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LAMPIRAN

Lampiran 1. Log Book Penelitian

Judul Penelitian : Studi Perkuatan Lentur Balok Beton Bertulang Pasca Korosi dengan Grouting dan GFRP Sheet

Nama Peneliti : Sugira Said

<table>
<tr><th>No.</th><th>Tanggal</th><th>Kegiatan</th><th>Hasil, Problem dan Solusi</th></tr>
<tr><td>1</td><td>14 Januari 2022</td><td>Pertemuan dan diskusi dengan tim penelitian dan mengurus administrasi mengenai perizinan penggunaan Laboratorium Struktur dan Bahan</td><td>Hasil:
Problem :
Solusi :</td></tr>
<tr><td colspan="4">Progres :
Dokumentasi :</td></tr>
<tr><td>2</td><td>18 Januari 2022</td><td>Pertemuan dan diskusi dengan tim penelitian membahas :
- Persiapan pembuatan benda uji
- Kelengkapan material</td><td>Hasil :
Problem :
Solusi :</td></tr>
<tr><td colspan="4">Progres :
Dokumentasi :</td></tr>
</table>

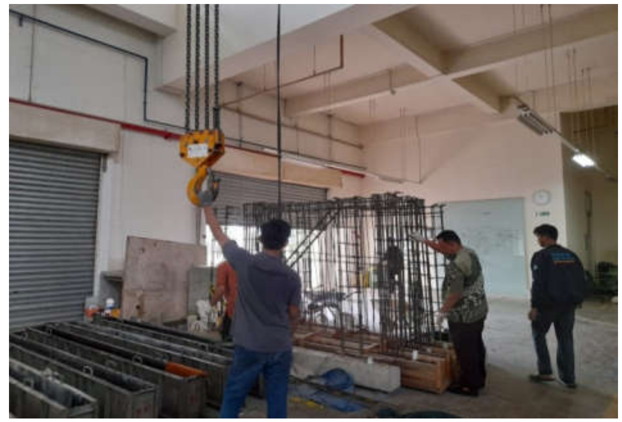
3	19 Januari 2022	Perakitan Bekisting untuk benda uji balok	**Hasil:** **Problem :** **Solusi :**
Progres : **Dokumentasi :**			

4	20 Januari 2022	Pertemuan dan diskusi dengan tim penelitian	**Hasil:** **Problem :** **Solusi :**
Progres : **Dokumentasi :**			

5	21 Januari 2022	Pertemuan dan diskusi dengan tim penelitian membahas : - Persiapan pembuatan benda uji - Kelengkapan material dalam hal ini adalah pengadaan besi Pengangkatan sampel di Laboratorium Struktur dan Bahan Melanjutan perakitan Bekisting untuk benda uji balok	**Hasil:** **Problem : -** **Solusi : -**

Progres :

Dokumentasi :

 			
6	22 Januari 2022	Melanjutkan Perakitan bekisting (pengencangan baut-baut pada bekisting) Pemotongan besi untuk tulangan balok	**Hasil:** 8 set bekisting selesai **Problem :** **Solusi :**

Progres :

Dokumentasi :

			
7	23 Januari 2022	Melanjutkan pembuatan set tulangan	**Hasil:** 3 set tulangan selesai **Problem :** **Solusi :**
Progres : **Dokumentasi :** 			

8	24 Januari 2022	Melanjutkan pembuatan set tulangan	**Hasil:** 3 Set tulangan selesai, total 6 set tulangan selesai **Problem :** **Solusi :**

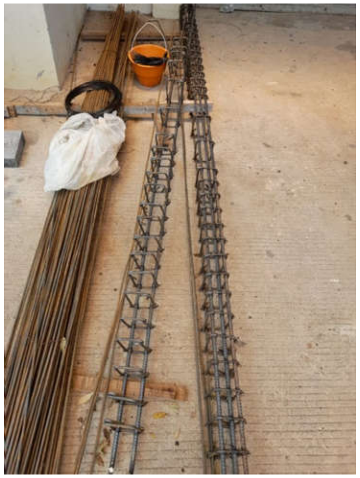
Progres :

Dokumentasi :

9	25 Januari 2022	Melanjutkan pembuatan set tulangan	**Hasil :** 3 set tulangan selesai, total 9 set tulangan selesai **Problem :** **Solusi :**

Progres :

Dokumentasi :


<table>
<tr>
<td>10</td>
<td>27 Januari 2021</td>
<td>Pengujian Kuat Tarik Tulangan dan FRP
- 8 buah tulangan D13
- 8 buah tulangan 8</td>
<td>Hasil: 8 buah tulangan D13 selesai
Problem :
Solusi :</td>
</tr>
<tr>
<td colspan="4">Progres :
Dokumentasi :
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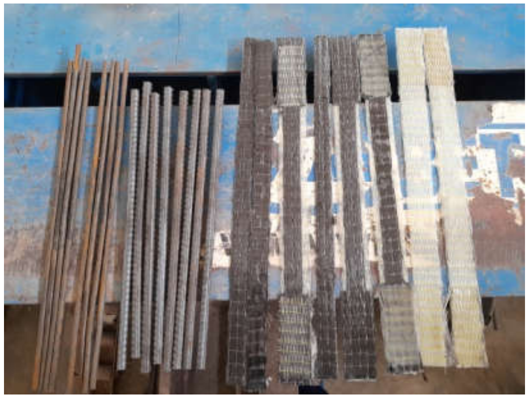
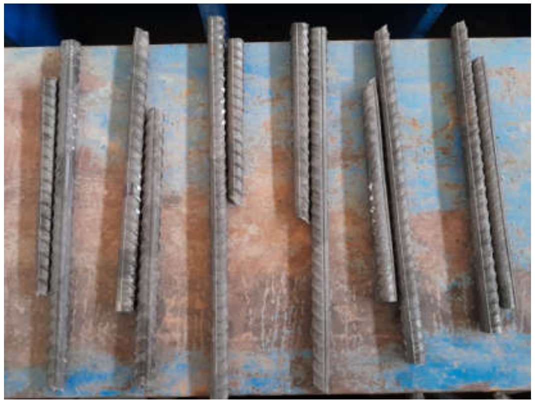
</tr>
</table>





11	28 Januari 202	Melanjutkan Pengujian Kuat Tarik Tulangan dan FRP - 8 buah tulangan D13 - 8 buah tulangan 8 - 2 buah lapisan GFRP Perakitan Mould Silinder ukuran 10 x 20	**Hasil: -** 8 buah tulangan 8 selesai, 8 buah tulangan D13 selesai, dan 2 buah GFRP selesai. **Problem : -** **Solusi : -**

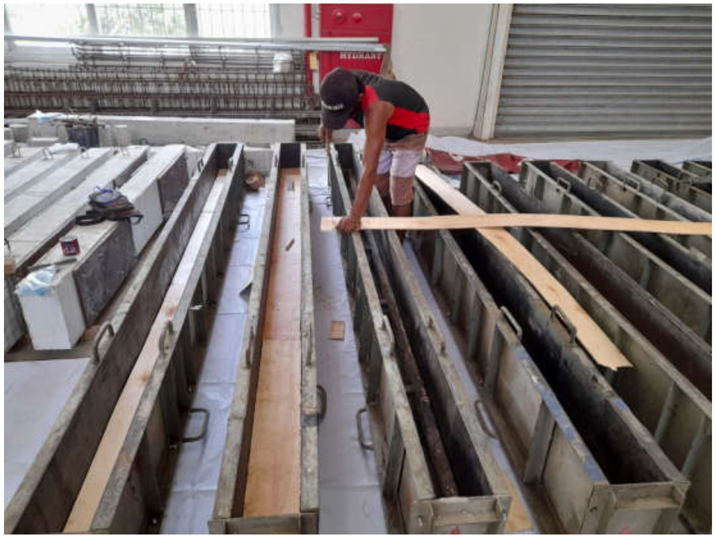
Progres :

Dokumentasi :

12	30 Januari 2022	- Pemberian alas pada bekisting - Melanjutkan perakitan Mould Silinder 10 x 20 - Perakitan Mould Silinder 15 x 30 - Perakitan Mould Balok 10 x 10 x 40	**Hasil:** 24 set mould silinder 10 x 20 selesai, 13 set mould silinder 15 x 30 selesai dan 8 set mould balok 10 x 10 x 40 selesai **Problem : -** **Solusi : -**

Progres :

Dokumentasi :



13	31 Januari 2022	Konsultasi mengenai pemasangan Strain Gauge kepada Ibu Dr. Eng. Rita Irmawati, ST,, MT	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :

14	1 Februari 2022	- Pemasangan Strain Gauge - Persiapan Pengecoran	**Hasil:** 21 tulangan terpasang **Problem :** **Solusi :**

Progres :

Dokumentasi :

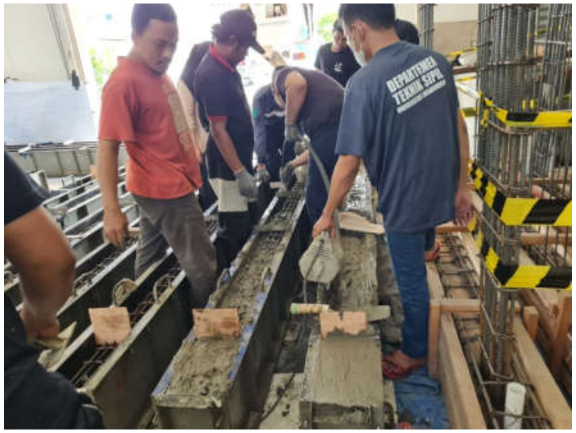



15	2 Februari 2022	Melakukan pengecoran - 21 buah balok - 24 buah silinder 10 x 20 (benda uji) - 13 buah silinder 15 x 30 (benda uji) - 8 buah balok 10 x 10 x 40 (benda uji)	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :





`16	3 Februari 2022	Membuka mould benda uji : - 24 buah silinder 10 x 20 - 13 buah silinder 15 x 30 - 8 buah balok 10 x 10 x 40 Melakukan moist curing	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :

17	12 Februari 2022	Melakukan moist curing	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :

18	14 Februari 2022	Perakitan Mould Silinder ukuran 10 x 20	**Hasil:** **Problem :** **Solusi :**

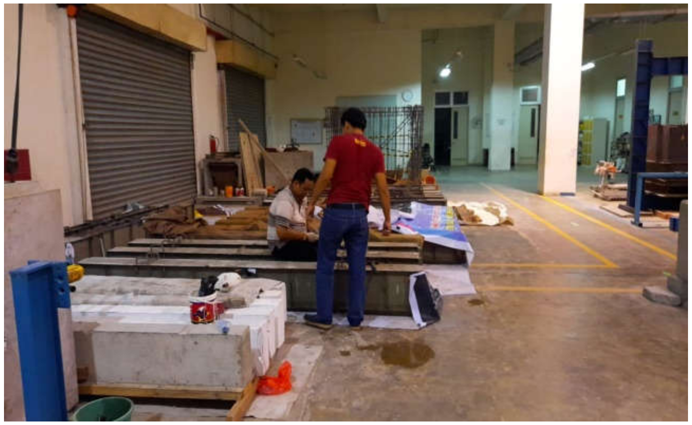
Progres :

Dokumentasi :

19	15 Februari 2022	Melakukan pembukaan bekisting	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :



20	16 Februari 2022	Melakukan pemindahan sampel yang ada di Laboratorium Struktur dan Bahan	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :

21	17 Februari 2022	- Pengadaan Bahan Grouting	**Hasil:** **Problem :** **Solusi :**

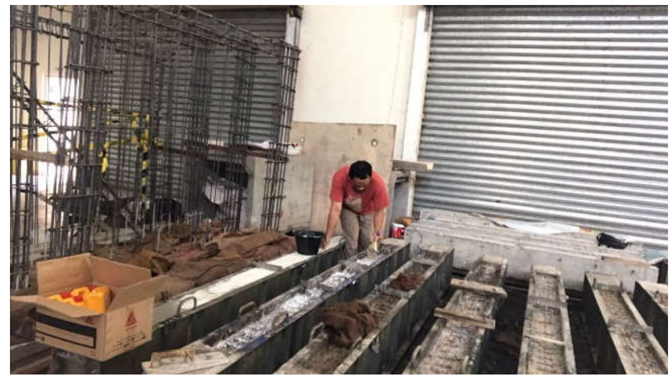
Progres :

Dokumentasi :

22	19 Februari 2022	Melakukan pekerjaan grouting - Pembersihan sampel sebelum dilakukan grouting - Pengolesan Sika bonding agent (cairan sika) dengan perbandingan 1:1 - Mixing Sika Grout dengan perbandingan 4L air : 25 kg	**Hasil:** **Problem :** **Solusi :**

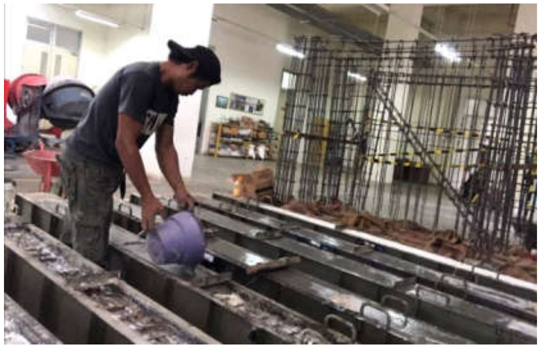
Progres :

Dokumentasi :










23	21 Februari 2022	Membuka mould benda uji : - 24 buah silinder 10 x 20 - 13 buah silinder 15 x 30 Melakukan moist curing	**Hasil:** **Problem :** **Solusi :**

Progres :

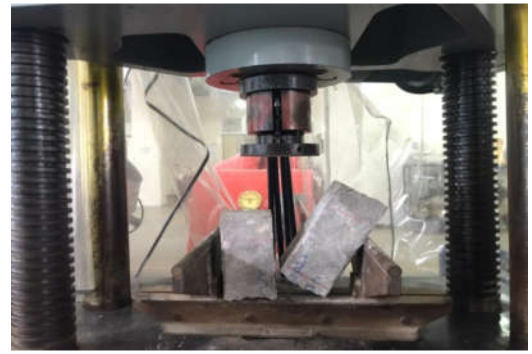
Dokumentasi :

24	3 Maret 2022	Melakukan Pengujian Kuat Tekan Silinder	**Hasil:** **Problem :** **Solusi :**

Progres :

Dokumentasi :


CAUTION




11.922


9.008

<table>
<tr><td>25</td><td>29 Maret 2022</td><td>Pemasangan GFRP pada balok</td><td>Hasil:
Problem :
Solusi :</td></tr>
<tr><td colspan="4">Progres :
Dokumentasi :
 
</td></tr>
</table>

<table>
<tr><td>26</td><td>30 Maret 2022</td><td>Pemasangan GFRP pada balok</td><td>Hasil:

Problem :

Solusi :</td></tr>
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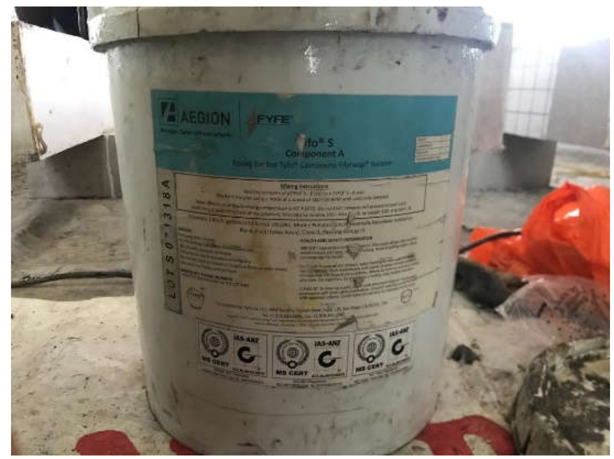
Dokumentasi :
 </td></tr>
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27	13 April 2022	Pengujian Kuat Lentur Balok Kontrol	**Hasil:** **Problem : -** **Solusi : -**

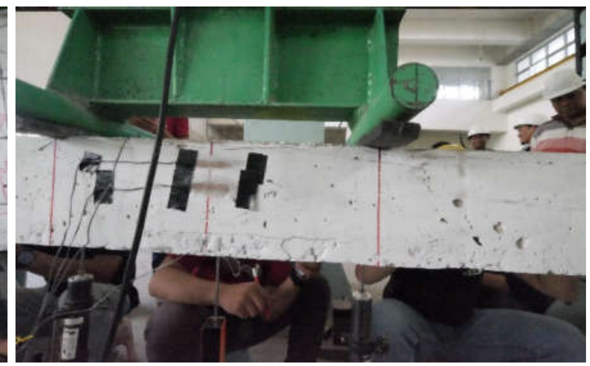
Progres :

Dokumentasi :

28	14 April 2022	Pengujian Kuat Lentur Balok Grouting	**Hasil:** **Problem : -** **Solusi : -**

Progres :

Dokumentasi :

29	19 April 2022	Pengujian kuat lentur balok grouting dan GFRP sheet (BGRS)	**Hasil:** **Problem : -** **Solusi : -**

Progres :

Dokumentasi :

30	21 April 2022	Pengujian kuat lentur balok BGRSF dan balok BGRST	**Hasil:** **Problem : -** **Solusi : -**

Progres :

Dokumentasi :

Lampiran 2. Perhitungan Kapasitas Momen - Balok Kontrol (BK)

1. Data Perencanaan

Kuat tekan beton	f'_c	=	**20.0**	MPa
Kuat leleh tulangan tarik	f_y	=	**280**	MPa
Kuat leleh tulangan tekan	f_y	=	**280.0**	MPa
Kuat leleh tulangan transversal	f_y	=	**280**	MPa
Modulus elastisitas beton	E_c	=	**21533.0**	MPa
Modulus elastisitas baja	E_s	=	**200000**	MPa
Berat jenis beton	γ_c	=	**2400**	kg/m^3
Lebar penampang	b	=	**150**	mm
Tinggi penampang	h	=	**200**	mm
Tinggi efektif penampang	d	=	**155.50**	mm
Jarak tulangan tekan ke serat tekan terluar	d'	=	**42.00**	mm

Luas tulangan tarik	A_s	=	**3**	D	**13**	=	398.20 mm^2
Luas tulangan tekan	A_s'	=	**2**	D	**8**	=	100.53 mm^2
Luas tulangan sengkang	A_{vs}	=	**2**	D	**8**	=	100.53mm^2

2. Momen Retak Pertama (Mcr)

Pada kondisi retak pertama, momen retak (M_{crack}) terjadi pada saat serattarik penampang balok mencapai modulus keruntuhan (F_r). Oleh SNI 2847.2013 pasal 9.5.2.3 diberikan persamaan sebagai berikut

$$M_{crack} = \frac{I_g \, . \, f_r}{y_t}$$

Diketahui:

Hasil uji modulus keruntuhan f_r $0.7 \times F_c^{0.5} = 3.21$ MPa

Momen inersia penampang bruto :

$$I_g = \frac{b \quad h^3}{12}$$

$= 112435956.7 \quad mm^4$

$y_{bawah} = h - y_{atas} = 96.05 \quad mm$

$$M_{crack} = \frac{Ig \quad fr}{y_t}$$

$$= \frac{112435956.7 \quad 3.21}{96.05}$$

$= 3754168.576 \quad N.mm$

Mcrack	**=**	**3.7542**	**kN.m**

Nilai P_{crack} diperoleh dengan cara substitusi M_{crack} ke persamaan :M = 0.8019 + 0.6 P

3.7542 = 0.8019 + 0.6P

Diperoleh

P_{cr} = 4.9204 kN

3. Momen Leleh (Myield)

Direncanakan menggunakan tulangan :

As	=	**3**	D	**13**	=	398.20 mm^2
As'	=	**2**	D	**8**	=	100.53 mm^2

Awal tulangan leleh

$$= \frac{Es}{Ec} = 9.3 \quad ; \quad nf = \frac{Ef}{Ec} = 0.97$$

k = 0.44065

kd = 68.521 mm

Regangan tulangan tarik dari ujung atas balok

$$\varepsilon y = \frac{fy}{Es} = \frac{280}{200000}$$

εy = 0.0014

Regangan beton bagian atas

$$\varepsilon c = \varepsilon s \left(\frac{kd}{d - kd} \right)$$

$$= 0.0014 \left(\frac{68.521}{155.50 - 68.52} \right)$$

εc = 0.001103

Regangan tulangan tekan

$$\varepsilon s' = \varepsilon c \left(\frac{kd - d'}{kd} \right)$$

$$= 0.0011 \left(\frac{68.521 - 42.00}{68.52} \right)$$

$\varepsilon s'$ = 0.000427

$fs' = Es \quad \varepsilon s'$

$= 200000 \quad 0.0004$

$= 85.376$ MPa

bila nilai fs' lebih kecil dari nol gunakan nol **fs' = 85.376 MPa**

Gaya tekan beton

$Cc = 0.5 \quad f'c \quad b \quad kd$

$= 0.5 \; . \; 20 \; . \; 150.00 \; . \; 68.52$

Cc = 107869.30 N

Gaya tekan baja

$C_s = A_s' \quad f_s'$

$= 100.53 \; . \; 85.376$

C_s = 8582.92 N

$T = C_c + C_s$

$= 107869.30 + 8582.92$

T = 116452.22 N

$T = A_s \; f_y$

$= 111495.12$ N

Nilai selisih T harus mendekati nol

$C_c + C_s - A_s \; f_y = 0$

$116452.22 - 111495.12 = -4957.09718$

$= -4957.1$

k = 0.44065

Jarak gaya (c) dari ujung atas (y)

$$y = \frac{C_S \; d' + C_C \; . \; 0.33 \; kd}{T}$$

$$y = \frac{8582.92 \; . \; 42.00 + 107869.30 \; . \; 22.84}{116452.22}$$

$y = 24.252$ mm

Jarak pusat total gaya tekan ke pusat tulangan tarik

$J_d = d - y$

$= 155.50 - 24.252$

J_d = 131.25 mm

Persamaan momen dan kurvatur

$M_y = A_s \; f_y \; J_d$

$= 14633457.53$ N.mm

My = 14.63 kN.m

14.63 = 0.8019 + 0.6 P kN.m

$M_y = M_{maks\ pada\ tengah\ bentang}$

$14.63 = 0.8019 + 0.6 \; P$

$13.83 = 0.6 \; P$

P = 23.05 kN

4. Momen Ultimit (Mu)

Mu = Φ Mn

$$Mu = \Phi * As * fy * \left(d - \frac{a}{2}\right)$$ faktor reduksi untuk lentur Φ = 0.9

dimana :

Untuk f'c ≤ 20 MPa

β1 = 0.85

Untuk f'c > 20 MPa

$$\beta 1 = 0.85 - \frac{0.05\,(f'c - 20)}{7}$$

Karena f'c = 20 MPa

Maka **β1 = 0.85**

$$a_b = \frac{600\ \beta_1\ d}{600 + f_y} = \frac{600\ .\ 0.85\ .\ 155.50}{600 + 280.00}$$

a_b = 90.119 mm

$$\rho_b = \frac{As_b}{b\,d}$$

$$= \frac{0.85\ f'_c\ a_b}{f_y\ d} = \frac{0.85 . 20 . 90 . 119}{280 . 155.5}$$

ρ_b = 3.69%

ρ_{max} = 0.75 ρ_b = 0.0277

ρ_{max} = 2.77%

$$\rho_{min} = \frac{1.4}{f_y} = 0.005$$

ρ_{min} = 0.50%

ρ = (A_s - A_s') = (398.2 - 100.53)

ρ = 1.28%

Kontrol Tulangan Tekan Sudah Leleh atau Belum

$$a = \frac{(As - As')\ fy}{0.85\ f'c\ b}$$

$$= \frac{(398.197 - 100.53096)\ .\ 280}{0.85\ .\ 20.99\ .\ 150}$$

a = 31.143 mm

$$a_{min\ Leleh} = \frac{600\ \beta 1\ d'}{600 - fy}$$

$$= \frac{600\ .\ 0.85\ .\ 42}{600 - 280}$$

$a_{min\ leleh}$ = 66.938 mm

$M_n = M_{nc} + M_{ns}$

Mn = 15006733.09 N.mm atau **Mn = 1.50067 t.m**

Ø Mn = 12005386.47 N.mm atau **Ø Mn = 1.20054 t.m**

Ø Mn = Mmaks

1.2005 = 0.0802 + 0.6 P

1.1203 = 0.6 P

Pmaks = 1.86725 ton

Untuk beban 0.5 P maka : **0.5 Pmaks = 0.93362 ton**

Mn = Mmaks

1.5007 = 0.0802 + 0.6 P

1.4205 = 0.6 P

Pmaks = 2.36747 ton

Untuk beban 0.5 P maka : **0.5 Pmaks = 1.18374 ton**

Pu = 23.67 kN

Lampiran 3. Perhitungan Kapasitas Momen - Balok Grouting (BGR)

1. Data Perencanaan

Kuat tekan beton	f'_c	=	**20.0**	MPa
Kuat leleh tulangan tarik	f_y	=	**280**	MPa
Kuat leleh tulangan tekan	f_y	=	**280.0**	MPa
Kuat leleh tulangan transversal	f_y	=	**280**	MPa
Modulus elastisitas beton	E_c	=	**21532.98**	MPa
Modulus elastisitas baja	E_s	=	**200000**	MPa
Berat jenis beton	γ_c	=	**2400**	kg/m^3
Lebar penampang	b	=	**150**	mm
Tinggi penampang	h	=	**200**	mm
Tinggi efektif penampang	d	=	**158.00**	mm
Jarak tulangan tekan ke serat tekan terluar	d'	=	**42.00**	mm

Luas tulangan tarik	A_s	=	**3**	D	**13**	=	150.80 mm^2
Luas tulangan tekan	A_s'	=	**2**	D	**8**	=	100.53 mm^2
Luas tulangan sengkang	A_{vs}	=	**2**	D	**8**	=	100.53mm^2

2. Momen Retak Pertama (Mcr)

Pada kondisi retak pertama, momen retak (M_{crack}) terjadi pada saat serattarik penampang balok mencapai modulus keruntuhan (F_r). Oleh SNI 2847.2013 pasal 9.5.2.3 diberikan persamaan sebagai berikut

$$\mathbf{M_{crack}} = \frac{\mathbf{I_g \,.\, f_r}}{\mathbf{y_t}}$$

Diketahui:

Hasil uji modulus keruntuhan f_r 0.7 x $F_c^{0.5}$ = 3.21 MPa

Momen inersia penampang bruto :

$$Ig = \frac{b \quad h^3}{12}$$

$= 106989086.3 \quad mm^4$

$y_{bawah} = h - y_{atas} = 99.25 \quad mm$

$$M_{crack} = \frac{Ig \quad fr}{y_t}$$

$$= \frac{106989086.3 \quad 3.21}{99.25}$$

$= 3754168.576 \quad N.mm$

Mcrack	**=**	**3.4572**	**kN.m**

Nilai P_{crack} diperoleh dengan cara substitusi M_{crack} ke persamaan :M = 0.8019 + 0.6 P

3.4572 = 0.8019 + 0.6P

Diperoleh

P_{cr} = 4.4255 kN

3. Momen Leleh (Myield)

Direncanakan menggunakan tulangan :

As	=	**3**	D	**13**	=	150.80 mm^2
As'	=	**2**	D	**8**	=	100.53 mm^2

Awal tulangan leleh

$$= \frac{Es}{Ec} = 9.3 \quad ; \quad nf = \frac{Ef}{Ec} = 0.97$$

k = 0.44065

kd = 69.623 mm

Regangan tulangan tarik dari ujung atas balok

$$\varepsilon y = \frac{fy}{Es} = \frac{280}{200000}$$

εy = 0.0014

Regangan beton bagian atas

$$\varepsilon c = \varepsilon s \left(\frac{kd}{d - kd} \right)$$

$$= 0.0014 \left(\frac{69.62}{158.00 - 69.62} \right)$$

εc = 0.001103

Regangan tulangan tekan

$$\varepsilon s' = \varepsilon c \left(\frac{kd - d'}{kd} \right)$$

$$= 0.0011 \quad \frac{69.62 - 42.00}{69.62}$$

$\varepsilon s'$ = 0.000438

$fs' = Es \quad \varepsilon s'$

$= 200000 \quad 0.0004$

$= 87.515$ MPa

bila nilai fs' lebih kecil dari nol gunakan nol **fs' = 87.515 MPa**

Gaya tekan beton

$Cc = 0.5 \quad f'c \quad b \quad kd$

$= 0.5 \quad . \quad 20 \quad . \quad 150.00 \quad . \quad 69.62$

Cc = 109603.54 N

Gaya tekan baja

$C_s = A_s' \quad f_s'$

$= 100.53 \quad . \quad 857.515$

C_s = 8797.99 N

$T = C_c + C_s$

$= 109603.54 + 8797.99$

T = 118401.52 N

$T = A_s \; f_y$
$= 42223.01$ N

Nilai selisih T harus mendekati nol

$C_c + C_s - A_s \; f_y = 0$

118401.52 - 42223.01 = -76178.5165
= -766178.52

k	=	**0.44065**

Jarak gaya (c) dari ujung atas (y)

$$y = \frac{C_S \; d' + C_C \; . \; 0.33 \; kd}{T}$$

$$y = \frac{8797.99 \; . \; 42.00 + 109603.54 \; . \; 23.21}{118401.52}$$

$$y = 24.604 \text{ mm}$$

Jarak pusat total gaya tekan ke pusat tulangan tarik

$J_d = d - y$
$= 158.0 - 24.6.4$

J_d	=	**133.40**	**mm**

Persamaan momen dan kurvatur

$M_y = A_s \; f_y \; J_d$
$= 5632381.53$ N.mm
My = 5.63 kN.m

5.63	**=**	**0.8019**	**+**	**0.6**	**P**	**kN.m**

$M_y = M_{\text{maks pada tengah bentang}}$

5.63 = 0.8019 + 0.6 P
4.83 = 0.6 P
P = 8.05 kN

4. Momen Ultimit (Mu)

$$Mu = \Phi\, Mn$$

$$Mu = \Phi * As * fy * \left(d - \frac{a}{2}\right)$$ faktor reduksi untuk lentur $\Phi = 0.9$

dimana :

Untuk $f'c \leq 20$ MPa

$\beta 1 = 0.85$

Untuk $f'c > 20$ MPa

$$\beta 1 = 0.85 - \frac{0.05\,(f'c - 20)}{7}$$

Karena $f'c = 20$ MPa

Maka $\boldsymbol{\beta 1 = 0.85}$

$$a_b = \frac{600\ \beta_1\ d}{600 + f_y} = \frac{600\ .\ 0.85\ .\ 158.00}{600 + 280.00}$$

a_b = 91.568 mm

$$\rho_b = \frac{As_b}{b\ d}$$

$$= \frac{0.85\ f'_c\ a_b}{f_y\ d} = \frac{0.85\ .\ 20\ .\ 91.568}{280\ .\ 158.0}$$

ρ_b = 3.69%

$\rho_{max} = 0.75\ \rho_b = 0.0277$

ρ_{max} = 2.77%

$$\rho_{min} = \frac{1.4}{f_y} = 0.005$$

ρ_{min} = 0.50%

$\rho = (A_s - A_s') = (150.8 - 100.53)$

ρ = 0.21%

Kontrol Tulangan Tekan Sudah Leleh atau Belum

$$a = \frac{(As - As')\ fy}{0.85\ f'c\ b}$$

$$= \frac{(150.796 - 100.53096)\ .\ 280}{0.85\ .\ 20\ .\ 150}$$

a = 5.259 mm

$$a_{min\ Leleh} = \frac{600\ \beta 1\ d'}{600 - fy}$$

$$= \frac{600\ .\ 0.85\ .\ 42}{600 - 280}$$

$a_{min\ leleh}$ = 66.938 mm

$M_n = M_{nc} + M_{ns}$

Mn = 9800917.405 N.mm atau **Mn = 0.98009 t.m**

Ø Mn = 7840733.924 N.mm atau **Ø Mn = 0.78407 t.m**

Ø Mn = Mmaks

0.7841 = 0.0802 + 0.6 P

0.7039 = 0.6 P

Pmaks = 1.49984 ton

Untuk beban 0.5 P maka : **0.5 Pmaks = 0.78407 ton**

Mn = Mmaks

0.9801 = 0.0802 + 0.6 P

0.8999 = 0.6 P

Pmaks = 1.49984 ton

Untuk beban 0.5 P maka : **0.5 Pmaks = 074992 ton**

Pu = 15 kN

Lampiran 4. Perhitungan Kapasitas Momen - Balok Grouting GFRP (BGRS)

1. Data Perencanaan

Kuat tekan beton	f'_c	=	**20.0**	MPa
Kuat leleh tulangan tarik	f_y	=	**280**	MPa
Kuat leleh tulangan tekan	f_y	=	**280.0**	MPa
Kuat leleh tulangan transversal	f_y	=	**280**	MPa
Modulus elastisitas beton	E_c	=	**21532.98**	MPa
Modulus elastisitas baja	E_s	=	**200000**	MPa
Berat jenis beton	γ_c	=	**2400**	kg/m^3
Lebar penampang	b	=	**150**	mm
Tinggi penampang	h	=	**200**	mm
Tinggi efektif penampang	d	=	**158.00**	mm
Jarak tulangan tekan ke serattekan terluar	d'	=	**42.00**	mm

Luas tulangan tarik	A_s	=	**3**	D	**13**	=	150.80 mm^2
Luas tulangan tekan	A_s'	=	**2**	D	**8**	=	100.53 mm^2
Luas tulangan sengkang	A_{vs}	=	**2**	D	**8**	=	100.55 mm^2

2. Momen Retak Pertama (Mcr)

Pada kondisi retak pertama, momen retak (M_{crack}) terjadi pada saat serattarik penampang balok mencapai modulus keruntuhan (F_r). Oleh SNI 2847.2013 pasal 9.5.2.3 diberikan persamaan sebagai berikut

$$\mathbf{M_{crack}} = \frac{\mathbf{I_g \, . \, f_r}}{\mathbf{y_t}}$$

Diketahui:

Hasil uji modulus keruntuhan f_r $0.7 \times F_c^{0.5}$ = 3.21 MPa

Momen inersia penampang bruto :

$$Ig = \frac{b \quad h^3}{12}$$

$$= 114268833.1 \quad mm^4$$

$$y_{bawah} = h - y_{atas} = 98.29 \quad mm$$

$$M_{crack} = \frac{Ig \quad fr}{y_t}$$

$$= \frac{114268833.1 \quad 3.21}{99.25}$$

$$= 3728524.315 \quad N.mm$$

Mcrack	**=**	**3.7285**	**kN.m**

Nilai P_{crack} diperoleh dengan cara substitusi M_{crack} ke persamaan :M = 0.8019 + 0.6 P

3.7285 = 0.8019 + 0.6P

Diperoleh

P_{cr} = 4.877 kN

3. Momen Leleh (Myield)

Direncanakan menggunakan tulangan :

As	=	**3**	D	**13**	=	150.80 mm^2
As'	=	**2**	D	**8**	=	100.53 mm^2

Awal tulangan leleh

$$= \frac{Es}{Ec} = 9.3 \quad ; \quad nf = \frac{Ef}{Ec} = 0.97$$

k = 0.44065

kd = 81.364 mm

Regangan tulangan tarik dari ujung atas balok

$$\varepsilon y = \frac{fy}{Es} = \frac{280}{200000}$$

εy = 0.0014

Regangan beton bagian atas

$$\varepsilon c = \varepsilon s \left(\frac{kd}{d - kd} \right)$$

$$= 0.0014 \left(\frac{81.36}{158.00 - 81.36} \right)$$

εc = 0.001537

Regangan tulangan tekan

$$\varepsilon s' = \varepsilon c \left(\frac{kd - d'}{kd} \right)$$

$$= 0.0015 \quad \frac{81.36 - 42.00}{81.36}$$

εs' = 0.002265

$$fs' = Es \quad \varepsilon s'$$

$$= 200000 \quad 0.0007$$

$$= 148.67 \quad MPa$$

bila nilai fs' lebih kecil dari nol gunakan nol

fs' = 148.67 MPa

Gaya tekan beton

$$Cc = 0.5 \quad f'c \quad b \quad kd$$

$$= 0.5 \;.\; 20 \;.\; 150.00 \;.\; 81.36$$

Cc = 128087.53 N

Gaya tekan baja

$$C_s = A_s' \quad f_s'$$

$$= 100.53 \;.\; 148.67$$

C_s = 14946.20 N

$$T = C_c + C_s$$

$$= 128087.53 + 8797.99$$

T = 143033.72 N

$T = A_s \; f_y$

$= 120725.72$ N

Nilai selisih T harus mendekati nol

$C_c + C_s - A_s \; f_y = 0$

143033.72 - 120725.72 = -22308.006

= -22308.01

k = 0.4016

Jarak gaya (c) dari ujung atas (y)

$$y = \frac{C_S \; d' + C_C \; . \; 0.33 \; kd}{T}$$

$$y = \frac{14946.20 \; . \; 42.00 + 128087.53 \; . \; 27.12}{143033.72}$$

y = 28.676 mm

Jarak pusat total gaya tekan ke pusat tulangan tarik

$J_d = d - y$

= 158.0 - 28.676

J_d = 120.82 mm

Persamaan momen dan kurvatur

$M_y = A_s \; f_y \; J_d$

= 5632381.53 N.mm

My = 15.31 kN.m

15.31 = 0.8019 + 0.6 P kN.m

$M_y = M_{\text{maks pada tengah bentang}}$

15.31 = 0.8019 + 0.6 P

14.51 = 0.6 P

P = 24.18 kN

4. Momen Ultimit (Mu)

Mu = Φ Mn

$$Mu = \Phi * As * fy * \left(d - \frac{a}{2}\right)$$ faktor reduksi untuk lentur $\Phi = 0.9$

dimana :

Material yang digunakan : **GFRP**

Lokasi balok berada di **Interior**

sehingga digunakan

$C_E = $ **0.75**

$f_{fu} = C_E \quad f^*_{fu}$

$= 0.75 \quad . \quad 460$

$= 345 \quad N/mm^2$

$\varepsilon_{fu} = C_E \quad \varepsilon^*_{fu}$

$= 0.75 \quad . \quad 0.02$

$= 0.015 \quad mm/mm$

Perhitungan *pre-eliminary*

$$\beta_1 = 1.05 - 0.05 \frac{f'_c}{6.9}$$

$$= 1.05 - 0.05 - \frac{20.99}{6.9}$$

β_1 = 0.8979

$A_s = 3 \quad D \quad 13$

$$= 3 \quad . \quad \frac{1}{4} \quad \pi \quad . \quad 13^2$$

A_s = 398.1969 mm^2

$A_s' = 2 \quad D \quad 8$

$$= 2 \quad . \quad \frac{1}{4} \quad \pi \quad . \quad 8$$

A_s' = 100.531 mm^2

digunakan **1** lembar GFRP tebal **1.3** mm

$A_f = n \quad t_f \quad w_f$

$= 1 \quad . \quad 1.3 \quad . \quad 150$

A_f = 195 mm^2

Nilai regangan balok sebelum balok ditempel FRP

Beban yang bekerja pada saat FRP ditempel hanya berat sendiri balok $n_{ekivalen\ tulangan\ ke\ beton}$ = 9.2881

Untuk memperkirakan nilai c dapat digunakan

$$0 = \frac{wf \quad c^{2}}{2} + (n\,A_s + (n - 1\,))\,c - 1\,A_s'\,d' - n$$

$$0 = \frac{150}{2} \quad c^{2} + 3706.8\ \ c - 575114 - 349$$

$$0 = 75\,c^{2} + 3706.8\ \ c - 610109$$

Maka c = 68.80536 mm

berdasarkan hasil analisa awal leleh maka :

k = **0.44065** (saat kondisi awal tulangan leleh setelah retak)

c	**= k d**		
	=	**68.52108**	**mm**

Menentukan nilai regangan desain untuk FRP

$$\varepsilon_{fd} = 0.41 \left(\frac{f'c}{n\ .\ Ef\ .\ tf} \right)^{0.5} \leq 0.9\ \varepsilon_{fu}$$

$$= 0.41 \left(\frac{20.99}{1\ .\ 20900\ .\ 1.3} \right)^{0.5}$$

$$= 0.011396 \leq 0.9\ .\ 0.02$$

$$0.011396 \leq 0.018$$

… debonding akan terjadi sebelum FRP putus

Gunakan **εfd = 0.011396**

Perkiraan nilai c (akan dicek kembali nantinya)

nilai c perkiraan sekitar

$c = 0.2\ d$

(nilai c selanjutnya akan dicek kembali apakah sesuai atau tidak)

$c = 0.2\ d$

$= 0.2 \cdot 155.5$

$= 31.1$ mm

coba nilai

$c = 60.823$ mm

Menghitung tegangan yang terjadi pada tulangan dan FRP

$f_s = E_s\ \varepsilon_s \leq f_y$

$= 200000 \cdot 0.00467$

$= 933.9557102$ N/mm^2

$f_s = 933.9557 > 280$

$f_s' = 185.6839882 < 280$

gunakan

$f_s = 280$ N/mm^2

$f_s' = 185.6839882$ N/mm^2

$f_{fe} = E_f\ \varepsilon_{fe}$

$= 20900 \cdot 0.006863$

$= 143.4342048$ N/mm^2

$$\varepsilon'_c = \frac{1.7 \quad f'c}{Ec}$$

$$\varepsilon'_c = \frac{1.7 \quad 20.99}{21532.97704}$$

$$= 0.001657$$

<u>Mengecek kesesuaian nilai *c*</u>

$$\beta_1 = \frac{4 \quad \varepsilon'c \quad - \quad \varepsilon c}{6 \quad \varepsilon'c \quad - \quad 2\,\varepsilon c}$$

$$= \frac{4 \;.\; 0.001657 \;-\; 0.003}{6 \;.\; 0.001657 \;-\; 2 \;.\; 0.003}$$

$$\beta_1 = 0.920294$$

$$\alpha_1 = \frac{3 \quad \varepsilon'c \quad \varepsilon c \quad - \quad \varepsilon c^2}{3 \quad \beta 1 \quad \varepsilon'c^2}$$

$$= 0.780069$$

$$\alpha_1 = \frac{A_S \; f_S + Af \; ffe - A_S' \; f_S'}{\alpha_1 \; f'_c \; \beta_1 \; w_f}$$

$$= 53.44358 \text{ mm}$$

<u>Kontribusi tulangan terhadap kuat lentur</u>

$$M_{ns} = A_s \; f_s \quad \frac{d - \beta_1 \; c}{2}$$

$$= 14217013.2 \text{ N.mm}$$

$M_{ns} = A_s \ (d - d')$

$= 101 \ . \ 185.68 \ (156 - 42)$

M_{ns}' = 2118703.42 N.mm

= 0.211 9 t.m

<u>Kontribusi FRP terhadap kuat lentur</u>

$$M_{nf} = A_f \ f_{fe} \ \frac{d_f - \beta_1 \ c}{2}$$

$= 14217013.2$ N.mm

M_{nf} = 4811130.67 N.mm

= 0.4811 t.m

<u>Kuat lentur nominal gabungan</u>

$Ø \ M_n = [\ M_{ns} + M_{ns}' + \psi_f \ M_{nf} \ ]$

$= 1 \ [\ 1.4217 + 0.2119 + 1 \ . \ 0.4811131]$

$= 2.11$ t.m

$M_n = 0.0802 + 0.6 \ P$

$2.11468 = 0.0802 + 0.6 \ P$

$2.03449 = 0.6 \ P$

P_u = 33.91 kN

Untuk Perhitungan lendutan secara teoritis dilakukan yaitu :

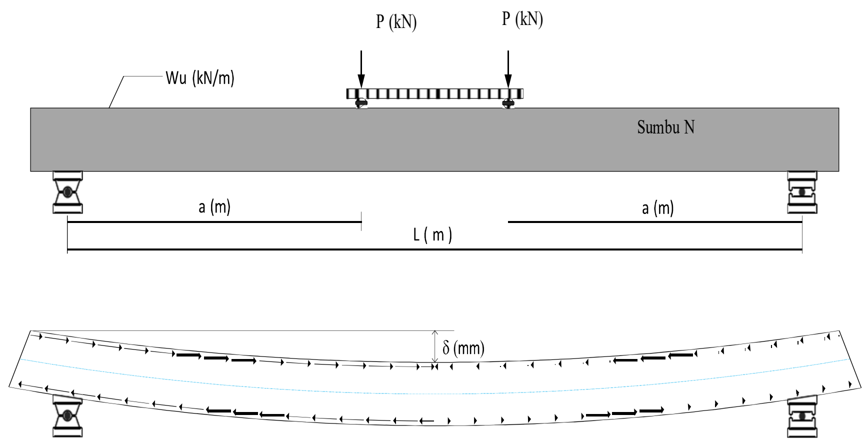
Dimana :

Ec = 21533 Mpa = 21.5 kN/mm^2

A = 1200 mm

L = 3000 mm

Q = 0.9 = 0.0009 kN/mm



Untuk Icr

$$\delta = \frac{1}{24} \times \frac{P * a}{Ec * Icr} \times (3*L^2 - 4a^2) + \frac{5}{384} \times \frac{q * L^4}{Ec * Icr}$$

$$= 0.042 \times \frac{1200P}{1970391430} \times 21240000 + 0.013 \times \frac{72900000000}{2026216698}$$

$$= 0.538979202 \quad P + 0.468468526$$

Untuk Ig

$$\delta = \frac{1}{24} \times \frac{P * a}{Ec * Ig} \times (3*L^2 - 4a^2) + \frac{5}{384} \times \frac{q * L^4}{Ec * Ig}$$

$$= 0.0416667 \times \frac{1200P}{2153300000} \times 21240000 + 0.013 \times \frac{72900000000}{2153300000}$$

$$= 0.493196489 \quad P + 0.440820485$$