2017

Flexural behaviour of BFRP rebar reinforced concrete beams

Rudziskis, E.

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

<table>
<thead>
<tr>
<th>Stage</th>
<th>Item</th>
<th>Reference or calculation</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>Characteristic strength</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>Standard deviation</td>
<td>Fig 3</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>Margin</td>
<td>C1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td>Target mean strength</td>
<td>C2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>Cement strength class</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>Aggregate type: coarse</td>
<td>Crushed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Crushed</td>
</tr>
<tr>
<td></td>
<td>1.7</td>
<td>Free-water/cement ratio</td>
<td>Table 2, Fig 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>Maximum free-water/</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cement ratio</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>Slump or Vee time</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>Maximum aggregate size</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>Free-water content</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
<td>Cement content</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>Maximum cement content</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.3</td>
<td>Minimum cement content</td>
<td>Specified</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
<td>Relative density of</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>aggregate (SDI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>Concrete density</td>
<td>Fig 5</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Total aggregate content</td>
<td>C4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.1</td>
<td>Grading of fine</td>
<td>Percentage passing 600 µm sieve</td>
</tr>
<tr>
<td></td>
<td>5.2</td>
<td>Proportion of fine</td>
<td>Fig 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>aggregate</td>
<td>C5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.4</td>
<td>Coarse aggregate content</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Quantities**

<table>
<thead>
<tr>
<th>Per m³ (to nearest 5 kg)</th>
<th>Cement (kg)</th>
<th>Water (kg or litres)</th>
<th>Fine aggregate (kg)</th>
<th>Coarse aggregate (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>per trial mix of</td>
<td>0.065 m³</td>
<td>21.45</td>
<td>14.6</td>
<td>49.725</td>
</tr>
<tr>
<td>4x (0.2x0.15x1.5) = 4x(Depth x Breadth x Length)</td>
<td>63.0</td>
<td>40.50</td>
<td>14.6</td>
<td>60.3</td>
</tr>
</tbody>
</table>

Items in tables are optional limiting values that may be specified (see Section 7).

Concrete strength is expressed in the units N/mm², 14 N/mm² = 1 MPa, 1 MPa = 100 N/mm² (N = newton, cm³ = cubic centimetre, MPa = Mega-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 equivalent volume of water. SDI = based on the saturated surface-dry condition.
Photo 6 – Aggregate Quantities for Concrete Mix.

Photo 7 – Plasticiser “MasterPolyheed”
## 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:**  
- [x] 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, 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  
- [x] Irritant  
- [ ] Carcinogenic  
- [ ] Gas under pressure  
- [ ] Toxic  
- [ ] Sensitiser  
- [ ] Highly flammable  
- [ ] Corrosive  
- [ ] Explosive  
- [ ] Flammable  
- [ ] Harmful  
- [ ] Oxidising  
- [ ] Environment

**Hazard Type (tick all that apply):**
- [ ] Gas  
- [ ] Vapour  
- [x] Mist  
- [ ] Fume  
- [x] Dust  
- [x] Liquid  
- [ ] Solid  
- [ ] Other  
- [ ] (Details)

**Route of Exposure (tick all that apply):**
- [ ] Inhalation  
- [x] Skin  
- [x] Eyes  
- [x] 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 eyes/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. |
| ☑ | 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:  Date: 22/12/2016

Name of Safety Manager/ HOS/ HOD.  Signed:  Date:

Review Date:  Signed:  Date:

Review Date:  Signed:  Date:
### Bar Bending Schedule

#### Bending schedule

**Job no.:**

**Site ref.:**

- **Date prepared:** 29/11/2016
- **Date revised:**
- **Prepared by:** E.R.
- **Checked by:** D.E

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

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.
Wash with soap and running water.

Skin Contact:
Immediately flush with plenty of water. Get medical attention if problem develops.

Eye contact:

Ingestion:
Ingestion of this material is unlikely. If it does occur, get medical attention.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Environmental protection: Prevent spread of basalt fibre dust and avoid dust-generating conditions.</td>
</tr>
<tr>
<td></td>
<td>Cleaning procedures: Vacuum clean dust. If sweeping is necessary, use a dust suppressant.</td>
</tr>
<tr>
<td>8. Exposure Limits and Personal Protective Equipment.</td>
<td>Fibrous basalt (Fibrous basalt dust), CAS No 65997-17-3.</td>
</tr>
<tr>
<td></td>
<td>Basalt fibre continuous filament:</td>
</tr>
<tr>
<td><strong>Size (µm)</strong></td>
<td>OSHA PEL (8 h TWA)</td>
</tr>
<tr>
<td></td>
<td>5 mg/m³</td>
</tr>
<tr>
<td></td>
<td>(respirable dust)</td>
</tr>
<tr>
<td></td>
<td>15 mg/m³</td>
</tr>
<tr>
<td></td>
<td>1 fibre/cm³</td>
</tr>
<tr>
<td><strong>Personal protective clothing and equipment.</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Respiratory protection:</strong></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Impervious gloves are recommended.</td>
</tr>
<tr>
<td></td>
<td>Impervious glasses are recommended.</td>
</tr>
<tr>
<td></td>
<td>Protect skin as much as possible by clothing.</td>
</tr>
<tr>
<td><strong>Protective gloves:</strong></td>
<td>The basalt continuous filament has a diameter &gt; 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</td>
</tr>
<tr>
<td>12. Ecology.</td>
<td>N/A. Basalt has its origin in nature.</td>
</tr>
<tr>
<td>16. Other Information.</td>
<td>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. <strong>This Material Safety Data Sheet is exclusively intended for professional use.</strong></td>
</tr>
</tbody>
</table>

Vulkan
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
Reinforcing Cage Photos

**Photo 8** – BFRP and Steel Reinforcement Setup in Beams B2 and B4.

**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
10.09.4  Beam B4
Steel Ultimate Load Calculations

\[ d = h - c_{\text{nom}} - \phi_{\text{link}} - \phi_{\text{bar}}/2 \]

\[ d = 200 - 25 - 8 - (8/2) = 160 \text{ mm} \]

\[ T = \text{Area of Steel Reinforcement} \times \text{Allowable Stress} = 50.5 \text{ kN} \]

<table>
<thead>
<tr>
<th>Area of Reinforcement</th>
<th>101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Stress</td>
<td>500</td>
</tr>
<tr>
<td>Materials Factor (Steel)</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\[ C = 0.8 \times X \times (\text{materials factor} \times F_{ck} / \text{materials factor}) \rightarrow X = \left( \frac{C}{10^3} \right) / (F_{ck} \times b) \]

\[ X = 15.02976 \text{ mm} \]
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)

P in (kN) = 15.86 (kN)

P in (kN) = 22.65

\( \delta_{\text{Uncracked(Max)}} = 0.25 \) (mm)

\( a(m) = 0.35 \)

\( E = 210000000 \)

\( I = 0.00005625 \)

\( a = \frac{P}{E} \)

\( R_A = R_B = P \)

\( \delta_{\text{max}} = \frac{P}{E} \left[ \frac{a}{2} - (a)^3 \right] \)
BFRP Ultimate Load Calculations

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

- \( L = 1.5 \) (m)
- \( h = 200 \) (mm)
- \( c_{nom} = 25 \) (mm)
- \( \phi = 8 \) (mm)

\[ \text{Area of Steel Reinforcement} \times \text{Allowable Stress} = 101 \text{ (kN)} \]

<table>
<thead>
<tr>
<th>Area of Reinforcement</th>
<th>101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Stress</td>
<td>1000</td>
</tr>
<tr>
<td>Materials Factor</td>
<td>1</td>
</tr>
</tbody>
</table>

For equilibrium, compression must be equal to tension, and tension is calculated as follows:

\[ T = \text{Area of Steel Reinforcement} \times \text{Allowable Stress} = 101 \text{ (kN)} \]

\[ C = 0.8 \times X \times \text{materials factor} \times F_{ck} / \text{materials factor} \rightarrow X = \frac{C \times 10^3}{F_{ck} \times b} \]

\[ X = \frac{101 \times 10^3}{28 \times 150} = 30.05952 \text{ (mm)} \]

- Statistical Factor = 1
- \( F_{ck} = 28 \)
- Section Width (b) = 150
- \( \lambda = 0.8 \)
$0.45d = 73.35$

BM Capacity = $T(0.8X/2)$

BM Capacity = 15.25 (kNm)

BM = Pa

$P_{\text{in (kN)}} = 43.57$ (kN)

$P_{\text{Total in (kN)}} = 87.13$ (kN)

$a(m) = 0.35$

$E = 50000000$

$I = 0.00005625$

$\delta_{\text{max}} = 2.8$ (mm)
Bending Moment and Shear Force Calculation (Beam B4)

**CALCULATIONS**

*BFRP REBAR REINFORCED BEAM B4*

\[ BM = 40.275 \times 0.251 \]
\[ = 10.109 \text{ kN} \]

**OUTPUT**

Approx. Location of BFRP Rebar Failure

BYO:

SFD:

[Diagram showing calculations and results]
CALCULATIONS

BENDING CHECK

\[ K = \frac{M}{bd^2 f_{ck}} \]

\[ = \frac{10 \times 10^9 \times 10^6}{150 \times 163^2 \times 28.4} \]

\[ = 0.0906 \]

\[ Z = \frac{d}{2} \left[ \frac{1}{d} + \sqrt{1 - 3.53 K^2} \right] \leq 0.95 \]

\[ = K \leq K' \]

\[ K' = 0.168 \]

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

\[ = 148.72 \leq 154.85 \]

\[ V \]

\[ HS = \frac{M}{f_{yd} \cdot Z} \]

\[ f_{yd} = f_{yk} \cdot \gamma_m = 1000 \]

\[ \gamma_m = 1.0 - \text{design material factor is not established.} \]
CALCULATIONS

- $f_yk = 1000 \text{ N/mm}^2$

- $f_yd = 1000/1$
  \hspace{1cm} = 1000 \text{ N/mm}^2$

- $A_s = \frac{10,109 \times 10^6}{1000 \times 148.72}$
  \hspace{1cm} = 68 \text{ mm}^2 < A_{pro} (BareB) = 101 \text{ 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
not occur in bending.

Shear check is required...
SHEAR CHECK

\[ V_{ed} = \frac{V_{ed}}{b_w \cdot t} \]
\[ = \frac{40.2 \times 10^3}{150 \cdot 148.72} \]
\[ = 1.11 \text{ N/mm}^2 \]

\[ A_{now} = \frac{V_{ed} \cdot b_w \cdot t}{f_{ynd} \cdot \cot \theta} \]
\[ = \frac{1.11 \times 120 \times 150}{435 \times 2.5} \]
\[ = 30 \text{ mm}^2 \]

3 H'8 links provide: 151 mm² > 30 mm²

Thus 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

### Beam 01

<table>
<thead>
<tr>
<th>Experimental Load Applied (kN)</th>
<th>Actual Deflection Recorded by External Gauge (mm)</th>
<th>Predicted Deflection (mm)</th>
<th>Difference (mm)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.11</td>
<td>0.10</td>
<td>0.01</td>
<td>4.6</td>
</tr>
<tr>
<td>8</td>
<td>0.18</td>
<td>0.18</td>
<td>0.00</td>
<td>4.9</td>
</tr>
<tr>
<td>12</td>
<td>0.25</td>
<td>0.26</td>
<td>0.01</td>
<td>4.6</td>
</tr>
<tr>
<td>16</td>
<td>0.36</td>
<td>0.34</td>
<td>0.02</td>
<td>4.9</td>
</tr>
<tr>
<td>20</td>
<td>0.44</td>
<td>0.42</td>
<td>0.02</td>
<td>4.9</td>
</tr>
</tbody>
</table>

### Beam 02

<table>
<thead>
<tr>
<th>Experimental Load Applied (kN)</th>
<th>Actual Deflection Recorded by External Gauge (mm)</th>
<th>Predicted Deflection (mm)</th>
<th>Difference (mm)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.20</td>
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</table>

### Beam 03

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<th>Actual Deflection Recorded by External Gauge (mm)</th>
<th>Predicted Deflection (mm)</th>
<th>Difference (mm)</th>
<th>%</th>
</tr>
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<tbody>
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### Beam 04

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<th>Experimental Load Applied (kN)</th>
<th>Actual Deflection Recorded by External Gauge (mm)</th>
<th>Predicted Deflection (mm)</th>
<th>Difference (mm)</th>
<th>%</th>
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<tbody>
<tr>
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<td>0.42</td>
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</tr>
</tbody>
</table>
10.14 Cracked Section Deflection Calculations

**neutral axis position**

\[ x = 30.1 \]

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

\[ I_c = \frac{bx^3}{3} + axAS(d-x)^2 \]

- \( b = 150 \text{ mm} \)
- \( aE = 5.81 \)
- \( E = 50 \text{ N/mm}^2 \)
- \( A_S = 101 \)
- \( d = 163 \)
- \( I_c = 11723848.4 \text{ mm}^4 \)

**Curvature \( \frac{1}{r} \) of Cracked Section**

\[ \frac{1}{r}C = \frac{M}{E_c,\text{eff} I_c} \]

- \( M = 15.25 \text{ kNm} \)
- \( E_c,\text{eff} = 8.61 \text{ kN/mm}^2 \)
- \( (1/r)C = 1.51E-04 /\text{mm} \)

**The Average of cracked and uncracked curvature**

\[ M_{cr} = f_{cm}^*(b_h h^2/8) \]

- \( f_{cm} = 2.6 \text{ N/mm}^2 \) or Mpa
- \( b = 150 \text{ mm} \)
- \( h = 40000 \text{ mm}^2 \)
- \( M_{cr} = 2.8 \text{ kNm} \)

\[ \epsilon = 1 - \beta (M_{cr}/M)^{1/2} \]

- \( \beta = 1 \) (assumed for a single short-term load). Also for sustained loads or cyclic loading is 0.5
- \( \epsilon = 0.966 \)

**Curvature \( \frac{1}{r} \) of Un-cracked Section**

\[ (1/r)u = \frac{M/E_c,\text{eff} + (1-c)\frac{1}{r}c}{bd^3/12} \]

\( \frac{1}{r}c = 100000000 \text{ mm}^4 \)

- \( \frac{1}{r} = 1.77108E-05 /\text{mm} \)

\[ \frac{1}{r} = 1.47E-04 \]
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:

\[ M = \frac{EId^2y}{dx^2} \]

\[ EIdy \quad \frac{dx}{dx} = Mx + A \]

A – constant of integration

\[ A + x = \frac{Ldy}{2dx} = 0 \]

\[ \therefore A = -\frac{ML}{2} \]

\[ -Ely = \frac{Mx^2}{2} + Ax + B \]

B – constant of integration

\[ -Ely = \frac{Mx^2}{2} + \frac{MLx}{2} + B \]

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 \( x = \frac{L}{2} \)

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

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

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

\[ y = 1.47 \times 10^{-4} \left( \frac{1300^2}{8} \right) \]

\[ y = 31.0 \text{ mm} \]
Transverse Steel Beam Deflection

Analysis undertaken using Two-Frame Structural Analysis software. (Deflection Units in mm; External Load in kN)
Graph 1 – Experimental Steel and BFRP Rebar Modulus of Elasticity.

Basalt Rebar Modulus of Elasticity:

\[ E = \frac{\text{Stress}}{\text{Strain}} = \frac{400}{0.0081} = 49383 \text{ MPa} = 49.4 \text{ kN/mm}^2 \]

Steel Rebar Steel Modulus of Elasticity:

\[ E = \frac{\text{Stress}}{\text{Strain}} = \frac{290}{0.0014} = 207143 \text{ MPa} = 207.1 \text{ kN/mm}^2 \]