SHEAR CRACK INDUCED
DEFORMATION OF FRP RC BEAMS

Thanongsak Imjai
Maurizio Guadagnini
Kypros Pilakoutas

Construction Innovation Research Group
Department of Civil and Structural Engineering
Outline

- Introduction: calculation of deflection
- Experimental programme / results
- Concluding Remarks
Deflection: why do we get it wrong?

Shear deformation + Bending deformation + Rigid body movement

3
Deflection: why do we get it wrong?

Prediction of deflection

\[
\Delta = \beta \left( \frac{M_{cr}}{M} \right)^2 \Delta_g + \left( 1 - \beta \left( \frac{M_{cr}}{M} \right)^2 \right) \Delta_{cr}
\]

Eq. (1)

- \( \Delta \) is the total deflection
- \( \Delta_g \) is the uncracked-state deflection
- \( \Delta_{cr} \) is the cracked-state deflection
- \( \beta \) is the duration or repetition of load factor
- \( M_{cr} \) is the cracking moment and
- \( M \) is the applied moment.
Material Preparation

- Shear links: Thermoplastic GFRP strips
- Flexural bars: Thermosetting GFRP bars
- Ready mixed Concrete (C45)

12 Tests on six FRP RC beams
Experimental Programme

Shear diagonal cracking zone

Beam TB1

Shear links: side B
GFRP links
s=164mm

Shear links: side A
GFRP links
s=164mm

<table>
<thead>
<tr>
<th>ID</th>
<th>1A</th>
<th>1B</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
<th>4A</th>
<th>4B</th>
<th>5A</th>
<th>5B</th>
<th>6A</th>
<th>6B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_l )</td>
<td>1.22%</td>
<td>1.30%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \rho_w )</td>
<td>0.24</td>
<td>0.37</td>
<td>0.41</td>
<td>0.18</td>
<td>0.24</td>
<td>0.36</td>
<td>0.30</td>
<td>0.48</td>
<td>0.24</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>r/t</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>
## Material preparation

### GFRP thermoplastic strip (10x3mm)

![GFRP thermoplastic strip](image)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>720</td>
</tr>
<tr>
<td>Tensile modulus (GPa)</td>
<td>28</td>
</tr>
<tr>
<td>Ultimate strain (%)</td>
<td>1.9</td>
</tr>
<tr>
<td>Glass content (%v/v)</td>
<td>35</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.48</td>
</tr>
</tbody>
</table>
Thermosetting GFRP bars

GFRP Flexural reinforcement

\[ \phi = 16 \text{ mm} \]
\[ E = 60 \text{ GPa} \]
\[ f_f = 1000 \text{ MPa} \]

\[ \phi = 13.5 \text{ mm} \]
\[ E = 45 \text{ GPa} \]
\[ f_f = 700 \text{ MPa} \]
GFRP shear reinforcement

Manufacturing of FRP shear links

Bending process

Beam cage
Strain measurement

Bottom reinforcement:
2 GFRP Bars (ComBar)
16 mm diameter
Deflection measurement

Load

Dimension in mm

© 2007 The University of Sheffield
Western Bank, Sheffield S10 2TN, UK
### Experimental Results

#### Capacity and failure mode

<table>
<thead>
<tr>
<th>Beam ID.</th>
<th>$P_{cr}$ (kN)</th>
<th>$P_{max}$ (kN)</th>
<th>ACI 440.1R-06 (kN)</th>
<th>$d_{max}$ (mm)</th>
<th>$w$ (crack 1) (mm @ P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB 1B</td>
<td>64.4</td>
<td>79.1</td>
<td>54.8</td>
<td>20.5</td>
<td>0.35 @ 60</td>
</tr>
<tr>
<td>TB 2B</td>
<td>66.5</td>
<td>131.4</td>
<td>63.8</td>
<td>41.2</td>
<td>0.50 @ 80</td>
</tr>
<tr>
<td>TB 3B</td>
<td>60.4</td>
<td>73.8</td>
<td>50.3</td>
<td>24.3</td>
<td>0.25 @ 60</td>
</tr>
<tr>
<td>TB 4B</td>
<td>65.0</td>
<td>118.6</td>
<td>60.0</td>
<td>45.4</td>
<td>0.35 @ 60</td>
</tr>
<tr>
<td>TB 5B</td>
<td>72.7</td>
<td>133.7</td>
<td>69.0</td>
<td>48.2</td>
<td>0.45 @ 60</td>
</tr>
<tr>
<td>TB 6B</td>
<td>-</td>
<td>58.1</td>
<td>33.3</td>
<td>16.8</td>
<td>0.29 @ 50</td>
</tr>
</tbody>
</table>
Experimental Results

Failure mode

© 2007 The University of Sheffield
Western Bank, Sheffield S10 2TN, UK
Experimental Results

Strain in flexural reinforcement

[Diagram showing strain gauges with various load levels (P=10KN, P=20KN, P=40KN, P=60KN, P=70KN, P=76.8KN) and strain limits (0.25% and 0.45%)]
Experimental Results (cont)

Strain in shear reinforcement

Side B:
Links = GFRP 10x3mm, Spacing = 164mm c/c

Load (kN)

link - B3
link - B4
link - B5
link - B6

(x10^3) Microstrains

© 2007 The University of Sheffield
Western Bank, Sheffield S10 2TN, UK
Experimental Results (cont.)

Shear deformation

**Beam TB 2B**
- Diagonal crack
- Eq. (1)
- Experiment

**Beam TB 4B**
- Diagonal crack
- Eq. (1)
- Experiment
Shear deformation

Experimental Results (cont.)
Concluding Remarks

- Shear deformation can become significant after diagonal cracking occurs (15-25% @ ULS)
- Deflection predicted according to current design guidelines do not account for ‘shear’ deformation
- Should ‘shear’ checks be included at SLS?