Anchorage of Shear Reinforcement in Prestressed Concrete Bridge Girders

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Presentation Outline

• Background
• Objective
• Subassemblage Tests
• Girder Tests
• Conclusions
Prestressed Girder Fabrication

Process:
- Girder form is placed in precasting bed
- Tension reinforcing steel strands
- Place stirrups that carry shear forces
- Pour concrete
- Let concrete harden
- Cut the steel anchored to the precasting bed
- Girder becomes “prestressed” and is ready for erection
Loading of PC Girder creates Shear Forces

- Resistance provided by:
  - Transverse reinforcement contribution
  - Concrete contribution

Concrete deck → Girder top flange → Girder web → Girder bottom flange → Prestressing steel → Stirrups

Load must travel to abutment

Abutment
Transverse Reinforcement Contribution

• Tension forces in the stirrups require:
  – Adequate anchorage & development of stirrups in bottom flange where prestressing compression helps.
Construction Practice

• “Straight leg” stirrups used to facilitate construction (past practice)
• Stirrups with “standard hook” considered for new construction
  • Mechanically anchor stirrups around strands
Objectives

• Investigate the effectiveness of straight-legged stirrup anchorage in developing yield
Subassemblage Test Specimens

- Shape (Embedment length)
  - M and MN
  - 7 in. to 9 in. embedment
- Precompression
  - $0.01 \cdot f'_c$ and $0.45 \cdot f'_c$
- Presence or absence of confinement steel
- Concrete strength
  - 6.4 ksi to 9.5 ksi
Full-Scale Girder Tests

- Nominal $f_c' = 7.5$ ksi
- Girder depth
  - 36 in. and 45 in.
- Nominal anchorage length
  - 8 in. anchorage for M shape
  - 6-¾ in. including tolerances
- Flexure-shear vs web-shear
- Stirrup spacing
  - $s = 18$ in. for flexure-shear
  - $s = 8$ or 24 in. for web-shear
Stirrup Spacing

- **Tight Spacing**
  - Group effect reduces anchorage strength

- **Wide Spacing**
  - Fewer stirrups crossed by cracks

Stirrups with limited anchorage resist shear

Greater effecting anchorage likely
Prestressing

- Relatively high number of strands
  - Provides flexural resistance
  - Varying levels of strand stress levels
- Prestress of $0.40 \cdot f'_c$ targeted
  - Achieved $0.23 \cdot f'_c$ in 36M
  - Achieved $0.30 \cdot f'_c$ in 45M
  - Cast on a single bed

Straight Strands:
- $X \cdot 0.1 \cdot f_{pu}$
- $\circ \cdot 0.60 \cdot f_{pu}$
- Debonded

Draped Strands:
- $\square \cdot 0.43 \cdot f_{pu}$
Test Setup

- Flexure-shear test
  - 2 concentrated loads
  - 220-kip actuator at midspan
- Web-shear test
  - 1 concentrated load
  - 600-kip MTS test machine
    - $a/d$ ratio $\approx 2.3 - 2.5$
Instrumentation

- Initial prestressing force
- Prestress losses
- Stirrup strains
Flexure-Shear Test Results

- Flexural cracks occurred at stirrup locations prior to shear cracking
- Yield strains exceeded
- Maximum applied load limited to flexural capacity
Web-Shear Test Results

- Strains exceeding yield measured throughout failure regions
Girder Shear Capacity

- **Shear contribution**
  - \( V_c = \min(V_{cw}, V_{ci}) \)
  - \( V_{cw} = (3.5 \cdot \sqrt{f'_c} + 0.3 \cdot f_{pc}) \cdot b_w \cdot d + V_p \)
  - \( V_{ci} = (0.6 \cdot \sqrt{f'_c} \cdot b_w \cdot d) + V_d + \frac{V_i \cdot M_{cr}}{M_{max}} \)
  - \( V_s = \frac{A_v \cdot f_y \cdot d}{s} \)
  - Assumes 45 degree crack
  - \( V_n = V_c + V_s \)

- **Applied shear determined at critical section using statics**
  - Location of expected failure initiation
  - \( h/2 \) for web-shear
Shear Distribution at Failure

36M – Flexure-shear test

108 kip

216 kip
Shear Distribution at Failure

45M – Web-shear test w/ 24 in. spacing
Shear Distribution at Failure

45M – Web-shear test w/ 8 in. spacing
Shear Distribution at Failure

36M – Web-shear test w/ 8 in. spacing
# Girder Capacities

- Nominal shear capacities exceeded at critical section

<table>
<thead>
<tr>
<th>Test Specimen</th>
<th>( V_{\text{max,test}} ) [kip]</th>
<th>( V_n ) [kip]</th>
<th>( V_{\text{max}}/V_n )</th>
<th>( V_{\text{cw,test}} ) [kip]</th>
<th>( V_{\text{cw}} @ h/2 ) [kip]</th>
<th>( V_{\text{cw,test}}/V_{\text{cw}} )</th>
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<td>230</td>
<td>1.35</td>
<td>114</td>
<td>104</td>
<td>1.09</td>
</tr>
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</table>
Girder Test Conclusions

• Stirrups yielded in all four static shear tests
  – All three web-shear cases (45M_24W, 45M_8W, 36M_8W) and flexure-shear case (36M_18F)

• Anchorage depth
  – Reduced anchorage depth did not inhibit ability to develop yield strains

• Shear capacity
  – Nominal shear capacity exceeded by applied shear in each test by an average of 1.29
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Questions?