Flexural behaviour of BFRP rebar reinforced concrete beams

Rudzinskis, E.

1. Appendices

10.01 **Basalt Rebar Tensile Test**

Photo 1 *– BFRP Rebar Sample Ends Sheared Off During Tensile Strength Test.*

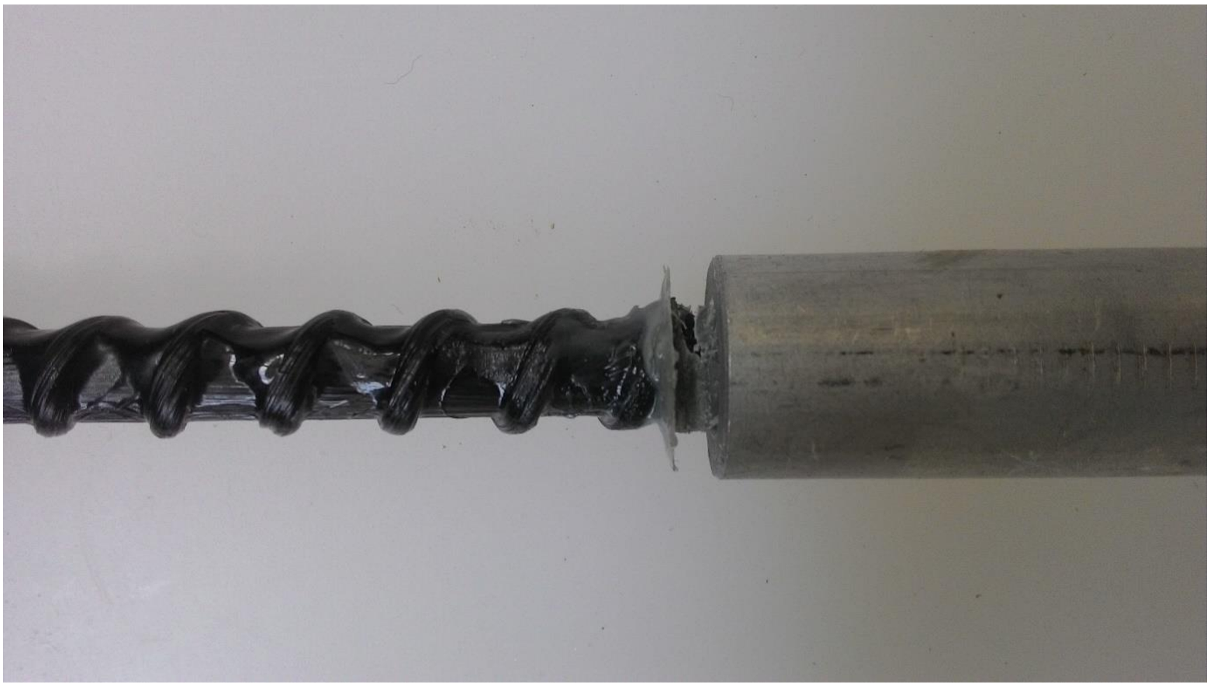


Photo 2 *– BFRP Rebar Pulled Out from Aluminium Encasement.*

Photo 3 *- Extensometer BFRP Rebar Inside The Testing Machine*

Photo 4 – *BFRP Spiral Sanded Off at Each End. Test Failed by one end crushed.*

Damaged "teeth" on the left-hand side.

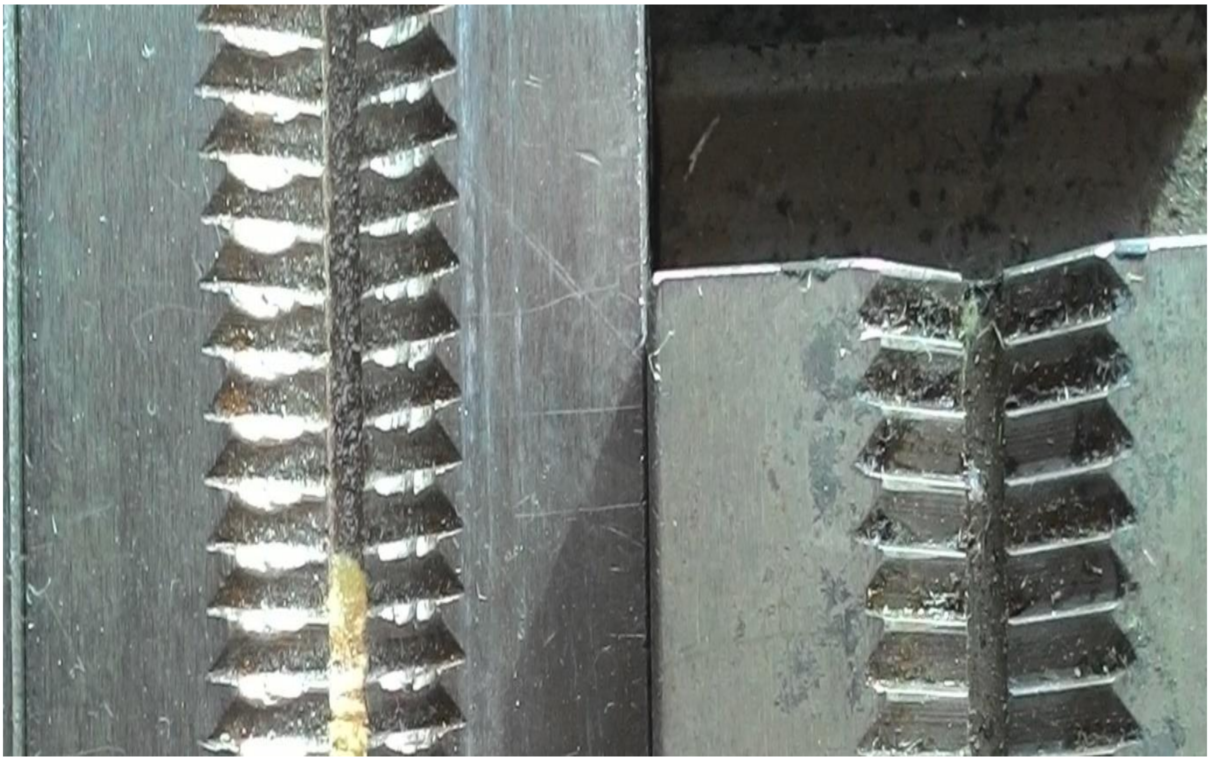


Photo 5 – *Damaged Upper Tensile Strength Testing Machine Clamp.*

10.02 **Concrete Cubes Class C40/50 Mix**

Concrete mix design was based on BS 8500-1-2005+A1 and *"Design of Normal Concrete Mixes"* design manual (refer to list of references).

5 Flow chart of procedures 11

Table 1 Concrete mix design form

Job title: Dissertation

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	Cube: 50 N/mm^2 at 28 days; Proportion defective .... %
	1.2	Standard deviation	Fig 3	0 N/mm^2 or no data - N/mm^2
	1.3	Margin	C1 or Specified	(k = 1.64) .... × .... = ... N/mm^2; .... N/mm^2
	1.4	Target mean strength	C2	0 + 50 = 50 N/mm^2
	1.5	Cement strength class	Specified	42.5/52.5
	1.6	Aggregate type: coarse Aggregate type: fine		Crushed/uncrushed Crushed/uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	.... } Use the lower value: 0.45
	1.8	*Maximum free-water/cement ratio*	*Specified*	....
2	2.1	Slump or Vebe time	Specified	Slump S2, 80 mm or Vebe time .... s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free-water content	Table 3	225 kg/m^3
3	3.1	Cement content	C3	225 ÷ 0.45 = 500 kg/m^3
	3.2	*Maximum cement content*	*Specified*	.... kg/m^3
	3.3	*Minimum cement content*	*Specified*	.... kg/m^3
				use 3.1 if ≤ 3.2 use 3.3 if > 3.1: 500 kg/m^3
	3.4	Modified free-water/cement ratio		....
4	4.1	Relative density of aggregate (SSD)		2.7 known/assumed
	4.2	Concrete density	Fig 5	2375 kg/m^3
	4.3	Total aggregate content	C4	2375 − 500 − 225 = 1650 kg/m^3
5	5.1	Grading of fine aggregate	Percentage passing 600 μm sieve	53 %
	5.2	Proportion of fine aggregate	Fig 6	38 %
	5.3	Fine aggregate content	C5	0.38 × 1650 = 627 kg/m^3
	5.4	Coarse aggregate content	C5	1650 − 627 = 1023 kg/m^3

Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm	20 mm	40 mm
per m^3 (to nearest 5 kg)	500	225	627	341	682	
per trial mix of .... m^3						

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm^2. 1 N/mm^2 = 1 MN/m^2 = 1 MPa. (N = newton; Pa = pascal.)
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

10.03 **Class C28/35 Concrete Design Mix**

Concrete mix design was based on BS 8500-1-2005+A1 and *“Design of Normal Concrete Mixes”* design manual (refer to list of references).

5 Flow chart of procedures 11

Table 1 Concrete mix design form

Job title ...Dissertation...

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	...Cube: 35... N/mm² at ...28... days; Proportion defective ... %
	1.2	Standard deviation	Fig 3	...0... N/mm² or no data ...-... N/mm²
	1.3	Margin	C1 or Specified	(k = ...) ... × ... = ... N/mm²; ... N/mm²
	1.4	Target mean strength	C2	...0... + ...35... = ...35... N/mm²
	1.5	Cement strength class	Specified	42.5/52.5
	1.6	Aggregate type: coarse Aggregate type: fine		Crushed/uncrushed Crushed/uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	...0.68... } Use the lower value [ ]
	1.8	*Maximum free-water/cement ratio*	*Specified*	...
2	2.1	Slump or Vebe time	Specified	Slump ...S2, 80... mm or Vebe time ... s
	2.2	Maximum aggregate size	Specified	...20... mm
	2.3	Free-water content	Table 3	... 225 kg/m³
3	3.1	Cement content	C3	...225... ÷ ...0.68... = ...330... kg/m³
	3.2	*Maximum cement content*	*Specified*	... kg/m³
	3.3	*Minimum cement content*	*Specified*	... kg/m³
				use 3.1 if ≤ 3.2 use 3.3 if > 3.1 — 330 kg/m³
	3.4	Modified free-water/cement ratio		... [ ]
4	4.1	Relative density of aggregate (SSD)		...2.7... known/assumed
	4.2	Concrete density	Fig 5	...2375... kg/m³
	4.3	Total aggregate content	C4	...2375... – ...330... – ...225... = ...1820... kg/m³
5	5.1	Grading of fine aggregate	Percentage passing 600 μm sieve	...53... %
	5.2	Proportion of fine aggregate	Fig 6	...42... %
	5.3	Fine aggregate content	C5	...0.42... × ...1820... = 764 kg/m³
	5.4	Coarse aggregate content	C5	...1800... – ...764... = 1056 kg/m³

Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm	20 mm	40 mm
per m³ (to nearest 5 kg)	330	225	765	350	705	...
per trial mix of ...0.065... m³	21.45	14.625	49.725	22.75	45.825	...

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal.)
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

Per 4 beams = 0.18 m3	63.0	40.50	14.5	60.3	119.7

4x (0.2x0.15x1.5) = 4x(Depth x Breadth x Length)

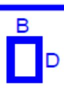


Photo 6–*Aggregate Quantities for Concrete Mix.*

Photo 7 *– Plasticiser "MasterPolyheed"*

Control of Substances Hazardous to Health (COSHH) Assessment

CIVIL AND COASTAL ENGINEERING WITH PLYMOUTH UNIVERSITY

Faculty/Department: Science and Engineering	**School/Section:** School of Engineering / Civil and Coastal Engineering
Assessment No.	**Assessor:** Tony Tapp

Description of procedure or experiment *(Include how long and how often this is carried out and the quantity of substance used)*.	BASF MasterPolyheed 410, a mid range plasticizer admixture based on polycarboxylate ether, used in concrete mixes to increase workability or to lower the water/cement ratio while maintaining workability. Added to a mix at a rate of 0.5 to 2% by weight of cement by incorporating into the final 40% of the mixing water. Product is supplied in 1 litre plastic screw-top container.					
Identify the persons at risk:	Staff	☑	Contractors	☐	Public/students	☑
Name the substance involved in the process, the supplier (*if known*) and the information source.	BASF MasterPolyheed 410, supplied as a light brown coloured alkali liquid which is soluble in water. Supplier: BASF plc, PO Box 4, Earl Road, Cheadle Hulme, Cheadle, Cheshire, SK8 6QG; 0161 485 6222; product-safety-north@basf.com; Emergency: 0049 180 2273 112					

Classification *(state the category of danger, tick all that apply)*

☐ Very Toxic	☑ Irritant	☐ Carcinogenic	☐ Gas under pressure
☐ Toxic	☐ Sensitiser	☐ Highly flammable	
☐ Corrosive	☐ Explosive	☐ Flammable	
☐ Harmful	☐ Oxidising	☐ Environment	

Hazard Type (*tick all that apply*)

Gas	Vapour	Mist	Fume	Dust	Liquid	Solid	Other	*(Details)*
☐	☐	☑	☐	☐	☑	☐	☐	

Route of Exposure (*tick all that apply*)

Inhalation	Skin	Eyes	Ingestion	Other	*(Details)*
☑	☑	☑	☑	☐	

Workplace Exposure Limits (WELs) *please indicate n/a where not applicable*

Long-term exposure level (*8hrTWA*): No limits given.	Short-term exposure level (*15 mins*): No limits given.

State the Risks to Health from Identified Hazards (*include Risk Phrases*)

R36/38 - Irritating to eyes and skin; S37/39 - Wear suitable gloves and eye/face protection.

Control Measures: *(for example extraction, ventilation, training, supervision). Include special measures for vulnerable groups, such as disabled people and pregnant workers. Take account of those substances that are produced from activities undertaken by another employer's employees. (include Safety Phrases)*					
Wear PPE. Avoid aerosol generation.					
Can a less hazardous substance be used ?		Yes	☐	No	☑
If **YES** why is it not being used ?:					
Is health surveillance or monitoring required ?		Yes	☐	No	☑

Personal Protective Equipment *(state type and standard)*			
☐ Dust mask		☑ Visor	To avoid splashes.
☐ Respirator		☑ Goggles	EN166 class 2FT or better.
☑ Gloves	Impermeable / chemical resistant; EN374	☐ Overalls	
☐ Footwear		☐ Other	

First Aid Measures

In all cases seek medical attention if symptoms persist. **Inhalation:** Remove casualty to fresh air. **Skin contact:** Wipe off immediately; wash with soap and plenty of warm water. Seek medical attention if irritation develops. **Eye contact:** Flush with water for at least 15 minutes. Seek immediate medical attention. **Ingestion:** Rinse mouth, then drink plenty of water; seek medical attention.

Spillage/Uncontrolled Release Procedures

Do not breathe vapours. Wear PPE. Avoid discharge into watercourses or drains. Contain spill and absorb spill with an inert absorbent or cloth; place collected product into suitable container for disposal.

Storage

Store at room temperature in tightly closed original container.

Disposal of Substances & Contaminated Items

Hazardous Waste	Skip	Run to Drain	Return to Supplier	Other	*(Details)*
☐	☑	☐	☐	☐	

Name of Assessor: Tony Tapp	Signed: [signature]	Date: 22/12/2016
Name of Safety Manager/ HOS/ HOD:	Signed:	Date:
Review Date:	Signed:	Date:
Review Date:	Signed:	Date:

10.04 **Bar Bending Schedule**

Bending schedule

Bar schedule ref: Rev letter

Job no.

Date prepared: 29/11/2016 Date revised:

Site ref:

Prepared by: E.R. Checked by: D.E

Member	Bar mark	Type & size	No. of mbrs.	No. bars in each	Total no.	Length of each bar (L) mm	Shape code	A° mm	B° mm	C° mm	D° mm	E/r° mm
Top/ Bottom	1	H8			10	1450	00	1450				
Shear Links	2	H8	4	6	24	660	51	100	150			
L-Bars	3	H8	1	4	4	399	11	115	300			

BFRP Rebar COSHH Assessment Form

Material Safety Data Sheet	**Vulkan- Europe B.V.**
Basalt Continuous Filament Fibres	**Continuous Basalt Fibre Distributor**
Date of print : 21-11-2016	

1) Identity and Distributor information. Identity of the Distributor.	Basalt fibre components : yarns , rovings , chopped strands , fabrics , non-woven mats , nets . With epoxy : rebars of different diameters , wall ties and composite mesh. VULKAN Continuous Basalt Fiber Distribution Europe BV. Raesbergenstraat 47 2804TJ Gouda The Netherlands. Tel: +31 182 535520 Mob: +31 6 54 907 214 E-mail : j.dewit@vulkan-europe.com Web site : www.vulkan-europe.com
4. Emergency and First Aid Procedures.	
Inhalation :	No specific treatment is necessary as this material is not likely to be inhaled, unless the material is in dust form : see infra 8.
Skin Contact:	Wash with soap and running water .
Eye contact :	Immediately flush with plenty of water . Get medical attention if problem develops.
Ingestion :	Ingestion of this material is unlikely. If it does occur , get medical attention .

6. Accidental Material Release or Spillage. Personal protective equipment : Environmental protection : Cleaning procedures :	 See infra 8. Prevent spread of basalt fibre dust and avoid dust-generating conditions . Vacuum clean dust. If sweeping is necessary , use a dust suppressant .
8. Exposure Limits and Personal Protective Equipment . Fibrous basalt (Fibrous basalt dust) , CAS No 65997-17-3 . Basalt fibre continuous filament : Size (µm) Personal protective clothing and equipment. Respiratory protection : Protective gloves : Eye protection : Body protection :	OSHA PEL — ACGIV TLV (8 h TWA) — (8 h TWA) 5 mg/m^3 — 5 mg/m^3 (respirable dust) — 1 fibre /cm^3 15 mg/m^3 (total dust) 1 fibre /cm^3 (suggested) N/A — N/A When , through mechanical processing , basalt dust is produced and when the dust levels exceed the recommended levels , use an approved respirator and local exhaust for processing machines . Impervious gloves are recommended. Impervious glasses are recommended. Protect skin as much as possible by clothing.
11. Toxicology.	The basalt continuous filament has a diameter > 5 µm and does not split longitudinally. Only when , through a mechanical process, the filaments are broken into dust particles , is the OSHA standard for nuisance dust of

	application . (if the respirable fraction of 5 mg/m^3 is reached)
12. Ecology.	N/A. Basalt has its origin in nature.
16. Other Information .	All data in the MSDS are based on the current state of knowledge , however they do not certify product properties and they do not justify legal liability. Vulkan- Europe bv. as the distributor cannot control the use of the end-product, the consumer has to determine under which circumstances the product can be used safely, **This Material Safety Data Sheet is exclusively intended for professional use.**

VULKAN Europe BV. Continuous Basalt Fiber Distribution

Raesbergenstraat 47

2804TJ Gouda

The Netherlands.

Tel: +31 182 535520

Mob: +31 6 54 907 214

E-mail : j.dewit@vulkan-europe.com

Web site : www.vulkan-europe.com

10.06 **Reinforcing Cage Photos**

Photo 8 *– BFRP and Steel Reinforcement Setup in Beams B2 andB4.*

Photo 9 *- BFRP and Steel Reinforcement Setup in Beams B1, B2 and B4*

10.07 **Concrete Cube Curing**

Photo 10 *– Concrete (C28/35) Concrete Cube Curing Inside the Water Chamber.*

10.08 **Location of external displacement gauge.**

Photo 11 *– External Vertical Displacement Gauge Location 1.*

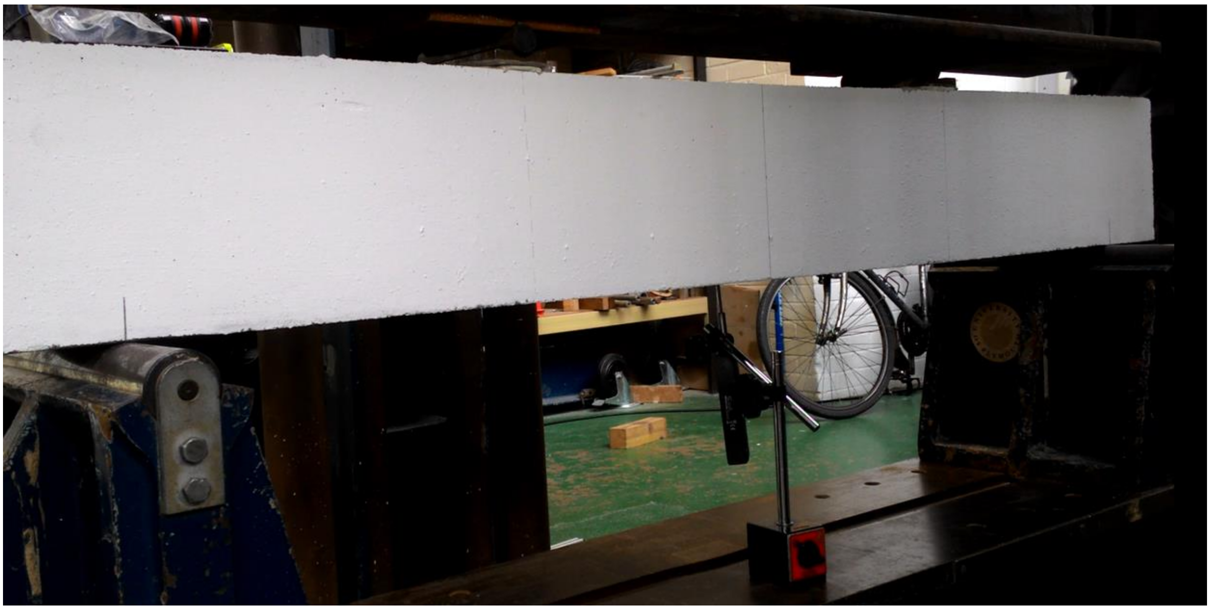
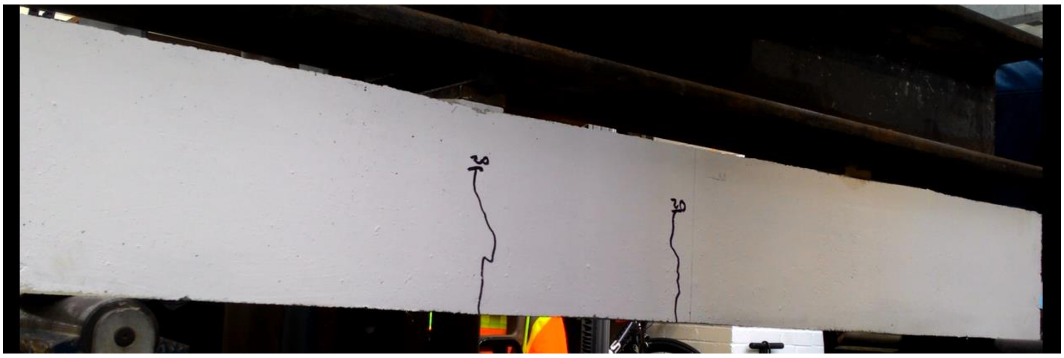


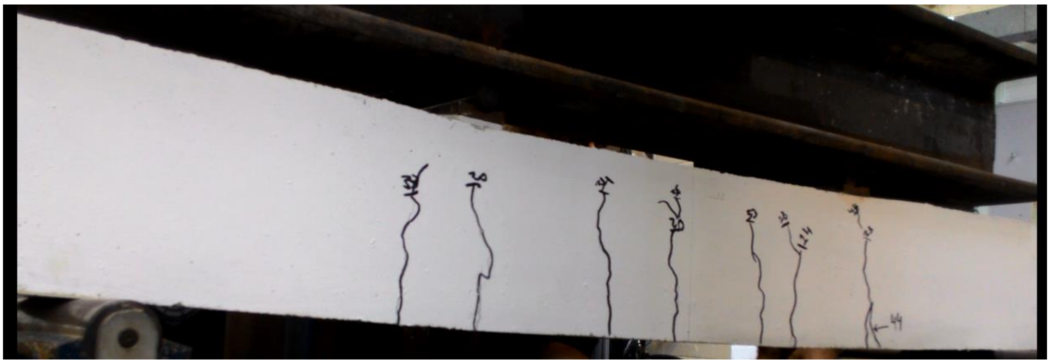
Photo 12 *- External Vertical Displacement Gauge Location 2.*

10.09 Crack Propagation

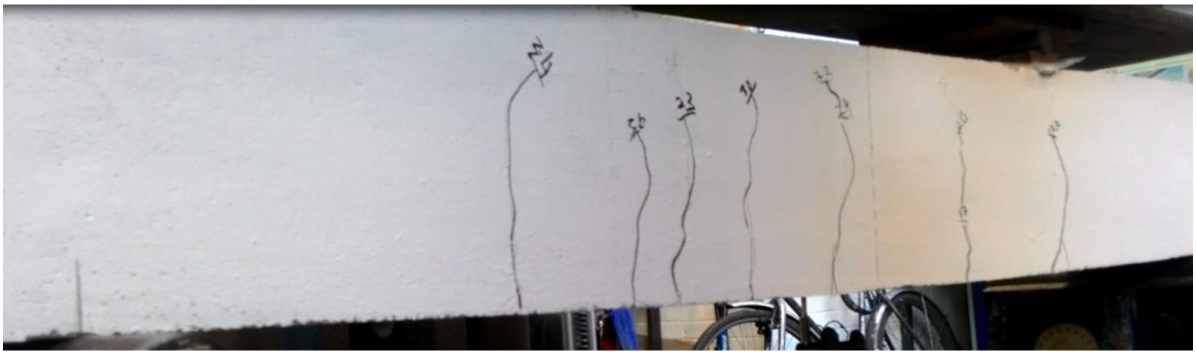
10.09.1 Beam B1 (Control Beam)

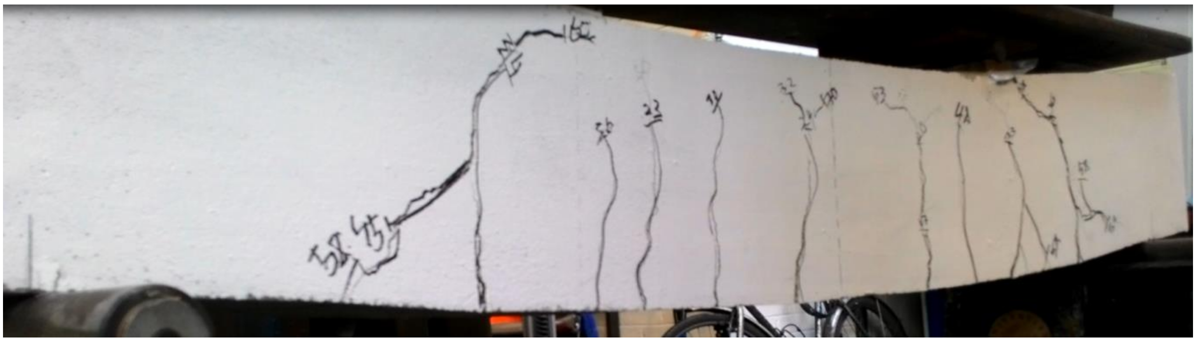
10.09.2 Beam B2



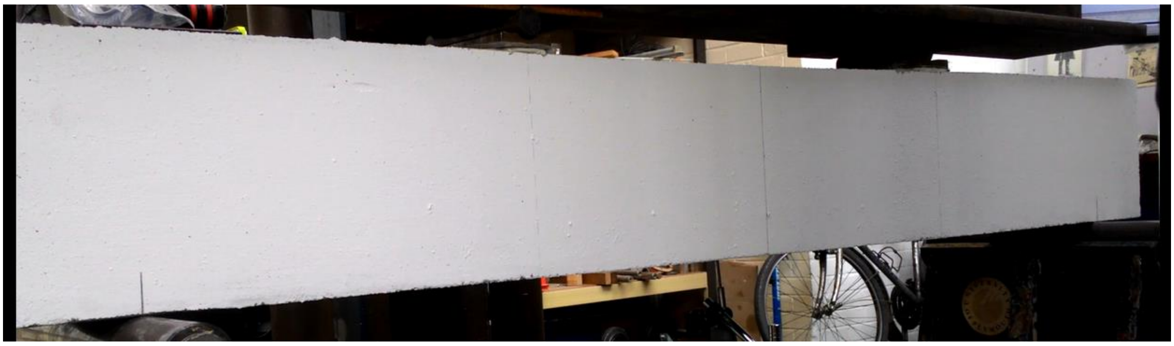


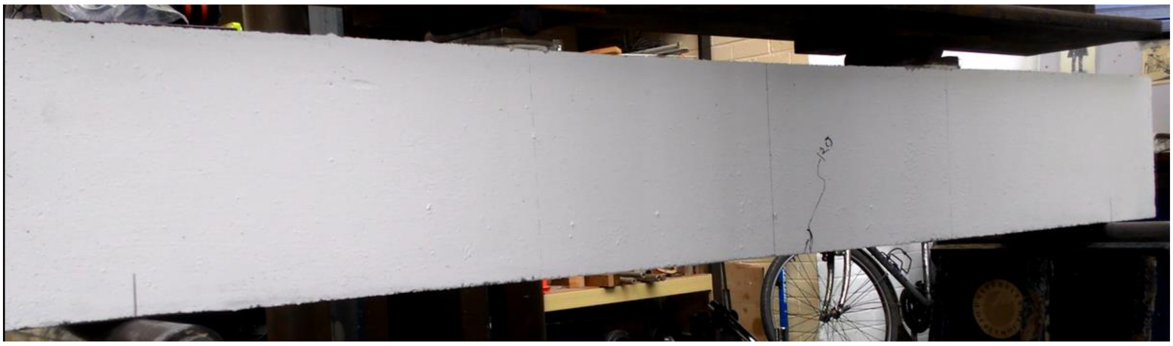
10.09.3 Beam B3

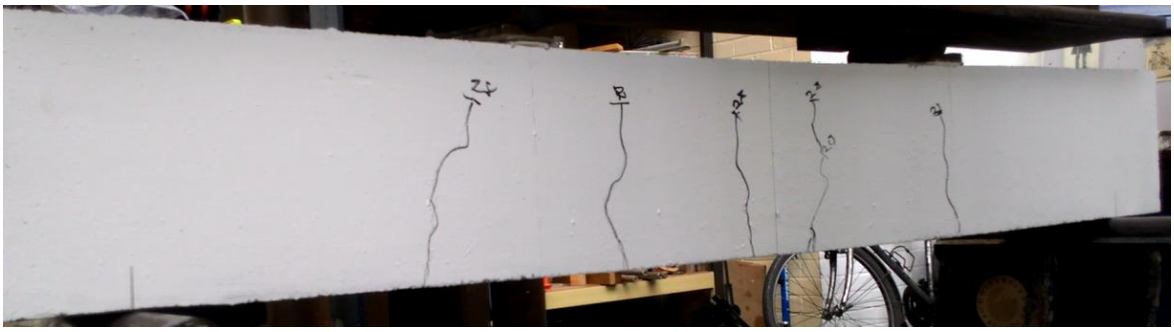


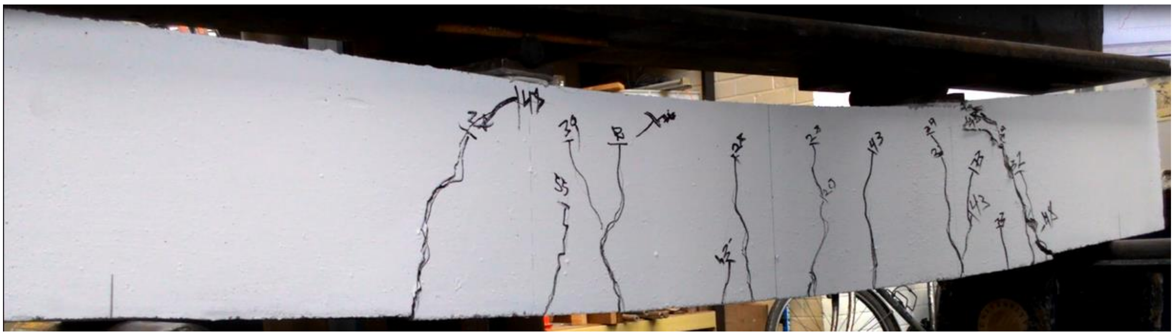


10.09.4 Beam B4

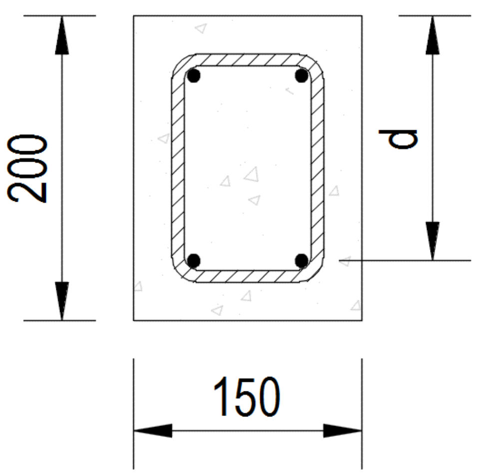








10.10 Steel Ultimate Load Calculations



$$d = h - c_{nom} - \phi_{link} - \phi_{bar}/2$$

d=200-25-8-(8/2)=	163 mm

L=	1.5	(m)
h=	200	(mm)
C_{nom}=	25	(mm)
Ø=	8	(mm)

T= Area of Steel Reinforcement x Allowable Stress=	50.5	**(kN)**

Area of Reinforcement=	101
Allowable Stress=	500
Materials Factor$_{(Concete)}$=	1.00
Materials Factor (Steel)=	1.00

FOR EQUILIBRIUM COMPRESION MUST BE EQUAL TENSION	50.5	(kN)

C=0.8*X*(materials factor*Fck/materials factor) --> X = (C*10^3)/(fck*b)	X=	15.02976	**(mm)**

Statistical Factor=	1
Fck=	28
Section Width (b)=	150
lambda	0.8

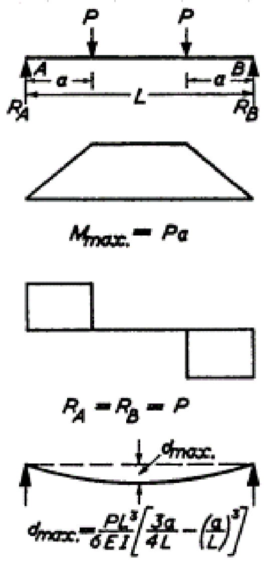
X < 0.45d

0.45d= 73.35

BM Capacity = T*(d-0.8*X/2)

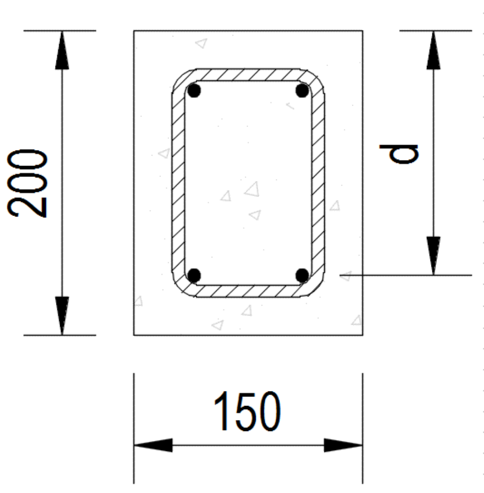
BM Capacity =	**7.93**	**(kNm)**

MB max=Pa		
P in (kN)=	**22.65**	**(kN)**
P_{Total} in (kN)=	**45.30**	**(kN)**



a(m)=	**0.35**	
E=	210000000	
I=	0.00005625	
δ Uncracked(Max)=	0.25	**(mm)**

10.11 BFRP Ultimate Load Calculations



➢ $d = h - c_{nom} - \phi_{link} - \phi_{bar}/2$

d=200-25-8-(8/2)=	163 mm

L=	1.5	(m)
h=	200	(mm)
C_{nom}=	25	(mm)
Ø=	8	(mm)

T= Area of Steel Reinforcement x Allowable Stress=	101	**(kN)**

Area of Reinforcement=	101
Allowable Stress=	1000
Materials Factor=	1

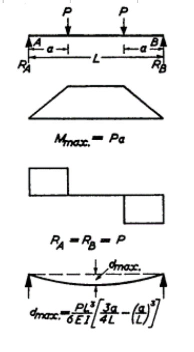
FOR EQUILIBRIUM <u>COMPRESION</u> MUST BE EQUAL <u>TENSION</u>	101	(kN)

C=0.8*X*(materials factor*Fck/materials factor) --> X = (C*10^3)/(fck*b)	X=	30.05952	**(mm)**

Statistical Factor=	1	
Fck=	28	
Section Width (b)=	150	
lambda?	0.8	0.8

X < 0.45d		
0.45d= 73.35		
BM Capacity = T*(d-0.8*X/2)		
BM Capacity =	**15.25**	**(kNm)**
BM=Pa		
P in (kN)=	**43.57**	**(kN)**
P_{Total} in (kN)=	**87.13**	**(kN)**
a(m)=	**0.35**	
E=	50000000	
I=	0.00005625	
δ_{max}=	2.8	**(mm)**

87.13



10.12 Bending Moment and Shear Force Calculation (Beam B4)

PROJECT Dissertation

ELEMENT BFRP BEAM B4

SHEET NO 1

DESIGNED BY E.R.

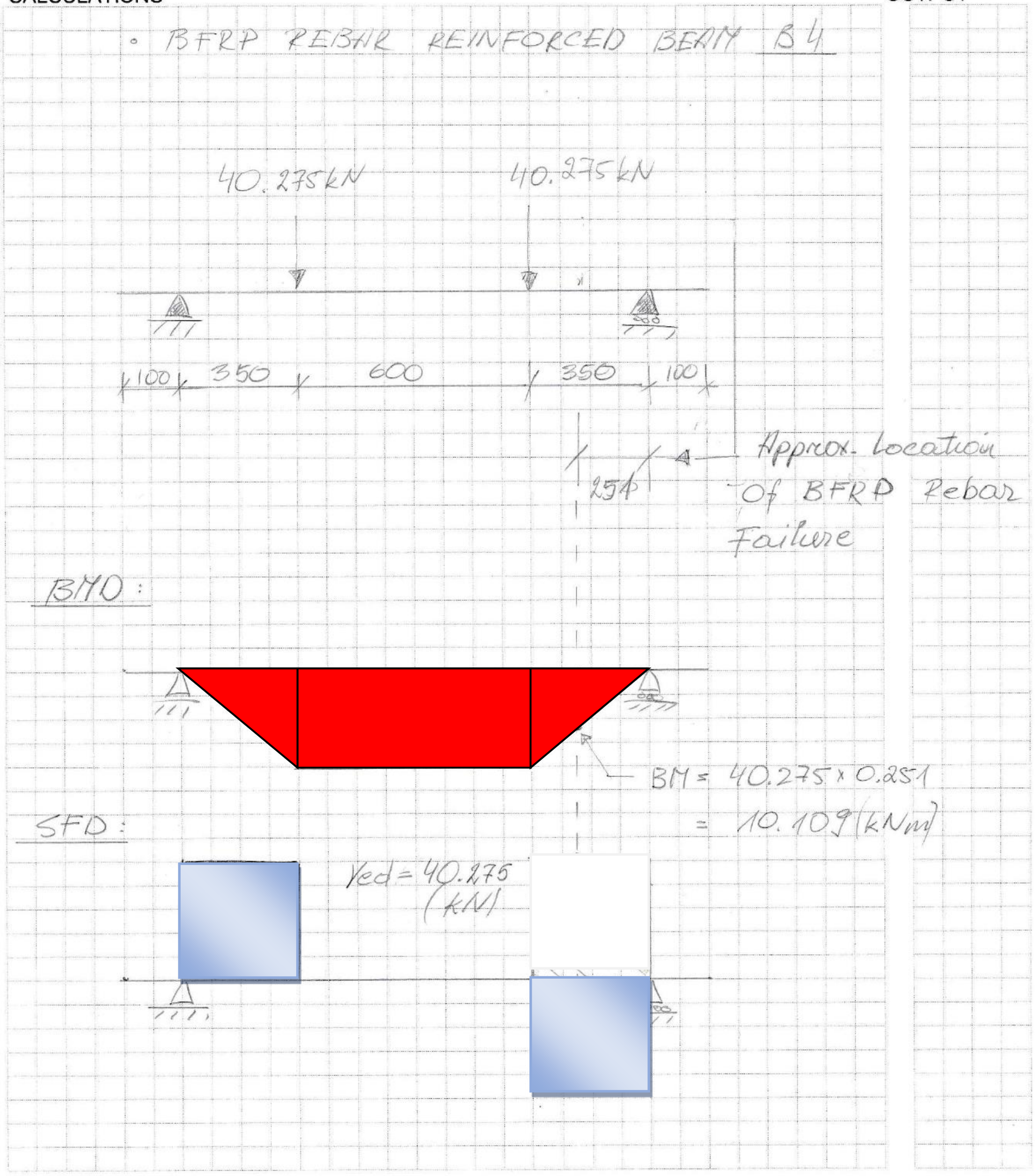
DATE 05/04/2017

MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY

School of Marine Science & Engineering
University of Plymouth
Reynolds Building
Drake Circus
Plymouth
PL4 8AA

CALCULATIONS

OUTPUT



PROJECT Dissertation

ELEMENT BFRP BEAM B4

SHEET NO 2

DESIGNED BY E.K

DATE 05/04/2017

MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY

School of Marine Science & Engineering
University of Plymouth
Reynolds Building
Drake Circus
Plymouth
PL4 8AA

CALCULATIONS | OUTPUT

BENDING CHECK

- $K = \frac{M}{bd^2 f_{ck}}$

$= \frac{10.109 \times 10^6}{150 \times 163^2 \times 28}$ ← C28/35 = 28 N/mm²

$= 0.0906$

- $z = \frac{d}{2}\left[1 + \sqrt{1 - 3.53K'}\right] \leq 0.95d$

- $K \leq K'$ — $K' = 0.168$

$z = \frac{163}{2}\left[1 + \sqrt{1 - 3.53(0.0906)}\right] \leq 0.95(1.63)$

$= 148.72 \leq 154.85$ ✓

- $A_s = \frac{M}{f_{yd} \times z}$

- $f_{yd} = f_{yk}/\gamma_m = \frac{1000}{1}$

$\gamma_m = 1.0$ – since material factor is not established.

PROJECT Dissertation

ELEMENT BFRP Beam B4

SHEET NO 3

DESIGNED BY ER

DATE 05/04/2017

School of Marine Science & Engineering
University of Plymouth
Reynolds Building
Drake Circus
Plymouth
PL4 8AA

CALCULATIONS | OUTPUT

- $f_{yk} = 1000$
- $f_{yd} = 1000/1 = 1000\ N/mm^2$

- $A_s = \dfrac{10.109 \times 10^6}{1000 \times 148.72}$

$= 68\ mm^2 < A_{s,prov}\ (Basalt) = 101\ mm^2$

Calculation above signifies that at point of failure BFRP had more than enough capacity to withstand the tension

Thus this suggest that Beam failure did <u>not</u> occur in bending.

Shear check is required...

PROJECT Dissertation

ELEMENT BFRP BEAM B4

SHEET NO 4

DESIGNED BY E.R.

DATE 05/04/2017

MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY

School of Marine Science & Engineering
University of Plymouth
Reynolds Building
Drake Circus
Plymouth
PL4 8AA

CALCULATIONS | OUTPUT

SHEAR CHECK

$V_{ed} = 40.275\ kN$

- $v_{Ed} = \dfrac{V_{Ed}}{b_w \cdot z}$

$= \dfrac{40.275 \cdot 10^3}{150 \cdot 148.72}$

$= 1.81\ N/mm^2$

- $A_{sw} = \dfrac{v_{Ed} \times b_w \times S}{f_{ywd} \times \cot\theta}$

$= \dfrac{1.81 \times 120 \times 150}{435 \times 2.5}$

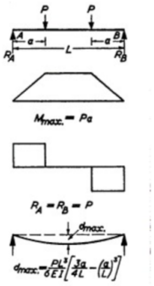
$= 30\ mm^2$

- 3 H8 links provide: $151\ mm^2 > 30\ mm^2$

This signifies that at the point of failure shear links had more than enough capacity to withstand shear force applied.

10.13 Un-cracked Section Deflection Calculations

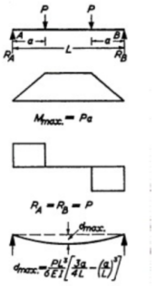
P_{Total} in (kN)=	8	(kN)
Length (m)=	1.3	
a(m)=	0.35	
E=	30000000	
I=	0.00005625	
δ $_{max}$=	Variable	(mm)



Beam B1

Experimental Load Applied (kN)	Actual Deflection Recorded by External Gauge (mm)	Predicted Deflection (mm)	Difference (mm)	%
4	0.11	0.10	0.01	4.6
8	0.18	0.18	0.01	4.9
12	0.25	0.26	0.01	5.3
16	0.36	0.34	0.02	4.9
20	0.48	0.42	0.06	12.2

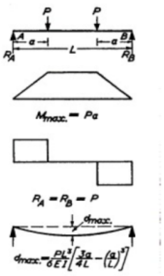
P_{Total} in (kN)=	8	(kN)
Length (m)=	1.3	
a(m)=	0.35	
E=	30000000	
I=	0.00005625	
δ $_{max}$=	Variable	(mm)



Beam B2

Experimental Load Applied (kN)	Actual Deflection Recorded by External Gauge (mm)	Predicted Deflection (mm)	Difference (mm)	%
4	0.1	0.10	0.00	4.9
8	0.18	0.18	0.00	2.2
12	0.27	0.26	0.01	2.5
16	0.41	0.34	0.07	16.5
20	1.28	0.42	0.86	67.1

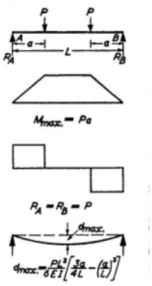
P_{Total} in (kN)=	8	(kN)
Length (m)=	1.3	
a(m)=	0.35	
E=	30000000	
I=	0.00005625	
δ $_{max}$=	Variable	(mm)



Beam B3

Experimental Load Applied (kN)	Actual Deflection Recorded by External Gauge (mm)	Predicted Deflection (mm)	Difference (mm)	%
4	0.1	0.10	0.00	4.9
8	0.18	0.18	0.00	2.2
12	0.26	0.26	0.00	1.2
16	0.36	0.34	0.02	4.9
20	0.5	0.42	0.08	15.7

P_{Total} in (kN)=	8	(kN)
Length (m)=	1.3	
a(m)=	0.35	
E=	30000000	
I=	0.00005625	
δ $_{max}$=	Variable	(mm)



Beam B4

Experimental Load Applied (kN)	Actual Deflection Recorded by External Gauge (mm)	Predicted Deflection (mm)	Difference (mm)	%
4	0.1	0.10	0.00	4.9
8	0.175	0.18	0.01	5.2
12	0.26	0.26	0.00	1.2
16	0.36	0.34	0.02	4.9
20	0.5	0.42	0.08	15.7

10.14 Cracked Section Deflection Calculations

neutral axis position

x= 30.1

bii **second moment of area of the cracked section**

Icr = bx^3/3+aeAS(d-x)^2

b=	150 mm				
ae=	5.81	E=	50 N/mm2	Ec,eff=	8.61 kN/mm2
As=	101				
d=	163				

Icr= 11723848.4 mm4

biii **Curvature Cracked Section**

(1/r)cr = M/Ec,eff Icr

M= 15.25 kNm

Ec,eff= 8.61 kN/mm2

(1/r)cr = 1.51E-04 /mm

c **The Average of cracked and uncracked curvature**

ci Mcr= $f_{ctm}*(b_w h^2/6)$

fctm= 2.8 N/mm2 or Mpa
bw= 150 mm
h2= 40000 mm2

Mcr= 2.8 kNm

cii ε = 1-β(Mcr/M)^2

β = 1 (assumed for a singe short-term load). Also for sustained loads or cyclic loading is 0.5

ε = 0.966

ciii 1/r= ε(1/r)cr+(1-ε)(1/r)uc

(1/r)uc= M/Ec,eff * Iuc
Iuc= bd^3/12 b= 150 d= 200
Iuc= 100000000 mm4

(1/r)uc= 1.77103E-05 /mm

1/r= 1.47E-04

The deflection of the beam can be calculated from the total curvature using elastic bending theory which for small deflections is based on the expression:

$$M = \frac{EId^2y}{dx^2}$$

$$\frac{EIdy}{dx} = Mx + A$$

$$A - constant\ of\ integration$$

$$A + x = \frac{L}{2}\frac{dy}{dx} = 0$$

$$.: A = \frac{-ML}{2}$$

$$-EIy = \frac{Mx^2}{2} + Ax + B$$

$$B - constant\ of\ integration$$

$$-EIy = \frac{Mx^2}{2} - \frac{MLx}{2} + B$$

$$when\ x = 0\ and\ y = 0$$

$$B = 0$$

$$y = \frac{M}{EI}\left(\frac{x^2}{2} - \frac{Lx}{2}\right)$$

$$Maximum\ Deflection\ Occurs\ at\ Midspan\ When\ x = \frac{L}{2}$$

$$y = -\frac{M}{EI}\left(\frac{L^2}{8}\right)$$

$$substitue\ -\frac{M}{EI}\ with\ \frac{1}{r}\ (refer\ to\ ciii)$$

$$y = \frac{1}{r}\left(\frac{L^2}{8}\right)$$

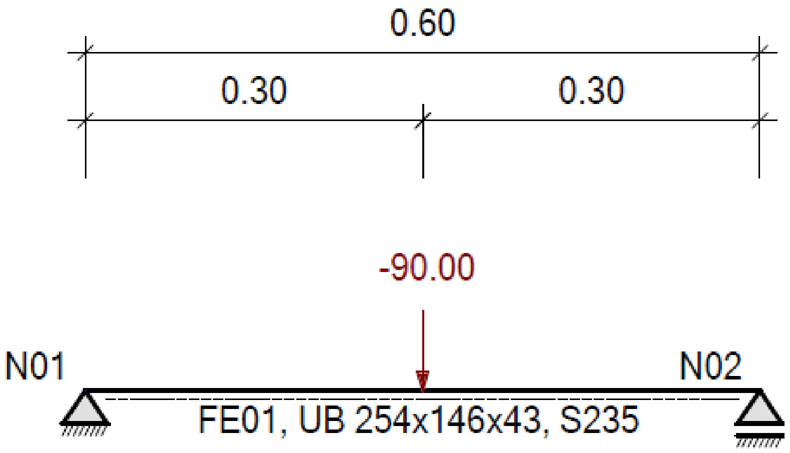
$$y = 1.47 * 10^{-4}\left(\frac{1300^2}{8}\right)$$

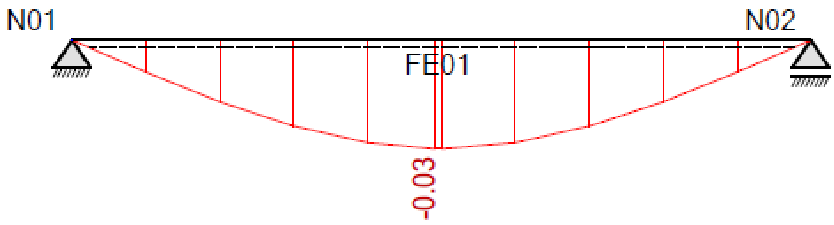
$$y = 31.0\ mm$$

10.15 **Transverse Steel Beam Deflection**

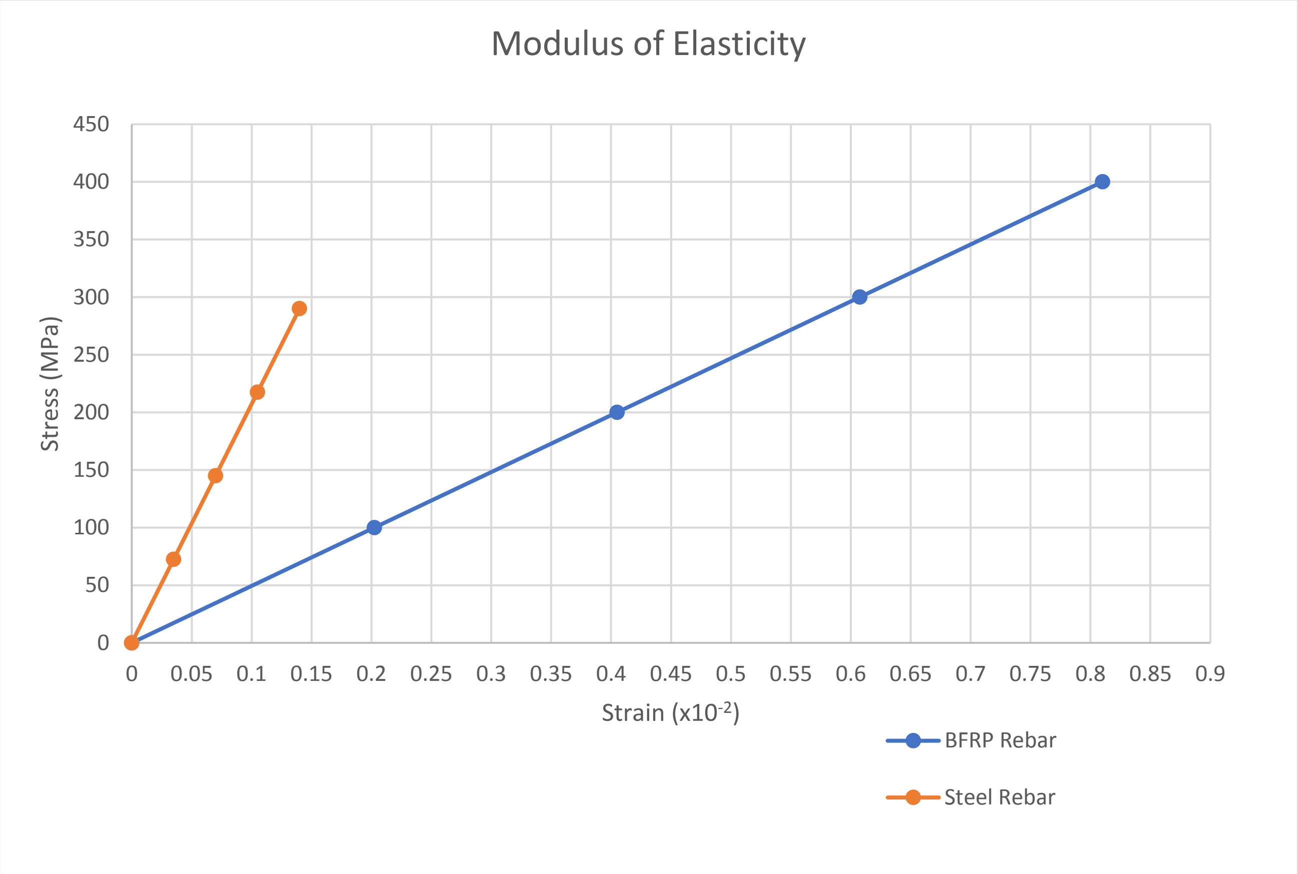
Analysis undertaken using Two-Frame Structural Analysis software.

(Deflection Units in mm; External Load in kN)





10.17 **Tensile Strength Test Modulus of Elasticity**



***Graph 1** – Experimental Steel and BFRP Rebar Modulus of Elasticity.*

Basalt Rebar Modulus of Elasticity:

$$E = \frac{Stress}{Strain} = \frac{400}{.0.0081} = 49383\ MPa = \mathbf{49.4}\ kN/mm^2$$

Steel Rebar Steel Modulus of Elasticity:

$$E = \frac{Stress}{Strain} = \frac{290}{.0.0014} = 207143\ MPa = \mathbf{207.1}\ kN/mm^2$$