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LAMPIRAN

Perhitungan Kapasitas Momen - Balok Normal (NB)

1 . Data Perencanaan

Kuat tekan beton	f'_c	=	30.02	Mpa
Lebar Penampang	b	=	150	mm
Tinggi Penampang	h	=	250	mm
Tinggi Efektif	d	=	210.5	mm
Tegangan Leleh Baja	Fy	=	406.86	Mpa
Modulus Elastisitas Baja	Es	=	200000	Mpa
Jarak tulangan tekan serat luar	d'	=	39.5	mm
Modulus Elastisitas Beton	Ec	=	25752	Mpa

2 . Momen Retak Pertama (M_{cr})

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

$$M_{cr} = \frac{f_r . I_g}{y_t}$$

Diketahui :

Hasil uji modulus pecah f_r 0.7 x Fc^0.5 = 3.86 Mpa

Momen inersia (I_p) penampang bruto :

$$I_g = \frac{bh^3}{12} = 195312500 \ mm^4$$

y = 1/2 h = 125 mm

$$M_{cr} = \frac{4 \times 2E+08}{125} = 6031250 \ Nmm = \mathbf{6.03 \ kNm}$$

Nilai P_{crack} diperoleh dengan cara subtitusi M_{crack} ke persamaan :

M = 1 + 0.6 P

6 = 1 + 0.6 P

diperoleh

$$P_{cr} = \frac{5}{1} = 8.7 \ kN = \mathbf{8702.1 \ N}$$

3 . Momen Leleh (Myield)

Direncanakan menggunakan tulangan :

Luas	3	ΦD	13	As	=	398.20	mm^2
Luas	2	Φ	8	As'	=	100.53	mm^2

Awal tulangan leleh

$$n = \frac{Es}{Ec} = \frac{200000}{25751.5398} = 7.766526$$

$r = \left(\frac{As}{b * d}\right) = \frac{398.197}{150 * 210.5} = 0.01261$

$r' = \left(\frac{As'}{b * d}\right) = \frac{100.531}{150 * 210.5} = 0.00318$

$(r + r')^2 * n^2 = 0.00025 * 60.31892 = 0.01505$

$2 (r + r' * d'/d) * n = 2.0 * 0.00066 * 7.76653 = 0.01021$

$(r + r') * n = 0.01580 * 7.76653 = 0.12267$

$k = [(r + r')^2 * n^2 + 2 (r + r' d'/d) n]^{0.5} - (r + r') * n$

$= \left(0.02526\right)^{0.5} - 0.12267 = 0.03626$

$kd = 0.03626 * 210.5$

$= 7.63261$ mm

Regangan tulangan tarik dari ujung atas balok

$\varepsilon_y = \frac{Fy}{Es} = \frac{406.86}{200000} = 0.002$

Regangan beton bagian atas

$\varepsilon_c = \varepsilon_s * \left(\frac{kd}{d - kd}\right)$

$= 0.002 \frac{7.63261}{210.5 - 7.63261} = 7.65E\text{-}05$

$f'c = Ec * \varepsilon_c = 25752 * 7.65E\text{-}05 = 1.97097$ Mpa

Regangan tulangan tekan

$\varepsilon_{s'} = \varepsilon_c \left(\frac{kd - d'}{kd}\right)$

$= 7.65E\text{-}05 \left(\frac{7.63261 - 40}{7.63261}\right) = 0.00032$

$f's = \varepsilon_{s'} * Ey = 0.00032 * 200000$

$= 63.9115$ Mpa

Gaya tekan beton

$C_c = 0.5 * f'c * b * kd$

$= 0.5 * 1.97097 * 150 * 7.63261$

$= 1128.2707$ N

Gaya tekan baja

$Cs = As' * f's = 100.5310 * 63.9115$

$= 6425.08836$ N

$T = Cc + Cs = 1128.2707 + 6425.0884$

$= 7553.3591$ N

$T = As * fy$

$= 162010.378$ N

$Cc + Cs - As * fy = 0$

$7553.359 - 162010.378 = -154457.019$

Jarak gaya (c) dari ujung atas (y)

$y = \left(\frac{(Cs * d') + (Cc * 1/3\ Kd)}{T}\right) = \frac{253790.99 + 2870.550}{7553.359}$

$= 33.9797881$ mm

Jarak pusat total gaya tekan ke pusat tulangan tarik

$jd = d - y = 210.5 - 33.9798$

$= 176.520$ mm

Persamaan momen dan kurvatur

$My = As * fy * jd$

$= 398.197 * 406.86 * 176.520$

$= 28598106.3$ Nmm

$=$ **28.598 KN.m**

$My = 1\ Py + 1$

Py = 46.31 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 :

$\rho_{max} = 0.75\ \rho b$

$\rho b = \beta_1 * \frac{0.85\ fc}{fy} * \frac{600}{600 + fy}$ untuk $\beta 1 = 0.85$ dimana f'c kecil atau sama dengan 30 Mpa

$= 0.85 * \frac{0.85 * 30}{406.86} * \frac{600}{600 + 406.9}$

$= 0.0533 * 0.5959 = 0.0318$

$\rho_{max} = 0.75 * 0.03177 = 0.02383$

$As = \rho b * b * d$

$= 0.02383 * 150 * 210.5$

$= 752.2987\ mm^2$

$a = \frac{As * fy}{0.85 * f'c * b}$

$= \frac{752.2987 * 406.86}{0.85 * 4503} = 79.9677\ mm$

$Mu = 0.90 * 752.299 * 406.86 * \left(210.5 - \frac{79.9677}{2} \right)$

$= 275472.236 * 170.5162$

$= 46972468.98\ Nmm$

$= \mathbf{46.972\ kNm}$

$Mu = 0.6Pu + 1$

$Pu = \frac{46.16}{0.6}$

Pu = 76.94 KN

Perhitungan Kapasitas Momen - Balok PET (PB)

1 . Data Perencanaan

Kuat tekan beton	f'_c	=	18.38	Mpa
Lebar Penampang	b	=	150	mm
Tinggi Penampang	h	=	250	mm
Tinggi Efektif	d	=	210.5	mm
Tegangan Leleh Baja	Fy	=	406.86	Mpa
Modulus Elastisitas Baja	Es	=	200000	Mpa
Jarak tulangan tekan serat luar	d'	=	39.5	mm
Modulus Elastisitas Beton	Ec	=	20150	Mpa

2 . Momen Retak Pertama (M_{cr})

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

$$M_{cr} = \frac{f_r . I_g}{y_t}$$

Diketahui :

Hasil uji modulus pecah f_r 0.7 x Fc^0.5 = 3.001 Mpa

Momen inersia (I_p) penampang bruto :

$$I_g = \frac{bh^3}{12} = 195312500 \ mm^4$$

y = 1/2 h = 125 mm

$$M_{cr} = \frac{3 \times 2E+08}{125} = 4689114 \ Nmm = \mathbf{4.69 \ kNm}$$

Nilai P_{crack} diperoleh dengan cara subtitusi M_{crack} ke persamaan :

M = 1 + 0.6 P

5 = 1 + 0.6 P

diperoleh

$$P_{cr} = \frac{4}{1} = 6.47 \ kN = \mathbf{6465.2 \ N}$$

3 . Momen Leleh (Myield)

Direncanakan menggunakan tulangan :

Luas	3	ΦD	13	As	=	398.20	mm^2
Luas	2	Φ	8	As'	=	100.53	mm^2

Awal tulangan leleh

$$n = \frac{Es}{Ec} = \frac{200000}{20149.794} = 9.92566$$

$$r = \left(\frac{As}{b * d}\right) = \frac{398.197}{150 * 210.5} = 0.01261 \qquad r' = \left(\frac{As'}{b * d}\right) = \frac{100.531}{150 * 210.5} = 0.00318$$

$(r + r')^2 * n^2 = 0.00025 * 98.51872 = 0.02458$

$2 (r + r' * d'/d) * n = 2.0 * 0.00066 * 9.92566 = 0.01305$

$(r + r') * n = 0.01580 * 9.92566 = 0.15678$

$$k = [(r + r')^2 * n^2 + 2 (r + r' d'/d) n]^{0.5} - (r + r') * n$$

$$= \left(0.03763\right)^{0.5} - 0.15678 = 0.03720$$

$kd = 0.03720 * 210.5$

$= 7.83141$ mm

Regangan tulangan tarik dari ujung atas balok

$$\varepsilon_y = \frac{Fy}{Es} = \frac{406.86}{200000} = 0.002$$

Regangan beton bagian atas

$$\varepsilon_c = \varepsilon_s * \left(\frac{kd}{d - kd}\right)$$

$$= 0.002 \frac{7.83141}{210.5 - 7.83141} = 7.86E\text{-}05$$

$f'c = Ec * \varepsilon_c = 20150 * 7.86E\text{-}05 = 1.58394$ Mpa

Regangan tulangan tekan

$$\varepsilon_{s'} = \varepsilon_c \left(\frac{kd - d'}{kd}\right)$$

$$= 7.86E\text{-}05 \left(\frac{7.83141 - 40}{7.83141}\right) = 0.00032$$

$f's = \varepsilon_{s'} * Ey = 0.00032 * 200000$

$= 63.5751$ Mpa

Gaya tekan beton

$C_c = 0.5 * f'c * b * kd$

$= 0.5 * 1.58394 * 150 * 7.83141$

$= 930.337255$ N

Gaya tekan baja

$Cs = As' * f's = 100.5310 * 63.5751$

$= 6391.26935$ N

$T = Cc + Cs = 930.3373 + 6391.2694$

$= 7321.6066$ N

$T = As * fy$

$= 162010.378$ N

$Cc + Cs - As * fy = 0$

$7321.607 - 162010.378 = -154688.771$

Jarak gaya (c) dari ujung atas (y)

$$y = \left(\frac{(Cs * d') + (Cc * 1/3\ Kd)}{T}\right) = \frac{252455.14 + 2428.618}{7321.607}$$

$= 34.8125447$ mm

Jarak pusat total gaya tekan ke pusat tulangan tarik

$jd = d - y = 210.5 - 34.8125$

$= 175.687$ mm

Persamaan momen dan kurvatur

My = As * fy * jd

= 398.197 * 406.86 * 175.687

= 28463191.1 Nmm

= **28.463 KN.m**

My = 1 Py + 1

Py = 46.09 KN

4 . Momen Ultimit (Mu)

$Mu = \Phi Mn$

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

dimana :

$\rho_{max} = 0.75\ \rho b$

$\rho b = \beta_1 * \frac{0.85\ fc}{fy} * \frac{600}{600 + fy}$ untuk β1 = 0.85 dimana f'c kecil atau sama dengan 30 Mpa

$= 0.85 * \frac{0.85 * 18}{406.86} * \frac{600}{600 + 406.9}$

= 0.0326 * 0.5959 = 0.0195

ρ_{max} = 0.75 * 0.01945 = 0.01459

As = ρb*b*d

= 0.01459 * 150 * 210.5

= 460.6013 mm^2

$a = \frac{As * fy}{0.85 * f'c * b}$

$= \frac{460.6013 * 406.86}{0.85 * 2757} = 79.9677$ mm

$Mu = 0.90 * 460.601 * 406.86 * \left(210.5 - \frac{79.9677}{2} \right)$

= 168660.216 * 170.5162

= 28759293.13 Nmm

= **28.759 kNm**

Mu = 0.6Pu + 1

$Pu = \frac{27.95}{0.6}$

Pu = 46.58 KN

Kontrol Inersia penampang terhadap lendutan benda uji Beton Normal (NB)

Radius modulus atau angka ekivalen

$n = \frac{Es}{Ec} = \frac{200000}{25752} = 7.7665$

Luas 3 ΦD 13 As = 398.20 mm^2

Luas 2 Φ 8 As' = 100.53 mm^2

b = 150 mm

d = 210.5 mm

d' = 39.5 mm

Ma = 46972468.98 Nmm

Momen Inersia Penampang

$Ig = 1/12 * b * h^3$

= 0.083333 * 150 * 15625000

= 195312500 mm4

Letak sumbu netral untuk penampang retak (x)

$\frac{b * x^2}{2} + (n-1) * As * (x - d') - n * As * (d - x) = 0$

$\frac{150 * x^2}{2} + \left(7.76652588 - 1\right) * 100.53 * \left(x - 39.5\right) - 7.767 * 398.20 * \left(210.5 - x\right) = 0$

$\frac{150 * x^2}{2} + \left(7.76652588 - 1\right) * 100.53 * \left(x - 39.5\right) = 7.767 * 398.20 * \left(210.5 - x\right)$

$75\ x^2 + 680.245376\ x - 26869.69 = 650994 - 3092.61\ x$

$x^2 + 50.3\ x = 9038.1775$

$x + 25.1523444 = \sqrt{9038.2 + \left(25.15234\right)^2}$

$x + 25.1523444 = 98.340317$

$x = 73.187973$ mm

Momen inersia penampang retak:

Icr = (1/3 * b * x3) + ((n - 1) * As' * (x - d')2) + (n * As * (d - x)2)

1/3 * b * y3 = 0.33333333 * 150 * 392030 = 2E+07

(n - 1) * As' * (x - d')2 = 6.7665 * 100.53 * 1134.88 = 771997

n * As (d - x)2 = 7.76652588 * 398.20 * 18854.59 = 58309832.4

Icr = 19601493.23 + 771996.54 + 58309832.35

Icr = 78683322.11 mm4

Modulus keruntuhan lentur beton:

fr = 0.7 * √F = 0.70 * 30.02 = 3.84

$Mc = \frac{fr * Ig}{ybeton}$

$Mc = \frac{3.84 * 195312500}{73.18797271} = 10235138$ Nmm

Ie = (Mcr/Ma)3 * Ig + 1-(Mcr/Ma)3 * Icr

(Mcr/Ma)3 * Ig = 0.0103455 * 195312500 = 2020602.99

1-(Mcr/Ma)3 * Icr = 1 - 0.010345 * 7.9E+07 = 77869304.8

Ie = 79889907.79 mm4

Kontrol Inersia Penampang terhadap retak :

Icr = 78683322.11 < Ie = 79889907.792 < Ig = 195312500 mm4 ……OK !!!

Untuk Perhitungan lendutan secara teoritis dilakukan yaitu :

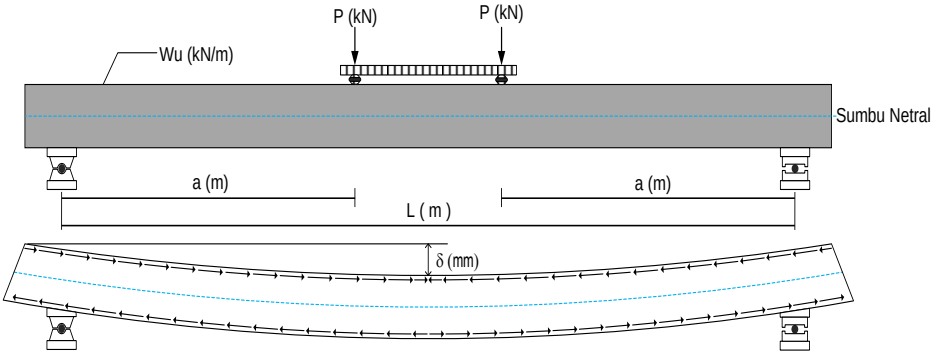
dimana :

Ec = 25751.5 Mpa = 25.8 kN/mm^2

a = 1200 mm

L = 3000 mm

q = 0.9 kN/m = 0.0009 kN/mm



Untuk Icr

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

$$= 0.042 \times \frac{1200P}{2E+09} \times 2.1E+07 + 0.013 \times \frac{72900000000}{2026216698}$$

$$= 0.524129527\ P + 0.46846853$$

Untuk Ig

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

$$= 0.042 \times \frac{1200P}{5E+09} \times 2.1E+07 + 0.013 \times \frac{72900000000}{5029597609}$$

$$= 0.211150092\ P + 0.18872658$$

Kontrol Inersia penampang terhadap lendutan benda uji Beton PET (PB)

Radius modulus atau angka ekivalen

$n = \frac{Es}{Ec} = \frac{200000}{20150} = 9.9257$

Luas 3 ΦD 13 As = 398.20 mm^2

Luas 2 Φ 8 As' = 100.53 mm^2

b = 150 mm

d = 210.5 mm

d' = 39.5 mm

Ma = 28759293.13 Nmm

Momen Inersia Penampang

$Ig = 1/12 * b * h^3$

$= 0.083333 * 150 * 15625000$

$= 195312500$ mm4

Letak sumbu netral untuk penampang retak (x)

$\frac{b * x^2}{2} + (n-1) * As * (x - d') - n * As * (d - x) = 0$

$\frac{150 * x^2}{2} + \left(9.92565976 - 1\right) * 100.53 * \left(x - 39.5\right) - 9.926 *$

$398.20 * \left(210.5 - x\right) = 0$

$\frac{150 * x^2}{2} + \left(9.92565976 - 1\right) * 100.53 * \left(x - 39.5\right) =$

$9.926 * 398.20 * \left(210.5 - x\right)$

$75\ x^2 + 897.305189\ x - 35443.55 = 831973 - 3952.37\ x$

$x^2 + 64.66\ x = 11565.556$

$x + 32.3311455 = \sqrt{11566 + \left(32.33115\right)^2}$

$x + 32.3311455 = 112.29808$

$x = 79.966937$ mm

Momen inersia penampang retak:

$Icr = (1/3 * b * x3) + ((n - 1) * As' * (x - d')2) + (n * As * (d - x)2)$

$1/3 * b * y3 = 0.33333333 * 150 * 511365 = 2.6E+07$

$(n - 1) * As' * (x - d')2 = 8.9257 * 100.53 * 1637.573 = 1469403$

$n * As (d - x)2 = 9.92565976 * 398.20 * 17038.88 = 67343902.7$

Icr = 25568272.92 + 1469402.8 + 67343902.7

Icr = 94381578.38 mm4

Modulus keruntuhan lentur beton:

$fr = 0.7 * \sqrt{F} = 0.70 * 4.2872 = 3.00$

$Mc = \frac{fr * Ig}{ybeton}$

$Mc = \frac{3.00 * 195312500}{79.9669373} = 7329770$ Nmm

$Ie = (Mcr/Ma)3 * Ig + 1-(Mcr/Ma)3 * Icr$

$(Mcr/Ma)3 * Ig = 0.0165553 * 195312500 = 3233452.8$

$1-(Mcr/Ma)3 * Icr = 1 - 0.016555 * 9.4E+07 = 92819065.1$

Ie = 96052517.88 mm4

Kontrol Inersia Penampang terhadap retak :

Icr = 94381578.38 < Ie = 96052517.879 < Ig = 195312500 mm4 ……OK !!!

Untuk Perhitungan lendutan secara teoritis dilakukan yaitu :

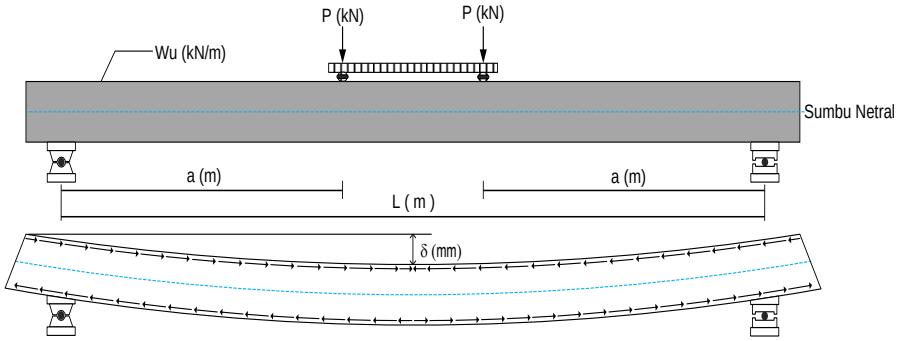
dimana :

Ec = 20149.8 Mpa = 20.1 kN/mm^2

a = 1200 mm

L = 3000 mm

q = 0.9 kN/m = 0.0009 kN/mm



Untuk Icr

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

$$= 0.042 \times \frac{1200P}{1.9E+09} \times 2.1E+07 + 0.013 \times \frac{72900000000}{1901769366}$$

$$= 0.558427336\ P + 0.49912401$$

0.558427336

Untuk Ig

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

$$= 0.042 \times \frac{1200P}{3.9E+09} \times 2.1E+07 + 0.013 \times \frac{72900000000}{3935506649}$$

$$= 0.269850897\ P + 0.24119353$$