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Introduction

• Advantages of Precast concrete deck systems
  • Accelerated construction
  • Improved quality
  • Minimized shrinkage cracking

Kearney East Bypass (2015)
Introduction

Deck-to-Girder Connections

Shear Pocket Connections

Wedged

HSS Formed

Longitudinal Channel Connections

(FHWA-IF-09-010, 2009) (Hatami, 2014) (Fallaha et al., 2004)
Problem Statement

• Existing design provisions for interface shear were developed primarily for CIP concrete decks with \textit{continuous shear connectors}.

• These provisions might not be applicable for precast concrete deck systems with \textit{clustered shear connectors}.
Research Objective

• Predict interface shear resistance of clustered shear connectors
Research Methodology

1. Collect clustered shear connector test data.

2. Determine the effect of design parameters on interface shear resistance.

3. Review interface shear resistance prediction models.

4. Compare interface shear resistance prediction models of AASHTO and International codes using collected test data.
Clustered Shear Connectors Test Data

- Total of 162 Experiments
- Shear Connectors:
  - Shear studs
  - Bars (Gr. 60)
  - High strength threaded rods (up to $f_y = 130$ ksi)
- Shear pocket filling material:
  - Grout
  - Concrete
- Shear pocket type:
  - Wedged
  - HSS
- Supporting girder:
  - Steel
  - Concrete

Shim et al., 2000
Wallenfelsz, 2006
Henely, 2009
Effect of Concrete Compressive Strength

Shear stress, $v$ (ksi) vs. Concrete compressive strength, $f_c$ (ksi)

$y = 0.13x + 0.99$

$R^2 = 0.07$
Effect of Concrete Compressive Strength

Shear stress, $v$ (ksi)

Concrete compressive strength, $f_c$ (ksi)

- RFT ratio $<2\%$
- RFT ratio 2-4%
- RFT ratio $>4\%$

Equations:

- $y = -0.05x + 1.60$  \( R^2 = 0.03 \)
- $y = 0.04x + 1.46$  \( R^2 = 0.02 \)
- $y = 0.30x + 0.63$  \( R^2 = 0.22 \)
- $y = -0.05x + 1.60$  \( R^2 = 0.03 \)
Effect of Reinforcement Ratio and Yield Strength

\[ y = 0.36x + 0.76 \]
\[ R^2 = 0.51 \]

Shear stress, \( v \) (ksi) vs. Reinforcement ratio, \( \rho \) (%)

- No Connectors (4)
- 36 ksi (10)
- 51 ksi (88)
- 60 ksi (22)
- 105 ksi (32)
- 130 ksi (3)

\( f_y \)
Interface Shear Resistance Prediction Models

- AASHTO LRFD
- Eurocode-4
- *fib* MC 2010
- CSA-S6
Interface Shear Resistance Prediction Models

Shear friction model proposed by Birkeland and Birkeland (1966)

\[ \nu_u = \rho f_y \tan \varphi = \rho f_y \mu \]

\[ V_{ni} = c A_{cv} + \mu (A_{vf} f_y + P_c) \]

\[ \nu_{Rdi} = c f_{ctd} + \mu \sigma_n + \rho f_y d (\mu \sin \alpha \cos \alpha) \leq 0.5 \nu f_{cd} \]

\[ \nu = c + \mu \left( \rho_v f_y + \frac{N}{A_{cv}} \right) \]

- Birkeland and Birkeland (1966)
- AASHTO LRFD
- Eurocode-4
- CSA-S6
Interface Shear Resistance Prediction Models

Extended Shear friction model by Randi (1997)

\[ \tau_{Rdi} = c_r f_{ck}^{1/3} + \mu \sigma_n + k_1 \rho f_{yd} (\mu \sin \alpha + \cos \alpha) + k_2 \rho \sqrt{f_{yd} f_{cc}} \leq \beta_c \nu f_{cc} \]

fib MC 2010
Assumptions:
- Strength reduction factor = 1.0
- Use measured concrete compressive strength
- Critical section is at shear pocket-haunch interface
a) AASHTO LRFD (2014) Eq. 5.8.4.1

\[ y = 1.27x \]

\[ R^2 = 0.65 \]
b) *fib MC 2010 Eq. 7.3-50*

\[ y = 1.28x \]

\[ R^2 = 0.78 \]

Source:
- Shim et al., 2000
- Issa et al., 2003
- Issa et al., 2006
- Wallenfelsz, 2006
- Larose, 2006
- Badie et al., 2008
- Henely, 2009
- Shim et al., 2014
- Hatami, 2014
- Huh et al., 2015
- Tawadrous, 2017

Linear (fib MC)
c) Eurocode (EN 1992-1 1:2004) Eq. 6.25

\[
y = 1.29x \\
R^2 = 0.78
\]

Source
- Shim et al., 2000
- Issa et al., 2003
- Issa et al., 2006
- Wallenfelsz, 2006
- Larose, 2006
- Badie et al., 2008
- Henely, 2009
- Shim et al., 2014
- Hatami, 2014
- Huh et al., 2015
- Tawadrous, 2017
d) CSA-S6-06 Sec. 8.9.5

\[ y = 1.92x \]

\[ R^2 = 0.62 \]

Source
- ▲ Shim et al., 2000
- ▲ Issa et al., 2003
- ▲ Issa et al., 2006
- ○ Wallenfelsz, 2006
- ▲ Larose, 2006
- ▲ Badie et al., 2008
- ▼ Henely, 2009
- ○ Shim et al., 2014
- ▲ Hatami, 2014
- □ Huh et al., 2015
- □ Tawadrous, 2017
- --- Linear (CSA)
## Code Comparison

<table>
<thead>
<tr>
<th>Code</th>
<th>Slope</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO LRFD</td>
<td>1.27</td>
<td>0.65</td>
</tr>
<tr>
<td><em>fib</em> MC 2010</td>
<td>1.28</td>
<td>0.78</td>
</tr>
<tr>
<td>EC-2 (EN 1992-1)</td>
<td>1.29</td>
<td>0.78</td>
</tr>
<tr>
<td>CSA-S6-06</td>
<td>1.92</td>
<td>0.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$V_{test}/V_{pred}$</th>
<th>AASHTO LRFD 2014</th>
<th><em>fib</em> MC 2010</th>
<th>EC2-2004</th>
<th>CSA-S6-06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.45</td>
<td>1.49</td>
<td>1.54</td>
<td>2.07</td>
</tr>
<tr>
<td>STD</td>
<td>0.76</td>
<td>0.58</td>
<td>0.56</td>
<td>1.05</td>
</tr>
<tr>
<td>COV</td>
<td>0.52</td>
<td>0.39</td>
<td>0.36</td>
<td>0.50</td>
</tr>
<tr>
<td>UEV(%)</td>
<td>70</td>
<td>86</td>
<td>88</td>
<td>93</td>
</tr>
</tbody>
</table>

$UEV = \text{percentage of underestimated values (} V_{test}/V_{pred} \geq 1.0)$
Conclusions

1. Existing code provisions are applicable for predicting interface shear resistance of clustered shear connectors with different levels of accuracy.

2. AASHTO LRFD, *fib* MC 2010, and EC-2 provisions provide close predictions ($V_{\text{test}}/V_{\text{pred}}$ of 1.27, 1.28, and 1.29, respectively).

3. EC-2 and *fib* MC code provide the least variability in prediction ($R^2 = 0.78$).

4. Reinforcement ratio is the most important factor in determining the interface shear resistance of clustered connectors. However, the tensile yield strength of shear connectors does not have a significant effect on interface shear resistance.

5. Concrete compressive strength has no significant effect on interface shear resistance when reinforcement ratio is less than 4%. However, it has slight effect when reinforcement ratio exceeds 4%;
Thank You

Questions?