What to Do with that Old Concrete Arch Bridge

Structural Engineering Considerations

2018 Ohio Transportation Engineering Conference
Michael A. Russell, PE, SE, MLSE
Mott MacDonald, Cleveland, Ohio
General Details of the Bridges
Lake Road Bridge
CUY-06-0257

Location
Lake Road (US 6) over Cahoon Creek
Bay Village, Ohio

Structure Type
Filled Spandrel RC Arch
City Beautiful Style

Year Built
c. 1917

Rehabilitation
2003
Parapets and Walks
Replaces

General Appraisal
2015 – 5 (Fair)
Lake Road Bridge

Particulars

Form
Part Elliptical

Span
70’-0” F/F Curtain Walls
84’-6” F/F Abutments

Rise
16’-0” along Fascia
24’-0” to Abutments

Barrel Width
41’-0”

Load Ratings
IR  4.0
OR  6.0
$f'_c = 2.0 \text{ ksi (Assumed)}$
Lake Road Bridge

Arch Section
Richmond Road Bridge  
CUY-175-1235

| Location             | Richmond Road (SR 175) over East Branch Euclid Creek  
| Richmond Heights, Ohio |

| Structure Type       | Filled Spandrel RC Arch  
| Rustic Style        | Sandstone Cladding |

| Year Built           | 1936 |

| Rehabilitation       | NA |

| General Appraisal    | 2017 – 4 (Poor) |
Richmond Road Bridge

Particulars

Form
Circular Sector

Span
36'-0"

Rise
16'-0"

Barrel Width
Varies
61’ Minimum

Load Ratings
IR 2.6
OR 3.7
$f_c = 3.0 \text{ ksi (Assumed)}$
Why are Arches so Robust?
Historic Analysis

Methods

Loads
Gravity Effects Only

Structural Model
- Transversely loaded beam with axial effects
- Limited number of live loads
- Limited number of live load configurations
- Computationally demanding by hand
Modern Analysis Methods

Loads
Gravity and Lateral Soil Effects Considered Together
Soil/Structure Interaction Considered if Applicable

Structural Model
• 2D FEM Beam Members
• Analyze as Un-Reinforced
• Include At-Rest Lateral Earth Pressure
• Several Live Loads
• Many Live Load Configurations
• Computationally Demanding by Computer
Comparisons

Barrel Thicknesses
Lake Road 18” to 48”
Richmond Rd 12” to 32”
BEBO 11” Throughout
CMP Arch 2” Throughout

Unit Width Flexural Stiffness
Lake Road (84’-6” Span)
   Average: 113,000,000 k-in²/ft
Richmond Rd (36’ Span)
   Average: 56,000,000 k-in²/ft
BEBO (C36T/5) (36’ Span)
   5,650,000 k-in²/ft
CMP Arch (30’ Span)
   81,000 k-in²/ft
You’re the Lucky Winner

Title and content layout subtitle

Having a reinforced concrete arch in your inventory can be a genuine asset.

- It’s hard to justify constructing a new bridge with an Inventory Rating above 1.0.
  - These can come in anywhere from 2 to 4.
- These bridges are very stable – as long as the abutments are.
- There can be a lot of community attachment to them.
- Watch out for asbestos containing materials.
  - Waterproofing membranes
An Achilles Heel
An Achilles Heel

Spandrel Walls

• Integral with Arch Barrel
• Designed for Lateral (At-Rest) Soil Pressure
• Not Designed for Parapet Loads
Disposition of the Two Bridges
### Side-by-Side Comparison

<table>
<thead>
<tr>
<th>Lake Road Bridge</th>
<th>Richmond Road Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Appraisal</strong></td>
<td><strong>General Appraisal</strong></td>
</tr>
<tr>
<td>5 “Fair” (2015)</td>
<td>4 “Poor” (2017)</td>
</tr>
<tr>
<td><strong>Load Ratings (As-Is)</strong></td>
<td><strong>Load Ratings (As-Is)</strong></td>
</tr>
<tr>
<td>IR 4.0 OR 6.0</td>
<td>IR 2.6 OR 3.7</td>
</tr>
<tr>
<td><strong>Year Built</strong></td>
<td><strong>Year Built</strong></td>
</tr>
<tr>
<td>c. 1917</td>
<td>1936</td>
</tr>
<tr>
<td><strong>Other Issues</strong></td>
<td><strong>Other Issues</strong></td>
</tr>
<tr>
<td>Roadway drainage system penetrates the barrel.</td>
<td>Sanitary sewer penetrates the barrel.</td>
</tr>
</tbody>
</table>
# Disposition of the Two Bridges

## Lake Road Bridge
- **Replace**

### Details
- **Cost:** (Estimate) $2,910,000
- **Schedule** (Proposed)
  - **Award:** 11-Feb-19
  - **Construction Complete:** 15-Oct-19
- **MOT:** Close and Detour

## Richmond Road Bridge
- **Rehabilitate**

### Details
- **Cost:** (Award) $925,500
- **Schedule** (Actual)
  - **Award:** 10-Feb-17
  - **Construction Complete:** 28-Oct-18
- **MOT:** Close and Detour
Rehabilitation
Richmond Road
Richmond Road Bridge

Issues
• Leakage Through Barrel
• Clogged Weeps
• Parapet Issues
• Barrel Issues
Richmond Road Bridge

Leakage Through Barrel

- Radial Cracks with Efflorescence
- Leaks at Horizontal Construction Joints
- Seepage at Fascia
Richmond Road Bridge

Clogged Weeps

- Record plans indicate that slag was used as fill.
- Aggregate filter not indicated in the record plans.
- Fines wash out.
- Slag is pozzolanic.

Slag fill may not be the best idea.
Richmond Road Bridge

Parapet Issues

- 15” Thick
- Two Wythes of Sandstone
- Reinforcing:
  #5 @ 2'-0” in a Single Layer
- Not Crashworthy
Richmond Road Bridge

Barrel Issues

- Gravity Sewer not Original
  - Not installed by ODOT
  - Reasonable to Assume Inexpertly Done
- Heavy Corrosion and Deep Spalls
- Capacity compromised?
Richmond Road Bridge Program

Prior to PIP
Remove and Replace Bridge
Place-Holder: $1,500,000

During PIP
Prepared Load Rating
Identified Substantial Reserve Capacity
Recommended Rehabilitate vs. Replace

Scope
Rehabilitate
Final Cost: $925,500
Richmond Road Bridge

Solutions

• Remove and Replace Fill
• Install Drains & Waterproofing
  • Leave Waterproofing In-Situ
• Patch Barrel & Inject Cracks
• Install Moment Slab at top of Spandrel Walls
• Preserve Stone Cladding Where Possible
Richmond Road Bridge

Remove and Replace Fill

- Remove Granulated Slag Fill
- Replace with Low-Strength Mortar Backfill
- Leave Existing Waterproofing Membrane Alone (ACM)
Richmond Road Bridge

Install Drains & Waterproofing

- Install Composite Drainboard on Arch Extrados
- Install Fabric-Wrapped French Drains at Bottom of Fill
- Pipe Through Each Weep Hole
Richmond Road Bridge

Repair Barrel Intrados

- Patch Spalls
- Inject Cracks
- Seal Sewer Penetrations
Richmond Road Bridge

Install Moment Slab

- Ensure TL-3 Capacity
- Eliminate Loads on Spandrel Walls
- Ensure Constructability
- Preserve Existing Cladding Wherever Possible
- Match Existing Aesthetics
Aesthetics – Before and After
Replace Lake Road
Lake Road Bridge

Hey! Aren’t these supposed to be “robust”?

Lots of Things are Going Right on This Bridge

• Load Ratings to kill for:
  • IR  4.0
  • OR  6.0
    (Considering Deterioration)

• Parapets and walks were upgraded recently.

• Weeps are draining.

• Nobody’s punched a sanitary sewer through it recently.
Lake Road Bridge

Issues

• Leakage Through Barrel
• Spalling
• Drainage Issues
• A Tell Tale
Lake Road Bridge

Leakage Through Barrel

- With Efflorescence
- Along Radial Construction Joints
- Around Penetrations

Indicates failed waterproofing system.
Lake Road Bridge

Spalling

• With Exposed Steel:
  • Along radial construction joints.

• Without Exposed Steel:
  • Around weep holes,
  • Along waterline, and
  • At drainage penetrations.
Lake Road Bridge

Drainage Issues
- Profile is a sag vertical.
- Low-point is on the bridge.
- Roadway drainage system penetrates the arch barrel.

Carrying road drainage is much more demanding of the waterproofing system and details versus draining the fill.
Lake Road Bridge

A Tell Tale

- Spalling at weep holes and at waterline is unusual.
- Reinforcing not observed in these spalls.
- Seems freeze-thaw driven rather than corrosion driven.

What’s going on?
Lake Road Bridge

Air Entrainment

• Introduced c. 1930
• Bridge Built c. 1917

Conclusion & Ramification

• Concrete is continually exposed to water flows at weep holes, and along waterline.
• Existing concrete is not air entrained.
• Freeze-thaw damage can only be expected to continue.
Lake Road Bridge – Replacement

Replacement

• Build 152’-0” simple span steel plate girder on integral abutments.
• Provide for multipurpose trail below.
• Move watermain onto bridge.
• Maintain profile.
• Provide scuppers galore.
  • 6 each side of rdwy
  • 4 at low point
  • 1 each flanking beyond
Thank You
Contact

Michael A. Russell, PE, SE, MLSE
216-535-3653
Michael.Russell@MottMac.com