Unexpected and Difficult to Observe Failures of Reinforced Concrete Bridges

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Synopsis

- Twelve cast-in-place five girder “T-beam” bridges (Left + Right) plus 13 other five girder, six-girder and box girder bridges
- Excessive but difficult-to-observe cracking and movement along horizontal construction joints between bridge decks and girders
- Rapid development of fractures in shear reinforcement and shear cracking
- Failures of this type had not been previously observed in California bridges by Caltrans
- All damaged bridges were demolished during the period of the investigation
Timeline

• **18 September 2003** – No damage observed in any bridge

• **15 January 2006** – construction joint slippage and inclined cracks near abutment observed only in “Mustang Wash Right”

• **28 March 2006** – Damage worsened, Shear failure in Girder #3

• **May 2006** – Construction joint cracking/slippage in all twelve bridges, bridges shored

• **September 2006** – Stirrup fractures found in multiple bridges, Eastbound bridges demolished

• **January 2007** – Westbound bridges demolished
Interstate-40

Willmington, NC
Port of Los Angeles
Barstow
Bridges

Willmington, NC
I-40 California
30 Miles
5-girder bridges

- CIP Deck & girder and normal reinforcing
- Constructed in 1973
- 2 and 3 span bridges
- 50-foot spans
- 1969 AASHO – HS20-44 Live Load
Typical Section

- 42 feet
- 6.5” deck
- 8’-6” girder spacing
- #5 stirrups GR60
- 13” width
- 3 ft
Fractures at construction joint

CRACK AT GIRDER/FILLET INTERFACE

FILLET

Construction Joint

Stirrup Fractures

STIRRUP FRACTURE CAN OCCUR BELOW INTERFACE CRACK

2 3/4" 13"

13"
After lanes reconfigured subsequent to discovery of damage...

Normal Configuration (prior to lane closure)
Characterization of Construction Joint Cracking

- **Light cracking** – “hairline” with few if any signs of chipping
- **Moderate cracking** – barely noticeable from several feet with minor chipping
- **Severe cracking** – clearly visible with heavier chipping and spalling
- **Episodic, rapid extension of construction joint cracks**, worsening in severity and typically terminating in a “turned-down” crack
- **Difficult to discern until cracking approached “severe” stage**
Fillet

“Light” construction joint cracking

Girder web
“Moderate” construction joint cracking
“Moderate” construction joint cracking
Fillet

“Severe” construction joint crack

Girder web
Fillet

“Severe” construction joint crack

Girder web
Girder

Fillet

"Severe" construction joint crack
Turned-down crack at interim termination point
Turned-down crack at interim termination point
• Once the construction joint cracks reach the **moderate-severe stage**, a majority of the stirrups crossing those portions of the cracks have probably fractured

• Of the 46 stirrups crossing moderate-severe or severe cracks in 6 bridges exposed during the investigation, 26 (57%) were fractured
Moderate-to-severe cracking with turned-down crack
### West bound bridges

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Girder 1</th>
<th>Girder 2</th>
<th>Girder 3</th>
<th>Girder 4</th>
<th>Girder 5</th>
<th>Totals</th>
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<tr>
<td>Marble L</td>
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<tr>
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<td><strong>148</strong></td>
<td><strong>97</strong></td>
<td><strong>22</strong></td>
<td><strong>475</strong></td>
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</tbody>
</table>

| % of Total   | 5%       | 39%      | 31%      | 20%      | 5%       |

### East bound bridges

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Girder 1</th>
<th>Girder 2</th>
<th>Girder 3</th>
<th>Girder 4</th>
<th>Girder 5</th>
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<td><strong>269</strong></td>
<td><strong>251</strong></td>
<td><strong>13</strong></td>
<td><strong>753</strong></td>
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</tbody>
</table>

| % of Total   | 3%       | 26%      | 36%      | 33%      | 2%       |
Fillet

Girder web

“Impromptu load testing”
Construction Joint

Fillet

Girder web
Notes:
• Traffic is in the “fast lane”
• The bridge is shored
Video

Fillet

Construction Joint

Girder web
Exposing stirrups identified by ground penetrating radar
MU S7 Fracture Surface

Note the indentation on the OD by the fracture origin.

MU S7 Canon Macro After Cleaning 7_2_2
Comparison to classic fatigue failure

Fig. 5-Fatigue fracture of a reinforcing bar
WHY?
3-D Analysis – Mustang Model
Lattice Modeling
Offset Wheel Loading
Average Daily Truck Count: 10 Week Period from July '05 - Dec. '05

- 0 - 40 kips: 1,840.3 - 25.5%
- 40 - 72 kips: 3,634.5 - 49.7%
- 72 - 100 kips: 1,783.4 - 24.4%
- 100+ kips: 58.8 - 0.8%
Findings

- Bridges failed due to cyclic degradation of deck/girder construction joint
  - Inadequate
    - Roughness and cleanliness
    - Quantity of stirrup reinforcing crossing the joints
    - Anchorage of stirrup reinforcing
  - Long-term cyclic loading from heavy trucks
  - Effects not considered in design
    - Offset wheel loading
    - Effect of reduced deck stiffness
Recommendations

• Develop inspection program
• Implement design changes
  – Intentionally roughen joint to min. ¼-inch
  – Thoroughly clean joint prior to casting deck
  – Properly cure lower surface of joint
  – Increase reinforcing across joint and improve stirrup anchorage
Inspection Program Considerations

• Include T-beam and Box-girder bridges
• Prioritize older bridges with heavier truck loads and higher truck traffic count
• Gain “arm’s length” access or equivalent
• Gain access to interior of box-girders, formwork removal required
• Document the ends of any crack along the construction joint, no matter how seemingly insignificant
• Schedule near term re-inspection of any bridge with documented cracking
See Standard Plan B6-5 for stirrup details and clearances for prestressed box girders.

TYPICAL BOX GIRDER DETAILS

Video