Proposed Revision to AASHTO Specifications for Bolted Single Support Bar MBJS based on Laboratory Fatigue Tests

2014 AASHTO Subcommittee on Bridges and Structures Annual Meeting
Technical Subcommittee for Bearings and Expansion Devices  T-2
Tuesday, June 24, 1:00 PM - 5:00 PM,
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Lehigh University
Bethlehem, PA
Modular Bridge Joint System (MBJS)

Single Support Bar System (SSB)  Multiple Support Bar System (MSB)
AASHTO Fatigue Test Specification

- Appendix A19 - Standard Test Methods for Modular Bridge Joint Systems
  - From NCHRP Project 12-40 (Report 402)
    - 6 SSB systems and 11 MSB systems tested
    - Results from SSB system tests not shown in detail (photos of cracking excluded)
    - Most tests completed for finite life
- Concentrates on welded multiple support bar MBEJs
- Little information about bolted SSB systems
Motivation for Fatigue Testing

<table>
<thead>
<tr>
<th>Type of Detail</th>
<th>Maximum Permitted Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welded Multiple CB-SB Connections</td>
<td>C</td>
</tr>
<tr>
<td>Welded Stirrup Attachments for SSB Systems</td>
<td>B???</td>
</tr>
<tr>
<td><strong>Bolted Stirrup Attachments for SSB Systems</strong></td>
<td>D???</td>
</tr>
<tr>
<td>Groove-Welded Centerbeam Splices</td>
<td>C</td>
</tr>
<tr>
<td>Miscellaneous Welded Connections</td>
<td>C</td>
</tr>
<tr>
<td>Miscellaneous Bolted Connections</td>
<td>D</td>
</tr>
</tbody>
</table>

- A higher CAFT can be used if established by minimum 10 data points
- Bolted CB-SB connection in SSB system is believed to be **Category B**
Welded Stirrup Connections

Category C (max.)
Test Objectives

- Establish infinite life fatigue resistance of CB-SB bolted connection (assumed Category B)
- Verify fatigue resistance of other details
Fatigue Test Plan

Substantiated by WSDOT Specs

![Fatigue Test Plan Diagram]

Test 10 CB-SB connections at 16 ksi (110 MPa) nominal stress range. 

- Upper Bound (95% confidence on 95% PS) 
- Lower Bound Design Curve (95% confidence on 95% PS) 

Substantiated by WSDOT Specs.
Horizontal Restraints during Testing

“If required, shims may be placed between the CBs at the SB locations only to prevent rotation of the CBs under load.”

- Top flange of CB rotates under vehicular load
  - observed in field testing
- Shims should only restrain bottom flange
Replacement of Elastomeric Parts

“[Elastomeric components] may be replaced in the fatigue test specimen with steel discs or rectangular blocks of the same dimensions.”

- Changes behavior of CB-SB connection!
Replacement of Elastomeric Parts (cont.)

- High prying forces on bolts with steel discs as CB rotates forward and stirrup remains stationary
  - bolt fracture occurred at about 40,000 cycles
- No bolt fracture occurred with elastomeric components
Test Arrangement

- Horizontal Shim
- Sliding Bearing (SB)
- Sliding Spring
- Stirrup (STIRRUP)
Fatigue Test Details

- Specimen inclined at 11.3°:
  \[ M_{\text{horizontal}} = 20\% M_{\text{vertical}} \]

- Reversal loading
  - 70% downward (down stroke, DS)
  - 30% upward (up stroke, US)

- Note: 30% US may not be realistic due to inherent damping
Fatigue Resistance of CB-SB Bolted Connection

Total 10 data points

⇒ : Runout

Nominal Stress Range (ksi)

Number of cycles

Nominal Stress Range (MPa)
Forces in Bolted Stirrups

- Bolt force changes very little when joint is precompressed
- Stirrup force changes as sliding bearings decompress

![Graphs showing forces in bolted stirrups]
Analytical Model - A19

- Two-span continuous
- Rigid supports

Vertical Bending Model:

- \( L = 36.22 \text{ in.}^4 (1.51 \times 10^7 \text{ mm}^4) \)
- \( A = 8.61 \text{ in.}^2 (5555 \text{ mm}^2) \)
- \( E = 29000 \text{ ksi (200000 MPa)} \)

Horizontal Bending Model:

- \( I_x = 6.77 \text{ in.}^4 (2.82 \times 10^6 \text{ mm}^4) \)
- \( A = 8.61 \text{ in.}^2 (5555 \text{ mm}^2) \)
- \( E = 29000 \text{ ksi (200000 MPa)} \)

Planar Frame
- Pinned at SB ends
- Rigid Connection between CBs and SBs

All dimensions in in. (1 in. = 25.4 mm)

P = Full Actuator Load (kip.)
Finite Element Analysis: Global Model

- 94,450 20-noded solid elements (1,661,043 DOFs)
- Contact surfaces simplified as ties
- Elastomeric springs simplified as linear elastic

**Overhead view**
- Sinus plate
- CB
- SB

**Underside view**
- Load location
- CB-SB stirrup
- Fixed BC
- Steering device
“For loads in the horizontal direction, more accurate results can be achieved by treating the centerbeams and support bars as a coplanar frame pinned at the ends of the support bars.”

- Does not make sense for SSB systems!
Modified Structural Analysis Model

**Vertical Bending Model**

- Two-span continuous
- Support settlement due to component deflection included

**Horizontal Bending Model**

- Two-span continuous
- Rigid supports - allows rotation between CBs and SBs

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**Vertical Bending Model Diagram**

- All dimensions in in. (1 in. = 25.4 mm)
- \( P = \) Full Actuator Load (kip)
- \( E_{bb} = 243 \text{ ksi} \) (1675 MPa)
- \( A_{bs} = 7.41 \text{ in.}^2 \) (4781 mm\(^2\))

**Horizontal Bending Model Diagram**

- All dimensions in in. (1 in. = 25.4 mm)
- \( I_y = 6.77 \text{ in.}^4 \) (2.82 x 10^6 mm\(^4\))
- \( A = 8.61 \text{ in.}^2 \) (5555 mm\(^2\))
- \( E = 29000 \text{ ksi} \) (200000 MPa)

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Advanced Technology for Large Structural Systems Center
Lehigh University
Analysis Results

Distance from center of CB (mm)

Distance from center of CB (in)

Stress Range (ksi)

Stress Range (MPa)

-1000 -500 0 500 1000

-54 -45 -36 -27 -18 -9 9 18 27 36 45 54

A19 MOD FEA EXP
Proposed Analytical Model for SSB

**Vertical Bending Model**

- Two-span continuous
- Rigid supports

\[ I_y = 36.22 \text{ in.}^4 \quad (1.51 \times 10^7 \text{ mm}^4) \]
\[ A = 8.61 \text{ in.}^2 \quad (5555 \text{ mm}^2) \]
\[ E = 29000 \text{ ksi} \quad (200000 \text{ MPa}) \]

\[ P = \text{Full Actuator Load (kip.)} \]
All dimensions in in. (1 in. = 25.4 mm)

**Horizontal Bending Model**

- Two-span continuous
- Rigid supports - allows rotation between CBs and SBs

\[ I_y = 6.77 \text{ in.}^4 \quad (2.82 \times 10^6 \text{ mm}^4) \]
\[ A = 8.61 \text{ in.}^2 \quad (5555 \text{ mm}^2) \]
\[ E = 29000 \text{ ksi} \quad (200000 \text{ MPa}) \]

\[ P = \text{Full Actuator Load (kip.)} \]
All dimensions in in. (1 in. = 25.4 mm)
Stress Range from Measurements

- Extrapolated Measured Stress Range ($Y_{3US} - Y_{3DS}$)
  - DS: -11.67 ksi
  - US: 4.85 ksi
  - $S_r = 16.52$ ksi
Interpretation of Stress Range at Details

Graph showing the interpretation of stress range at details with various data points and lines indicating different experimental and simulated results.

Legend:
- A19 - DS
- ADV - DS
- FEA - DS
- EXP - DS
- A19 - US
- ADV - US
- FEA - US
- EXP - US

Axes:
- Distance from Center of CB (mm)
- Normal Stress (ksi)
- Normal Stress (MPa)

Detailed analysis and comparison of stress ranges across different experimental and simulated conditions.
# Calibrated $S_r$ per A19

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Experimental Stress</th>
<th>Variation of Exp. $S_r$</th>
<th>A19 $S_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DS</td>
<td>US</td>
<td>$S_r$</td>
</tr>
<tr>
<td>BF_SW_WLD</td>
<td>6.21</td>
<td>-2.83</td>
<td>9.04</td>
</tr>
<tr>
<td>BF_SW2</td>
<td>-1.15</td>
<td>0.26</td>
<td>1.41</td>
</tr>
<tr>
<td>BF_SW1</td>
<td>-9.00</td>
<td>3.81</td>
<td><strong>12.81</strong></td>
</tr>
<tr>
<td>BF_SE1</td>
<td>-9.26</td>
<td>3.91</td>
<td><strong>13.17</strong></td>
</tr>
<tr>
<td>BF_SE2</td>
<td>-1.48</td>
<td>0.49</td>
<td>1.97</td>
</tr>
<tr>
<td>BF_SE_WLD</td>
<td>6.06</td>
<td>-2.76</td>
<td>8.82</td>
</tr>
</tbody>
</table>

All stresses in ksi
Consequences of using A19 $S_r$

- Experimental Stress Range = 12 ksi
- Analytical Stress Range = 16 ksi

Diagram shows:
- Nominal Stress Range (ksi) on the y-axis
- Number of cycles ($3 \times 10^6$) on the x-axis
- Runout indicated by an arrow
- Lines for B, B', C, C', B' & C', and B & C
Proposed Specification Changes

- Test configuration (sub-assembly testing)
- Structural analysis model and calibration
- Static test procedure
- Finite and Infinite life fatigue testing
- Interpretation of stress range at details
- Horizontal restraints during testing
- Fatigue resistance of bolted and welded stirrup connections
- Other clarifications

Recommended Specifications
"The specimen may be tested in the normal configuration with the centerbeams on top of the support bars or upside down, with the centerbeam below the support bars."
Conclusions

- CB-SB bolted connection in single support bar MBEJs can provide CAFL of Category B
- Full size fatigue testing of MBEJ systems is important for design improvement and ensuring adequate performance in service
- AASHTO fatigue test provisions for MBEJs should be revised to provide realistic performance measures, particularly for single support bar systems
Acknowledgements

- mageba
- Support Staff at Lehigh/ATLSS
Thank You
Test Fixture and Loading Mechanism

- Reaction wall
- Reaction frame
- Actuator
- Spreader beam
- Loading mechanism
- Specimen
- Support frame
- Reaction floor

Loading Mechanism Detail

- Hinge
- Upper loading block
- Rubber pad
- CB
- Lower loading block
- Anchor rod
- 11.3°
Specimen Configuration

Note: A19 requires full assembly test for SSB systems (?)

* A19: SB sections and spans shall be chosen to give a $S_r$ in the SB within 40% of the $S_r$ in the CB.
FEA Submodel

- 55,166 20-noded solid elements (807,195 DOFs)
- Connection pre-compressed
- Contact interactions
- Bolt preloads

Diagram:
- CB
- Bolt
- Sliding bearing
- Shim plate
- Stirrup
- Sliding spring
- SB
FEA Submodel Results

Step 1: Assembly
Step 2: Bolt Pretension
Step 3: Downward Load
Step 4: Upward Load
Specified Gauge Locations - CB

Specified gauges are located approximately at point of inflection.
Low stress readings confounded by noise error in extrapolated stress.

![Diagram showing specified gauge locations](image)
Specified Gauge Locations - SB

Not possible with single support bar system!

Gauges would need to be placed in same position as compression springs.