Paper #161: Performance of composite local glass fibre sheets and epoxy on flexural strengthening of reinforced concrete beams

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Introduction

- Change in Indonesian Seismic Code ➔ some areas in Indonesia increase the seismic loading, therefore existing structures need to be evaluated.
- Some structures need to be retrofitted ➔ the structural elements such as Beam may experience flexure deficiency.
- Retrofitting RC for Flexure ➔ commonly use glued CFRP method at tension surface
Introduction

- CFRP and Epoxy → Import material and expensive → alternative materials locally available
- The main problem for glued CFRP is delamination from concrete surface → need technique to prevent premature failure.

- The paper presents “performance of local composite woven roving GFRP with epoxy as strengthening material and the effect of end anchorages"
Experimental Program

- **Material Properties**
  - Compressive concrete strength ($f'_c$) for phase I is 31.99 MPa and phase II is 21.13 MPa.
  - Epoxy (© Avian) with $f_{au}$ and $E_{au}$ is 51.43 MPa and 20192.2 MPa, respectively.
  - Composite GFRP sheet has $f_{fm}$ of 123.33 MPa and $E_{fm}$ of 5535.4 MPa.
  - Rebar diameter 10 mm and 6 mm has $f_y$ of 389 Mpa.

GFRP sheet Woven Roving

Local Epoxy Resin
Experimental Program

◆ Specimen Detail

- Phase-I to study the effect of GFRP layers number (0, 1 and 2 layers)
- Each parameter was consisted of 3 beams
Experimental Program

- Specimen Detail phase II

- Phase-II to study the effect of end anchor on 2 layers GFRP sheet:
  - BN: No GFRP Layer
  - B2: No end anchors
  - B3: End Anchor GFRP U-straps
  - B4: End anchor Bolts
  - B5: End anchor GFRP fasteners
Experimental Program

◆ Test Setup

- Load applied incrementally at 2.5 kN
- 2 dial gauges at midspan beams to measure beam deflections
RESULTS and DISCUSSION:

a) Failure modes and ultimate capacity

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Phase</th>
<th>Variations</th>
<th>Ultimate Loads (Pult) kN</th>
<th>Failure Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BN1</td>
<td></td>
<td>Control specimen</td>
<td>52.5</td>
<td>Flexure</td>
</tr>
<tr>
<td>BN2</td>
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<td>Phase I</td>
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<tr>
<td>BS11</td>
<td>I</td>
<td>One-layer GFRP</td>
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<td>Flexure, GFRP Rupture</td>
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<td>Flexure, GFRP Rupture</td>
</tr>
<tr>
<td>BS21</td>
<td></td>
<td>Two layers GFRP</td>
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<td>Flexure, GFRP debonding</td>
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<tr>
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<td>BS23</td>
<td></td>
<td></td>
<td>60.0</td>
<td>Flexure, GFRP debonding</td>
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</tbody>
</table>

- All beams failed in flexure
- Beams with 1 layer, GFRP Rupture before flexure
- Beams with 2 layer, GFRP debonding before flexure
### RESULTS and DISCUSSION:

#### a) Failure modes and ultimate capacity

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Phase</th>
<th>Variations</th>
<th>Ultimate Loads (Pull) (kN)</th>
<th>Failure Modes</th>
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<tbody>
<tr>
<td>BN1</td>
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<td>Control - specimen</td>
<td>51.5</td>
<td>Flexure</td>
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<td>BN3</td>
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<td>Two layers GFRP with end anchor of</td>
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<td>Flexure, GFRP rupture</td>
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<tr>
<td>B53</td>
<td></td>
<td></td>
<td>69.0</td>
<td>Flexure, Anchorage rupture, GFRP debonding</td>
</tr>
</tbody>
</table>

- All beams in phase II failed in flexure with higher loads
- Beams with U-straps, Anchor Rupture/delamination before flexure.
- Beams with Anchor Bolts, All GFRP performs well to reach their capacity → GFRP Ruptures
- Beams with GFRP fastener → mostly anchor rupture and debonding → slow debonding.
RESULTS and DISCUSSION:
a) Example beam failure for phase I

BN: Control beam

BS1: Beam with 1 layer GFRP, GFRP Rupture

BS1: Beam with 2 layer GFRP, GFRP Debonding
RESULTS and DISCUSSION:

b) Beam Deflection for Phase-I:

- All beams show yielding of flexure reinforcement.
- Yield loads of strengthening beams higher than normal beam (control beam).
- After failure of strengthening materials due to rupture or debonding, the beams behave as control beams.
RESULTS and DISCUSSION:

b) Beam Deflection for Phase-II:

- Load-deflection curve BN vs B2 (no end anchor) and BN vs B3 (with U-strap)
- P-δ Behavior of beams similar to beams in phase I
RESULTS and DISCUSSION:
b) Beam Deflection for Phase-II:

- Load-deflection curve BN vs B4 (with anchor bolts) and BN vs B5 (with GFRP fasteners)
- P-δ Behavior of beams similar to beams in phase I
Results & Discussion

c) Beam Capacity:

<table>
<thead>
<tr>
<th>Beam ID</th>
<th>Phase</th>
<th>Loads (Pult)</th>
<th>$M_{ult}$ (kNm)</th>
<th>$M_{ult\ avg}$ (kNm)</th>
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</thead>
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<td>I</td>
<td>55.0</td>
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<td>BS11</td>
<td>I</td>
<td>58.0</td>
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<td>B3</td>
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<td>51.5</td>
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<td>B4</td>
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<td>B15</td>
<td>II</td>
<td>69.0</td>
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</tbody>
</table>

- Increase no. of layers, increase nominal moment of beams (data of phase I)
- Type of end anchors affects the ultimate beam flexure capacity (data of phase II)
Conclusion

- For the beams without end anchors, the full strength of GFRP can only be achieved in one-layer GFRP specimens. Up to two-layers GFRP sheets, the debonding failure occurred at the interface between concrete and epoxy results in GFRP delamination.

- The beam flexural capacity can be increased by 10.8% and 13.4% of the control beams for one and two layers of GFRP sheet, respectively.
Conclusion

- In the presence of end anchors performance of GFRP improved. End anchors changes the initial GFRP delamination from cut-off end to the middle beam span.

- The flexural capacity increased by 31.4%, 18.3% and 22.9% of the 2nd phase control beams, respectively for fastener, U-strap and bolts anchor’s types.
Thank you

Terima Kasih