Guardrails for Use on Historic Bridges

Anne Rearick
Indiana Department of Transportation
Background

Addressing railings on historic bridges is challenging
  • Regulations
  • Required State Historic Preservation approval
  • Aesthetics
  • Community preferences

Two part study
  • Replacement Strategies
  • Deck overhang design
SPR – 3714 Guardrails for use on Historic Bridges

Robert Frosch – Purdue University
SPR – 3714 Guardrails for use on Historic Bridges
Part 1 Replacement Strategies

Robert Frosch
Adam Claus
Introduction

• Typically railings on historic bridges are not adequate due to
  • Not meeting current crash test requirements
  • Strength
  • Configuration
Objective

Develop railing strategies that improve safety and maintain historic value
Phase 1

• Review of current practice
  • Crash testing requirements
  • Design standards
  • Looked at other states
  • TTI railing research
  • Look at modern railings for ideas
TxDOT Bridge Railing Manual

- Historic Bridge Railing
  - Inboard
  - Replacement
  - Incorporation
  - Design
Historic Replacement Railings

(a) TxDOT T411
(b) TxDOT C411
(c) TxDOT C412
TTI Railing Research

Designed and tested 2 railings
Incorporated original railing

Roy B Links Bridge
Plano Texas
Modern Aesthetic Railings
Phase 2

Documentation of Historic railings in Indiana
Historic Bridge Inventory
December 2010
796 total
705 in service
January 2014
658 in service
Phase 2

Railing Statistics
- 61 distinct railing types on 658 bridges
- 35 bridges with no railing
- 25 types only on one bridge
- 11 types on two bridges
Phase 2

Bridge Statistics

58% are one of:
- Concrete Arch
- Pony Truss
- Thru Truss

73% cross small waterways

13% carry state or U.S. Highway
Phase 2

Railing Types
• Concrete – 26
• Metal – 14
• Metal and Concrete – 4
• Pedestrian – 8
• Stone – 6
• Timber - 3
Top 8 Railings: 1-4

1. Metal 6
2. Metal 5
3. Concrete 1
4. Timber 1
Top 8 Railings: 5-8

- Concrete 2
- Concrete 6
- Metal 10
- None
Phase 3

Retrofit Strategies

Based on previously accepted railings

- Inboard
- Curb railing
- Replacement railing
Phase 3

Inboard Retrofit

Install modern railing inside historic railing
Phase 3

Curb Retrofit

Installed on curb
protects sidewalk
TL-2 Railing
Phase 3

Develop specific railing replacement strategies for Indiana

• 42 of 61 historic railings simulated

• 19 not simulated
  • 3 timber railing types (outside scope)
  • 16 railing types
    • Poor geometry
    • No historic appearance
    • No historic craftsmanship
Concrete Railings
Concrete Railing Modification

- Custom formwork
- Formliners
Bush-Hammered Panel
Modified TxDOT T221
Simulated Bush-Hammered Panel
Concrete 7
Modified ODOT Concrete Beam and Post
Simulated Concrete 7
Metal Tube Railings
Metal 14
ODOT 2-Tube
Simulated Metal 14
Pedestrian Railings

• Geometry and force requirements

• Loosely based on:
  1. TxDOT PR3
  2. ODOT Pedestrian Rail
Pedestrian 3
TxDOT PR3
Simulated Pedestrian 3
Other examples
Conclusions

Through the use of the strategies developed in this research program, it is possible to retain historic railing appearance of the majority of historic bridges in Indiana. In many cases, it is also possible to improve aesthetics. Most importantly, however, these strategies allow for improvement in the safety of the traveling public.
SPR – 3714 Guardrails for use on Historic Bridges
Part 2 Bridge Deck Overhang Design

Robert Frosch
Adam Morel
Overhang Design

\[ F_v \]

\[ R_w \]

\[ F_{\text{axle}} \]
Overhang Design for TL-4 Barrier

Case 1

Case 2

Case 3

Graph showing the relationship between Moment (ft·kip/ft) and Overhang Length (ft) for different cases.

- Case 1: Linear increase with a moment of approximately 25 ft·kip/ft at 10 ft of overhang length.
- Case 2: Linear increase with a moment of approximately 5 ft·kip/ft at 10 ft of overhang length.
- Case 3: Linear increase with a moment of approximately 15 ft·kip/ft at 10 ft of overhang length.
Yield Line Analysis

\[ W_{INT} = W_{EXT} \]

\[ F \cdot \Delta = \sum M\theta \]

\[ F = R_w \text{ (nominal railing resistance)} \]
## Barrier Design Forces

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>Railing Test Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL-1</td>
</tr>
<tr>
<td>$F_L$ Longitudinal (kips)</td>
<td>4.5</td>
</tr>
<tr>
<td>$F_v$ Vertical (kips) Down</td>
<td>4.5</td>
</tr>
<tr>
<td>$L_t$ and $L_L$ (ft)</td>
<td>4.0</td>
</tr>
<tr>
<td>$L_v$ (ft)</td>
<td>18.0</td>
</tr>
<tr>
<td>$H_e$ (min) (in.)</td>
<td>18.0</td>
</tr>
<tr>
<td>Minimum $H$ Height of Rail (in.)</td>
<td>27.0</td>
</tr>
</tbody>
</table>
Barrier Resistance

- Barrier overdesign
  - more reinforcement required in overhangs

- Overhang must resist larger moments and axial forces

$R_w = 150 \text{ kips}$
$F_t = 54 \text{ kips}$

INDOT Type FC TL-4 Barrier
Reducing Collision Forces

• AASHTO procedure requires more reinforcement ($\sim 3 \times F_t$)
  • Design for barrier capacity

• Past practice required less reinforcement
  • Lower design forces

• INDOT and other states reduce collision force ($1.25 \times F_t$)
  • Design for transverse force

• What is the appropriate design procedure?
Research Objective

- Investigate appropriate design procedure
- Determine failure mechanism in overhang specimens
- Improve design assumptions
Schematic Design
15ft Specimen Design

Specimen #1

Specimen #2

3, typ.
Experimental Setup

- Jack w/ Load Cell
- Horizontal Pot.
- Strain Gages
- Dial Gage
- Vertical Pot.
Specimen #1 Cracking

Barrier Cracking Pattern
Specimen #2 Cracking

Barrier Cracking Pattern
Vertical Displacement

Specimen #1

Specimen #2

Displacement (in.)

Potentiometer Location (ft)
3’ Strip Specimens

- 5 full scale INDOT Type FC specimens
- 2 half scale specimens
Full-Scale Specimen Design

Test Variables:

- Top Transverse Bar Size
  - #5 and #6
- End Condition
  - Straight and Hook
- Bar Coating
  - Epoxy coat and black
Half-Scale Specimen Design

Specimen #1 and #2

3 straight (Strip Sp. #7)
Experimental Setup

- Jack w/ Load Cell
- Horizontal Pot.
- Strain Gages
- Vertical Pot.
Full-Scale Cracking Behavior

Strip Specimen #1 at 14 kips

Strip Specimen #2 at 14 kips
Full-Scale Cracking Behavior

Strip Specimen #3 at 15 kips

Strip Specimen #4 at 15 kips
Full-Scale Cracking Behavior

Strip Specimen #5 at 14 kips

Typical Specimen Failure Plane (#1)
Half-Scale Cracking Behavior

Strip Specimen #6 at 8 kips

Strip Specimen #7 at 6 kips
27ft Specimens

- Form Barrier Mechanism
- Refine Distribution Length
27ft Specimen Design

Specimen #1

Specimen #2

hooked #3, typ.
Experimental Setup

Specimen #1L Loading

Specimen #2L Loading
Behavior at Ultimate Load

Specimen #1L at 29.2 kips

Punching Shear Failure
Behavior at Ultimate Load

Specimen #2 at 23.7 kips

Punching Shear Failure
Distribution Length

$L_{eff} = 10L_d$
Lower Punching Shear
Upper Punching Shear
Nonsymmetrical Failure
Conclusions

• Diagonal tension joint failure (15ft and 3ft strip specimens)
  • Concrete failure rather than reinforcement anchorage in overhang
  • Only applicable for short bridge lengths (< 30 ft)

• Punching shear failure (27ft specimens)
  • Punching controls prior to forming barrier mechanism (110 kips vs 150 kips)
  • Consistent with actual failures

• Research suggests overhang reinforcement not critical
  • Punching shear governs design
  • Large distribution length (10Lc)
  • Reinforcement can be reduced in overhang
  • Design overhang for vertical loads
Questions?