2017

# Flexural behaviour of BFRP rebar reinforced concrete beams

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# 1. Appendices

## 10.01 Basalt Rebar Tensile Test

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

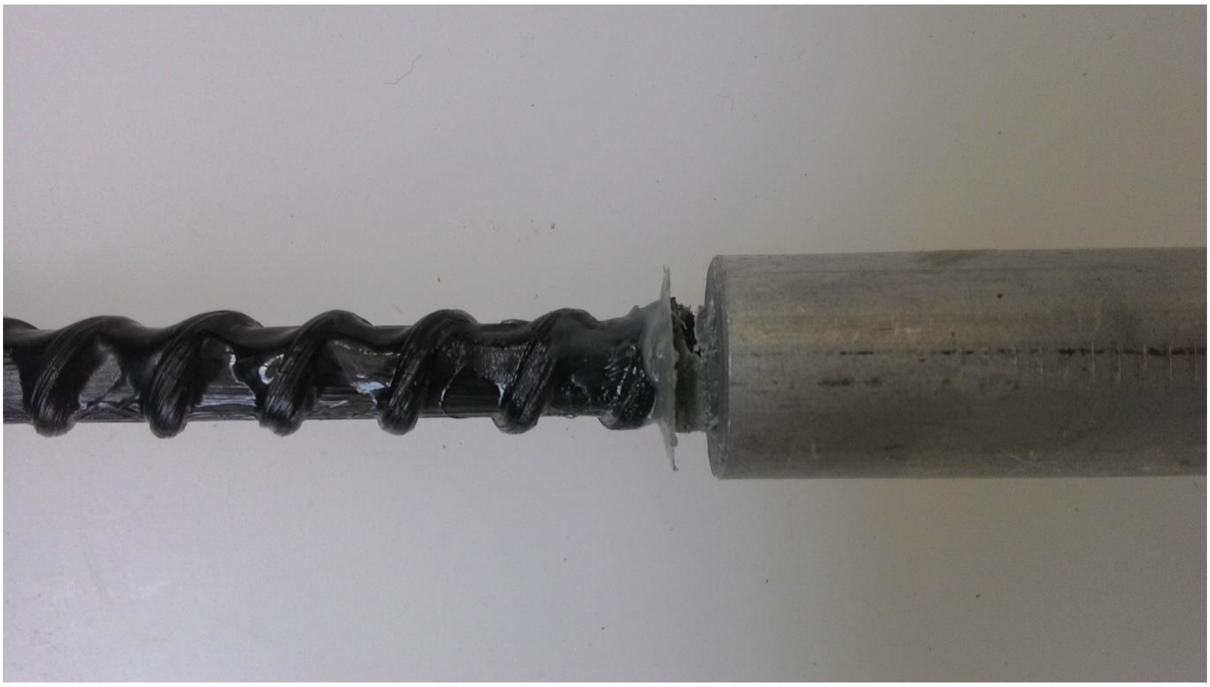

***Photo 2*** *– BFRP Rebar Pulled Out from Aluminium Encasement.*

***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.**

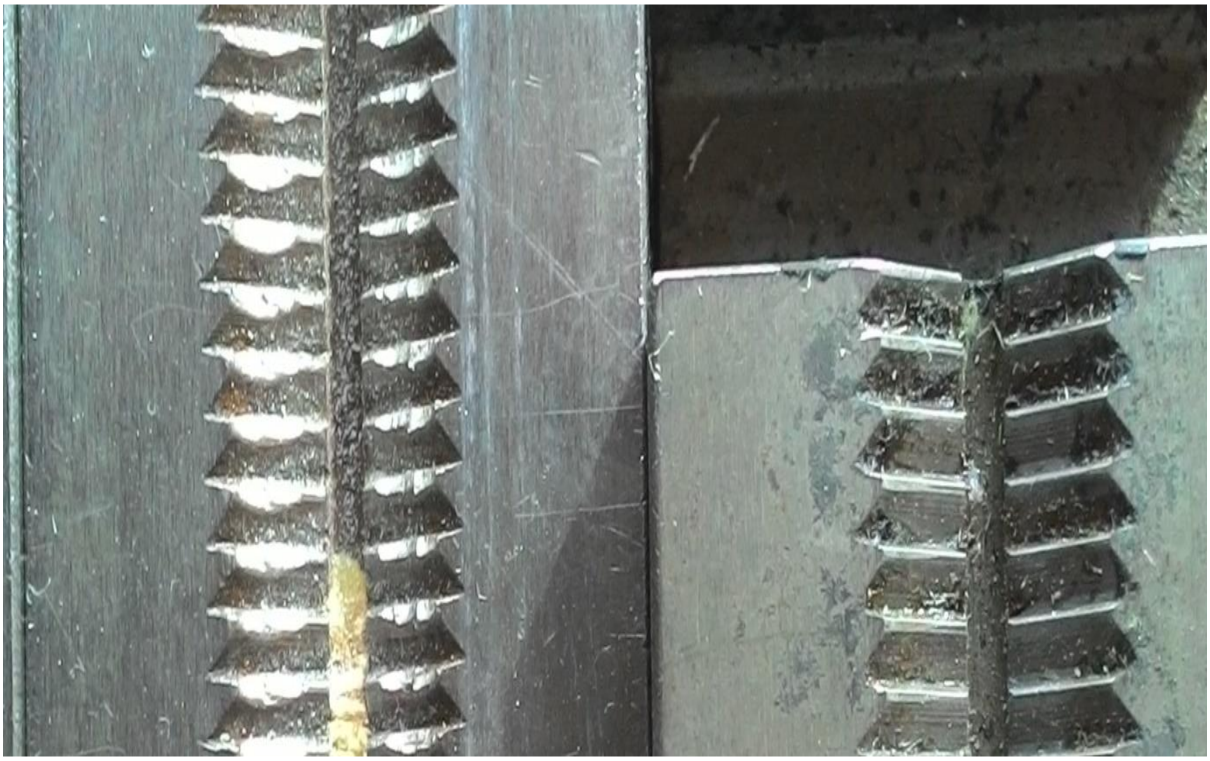

***Photo 5 –*** *Damaged Upper Tensile Strength Testing Machine Clamp.*

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/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 = 1.64) ... × ... = ... N/mm²; ... N/mm² |
| | 1.4 | Target mean strength | C2 | 0 + 50 = 50 N/mm² |
| | 1.5 | Cement strength class | Specified | 42.5/52.5 |
| | 1.6 | Aggregate type: coarse<br>Aggregate type: fine | | Crushed/uncrushed<br>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/m³ |
| 3 | 3.1 | Cement content | C3 | 225 ÷ 0.45 = 500 kg/m³ |
| | 3.2 | *Maximum cement content* | *Specified* | ... kg/m³ |
| | 3.3 | *Minimum cement content* | *Specified* | ... kg/m³ |
| | | | | use 3.1 if ≤ 3.2<br>use 3.3 if > 3.1 — 500 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 − 500 − 225 = 1650 kg/m³ |
| 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/m³ |
| | 5.4 | Coarse aggregate content | C5 | 1650 − 627 = 1023 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) | 500 | 225 | 627 | 341 | 682 | ... |
| per trial mix of ... m³ | ... | ... | ... | ... | ... | ... |

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.

## 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).**



**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<br>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<br>........ 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<br>Aggregate type: fine | | Crushed/uncrushed<br>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<br>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)

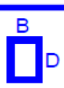

***Photo 6****–Aggregate Quantities for Concrete Mix.*


***Photo 7*** *– Plasticiser "MasterPolyheed"*

CIVIL AND COASTAL ENGINEERING WITH PLYMOUTH UNIVERSITY

# Control of Substances Hazardous to Health (COSHH) Assessment

| | |
|---|---|
| **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 | |

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| 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.

Site ref:

Date prepared: 29/11/2016

Date revised:

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 | | | |
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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. | Basalt fibre components :<br>yarns , rovings , chopped strands , fabrics , non-woven mats , nets .<br>With epoxy : rebars of different diameters , wall ties and composite mesh. |
| Identity of the Distributor. | Raesbergenstraat 47<br>2804TJ Gouda<br>The Netherlands.<br>Tel: +31 182 535520<br>Mob: +31 6 54 907 214<br>E-mail : j.dewit@vulkan-europe.com<br>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 .<br>Get medical attention if problem develops. |
| Ingestion : | Ingestion of this material is unlikely.<br>If it does occur , get medical attention . |

| | |
|---|---|
| 6. Accidental Material Release or Spillage.<br><br>Personal protective equipment :<br><br>Environmental protection :<br><br>Cleaning procedures : | <br><br>See infra 8.<br><br>Prevent spread of basalt fibre dust and avoid dust-generating conditions .<br><br>Vacuum clean dust. If sweeping is necessary , use a dust suppressant . |
| 8. Exposure Limits and Personal Protective Equipment .<br><br>Fibrous basalt ( Fibrous basalt dust ) , CAS No 65997-17-3 .<br><br>Basalt fibre continuous filament :<br><br>Size ( µm)<br><br>Personal protective clothing and equipment.<br><br>Respiratory protection :<br><br>Protective gloves :<br><br>Eye protection :<br><br>Body protection : | OSHA PEL ACGIV TLV<br>( 8 h TWA ) ( 8 h TWA)<br>5 mg/m$^3$ 5 mg/m$^3$<br>( respirable dust ) 1 fibre /cm$^3$<br>15 mg/m$^3$<br>(total dust )<br>1 fibre /cm$^3$<br>( suggested )<br><br>N/A N/A<br><br>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 .<br><br>Impervious gloves are recommended.<br><br>Impervious glasses are recommended.<br><br>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.<br>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.*

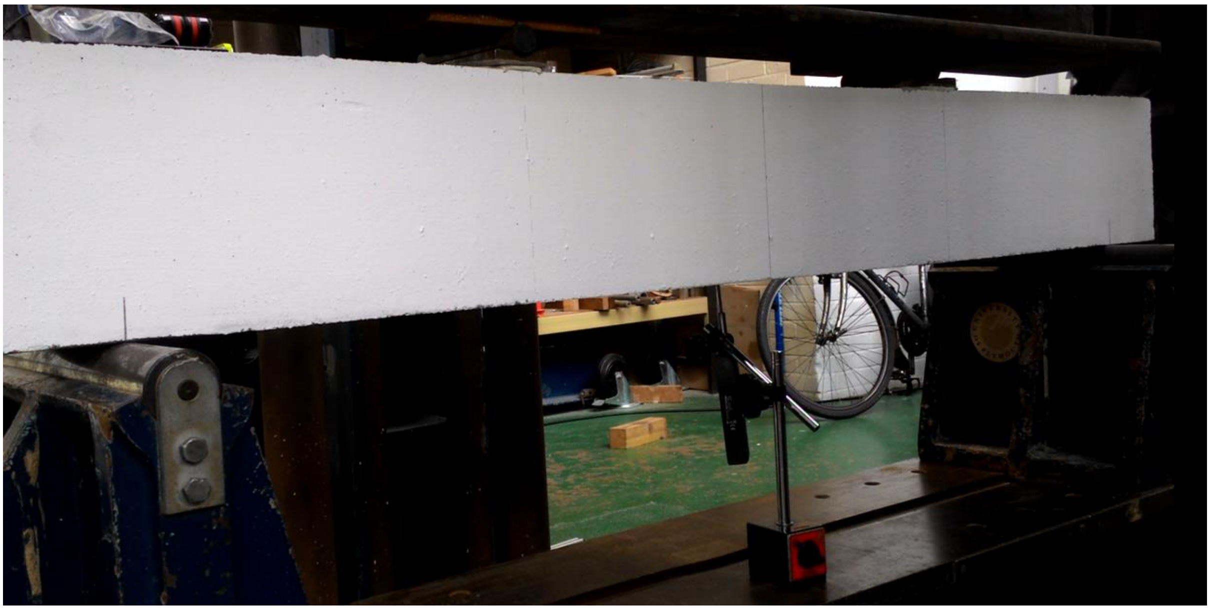
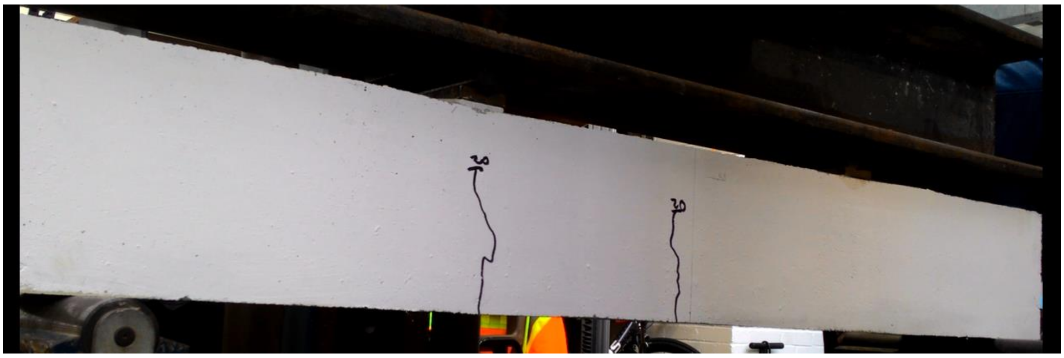


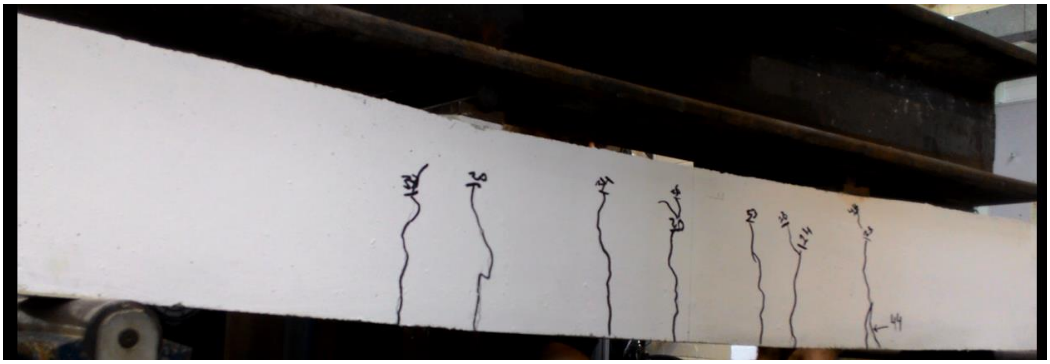
***Photo 12*** *- External Vertical Displacement Gauge Location 2.*

## 10.09 Crack Propagation

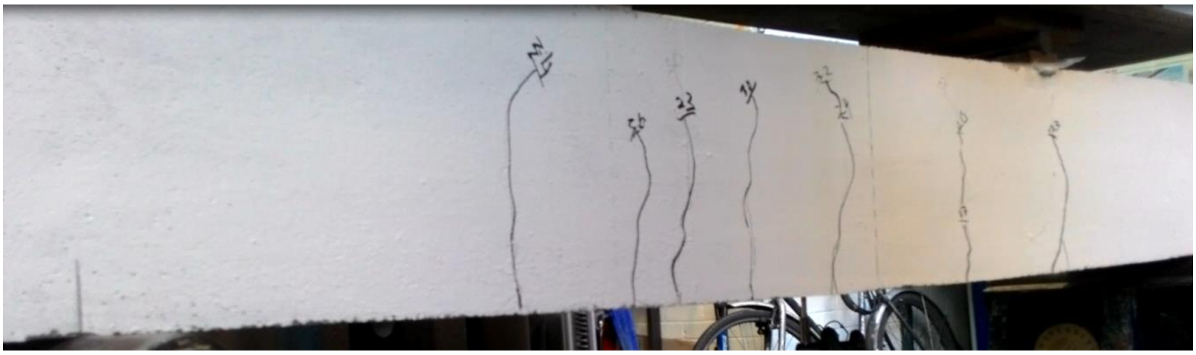
### *10.09.1 Beam B1 (Control Beam)*

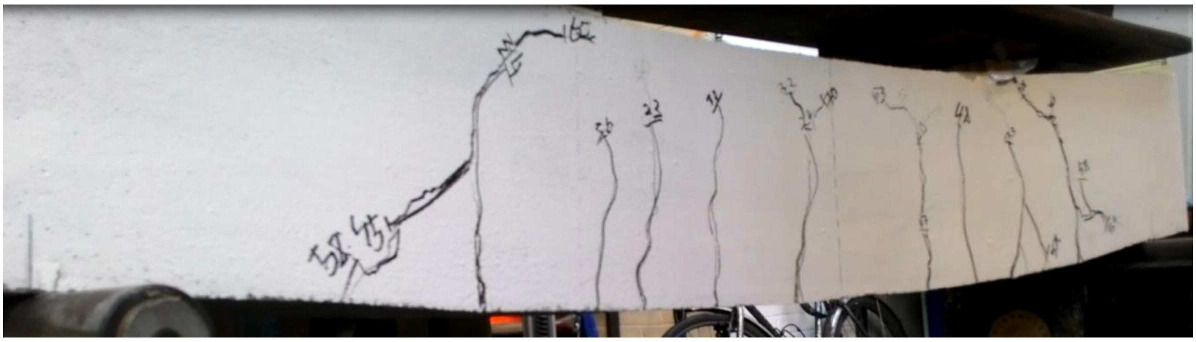
*10.09.2 Beam B2*



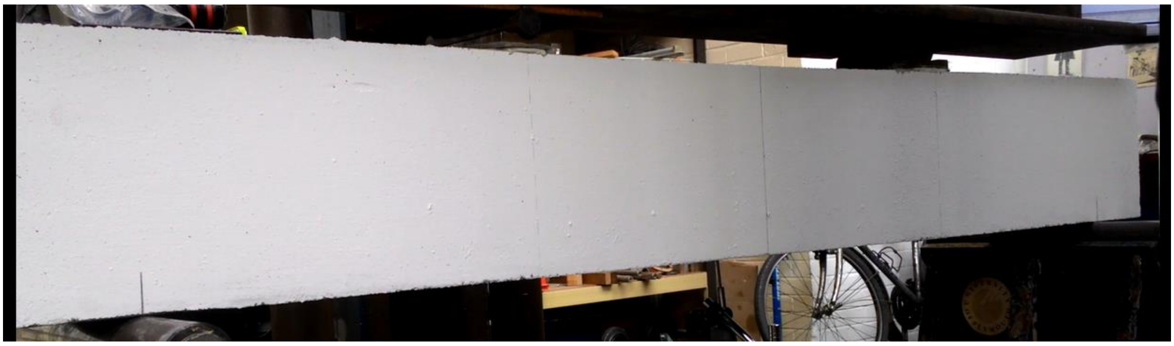


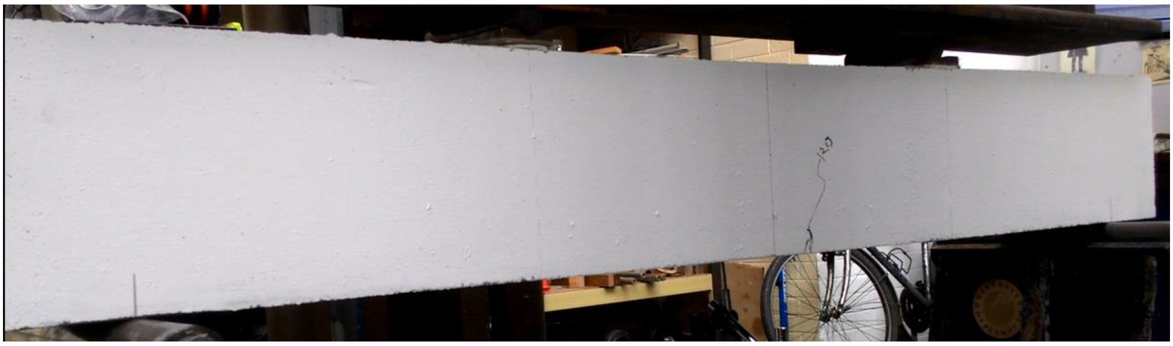
*10.09.3 Beam B3*

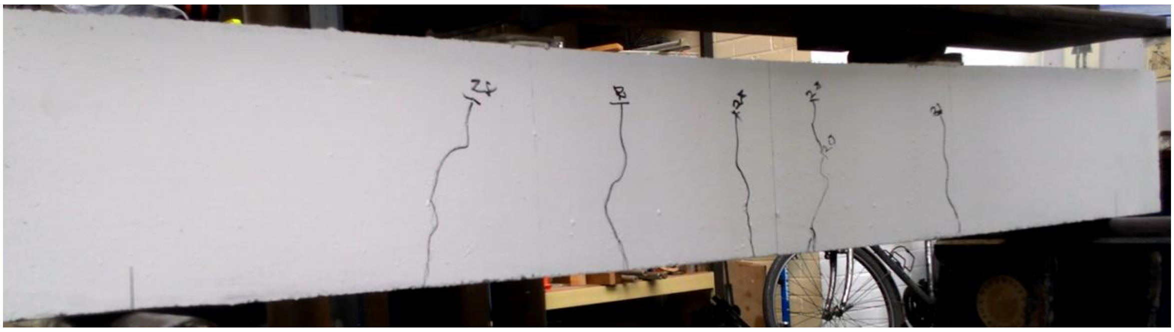


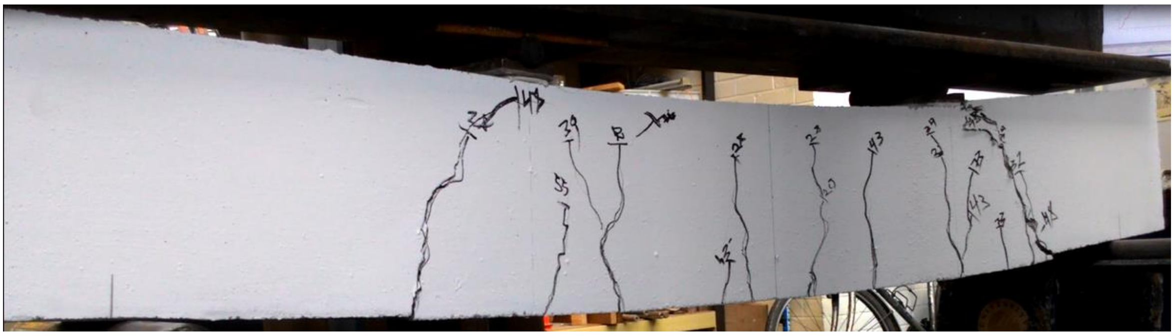


*10.09.4 Beam B4*

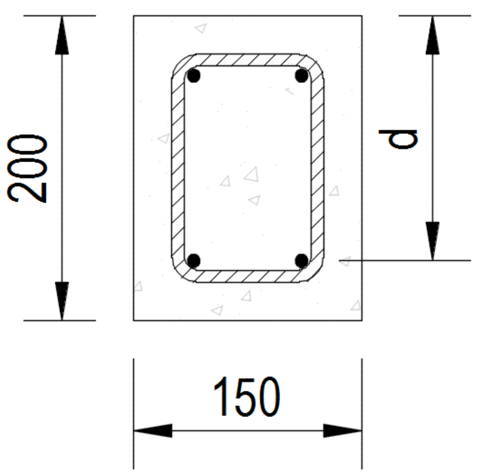








## 10.10 Steel Ultimate Load Calculations




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

| | |
|---|---|
| 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 <u>COMPRESION</u> MUST BE EQUAL <u>TENSION</u>** | 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

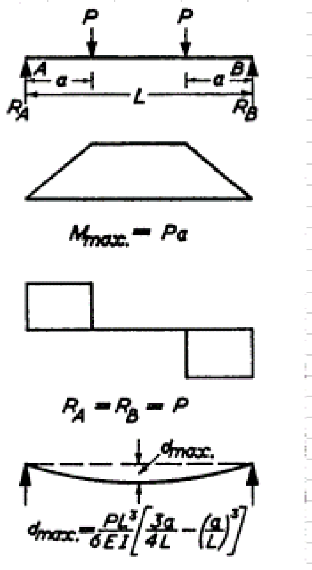
**BM Capacity = T*(d-0.8*X/2)**

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

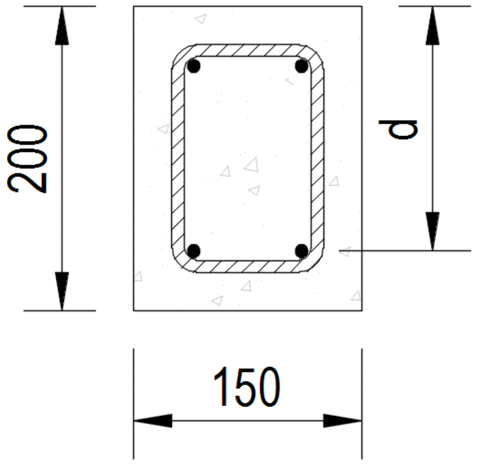
**MB max=Pa**

| | | |
|---|---|---|
| **P in (kN)=** | **22.65** | **(kN)** |
| **$P_{Total}$ in (kN)=** | **45.30** | **(kN)** |

| | | |
|---|---|---|
| **a(m)=** | **0.35** | |
| **E=** | 210000000 | |
| **I=** | 0.00005625 | |
| **$\delta$ $_{Uncracked(Max)}$=** | 0.25 | **(mm)** |



10.11 **BFRP Ultimate Load Calculations**




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

| | |
|---|---|
| **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 COMPRESION MUST BE EQUAL TENSION** | 101 | (kN) |

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

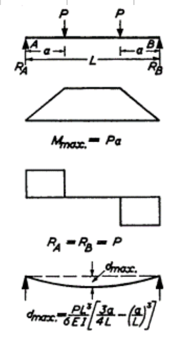
| | | |
|---|---|---|
| Statistical Factor= | 1 | |
| Fck= | 28 | |
| Section Width (b)= | 150 | |
| lambda? | 0.8 | 0.8 |

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)** |

87.13

| | | |
|---|---|---|
| **a(m)=** | **0.35** | |
| **E=** | 50000000 | |
| **I=** | 0.00005625 | |

| | | |
|---|---|---|
| **$\delta_{max}$=** | 2.8 | **(mm)** |

# 10.12 Bending Moment and Shear Force Calculation (Beam B4)

PROJECT Dissertation

ELEMENT BFRP BEAM B4

SHEET NO 1

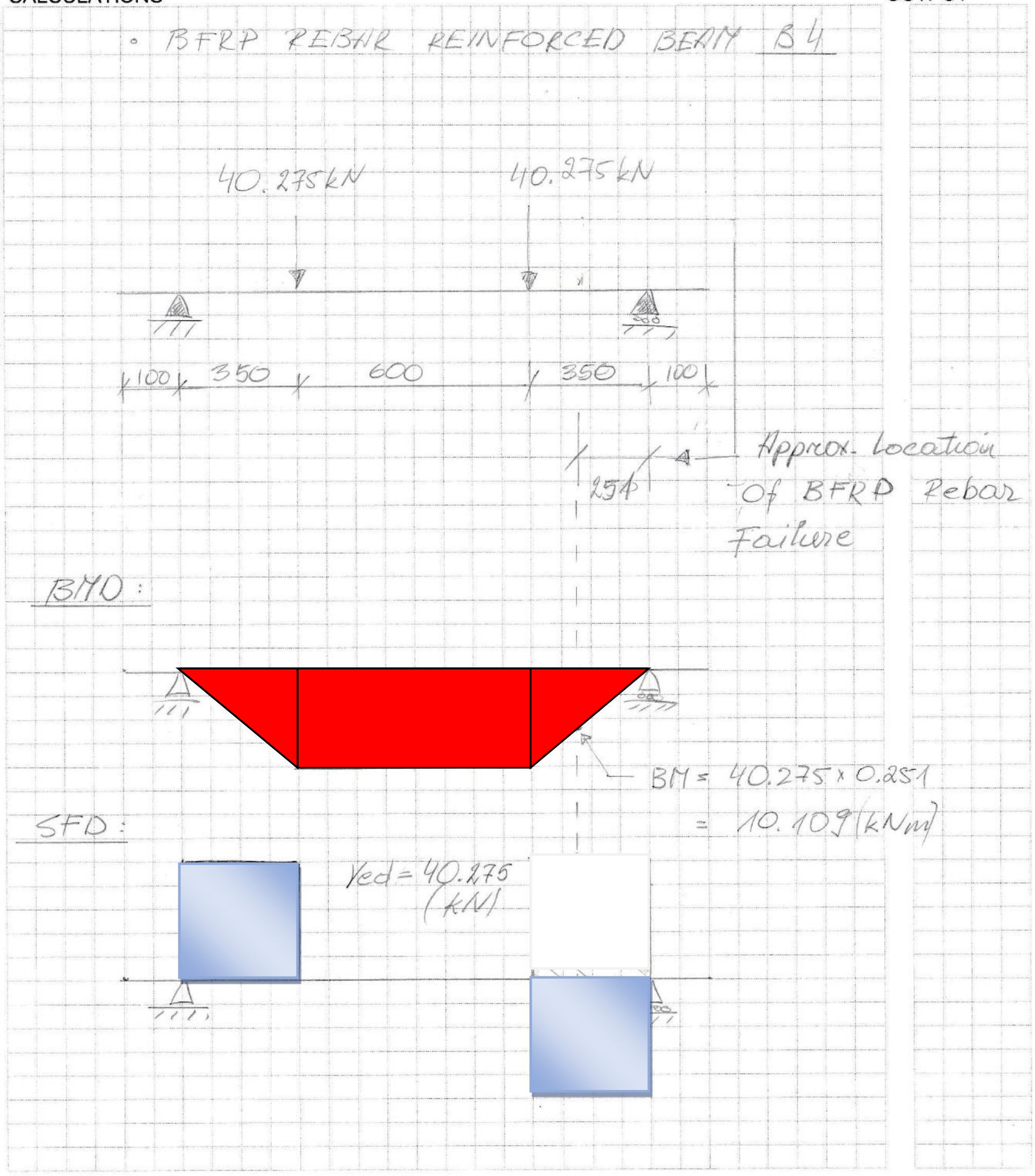
DESIGNED BY E.R.

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

$= 0.0906$

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

- $K \leq K'$ — $K' = 0.168$

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

$= 148.72 \leq 154.85$ ✓

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

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

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

PROJECT Dissertation

ELEMENT BFRP Beam B4

SHEET NO 3

DESIGNED BY ER

DATE 05/04/2017

**MARINE SCIENCE & ENGINEERING WITH PLYMOUTH UNIVERSITY**

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

CALCULATIONS | OUTPUT

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

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

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

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

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Reynolds Building
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Plymouth
PL4 8AA

CALCULATIONS | OUTPUT

SHEAR CHECK

$V_{ed} = 40.275\ kN$

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

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

$= 1.81\ N/mm^2$

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

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

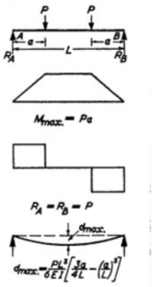
$= 30\ mm^2$

• 3 H'8 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

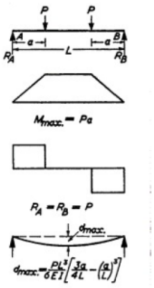
| | | |
|---|---|---|
| $P_{Total}$ in (kN)= | 8 | (kN) |
| Length (m)= | 1.3 | |
| a(m)= | 0.35 | |
| E= | 30000000 | |
| I= | 0.00005625 | |
| $\delta_{max}$= | Variable | (mm) |




**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 |

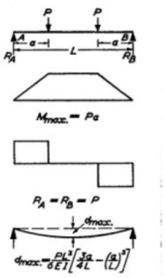
| | | |
|---|---|---|
| $P_{Total}$ in (kN)= | 8 | (kN) |
| Length (m)= | 1.3 | |
| a(m)= | 0.35 | |
| E= | 30000000 | |
| I= | 0.00005625 | |
| $\delta_{max}$= | Variable | (mm) |




**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 |

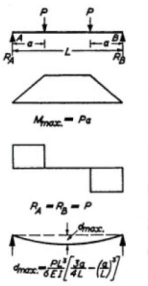
| | | |
|---|---|---|
| $P_{Total}$ in (kN)= | 8 | (kN) |
| Length (m)= | 1.3 | |
| a(m)= | 0.35 | |
| E= | 30000000 | |
| I= | 0.00005625 | |
| $\delta_{max}$= | Variable | (mm) |




**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 | |
| $\delta_{max}$= | 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:

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

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

$$A - constant\ of\ integration$$

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

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

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

$$B - constant\ of\ integration$$

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

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

$$B = 0$$

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

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

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

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

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

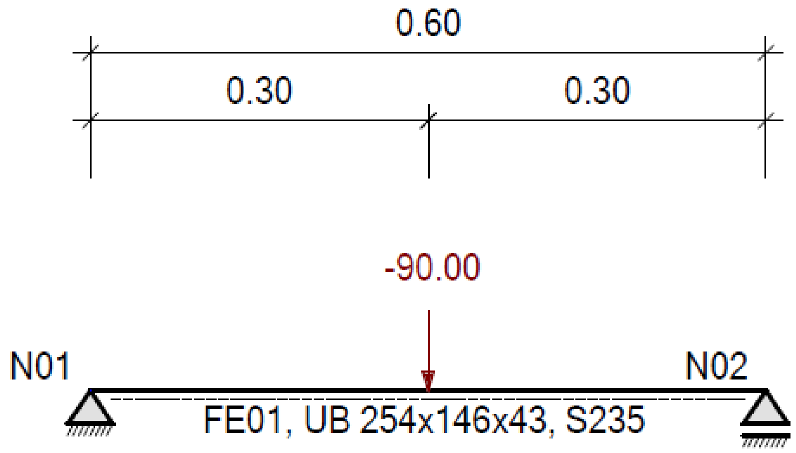
$$y = 1.47 * 10^{-4}\left(\frac{1300^2}{8}\right)$$

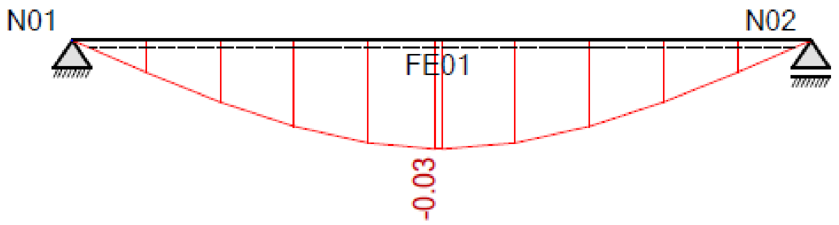
$$y = 31.0\ mm$$

10.15 **Transverse Steel Beam Deflection**

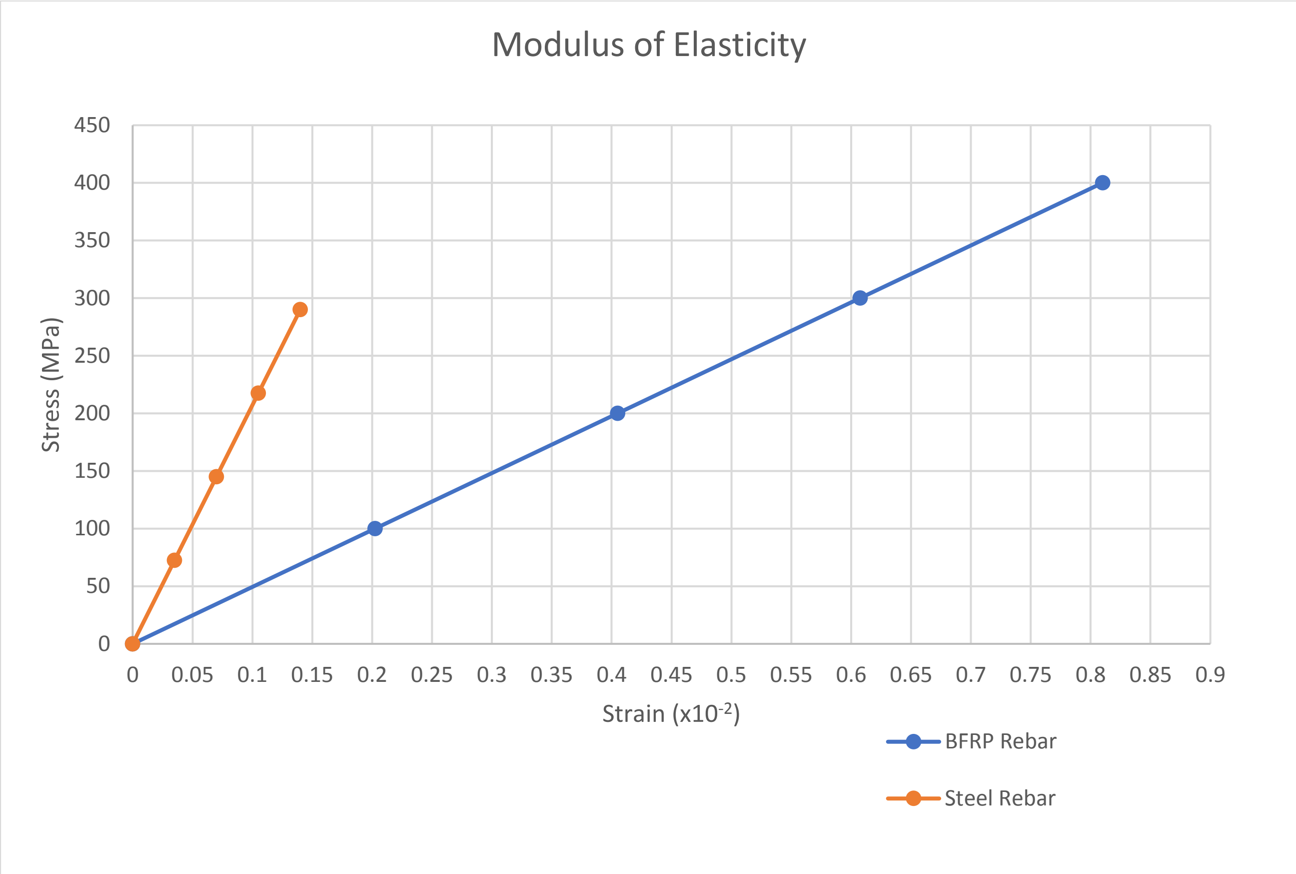
Analysis undertaken using Two-Frame Structural Analysis software.

(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:

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