Lean on Bracing

Design and Construction
Design
* What is Lean-on-Bracing?
* Benefits of Lean-on-Bracing
* How to design a Lean-on-Bracing System

Construction & Research Results
* US 82 Underpass @ 9th Street
* US 82 Underpass @ 19th Street EB & WB
Design of Lean on Bracing

Research Report 1772-1
Critical Stage for Lateral Torsional Buckling
What is Lean-on-Bracing?
* Fewer cross frames - Significant Cost Savings
* Improved Fatigue Performance
* Reduced Construction Timeline
* Simplifies Future Inspections
Cross Frame layout for US 82 Underpass @ 19th Street WB

2/15/2012
Cross Frames

SECTION A-A

Top & Bottom Struts

SECTION B-B

Lean-on-Bracing
Lean-On-Bracing
Stiffness & Strength Requirements
\[
\frac{1}{\beta_b} + \frac{1}{\beta_g} + \frac{1}{\beta_{sec}} = \frac{1}{\beta_t}
\]

\(\beta_t\) = Torsional system brace stiffness
\(\beta_b\) = Brace stiffness
\(\beta_{sec}\) = Cross Section stiffness (web distortional stiffness)
\(\beta_g\) = In-plane girder stiffness
\[ \beta_{ti} := \frac{1.2 \cdot L \cdot (Mu)^2}{C_{bb}^2 \cdot n \cdot I_{eff} \cdot E} \]

**Ideal Total Stiffness**

\[ \beta_{t} := \frac{3.2 \cdot L}{C_{bb}^2 \cdot n \cdot I_{eff} \cdot E} \cdot \left( M_{dl} + M_{constl} \right)^2 \]

**Required System Stiffness**

**Torsional System Brace Stiffness**
\[ \beta_{\text{sec}} := 0.5 \cdot 3.3 \cdot \frac{E}{h_j} \left( \frac{h}{h_j} \right)^2 \left[ \frac{1.5 \cdot h_j \cdot t_w}{12} + \left( \frac{t_s \cdot b_s}{12} \right)^3 \right] \]
\[ \beta_g := \frac{12 \cdot (n_g - 1)^2 \cdot S^2 \cdot E \cdot I_x}{n_g \cdot L^3} \]
\[ \beta_{b1} := \frac{E \cdot S^2 \cdot h_b^2 \cdot A_b}{n_g \cdot L_d^3 + S^3 \cdot \left( \frac{n_g}{2} \right)^2} \]

**Braces @ Mid-span**

\[ \beta_{b1} := \frac{E \cdot S^2 \cdot h_b^2 \cdot A_b}{n_g \cdot L_d^3 + S^3 \cdot (n_g - 1)^2} \]

**Braces @ supports**
\[ \beta_{b2} := \frac{1}{\left( \frac{1}{\beta_t} - \frac{1}{\beta_g} - \frac{1}{\beta_{sec}} \right)} \]

\[ A_b := \frac{\beta_{b2}}{\beta_{b1}} \]

Brace Area Required for Stiffness
\[ \Phi_o := \frac{L_b}{500 \cdot h} \]

\[ M_{br} = F_{br} \cdot h_b = \beta_t \cdot \Phi_o \]

\[ F := \beta_t \cdot \frac{\Phi_o}{h_b} \]

**Strength Requirements**
\[ F_d := \frac{n_g \cdot F \cdot L_d}{N_c \cdot S} \]  
**Force in Diagonal**

\[ F_s := (n_g - 1) \cdot \frac{F}{N_c} \]  
**Force in Struts @ Supports**

\[ F_s := \left( \frac{n_g}{N_c \cdot 2} \right) \cdot F \]  
**Force in Struts @ Mid-Span**

**Angle Forces**
Construction of Lean on Bracing
US 82 Underpass at 9th Street
US 82 Underpass at 9th Street
US 82 Underpass at 9th Street
US 82 Underpass at 19th Street EB & WB
US 82 Underpass at 19th Street WB
US 82 Underpass at 19th Street WB
Deck Placement
Instrumentation & Live Load Testing
Cross Frame Instrumentation
Girder Instrumentation
Changes in Strain
Girder Rotations
Girder Deflections

Recorded Measurements
Mid-Span Cross Frame Forces

Predicted

Actual

$F_d = 26.4$ kips

$F_d = 14.3$ kips

$F_b = 12.1$ kips

$F_b = 4.1$ kips

$F_b = 3.6$ kips

$F_d = 10.9$ kips
Predicted

Actual

End Cross Frame Forces
Live Load Testing
<table>
<thead>
<tr>
<th>Load Test</th>
<th>X2-DT (kips)</th>
<th>Location (ft.)</th>
<th>X2-DB (kips)</th>
<th>Location (ft.)</th>
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<tbody>
<tr>
<td>Staggered Ahead</td>
<td>0.7</td>
<td>350</td>
<td>-27.8</td>
<td>100</td>
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<tr>
<td>Staggered Back</td>
<td>0.45</td>
<td>220</td>
<td>8.26</td>
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<tr>
<td>Side-by-Side South</td>
<td>0.6</td>
<td>350</td>
<td>6.8</td>
<td>240</td>
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<tr>
<td>Side-by-Side North</td>
<td>0.6</td>
<td>140</td>
<td>8.9</td>
<td>120</td>
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<tr>
<td>End to End South</td>
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<td>140</td>
<td>-25.7</td>
<td>120</td>
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<tr>
<td>End to End Central</td>
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<td>220</td>
<td>10.3</td>
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</table>

<table>
<thead>
<tr>
<th>Load Test</th>
<th>X3-DT (kips)</th>
<th>Location (ft.)</th>
<th>X3-DB (kips)</th>
<th>Location (ft.)</th>
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<tbody>
<tr>
<td>Staggered Ahead</td>
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<td>140</td>
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<td>Staggered Back</td>
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<td>-5.6</td>
<td>180</td>
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<tr>
<td>End to End Central</td>
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<td>140</td>
<td>36.1</td>
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</table>
* Design of Lean-on-Bracing is not difficult
* Improves fatigue performance
* Significant cost savings
* Reduces construction time
* It is a conservative method of torsional bracing that works
Questions?
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* Todd Helwig, Ph.D., P.E.
* Anthony Battistini, M.S.E.