LAMPIRAN I
PERHITUNGAN MOMEN-KURVATUR

L1.1 Model Tegangan-Regangan A

Perhitungan Momen Kurvatur sebagai berikut:

1. Pada saat pertama kali retak (*first cracking*) dari beton

Analisis dilakukan dengan menggunakan teori elastik dan transformasi penampang, dimana baja tulangan ditransformasikan menjadi suatu luasan beton ekivalen [Park, 1975].

Persamaan transformasi penampang,

$$n = \frac{E_s}{E_c} = \frac{200000}{15000} = 13,333$$

$$A = (b.h) + (n-1).(A_s + A_s') = (100.200) + (13,333-1).(100,571+100,571)$$

$$= 22480,762 \text{ mm}^2$$

Menghitung $\bar{y}$,

$$\bar{y} = \frac{\left((b.h).\frac{h}{2}\right) + \left((A_s.(n-1)).d\right).\left((A_s'.(n-1)).d'\right)}{A}$$

$$= \frac{\left((100.250).\frac{250}{2}\right) + \left((100,571.(13,33-1)).180\right).\left((100,571.(13,33-1)).20\right)}{A}$$

$$= 100 \text{ mm}$$

$$y_{bottom} = h - \bar{y} = 200 - 100 = 100 \;= 200\text{-}100 = 100 \text{ mm}$$

Menghitung momen inersia penampang,

$$I = \left(\frac{1}{12}.b.h^3\right) + \left((b.h).\left(\bar{y} - \frac{h}{2}\right)^2\right) + \left(A_s.(n-1).(d-\bar{y})^2\right) + \left(A_s'.(n-1).(\bar{y}-d')^2\right)$$

$$= \left(\frac{1}{12}.100.200^3\right) + \left((100.200).\left(100 - \frac{200}{2}\right)^2\right) + \left(100,571.(13,333-1).(180-100)^2\right)$$

$$+ \left(100,571.(13,333-1).(100-20)^2\right)$$

$= 82543542{,}857\ \text{mm}^4$

Menghitung *modulus rupture* (f_r),

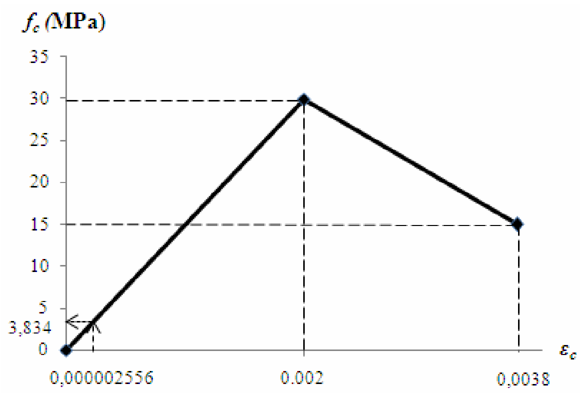
$$f_r = 0{,}7.\sqrt{f_c} = 0{,}7.\sqrt{30} = 3{,}834 \text{ MPa}$$

$$\varepsilon_r = \frac{f_r}{E_c} = \frac{3{,}834}{15000} = 0{,}0002556$$

Momen dan kelengkungan dapat dihitung sebagai berikut,

$$M_{crack} = \frac{f_r.I}{y_{bottom}} = \frac{3{,}834.82543542{,}857}{100} = 3164767{,}228 \text{ Nmm}$$

$$\phi_{crack} = \frac{f_r / E_c}{y_{bottom}} = \frac{3{,}834/15000}{100} = 0{,}000002556 \text{ rad/mm}$$



Gambar L1.1 Model Tegangan-Regangan Beton A Pertama Retak

2. Pada saat pertama kali leleh (*first yield*) dari baja tulangan tarik

Contoh perhitungan Momen-Kurvatur untuk kondisi baja pertama leleh, ditampilkan untuk nilai f_{s1} = 250 MPa.

$$f_{s1} = f_y = 250 \text{ MPa}$$

$$\varepsilon_{s1} = \frac{f_{s1}}{E_s} = \frac{250}{200000} = 0{,}00125$$

Dari diagram regangan diperoleh hubungan:

$$\frac{\varepsilon_{c1}}{c} = \frac{\varepsilon_{s1}}{d-c}$$

$$\varepsilon_{c1} = \varepsilon_{s1}.\frac{c}{d-c} = 0{,}00125.\frac{c}{180-c} = -\frac{0{,}00125.c}{c-180}$$

$f_{c1} \quad = \varepsilon_{c1}.E_c = -\dfrac{0{,}00125.c}{c-180}.20000 = -\dfrac{25.c}{c-180}$

$\dfrac{\varepsilon_{c1}}{c} \quad = \dfrac{\varepsilon_{s2}}{c-d'}$

$\varepsilon_{s2} \quad = \varepsilon_{c1}.\dfrac{c-d'}{c} = -\dfrac{0{,}00125.c-0{,}025}{c-180}$

$f_{s2} \quad = \varepsilon_{s2}.E_s = -\dfrac{0{,}00125.c-0{,}025}{c-180}.200000 = -\dfrac{250.c-5000}{c-180}$

$C_c \quad = \dfrac{1}{2}.f_{c1}.b.c = \dfrac{1}{2}.-\dfrac{25.c}{c-180}.100.c = -\dfrac{1250.c^2}{c-180}$

$C_s \quad = A_s'.f_{s2} = 100{,}571.-\dfrac{250.c-5000}{c-180} = -\dfrac{176000.c-3{,}52.10^6}{7.c-1260}$

$T \quad = A_s.f_{s1} = 100{,}571.250 = 25142{,}857$ N

$\Sigma H = 0$

$C_c + C_s - T = 0$

$-\dfrac{1250.c^2}{c-180} - \dfrac{176000.c-3{,}52.10^6}{7.c-1260} - 25142{,}857 = 0$

$c = -86{,}653$ mm atau $c = 51{,}581$ mm

Pakai $c = 51{,}581$ mm

$\varepsilon_{c1} \quad = \varepsilon_{s1}.\dfrac{c}{d-c} = 0{,}00125.\dfrac{51{,}581}{180-51{,}581} = 0{,}000502$

$f_{c1} \quad = \varepsilon_{c1}.E_c = 0{,}000502.15000 = 7{,}531$ MPa

$\varepsilon_{s2} \quad = \varepsilon_{c1}.\dfrac{c-d'}{c} = 0{,}000502.\dfrac{51{,}581-20}{51{,}581} = 0{,}0003074$

$f_{s2} \quad = \varepsilon_{s2}.E_s = 0{,}0003074.200000 = 61{,}481$ MPa

$C_c \quad = \dfrac{1}{2}.f_{c1}.b.c = \dfrac{1}{2}.7{,}531.100.51{,}581 = 19423{,}386$ N

$C_s \quad = A_s'.f_{s2} = 100{,}571.61{,}481 = 6183{,}212$ N

$T \quad = A_s.f_y = 100{,}571.250 = 25142{,}858$ N

$\Sigma M_T = 0$

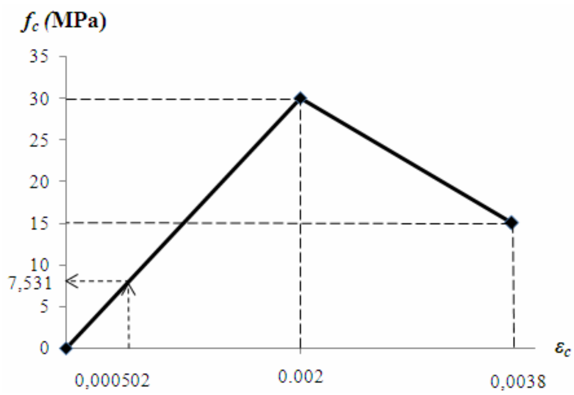
$\left(C_c.\left(d - \dfrac{1.c}{3}\right)\right) + \left(C_s.(d-d')\right) - M_1 = 0$

$$M_1 = \left(C_c.\left(d - \frac{1.c}{3}\right)\right) + \left(C_s.(d - d')\right)$$

$$M_1 = \left(19423,386.\left(180 - \frac{1.51,581}{3}\right)\right) + \left(6183,212.(180 - 20)\right)$$

$$M_1 = 4077364,539 \text{ Nmm}$$

$$\phi = \frac{\varepsilon_{c1}}{c} = \frac{0,000502}{51,581} = 0,000009734 \text{ rad/m}$$

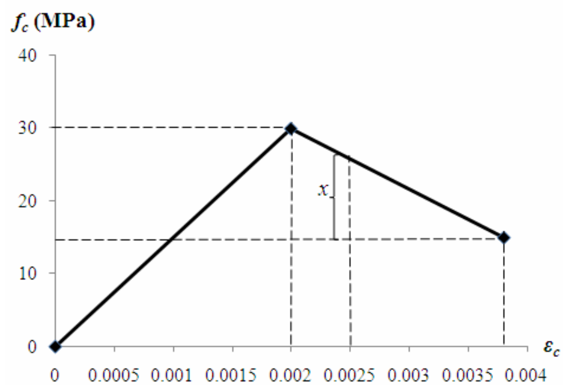


Gambar L1.2 Model Tegangan-Regangan Beton A Pertama Leleh

3. Kondisi setelah baja pertama leleh sampai kondisi ultimit

Contoh perhitungan Momen-kurvatur untuk kondisi setelah baja leleh, ditampilkan untuk nilai ε_c = 0,0025.

Dari diagram tegangan-regangan beton Sozen, setelah mencapai ε_c = 0,002, maka untuk mencari nilai f_c' harus mengggunakan cara interpolasi antara f_c 30-15 MPa (Gambar 3.4).



Gambar L1.3 Interpolasi Tegangan

Dari Gambar L1.3 dapat dihitung nilai *x* sebagai berikut,

$$\frac{30-15}{0,0038-0,002}=\frac{x}{0,0038-0,0025}$$

$$x=10,833$$

Maka perhitungan f_{c1}' sebagai berikut,

f_{c1} = 15 + 10,833 = 25,833 MPa

Mencari nilai *c* dari metode numerik *Bi-section* dengan Microsoft Excel.

Contoh perhitungan:

c = 180 mm

$c_1 = \frac{1}{3}.c = \frac{1}{3}.180 = 60$ mm

$c_2 = 2.c_1 = 2.60 = 120$ mm

$C_{c1} = \frac{1}{2}.c_1.\left(f_c - f_{c1}\right).b = \frac{1}{2}.60.\left(30-25,833\right).100 = 12501$ N

$C_{c2} = c_1.f_{c1}.b = 60.25,833.100 = 154998$ N

$C_{c3} = \frac{1}{2}.c_2.f_c.b = \frac{1}{2}.120.30.100 = 180000$ N

$\varepsilon_{s1} = \varepsilon_{c1}.\frac{d-c}{c} = 0,0025.\frac{180-180}{180} = 0$

$\varepsilon_{s2} = \varepsilon_{c1}.\frac{c-d'}{c} = 0,0025.\frac{180-20}{180} = 0,00222$

$f_{s1} = \varepsilon_{s1}.E_s = 0.200000 = 0$

$f_{s2} = f_y = 250$ MPa (karena tulangan tekan sudah leleh)

$C_s = A_s'.f_{s2} = 100,571.250 = 25142,9$ N

$T = A_s.f_{s1} = 100,571.0 = 0$

$\Sigma H = C_{c1} + C_{c2} + C_{c3} + C_s - T$

$= 12501 + 154998 + 180000 + 25142,9 - 0$

$= 372641,9$

Berikut adalah hasil perhitungan dengan metode numerik *Bi-section* selengkapnya ditampilkan dalam Tabel L1.1.

Tabel L1.1 Mencari Nilai c dengan Metode Numerik *Bi-section* (satuan: N, mm)

No.	c	c_1	c_2	C_{c1}	C_{c2}	C_{c3}	ε_{s1}	ε_{s2}	f_{s1}	f_{s2}	C_s	T	$\Sigma H = 0$
	180	60	120	12501	154998	180000	0	0.0022222	0	250	25142.857	0	372641.86
1	0.0001	3.333E-05	6.667E-05	0.006945	0.08611	0.1	4499.9975	-499.9975	250	250	25142.857	25142.857	-50285.521
	90	30	60	6250.5	77499	90000	0.0025	0.0019444	250	250	25142.857	25142.857	173749.5
2	0.0001	3.333E-05	6.667E-05	0.006945	0.08611	0.1	4499.9975	-499.9975	250	250	25142.857	25142.857	-50285.521
	45	15	30	3125.25	38749.5	45000	0.0075	0.0013889	250	250	25142.857	25142.857	86874.75
3	0.0001	3.333E-05	6.667E-05	0.006945	0.08611	0.1	4499.9975	-499.9975	250	250	25142.857	25142.857	-50285.521
	22.5	7.5	15	1562.625	19374.75	22500	0.0175	0.0002778	250	55.555556	5587.3016	25142.857	23881.819
4	0.0001	3.333E-05	6.667E-05	0.006945	0.08611	0.1	4499.9975	-499.9975	250	250	25142.857	25142.857	-50285.521
	11.25	3.75	7.5	781.3125	9687.375	11250	0.0375	-0.0019444	250	250	25142.857	25142.857	-28567.027
5	22.5	7.5	15	1562.625	19374.75	22500	0.0175	0.0002778	250	55.555556	5587.3016	25142.857	23881.819
	22.5	7.5	15	1562.625	19374.75	22500	0.0175	0.0002778	250	55.555556	5587.3016	25142.857	23881.819
6	16.875	5.625	11.25	1171.9688	14531.063	16875	0.0241667	-0.000463	250	-92.592593	-9312.1693	25142.857	-1876.9952
	19.6875	6.5625	13.125	1367.2969	16952.906	19687.5	0.0203571	-3.968E-05	250	-7.9365079	-798.18594	25142.857	12066.66
7	16.875	5.625	11.25	1171.9688	14531.063	16875	0.0241667	-0.000463	250	-92.592593	-9312.1693	25142.857	-1876.9952
	18.28125	6.09375	12.1875	1269.6328	15741.984	18281.25	0.0221154	-0.000235	250	-47.008547	-4727.7167	25142.857	5422.2933
8	16.875	5.625	11.25	1171.9688	14531.063	16875	0.0241667	-0.000463	250	-92.592593	-9312.1693	25142.857	-1876.9952
	17.8121	5.9373667	11.874733	1237.0503	15337.999	17812.1	0.0227637	-0.0003071	250	-61.416116	-6176.7065	25142.857	0.3655687
9	16.875	5.625	11.25	1171.9688	14531.063	16875	0.0241667	-0.000463	250	-92.592593	-9312.1693	25142.857	-1876.9952

Dari hasil Tabel L1.1 dapat diperoleh bahwa pada langkah iterasi ke-9 telah diperoleh hasil nilai *c* yang konvergen, maka iterasi dihentikan. Setelah diperoleh nilai *c*, maka perhitungan Momen-Kurvatur dapat dilanjutkan.

Dari hasil perhitungan di atas diperoleh:

c = 17,8121 mm

c_1 = 5,9373667 mm

c_2 = 11,874733 mm

C_{c1} = 1237,0503 N

C_{c2} = 15337,999 N

C_{c3} = 17812,1 N

ε_{s1} = 0,0227637

ε_{s2} = -0,0003071

f_{s1} = 250 MPa

f_{s2} = -61,416116 MPa

C_s = -6176,7065 N

T = 25142,857 N

ΣH = 0,3655687

$$\Sigma M_T = 0$$

$$\left(C_{c1}\cdot\left(d-\frac{2.c_1}{3}\right)\right)+\left(C_{c2}\cdot\left(d-\frac{1.c_1}{2}\right)\right)+\left(C_{c3}\cdot\left(d-c_1-\frac{1.c_2}{3}\right)\right)+\left(C_s\cdot\left(d-d'\right)\right)-M_1=0$$

$$M_1=\left(C_{c1}\cdot\left(d-\frac{2.c_1}{3}\right)\right)+\left(C_{c2}\cdot\left(d-\frac{1.c_1}{2}\right)\right)+\left(C_{c3}\cdot\left(d-c_1-\frac{1.c_2}{3}\right)\right)+\left(C_s.\left(d-d'\right)\right)$$

$$=\left(1237,0503.\left(180-\frac{2.60}{3}\right)\right)+\left(15337,999.\left(180-\frac{1.60}{2}\right)\right)+\left(17812,1.\left(180-60-\frac{1.120}{3}\right)\right)$$
$$+\left(-6176,7065.\left(180-20\right)\right)$$

= 4453422,672 Nmm

$$\phi = \frac{\varepsilon_{c1}}{c}=\frac{0,0025}{17,8121}= 0,0001071 \text{ rad/mm}$$

L1.2 Model Tegangan-Regangan B

Perhitungan Momen-Kurvatur sebagai berikut:

1. Pada saat pertama kali retak (*first cracking*) dari beton

Analisis dilakukan dengan menggunakan teori elastik dan transformasi penampang, dimana baja tulangan ditransformasikan menjadi suatu luasan beton ekivalen [Park, 1975].

Persamaan transformasi penampang,

$$n = \frac{E_s}{E_c} = \frac{200000}{15000} = 13,333$$

$$A = (b.h) + (n-1).(A_s + A_s') = (100.200) + (13,333-1).(100,571+100,571)$$

$$= 22480,762 \text{ mm}^2$$

Menghitung $\bar{y}$,

$$\bar{y} = \frac{\left((b.h).\frac{h}{2}\right) + \left((A_s.(n-1)).d\right).\left((A_s'.(n-1)).d'\right)}{A}$$

$$= \frac{\left((100.250).\frac{250}{2}\right) + \left((100,571.(13,33-1)).180\right).\left((100,571.(13,33-1)).20\right)}{A}$$

$$= 100 \text{ mm}$$

$$y_{bottom} = h - \bar{y} = 200 - 100 = 100 \text{ = 200-100 = 100 mm}$$

Menghitung momen inersia penampang,

$$I = \left(\frac{1}{12}.b.h^3\right) + \left((b.h).\left(\bar{y} - \frac{h}{2}\right)^2\right) + \left(A_s.(n-1).(d-\bar{y})^2\right) + \left(A_s'.(n-1).(\bar{y}-d')^2\right)$$

$$= \left(\frac{1}{12}.100.200^3\right) + \left((100.200).\left(100 - \frac{200}{2}\right)^2\right) + \left(100,571.(13,333-1).(180-100)^2\right)$$

$$+\left(100,571.(13,333-1).(100-20)^2\right)$$

$$= 82543542,857 \text{ mm}^4$$

Menghitung *modulus rupture* (f_r),

$$f_r = 0,7.\sqrt{f_c} = 0,7.\sqrt{30} = 3,834 \text{ MPa}$$

$$\varepsilon_r = \frac{f_r}{E_c} = \frac{3,834}{15000} = 0,0002556$$

Momen dan kelengkungan dapat dihitung sebagai berikut,

$M_{crack} = \dfrac{f_r.I}{y_{bottom}} = \dfrac{3,834.82543542,857}{100}$ = 3164767,228 Nmm

$\phi_{crack} = \dfrac{f_r / E_c}{y_{bottom}} = \dfrac{3,834/15000}{100}$ = 0,000002556 rad/mm

2. Pada saat pertama kali leleh (*first yield*) dari baja tulangan tarik

Contoh perhitungan Momen-Kurvatur untuk kondisi baja pertama leleh, ditampilkan untuk nilai ε_{c1} = 0,000325.

$$f_{c1} = f_c.\left(\left(\frac{2.\varepsilon_{c1}}{\varepsilon_c}\right)-\left(\frac{\varepsilon_{c1}}{\varepsilon_c}\right)^2\right) = 30.\left(\left(\frac{2.0,000325}{0,002}\right)-\left(\frac{0,000325}{0,002}\right)^2\right)$$

= 8,947 MPa

Dari diagram regangan diperoleh hubungan:

$$\frac{\varepsilon_{c1}}{c} = \frac{\varepsilon_{s1}}{d-c}$$

$$\varepsilon_{s1} = \varepsilon_{c1}.\frac{d-c}{c} = 0,000325.\frac{180-c}{c} = \frac{0,0585-0,000325.c}{c}$$

$$f_{s1} = \varepsilon_{s1}.E_s = \frac{0,0585-0,000325.c}{c}.200000 = \frac{11700-65.c}{c}$$

$$\frac{\varepsilon_{c1}}{c} = \frac{\varepsilon_{s2}}{c-d'}$$

$$\varepsilon_{s2} = \varepsilon_{c1}.\frac{c-d'}{c} = 0,000325.\frac{c-20}{c} = \frac{0,000325.c-0,0065}{c}$$

$$f_{s2} = \varepsilon_{s2}.E_s = \frac{0,000325.c-0,0065}{c}.200000 = \frac{65.c-1300}{c}$$

$$C_c = \frac{2.c.f_{c1}.b}{3} = \frac{2.c.8,947.100}{3} = 596,467.c$$

$$C_s = A_s'.f_{s2} = 100,571.\frac{65.c-1300}{c} = \frac{6537,115.c-130742,3}{c}$$

$$T = A_s.f_{s1} = 100,571.\frac{11700-65.c}{c} = \frac{1176680,7-6537,115.c}{c}$$

$$\Sigma H = 0$$

$$C_c + C_s - T = 0$$

$$596{,}467.c + \frac{6537{,}115.c - 130742{,}3}{c} - \frac{1176680{,}7 - 6537{,}115.c}{c} = 0$$

$c = -59{,}044$ mm atau $c = 37{,}106$ mm

Pakai c = 37,106 mm

$$\varepsilon_{s1} = \varepsilon_c.\frac{d-c}{c} = 0{,}000325.\frac{180-37{,}106}{37{,}106} = 0{,}00125$$

$$\varepsilon_{s2} = \varepsilon_c.\frac{c-d'}{c} = 0{,}000325.\frac{37{,}106-20}{37{,}106} = 0{,}00015$$

$$f_{s1} = \varepsilon_{s1}.E_s = 0{,}00125.200000 = 250 \text{ MPa}$$

$$f_{s2} = \varepsilon_{s2}.E_s = 0{,}00015.200000 = 29{,}927 \text{ MPa}$$

$$C_c = \frac{2.c.f_{c1}.b}{3} = \frac{2.37{,}106.10{,}588.100}{3} = 22133{,}424 \text{ N}$$

$$C_s = A_s'.f_{s2} = 100{,}571.29{,}927 = 3009{,}793 \text{ N}$$

$$T = A_s.f_y = 100{,}571.250 = 25142{,}857 \text{ N}$$

$$\Sigma M_T = 0$$

$$\left(C_c.\left(d - \frac{3.c}{8}\right)\right) + \left(C_s.(d-d')\right) - M_1 = 0$$

$$M_1 = \left(C_c.\left(d - \frac{3.c}{8}\right)\right) + \left(C_s.(d-d')\right)$$

$$M_1 = \left(22133{,}424.\left(180 - \frac{3.37{,}106}{8}\right)\right) + \left(3009{,}793.(180-20)\right)$$

$$M_1 = 4157605{,}7 \text{ Nmm}$$

$$\phi = \frac{\varepsilon_{c1}}{c} = \frac{0{,}000325}{37{,}106} = 0{,}000008748 \text{ rad/mm}$$

3. Kondisi setelah baja pertama leleh sampai kondisi ultimit

Contoh perhitungan Momen-Kurvatur untuk kondisi baja setelah leleh, dalam subbab ini ditampilkan untuk nilai ε_{c1} = 0,0035. Dari diagram tegangan-regangan beton Model B, setelah mencapai ε_c = 0,002, maka untuk mencari nilai f_c dapat menggunakan Persamaan 2.5 sebagai berikut:

$$f_{c1} = f_c.\left(1 - \left(100.(\varepsilon_{c1} - \varepsilon_c)\right)\right) = 30.\left(1 - \left(100.(0{,}0035 - 0{,}002)\right)\right) = 25{,}5 \text{ MPa}$$

Mencari nilai *c* dari metode numerik *Bi-section* dengan Microsoft Excel. Dari hasil perhitungan Metode Numerik *Bi-section* dapat diperoleh bahwa pada langkah iterasi ke-24 telah diperoleh hasil nilai *c* yang konvergen. Maka iterasi dihentikan. Setelah diperoleh nilai *c*, maka perhitungan Momen-Kurvatur dapat dilanjutkan.

c = 16,214 mm

$c_1 = \frac{1}{3}.c = \frac{1}{3}.16,214$ = 5,405 mm

$c_2 = 2.c_1$ = 2.5,405 = 10,809 mm

$C_{c1} = \frac{1}{2}.c_1.\left(f_c - f_{c1}\right).b = \frac{1}{2}.5,405.\left(30-25,2\right).100$ = 1216,125 N

$C_{c2} = c_1.f_{c1}.b$ = 5,405.25,2.100 = 13782,75 N

$C_{c3} = \frac{2}{3}.c_2.f_c.b = \frac{2}{3}.10,809.30.100$ = 21618 N

$\varepsilon_{s1} = \varepsilon_{c1}.\frac{d-c}{c} = 0,0035.\frac{180-16,214}{16,214}$ = 0,0354

$\varepsilon_{s2} = \varepsilon_{c1}.\frac{c-d'}{c} = 0,0035.\frac{16,214-20}{16,214}$ = -0,000817

f_{s1} = 250 MPa

$f_{s2} = \varepsilon_{s2}.E_s$ = -0,000817.200000 = -163,436 MPa

$C_s = A_s'.f_{s2} = 100,571.-163,436$ = -16436,945 N

$T = A_s.f_{s1} = 100,571.250$ = 25142,857 N

ΣH = -0,005

$\Sigma M_T = 0$

$$\left(C_{c1}.\left(d-\frac{2.c_1}{3}\right)\right)+\left(C_{c2}.\left(d-\frac{1.c_1}{2}\right)\right)+\left(C_{c3}.\left(d-c_1-\frac{3.c_2}{8}\right)\right)+\left(C_s.\left(d-d'\right)\right)-M_1=0$$

$$M_1=\left(C_{c1}.\left(d-\frac{2.c_1}{3}\right)\right)+\left(C_{c2}.\left(d-\frac{1.c_1}{2}\right)\right)+\left(C_{c3}.\left(d-c_1-\frac{3.c_2}{8}\right)\right)+\left(C_s.\left(d-d'\right)\right)$$

$$M_1=\left(1216,125.\left(180-\frac{2.60}{3}\right)\right)+\left(13782,75.\left(180-\frac{1.60}{2}\right)\right)+\left(21618.\left(180-60-\frac{3.120}{8}\right)\right)$$

$$-\left(16436,945.\left(180-20\right)\right)$$

M_1 = 4579352,679 Nmm

$$\phi = \frac{\varepsilon_{c1}}{c} = \frac{0,0035}{16,214} = 0,0002159 \text{ rad/mm}$$

L1.3 Model Tegangan-Regangan C

Model tegangan-regangan C menggunakan kurva tegangan regangan beton Hognestead (Gambar 2.3b) dan kurva tegangan baja lengkap hasil uji tarik baja (Gambar 2.6b). Perhitungan Momen-Kurvatur sebagai berikut:

1. Pada saat pertama kali retak (*first cracking*) dari beton

Analisis dilakukan dengan menggunakan teori elastik dan transformasi penampang, dimana baja tulangan ditransformasikan menjadi suatu luasan beton ekivalen [Park, 1975].

Persamaan transformasi penampang,

$$n = \frac{E_s}{E_c} = \frac{200000}{15000} = 13,333$$

$$A = (b.h) + (n-1).(A_s + A_s') = (100.200) + (13,333-1).(100,571+100,571)$$

$$= 22480,762 \text{ mm}^2$$

Menghitung $\bar{y}$,

$$\bar{y} = \frac{\left((b.h).\frac{h}{2}\right) + \left((A_s.(n-1)).d\right).\left((A_s'.(n-1)).d'\right)}{A}$$

$$= \frac{\left((100.250).\frac{250}{2}\right) + \left((100,571.(13,33-1)).180\right).\left((100,571.(13,33-1)).20\right)}{A}$$

$$= 100 \text{ mm}$$

$$y_{bottom} = h - \bar{y} = 200 - 100 = 100 \ = 200\text{-}100 = 100 \text{ mm}$$

Menghitung momen inersia penampang,

$$I = \left(\frac{1}{12}.b.h^3\right) + \left((b.h).\left(\bar{y} - \frac{h}{2}\right)^2\right) + \left(A_s.(n-1).(d-\bar{y})^2\right) + \left(A_s'.(n-1).(\bar{y}-d')^2\right)$$

$$= \left(\frac{1}{12}.100.200^3\right) + \left((100.200).\left(100 - \frac{200}{2}\right)^2\right) + \left(100,571.(13,333-1).(180-100)^2\right)$$

$$+ \left(100,571.(13,333-1).(100-20)^2\right)$$

$$= 82543542,857 \text{ mm}^4$$

Menghitung *modulus rupture* (f_r),

$$f_r = 0,7.\sqrt{f_c} \;=\; 0,7.\sqrt{30} \;= 3,834 \text{ MPa}$$

$$\varepsilon_r = \frac{f_r}{E_c} = \frac{3,834}{15000} = 0,0002556$$

Momen dan kelengkungan dapat dihitung sebagai berikut,

$$M_{crack} = \frac{f_r.I}{y_{bottom}} = \frac{3,834.82543542,857}{100} = 3164767,228 \text{ Nmm}$$

$$\phi_{crack} = \frac{f_r / E_c}{y_{bottom}} = \frac{3,834/15000}{100} = 0,000002556 \text{ rad/mm}$$

2. Pada saat pertama kali leleh (*first yield*) dari baja tulangan tarik

Contoh perhitungan Momen-Kurvatur untuk kondisi baja pertama leleh, ditampilkan untuk nilai f_{s1} = 255 MPa.

f_{s1} $= f_y$ = 255 MPa

ε_{s1} = 0,001275

Mencari nilai *c* dengan Metode Numerik *Bi-section* pada program Microsoft Excel. Dari hasil perhitungan metode numerik *Bi-section* dapat diperoleh bahwa pada langkah iterasi ke-20 telah diperoleh hasil nilai *c* yang konvergen. Maka iterasi dihentikan. Setelah diperoleh nilai *c*, maka perhitungan Momen-Kurvatur dapat dilanjutkan. Hasil dari iterasi ke-20 adalah sebagai berikut:

c = 37,132 mm

$$\varepsilon_{c1} = \varepsilon_{s1}.\frac{c}{d-c} = 0,001275.\frac{37,132}{180-37,132} = 0,000331$$

$$f_{c1} = f_c.\left(\left(\frac{2.\varepsilon_{c1}}{\varepsilon_c}\right)-\left(\frac{\varepsilon_{c1}}{\varepsilon_c}\right)^2\right) = 30.\left(\left(\frac{2.0,000331}{0,002}\right)-\left(\frac{0,000331}{0,002}\right)^2\right)$$

= 9,118 MPa

$$\varepsilon_{s2} = \varepsilon_{c1}.\frac{c-d'}{c} = 0,000331.\frac{37,132-20}{37,132} = 0,0001529$$

f_{s1} = 255 MPa

f_{s2} = $\varepsilon_{s2}.E_s$ = 0,0001529.200000 = 30,578 MPa

$$C_c = \frac{2}{3}.c.f_{c1}.b = \frac{2}{3}.37,132.9,118.100 = 22570,692 \text{ N}$$

$C_s \quad = A_s'.f_{s2} = 100,571.30,578 = 3075,303$ N

$T \quad = A_s.f_{s1} = 100,571.255 = 25645,715$ N

$\Sigma H \quad = 0,09$

$\Sigma M_T = 0$

$$\left(C_c.\left(d - \frac{3.c}{8}\right)\right) + \left(C_s.(d - d')\right) - M_1 = 0$$

$$M_1 = \left(C_c.\left(d - \frac{3.c}{8}\right)\right) + \left(C_s.(d - d')\right)$$

$$= \left(22570,692.\left(180 - \frac{3.37,132}{8}\right)\right) + \left(3075,303.(180 - 20)\right)$$

$$= 4240487,506 \text{ Nmm}$$

$$\phi = \frac{\varepsilon_{c1}}{c} = \frac{0,000331}{37,132} = 0,000008924 \text{ rad/mm}$$

3. Kondisi setelah baja pertama leleh sampai kondisi ultimit

Contoh perhitungan Momen-Kurvatur untuk kondisi baja setelah leleh, ditampilkan untuk nilai ε_{c1} = 0,0035.

Mencari nilai *c* dengan metode numerik *Bi-section* pada program Microsoft Excel. Dari hasil perhitungan metode numerik *Bi-section* dapat diperoleh bahwa pada langkah iterasi ke-18 telah diperoleh hasil nilai *c* yang konvergen. Maka iterasi dihentikan. Setelah diperoleh nilai *c*, maka perhitungan Momen-Kurvatur dapat dilanjutkan. Hasil dari iterasi ke-18 adalah sebagai berikut:

$c \quad = 17,253$ mm

$$c_1 = \frac{1}{3}.c = \frac{1}{3}.17,253 = 5,751 \text{ mm}$$

$c_2 \quad = 2.c_1 = 2.5,751 = 11,502$ mm

$$f_{c1} = f_c.\left(1 - \left(100.(\varepsilon_{c1} - \varepsilon_c)\right)\right) = 30.\left(1 - \left(100.(0,0035 - 0,002)\right)\right)$$

$$= 25,5 \text{ MPa}$$

$$\varepsilon_{s2} = \varepsilon_{c1}.\frac{c - d'}{c} = 0,0035.\frac{17,253 - 20}{17,253} = -0,0005573$$

$$\varepsilon_{s1} = \varepsilon_{c1}.\frac{d-c}{c} = 0,0035.\frac{180-17,253}{17,253} = 0,0033$$

$0,006 \le \varepsilon_s \le 0,03$ maka $f_s = 198,9 + 11899.\varepsilon_s - 253094.\varepsilon_s{}^2$

$$f_{s1} = 198,9 + 11899.\varepsilon_{s1} - 253094.\varepsilon_{s1}{}^2$$

$$= 198,9 + 11899.0,0033 - 253094.0,0033^2$$

$$= 235,411 \text{ MPa}$$

$$f_{s2} = \varepsilon_{s2}.E_s = -0,0005573.200000 = -111,469 \text{ MPa}$$

$$C_{c1} = \frac{1}{2}.c_1.\left(f_c - f_{c1}\right).b = \frac{1}{2}.5,751.\left(30-25,5\right).100 = 1293,975 \text{ N}$$

$$C_{c2} = c_1.f_{c1}.b = 5,751.25,5.100 = 14665,05 \text{ N}$$

$$C_{c3} = \frac{2}{3}.c_2.f_c.b = \frac{2}{3}.11,502.30.100 = 23004 \text{ N}$$

$$C_s = A_s'.f_{s2} = 100,571.-111,469 = -11210,628 \text{ N}$$

$$T = A_s.f_{s1} = 100,571.235,411 = 23675,519 \text{ N}$$

$$\Sigma H = 0,001$$

$$\Sigma M_T = 0$$

$$\left(C_{c1}.\left(d-\frac{2.c_1}{3}\right)\right) + \left(C_{c2}.\left(d-\frac{1.c_1}{2}\right)\right) + \left(C_{c3}.\left(d-c_1-\frac{3.c_2}{8}\right)\right) + \left(C_s.\left(d-d'\right)\right) - M_1 = 0$$

$$M_1 = \left(C_{c1}.\left(d-\frac{2.c_1}{3}\right)\right) + \left(C_{c2}.\left(d-\frac{1.c_1}{2}\right)\right) + \left(C_{c3}.\left(d-c_1-\frac{3.c_2}{8}\right)\right) + \left(C_s.\left(d-d'\right)\right)$$

$$M_1 = \left(1239,975.\left(180-\frac{2.5,751}{3}\right)\right) + \left(14665,05.\left(180-\frac{1.5,751}{2}\right)\right) +$$

$$\left(23004.\left(180-60-\frac{3.11,502}{8}\right)\right) + \left(-11210,628.\left(180-20\right)\right)$$

$$M_1 = 5858481,978 \text{ Nmm}$$

$$\phi = \frac{\varepsilon_{c1}}{c} = \frac{0,0035}{17,253} = 0,0002029 \text{ rad/mm}$$

LAMPIRAN II
PERHITUNGAN BEBAN-LENDUTAN EKSAK

1. Kurvatur-Bentang

Untuk perhitungan dengan berat sendiri, maka balok selain memikul beban akibat beban terpusat (*third point loading*) juga memikul berat sendiri yang diaplikasikan sebagai beban terdistribusi merata seperti pada Gambar 2.20. Perhitungan hubungan Momen-Bentang sebagai berikut:

Reaksi perletakan:

$\Sigma M_B = 0$

$$V_A.L - P.\frac{2.L}{3} - P.\frac{L}{3} - q.L.\frac{L}{2} = 0$$

$$V_A = P + \left(\frac{1}{2}.q.L\right)$$

$$V_B = V_A = P + \left(\frac{1}{2}.q.L\right)$$

Diagram benda bebas segmen AB $\left(0 \le x_1 \le L/3\right)$:

$$\Sigma M_x = 0$$

$$V_A.x_1 - q.x_1.\frac{x_1}{2} - M_x = 0$$

$$M_x = V_A.x_1 - \left(\frac{1}{2}.q.x_1^2\right)$$

$$M_x = \left(P + \frac{1}{2}.q.L\right).x_1 - \left(\frac{1}{2}q.x_1^2\right)$$

Saat $x_1 = 0$

$$M_x = \left(P + \frac{1}{2}.q.L\right).0 - \left(\frac{1}{2}q.0^2\right) = 0$$

Saat $x_1 = L/3$

$$M_x = \left(P + \frac{1}{2}.q.L\right).\frac{L}{3} - \left(\frac{1}{2}q.\left(\frac{L}{3}\right)^2\right) = \frac{PL}{3} + \frac{qL^2}{9}$$

Diagram benda bebas segmen CD $\left(0 \le x_2 \le L/3\right)$:

$\Sigma M_x = 0$

$$V_A.\left(\frac{L}{3} + x_2\right) - P.x_2 - q.\left(\frac{L}{3} + x_2\right).\frac{\left(\frac{L}{3} + x_2\right)}{2} - M_x = 0$$

$$M_x = V_A.\left(\frac{L}{3} + x_2\right) - \left(P.x_2\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + x_2\right)^2\right)$$

$$M_x = \left(P + \left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3} + x_2\right) - \left(P.x_2\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + x_2\right)^2\right)$$

Saat $x_2 = 0$

$$M_x = \left(P + \left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3} + 0\right) - \left(P.0\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + 0\right)^2\right) = \frac{PL}{3} + \frac{qL^2}{9}$$

Saat $x_2 = L/3$

$$M_x = \left(P + \left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3} + \frac{L}{3}\right) - \left(P.\frac{L}{3}\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + \frac{L}{3}\right)^2\right) = \frac{PL}{3} + \frac{qL^2}{9}$$

Diagram benda bebas segmen BD $\left(0 \le x_3 \le L/3\right)$:

$\Sigma M_x = 0$

$$-V_B.x_3 + q.x_3.\frac{x_3}{2} + M_x = 0$$

$$M_x = V_B.x_3 - \left(\frac{1}{2}.q.x_3^{\ 2}\right)$$

$$M_x = \left(P + \frac{1}{2}.q.L\right).x_3 - \left(\frac{1}{2}q.x_3^{\ 2}\right)$$

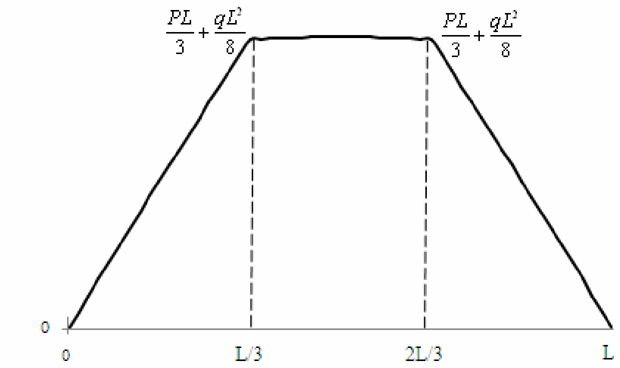
Saat $x_3 = 0$

$$M_x = \left(P + \frac{1}{2}.q.L\right).0 - \left(\frac{1}{2}q.0^2\right) = 0$$

Saat $x_3 = L/3$

$$M_x = \left(P + \frac{1}{2}.q.L\right).\frac{L}{3} - \left(\frac{1}{2}q.\left(\frac{L}{3}\right)^2\right) = \frac{PL}{3} + \frac{qL^2}{8}$$

Maka hubungan Momen-Bentang adalah sebagai berikut:



Gambar L2.1 Hubungan Momen-Bentang Model AN

Dari hubungan Momen-Kurvatur model tegangan-regangan A diperoleh:

M = 3164767,228 Nmm

ϕ = 2.556E-06 rad/mm

Maka hubungan Momen-Bentang dihitung dengan menggunakan diagram benda bebas seperti contoh perhitungan di atas. Nilai momen dan kurvatur di atas adalah nilai pada saat di tengah bentang. Balok memiliki dimensi *b* = 100 mm dan *h* = 200 mm, dengan panjang bentang *L* = 2700 mm. Maka perhitungan berat sendiri *q* sebagai berikut:

$A = b.h$ = 100.200 = 20000 mm^3 = 0,02 m^3

$q = A.\gamma_{beton}$ = 0,02.2400 = 47,088 kg/m = 0,47088 N/mm

Diagram benda bebas segmen CD $\left(0 \le x_2 \le 900\right)$:

$$\Sigma M_x = 0$$

$$M_x = \left(P + \left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3} + x_2\right) - \left(P.x_2\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + x_2\right)^2\right)$$

Saat x_2 = 450 mm

$$M_x = \left(P + \left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3} + x_2\right) - \left(P.x_2\right) - \left(\frac{q}{2}.\left(\frac{L}{3} + x_2\right)^2\right)$$

$$3164767,228=\left(P+\left(\frac{1}{2}.0,47088.2700\right)\right).\left(\frac{2700}{3}+450\right)-\left(P.450\right)-\left(\frac{0,47088}{2}.\left(\frac{2700}{3}+450\right)^{2}\right)$$

$$3164767,228=900.P+429089,4$$

$$P=3039,642\text{ N}$$

Setelah dihitung *P*, lalu dicari nilai momen dari diagram benda bebas.

Diagram benda bebas AB $\left(0\le x_1\le 900\right)$:

$$M_x=\left(P+\frac{1}{2}.q.L\right).x_1-\left(\frac{1}{2}q.x_1{}^2\right)$$

Saat $x_1 = 0$

$$M_x=\left(3039,642+\frac{1}{2}.0,47088.2700\right).0-\left(\frac{1}{2}.0,47088.0^2\right)=0$$

Saat $x_1 = 450$ mm

$$M_x=\left(3039,642+\frac{1}{2}.0,47088.2700\right).450-\left(\frac{1}{2}.0,47088.450^2\right)$$

= 1606221,914 Nmm

Saat $x_1 = 900$ mm

$$M_x=\left(3039,642+\frac{1}{2}.0,47088.2700\right).900-\left(\frac{1}{2}.0,47088.900^2\right)$$

= 3117090,628 Nmm

Diagram benda bebas CD $\left(0\le x_2\le 900\right)$:

$$M_x=\left(P+\left(\frac{1}{2}.q.L\right)\right).\left(\frac{L}{3}+x_2\right)-\left(P.x_2\right)-\left(\frac{q}{2}.\left(\frac{L}{3}+x_2\right)^2\right)$$

Saat $x_2 = 0$

$$M_x=\left(3039,642+\left(\frac{1}{2}.0,47088.2700\right)\right).\left(\frac{2700}{3}+0\right)-\left(3039,642.0\right)-\left(\frac{0,47088}{2}.\left(\frac{2700}{3}+0\right)^2\right)$$

= 3416709,046 Nmm

Saat $x_2 = 450$ mm

$$M_x=\left(3039,642+\left(\frac{1}{2}.0,47088.2700\right)\right).\left(\frac{2700}{3}+450\right)-\left(3039,642.450\right)-\left(\frac{0,47088}{2}.\left(\frac{2700}{3}+450\right)^2\right)$$

= 3164767,228 Nmm

Saat $x_2 = 900$ mm

$$M_x = \left(3039,642 + \left(\frac{1}{2}.0,47088.2700\right)\right).\left(\frac{2700}{3}+900\right) - (3039,642.900) - \left(\frac{0,47088}{2}.\left(\frac{2700}{3}+900\right)^2\right)$$

= 3117090,628 Nmm

Diagram benda bebas BD $(0 \le x_3 \le 900)$:

$$M_x = \left(P + \frac{1}{2}.q.L\right).x_3 - \left(\frac{1}{2}q.x_3^{\ 2}\right)$$

Saat $x_3 = 0$

$$M_x = \left(3039,642 + \frac{1}{2}.0,47088.2700\right).0 - \left(\frac{1}{2}.0,47088.0^2\right) = 0$$

Saat x_3 = 450 mm

$$M_x = \left(3039,642 + \frac{1}{2}.0,47088.2700\right).450 - \left(\frac{1}{2}.0,47088.450^2\right)$$

= 1606221,914 Nmm

Saat x_3 = 900 mm

$$M_x = \left(3039,642 + \frac{1}{2}.0,47088.2700\right).900 - \left(\frac{1}{2}.0,47088.900^2\right)$$

= 3117090,628 Nmm

Setelah memperoleh nilai momen di tiap bentang, maka besarnya kurvatur dihitung dengan mengeplot nilai momen tiap bentang pada kurva Momen-Kurvatur.

Diagram benda bebas AB $(0 \le x_1 \le 900)$:

Saat x_1 = 0 diperoleh

$$M_x = 0$$

$$\varphi = 0$$

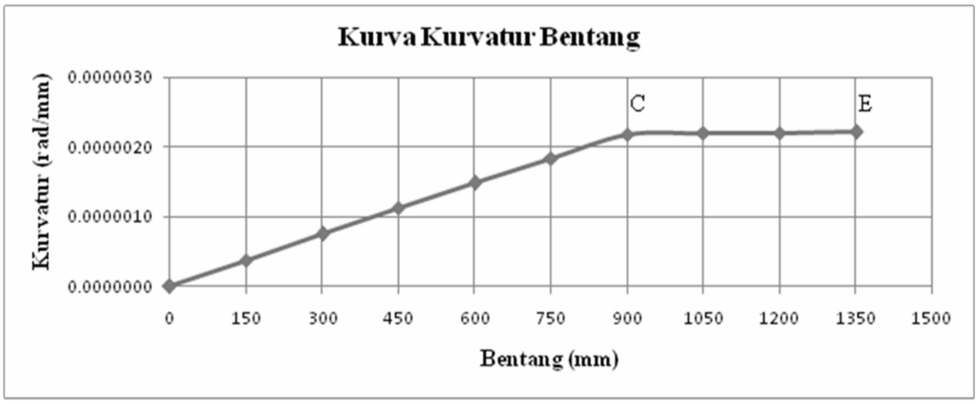
Saat x_1 = 450 mm

$$M_x = 1606221,914 \text{ Nmm}$$

Nilai M_x diplot pada kurva Momen-Kurvatur model tegangan-regangan A maka diperoleh nilai kurvatur, φ = 1,297E-06 rad/mm.

2. Beban-Lendutan

Metode perhitungan lendutan menggunakan metode momen area, yaitu menggunakan luasan kurvaturnya. Luasan kurvaturnya berupa luasan parabola dan persegi. Dalam perhitungan besarnya momen akibat berat sendiri balok diperhitungkan, maka luasan bidang *M/EI* sebagai suatu fungsi parabola dapat dihitung dengan menggunakan Gambar 2.10.



Gambar L2.2 Kurva Kurvatur-Bentang Model AN

Berat sendiri diaplikasikan berupa beban terdistribusi merata pada balok. Akibat beban merata, maka diagram momennya berbentuk parabola. Hubungan Momen-Bentang digunakan untuk menghitung kurva Kurvatur-Bentang. Oleh karena itu, kurva Kurvatur-Bentangnya juga berbentuk parabola.

Tabel L2.1 Perhitungan Lendutan Model AN

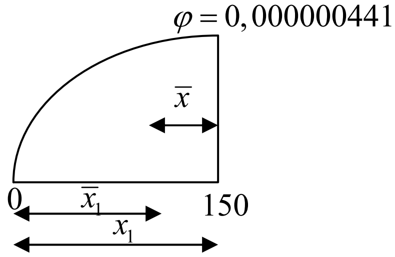
Bentang (mm)	Momen (N/mm)	Kurvatur (rad/mm)	Titik Berat (mm)		A_i (mm^2)		δ_i (mm)	δ_{CE} (mm)
			Parabola	Persegi	Parabola	Persegi		
150	546002.105	0.0000004410	93.75	0	0.00004410	0	0.004134	-
300	1081409.409	0.0000008734	243.75	225	0.00004324	0.00006615	0.025423	-
450	1606221.914	0.0000012973	393.75	375	0.00004239	0.00013101	0.065819	-
600	2120439.619	0.0000017126	543.75	525	0.00004153	0.00019459	0.124743	-
750	2624062.523	0.0000021193	693.75	675	0.00004068	0.00025689	0.201618	-
900	3117090.628	0.0000025175	843.75	825	0.00003982	0.00031790	0.295866	-
1050	3143577.628	0.0000025389	993.75	975	0.00000214	0.00037763	0.370315	0.028523
1200	3159469.828	0.0000025518	1143.75	1125	0.00000128	0.00038084	0.429912	0.086002
1350	3164767.228	0.0000025560	1293.75	1275	0.00000043	0.00038276	0.488578	0.143705
TOTAL							2.006407	0.258229

Contoh perhitungan:

Saat x_1 = 150 mm

M_1 = 546002,105 Nmm

φ_1 = 0,0000004410 rad/mm



Gambar L2.3 Luasan Kurvatur-Bentang Segmen 1

$\overline{x}$ $= \frac{3}{8}.x_1 = \frac{3}{8}.150 = 56,25\,\text{mm}$

$\overline{x}_1$ $= x_1 - \overline{x} = 150 - 56,25 = 93,75\,\text{mm}$

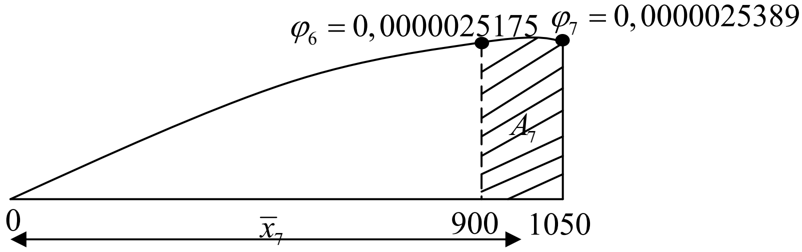
A_1 $= \frac{2}{3}.x_1.\phi_1 = \frac{2}{3}.150.0,000000441 = 0,0000441\ \text{mm}^2$

δ_1 $= A_1.\overline{x}_1 = 0,0000441.93,75 = 0,00413\,\text{mm}$

Saat x_7 = 1050 mm

M_7 = 3143577,628 Nmm

φ_7 = 0,0000025389 rad/mm



Gambar L2.4 Luasan Kurvatur Bentang Segmen 7

Luasan kurva segmen 7 (A_7) dibagi menjadi luasan persegi (pe) dan parabola (pa) dengan perhitungan sebagai berikut:

$$\bar{x}_7 pe = 900 + \frac{150}{2} = 975 \text{ mm}$$

$$\bar{x}_7 pa = x_7 - \left(\frac{3}{8}.x_1\right) = 1050 - \left(\frac{3}{8}.150\right) = 993,75 \text{ mm}$$

$$A_{7pe} = (x_7 - x_6).\varphi_6 = (1050 - 900).0,0000025175 = 0,000337763 \text{ mm}^2$$

$$A_{7pa} = (x_7 - x_6).(\varphi_7 - \varphi_6) = (1050 - 900).(0,0000025389 - 0,000002175)$$

$$= 0,000054585 \text{ mm}^2$$

$$\delta_7 = \left(A_{7pe}.\bar{x}_{7pe}\right) + \left(A_{7pa}.\bar{x}_{7pa}\right) = (0,000337763.975) + (0,000054585.993,75)$$

$$= 0,38356 \text{ mm}$$

$$\delta_{CE7} = A_{7pe}.\left(\bar{x}_{7pe} - \frac{L}{3}\right) + A_{7pa}.\left(\bar{x}_{7pa} - \frac{L}{3}\right)$$

$$= 0,000337763.\left(975 - \frac{2700}{3}\right) + 0,000054585.\left(993,75 - \frac{2700}{3}\right)$$

$$= 0,028523 \text{ mm}$$

$$\delta_E = \delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 + \delta_7 + \delta_8 + \delta_9$$

= 0,004134+0,025423+0,065819+0,124743+0,201618+0,295866+ 0,370315+0,429912+0,488578

= 2,006407 mm

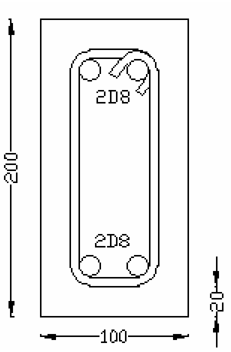
$$\delta_{CE} = \delta_{CE7} + \delta_{CE8} + \delta_{CE9} = 0,028523 + 0,086002 + 0,143705 = 0,258229 \text{ mm}$$

$$\delta_C = \delta_E - \delta_{CE} = 2,006407 - 0,258229 = 1,748178 \text{ mm}$$

LAMPIRAN III

PRELIMINARY DESIGN BALOK

Balok beton bertulang dengan penampang b = 100 mm dan h = 200 mm menggunakan tulangan ganda. Tulangan tekan (A_s') dan tulangan tarik (A_s) menggunakan masing-masing dua buah tulangan diameter 8 mm. Tulangan sengkang menggunakan diameter 10 mm. Mutu beton f_c = 30 MPa dan mutu tulangan f_y = 250 MPa. Selimut beton setebal 20 mm. Penampang balok seperti Gambar L2.1. Penampang menerima momen positif, yaitu tarik pada sisi bawah. Maka kekuatan momen nominal dapat dihitung seperti di bawah ini:



Gambar L3.1 Penampang balok

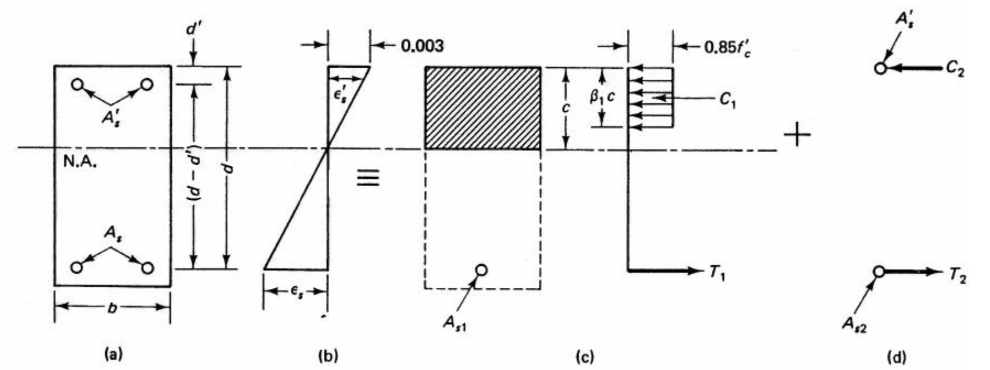


Figure 5.16 Doubly reinforced beam design: (a) cross-section; (b) strains; (c) part I of the solution, singly reinforced part; (d) part 2 of the solution, contribution of compression reinforcement.

Gambar L3.2 Penampang Balok Tulangan Ganda dan Distribusi Tegangan-Regangan

$$d = h - d_{sengkang} - 0,5.d_{tulangan} = 200 - 6 - 0,5.8 = 190\,\text{mm}$$

$$d' = selimut + d_{sengkang} + 0,5.d_{tulangan} = 20 + 6 - 0,5.8 = 30\,\text{mm}$$

Perhitungan luas tulangan tekan A_s' dan tulangan tarik A_s adalah sebagai berikut:

$$A_s = 2.\frac{1}{4}.\pi.d_{tul}{}^2 = 2.\frac{1}{4}.\pi.8^2 = 100,571\,\text{mm}^2$$

$$A_s' = 2.\frac{1}{4}.\pi.d_{tul}{}^2 = 2.\frac{1}{4}.\pi.8^2 = 100,571\,\text{mm}^2$$

$$\rho = \frac{A_s}{b.d} = \frac{100,571}{100.190} = 0,005293$$

$$\rho' = \frac{A_s'}{b.d} = \frac{100,571}{100.190} = 0,005293$$

$$\rho - \rho' = 0,005293 - 0,005293 = 0$$

$$\rho_b = \beta_1.\frac{0,85.f_c'}{f_y}.\frac{600}{600 + f_y} = 0,85.\frac{0,85.30}{250}.\frac{600}{600 + 250} = 0,0612$$

$$\rho_{\min} = \frac{\sqrt{f_c}}{4.f_y} = \frac{\sqrt{30}}{4.250} = 0,005477 < \frac{1,4}{f_y} = \frac{1,4}{250} = 0,0056$$

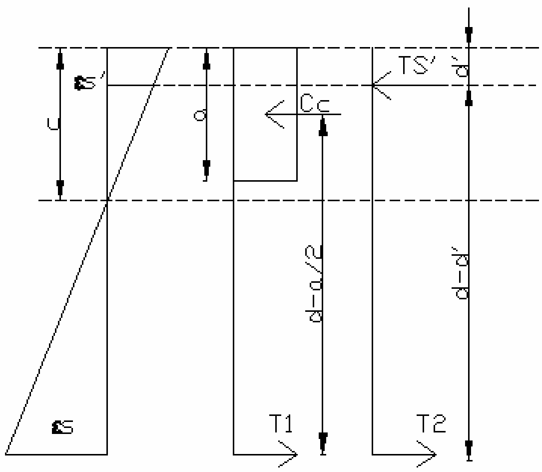
Maka pakai $\rho_{\min} = 0,0056$

$\rho_{\min} = 0,0056 > \rho = 0,005293$

maka di cek jika tulangan tekan sudah leleh:

$$\rho - \rho' = 0 < \beta_1.\frac{0,85.f_c.d'}{f_y.d}.\frac{600}{600 - f_y} = 0,85.\frac{0,85.30.30}{250.190}.\frac{600}{600 - 250} = 0,02347$$

Pakai kompatibilitas regangan:



Gambar L3.3 Distribusi Tegangan dan Regangan Balok Asumsi

Dari segitiga regangan Gambar L3.3 regangan ε_s' dapat dirumuskan sebagai berikut:

$$\varepsilon_s' = \frac{0,003.(c-d')}{c} = \frac{0,003.(c-30)}{c}$$

$$f_s' = E_s.\varepsilon_s' = 200000.\frac{0,003.(c-30)}{c} = \frac{600.(c-30)}{c}$$

$\Sigma H = 0$, maka

$$T_s = C_c + T_s'$$

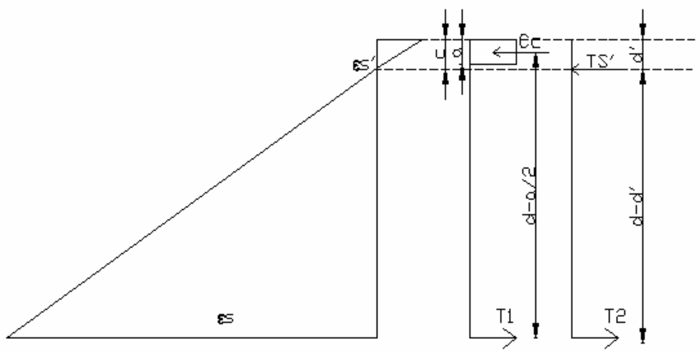
$$A_s.f_y = 0,85.f_c.a.b + A_s'.f_s'$$

$$100,571.250 = (0,85.30.(0,85.c).100) + \left(100,571.\frac{600.(c-30)}{c}\right)$$

$$2290,325.c^2 + 35199,85.c - 1810278 = 0$$

c = 21,9 mm atau c = -38,14 mm, gunakan c = 21,9 mm

Karena c = 21,9 mm < d' = 30 mm, maka gambar kompatibilitas regangan harus diperbaiki, yaitu sebagai berikut:



Gambar L3.4 Distribusi Tegangan dan Regangan Balok Sebenarnya

$$a = 0,85.c = 0,85.21,9 = 18,615 \text{ mm}$$

$$\varepsilon_s' = \frac{0,003.(c-d')}{c} = \frac{0,003.(21,9-30)}{21,9} = -0,00111$$

$f_s' = E_s.\varepsilon_s' = 200000.-0,00111 = -222$ MPa < f_y = 250 MPa

Kontrol:

$$T_s = A_s.f_y = 100,571.250 = 25142,75 \text{ N}$$

$$T_s' = A_s'.f_s' = 100,571.-222 = -22326,762 \text{ N}$$

$C_c = 0,85.f_c.a.b = 0,85.30.18,615.100 = 47468,25 \text{ N}$

$\Sigma H = T_s - T_s' - C_c = 25142,75 + 22326,762 - 47468,25 = 1,262 \text{ N}$

$$f_{sb}' = 600 - \frac{d'}{d}.\left(600 + f_y\right) = 600 - \frac{30}{190}.\left(600 + 250\right) = 465,789 \text{ MPa}$$

$f_{sb}' = 465,789\ MPa > f_y = 250\ MPa$ maka $f_{sb}' = f_y = 250\ MPa$

$$\rho_{\max} = 0,75.\rho_b + \rho'.\frac{f_{sb}'}{f_y} = 0,75.0,0612 + 0,005293.\frac{250}{250} = 0,051193 > \rho = 0,005293$$

$$M_n = C_c.\left(d - \frac{a}{2}\right) - T_s'.\left(d - d'\right)$$

$$= 47468,25.\left(190 - \frac{18,9}{2}\right) - \left(22326,762.\left(190 - 30\right)\right)$$

$= 4998110,618$ Nmm

$$P_n = \frac{M_n - 429089,4}{L} = \frac{4998110,618 - 429089,4}{900} = 5076,69 \text{ N}$$

LAMPIRAN IV
HASIL ANALISIS SEMEN DAN AGREGAT SERTA PERHITUNGAN *MIX DESIGN*

L4.1 Hasil Analisis Semen dan Agregat

L4.1.1 Semen

1. Hasil Perhitungan Pengujian Berat Jenis Semen

Diketahui:

Suhu Awal : 25°C

Semen : 64 gram

Piknometer I

a. Berat semen : 64 gram
b. Volume I zat cair : 0,2 ml
c. Volume II zat cair : 18,5 ml
d. Berat isi air : 1 gr/cm^3

Berat jenis Semen = $\frac{a}{c-b}.d = \frac{64}{18,5-0,2}.1$ = 3,49 gr/cm^3

Piknometer II

a. Berat semen : 64 gram
b. Volume I zat cair : 1,1 ml
c. Volume II zat cair : 19,5 ml
d. Berat isi air : 1 gr/cm^3

Berat jenis Semen = $\frac{a}{c-b}.d = \frac{64}{19,5-1,1}.1$ = 3,47 gr/cm^3

Berat jenis rata-rata = $\frac{3,49+3,47}{2}$ = 3,48 gr/cm^3

Maka diperoleh berat jenis rata-rata semen sebesar 3,48 gr/cm^3.

2. Hasil Perhitungan Pengujian Konsistensi Normal Semen

Diketahui:

Berat Semen : 400 gram

Ø Jarum Vicat : 10 mm

Suhu : 27°C

Tabel L4.1 Penurunan Semen Bergantung pada % Air

Air (%)	Penurunan Tiap 30 Detik (mm)
25	17
26	22
27	30
28	42
29	45
30	48

Dari Tabel L4.1 dapat dilakukan perhitungan berat air dapat mengunakan rumus sebagai berikut:

Berat air = Konsistensi.Berat semen

a. 25 % $\rightarrow \frac{25}{100}.400gr = 100gr \approx 100cc$

b. 26 % $\rightarrow \frac{26}{100}.400gr = 104gr \approx 104cc$

c. 27 % $\rightarrow \frac{27}{100}.400gr = 108gr \approx 108cc$

d. 28 % $\rightarrow \frac{28}{100}.400gr = 112gr \approx 112cc$

e. 29 % $\rightarrow \frac{29}{100}.400gr = 116gr \approx 116cc$

f. 30 % $\rightarrow \frac{30}{100}.400gr = 120gr \approx 120cc$

Dalam perhitungan selanjutnya digunakan prosentase air sebesar 27 % (Tabel L4.2), maka penurunan semen dapat dihitung sebagai berikut:

Jumlah Air = $\frac{27}{100}.400gr = 108gr \approx 108cc$

Tabel L4.2 Penurunan Semen dengan Prosentase Air 27 %

Waktu Penurunan Air (menit)	Penurunan Tiap 15 menit (mm)
0	50
15	50
30	50
45	50
60	48
75	47
90	47
105	47
120	40
135	39
150	37
165	35
180	27
195	24
210	23

L4.1.2 Agregat Kasar

1. Hasil Perhitungan Pengujian Kadar Air Agregat Kasar

Agregat Kasar 1

Diketahui:

a. Berat Wadah = 0,036 kg

b. Berat Wadah + Benda uji = 0,236 kg

c. Berat Benda Uji (b-a) = 0,2 kg

d. Berat Benda Uji Kering = 0,186 kg

Kadar air = $\frac{c-d}{d}.100\% = \frac{0,2-0,186}{0,186}.100\% = 7,5269\%$

Agregat Kasar 2

a. Berat Wadah = 0,031 kg

b. Berat Wadah + Benda uji = 0,531 kg

c. Berat Benda Uji (b-a) = 0,5 kg

d. Berat Benda Uji Kering = 0,466 kg

Kadar air = $\frac{c-d}{d}.100\% = \frac{0,5-0,466}{0,466}.100\% = 7,2961\%$

Dari hasil pengujian diperoleh kadar air rata-rata sebesar 7,4115%.

2. Hasil Perhitungan Pengujian Analisa *Spesific Gravity* dan Penyerapan Agregat Kasar

Diketahui:

a. Berat contoh SSD = 1200 gram

b. Berat contoh dalam air = 653 gram

c. Berat contoh kering udara = 1015 gram

Apparent Specific Grafity $= \dfrac{c}{c-b} = \dfrac{1015}{1015-653} = 2{,}84$

Bulk Specific Grafity kondisi kering $= \dfrac{c}{a-b} = \dfrac{1015}{1200-653} = 1{,}87$

Bulk Specific Grafity kondisi SSD $= \dfrac{a}{a-b} = \dfrac{1200}{1200-653} = 2{,}19$

% Penyerapan Air $= \dfrac{a-c}{a}.100\% = \dfrac{1200-1015}{1015}.100\% = 18{,}20\%$

Dari hasil pengujian diperoleh penyerapan agregat kasar sebesar 18,20%.

L4.1.3 Agregat Halus

1. Menentukan Kadar Organik dalam Agregat Halus

Tabel L4.3 Warna Larutan

Nomor Sampel	Dibandingkan dengan Warna Larutan Standar
1	Lebih muda
2	Lebih muda
3	Lebih muda

Dari hasil pengujian tersebut (Tabel L4.3) dapat disimpulkan bahwa agregat halus memenuhi standar dan dapat langsung digunakan. Kadar senyawa organik yang terdapat dalam larutan tersebut lebih kecil dari standar maksimum yang diijinkan.

2. Hasil Perhitungan Penyerapan Agregat Halus

Tabel L4.4 Penyerapan Agregat Halus

Nomor Sampel Pasir	I Sampel A	II Sampel B	III Sampel C	IV Sampel D
Berat sampel SSD (X gram)	100	100	100	100

Tabel L4.4 Penyerapan Agregat Halus (Lanjutan)				
Berat container (gram)	30	41	29	31
Berat sampel kering + container (gram)	122	133	122	123
Berat sampel kering (Y gram)	92	92	93	92
Absorpsi = (X-Y)/Y.100 %	8.6	8.6	7.5	8.6
Absorpsi rata-rata (%)	8.315			

Dari hasil pengujian pada Tabel L4.4 diperoleh penyerapan agregat halus sebesar 8,315%. Harga penyerapan agregat halus yang disyaratkan dalam Peraturan Beton Bertulang Indonesia 1971 kurang dari 3%. Maka kadar penyerapan agregat halus terlalu tinggi.

3. *Bulking Factor*

Hasil pengujian *Bulking Factor* ditampilkan selengkapnya pada Tabel L4.5.

Tabel L4.5 *Bulking Factor*

Nomor Gelas Ukur	**I Sampel A**	**II Sampel B**	**III Sampel C**	**IV Sampel D**
1. Isi pasir lembab: (X ml)	300	310	300	305
2. Isi pasir dalam air: (Y ml)	195	205	195	200
3. *Bulking Factor* (X-Y)/Y.100 %	53.84	51.22	53.84	52.5
Bulking Factor rata-rata (%)	52.85			

Dari hasil pengujian diperoleh *Bulking Factor* rata-rata agregat halus sebesar 52,85%.

4. Menentukan Kadar Air Agregat Halus

Hasil pengujian kadar air agregat halus ditampilkan selengkapnya pada Tabel L4.6.

Tabel L4.6 Kadar Air

Nomor Sampel Pasir	I Sampel A	II Sampel B	III Sampel C	IV Sampel D
Berat container (gram)	30	37	35	35
Sampel + container (gram)	130	137	135	135
Berat sampel (X gram)	100	100	100	100
Berat sampel kering + container (gram)	123	130	128	128
Sampel kering (Y gram)	93	93	93	93
Kadar air = (X-Y)/Y.100 %	7	7	7	7
Kadar air rata-rata (%)	7			

Dari hasil pengujian diperoleh kadar air rata-rata agregat halus sebesar 7%.

5. Menentukan Kadar Lumpur dan Kadar Lempung Agregat Halus

Hasil pengujian kadar lumpur dan kadar lempung agregat halus ditampilkan pada Tabel L4.7.

Tabel L4.7 Kadar Lumpur dan Kadar Lempung

Nomor Sampel Pasir	I Sampel A	II Sampel B	III Sampel C	IV Sampel D
Berat container (gram)	30	37	35	35
Berat awal sampel kering + container (gram)	123	130	128	128
Berat awal sampel kering (X gram)	93	93	93	93
Berat sampel kering + container (gram)	122	128	127	126
Berat Akhir Sampel kering (Y gram)	92	91	92	91
Kadar lumpur dan lempung = (X-Y)/Y.100 %	1.0869	2.1978	1.0869	2.1978
Kadar lumpur dan lempung rata-rata (%)	1.6424			

Dari hasil pengujian didapat kadar lumpur rata-rata dalam agregat halus sebesar 1,6424 %. Kadar lumpur yang diijinkan dalam Peraturan Beton Bertulang Indonesia 1971 tidak boleh lebih besar dari 5%. Maka kadar lumpur dalam agregat halus memenuhi persyaratan.

6. Menentukan *Spesific Gravity*

Hasil pengujian *Spesific Gravity* agregat halus ditampilkan pada Tabel L4.8.

Tabel L4.8 *Spesific Gravity*

Nomor Sampel Pasir	I Sampel A	II Sampel B	III Sampel C	IV Sampel D
Berat sampel SSD (X gram)	100	100	100	100
Berat gelas + air + sampel (Y gram)	920	916	908	917
Berat gelas + air (Z gram)	860	868	864	860
Spesific Gravity = (X-Y)/Y.100 %	2.5	1.923	1.786	2.326
Spesific Gravity rata-rata (%)	2.13			

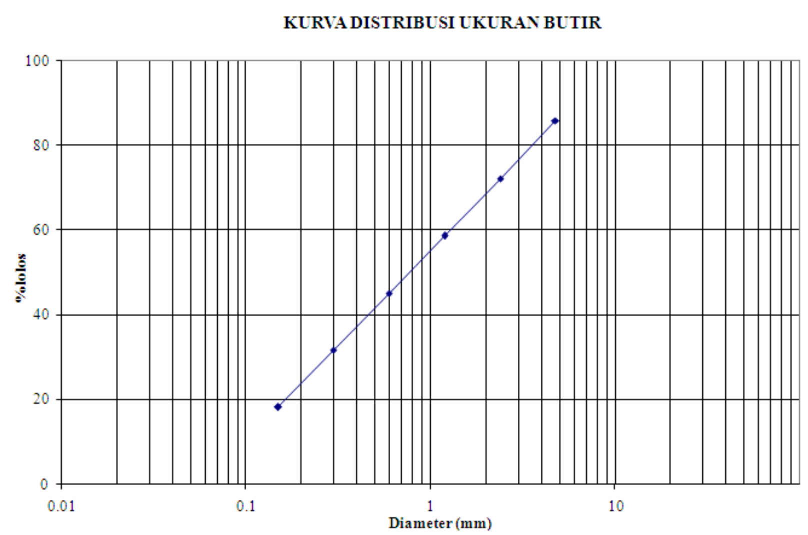
7. Menentukan Analisis Ayak Agregat Halus

Hasil pengujian analisis ayak agregat halus ditampilkan pada Tabel L4.9.

Tabel L4.9 Analisis Ayak Agregat Halus

Nomor dan Ukuran ayakan	Berat tertahan (gram)	Berat tertahan (%)	Berat tertahan kumulatif (%)	Berat lolos kumulatif (%)
No. 4 (4.76 mm)	71	14.2284	14.2284	85.7716
No. 8 (2.40 mm)	68	13.6272	27.8556	72.1444
No. 16 (1.20 mm)	68	13.6272	41.4828	58.5172
No. 30 (0.60 mm)	67	13.4268	54.9096	45.0904
No. 50 (0.30 mm)	67	13.4268	68.3364	31.6636
No. 100 (0.15 mm)	68	13.6272	81.9636	18.0364
Pan	90	18.0364	-	-
Total	499	100	288.7764	-

Dari analisis ayak agregat halus dapat dibuat kurva distribusi ukuran butir seperti pada Gambar L4.1



Gambar L4.1 Kurva Distribusi Ukuran Butir Agregat Halus

L4.2 Perhitungan *Mix Design*

Perhitungan *Mix Design* direncanakan berdasarkan SNI 03-2834-1993 adalah sebagai berikut:

1. Menetapkan kuat tekan beton yang disyaratkan (f_c') pada umur tertentu. Dalam eksperimental direncanakan menggunakan kuat tekan beton f_c' = 40 MPa pada umur 28 hari dengan benda uji berupa silinder.
2. Penetapan nilai deviasi standar (*s*)

   Karena tidak ada catatan, maka nilai margin diambil 12 MPa.
3. Perhitungan nilai tambah (*M*)

   Karena nilai margin sudah diambil 12 MPa, maka dari butir 2 langsung ke butir 4.
4. Penetapan kuat tekan rata-rata yang direncanakan (f'_{cr})

   $$f'_{cr} = f'_c + M$$

   $$f'_{cr} = 40 + 12 = 52\,\text{MPa}$$
5. Penetapan jenis Semen *Portland*

   Pada uji eksperimental ditetapkan jenis semen yang digunakan adalah Semen Portland tipe I.
6. Penetapan jenis agregat

   Agregat halus yang digunakan adalah pasir Galunggung wilayah 1 dengan ukuran butir maksimum 40 mm dan Berat jenis pasir sebesar 2400 kg/m^3.

Agregat kasar yang digunakan adalah batu pecah dengan Berat jenis agregat kasar sebesar 2840 kg/m^3.

7. Penetapan faktor air-semen (fas)

   Penetapkan faktor air semen menggunakan cara I yang berlaku untuk benda uji silinder beton. Telah dihitung kuat tekan rata-rata rencana $f'_{cr} = 52$ MPa pada umur beton 28 hari. Maka perpotongan antara sumbu kuat tekan dan kurva 28 hari garis menerus (karena semen tipe I, jadi bukan garis putus-putus) menghasilkan nilai fas sebesar 0,32.

8. Penetapan fas maksimum

   a. Struktur beton akan digunakan di luar ruang bangunan, namun terlindung dari hujan dan terik matahari langsung sehingga fas maksimum = 0,60
   b. Struktur beton tidak berhubungan dengan tanah yang mengandung sulfat
   c. Struktur beton tidak berada di dalam air

   Fas yang dipakai adalah fas yang paling rendah antara butir 7 dan butir 8, sehingga digunakan fas sebesar 0,32.

9. Penetapan nilai slump

   Dijelaskan bahwa struktur beton untuk fondasi telapak tidak bertulang sehingga:

   $$slump = \frac{15 - 7,5}{2} = 3,75 \text{ cm} = 37,5 \text{ mm}$$

10. Penetapan ukuran butir agregat maksimum

    Diketahui tebal pelat = 12 cm, maka:

    Ukuran agregat maksimum = 4 cm = 40 mm.

11. Menghitung jumlah air yang diperlukan

    Untuk ukuran agregat maksimum 40 mm, jenis agregat kasar batu pecah dan nilai slump 32,5 mm, maka kebutuhan air adalah sebesar 190 liter.

    Karena digunakan pasir alami (pasir Galunggung), maka dipakai rumus:

    $$A = 0,67.A_h + 0,33.A_k$$

    Dengan diameter maksimum 10 mm dan slump 37,5 mm sehingga A_h = 205 liter, sedangkan A_k sudah diketahui 190 liter, maka:

    A = 0,67.205 + 0,33.190 = 200,05 liter

12. Menghitung berat semen yang diperlukan

Berat semen = jumlah air dari butir 11 : fas yang dipakai

Sehingga:

Berat semen = 200,5 : 0,32 = 625,1563 kg

13. Menghitung kebutuhan semen minimum

Kebutuhan semen minimum merujuk pada Tabel 6.8, 6.9, dan 6.10

Dijelaskan bahwa: struktur beton akan digunakan di luar ruang bangunan, namun terlindung dari hujan dan terik matahari langsung sehingga kebutuhan semen minimum = 275 kg/m^3.

14. Penyesuaian kebutuhan semen

Oleh karena berat semen dari butir 12 > dari berat semen butir 13, maka dipakai berat semen butir 12, yaitu 625,1563 kg.

15. Penyesuaian jumlah air atau fas

Tidak ada penyesuaian fas karena jumlah semen yang dipakai tetap 625,1563 kg (karena berat semen dari butir 12 > dari berat semen butir 13), sehingga fas tetap 0,32.

16. Penentuan gradasi agregat halus

Menurut analisa hasil ayakan diketahui masuk wilayah 1.

17. Menghitung perbandingan agregat halus dan kasar

Bila pasir termasuk wilayah 1 dan fas 0,4, serta nilai slump 32,5 mm, maka titik perpotongan antara sumbu fas dan kurva garis miring wilayah gradasi pasir, maka diperoleh proporsi pasir sebesar 34%.

18. Menghitung berat jenis campuran

$$BJ\ campuran = \frac{P}{100}.BJ\ agregat\ halus + \frac{K}{100}.BJ\ agregat\ kasar$$

$$BJ\ campuran = \frac{34}{100}.2400 + \frac{66}{100}.2840 = 2690{,}4\ \text{kg/m}^3$$

dimana:

P = prosentase pasir terhadap campuran = 58%

K = (100-34)% = 66%

19. Menghitung berat jenis beton

Berat jenis campuran 2690,4 kg/m^3 = 2,6904 ton/m^3 ~ 2,7 ton/m^3, kandungan air 200,5 liter, maka berat jenis beton merupakan titik perpotongan antara kurva miring berat jenis campuran dan sumbu kandungan air, yaitu sebesar 2410 kg/m^3.

20. Menghitung kebutuhan agregat campuran

$$W_{\text{pasir+kerikil}} = W_{beton} - A - S$$

$$W_{pasir+kerikil} = 2410 - 200,5 - 625,1563 = 1584,344 \text{ kg/m}^3$$

21. Menghitung kebutuhan agregat halus

$$W_{pasir} = \frac{P}{100}.W_{pasir+kerikil}$$

$$W_{pasir} = \frac{34}{100}.1584,344 = 538,6769 \text{ kg/m}^3$$

22. Menghitung kebutuhan agregat kasar

$$W_{kerikil} = W_{pasir+kerikil} - W_{pasir}$$

$W_{kerikil}$ = 1584,344-538,6769 = 1045,667 kg/m^3

Jadi, untuk 1 m^3 beton, kebutuhan untuk campuran beton adalah:

Air = 200,5liter

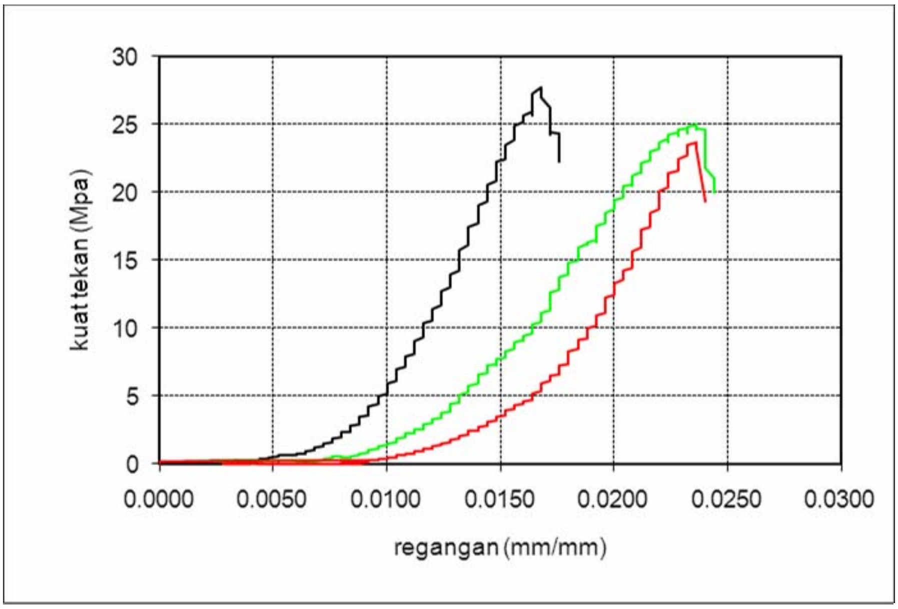
Semen = 625,1563 kg

Pasir = 538,6769 kg/m^3

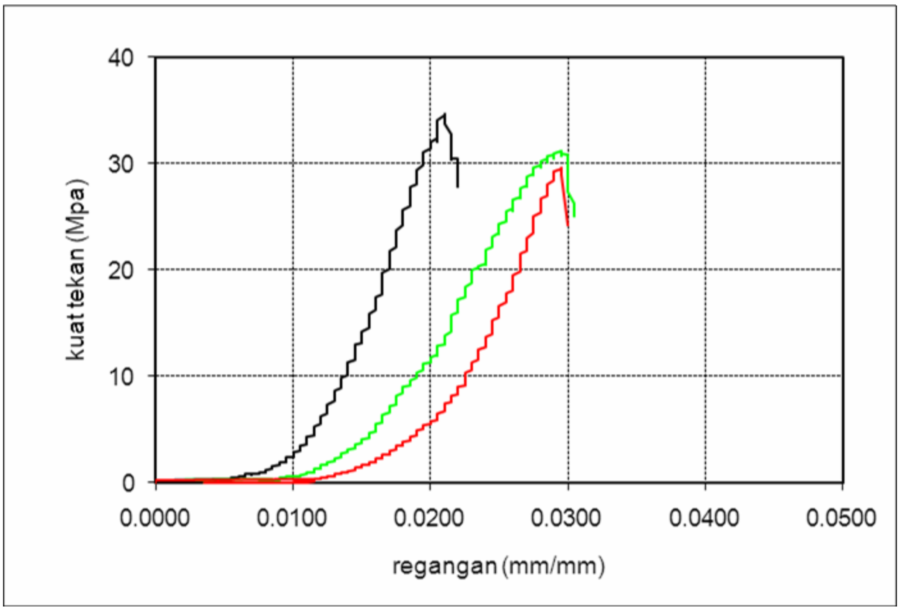
Kerikil = 1045,667 kg/m^3

Perbandingan berat antara semen : pasir : kerikil

$$\text{semen : pasir : kerikil} = \frac{625,1563}{625,1563} : \frac{538,6769}{625,1563} : \frac{1045,6678}{625,1563} = 1 : 0,86 : 1,67$$



(a). Benda uji usia 14 hari



(b). Benda uji usia 28 hari

Gambar L4.2 Hasil uji tekan silinder

LAMPIRAN V

ASTM 04.02

Standard Test Method for
FLEXURAL STRENGTH OF CONCRETE (USING SIMPLE BEAM WITH THIRD-POINT LOADING)[1]
This standard is issued under the fixed designation C-78; the number immediately following the designation indicates the year of original adoption or, in the case of revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ($_{\varepsilon}$) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope
1.1 This test method covers determination of the flexural strength of concrete by the use of a simple beam with third-point loading.
1.2 The values stated in inch-pound units are to be regarded as the standard.
Note 1-For methods of molding concrete specimens, see Methods C 31 and C 192.
NOTE 1-For methods of molding concrete specimens, see Methods C 31 and C192.
1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Applicable Documents
2.1 ASTM Standards:
C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]
C 192 Method of Making and Curing Concrete Test Specimens in the Laboratory[2]
E 4 Practices for Load Verification of Testing Machines[3]

3. Apparatus

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.03.01 on Methods of Testing Concrete for Strength.
Current edition approved March 1, 1984. Published May 1984. Originally published as C 78-30 T. Last previous edition C 78-75 (1982).
[2] Annual Book of ASTM Standards, Vol 04.02.
[3] Annual Book of ASTM Standards, Vol 03.01.

3.1 The testing machine shall conform to the requirements of the sections on Basis of Verification, Corrections, and Time Interval Between Verifications of Practices E 4. Hand-operated testing machines having pumps that do not provide a continuous loading in one stroke shall not be permitted. Motorized pumps or hand-operated positive displacement pumps having sufficient volume in one continuous stroke to complete a test without requiring replenishment are permitted and shall be capable of applying loads at uniform rate without shock or interruption. The third point loading method shall be used in making flexure tests of concrete employing bearing blocks which will ensure that forces applied to the beam will be perpendicular to the face of specimen and applied without eccentricity. A diagram of an apparatus that accomplishes this purpose is shown in Fig. 1.

3.2 All apparatus for making flexure tests of concrete shall be capable of maintaining the specified span length and distances between load-applying blocks and support blocks constant within ± 0.05 in. (± 1.3 mm).

3.3 Reactions should be parallel to the direction of the applied forces at all times during the test and the ratio of distance between the point of load application and nearest reaction to the depth of the beam should not be less than one.

NOTE 2-If an apparatus similar to that illustrated in Fig. 1 is used:

(a) The load-applying and support blocks should not be more than 2½ in. (64 mm) high, measured from the center or axis of pivot, and should extend entirely across or beyond the full width of the specimen. Each case-hardened bearing surface in contact with the specimen shall not depart from a plane by more than 0.002 in. (0.05 mm) and should be a portion of a cylinder, the axis of which is coincidental with either the axis of the rod or center of the ball, whichever the block is pivoted upon. The angle subtended by the curved surface of each block should be at least 45º (0.79 rad).

(b) The load-applying and support blocks should be maintained in a vertical position and in contact with the rod or ball by means of spring-loaded screws which hold them in contact with the pivot rod or ball.

(c) The uppermost bearing plate and center point ball in Fig. 1 may be omitted when a spherically seated bearing block is used, provided one rod and one ball are used as pivots for the upper load-applying blocks.

4. Test Specimen

4.1 The test specimen shall conform to all applicable requirements of Methods C 31 and C 192. The specimen shall have a test span within 2% of being three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. All surfaces in contact with load-applying and support blocks shall be smooth and free of scars, indentations, holes, or identifications.

5. Procedure

5.1 Turn the test specimen on its side with respect to its side with respect to its position as molded and center on the bearing blocks. Center the loading system in relation to the applied force. Bring the load-applying blocks in contact with the surface of the specimen at the third points between the supports. If full contact is not obtained at no load between the specimen and the load-applying blocks and the supports so that there is a 1 in. (25 mm) or longer gap in excess of 0.004 in. (0.1 mm), grind or cap the contact surfaces of the specimen, or shim with leather strips.

NOTE 3-It is recommended that grinding lateral surfaces of the specimens be minimized as it may change the physical characteristics of the specimens and thereby affect the test results.

5.2 Use leather shims only when the specimen surfaces in contact with the blocks or supports depart from a plane by not more than 0.015 in. (0.38 mm). Leather shims shall be of uniform ¼ in. (6.4 mm) thickness, 1 to 2 in. (25 to 50 mm) in width of the specimens. The load may be applied rapidly, up to approximately 50% of the breaking load continuously at a rate which constantly increases the extreme fiber stress between 125 and 175 psi (861 and 1207 kPa)/min, when calculated in accordance with 7.1, until rupture occurs.

6. Measurement of Specimen After Test

6.1 Take three measurements across each dimension (one at each edge and at the center) to the nearest 0.05 in. (1.3 mm) to determine the average width, average depth, and line of fracture location of the specimen at the section of failure.

7. Calculations

7.1 If the fracture initiates in the tension surface within the middle third of the span length, calculate the modulus rupture as follows:

$$R = Pl / bd^2$$

where:

R = modulus of rupture, psi, (or MPa),

P = maximum applied load indicated by the testing machine, lbf, (or MPa),

l = span length, in., (or mm)

b = average width of specimen, in., (or mm), and

d = average depth of specimen, in., (or mm).

7.1.1 If fracture occurs at a capped section, include the cap thickness in the measurement.

NOTE 4-The weight of the beam is not included in the above calculation.

7.2 If the fracture occurs in the tension surface outside of the middle third of the span length, calculate the modulus or rupture as follows:

$$R = 3.Pa / bd^2$$

where:

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, in, (or mm).

7.3 If the fracture occurs in the tension surface outside of the middle third of the span length by more than 5% of the span length, discard the results of the test.

8. Report

8.1 The report shall include the following:

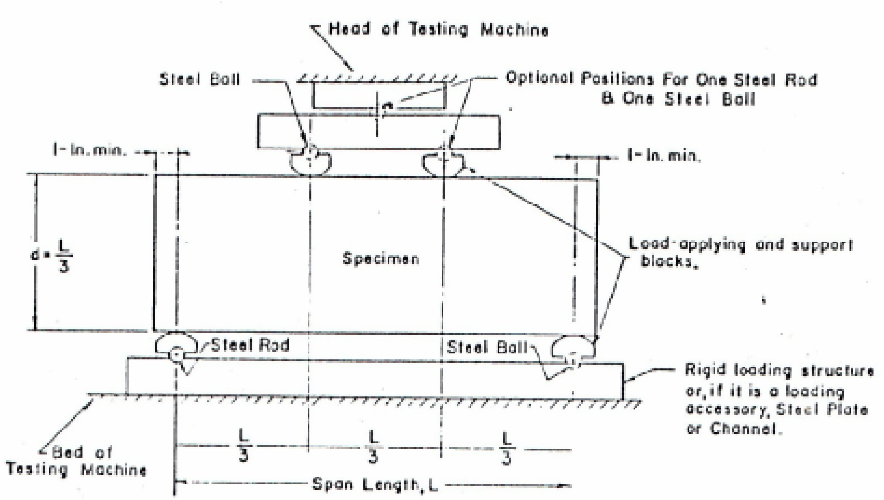
8.1.1 Identification number,

8.1.2 Average width to the nearest 0.05 in (1.3 mm),

8.1.3 Average depth to the nearest 0.05 in (1.3 mm),
8.1.4 Span length in inches (or millimeters),
8.1.5 Maximum applied load in pounds force (or newtons),
8.1.6 Modulus of rupture calculated to the nearest 5 psi (0.03 MPa),
8.1.7 Curing history and apparent moisture condition of the specimen at the time of test,
8.1.8 If specimen were capped, ground, or if leather shims were used,
8.1.9 Defects in specimens, and
8.1.10 Age of specimens.

9. Precision and Bias

9.1 Precision of this test method has not yet been established, but is currently under investigation. A precision statement will be included when the proper data have been obtained and analyzed.



NOTE-This apparatus may be used inverted. If the testing machine applies force through spherically seated head, the center pivot may be omitted, provided one load-applying block pivots on a rod and the other on a ball.

NOTE-1 in. = 25.4 mm.

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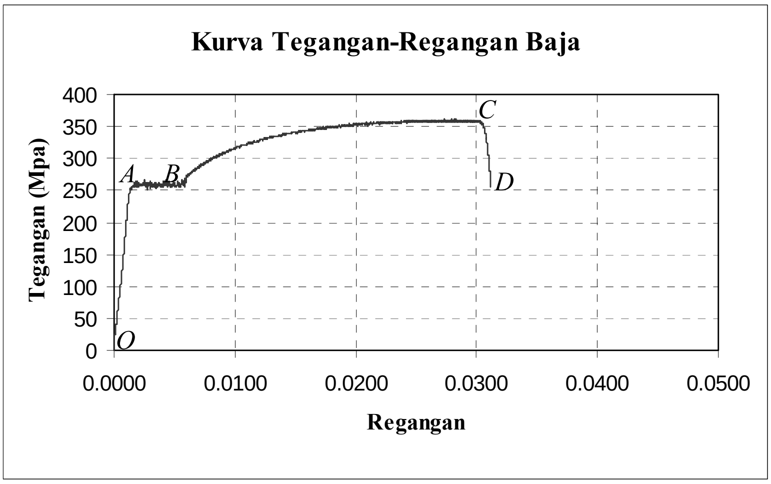
This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

LAMPIRAN VI
HASIL UJI EKSPERIMENTAL

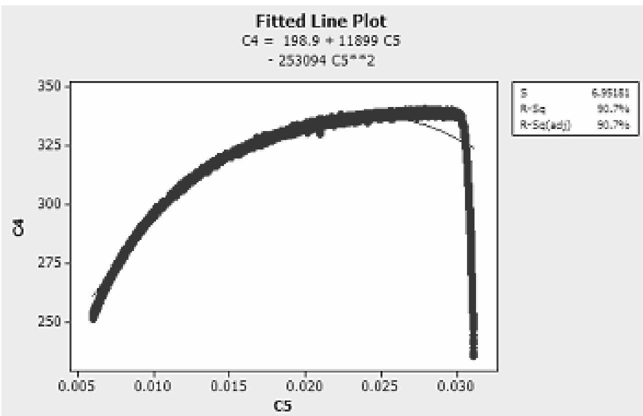
L6.1 Hasil Uji Tarik Tulangan Baja dengan *Universal Testing Machine*

Uji tarik baja menghasilkan kurva tegangan-regangan baja yang digunakan pada Model tegangan-regangan C. Hasil uji tarik baja tampak pada Gambar L6.1.



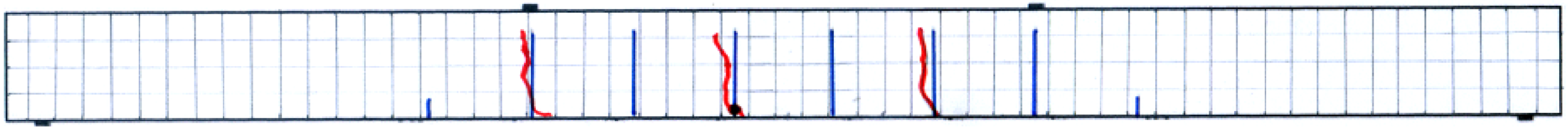
Gambar L6.1 Kurva Tegangan-Regangan Baja Hasil Uji Tarik

Untuk segmen BC digunakan program MINITAB 14 untuk mencari rumus parabola pada segmen tersebut.



Gambar L6.2 *Output* MINITAB

Berikut adalah gambar pola retak balok hasil output *Response2000* dan uji eksperimental.



Response2000

Uji eksperimental

Gambar L6.3 Pola Retak Balok

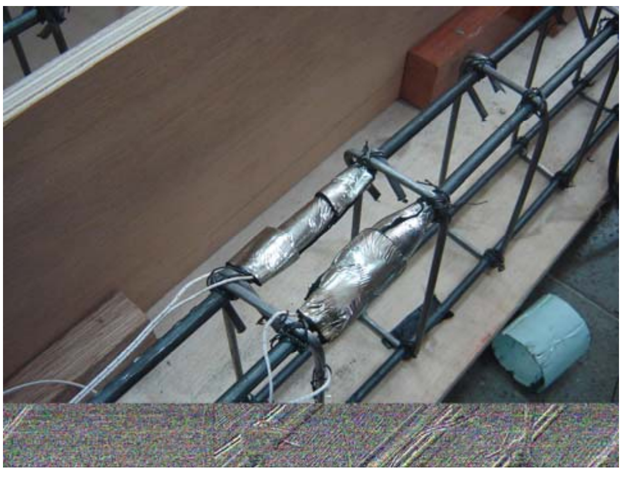
Berikut ditampilkan foto-foto dokumentasi selama eksperimental berlangsung:

Gambar L6.4 Bekisting Balok

Gambar L6.5 Tulangan Baja Diamplas

Gambar L6.6 ***Strain Gauges*** **Dilem pada Tulangan Baja**

Gambar L6.7 ***Strain Gauges*** **Dilapisi Solatip**



Gambar L6.8 ***Strain Gauges*** **Dilapisi Aspal**

Gambar L6.9 Bekisting Dilapisi Oli

Gambar L6.10 Tulangan Dimasukkan dalam Bekisting

Gambar L6.11 Material yang Digunakan

Gambar L6.12 Material Dicampur dalam Molen

Gambar L6.13 Tes *Slump*

Gambar L6.14 Campuran Beton Dicetak dalam Bekisting

Gambar L6.15 Balok Telah Dicetak

Gambar L6.16 Beton Silinder

Gambar L6.17 Pengujian Silinder

Gambar L6.18 Pengujian Silinder dengan UTM

Gambar L6.19 Balok Diset pada UTM

Gambar L6.20 Balok Setelah Diuji

Gambar L6.21 Balok Setelah Diuji 2

Gambar L6.22 Pola Retak Balok