Uncontrolled Concrete Bridge Parapet Cracking

Final Report
6/19/2013

Sponsored by:

Cleveland State University
engagedlearning
What is the problem?

- Widespread premature cracking of concrete bridge parapets
  - Many vertical cracks (between joints)
  - Some horizontal cracks (at level of top bars)
  - A few map cracks
  - Some spalling at cracks
Problem Statement

- Vertical cracks
Problem Statement

- Horizontal cracks
Problem Statement

- Map Cracking
Problem Statement

- Spalling
Problem Statement

Where is the problem occurring?

• Numerous bridges throughout District 12
• Also common throughout Ohio and other states
• Four specific District 12 bridges were identified for this study
  • Canterbury Road over I-90 (Westlake)
  • Wagar Road over I-90 (Rocky River)
  • Sheldon Road over I-71 (Middleburgh Heights)
  • Spring Road over Jennings Freeway (Cleveland)
When did the problem occur?

- Timeframe of cracking initiation is uncertain
- The four bridges under study were either built or rehabilitated approximately 10 - 15 years ago

<table>
<thead>
<tr>
<th>Spring Road</th>
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<tr>
<td>built 1997</td>
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<tr>
<th>Sheldon Road</th>
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<tr>
<td>rehab. 1999</td>
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<th>Wagar Road</th>
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<td>rehab. 2001</td>
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<table>
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<tr>
<th>Canterbury Road</th>
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<td>rehab. 2002</td>
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Why study this problem?

- Excessively cracked parapets are an eyesore and may represent a safety concern. Concrete parapets are replaced when the bridge deck itself is replaced.
- Replacement of parapets prior to the regularly anticipated deck replacement is costly.
- This expense is ultimately wasted when the deck is eventually replaced.
Why study this problem?

- Example:
  - Bridge over I-271 with excessively cracked parapets
  - In 2002, parapets replaced prior to the normal replacement of the bridge deck
  - Cost: Approximately $140,000
  - Cost does not include sealing, fence repairs, expansion joint repairs

- Result: Higher bridge life-cycle costs
Objectives

- Determine causes of parapet cracking
- Identify applicable measures for repair and prevention
- Make recommendations to ODOT that will help reduce bridge life-cycle costs caused by prematurely cracked parapets
Principal Tasks

- Develop hypotheses for causes of parapet cracking
- Identify comparison bridge
- Desk study
  - Literature review
  - Construction plans
  - Inspection records
Project Work Plan

Principal Tasks (cont.)

- Site Visits
  - Record field observations
  - Crack measurement and mapping
  - Comparison of planned/as-built conditions
  - Nondestructive evaluation
- Results Analysis
  - Identify most likely causes
  - Develop possible solutions
Summary of Progress

- Literature review completed
- List of hypotheses developed
- Gathered available documents for each of the four bridges under study
- Completed background case studies for each of the four bridges
Summary of Progress

- **Site Visits**
  - Gathered field observations
  - Took digital photographs
  - Collected crack measurements
    - Sept. 2011 and Feb. 2012, for comparison of warm and cold weather crack data
- **Searched for comparison bridge**
  - Unable to identify a suitable comparison bridge
  - However, comparison amongst the four bridges under study should be useful
Findings from other State DOTs

- Illinois
- Michigan
- Connecticut

Correlation to other research studies

- Early age cracking of concrete barrier walls
- Slipform construction of parapets
- Structural contribution of concrete parapets
- Cracking of concrete bridge decks
Other State DOT Findings

- Illinois Department of Transportation
  - 2003 FHWA/IDOT Joint Process Review on Bridge Parapets Construction
    - Studied uncontrolled vertical cracking in recently constructed bridge parapets
    - Identified causes:
      - Inadequate spacing of control joints in parapets
      - Lack of sufficient concrete consolidation in parapets constructed using slipform method
      - Issued temporary moratorium on slipform construction
Illinois Department of Transportation

- *Guide Bridge Special Provision #61 (2007)*
  - Lifted slipform moratorium for a few specific projects meeting certain restrictions
  - Adjusted specs for slipform operations with more quality control standards, including:
    - Limited speed of slipform paver
    - Limited continuity of parapet reinforcement
    - Use of glass fiber reinforcement polymer
    - Stricter tolerance limits for parapet dimensions
    - Higher quality curing procedures
Michigan Department of Transportation

- **Performance of Michigan’s Concrete Barriers (2007)**
  - Studied barrier performance as related to changes in design and standard practice
  - Identified factors causing premature deterioration of concrete barriers
    - New solid-face designs trap snow and deicing chemicals
    - Slipform methods expose concrete to higher shrinkage stresses
    - Use of high-absorptive aggregates has reduced freeze-thaw durability
Other State DOT Findings

- Connecticut Department of Transportation
  - Noticed increase in parapet cracking
  - Cited recent removal of paraffin coated joints from parapet design spec as cause
  - In 2005, issued memorandum to Bridge Design Standard Practices
    - Reintroduced paraffin coated joints to reduce shrinkage cracking
Other State DOT Findings

CONNECTICUT BRIDGE DESIGN MANUAL

PARAFFIN COATED JOINTS IN SIDEWALK PARAPETS
Early Age Cracking of Concrete Barrier Walls – Quebec, Canada 2000

- Many barriers exhibited significant transverse cracking shortly after construction
- Studies revealed initial cracking often occurred within 48 hours of concrete pour
- Factors identified:
  - High cement content
  - Traffic vibrations prior to adequate strength development of concrete
  - Thermal gradients due to use of different formwork material on either side of barrier
Other Research Studies

Parapet Wall Cracking – GOMACO Corporation 2006

- Studied problems associated with slipform construction of decks and parapets
- Remedial suggestions:
  - Avoid using too much reinforcement, which inhibits adequate consolidation
  - Increase rigidity of rebar cage to prevent excessive deflections
  - Careful vibrator placement within slipform mold
  - Monitor speed of slipform paver
Other Research Studies

Typical slipform operation (GOMACO, 2006)
Structural contribution of parapets

• Several academic studies performed
• General conclusions:
  • Concrete parapets WILL carry live load stresses
  • Parapets that act compositely with deck can increase overall stiffness of the structure by up to 25%
  • Parapets designed only as barriers can experience significant stresses caused by unintended composite structural action
Cracking of Concrete Bridge Decks

- Many studies performed by various organizations and for various types of cracking
- Some of the factors identified are also applicable to concrete parapets, including:
  - Excessive shrinkage in high performance concretes
  - Excessive longitudinal restraint
  - Insufficient curing
  - Insufficient monitoring of ambient conditions
## Bridge Case Studies

### Overview

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Length (ft)</th>
<th>No. of spans</th>
<th>Max span length (ft)</th>
<th>No. of lanes carried</th>
<th>Years since build/rehab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canterbury</td>
<td>247.7</td>
<td>4</td>
<td>67.5</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Sheldon</td>
<td>227</td>
<td>4</td>
<td>62.5</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Spring</td>
<td>252</td>
<td>2</td>
<td>132</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Wagar</td>
<td>124.5</td>
<td>2</td>
<td>62.25</td>
<td>4</td>
<td>11</td>
</tr>
</tbody>
</table>
General Observations

- For all 4 bridges, the most recently measured traffic data is already significantly greater than the projected numbers for the design year.
- Most recent parapet condition rating for all 4 bridges is either “1” or “2”:
  - 1 – new, some minor problems, minor impact damage
  - 2 – structural elements show minor deterioration, section loss, or spalling
- Common vertical crack locations:
  - About midway between control joints
  - Below or near VPF post base plates
Canterbury Road over I-90 (Westlake)

- Most recent parapet condition rating: 1
- Vertical cracks at typical locations
- Horizontal cracks at top layer of rebar
- Typical control joint spacing:
  - Between 70 and 96 inches
Sheldon Road over I-71 (Middleburgh Heights/Brook Park)

- Most recent parapet condition rating: 2
- Vertical cracks at typical locations
  - South wall – more mid joint cracks
  - North wall – more fence post cracks
- Map cracking along inner face of parapets
- Typical control joint spacing:
  - West end – 84 inches
  - East end – 140 inches (more mid joint cracks)
- Most severe of the 4 bridges
Spring Road over Jennings Freeway (Cleveland)

- Most recent parapet condition rating: 1
- Least severe of the 4 bridges
- Contains inner and outer barrier wall with sidewalk in between

- Inner walls
  - Many mid joint vertical cracks
Spring Road (cont.)

- Outer wall – good condition, minimal cracking
  - North wall
    - Some vertical cracks at expected locations
    - Concrete flaking off below some VPF base plates
  - South wall
    - A few vertical cracks near fence posts
    - Less severe than North wall
  - Cracking of outer walls is virtually negligible compared to the other bridges
- Typical control joint spacing:
  - 90 inches around bearing pier
  - 192 inches elsewhere
Wagar Road over I-90 (Rocky River)

- Most recent parapet condition rating: 1
- Vertical cracks at typical locations
- Some fence post base plates are mounted directly over control joints
- Typical control joint spacing:
  - 96 inches
4 categories of potential causes of cracking

- Design
- Materials
- Construction
- Service/Maintenance
Summary of Potential Causes

- **Design Factors**
  - Control Joints
  - Section Properties
  - Reinforcement Details
  - Composite Structural Action
  - Vandal Protection Fence
Summary of Potential Causes

- Materials factors
  - Concrete Mixture
  - Reinforcement Coating
  - Concrete Sealants
Summary of Potential Causes

- Construction Factors
  - Concrete Curing
  - Concrete Consolidation
  - Control Joints
  - Concrete Uniformity
  - Application of coating materials
  - Restraint of parapets
Summary of Potential Causes

- Service/Maintenance Factors
  - Fatigue Effects
  - Impact Effects
  - Crack Propagation from Deck/Sidewalk
  - Previous Crack Repairs
  - Traffic Demand
  - Corrosion Effects
Probable Causes Identified

- Insufficient concrete consolidation below top rebar layer (horizontal cracks)
- Control joints spacing too large to effectively control shrinkage cracks
- Improper construction of control joints
  - Inadequate depth of sawcut
  - Improper sealing of control joints
  - Sawcutting not performed at appropriate time in curing process
Probable Causes Identified

- Stresses created by anchorage details of vandal protection fence post base plates
- Excessive drying shrinkage due to high water and cement content of concrete
- Development of stresses due to unintended composite structural action
  - Especially in negative moment regions
- Fatigue effects
  - Especially due to underestimated traffic demand shown in construction plans
Field Observations and Analysis

- Crack measurements
  - Photographs
  - Crack mapping – location and width
  - Compared summer and winter crack widths

- Nondestructive testing
  - Rebound hammer (Schmidt)
  - James R-meter cover meter – location and depth of reinforcement
Example Scan Map, Sheldon Road
<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Supporting Evidence</th>
<th>Refuting Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete mixture used in parapets</td>
<td>Concrete mixture used for parapets has a much higher strength and stiffness than necessary, which may be vulnerable to excessive shrinkage.</td>
<td>Recent changes in the concrete mixture typically used for parapets have shown a lower cracking tendency.</td>
</tr>
<tr>
<td>Parapet construction techniques</td>
<td>The types of cracks found on the investigated bridge parapets show a high degree of similarity.</td>
<td>ODOT has historically avoided the slipform method for parapet construction. This method has been shown in other states to greatly reduce the durability of concrete parapets.</td>
</tr>
<tr>
<td>Structural effects on parapets</td>
<td>Studies have shown that parapets can still absorb a significant portion of the live load stresses when constructed compositely with the bridge deck.</td>
<td>Parapet cracks did not appear to be more frequent in the negative moment regions of the investigated bridges, as would be expected from the high tensile stresses in these locations.</td>
</tr>
<tr>
<td>Parapet joint details</td>
<td>Older parapet specifications showed a lower tendency toward premature cracking than the new specifications used on the case study bridges.</td>
<td>Parapet cracks appear in other locations besides those influenced by the effectiveness of the control joints.</td>
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Conclusions

- Ineffective control joints – shallow sawcut, does not form a true joint
  - Construction – shallow cuts, terminate above base of parapet, possible timing, generally need to remove formwork first
  - Design – continuous
- VPF Post Base Plates – possibly prying effect
Conclusions

- Drying shrinkage – concrete composition, curing
- Composite structural action – negative moment stresses in parapets
- Poorly consolidated concrete (horizontal cracks)
Recommendations

- Remediation – sealing
- Prevention – redesign of VPF base plates (done), joint spacing, reinforcement continuity
- Future research
  - Review other DOT practices
  - Analysis of shrinkage and temperature effects
  - Internal curing
  - Fibers in concrete mixture
Implementation Plan

- Present results
- Parapet condition evaluations
- Changes to design and specifications
  - Reduce spacing between control joints
  - Reduce spacing of VPF posts
  - Form control joints with inserts
  - Use discontinuous reinforcement
Implementation

- Expected benefits – reduce frequency of uncontrolled premature cracking in concrete bridge parapets in future construction, and hopefully eliminate altogether
- Risks and obstacles – additional costs and time of implementation (e.g., cutting rebar)
Potential users and organizations - bridge designers, contractors, inspectors and various ODOT other Construction and Engineering personnel, other DOTs

Costs – construction costs would increase slightly if a more labor-intensive method is adopted. Potential material costs with GFRP rebar, paraffin joints
September 28, 2012, ODOT research summit
D12 considering implementing our findings
Extended current project for monitoring implementation
Follow on project “Development, Field Testing, and Implementation of Improved Bridge Parapet Designs” start July 1
Review other transportation agency (e.g., state DOT) details and specifications for parapet construction, and summarize
Meet with District 12 personnel to refine the experimental plan and design for the implementation (March 7, 2013)
Develop a field monitoring plan
Observe construction of test site parapets and gather data (for projects prior to June 30, 2013)
Revise the final report
Review – Other State DOT Details

- Found 10 other details
- Follow up – find more
- Review, contact engineers in other states
  - Performance of details
  - Associated specifications and special provisions
New Project

- Development, Field Testing, and Implementation of Improved Bridge Parapet Designs
- Scheduled start 1 July 2013, 16 months
- Field monitoring covers summer 2013 and 2014
Project Goals

- Review other transportation agency (e.g., state DOT) details and specifications for parapet construction, and summarize
- Develop improved parapet designs and/or materials to reduce cracking
- Develop an experimental plan to implement some of the proposed solutions.
- Meet with District 12 personnel to refine the experimental plan and design for the implementation
- Monitor bridge parapets during and immediately after construction.
10 bridges on I-90 in Lake County, 2 parapets each, total 20 parapets
Marginal Road over I-90
Control parapets – 3 bridges built in 2012 in Lake County, also 3 parapets in 2014 construction season
2013 – 4 Lake County bridges, Marginal Road
2014 – 3 Lake County bridges
Test Variables

- Polypropylene fibers (two dosages, 1 or 2 pcf)
- 3 ½ inch deep saw cut, combined with either:
  - Glass fiber reinforced polymer (GFRP) reinforcing bars
  - Field cut steel reinforcing bars
- Cut spacing 5 to 6 feet in the tension zones, over bridge piers, and 10 to 15 feet at other locations
FIELD CUT BARS

FIELD CUT 9" OF STEEL

BARS IN 12" SPACE

LOCATE CONTROL JOINT IN CENTER OF 9" GAP IN REINFORCING

PART PLAN AT ABUTMENT

SECTION A-A
Hermitage Road: EB I-90-13.79R, Form & set rebar for parapet, June 3 thru 7, Pour parapet, June 28, Cure Parapet, June 29 thru July 5

Auburn Road: EB I-90-14.87R, Form & set rebar for parapet, June 24 thru 26, Pour parapet, June 28, Cure parapet, June 29 thru July 5

Paine Creek: WB I-90-20.03L, Form & set rebar for parapet, July 1 thru 11, Pour Parapet, July 13 thru 15, Cure parapet, July 16 thru 22

Paine Road: WB I-90-21.10L, Form & set rebar for parapet, July 5 thru 11, Pour Parapet, July 18, Cure parapet, July 19 thru 25

Marginal Road over I-90, due to a delay in the fabrication of the new expansion joints, the deck might not be poured until July. Therefore, the parapets would be poured a week after the deck, sometime in July.
Field Testing Plan

- Pre-construction observation – steel reinforcement location, cuts, etc.
- Installation of maturity sensors for temperature monitoring
- Placement observations – weather conditions, sample concrete
- Sawcut observations – timing, depth, whether concrete has already cracked
Field Testing Plan

- Maturity data collection – temperature history, thermal shock
- Investigate whether joints have cracked
  - James R-meter for reinforcement depth, location, continuity
  - James V-meter for continuity – wave speed and signal across joint or crack
- Post construction crack survey – also for control bridges
This study is based upon work supported in part by the Ohio Department of Transportation through State Job Number 134602. The conclusions expressed herein are the conclusions of the authors and not necessarily those of the Ohio Department of Transportation. The authors gratefully acknowledge this support.
Principal Investigator – Dr. Norbert Delatte
Graduate Research Assistants – Jeff Bazzo, Amy Kalabon, Lauren Hedges (new project)