required – two-stage process.
Stud welding

Key learnings from site

• Power supply
  - Initial generator insufficient power (field losses).

• Installation rate
  - four studs per minute (1200+ per cell installed in five hours).

• Quality
  - Setting up equipment is critical
  - High quality weld with low failure rate (with correct power).

• Training
  - Welding process is readily learnt.
Stud welding – equipment

Generator

Welder

Welding gun

Surface preparation
Stud welding

Surface preparation

Welding

Rear face (inlet)

Bend test

Surface treatment
Steel fixing

Weld versus tied
• Issues with circular shape
• Approval to tack weld.
Ready for spraying
Ready for spraying (cont.)
Concrete spraying
Concrete spraying (cont.)

• Production rate
  - Each cell (32 m$^3$) in seven hours
  - Co-ordinate concrete supply
    ▪ (Eight truckloads).

• Resources
  - Large direct work crew
    ▪ Could be reduced.
  - Subcontractor for spraying and finishing.

• Geometry control
  - Depth gauges utilised
  - Needs further refinement.
Surface finish

Screeding/as Sprayed
- Screeding of invert specified
- High disturbance to sprayed concrete
- Changed to as-sprayed.
Edge treatment
Edge seal
Polymer modified cementitious coating
Edge forms
Inlet/outlet

- Site dependent
- Transition to natural stream
- Sprayed concrete/rock
- Embankment sealed.
Concrete quality

- Test results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>28-Day Strength (Mpa)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinders</td>
<td>&gt; 60</td>
<td>2340 - 2380</td>
</tr>
<tr>
<td>Cores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell 1</td>
<td>40 – 43</td>
<td>2280 - 2380</td>
</tr>
<tr>
<td>Cell 2</td>
<td>&lt;25</td>
<td>2300 - 2340</td>
</tr>
</tbody>
</table>
Finished product
Finished inlet
Finished outlet
Outcomes and conclusions
## Project costs

### Pre-works

<table>
<thead>
<tr>
<th>Phase</th>
<th>Item</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development</td>
<td>Investigations and Design</td>
<td>$85,000</td>
</tr>
<tr>
<td>Interim Treatment</td>
<td>Grout voids</td>
<td>$41,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$125,000</strong></td>
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### Works

<table>
<thead>
<tr>
<th>Phase</th>
<th>Item</th>
<th>Costs</th>
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</thead>
<tbody>
<tr>
<td>Delivery</td>
<td>DA Submission</td>
<td>$13,000</td>
</tr>
<tr>
<td></td>
<td>Spray Concrete Trials (2 No.)</td>
<td>$41,000</td>
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<tr>
<td></td>
<td>Works</td>
<td>$331,000</td>
</tr>
<tr>
<td></td>
<td>Miscellaneous</td>
<td>$20,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$405,000</strong></td>
</tr>
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</table>

**Total works - $6,000/cell-m ($1,250/m²)**
Project economics

Cost

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost</th>
<th>Projected Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reline or replace</td>
<td>$2,000,000 (estimate)</td>
<td>100 years</td>
</tr>
<tr>
<td>Structural Base</td>
<td>$530,000 (incl. development)</td>
<td>10 years minimum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 years likely</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35+ years possible</td>
</tr>
<tr>
<td>Initial Savings</td>
<td>$1,470,000</td>
<td></td>
</tr>
</tbody>
</table>

Payback period

- Seven years at Internal Rate of Return (IRR) of 4%
- Five years at IRR of 6%.
Learnings

1. A sprayed-concrete structural base can be a cost-effective treatment for corroding steel culverts to:
   i. Mitigate structural risk
   ii. Extend the life.

2. Welded shear studs are an inexpensive method for achieving quality shear connection in multi-plate steel culverts

3. Sprayed concrete can provide adequate strength and durability for this application, but needs tight controls

4. For a development project such as this:
   i. Planning is critical
   ii. A good quality team working together is essential
   iii. Early contractor (and sub-contractor) involvement is beneficial.
Further investigation

- Smaller pipe with thinner plate
  - Verify stud welding
  - Review stud spacing.

- Sprayed concrete specification
  - Refine spray trial and acceptance criteria
  - Refine acceptance criteria for core test results
    - Core strengths lower than cylinder strengths.

- Placing circumferential reinforcement
  - Consider sacrificial welded studs.

- Geometric tolerances
  - Review method for achieving profile.
Thank you