# Effect of Existing Steel-to-Embedded FRP Shear Reinforcement Ratio on the Behaviour of Reinforced Concrete T-Beams


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9th International Conference on Advanced Composites in Construction (ACIC 2019)

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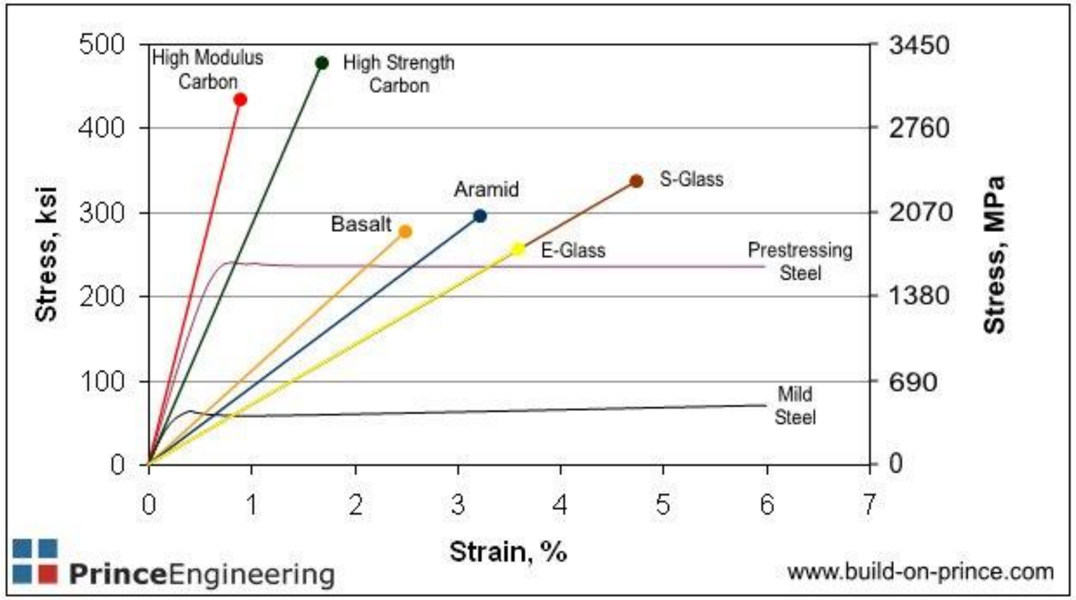
# Background

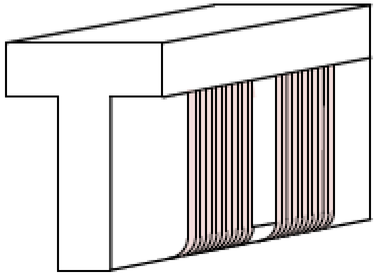
http://expcep.com/en/bulletin/structural-behavior-of-concrete/

# Background

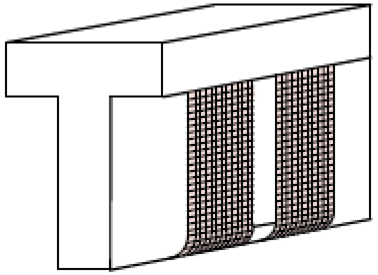
- **Fibre reinforced polymers (FRPs) offer excellent mechanical and durability properties**
- **High strength-to-weight ratio, non-corrosive, ease of application**
- **But elastic brittle**



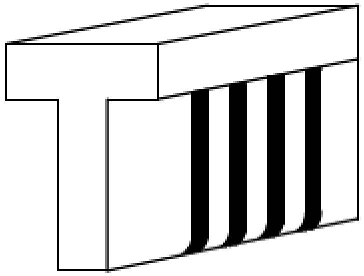
# FRP SHEAR *STRENGTHENING*



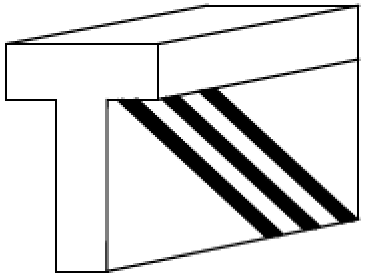
(a)EB unidirectional FRP sheets



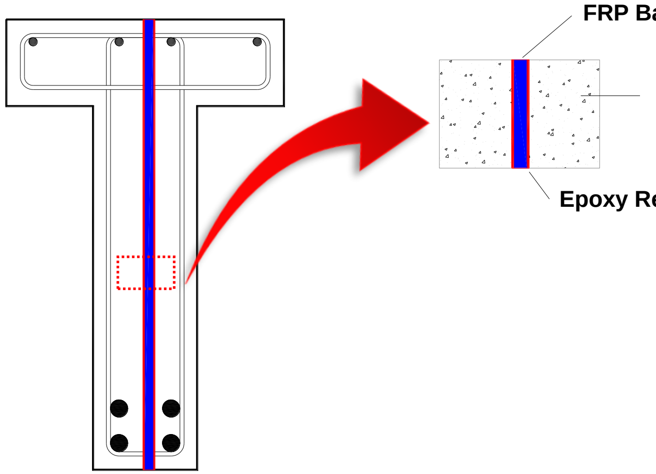
(b)EB bi-directional FRP sheets



(c)EB laminated FRP sections



(d)NSM FRP reinforcement

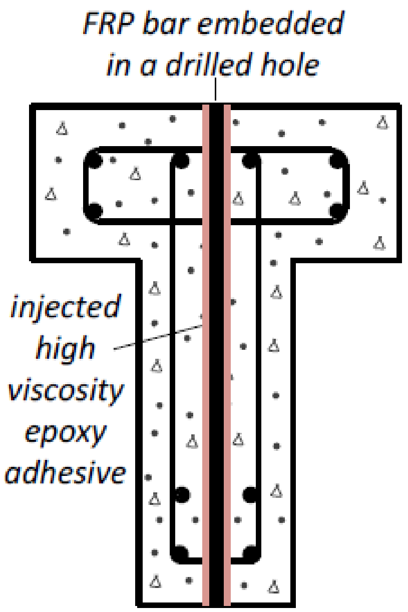



## Deep Embedment Technique

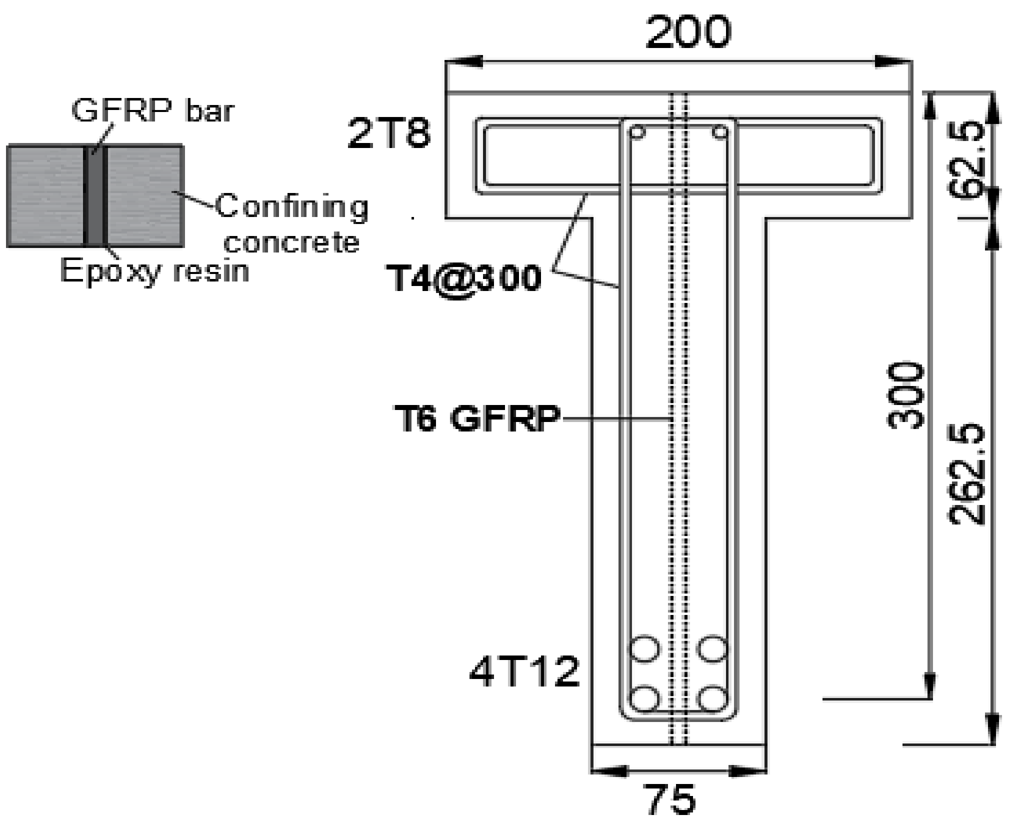
- ✓ **Easier to apply**
- ✓ **Less epoxy consumption**
- ✓ **Higher effectiveness**

# Research Questions

- The Effect of existing steel-to-embedded FRP shear reinforcement ratio is not quantified.
- Do existing design models provide accurate predictions of the shear strength enhancement?

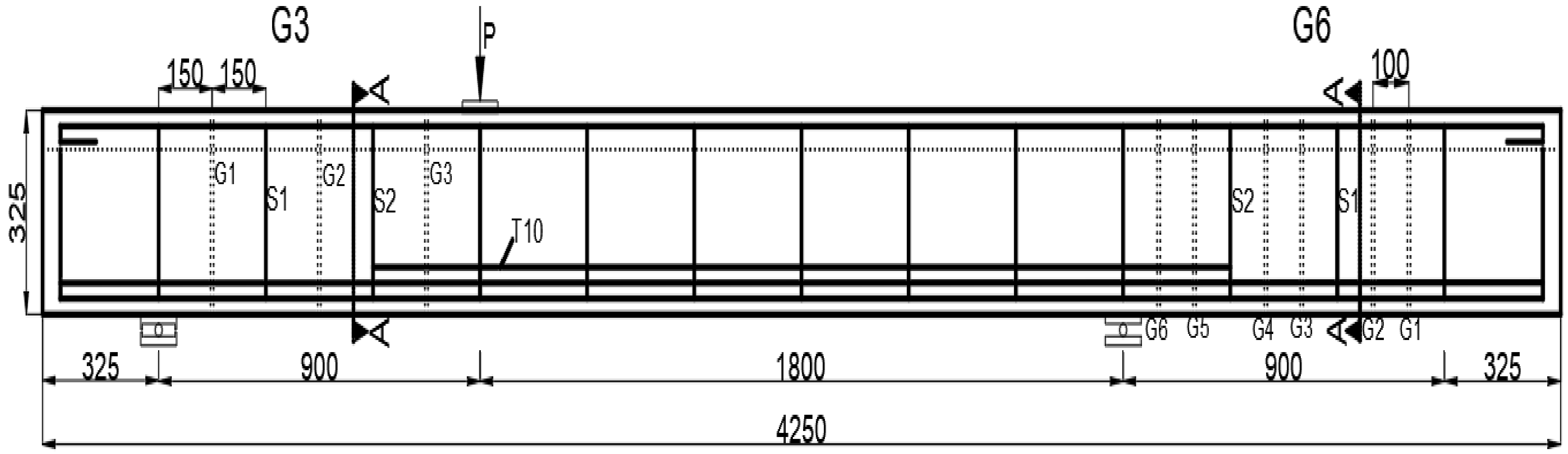


# Experimental programme




All dimensions in mm.

# Experimental programme




All dimensions in mm.

# Experimental programme

| Beam | Steel Shear Reinforcement Ratio | GFRP Shear Reinforcement Ratio | Steel-to-FRP Shear Reinforcement Ratio |
|---|---|---|---|
| Control | 0.11% | - | - |
| G3 | 0.11% | 0.125% | 0.88 |
| G6 | 0.11% | 0.25% | 0.44 |

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# Experimental programme: Material Properties

| Material | Elastic modulus (GPa) | Compressive strength (MPa) | Ultimate strain mm/mm | Yield strength (MPa) | Ultimate strength (MPa) |
|---|---|---|---|---|---|
| Concrete | - | 40* | - | - | - |
| Ø4mm bar | 200 | - | - | 540 | 680 |
| Ø8mm bar | 200 | - | - | 540 | 680 |
| Ø10mm bar | 200 | - | - | 580 | 680 |
| Ø12mm bar | 200 | - | - | 580 | 680 |
| Ø6 mm GFRP bar | 40 | - | 0.0243 | - | 973 |
| * Cylinder compressive strength; Cube strength ≈ 50.5 MPa | | | | | |

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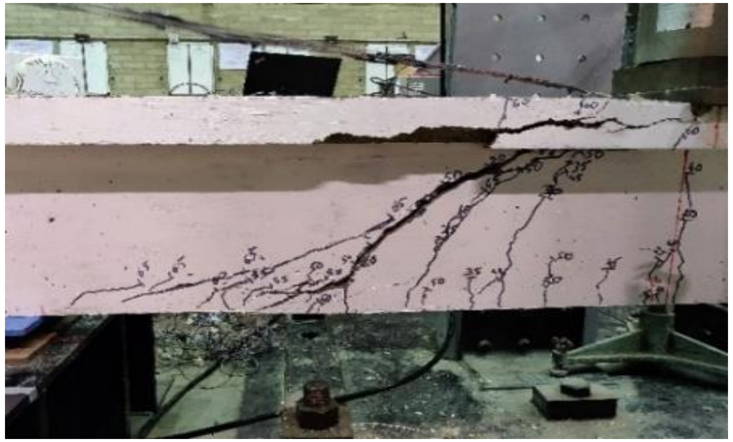
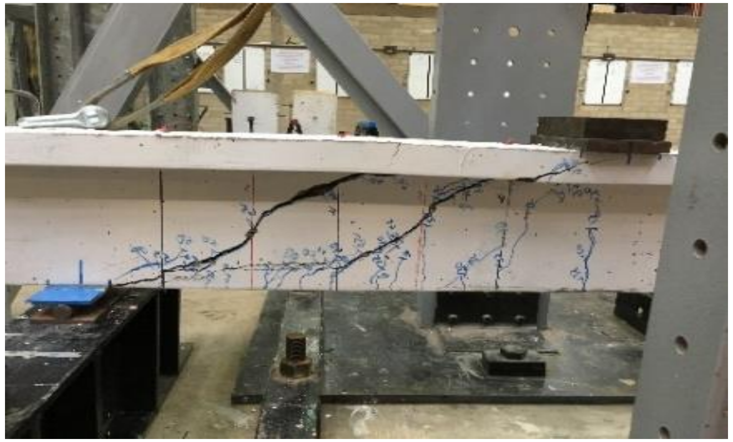
# Results: Failure Mode

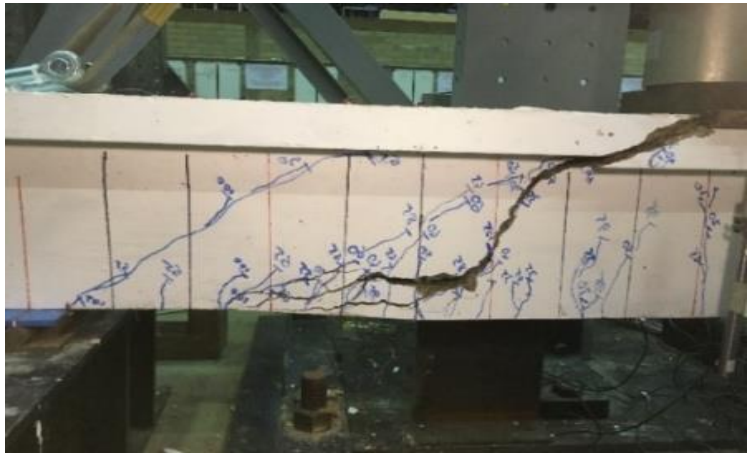
Control



G3



G6



# Results: Failure Mode

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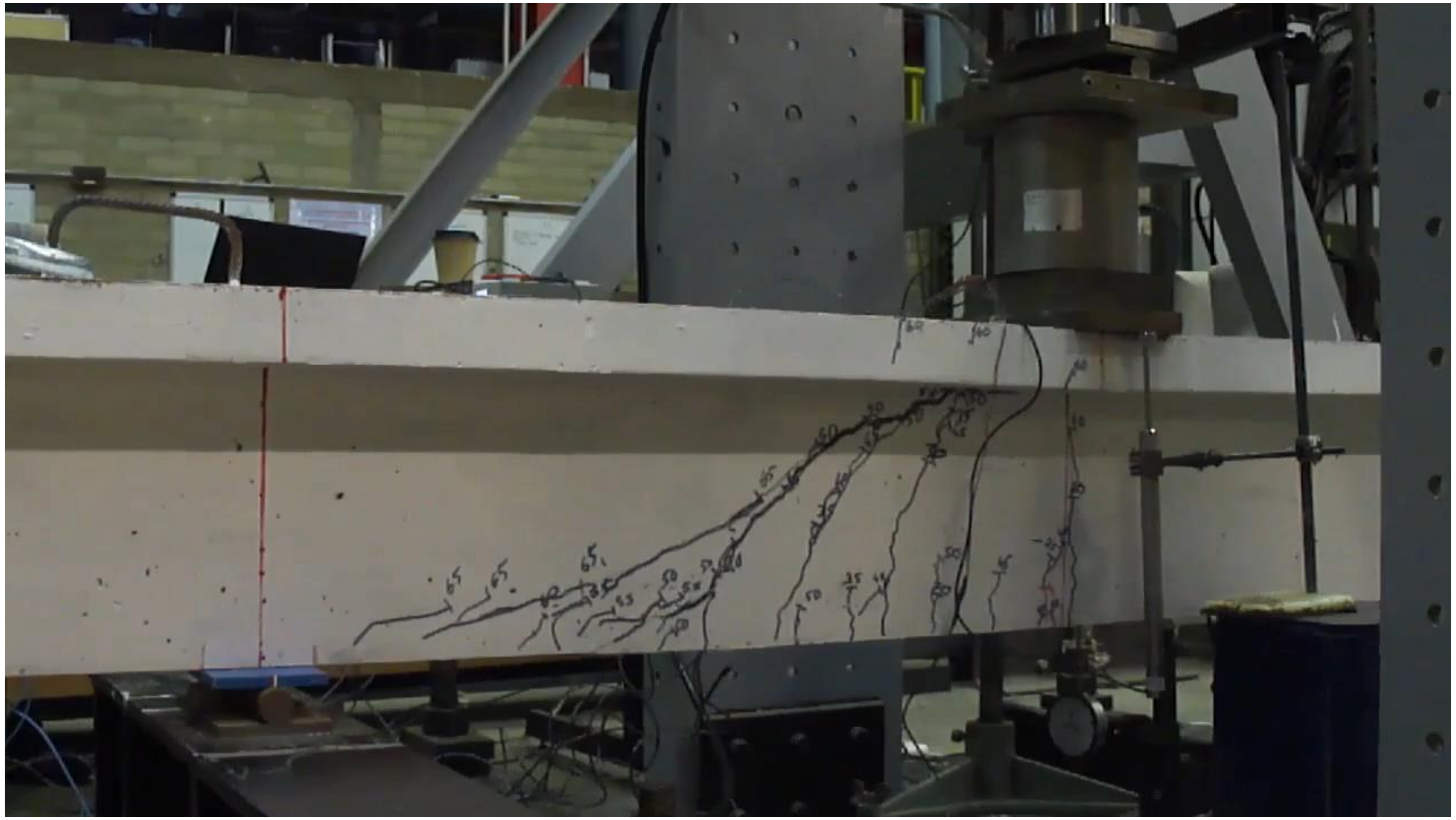

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# Results: Shear Force-Deflection Response

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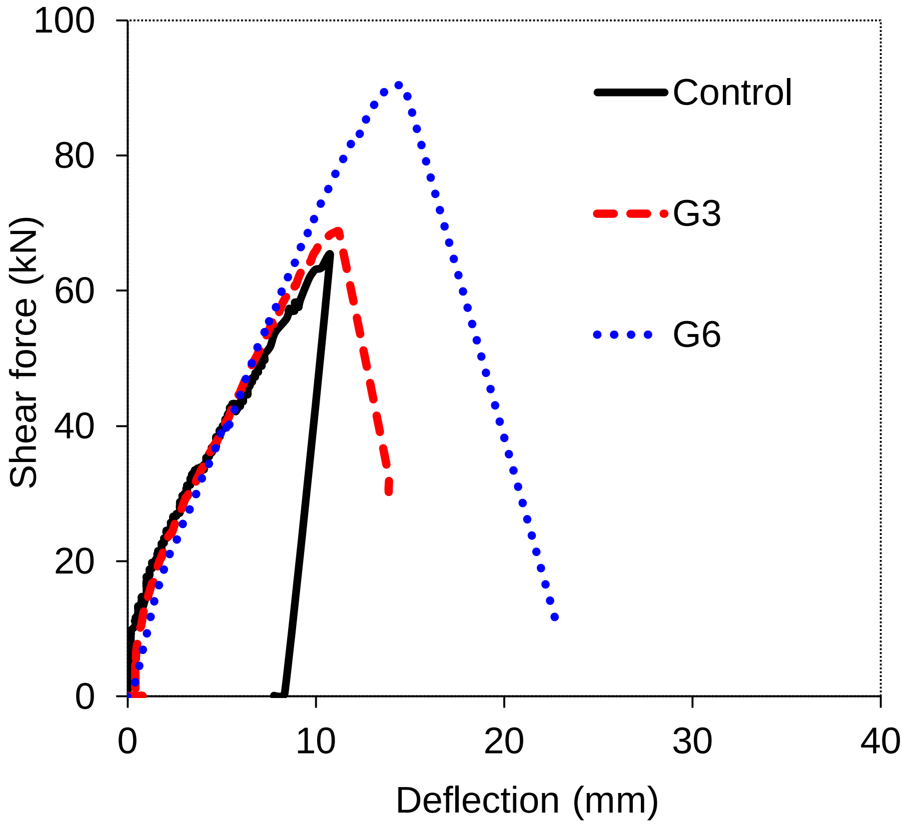


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# Results: Shear Force Capacity

| Beam | Unstrengthened shear force capacity (kN) | Shear force at failure (kN) | Gain attributable to GFRP (kN) | Gain attributable to GFRP (%) |
|---|---|---|---|---|
| Control | 65.5 | 65.5 | - | - |
| G3 | 65.5 | 68.7 | 3.2 | 4.8 |
| G6 | 65.5 | 90.5 | 25 | 38.1 |

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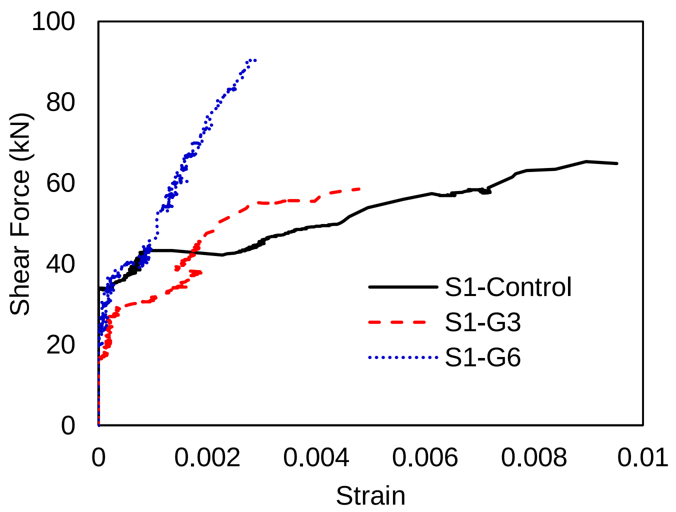
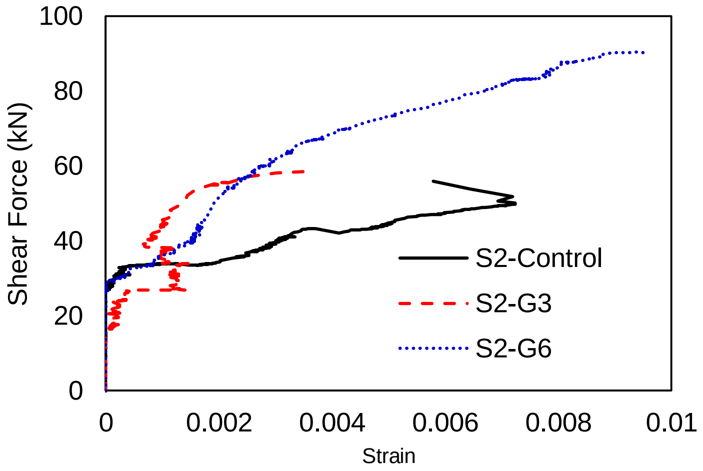
# Results: Strain Response (Shear Links)



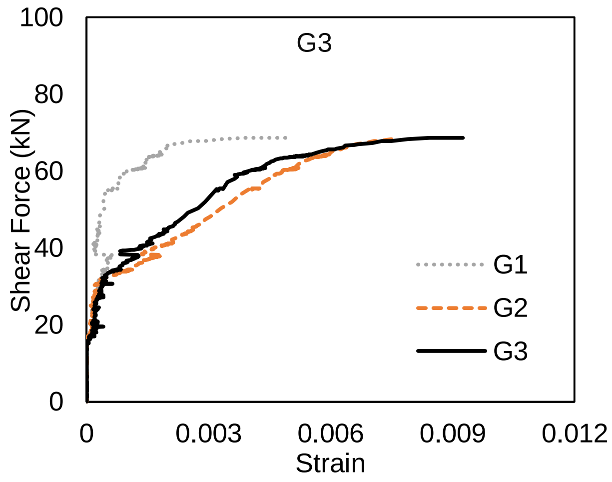



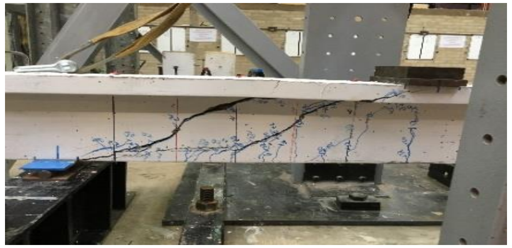

All shear links attained or exceeded the yield strain of 0.0027
Steel contribution to shear force capacity of the control beam may be computed:
The yield strength (540MPa) multiplied by the cross-sectional area of the two shear links (25.1 mm$^2$ per shear link)

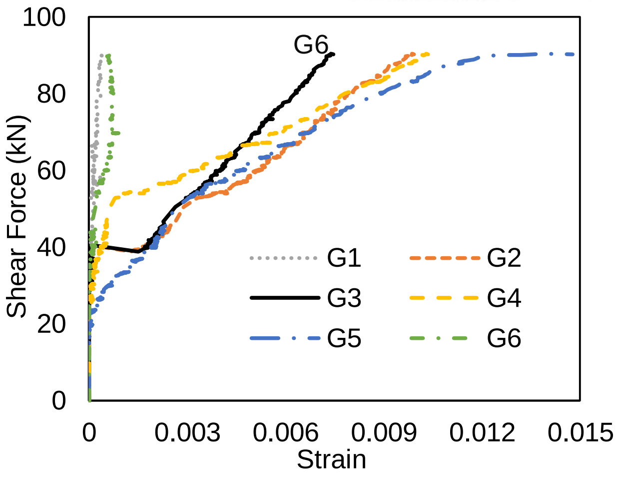
Vs = 27.1 kN

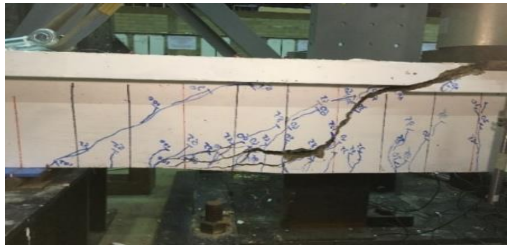
Vc = 65.5-27.1 = 38.4 kN

# Results: Strain Response (GFRP bars)



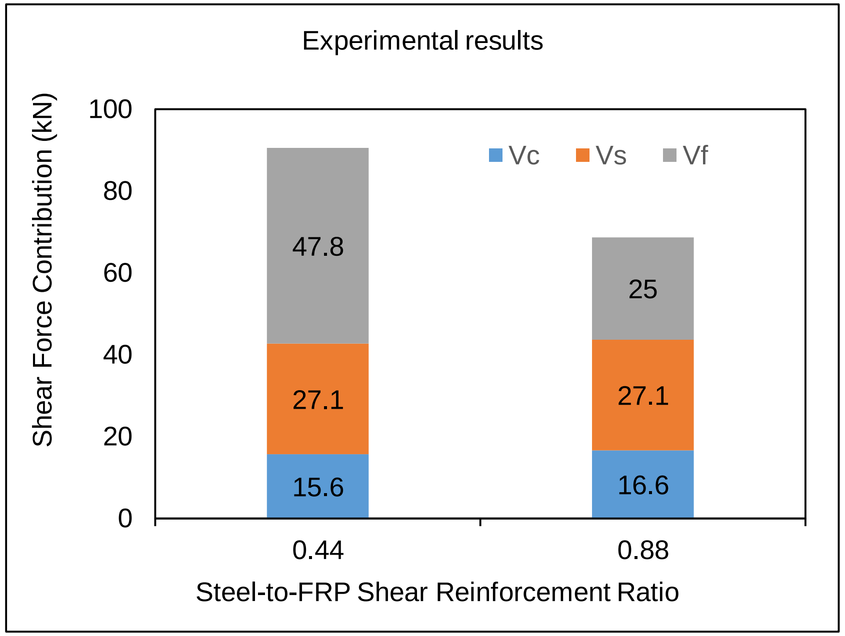


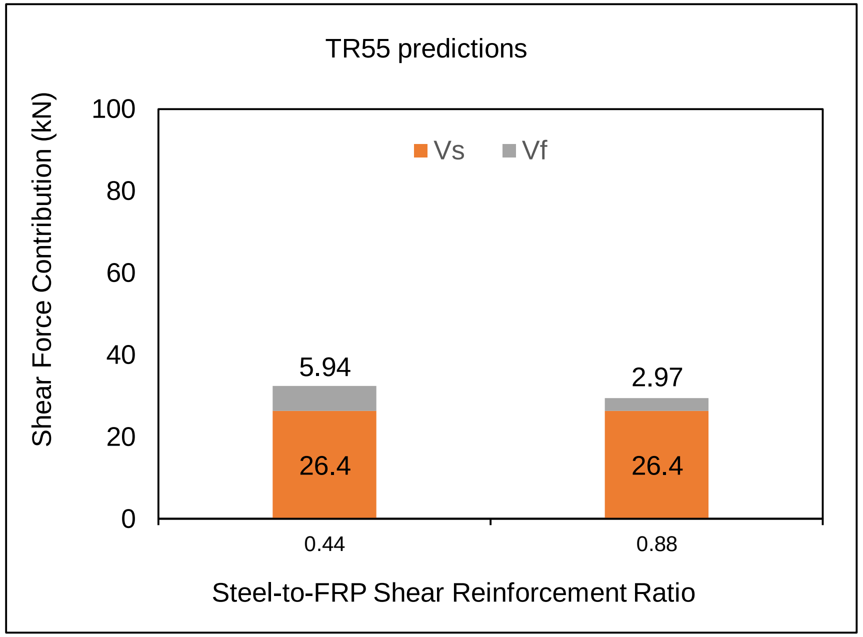



The FRP contribution to shear resistance ($V_f$) may be calculated as the strain in the GFRP bars crossed by the shear crack that caused failure multiplied by the axial rigidity (i.e. elastic modulus multiplied by the cross-sectional area) of the GFRP bars.
Beam G6 (G2, 3,4,5 bars)
Beam G3 ( G1,2,3 bars)

| Beam | V(kN) | Vs(kN) | Vf (kN) | Vc(kN) |
|---|---|---|---|---|
| G3 | 68.7 | 27.1 | 25 | 16.6 |
| G6 | 90.5 | 27.1 | 47.8 | 15.6 |

# Results: Comparison between Experimental Results and TR55 Predictions




$$lb,max = \frac{\mathcal{E}fe * Efd * Af}{(\pi * db * \frac{\tau b}{\gamma A})}$$

Weff = (h-2*lb,max)

TR55 ignores the concrete contribution to shear resistance and calculates the total shear force capacity as $Vs + Vf = \frac{Asw}{s} * z * f_{ywd} * cot\theta + \frac{\mathcal{E}_{fse} E_{fd} A_f}{s_b} w_{ef}$

## Summary

- The gain in shear strength was 3.2 kN (4.8%) and 25.0 kN (38.1%) for the beams with steel-to-FRP shear reinforcement ratios of 0.88 and 0.44, respectively.
- The strengthened beams had slightly higher post-cracking stiffness than the unstrengthened control beam.
- Strain readings showed that the concrete contribution to shear resistance of the strengthened beams was about 22.5 kN (58%) less than that of the control beam.
- The FRP contribution to shear resistance decreased by 48% with the increase in steel-to-FRP shear reinforcement ratio from 0.44 to 0.88.
- TR55 design model significantly underestimated the FRP contribution to shear resistance.

# Thank You

Any questions?