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GFRP REINFORCED GFRC FOR THIN PERMANENT FORMWORK APPLICATIONS

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Outline

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- ❖ New systems incorporating GFRP reinforced GFRC
- ❖ Interaction between FRP and GFRC
  - – Bond (GFRC and FRP)
  - – GFRC tensile characteristics
  - – Deflections
  - – Shear capacity
- ❖ Maximise span / length of unreinforced thin GFRC element
- ❖ Design guidelines for FRP / GFRC thin structural elements

Introduction

Thin concrete permanent formwork and other structural elements

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Minimum cover for durability; For aggressive environments, minimum 100mm thickness

↓

GFRC is lightweight, high strength and has excellent resistance to corrosion

↓

FRP reinforcement can be used to structurally reinforce GFRC to enable the development of much larger spans

Main design issues

Bond
Tension stiffening
Deflections
Shear capacity

GFRP reinforced GFRC of thin panels

Options for increasing the performance of the section
Amount of FRP reinforcement
Depth of the cross-section
Intermediate supports

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Bond behaviour in GFRC

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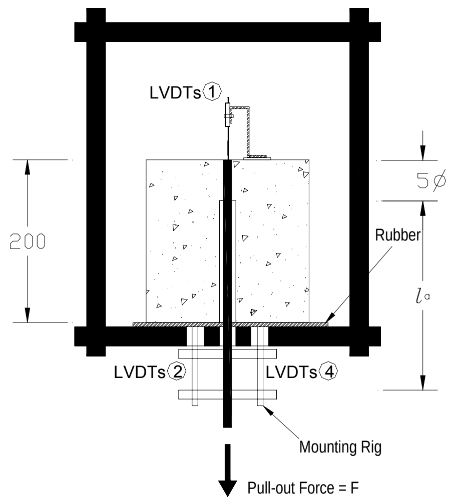
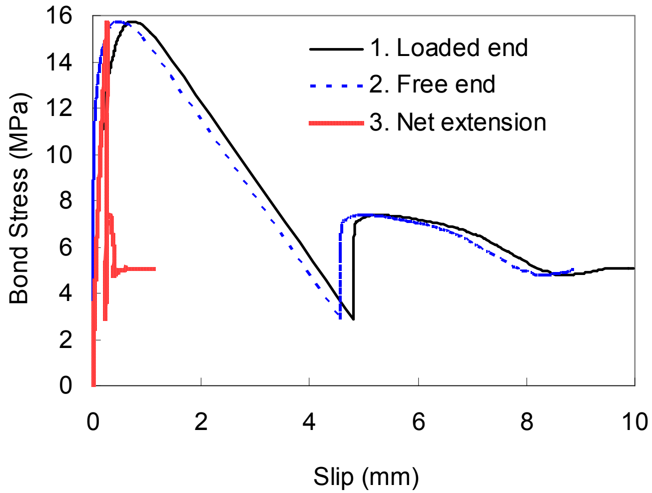
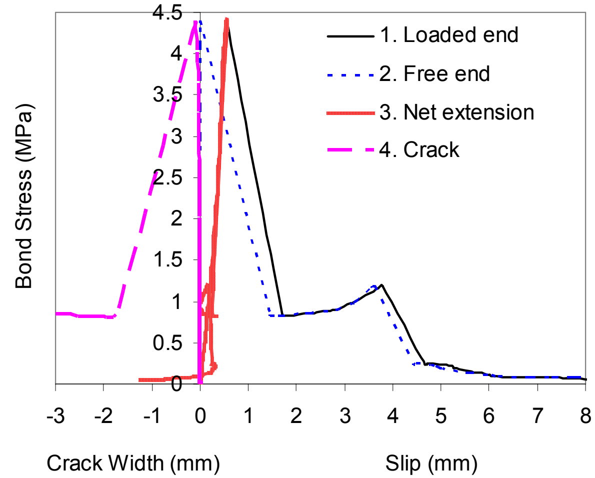
Standard pull-out tests

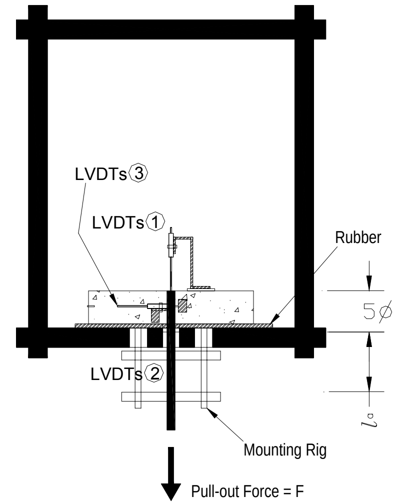
GFRC cubic block specimens
(200 x 200 x 200 mm)





Splitting pull-out tests





GFRC prismatic elements
(30 or 40 x 200 x 100 mm)

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Bond behaviour in GFRC

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❑ MATERIALS

- W/C = 0.35, S/C = 1.0 - f_c = 54 and 66 MPa - f_{ct} = 6 and 7MPa (by Brazilian Test)

- f_{t_steel} = 500 MPa, f_{t_GFRP} = 900 MPa - E_{GFRP} = 41 GPa, E_{steel} = 205 GPa

Summary of test results

Specimen type	Strength (MPa)	Bond strength, τ (MPa)	Normalised bond strength, τ' (MPa)
GFRC	66	14.2	9.9
GFRC	54	11.0	8.5
Plain concrete	32	8.5	8.5

- GFRP reinforced GFRC similar to steel RC
- Pull-out resistance of FRP is greater in GFRC (by 16%)

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Optimised Section

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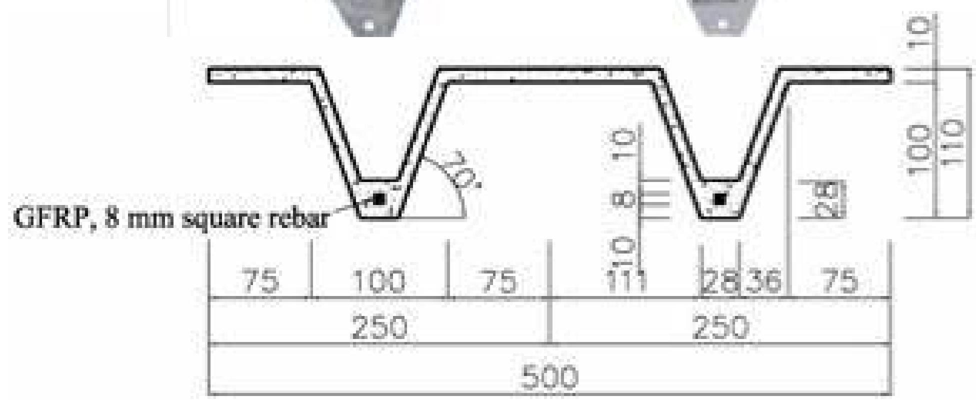
- Thin GFRC section (t = 10 mm) was chosen after an optimisation exercise* was undertaken to identify the sections that minimise weight for a particular span

* Kim, G. B., “Development of thin FRP GFRC permanent formwork systems” PhD Thesis, University of Sheffield, Department of Civil and Structural Engineering, Sheffield, UK, 2006.



Structural Testing

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Test specimens

(I) L15G3

(II) L30G3

(III) L30G2

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GFRC tensile characteristics

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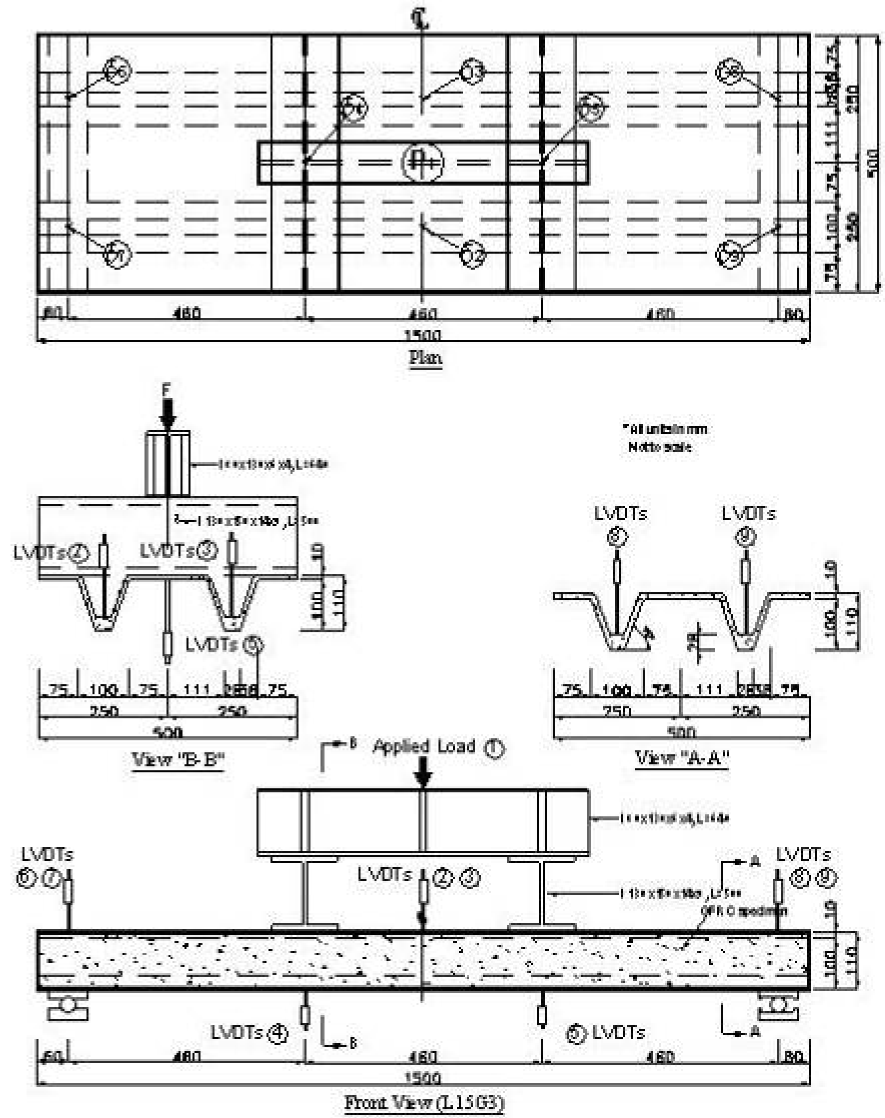
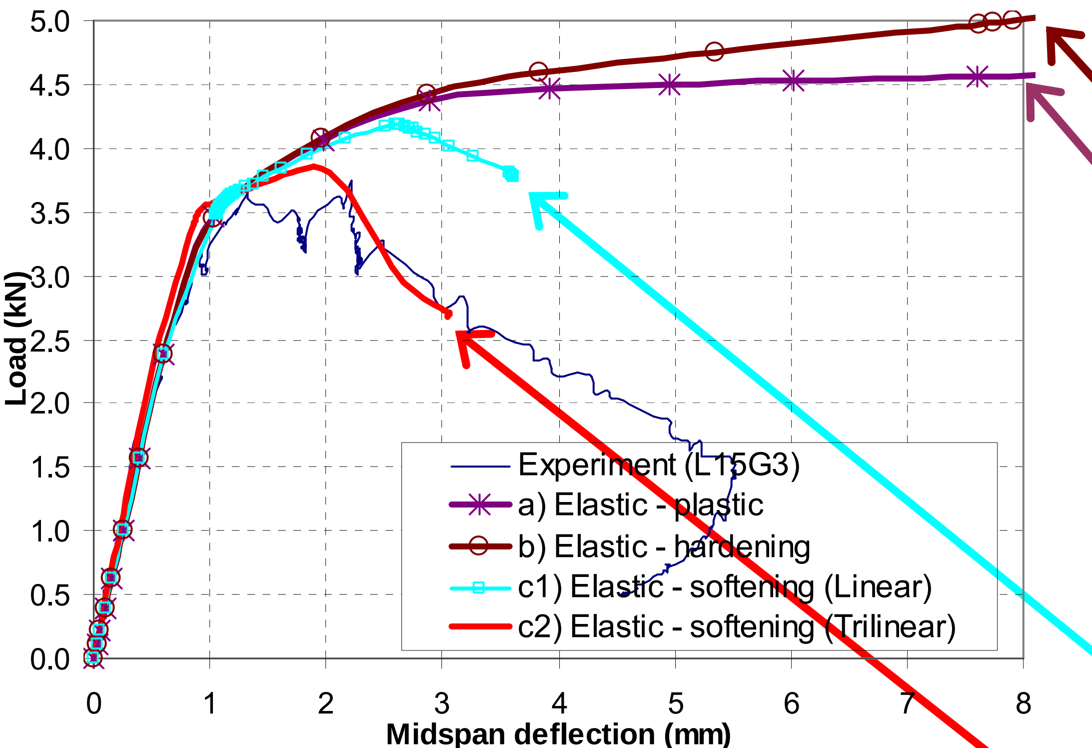
To evaluate the GFRC tensile characteristics

GFRC panel (L15G3)

- ✓ Reinforced with 3% (by weight) of chopped glass fibre
- ✓ Length of panel = 1500 mm
- ✓ Four point loads test

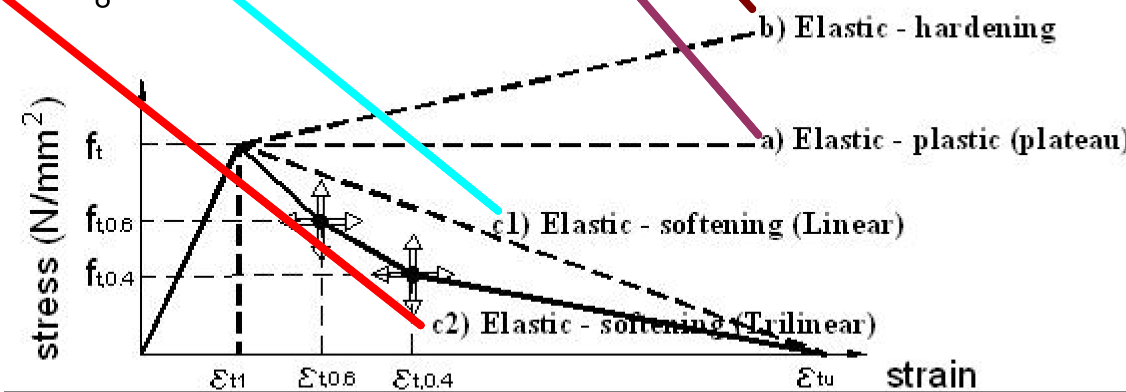


Optimised Section



Softening model with trilinear gives the best results !!

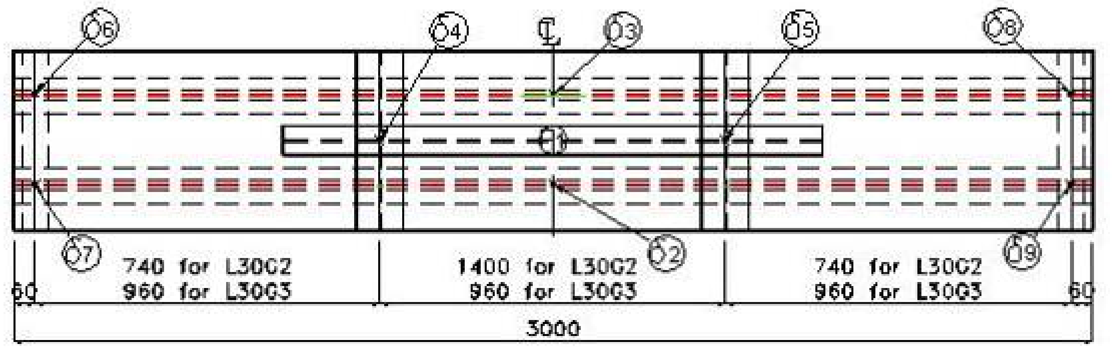
$\varepsilon_{tu} = 0.05$



Deflections of FRP GFRC

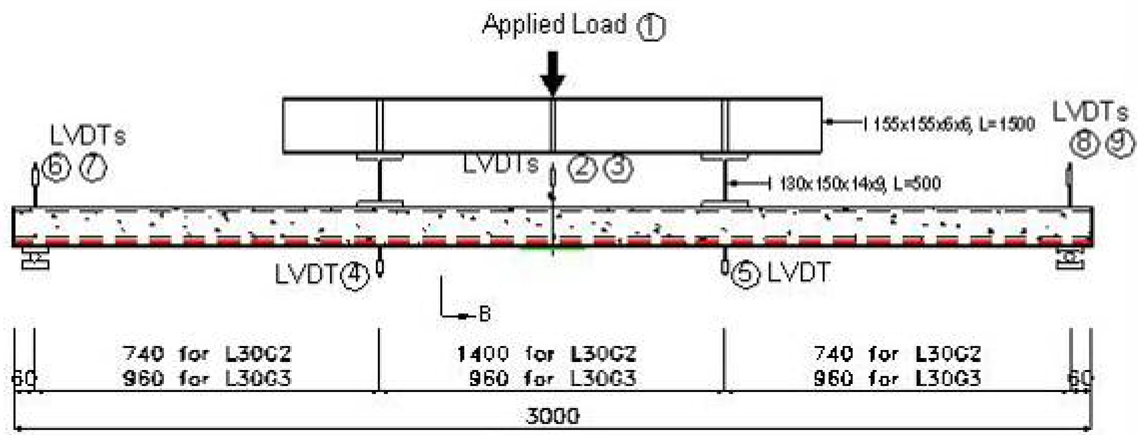
Two GFRC panels (L30G2, L30G3)

- ✓ Reinforced with 2 and 3% (by weight) of chopped glass fibre
- ✓ Single 8mm square rebar
- ✓ Length of panel = 3000 mm
- ✓ Four point loads test



Plan

* All units in mm



Front View

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Deflections of FRP GFRC

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- Both panels achieved remarkable deformations up to about 110mm before shear failure
- Excessive deformation is normally the governing design criterion for thin permanent formwork, especially for long spans
- Acceptance deflection limits for this type are limited to L / 250

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Deflections of FRP GFRC

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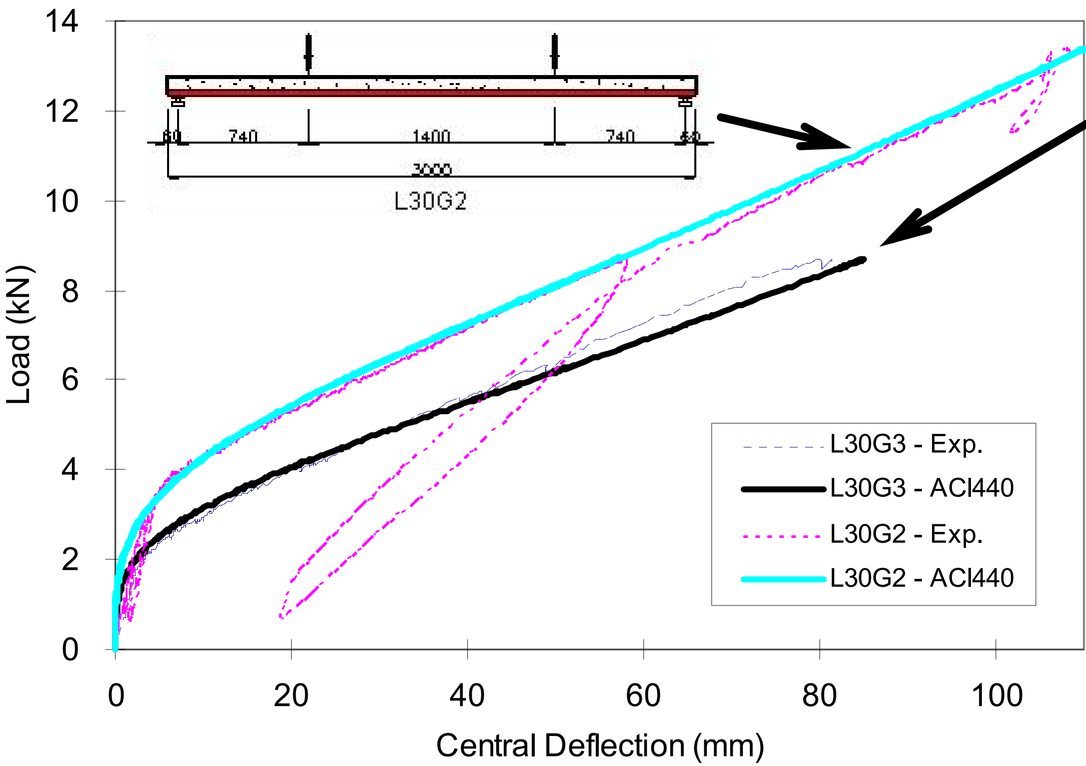
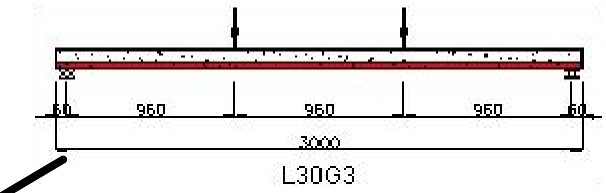
◆ Test Results: Flexural capacity





$$I_{cr,e} = \left(\frac{M_{cr}}{M_a}\right)^3 \beta_d I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \le I_g$$

$$\beta_d = \alpha_b \left[\frac{E_f}{E_s} + 1\right]$$

Bond dependent coefficient

✓ ACI440 equations are appropriate for thin GFRC reinforced with FRP

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Shear capacity

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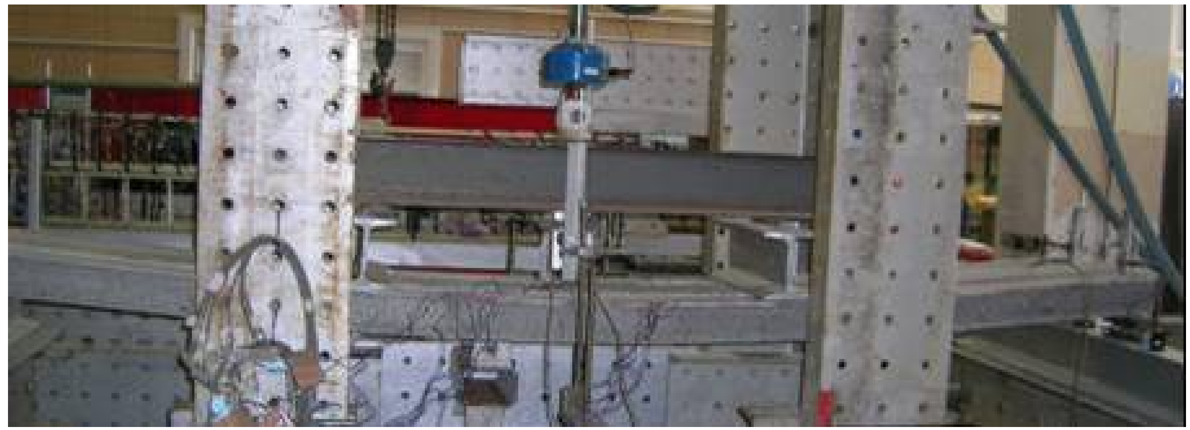
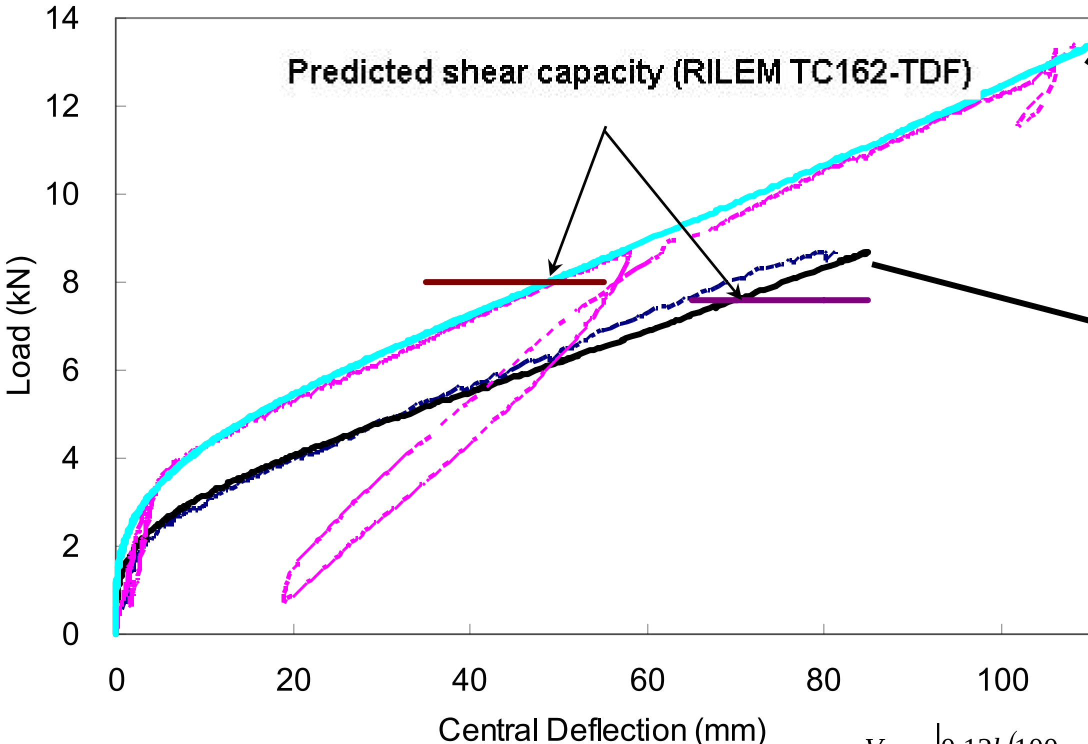
Two GFRC panels (L30G2, L30G3)

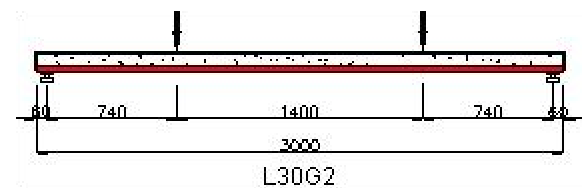
- ✓ Reinforced with 2 and 3% (by weight) of chopped glass fibre
- ✓ Single 8mm square rebar
- ✓ Length of panel = 3000 mm
- ✓ Four point loads test

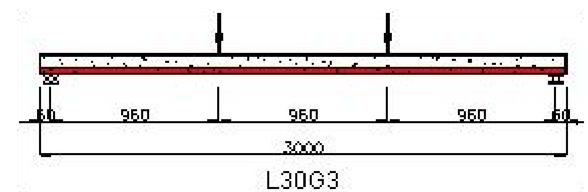


- Both panels failed due to the shear

Test Results: Shear capacity







RILEM TC162-TDF

$$V_c = V_{cd} + V_{fd} + V_{wd}$$

$$V_{cd} = \left[0.12k\left(100\rho_1 f_{ck}\right)^{1/3} + 0.15\sigma_{cp}\right] \cdot b_w d$$

$$V_{fd} = 0.7 k_f k_l \tau_{fd} b_w d$$

$$V_{wd} = \frac{A_{sw}}{s} 0.9 d f_{ywd} (1 + \cot\alpha) \sin\alpha$$

✓ RILEM recommendation shown to offer the least conservative estimate of shear resistance

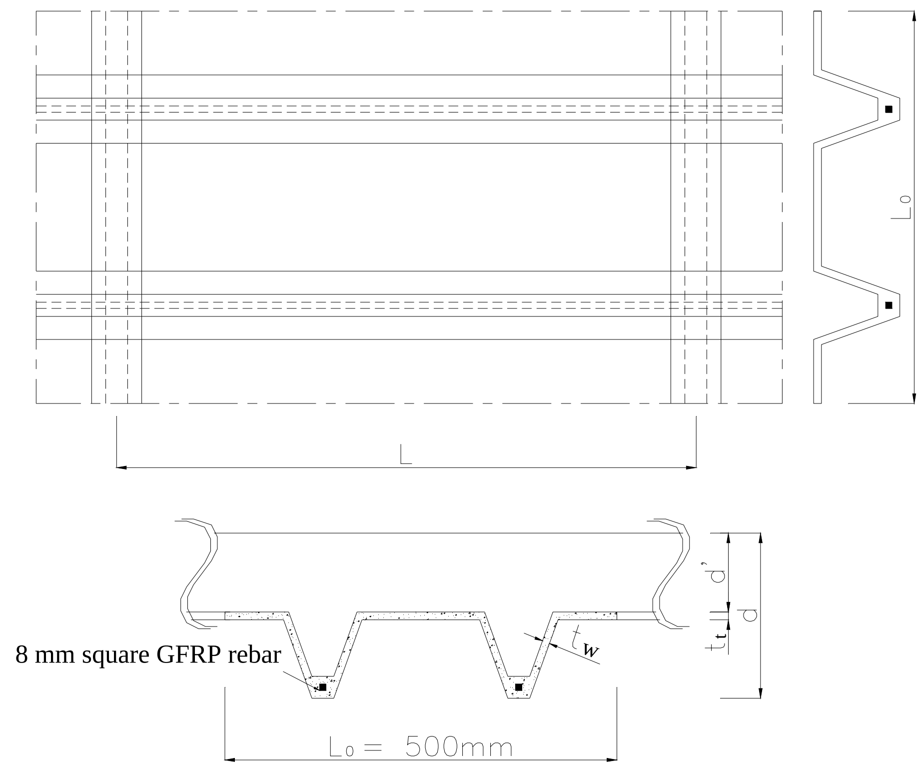
Design thin FRP GFRC

- ‘Type W_1’ = 10mm
- ‘Type W_2’ = 20mm
- ‘Type W_3’ = 20mm

- L_d=200 (typical of buildings)
- L_d=500 (typical of bridges)

- For the cracked section, the crack widths and deflections are calculated by using the ACI 440 equations
- Shear capacity is calculated by using the RILEM TC162.

Type W



Analysis of thin FRP GFRC

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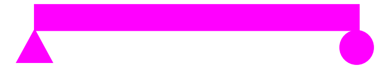
Type W_1 (t_w =10mm, t_t = 10mm)



	Ww (kg/m)	I (mm^4)	y_b (mm)	y_t (mm)	f_t (MPa)	M_{sag} (kN-m)	M_{hog} (kN-m)	$L_{d=200}$ (mm)	$L_{d=500}$ (mm)
Type W1	16.73	11952871	67.9	42.1	6	1.06	1.70	1461	870
					10	1.76	2.83	1886	1124
					14	2.47	3.98	2232	1329
Type W2	24.06	14010167	68.2	41.8	6	1.23	2.00	1578	940
					10	2.05	3.34	2037	1214
					14	2.88	4.69	2410	1436
Type W3	30.32	15916310	72.7	37.3	6	1.31	2.55	1629	970
					10	2.19	4.26	2103	1253
					14	3.07	5.98	2488	1482

GFRP square rebar (mm)	f_t (MPa)	Flexure		Shear		Deflection (<L/250)	Crack width (<0.5)
		M_{ult} (kN-m)	$L_{d=200}$ (mm)	$P_{ult,}$ (kN)	$L_{d=200}$ (mm)	$L_{d=200}$ (mm)	$L_{d=200}$ (mm)
8	6	5.44	3315			2700	
	10	6.03	3491	6.92	3496	3200	2600
	14	6.58	3645			3500	
10	6	6.03	3492			2900	
	10	6.52	3630	7.66	3871	3200	4400
	14	6.97	3754			3700	
12	6	6.54	3634			3200	
	10	6.94	3746	8.36	4221	3400	5400
	14	7.32	3846			3600	

For slabs up to 200mm thick (Building)

2.23m

3.85m

For slabs up to 500mm thick (Bridge)

1.33m

- Beyond 2.6m, it could have problems with deflection and or cracking, as shown Table.

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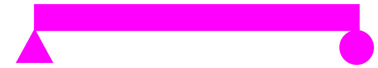
Type W_2 (t_w =20mm, t_t = 10mm)



	Ww (kg/m)	I (mm^4)	y_b (mm)	y_t (mm)	f_t (MPa)	M_{sag} (kN-m)	M_{hog} (kN-m)	$L_{d=200}$ (mm)	$L_{d=500}$ (mm)
Type W1	16.73	11952871	67.9	42.1	6	1.06	1.70	1461	870
					10	1.76	2.83	1886	1124
					14	2.47	3.98	2232	1329
Type W2	24.06	14010167	68.2	41.8	6	1.23	2.00	1578	940
					10	2.05	3.34	2037	1214
					14	2.88	4.69	2410	1436
Type W3	30.32	15916310	72.7	37.3	6	1.31	2.55	1629	970
					10	2.19	4.26	2103	1253
					14	3.07	5.98	2488	1482

For slabs up to 200mm thick (Building)

2.41m

For slabs up to 500mm thick (Bridge)

1.43m

2.66m

GFRP square rebar (mm)	f_t (MPa)	Flexure		Shear		Deflection (<L/250)	Crack width (<0.5)
		M_{ult} (kN-m)	$L_{d=500}$ (mm)	$P_{ult,}$ (kN)	$L_{d=500}$ (mm)	$L_{d=500}$ (mm)	$L_{d=500}$ (mm)
8	6	7.11	2258	8.19	1468	1800	
	10	8.07	2405			2000	2100
	14	8.96	2534			2200	
10	6	7.87	2375	9.13	1637	1900	
	10	8.69	2496			2100	3500
	14	9.44	2601			2200	
12	6	8.54	2474	10.02	1795	2100	
	10	9.23	2572			2200	4200
	14	9.87	2660			2300	

- Beyond 1.8m, it will have problems with deflection and possible cracking, as shown Table.

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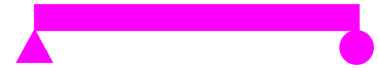
Type W_3 (t_w =20mm, t_t = 20mm)



	Ww (kg/m)	I (mm^4)	y_b (mm)	y_t (mm)	f_t (MPa)	M_{sag} (kN-m)	M_{hog} (kN-m)	$L_{d=200}$ (mm)	$L_{d=500}$ (mm)
Type W1	16.73	11952871	67.9	42.1	6	1.06	1.70	1461	870
					10	1.76	2.83	1886	1124
					14	2.47	3.98	2232	1329
Type W2	24.06	14010167	68.2	41.8	6	1.23	2.00	1578	940
					10	2.05	3.34	2037	1214
					14	2.88	4.69	2410	1436
Type W3	30.32	15916310	72.7	37.3	6	1.31	2.55	1629	970
					10	2.19	4.26	2103	1253
					14	3.07	5.98	2488	1482

GFRP square rebar (mm)	f_t (MPa)	Flexure		Shear		Deflection (<L/250)	Crack width (<0.5)
		M_{ult} (kN-m)	$L_{d=500}$ (mm)	$P_{ult,}$ (kN)	$L_{d=500}$ (mm)	$L_{d=500}$ (mm)	$L_{d=500}$ (mm)
8	6	8.44	2460	9.17	1644	1900	2100
	10	9.75	2644			2100	
	14	10.96	2803			2300	
10	6	9.33	2586	10.27	1841	2000	3500
	10	10.45	2737			2200	
	14	11.48	2869			2300	
12	6	10.12	2693	11.30	2026	2200	4200
	10	11.08	2818			2300	
	14	11.97	2929			2400	

For slabs up to 200mm thick (Building)

2.49m

For slabs up to 500mm thick (Bridge)

1.48m

2.93m

- Beyond 1.9m, it will have problems with deflection and possible cracking, as shown Table.

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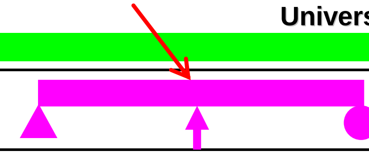
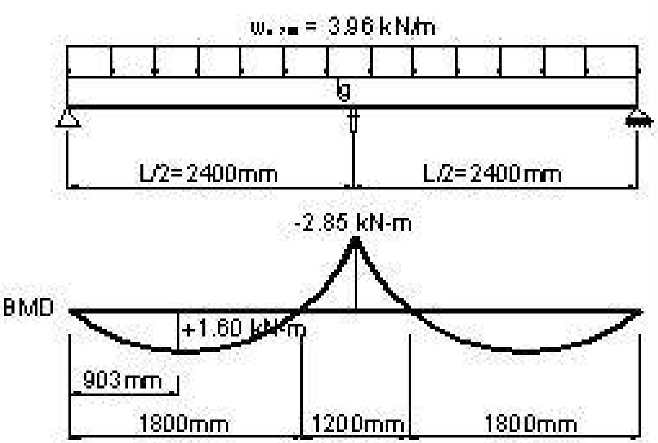
Hogging Moment !!

For slabs up to 200mm thick (Building)

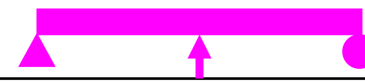




W1

4.8m EBR → 10.0m

For slabs up to 500mm thick (Bridge)



W2

3.1m EBR → 7.0m

W3

3.8m EBR → 7.8m

Conclusions

- **For design purposes for FRP RC GFRC**
  - Modified ACI 440 equation can be used for deflections and crack widths
  - Modified RILEM TC162 equations can be used for shear
- **For building slabs up to 200mm thick, W shape**
  - Without reinforcement SS up to 2.23m; Reinforced up to 3.85m,
  - With intermediate support and EBR, a total span of 10m is possible.
  - **A 3.29m by 0.5m panel weights less that 55kg and can be put in place by two men**
  - **For bridge slabs up to 500mm thick,**
  - Without reinforcement SS up to 1.43m; Reinforced up to 2.66m,
  - With intermediate support and EBR, a total span of 7.8m is possible.

Thank you for your attention !!