BAB IV

ANALISIS BALOK KOMPOSIT PRATEGANG MENGGUNAKAN PERANCAH DAN TANPA PERANCAH

4.1 Pendahuluan

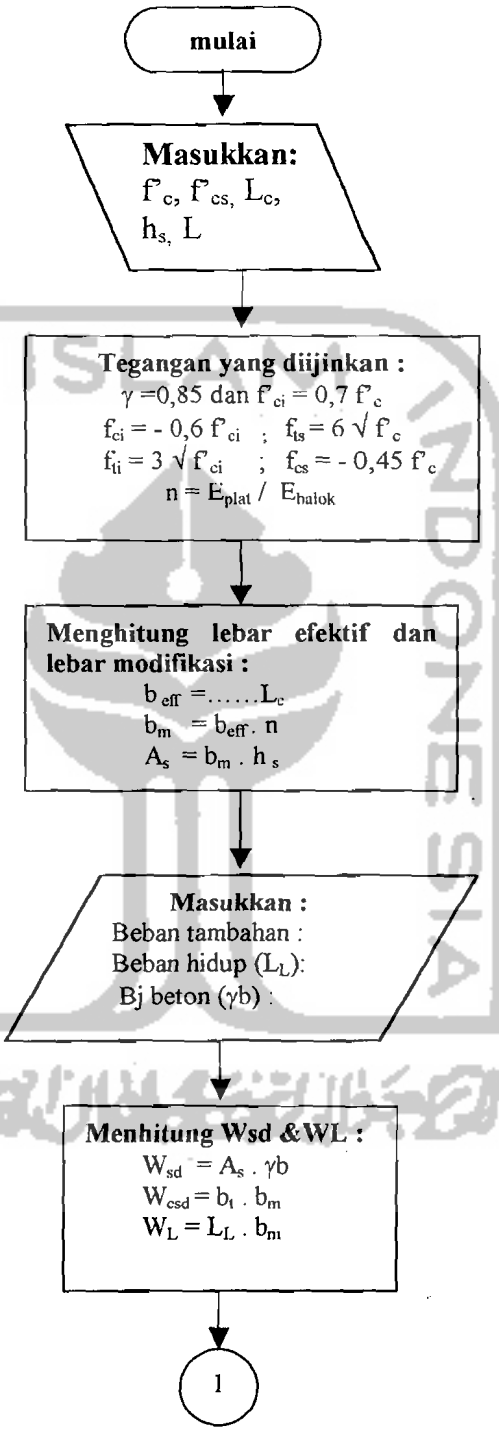
Untuk membuktikan dan memperjelas uraian yang telah diungkapkan sebelumnya, pada bab ini akan diberikan contoh perencanaan balok prategang komposit menggunakan perancah dan tanpa perancah. Pembahasan yang akan dilakukan meliputi perhitungan kapasitas penampang balok terhadap perilaku-perilaku struktur seperti lentur, geser, dan lendutan.

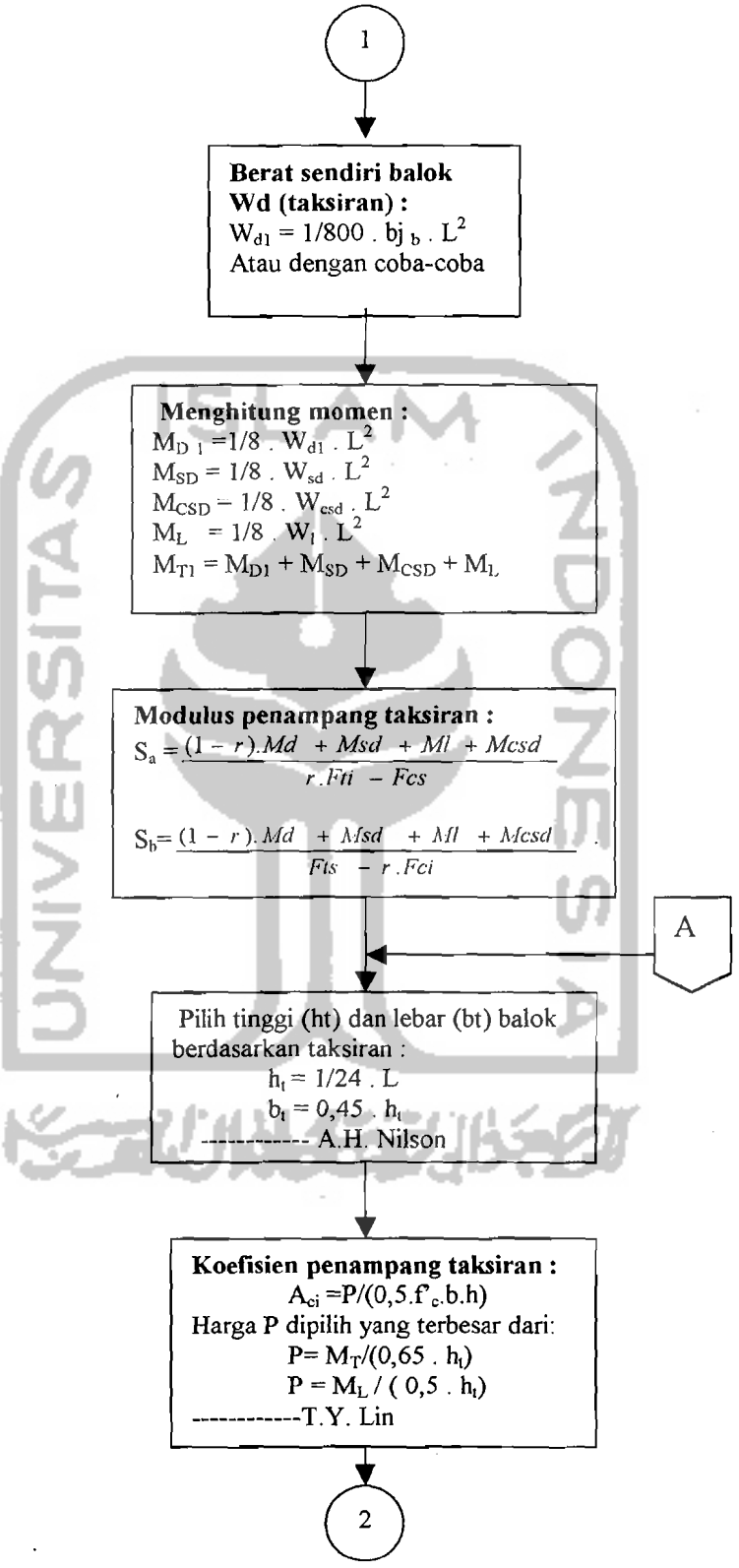
Kondisi balok diasumsikan tertumpu sederhana (*simple beam*) dalam analisis dan perencanaan. Panjang bentang balok yang dianalisis bervariasi yaitu 50 ft, 66 ft, 82 ft, 98,5 ft, 115 ft dan 131,5ft. Balok pracetak yang digunakan adalah tampang I simetris dan beton cor ditempat (plat) setebal 5 in. Panjang bentang yang diambil untuk contoh perhitungan lengkap adalah 98,5 ft.

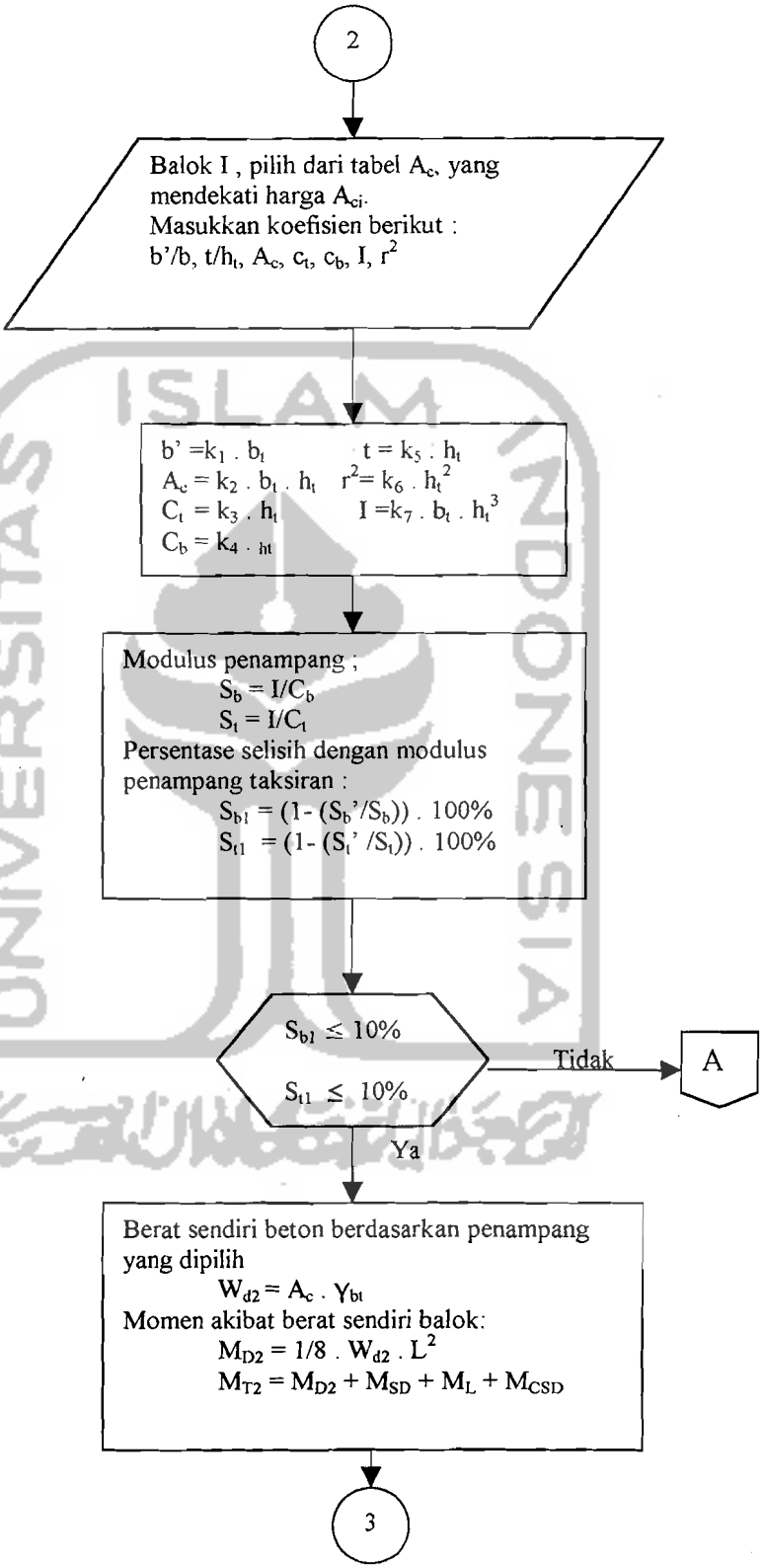
4.2 Perencanaan balok komposit prategang

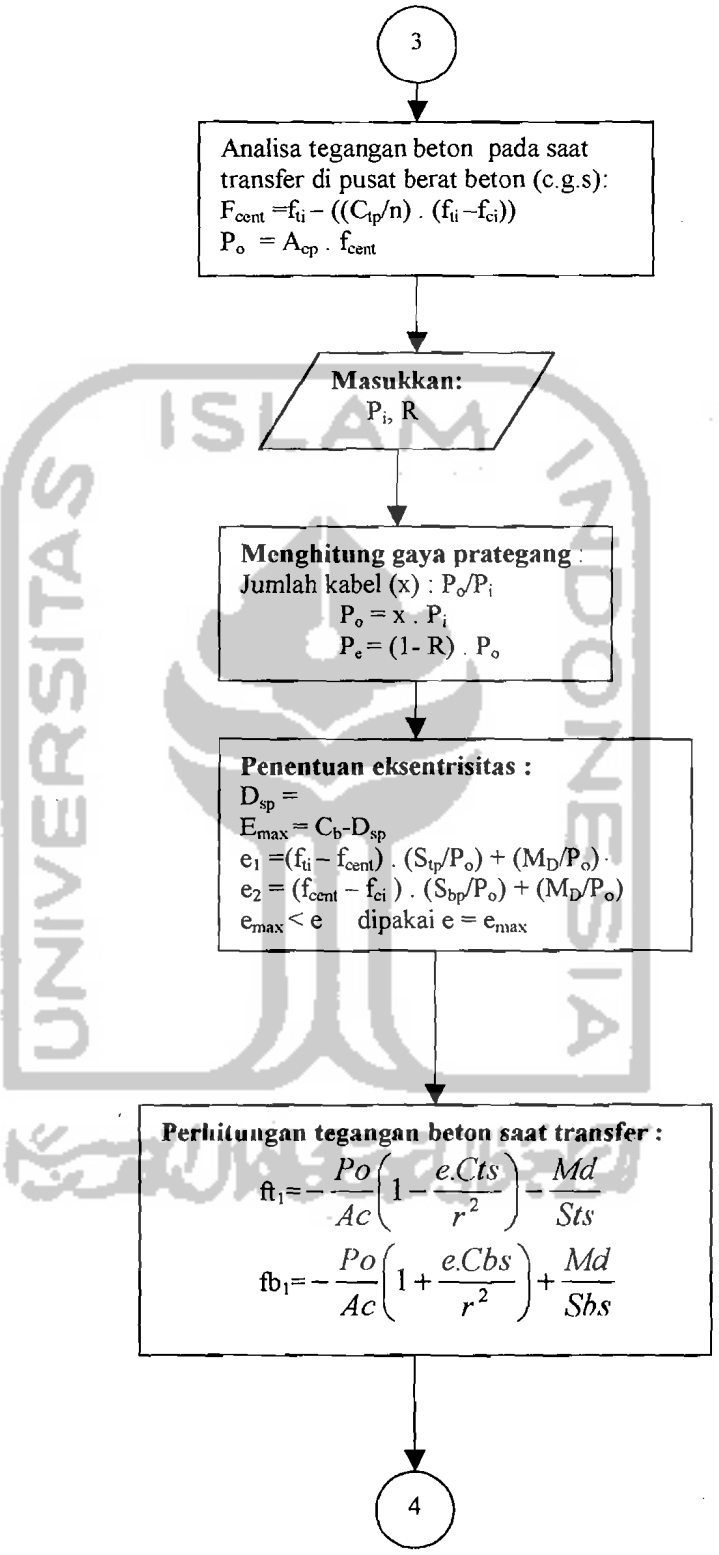
Perencanaan balok komposit prategang dikerjakan dengan bantuan program bahasa basic yang flow chartnya seperti tergambar di bawah ini.

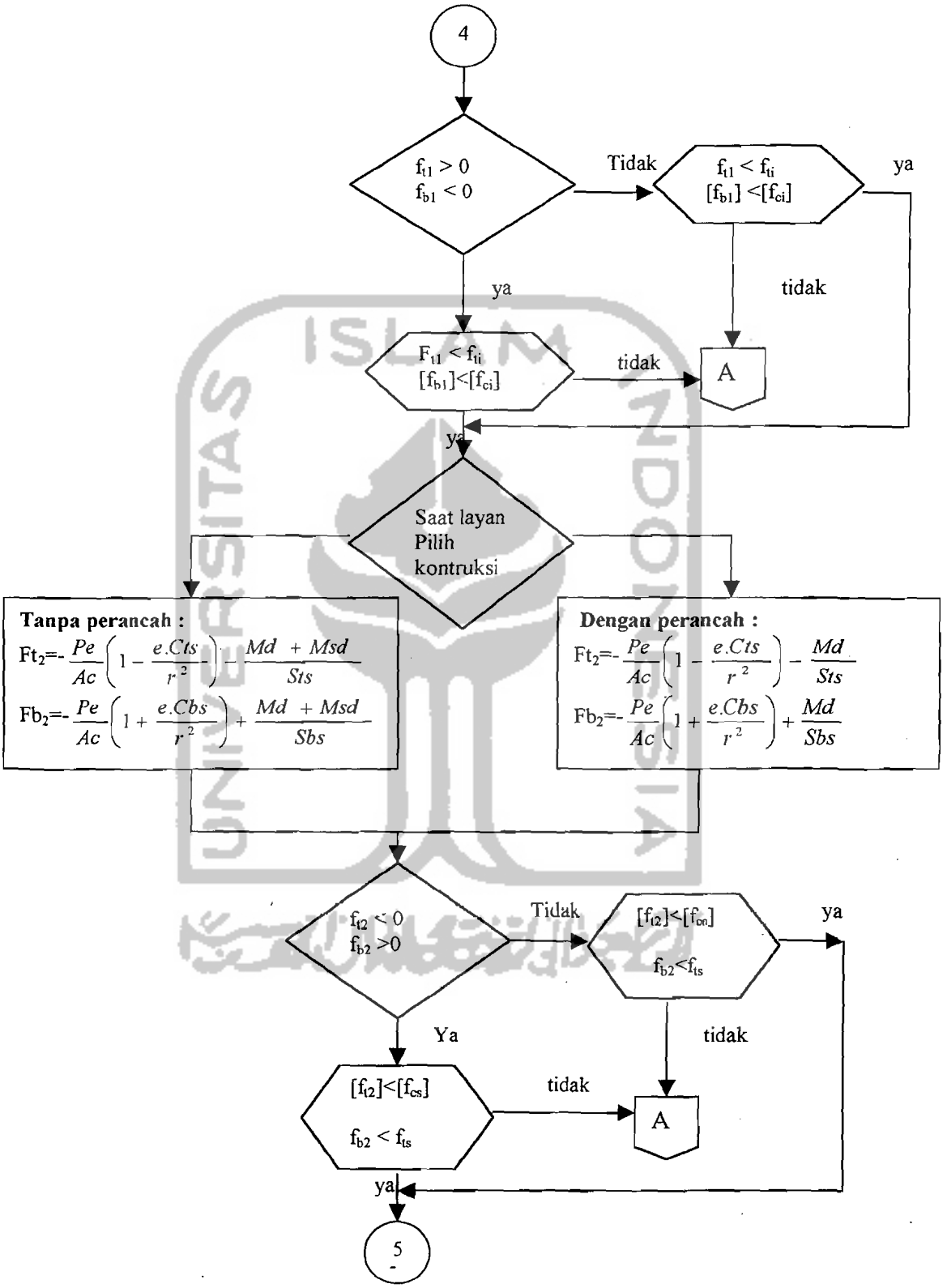
FLOW CHART BETON PRATEGANG KOMPOSIT

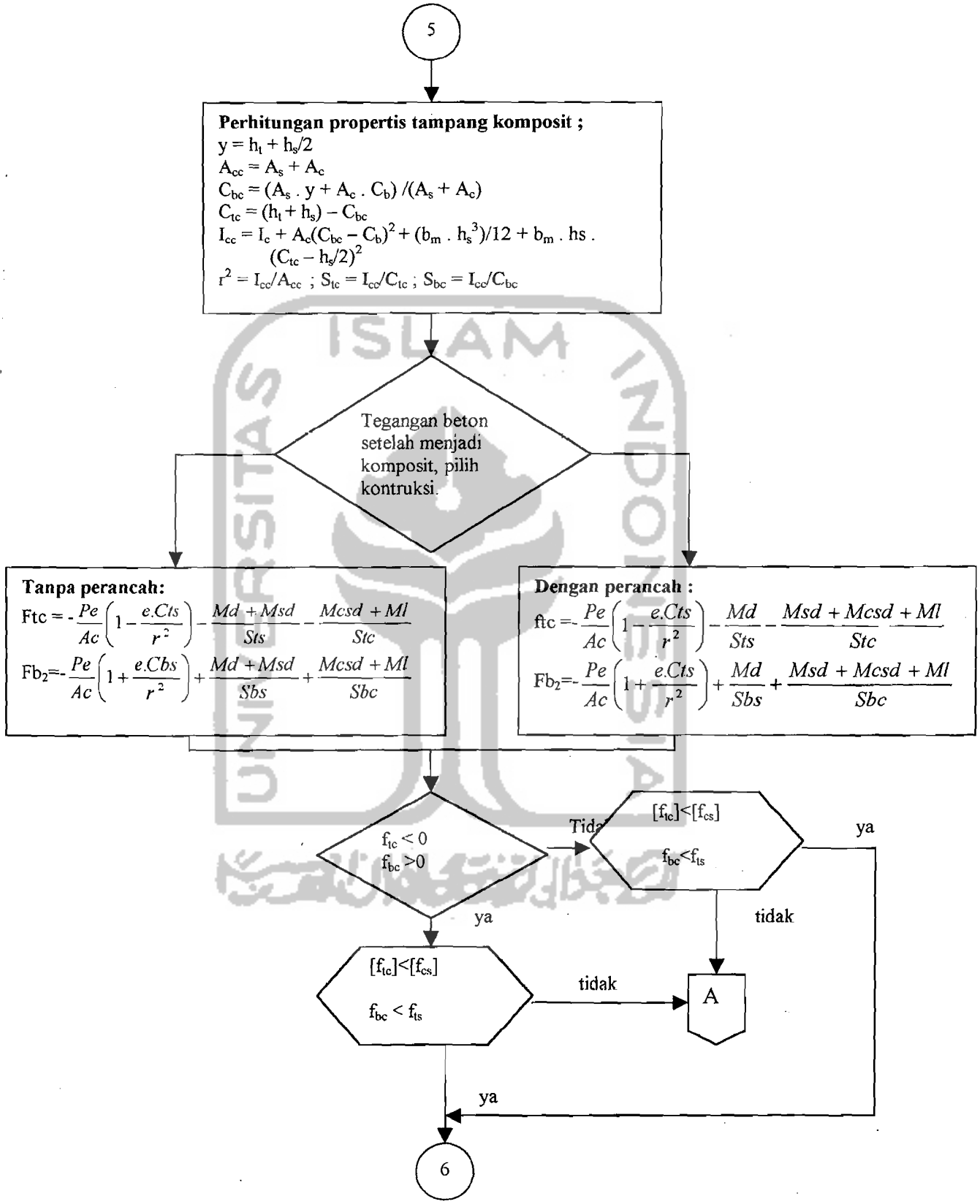


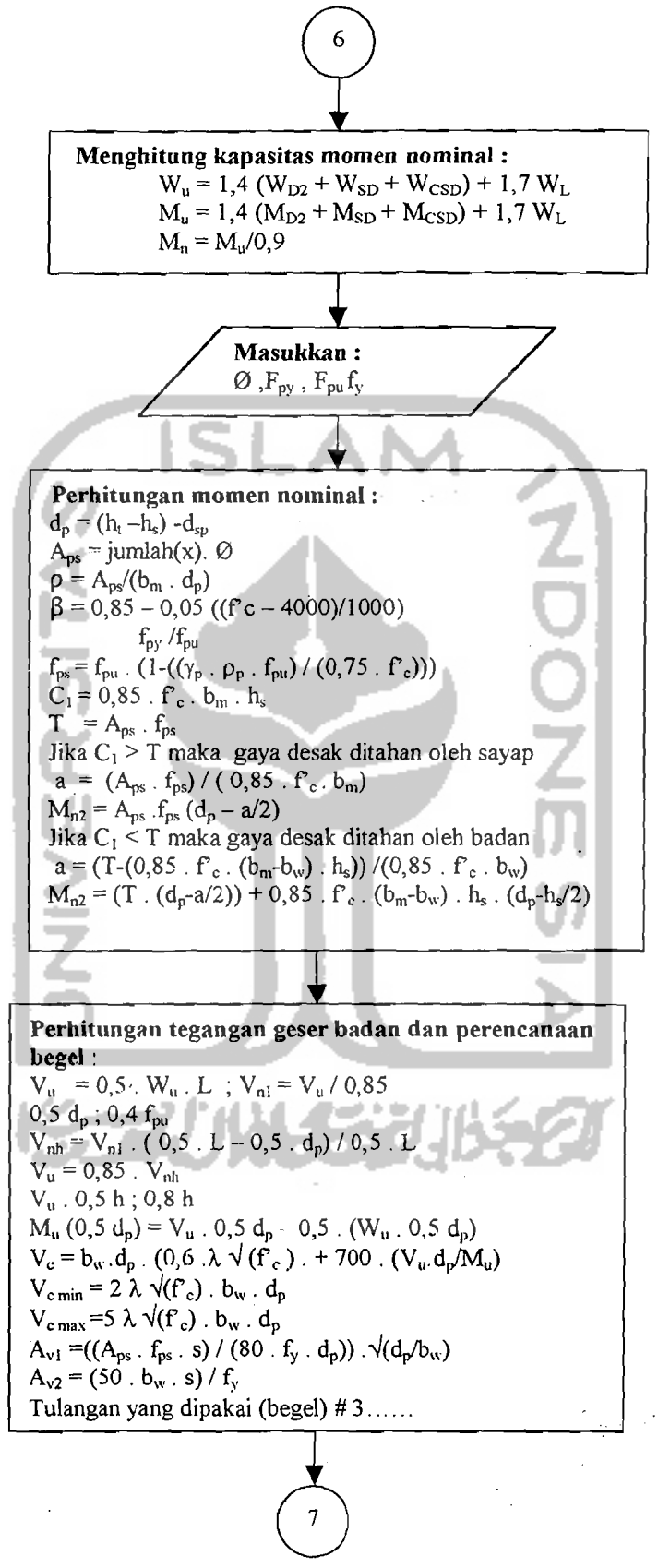

1
Berat sendiri balok
Wd (taksiran) :
$W_{d1} = 1/800 . bj_b . L^2$
Atau dengan coba-coba
Menghitung momen :
$M_{D1} = 1/8 . W_{d1} . L^2$
$M_{SD} = 1/8 . W_{sd} . L^2$
$M_{CSD} = 1/8 . W_{csd} . L^2$
$M_L = 1/8 . W_l . L^2$
$M_{T1} = M_{D1} + M_{SD} + M_{CSD} + M_L$
Modulus penampang taksiran :
$S_a = \frac{(1 - r).Md + Msd + Ml + Mcsd}{r.Fti - Fcs}$
$S_b = \frac{(1 - r).Md + Msd + Ml + Mcsd}{Fts - r.Fci}$
A
Pilih tinggi (ht) dan lebar (bt) balok berdasarkan taksiran :
$h_t = 1/24 . L$
$b_t = 0,45 . h_t$
---------- A.H. Nilson
Koefisien penampang taksiran :
$A_{ci} = P/(0,5.f'_c.b.h)$
Harga P dipilih yang terbesar dari:
$P = M_T/(0,65 . h_t)$
$P = M_L / (0,5 . h_t)$
----------T.Y. Lin
2

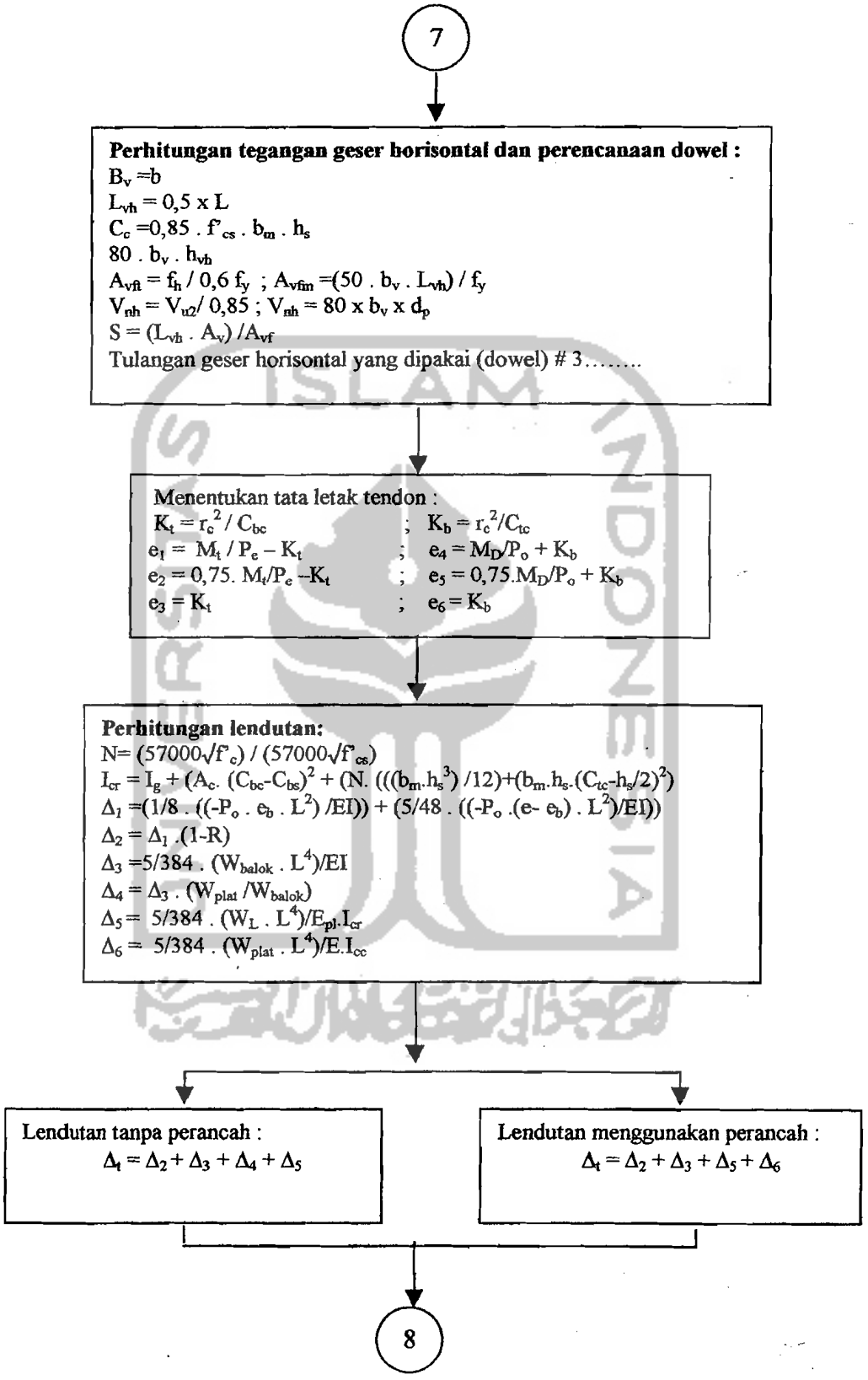

2
Balok I , pilih dari tabel A_c, yang mendekati harga A_{ci}.
Masukkan koefisien berikut :
b'/b, t/h_t, A_c, c_t, c_b, I, r^2
$b' = k_1 . b_t$
$t = k_5 . h_t$
$A_c = k_2 . b_t . h_t$
$r^2 = k_6 . h_t^2$
$C_t = k_3 . h_t$
$I = k_7 . b_t . h_t^3$
$C_b = k_4 . h_t$
Modulus penampang ;
$S_b = I/C_b$
$S_t = I/C_t$
Persentase selisih dengan modulus penampang taksiran :
$S_{b1} = (1 - (S_b'/S_b)) . 100\%$
$S_{t1} = (1 - (S_t'/S_t)) . 100\%$
$S_{b1} \leq 10\%$
$S_{t1} \leq 10\%$
Tidak
A
Ya
Berat sendiri beton berdasarkan penampang yang dipilih
$W_{d2} = A_c . \gamma_{bt}$
Momen akibat berat sendiri balok:
$M_{D2} = 1/8 . W_{d2} . L^2$
$M_{T2} = M_{D2} + M_{SD} + M_L + M_{CSD}$
3

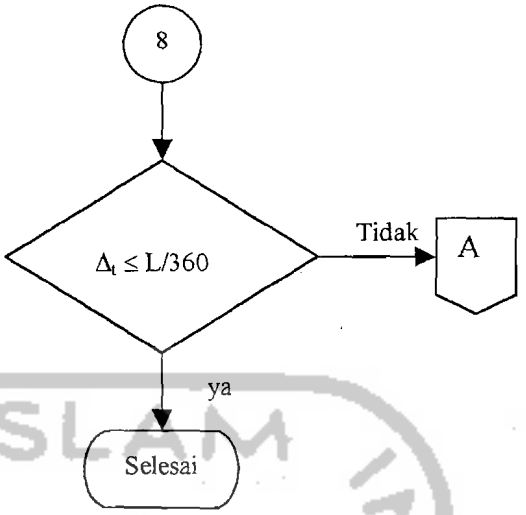

3
Analisa tegangan beton pada saat transfer di pusat berat beton (c.g.s):
$F_{cent} = f_{ti} - ((C_{tp}/n) \cdot (f_{ti} - f_{ci}))$
$P_o = A_{cp} \cdot f_{cent}$
Masukkan:
P_i, R
Menghitung gaya prategang :
Jumlah kabel (x) : P_o/P_i
$P_o = x \cdot P_i$
$P_e = (1 - R) \cdot P_o$
Penentuan eksentrisitas :
D_{sp} =
$E_{max} = C_b - D_{sp}$
$e_1 = (f_{ti} - f_{cent}) \cdot (S_{tp}/P_o) + (M_D/P_o)$
$e_2 = (f_{cent} - f_{ci}) \cdot (S_{bp}/P_o) + (M_D/P_o)$
$e_{max} < e$ dipakai $e = e_{max}$
Perhitungan tegangan beton saat transfer :
$ft_1 = -\frac{Po}{Ac}\left(1 - \frac{e.Cts}{r^2}\right) - \frac{Md}{Sts}$
$fb_1 = -\frac{Po}{Ac}\left(1 + \frac{e.Cbs}{r^2}\right) + \frac{Md}{Sbs}$
4


4
$f_{t1} > 0$
$f_{b1} < 0$
Tidak
$f_{t1} < f_{ti}$
$[f_{b1}] < [f_{ci}]$
ya
tidak
ya
$F_{t1} < f_{ti}$
$[f_{b1}] < [f_{ci}]$
tidak
A
ya
Saat layan
Pilih
kontruksi
Tanpa perancah :
$Ft_2 = -\frac{Pe}{Ac}\left(1 - \frac{e.Cts}{r^2}\right) - \frac{Md + Msd}{Sts}$
$Fb_2 = -\frac{Pe}{Ac}\left(1 + \frac{e.Cbs}{r^2}\right) + \frac{Md + Msd}{Sbs}$
Dengan perancah :
$Ft_2 = -\frac{Pe}{Ac}\left(1 - \frac{e.Cts}{r^2}\right) - \frac{Md}{Sts}$
$Fb_2 = -\frac{Pe}{Ac}\left(1 + \frac{e.Cbs}{r^2}\right) + \frac{Md}{Sbs}$
$f_{t2} < 0$
$f_{b2} > 0$
Tidak
$[f_{t2}] < [f_{cn}]$
$f_{b2} < f_{ts}$
ya
Ya
tidak
$[f_{t2}] < [f_{cs}]$
$f_{b2} < f_{ts}$
tidak
A
ya
5


5
Perhitungan propertis tampang komposit ;
y = ht + hs/2
Acc = As + Ac
Cbc = (As . y + Ac . Cb) /(As + Ac)
Ctc = (ht + hs) – Cbc
Icc = Ic + Ac(Cbc – Cb)2 + (bm . hs3)/12 + bm . hs . (Ctc – hs/2)2
r2 = Icc/Acc ; Stc = Icc/Ctc ; Sbc = Icc/Cbc
Tegangan beton setelah menjadi komposit, pilih kontruksi.
Tanpa perancah:
Ftc = -Pe/Ac (1 - e.Cts/r2) - (Md + Msd)/Sts - (Mcsd + Ml)/Stc
Fb2 = -Pe/Ac (1 + e.Cbs/r2) + (Md + Msd)/Sbs + (Mcsd + Ml)/Sbc
Dengan perancah :
ftc = -Pe/Ac (1 - e.Cts/r2) - Md/Sts - (Msd + Mcsd + Ml)/Stc
Fb2 = -Pe/Ac (1 + e.Cts/r2) + Md/Sbs + (Msd + Mcsd + Ml)/Sbc
ftc < 0
fbc > 0
Tida
[ftc]<[fcs]
fbc<fts
ya
tidak
ya
[ftc]<[fcs]
fbc < fts
tidak
A
ya
6


6
Menghitung kapasitas momen nominal :
$W_u = 1,4 (W_{D2} + W_{SD} + W_{CSD}) + 1,7 W_L$
$M_u = 1,4 (M_{D2} + M_{SD} + M_{CSD}) + 1,7 W_L$
$M_n = M_u/0,9$
Masukkan :
Ø ,F_{py} , F_{pu} f_y
Perhitungan momen nominal :
$d_p = (h_t - h_s) - d_{sp}$
A_{ps} = jumlah(x). Ø
$\rho = A_{ps}/(b_m . d_p)$
$\beta = 0,85 - 0,05 ((f'c - 4000)/1000)$
f_{py}/f_{pu}
$f_{ps} = f_{pu} . (1-((\gamma_p . \rho_p . f_{pu}) / (0,75 . f'_c)))$
$C_1 = 0,85 . f'_c . b_m . h_s$
$T = A_{ps} . f_{ps}$
Jika $C_1 > T$ maka gaya desak ditahan oleh sayap
$a = (A_{ps} . f_{ps}) / (0,85 . f'_c . b_m)$
$M_{n2} = A_{ps} . f_{ps} (d_p - a/2)$
Jika $C_1 < T$ maka gaya desak ditahan oleh badan
$a = (T-(0,85 . f'_c . (b_m-b_w) . h_s)) /(0,85 . f'_c . b_w)$
$M_{n2} = (T . (d_p-a/2)) + 0,85 . f'_c . (b_m-b_w) . h_s . (d_p-h_s/2)$
Perhitungan tegangan geser badan dan perencanaan begel :
$V_u = 0,5 . W_u . L$; $V_{nl} = V_u / 0,85$
$0,5 d_p$; $0,4 f_{pu}$
$V_{nh} = V_{nl} . (0,5 . L - 0,5 . d_p) / 0,5 . L$
$V_u = 0,85 . V_{nh}$
$V_u . 0,5 h$; $0,8 h$
$M_u (0,5 d_p) = V_u . 0,5 d_p - 0,5 . (W_u . 0,5 d_p)$
$V_c = b_w . d_p . (0,6 . \lambda \sqrt{(f'_c)} . + 700 . (V_u . d_p/M_u)$
$V_{c\,min} = 2 \lambda \sqrt{(f'_c)} . b_w . d_p$
$V_{c\,max} = 5 \lambda \sqrt{(f'_c)} . b_w . d_p$
$A_{v1} = ((A_{ps} . f_{ps} . s) / (80 . f_y . d_p)) . \sqrt{(d_p/b_w)}$
$A_{v2} = (50 . b_w . s) / f_y$
Tulangan yang dipakai (begel) # 3.....
7

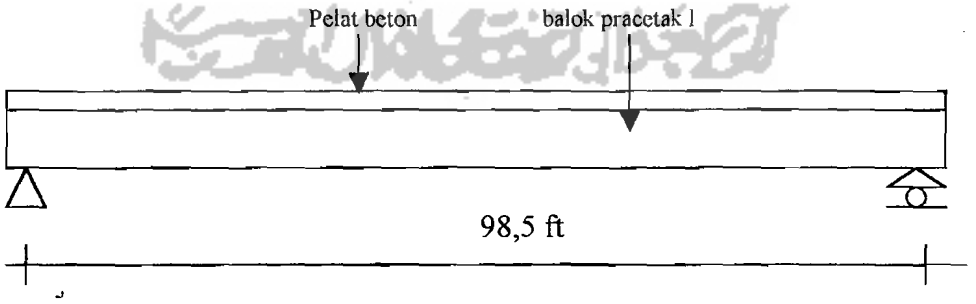

7
Perhitungan tegangan geser horisontal dan perencanaan dowel :
$B_v = b$
$L_{vh} = 0,5 \times L$
$C_c = 0,85 . f'_{cs} . b_m . h_s$
$80 . b_v . h_{vh}$
$A_{vfi} = f_h / 0,6 f_y$; $A_{vfm} = (50 . b_v . L_{vh}) / f_y$
$V_{nh} = V_{u2} / 0,85$; $V_{nh} = 80 \times b_v \times d_p$
$S = (L_{vh} . A_v) / A_{vf}$
Tulangan geser horisontal yang dipakai (dowel) # 3.....
Menentukan tata letak tendon :
$K_t = r_c^2 / C_{bc}$; $K_b = r_c^2 / C_{tc}$
$e_1 = M_t / P_e - K_t$; $e_4 = M_D / P_o + K_b$
$e_2 = 0,75 . M_t / P_e - K_t$; $e_5 = 0,75 . M_D / P_o + K_b$
$e_3 = K_t$; $e_6 = K_b$
Perhitungan lendutan:
$N = (57000\sqrt{f'_c}) / (57000\sqrt{f'_{cs}})$
$I_{cr} = I_g + (A_c . (C_{bc} - C_{bs})^2 + (N . (((b_m . h_s^3) / 12) + (b_m . h_s . (C_{tc} - h_s / 2)^2)$
$\Delta_1 = (1/8 . ((-P_o . e_b . L^2) / EI)) + (5/48 . ((-P_o . (e - e_b) . L^2) / EI))$
$\Delta_2 = \Delta_1 . (1-R)$
$\Delta_3 = 5/384 . (W_{balok} . L^4) / EI$
$\Delta_4 = \Delta_3 . (W_{plat} / W_{balok})$
$\Delta_5 = 5/384 . (W_L . L^4) / E_{pl} . I_{cr}$
$\Delta_6 = 5/384 . (W_{plat} . L^4) / E . I_{cc}$
Lendutan tanpa perancah :
$\Delta_t = \Delta_2 + \Delta_3 + \Delta_4 + \Delta_5$
Lendutan menggunakan perancah :
$\Delta_t = \Delta_2 + \Delta_3 + \Delta_5 + \Delta_6$
8



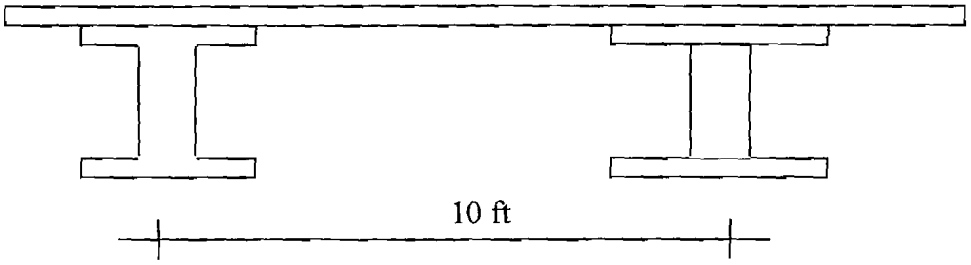
4.3 Contoh Analisis

4.3.1 Data Struktur

Balok prategang sederhana mendukung pelat lantai dengan panjang bentang 98,5 ft, bangunan digunakan untuk ruangan rumah sakit dengan beban hidup sebesar 80 psf dan jarak antar balok 10 ft. balok direncanakan menjadi satu (komposit) dengan pelat lantai. Tebal pelat lantai adalah 5 in, pelat dilapisi dengan lantai terasso dengan beban tambahan sebesar 19 psf.



Gambar 4.1 Struktur balok komposit prategang pada tampang memanjang



Gambar 4.2 Struktur balok komposit prategang pada tampang membujur

1. Balok pracetak :

f'_c yang disyaratkan untuk beton mutu tinggi 4000 psi – 7800 psi atau 28 MPa – 55 MPa, diambil f'_c = 6400 psi (45 MPa)

γ_{bt} = 150 lb/ft^3

2. Pelat beton (pelat lantai) :

f'_{cs} yang disyaratkan untuk beton biasa 2430 psi – 4280 atau 17 MPa-30 MPa, diambil f'_{cs} = 3800 psi (26,7 MPa)

3. Baja prategang :

F_{pu} = 270 ksi (1898.37 MPa) ; f_y = 60 ksi (421.86 MPa)

4. Tegangan ijin beton

$f'_{ci} = 0{,}7\ f'_c$ = 4480 psi (32 MPa) $f_{ci} = -0{,}6\ f'_{ci}$ = -2688 psi (-19 MPa)

$f_{ts} = 6\sqrt{f'_c}$ = 480 psi (3,375 MPa) $f_{ti} = 3\sqrt{f_{ci}}$ = 200,7984 psi (1.41 MPa)

$f_{cs} = -0{,}45\ f_c$ = -2880 psi (-20,25 MPa)

4.3.2 Hitungan perencanaan balok komposit dengan menggunakan perancah

Adapun hitungan perencanaan meliputi langkah-langkah sebagai berikut :

1. Hitungan beban

$$n = \frac{E_{pelat}}{E_{balok}} = \frac{57000\sqrt{f'_{cs}}}{57000\sqrt{f'_{c}}} = 0{,}77055$$

$b_{eff} = 12 \times 10 = 120$ in $= 3048$ mm

$b_m = b_{eff} \cdot n = 120 \times 0{,}77055 = 92{,}466$ in $= 2348{,}64$ mm

$A_s = b_m \cdot h_s = 92{,}466 \times 5 = 462{,}3311$ in^2 $= 298296.03$ mm^2

Beban tambahan (teraso) $= 19$ lb/ft^2 (277,267 N/m)

Beban hidup (rumah sakit) $= 80$ lb/ft^2 (1167,44 N/m)

Panjang (L) $= 98{,}5$ ft (30 m)

$W_{sd} = A_s \cdot B_j = 462{,}3311 \times 150 / 1728 = 40{,}1329$ lb/in $= 7028{,}628$ N/m

$W_{csd} = b_m \cdot q_{osd} = 92{,}4662 \times 19 / 144 = 12{,}2004$ lb/in $= 2136{,}703$ N/m

$W_l = b_m \cdot q_l = 92{,}4662 \times 80 / 144 = 51{,}37012$ lb/in $= 8996{,}644$ N/m

W_d (berat sendiri) diasumsikan 55 lb/in (9632,36 N/m)

$M_d = 1/8 \cdot W_d \cdot L^2 = 1/8 \times 55 \times 98{,}5^2 \times 144$

$= 9605227,5$ lb in $= 1085294,65$ N.m

$M_{sd} = 1/8 . W_{sd} . L^2 = 1/8 . 40,1329 . 98,5^2 . 144$

$= 7008830,363$ lb in $= 791927,8$ N.m

$M_{csd} = 1/8 . W_{csd} . L^2 = 1/8 . 12,2004 . 98,5^2 . 144$

$= 2130684,43$ lb in $= 240746$ N.m

$M_l = 1/8 . W_l . L^2 = 1/8 . 51,37012 . 98,5^2 . 144$

$= 8971302,864$ lb in $= 1013668$ N.m

$$S_a' = \frac{(1 - R)M_d + M_{sd} + M_{csd} + M_l}{R f_{ti} - f_{cs}}$$

$$= \frac{(1 - 0,8)9605227,5 + 7008830,363 + 2130684,43 + 8971302,864}{0,8 \times 200,7984 - (-2880)}$$

$= 6588,44$ in^3 $= 107,96.10^6$ mm^3

$$S_b' = \frac{(1 - R) M_d + M_{sd} + M_{csd} + M_l}{f_{ts} - R f_{ci}}$$

$$= \frac{(1 - 0,8) 9605227,5 + 7008830,363 + 2130684,43 + 8971302,864}{480 - (0,8 \times -2688)}$$

$= 7615,52$ in^3 $= 124,796.10^6$ mm^3

$H_t = 1/24\ L = 1/24.\ 98{,}5\ .\ 12 = 49{,}25$ in

$B_t = 0{,}45\ H_t = 0{,}45\ .\ 49{,}25 = 22{,}1625$ in

Dicoba menggunakan $H_t = 55$ in $= 1397$ mm

$B_t = 24$ in $= 609{,}6$ mm

3. Koefisien A_c taksiran

$P_1 = M_T/(0{,}65.H) = 27716045{,}15\ /(0{,}65\ .\ 55) = 775273{,}99$ lb

$P_2 = M_L/(0{,}5.H) = 8971302{,}86\ /\ (0{,}5\ .\ 55) = 326229{,}19$ lb

$P = P$ terbesar $= P_1 = 775273{,}99$ lb

$A_c = P/(0{,}5\ f_{cs}\ .\ b\ .\ h\ ) = 775273{,}99\ /\ (0{,}5\ .\ 2880\ .\ 55\ .\ 24\ ) = 0{,}309$

Dari tabel Nilson (1987) didapat koefisien sebagai berikut,

$b'/b = 0{,}3$; $C_b' = 0{,}5$; $r^2 = 0{,}121$

$t/h = 0{,}1$; $C_t = 0{,}5$; $A_c = 0{,}44$; $I = 0{,}0535$

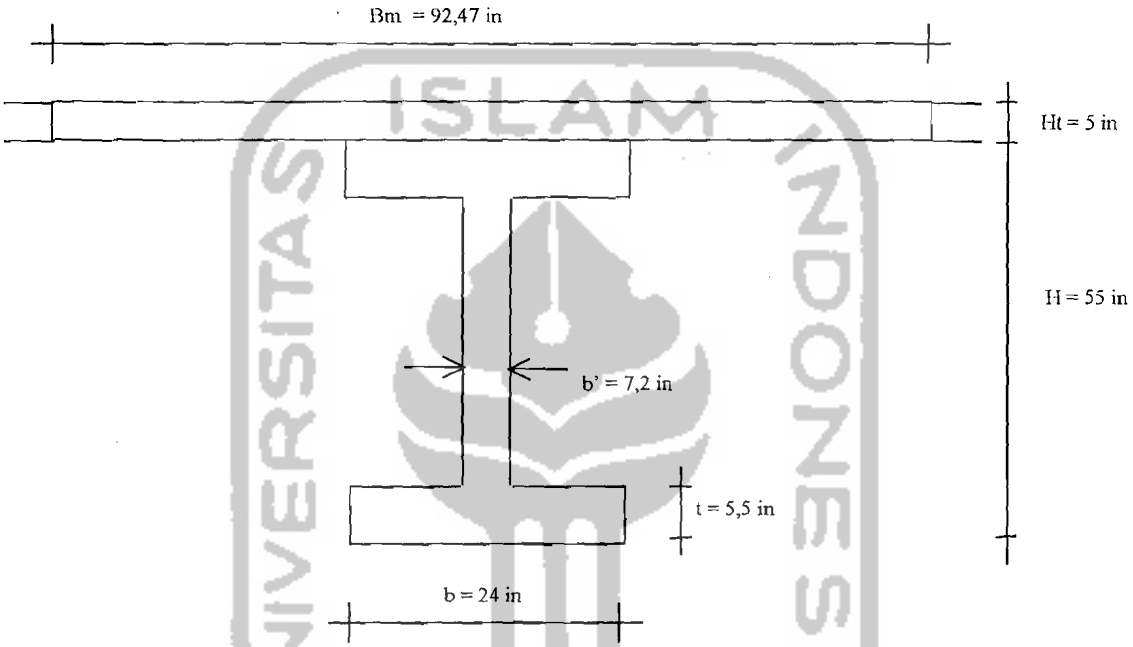
$b = 0{,}3 \times 24 = 7{,}2$ in $= 182{,}88$ mm ; $C_b = C_t = 0{,}5 \times 55 = 27{,}5$ in

$= 698{,}5$ mm

t = 0,1 x 55 = 5,5 in = 139,7 mm ; I = 0,0535 x 24 x 55^3 = 213625,5 in^4

A_c = 0,44 x 55 x 24 = 580,8 in^2 = 374732,16 mm^2 ; r^2 = 0,121x 55^2=366,025

$S_t = S_b$ = 213625,5 / 27,5 = 7768,2 in^3 = 127,3 .10^6 mm^3



Gambar 4.3 Propertis penampang balok komposit dengan perancah

Perbandingan modulus penampang taksiran dengan modulus penampang,

(1 - S_b/S_b') x 100% = (1 –7768,2/7615,5) x 100% = - 2 %

(1 - S_t/S_t') x 100% = (1 – 7768,2 / 6588,044) x 100% = -17,91%

W_d baru = Ac . γbt = 580,8 x 150/1728 = 50,42 lb/in = 8830,24 N/m

M_d baru = 1/8 . 50,42 x $98,4^2$ x 144 = 8804791,88 lb in = 994853,43 N.m

M_T = 8804791,88 + 7008830,363 + 2130684,43 + 8971302,864

= 26915609,53 lb in = 3041194,75 N.m

4. Menentukan tegangan pada pusat (sentral)

$$f_{cent} = f_{ti} - \frac{C_t}{h}(f_{ti} - f_{ci}) = 200,7984 - \frac{27,5}{55}(200,7984 + 2688) = -1243,6007 \text{ lb/in}^2$$

$$P_o = A_{cp} \cdot f_{cent} = 580,8 \times 1243,6007 = 722283,29 \text{ lb} = 3238646,04 \text{ N}$$

5. Mencari jumlah kabel

Dipakai untuaian 7 kawat ϕ ½ " $\rightarrow$ P_i = 28900 lb = 129584,71 N

X = P_o / P_i =722283,29 / 28900 = 24,09 ≈ 26 kabel

P_o = X . P_i = 26 x 28900 = 751400 lb = 3369202,46 N

P_e = (1-0,2).P_o = (1-0,2) x 751400 = 601120 lb = 2695361,97 N

$e_{max} = C_b - D_{sp} = 27,5 - 9,75 = 17,75$ in

$$e_1 = (f_{ti} - f_{cent})\frac{S_t}{P_o} + \frac{M_d}{P_o}$$

$$= (200,7984 - 1243,6007)\frac{7768,2}{751400} + \frac{8804791,88}{751400} = 0,94 \text{ in}$$

$$e_2 = (f_{cent} - f_{ti})\frac{S_b}{P_o} + \frac{M_d}{P_o} = (1243{,}3007 - 200{,}7984)\frac{7768{,}2}{751400} + \frac{8804791{,}88}{751400}$$

$$= 22{,}5 \text{ in}$$

$$e_2 > e_{max} \longrightarrow e = e_{max} = 17{,}75 \text{ in} = 450{,}85 \text{ mm}$$

6. Hitungan tegangan beton saat transfer

$$f_{t1} = -\frac{P_o}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d}{S_t} = -\frac{751400}{580{,}8}\left(1 - \frac{17{,}75 \times 27{,}5}{366{,}025}\right) - \frac{8804791{,}88}{7768{,}2}$$

$$= -701{,}87 \text{ psi} < fti = 200{,}7984 \text{ psi}$$

$$= -4{,}93 \text{ MPa} < = 1{,}4118 \text{ MPa}$$

$$f_{b1} = -\frac{P_o}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d}{S_t} = -\frac{751400}{580{,}8}\left(1 + \frac{17{,}75 \times 27{,}5}{366{,}025}\right) + \frac{8804791{,}88}{7768{,}2}$$

$$= -1281{,}79 \text{ psi} < fci = -2688 \text{ psi}$$

$$= -13{,}26 \text{ MPa} < fci = -18{,}89933 \text{ MPa}$$

7. Hitungan tegangan beton saat layan

$$f_t = -\frac{P_o}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d}{S_t} = -\frac{601120}{580{,}8}\left(1 - \frac{17{,}75 \times 27{,}5}{366{,}025}\right) - \frac{8804791{,}88}{7768{,}2}$$

$$= -788{,}18 \text{ psi} < fcs = -2880 \text{ psi}$$

$$= -5,54 \text{ MPa} \quad < -20,2493 \text{ MPa}$$

$$f_b = -\frac{P_o}{A_c}\left(1 - \frac{e.C_b}{r^2}\right) - \frac{M_d}{S_b} = -\frac{601120}{580,8}\left(1 + \frac{17,75 \times 27,5}{366,025}\right) + \frac{8804791,88}{7768,2}$$

$$= -1281,79 \text{ psi} < \text{fts} = -480 \text{ psi}$$

$$= -9,01 \text{ MPa} < 3,37488 \text{ MPa}$$

8. Hitungan Propertis penampang setelah beton menjadi komposit

$y = h_t + h_s/2 = 55 + 5/2 = 57,5 \text{ in} = 1460,5 \text{ mm}$

$A_{cc} = A_s + A_c = 462,331 + 580,8 = 1043,131 \text{ in}^2 = 673028,12 \text{ mm}^2$

$$C_{bc} = \left(\frac{As.y + Ac.Cb}{Ac + As}\right) = \frac{642,331 \times 57,5 + 580,8 \times 27,5}{462,331 + 580,8} = 40,8 \text{ in} = 1036,32 \text{ mm}$$

$C_{tc} = (ht+hs)-Cbc \quad = 55+5-40,8 \quad = 19,20 \text{ in} = 487,68 \text{ mm}$

$I_{cc} = I_c + A_c(C_{bc}-C_b)^2 + 1/12\,(b_m.h_s^3) + b_m.h_s(C_{tc}-h_s/2)^2$

$= 213625,5 + 580,8(40,8-27,5)^2 + 1/12(92,466x5^3) + 92,4662x5(19,20 - 5/2)^2$

$= 496265,61 \text{ in}^4$

$r_c^2 = I_{cc}/A_{cc} = 496265,61 / 1043,131 = 427,81 \text{ in}^2 = 276023,012 \text{ mm}^2$

$S_{tc} = I_{cc}/C_{tc} = 496265,61 / 19,20 = 23243,00\ in^3 = 380,88.10^6\ mm^3$

$S_{bc} = I_{cc}/C_{bc} = 496265,61 / 40,8 = 10937,88\ in^3 = 179,24.10^6\ mm^3$

9. Tegangan beton saat layan setelah beton menjadi komposit

$$F_{tc} = -\frac{P_e}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d}{S_t} - \frac{M_{sd} + M_{csd} + M_l}{S_{tc}}$$

$$= -\frac{601120}{580,8}\left(1 - \frac{17,75.27,5}{366,025}\right) - \frac{8804791,88}{7768,2} - \frac{7008830,4 + 2130684,43 + 8971302,864}{23243,00}$$

$$= -1567,38\ psi = -11,02\ MPa < fcs = -2880\ psi = -20,249\ MPa$$

$$F_{tc} = -\frac{P_e}{A_c}\left(1 + \frac{e.C_b}{r^2}\right) + \frac{M_d}{S_b} + \frac{M_{sd} + M_{csd} + M_l}{S_{bc}}$$

$$= -\frac{601120}{580,8}\left(1 + \frac{17,75.27,5}{366,025}\right) + \frac{8804791,88}{7768,2} + \frac{7008830,4 + 2130684,43 + 8971302,864}{23243,00}$$

$$= 374\ psi = 2,63\ MPa < fts = 480\ psi = 3,37488\ MPa$$

10. Hitungan Kapasitas Momen Nominal

$M_u = 1,4\ (M_d + M_{sd} + M_{csd}) + 1,7\ M_l$

$= 1,4\ (8804791,88 + 7008830,4 + 2130684,43) + 1,7 \times 8971302,864$

= 40373244,19 lb.in = 4561772,88 N.m

$M_n = M_u/0,9$ = 40373244,19 / 0,9 =44859160,15 lb in = 5068636,51 N.m

$A_{ps} = X \cdot \phi_{kabel}$ = 26 x 0,153 = 3,978 in^2 = 2566,61 mm^2

$D_p = H_s + H_p - D_{sp}$ = 5 + 55 – 9,75 = 50,25 in = 1276,35 mm

$\rho = A_{ps}/(B_m.D_p)$ = 3,978 / (92,4662x50,25) = 8,56 . 10^{-4}

β = 0,85 – 0,5(6400 – 4000)/1000 = 0,73

f_{py}/f_{pu} = 229500/270000 = 0,85 $\longrightarrow$ γp = 0,4 (Nawy,1995)

$$f_{ps} = f_{pu}\left(1 - \frac{\gamma_p . \rho_p . f_{pu}}{0,75 f_c}\right)$$

$$= 270000\left(1 - \frac{0,4x0,000856x270000}{0,73 \times 6400}\right) = 264657,33 \text{ psi} = 1860,81 \text{ MPa}$$

$T = A_{ps}.f_{ps}$ = 3,978 x 264657,33 = 1052806,85 lb =4720680,64 N

$C = 0,85 f_c . B_m . H_s$

= 0,85x6400 x 92,4662 x 5 = 2515080,912 > T $\longrightarrow$ gaya desak ditahan sayap

$$a = \frac{A_{ps}.f_{ps}}{0,85.f_c.B_m} = \frac{1210995,58}{0,85x6400\ x92,4662} = 2,414 \text{ in} = 61,32 \text{ mm}$$

$M_n = A_{ps}.f_{ps}(d_p - a/2)$

$= 1210995,58\ (50,25 - 2,414/2)$

$= 51634911,96$ lb in $> 44859160,15$ lb in $\longrightarrow$ OK

$= 5834228,702$ N.m $> 5068636,51$ N.m

11. Hitungan Tegangan Geser dan Perencanaan Begel

$W_u = 1,4\ (W_d + W_{sd} + W_{csd}) + 1,7\ W_l$

$W_u = 1,4\ (50,42 + 40,1329 + 12,2004) + 1,7 \times 51,37012$

$= 231,179$ lb/in $= 40487,26$ Nm

$V_u = W_u.L/2 = 231,179 \times 98,5 \times 12/2 = 136626,79$ lb $= 612620,86$ N

$V_n = V_u/0,85 = 136626,79/\ 0,85 = 160737,4$ lb $= 720730,43$ N

Diasumsikan V_u terjadi pada setengah tinggi tampang

$0,5D_p = 0,5x50,25 = 25,125$ in $= 638,175$ mm

$$V_{nh} = V_n\left(\frac{L/2 - D_p/2}{L/2}\right)$$

$$V_{nh} = 160737,4\left(\frac{98,5x12/2 - 25,125}{98,5x12/2}\right) = 153904,02 \text{ lb} = 690090,24 \text{ N}$$

$V_{u2} = 0,85\ V_{nh} = 0,85x153904,02 = 130818,417$ lb = 586576,7 N

$f_{pe} = 0,8\ f_{pi} = 0,8x(0,7\ fpu) = 0,8\ (0,7x270000) = 151200$ psi

$0,4\ f_{pu} = 0,4x270000 = 108000$ psi

$f_{pe} > 0,4\ f_{pu}$

$$M_u = V_u \times 0,5d_p - \left(\frac{W_u \times (0,5\,d_p)^2}{2}\right)$$

$M_u = 136626,79 \times 25,125 - 0,5x231,179x25,125^2 = 3359780,421$ lb in

$D_p = 50,25$ bila dp > 0,8 h maka yang dipakai

$0,8h = 48$ adalah $d_p = 50,25$ in

$$\frac{V_u.d_p}{M_u} = \frac{130818,417 \times 50,25}{3359780,421} = 1,956 > 1 \text{ maka digunakan } \frac{V_u.d_p}{M_u} = 1$$

$$V_c = b_w.d_p\left(0,6\lambda\sqrt{f_c} + 700\frac{V_u.d_p}{M_u}\right)$$

$V_c = 7,2x50,25\ (0,6x1\sqrt{6400} + 700) = 270626,4$ lb = 1213461,72 N

$V_{c\ min} = 2\lambda.\sqrt{f'_c}.b_w.d_p = 2 \times 1 \times \sqrt{6400} \times 7,2 \times 50,25 = 57888$ lb = 259564 N

$V_{c\ mak} = 5\lambda.\sqrt{f'_c}.b_w.d_p = 5 \times 1 \times \sqrt{6400} \times 7,2 \times 50,25 = 144720$ lb = 648910 N

$V_c > V_{cmak}$, maka digunakan $V_c = 144720$ lb $= 648910$ N

$V_u/\phi = V_{nh} = 153904{,}02$ lb $> 0{,}5\ V_c = 72360$ lb

$= 690090{,}24$ N > 324455 N

Perlu tulangan geser dengan tulangan geser minimum dan jarak maksimum antar tulangan 24 in

$$A_v = \frac{Aps.fps.s}{80.fy.dp}\sqrt{\frac{dp}{bw}} \quad \text{atau} \quad A_v = \frac{50.bw.s}{fy}$$

$$A_v = \frac{3{,}978 \times 264657{,}33 \times 24}{80 \times 60000 \times 50{,}25}\sqrt{\frac{50{,}25}{7{,}2}} = 0{,}28\ in^2 = 180656\ mm^2$$

$$A_v = \frac{50 \times 7{,}2 \times 24}{60000} = 0{,}144\ in^2 = 92{,}91 mm^2$$

Digunakan A_v minimum $= 0{,}144\ in^2 = 92{,}91\ mm^2$

Digunakan tulangan geser #3 dengan Av $= 0{,}11\ in^2 \times 2 = 0{,}22\ in^2 > 0{,}144\ in^2$

Maka digunakan tulangan geser # 3-24 in

12. Perhitungan tegangan Geser Horisontal dan Perencanaan dowel

b_v = 24 in = 609,5 mm

L_{vh} = 0,5 L = 0,5x98,5x12 = 591 in =15011,4 mm

C_c = 0,85 $f'_{cs}.b_m.h_s$ = 0,85 x 3800 x 92,466 x 5 = 1493329,13 lb = 6695938,49 N

$C_c > A_{ps}.f_{ps}$ = T = 1052806,85 lb digunakan F_h = 1052806,85 lb = 4720680,64 N

$80.b_v.l_{vh}$ = 80 x 24 x 591 = 1134720 lb >F_h maka F_h menentukan – 1052806,85 lb

permukaan singgung dianggap halus (μ = 0,6) dan untuk itu diperlukan dowel minimum dengan luasan dowel,

V_{nh} =V_u/0,85 = 136626,79 / 0,85 = 153904,02 lb = 690090,24 N

V_{nh} = 80. B_v. d_p =80 x 24 x 50,25 = 9648 lb ambil yang terbesar Vnh = 153904,02 lb

V_{nh} < 1052806,85 lb maka F_h yang menentukan

Total A_{vf} = V_{nh} / 0,6 f_y =1052806,85 / (0,6x60000) = 29,24 in^2 = 18865,65 mm^2

Min A_{vf} = $50.b_v.l_{vh}/f_y$ =50 x 24 x 591 / 60000 = 11,82 in^2 = 7626,26 mm^2

Digunakan A_{vf} = 29,24 in^2 = 18865,65 mm^2

Jarak antar dowel ,

$S = l_{vh}.A_v/A_{vf} = 591 \times 0,22 / 29,24 = 4,45$ in $= 113,03$ mm

Jarak maksimum antar dowel = 24 in

Digunakan dowel #3 – 4 in

13. Tata letak tendon

$P_o = 751400$ lb $= 3369202,40$ N

$P_e = 0,8. P_o = 601120$ lb $= 2695361,97$ N

$M_D = 8804791,88$ lb.in $= 994853,4$ N.m

$M_T = 2,7.10^7$ lb.in $= 3041194,72$ N.m

1. Momen pada seperempat bentang

$M_D = 0,75 . 8804791,88 = 6603593,91$ lb $= 746140,08$ N

$M_T = 0,75 . 2,7.10^7 = 20186707,15$ lb $= 2280896,04$ N

$$K_b = \frac{r^2_c}{c_{tc}} = \frac{427,81}{19,20} = 22,28 \text{ in} = 565,9 \text{ mm}$$

$$K_t = \frac{r^2_c}{c_{bc}} = \frac{427,81}{40,8} = 10,486 \text{ in} = 266,34 \text{ mm}$$

2. Batas pada daerah bawah (lower envelope)

a. Tinjauan pada tengah bentang

$$a_{min} = \frac{M_D}{P_o} = \frac{8804791,88}{751400} = 11,72 \text{ in} = 297,69 \text{ mm}$$

$$e_1 = K_b + a_{min} = 22,28 + 11,72 = 33,997 \text{ in} = 863,52 \text{ mm}$$

b. Tinjauan pada seperempat bentang

$$a_{min} = \frac{M_D}{P_o} = \frac{6603593,91}{751400} = 8,79 \text{ in} = 223,27 \text{ mm}$$

$$e_2 = K_b + a_{min} = 22,28 + 8,79 = 31,07 \text{ in} = 789,18 \text{ mm}$$

c. Tinjauan pada Dukungan

$$e_3 = K_b = 22,28 \text{ in} = 565,91 \text{ mm}$$

3. batas pada daerah atas (upper envelope)

a. Tinjauan pada setengah bentang

$$a_{max} = \frac{M_T}{P_e} = \frac{2,72.10^7}{601120} = 44,78 \text{ in} = 1137,412 \text{ mm}$$

$$e_4 = a_{max} - K_t = 44,78 - 10,486 = 34,29 \text{ in} = 870,97 \text{ mm}$$

b. Tinjauan pada seperempat bentang

$$a_{max} = \frac{M_T}{P_e} = \frac{20186707,15}{601120} = 33,582 \text{ in} = 852,98 \text{ mm}$$

$e_5 = a_{max} - K_t = 33,582 - 10,486 = 23,1$ in $= 586,74$ mm

b. Tinjauan pada dukungan

$e_6 = K_t = 10,486$ in $= 266,34$ mm

14. Lendutan yang terjadi

$E_p = 57000 \times \sqrt{f'_{cs}} = 57000 \times \sqrt{3800} = 3513715,902$ Psi

$E_p = 57000 \times \sqrt{f'_c} = 57000 \times \sqrt{6400} = 4560000$ Psi

$$N = \frac{E_P}{E_B} = \frac{3513715,902}{4560000} = 0,771$$

$$I_{cr} = I_g + (A_c (C_{bc} - C_{bs})^2) + N \frac{B_m . H_s^3}{12} + B_m \times H_s \times (C_{tc} - \left(\frac{H_s}{2}\right)^2)$$

$$= 213625,5 + (580,8 \times (40,8 - 27,5)^2) + (0,771 \times \frac{92,4662 \times 5^3}{12}) + (92,4662 \times 5 \times (19,20 - \left(\frac{5}{2}\right)^2))$$

$= 416517,96$ in^4

1. Lendutan akibat gaya prategang dengan tendon parabolik dan angkur eksentris sebesar e_1 ditengah bentang serta e_2 pada penampang diatas tumpuan

$$\Delta_1 = \frac{-P_o . e_2 . L^2 . 144}{8 . E_B . I_g} + \frac{-P_o . e_1 . L^2 . 144}{24 . E_B . I_g}$$

$$= \frac{-751400 \times 5,897 \times 98,5^2 \times 144}{8 \times 4560000 \times 213625,5} + \frac{-5 \times 751400 \times (17,75 - 5,897) \times 98,5^2 \times 144}{48 \times 4560000 \times 213625,5}$$

$= -1,86$ in $= -47,24$ mm

2. Lendutan efektif setelah kehilangan gaya prategang

$$\Delta_2 = \Delta_1 . (1 - R)$$

$= -1,86 \times (1-0,2)$

$= -1,49$ in $= -37,85$ mm

3. Lendutan akibat berat sendiri balok pracetak

$$\Delta_3 = \frac{5 . W_d . (L . 12)^4}{384 . E_B . I_g}$$

$$= \frac{5 \times 50,42 \times (98,5 \times 12)^4}{384 \times 4560000 \times 213625,5} = 1,32 \text{ in} = 33,53 \text{ mm}$$

4. Lendutan balok pracetak akibat berat sendiri pelat cor ditempat

$$\Delta_4 = \Delta_3 . \frac{W_{sd}}{W_d} = 1,32 \times \frac{40,13}{50,42} = 1,05 \text{ in} = 26,67 \text{ mm}$$

5. Lendutan balok komposit akibat beban hidup

$$\Delta_5 = \frac{5 . W_l . (L . 12)^4}{384 . E_p . I_{cr}}$$

$$= \frac{5 \times 51,37 \times (98,5 \times 12)^4}{384 \times 3513715,982 \times 416517,96} = 0,82 \text{ in} = 20,83 \text{ mm}$$

6. Lendutan balok komposit akibat berat sendiri pelat cor ditempat

$$\Delta_6 = \frac{5 . W_{sd} . (L . 12)^4}{384 . E_B . I_{cc}}$$

$$= \frac{5 \text{ x } 40,13 \text{ x } (98,5 \text{ x } 12)^4}{384 \text{ x } 4560000 \text{ x } 446265,61} = 0,501 \text{ in} = 12,73 \text{ mm}$$

7. Lendutan pada kontruksi menggunakan perancah

$$\Delta_t = \Delta_2 + \Delta_3 + \Delta_5 + \Delta_6$$

$$\Delta_t = -1,49 + 1,32 + 0,83 + 0,501$$

$$= 1,16 \text{ in} = 29,46 \text{ mm} < \frac{L}{360} = 3,283 \text{ in} = 83,4 \text{ mm} \longrightarrow \text{aman}$$

- Dicoba tanpa perancah

saat layan sebelum menjadi komposit

$$f_t = \frac{-P_o}{A_c}\left(1 - \frac{e . C_t}{r^2}\right) - \frac{M_d + M_{sd}}{S_t}$$

$$= -\frac{601120}{580,8}\left(1 - \frac{17,75 \text{ x } 27,5}{366,025}\right) - \frac{8804791,88 + 7008830,4}{7768,2}$$

$$= -1690,43 \text{ psi} < fcs = -2880 \text{ psi}$$

$$= -11,88 \text{ MPa} < -20,24928 \text{MPa}$$

$$f_b = \frac{-P_e}{A_c}\left(1+\frac{e.C_b}{r^2}\right)+\frac{M_d+M_{sd}}{S_b}$$

$$=-\frac{601120}{580,8}\left(1+\frac{17,75 \text{ x } 27,5}{366,025}\right)+\frac{8804791,88+7008830,4}{7768,2}$$

$$= -379,54 \text{ psi} < \text{fts} = 480 \text{ psi}$$

$$= -2,67 \text{ MPa} < 3,37488 \text{ MPa}$$

a. Tanpa perancah saat layan sesudah menjadi komposit

$$f_{tc} = -\frac{P_e}{A_c}\left(1-\frac{e.C_t}{r^2}\right)-\frac{M_d+M_{sd}}{S_t}-\frac{M_{csd}+M_l}{S_{tc}}$$

$$=-\frac{601120}{580,8}\left(1-\frac{17,75 \text{ x } 27,5}{366,025}\right)-\frac{8804791,88+7008830,4}{7768,2}-\frac{2130684,43+8971302,864}{23243}$$

$$= -2168,08 \text{ psi} < \text{fcs} = -2880 \text{ psi}$$

$$= -15,24 \text{ MPa} < -20,249 \text{ MPa}$$

$$f_{bc} = -\frac{P_e}{A_c}\left(1+\frac{e.C_t}{r^2}\right)+\frac{M_d+M_{sd}}{S_b}+\frac{M_{csd}+M_l}{S_{bc}}$$

$$=-\frac{601120}{580,8}\left(1+\frac{17,75 \text{ x } 27,5}{366,025}\right)+\frac{8804791,88+7008830,4}{7768,2}+\frac{2130684,43+8971302,864}{23243}$$

= 635,4633 psi > fts = 480 psi ⟶ tidak aman penampang harus dirubah

= 4,47 MPa > 3,37488 MPa

4.3.3 Hitungan perencanaan balok komposit tanpa menggunakan perancah

Adapun hitungan perencanaan langkah-langkah seperti pada hitungan perencanaan menggunakan perancah.

1. Hitungan beban

W_d (berat sendiri) diasumsikan 60 lb/ft (10508,028 N/m)

$M_d = 1/8 . W_d . L^2 = 1/8 . 60 . 98{,}5^2 . 144 = 12224835$ lb in

$$S_a' = \frac{(1-R)M_d + M_{sd} + M_{csd} + M_l}{R f_{ti} - f_{cs}}$$

$$= \frac{(1-0{,}8)\times 12224835 + 7008830{,}363 + 2130684{,}43 + 8971302{,}864}{0{,}8 \times 200{,}7984 - (-2880)}$$

$= 6760{,}351$ in^3

$$S_b' = \frac{(1-R)M_d + M_{sd} + M_{csd} + M_l}{f_{ts} - R f_{ci}}$$

$$= \frac{(1-0,8)12224835+7008830,363+2130684,43+8971302,864}{480-(0,8\,x-2688)}$$

$= 7814,699\ in^3$

$H_t = 1/24\ L = 1/24.\ 98,5\ .\ 12 = 49,25$ in

$B_t = 0,45\ H_t = 0,45\ .\ 49,25 = 22,1625$ in

Dicoba menggunakan $H_t = 55$ in $=1397$ mm

$B_t = 24$ in $= 609,6$ mm

3. Koefisien A_c taksiran

$P_1 = M_T/(0,65.H) = 30335652,66\ /(0,65\ .\ 55) = 848549,7248$ lb

$P_2 = M_L/(0,5.H) = 326229,195\ /\ (0,5\ .\ 55) = 326229,195$ lb

P = P terbesar $= P_1 = 848549,7248$ lb

$A_c = P/(0,5\ f_{cs}\ .\ b\ .\ h) = 848549,7248\ /\ (0,5\ .\ 2880\ .\ 55\ .\ 24) = 0,4464172$

Dari tabel A.H. Nilson (1987) didapat koefisien sebagai berikut,

$b'/b = 0,2$; $C_b = 0,5$; $r^2 = 0,132$

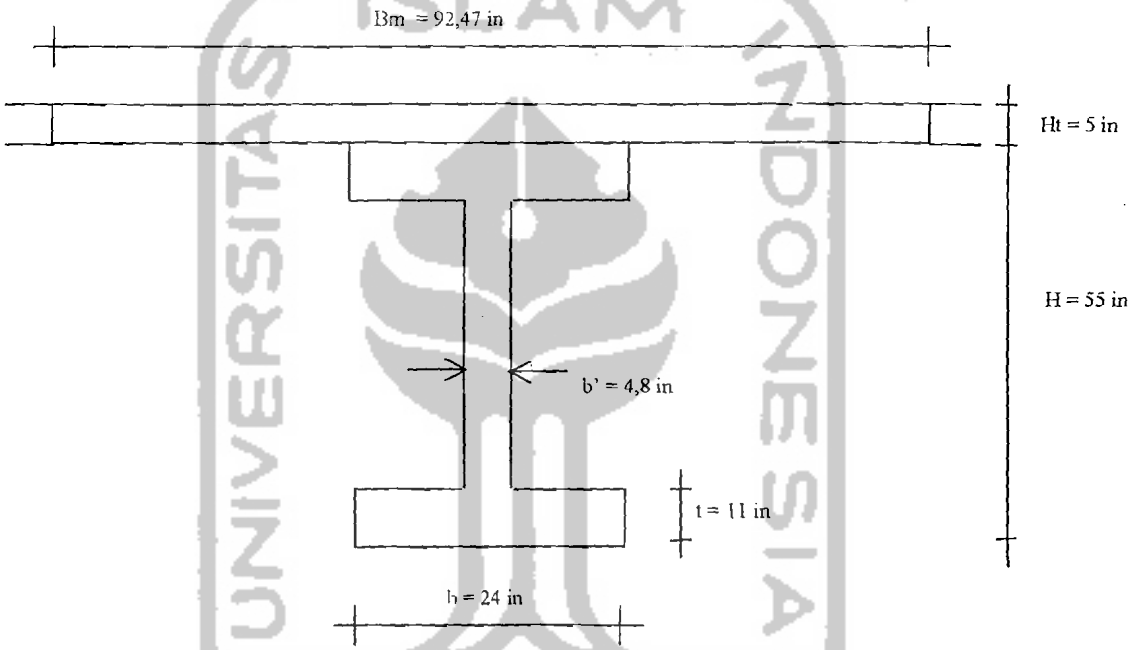
$t/h = 0,2$; $C_t = 0,5$; $A_c = 0,52$; $I = 0,0689$

b = 0,2 . 24 = 4,8 in = mm ; $C_b = C_t$ = 0,5 . 55 = 27,5 in = 698,5 mm

t = 0,2 . 55 = 11 in = 279.4mm ; I = 0,0689 . 24 x 55^3 = 275117,7 in^4

A_c = 0,52 . 55 . 24 = 686,4 in^2 = 442865,28 mm^2 ; r^2 = 0,132 . 55^2 = 399,2

$S_t = S_b$ = 275117,7 / 27,5 = 10004,28 in^3 = 163,95.10^6 mm^3



Gambar 4.4 Propertis penampang balok komposit tanpa menggunakan perancah

Perbandingan modulus penampang taksiran dengan modulus penampang,

(1 - S_b/S_b') x 100% = (1 – 10004,28 / 6760,351) x 100% = - 47,98 %

$(1 - S_t/S_t') \times 100\% = (1 - 10004{,}28 / 7814{,}699) \times 100\% = -28{,}02\ \%$

W_d baru = Ac . γbt = 686,4 x 150/1728 = 59,58 lb/in = 10434,47 N/m

M_d baru = 1/8 . 52,70833 x $98{,}4^2$ x 144 = 10405663,13 lb in = 1175735,88 N.m

M_T = 10405663,13 + 7008830,363 + 2130684,43 + 8971302,864

= 28516480,78 lb in = 3222077,163 N.m

4. Menentukan tegangan pada pusat (sentral)

$$f_{cent} = f_{ti} - \frac{C_t}{h}(f_{ti} - f_{ci}) = 200{,}7984 - \frac{27{,}5}{55}(200{,}7984 + 2688) = -1243{,}6007\ lb/in^2$$

$P_o = A_{cp} . f_{cent} = 686{,}4 \times 1243{,}6007 = 853607{,}52\ lb = 3827490{,}76\ N$

5. Mencari jumlah kabel

Dipakai untuaian 7 kawat ϕ ½ " $\longrightarrow$ $P_i = 28900\ lb = 129584{,}71\ N$

$X = P_o / P_i = 853607{,}52 / 28900 = 29{,}54 \approx 30$ kabel

$P_o = X . P_i = 30 \times 28900 = 867000\ lb = 3887541{,}3\ N$

$P_e = (1\text{-}0{,}2).P_o = (1\text{-}0{,}2) \times 867000 = 693600\ lb = 3110033{,}04\ N$

$e_{max} = C_b - D_{sp} = 27{,}5 - 9{,}75 = 17{,}75$ in

$$e_1 = (f_{ti} - f_{cent})\frac{S_t}{P_o} + \frac{M_d}{P_o}$$

$$= (200{,}7984 - 1243{,}6007)\,x\frac{10004{,}28}{867000} + \frac{10405663{,}13}{867000} = -0{,}031 \text{ in}$$

$$e_2 = (f_{cent} - f_{ti})\frac{S_b}{P_o} + \frac{M_d}{P_o} = (1243{,}3007 - 200{,}7984)\,x\,\frac{10004{,}28}{867000} + \frac{10405663{,}13}{867000} = 24{,}034 \text{ in}$$

$e_2 > e_{max} \longrightarrow e = e_{max} = 17{,}75$ in

6. Hitungan tegangan beton saat transfer

$$f_{t1} = -\frac{P_o}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d}{S_t} = -\frac{867000}{686{,}4}\left(1 - \frac{17{,}75 \text{ x } 27{,}5}{399{,}2}\right) - \frac{10405663{,}13}{10004{,}28}$$

$$= -759{,}14 \text{ psi} < fti = 200{,}7984 \text{ psi}$$

$$= -5{,}34 \text{ MPa} \quad < \quad = 1{,}4118 \text{ MPa}$$

$$f_{b1} = -\frac{P_o}{A_c}\left(1 + \frac{e.C_t}{r^2}\right) + \frac{M_d}{S_t} = -\frac{867000}{686{,}4}\left(1 + \frac{17{,}75 \text{ x } 27{,}5}{399{,}2}\right) + \frac{10405663{,}13}{10004{,}28}$$

$$= -1767{,}08 \text{ psi} < fci = -2688 \text{ psi}$$

$$= -12{,}42 \text{ MPa} < fci = -18{,}89933 \text{ MPa}$$

7. Hitungan tegangan beton saat layan

$$f_t = \frac{-P_e}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d + M_{sd}}{S_t}$$

$$= -\frac{693600}{686,4}\left(1 - \frac{17,75 \text{ x } 27,5}{399,2}\right) - \frac{10405663,13 + 7008831}{10004,24}$$

$$= -1515,29 \text{ psi} < fcs = -2880 \text{ psi}$$

$$= -10,66 \text{ MPa} < -20,24928 \text{MPa}$$

$$f_b = \frac{-P_e}{A_c}\left(1 + \frac{e.C_b}{r^2}\right) + \frac{M_d + M_{sd}}{S_b}$$

$$= -\frac{693600}{686,4}\left(1 + \frac{17,75 \text{ x } 27,5}{399,2}\right) + \frac{10405663,13 + 7008831}{10004,24}$$

$$= -505,06 \text{ psi} < fts = 480 \text{ psi}$$

$$= -3,55 \text{ MPa} < 3,37488 \text{ MPa}$$

8. Hitungan Propertis penampang setelah beton menjadi komposit

$y = h_t + h_s/2 = 55 + 5/2 = 57,5 \text{ in} = 1460,5 \text{ mm}$

$A_{cc} = A_s + A_c = 462,331 + 686,4 = 1148,731 \text{ in}^2 = 741161,24 \text{ mm}^2$

$$C_{bc} = \left(\frac{As.y + Ac.Cb}{Ac + As}\right) = \frac{462{,}331 \times 57{,}5 + 686{,}4 \times 27{,}5}{462{,}331 + 686{,}4} = 39{,}57 \text{ in} = 1005{,}08 \text{ mm}$$

$C_{tc} = (ht+hs)-Cbc \quad = 55+5 - 39{,}57 \quad = 20{,}43 \text{ in} = 518{,}992 \text{ mm}$

$I_{cc} = I_c + A_c(C_{bc}-C_b)^2 + 1/12\,(b_m.h_s^3) + b_m.h_s(C_{tc}-h_s/2)^2$

$= 26790{,}3 + 686{,}4 \times (39{,}57 - 27{,}5)^2 + 1/12(92{,}466 \times 5^3) + 92{,}4662 \times 5 \times (20{,}43 - 5/2)^2$

$= 524711{,}12 \text{ in}^4$

$r_c^2 = I_{cc}/A_{cc} = 524711{,}12 / 1148{,}731 = 456{,}77 \text{ mm}^2 = 294708{,}004 \text{ mm}^2$

$S_{tc} = I_{cc}/C_{tc} = 524711{,}12 / 20{,}43 \quad = 25683{,}36 \text{ in}^3 = 420{,}9.10^6 \text{ mm}^3$

$S_{bc} = I_{cc}/C_{bc} = 524711{,}12 / 39{,}57 \quad = 13260{,}33 \text{ in}^3 = 217{,}31.10^6 \text{ mm}^3$

9. Tegangan beton saat layan setelah beton menjadi komposit

$$f_{tc} = -\frac{P_e}{A_c}\left(1 - \frac{e.C_t}{r^2}\right) - \frac{M_d + M_{sd}}{S_t} - \frac{M_{csd} + M_l}{S_{tc}}$$

$$= -\frac{693600}{686{,}4}\left(1 - \frac{17{,}75 \times 27{,}5}{399{,}2}\right) - \frac{1040566{,}13 + 7008831}{10004{,}24} - \frac{213068{,}43 + 897130{,}86}{25683{,}36}$$

$= -1948{,}1 \text{ psi} < fcs = -2880 \text{ psi}$

$= -13{,}93 \text{ MPa} \quad < -20{,}249 \text{ MPa}$

$$f_{bc} = - \frac{P_e}{A_c}(1 + \frac{e.C_t}{r^2}) + \frac{M_d + M_{sd}}{S_b} + \frac{M_{csd} + M_l}{S_{bc}}$$

$$= - \frac{693600}{686,4}(1 + \frac{17,75 \times 27,5}{399,2}) + \frac{1040566313 + 7008831}{10004,24} + \frac{213068443 + 897130286}{2568336}$$

$$= 332,26 \text{ psi} < \text{fts} = 480 \text{ psi}$$

$$= 2,34 \text{ MPa} < 3,37488 \text{ MPa}$$

10. Hitungan Kapasitas Momen Nominal

$M_u = 1,4 (M_d + M_{sd} + M_{csd}) + 1,7 M_l$

$= 1,4 (10405663,13 + 7008830,4 + 2130684,43) + 1,7 \times 8971302,864$

$- 42614463,85 \text{ lb.in} = 4815008,27 \text{ N.m}$

$M_n = M_u/0,9 = 42614463,85 / 0,9 = 47349404,28 \text{ lb in} = 5350009,19 \text{ N.m}$

$A_{ps} = X . \phi_{kabel} = 28 \times 0,153 = 4,284 \text{ in}^2 = 2961,468 \text{ mm}^2$

$D_p = H_s + H_p - D_{sp} = 5 + 55 - 9,75 = 50,25 \text{ in}$

$\rho = A_{ps}/(B_m.D_p) = 4,59 / (92,4662 \times 50,25) = 9,8 . 10^{-4}$

$\beta = 0,85 - 0,5(6400 - 4000)/1000 = 0,73$

$f_{py}/f_{pu} = 229500/270000 = 0,85 \longrightarrow \gamma p = 0,4$ (Nawy,1995)

$$f_{ps} = f_{pu}\left(1 - \frac{\gamma_p . \rho_p . f_{pu}}{0,75\, f_c}\right)$$

$$= 270000\left(1 - \frac{0,4x0,00098 \times 270000}{0,73 \times 6400}\right) = 263833,46 \text{ psi}$$

$T = A_{ps}.f_{ps}$

$= 4,59 \times 263833,46 = 1210995,58$ psi

$C = 0,85\, f_c\, .\, B_m\, .\, H_s$

$= 0,85 \times 6400 \times 92,4662x5 = 2515080,912 > T \longrightarrow$ gaya desak ditahan sayap

$$a = \frac{A_{ps}.f_{ps}}{0,85.f_c.B_m} = \frac{1210995,58}{0,85x6400x92,4662} = 2,41 \text{ in} = 61,214 \text{ mm}$$

$M_n = A_{ps}.f_{ps}(d_p - a/2)$

$= 1210995,58 \times (50,25 - 2,41 / 2)$

$= 6,08.\ 10^7$ lb in $> 47349404,28$ lb in $\longrightarrow$ OK

$= 6869792$ N.m $> 5350009,19$ N.m

11. Hitungan Tegangan Geser dan Perencanaan Begel

$W_u = 1,4\ (W_d + W_{sd} + W_{csd}) + 1,7\ W_l$

$W_u = 1,4\ (59,58 + 40,1329 + 12,2004) + 1,7 \times 51,37012$

$= 244,01$ lb/in $= 42734,4$ Nm

$V_u = W_u.L/2 = 244,01 \times 98,5 \times 12/2 = 144211,91$ lb $= 646629,5$ N

$V_n = V_u/0,85 = 144211,91 / 0,85 = 169660,47$ lb $= 760740,58$ N

Diasumsikan V_u terjadi pada setengah tinggi tampang

$0,5D_p = 0,5 \times 50,25 = 25,125$ in $= 638,175$ mm

$$V_{nh} = V_n\left(\frac{L/2 - D_p/2}{L/2}\right)$$

$$V_{nh} = 169660,4 \times \left(\frac{98,5x12/2 - 25,125}{98,5x12/2}\right) = 162447,75 \text{ lb} = 728399,47 \text{ N}$$

$V_{u2} = 0,85\ V_{nh} = 0,85 \times 162447,75 = 138080,58$ lb $= 619139,51$ N

$f_{pe} = 0,8\ f_{pi} = 0,8.\ (0,7\ fpu) = 0,8\ (0,7 \times 270000) = 151200$ psi

$0,4\ f_{pu} = 0,4 \times 270000 = 108000$ psi

$f_{pe} > 0,4\ f_{pu}$

$$M_u = V_u . 0{,}5d_p - \left(\frac{W_u . (0{,}5\, d_p)^2}{2}\right)$$

$M_u = 144211{,}4 \times 25{,}125 - 0{,}5 \times 244{,}01 \times 25{,}125^2 = 3546293{,}86$ lb in

$D_p = 50{,}25$ bila dp > 0,8 h maka yang dipakai

$0{,}8h = 48$ adalah $d_p = 50{,}25$ in

$$\frac{V_u . d_p}{M_u} = \frac{138080{,}58 \times 50{,}25}{3546293{,}86} = 1{,}96 > 1 \text{ maka digunakan } \frac{V_u . d_p}{M_u} = 1$$

$$V_c = b_w . d_p \left(0{,}6\lambda\sqrt{f_c} + 700\frac{V_u . d_p}{M_u}\right)$$

$V_c = 4{,}8 \times 50{,}25\ (0{,}6 \times 1\sqrt{6400} + 700) = 180417{,}6$ lb $= 808974{,}48$ N

$V_{c\,min} = 2\lambda . \sqrt{f'_c} . b_w . d_p = 2 \times 1 \times \sqrt{6400} \times 4{,}8 \times 50{,}25 = 38592$ lb $= 173042{,}69$ N

$V_{c\,mak} = 5\lambda . \sqrt{f'_c} . b_w . d_p = 5 \times 1 \times \sqrt{6400} \times 4{,}8 \times 50{,}25 = 96480$ lb $= 432606{,}67$ N

$V_c > V_{cmak}$, maka digunakan $V_c = 96480$ lb $= 432606{,}67$ N

$V_u/\phi = V_{nh} = 162447{,}75$ lb $> 0{,}5\, V_c = 48240$ lb

$= 728399{,}47$ N $> 216303{,}38$ N

Perlu tulangan geser dengan tulangan geser minimum dan jarak maksimum antar tulangan 24 in

$$A_v = \frac{Aps.fps.s}{80.fy.dp}\sqrt{\frac{dp}{bw}} \quad \text{atau} \quad A_v = \frac{50.b_w.s}{f_y}$$

$$A_v = \frac{4,59 \times 263833,46 \times 24}{80 \times 60000 \times 50,25}\sqrt{\frac{50,25}{4,8}} = 0.39 \text{ in}^2 = 251,63 \text{ mm}^2$$

$$A_v = \frac{50 \times 4,8 \times 24}{60000} = 0,096 \text{ in}^2 = 61,94 \text{ mm}^2$$

Digunakan A_v minimum = 0,096 in^2 = 61,94 m^2

Digunakan tulangan geser #3 dengan Av = 0,11 in^2 x 2 =0,22 in^2 > 0,096 in^2

Maka digunakan tulangan geser # 3-24 in

12. Perhitungan tegangan Geser Horisontal dan Perencanaan dowel

b_v = 24 in

L_{vh} = 0,5 L = 0,5x98,5x12 = 591 in

C_c = 0,85 $f'_{cs}.b_m.h_s$ = 0,85 x 3800 x 92,466 x 5 = 1493329,13 lb

$C_c > A_{ps}.f_{ps} = T$ = 1210995,58 lb digunakan F_h = 1210995,58 lb

$80.b_v.l_{vh}$ = 80 x 24 x 591 = 1134720 lb < F_h maka F_h menentukan = 1134720 lb

permukaan singgung dianggap halus (μ = 0,6) dan untuk itu diperlukan dowel minimum dengan luasan dowel,

V_{nh} =V_u/0,85 = 138080,58/ 0,85 = 162447,06 lb = 728399,47 N

V_{nh} = 80. B_v . d_p =80 x 24 x 50,25 = 9648 lb ambil yang terbesar Vnh =162447,06 lb

V_{nh} < 1134720 lb maka F_h yang menentukan

Total A_{vf} = V_{nh} / 0,6 f_y =1134720 / (0,6 x 60000) = 31,52 in^2 = 20336,7 mm^2

Min A_{vf} = 50. b_v . l_{vh} / f_y =50 x 24 x 591 / 60000 = 11,82 in^2 = 7626,26 mm^2

Digunakan A_{vf} = 31,52 in^2 = 20336,7 m^2

Jarak antar dowel ,

S = l_{vh} . A_v / A_{vf} = 591 x 0,22 / 31,52= 4,125 in

Jarak maksimum antar dowel = 24 in

Digunakan dowel #3 – 4 in

13. Tata letak tendon

P_o = 867000 lb = 3887541,3 N

P_e = 0,8. P_o = 693600 lb = 3110033,04 N

M_D = 10405663,13 lb.in = 1175735,88 N.m

M_T = 2,85.10^7 lb.in = 3322077,163 N.m

1. Momen pada seperempat bentang

$M_D = 0,75 \,.\, 10405663,13 = 7804247,35$ lb = 881801,91 N

$M_T = 0,75 \,.\, 2,85.10^7 = 21387360,14$ lb = 2416557,82 N

$$K_b = \frac{r^2_c}{c_{tc}} = \frac{456,77}{20,43} = 22,36 \text{ in} = 567,94 \text{ mm}$$

$$K_t = \frac{r^2_c}{c_{bc}} = \frac{456,77}{39,57} = 11,54 \text{ in} = 285,75 \text{ mm}$$

2. Batas pada daerah bawah (lower envelope)

a. Tinjauan pada tengah bentang

$$a_{min} = \frac{M_D}{P_o} = \frac{10405663,13}{867000} = 12 \text{ in} = 304,80 \text{ mm}$$

$e_1 = K_b + a_{min} = 22,36 + 12 = 34,36$ in = 872,744 mm

b. Tinjauan pada seperempat bentang

$$a_{min} = \frac{M_D}{P_o} = \frac{7804247,35}{867000} = 9 \text{ in} = 228,6 \text{ mm}$$

$e_2 = K_b + a_{min} = 22,36 + 9 = 31,36$ in = 796,544 mm

c. Tinjauan pada Dukungan

$e_3 = K_b = 22{,}36$ in $= 613{,}66$ mm

3. batas pada daerah atas (upper envelope)

a. Tinjaun pada setengah bentang

$$a_{max} = \frac{M_T}{P_e} = \frac{2{,}85.10^7}{693600} = 41{,}11 \text{ in} = 1044{,}19 \text{ mm}$$

$e_4 = a_{max} - K_t = 41{,}11 - 11{,}54 = 29{,}59$ in $= 751{,}59$ mm

b. Tinjauan pada seperempat bentang

$$a_{max} = \frac{M_T}{P_e} = \frac{21387360{,}14}{693600} = 30{,}84 \text{ in} = 783{,}336 \text{ mm}$$

$e_5 = a_{max} - K_t = 30{,}84 - 11{,}54 = 19{,}30$ in $= 490{,}22$ mm

c. Tinjauan pada dukungan

$e_6 = K_t - 11{,}54$ in $= 285{,}75$ mm

14. Lendutan yang terjadi

$E_p = 57000 \times \sqrt{f'_{cs}} = 57000 \times \sqrt{3800} = 3513715{,}902$ Psi

$E_p = 57000 \times \sqrt{f'_c} = 57000 \times \sqrt{6400} = 4560000$ Psi

$$N = \frac{E_P}{E_B} = \frac{3513715{,}902}{4560000} = 0{,}771$$

$$I_{cr} = I_g + (A_c (C_{bc} - C_{bs})^2) + N \frac{B_m . H_s^3}{12} + B_m \times H_s \times (C_{tc} - \left(\frac{H_s}{2}\right)^2)$$

$$= 275117,7 + (686,4 \text{ x } (39,54 - 27,5)^2) + (0,771 \text{ x } \frac{92,4662 \text{ x } 5^3}{12}) + (92,4662 \text{ x } 5 \text{ x } (20,43 - \left(\frac{5}{2}\right)^2))$$

$$= 496337,27 \text{ in}^4$$

8. Lendutan akibat gaya prategang dengan tendon parabolik dan angkur eksentris sebesar e_1 ditengah bentang serta e_2 pada penampang diatas tumpuan

$$\Delta_1 = \frac{-P_o . c_2 . L^2 . 144}{8 . E_B . I_g} + \frac{-5 . P_o . e_1 . L^2 . 144}{48 . E_B . I_g}$$

$$= \frac{-867000 \text{ x } 5,41 \text{ x } 98,5^2 \text{ x } 144}{8 \text{ x } 4560000 \text{ x } 275117,7} + \frac{-5 \text{x} 867000 \text{ x } (17,75 - 5,41) \text{ x } 98,5^2 \text{ x } 144}{48 \text{ x } 4560000 \text{ x } 275117,7}$$

$$= -1,64 \text{ in} = -41,66 \text{ mm}$$

9. Lendutan efektif setelah kehilangan gaya prategang

$$\Delta_2 = \Delta_1 . (1 - R)$$

$$= -1,64 \text{ x } (1-0,2)$$

$$= -1,312 \text{ in} = -33,32 \text{ mm}$$

10. Lendutan akibat berat sendiri balok pracetak

$$\Delta_3 = \frac{5 . W_d . (L . 12)^4}{384 . E_B . I_g}$$

$$= \frac{5 \text{ x } 59,58 \text{ x } (98,5 \text{ x } 12)^4}{384 \text{ x } 4560000 \text{ x } 275117,7} = 1,21 \text{ in} = 30,73 \text{ mm}$$

11. Lendutan balok pracetak akibat berat sendiri pelat cor ditempat

$$\Delta_4 = \Delta_3 . \frac{W_{sd}}{W_d} = 1{,}21 \text{ x } \frac{40{,}13}{59{,}58} = 0{,}81 \text{ in} = 20{,}57 \text{ mm}$$

12. Lendutan balok komposit akibat beban hidup

$$\Delta_5 = \frac{5 . W_l . (L.12)^4}{384 . E_p . I_{cr}}$$

$$= \frac{5 \text{ x } 51{,}37 \text{ x } (98{,}5 \text{ x } 12)^4}{384 \text{ x } 3513715{,}982 \text{ x } 496337{,}27} = 0{,}71 \text{ in} = 18{,}034 \text{ mm}$$

13. Lendutan balok komposit akibat berat sendiri pelat cor ditempat

$$\Delta_6 = \frac{5 . W_{sd} . (L.12)^4}{384 . E_B . I_{cc}}$$

$$= \frac{5 \text{ x } 40{,}13291 \text{ x } (98{,}5 \text{ x } 12)^4}{384 \text{ x } 4560000 \text{ x } 524711{,}12} = 0{,}43 \text{ in} = 10{,}92 \text{ mm}$$

14. Lendutan pada kontruksi tanpa perancah :

$$\Delta_t = \Delta_2 + \Delta_3 + \Delta_4 + \Delta_5$$

$$= -1{,}321 + 1{,}21 + 0{,}81 + 0{,}71$$

$$= 1{,}42 \text{ in} = 36{,}07 \text{ mm} < \frac{L}{360} = 3{,}283 \text{ in} = 83{,}4 \text{ mm} \longrightarrow \text{aman}$$

Untuk bentang yang lain dengan menggunakan program basic dapat dilihat pada tabel berikut ini.

Tabel 4.1 Hasil perhitungan kontruksi balok komposit beton prategang dengan perancah

No	NOTASI	PANJANG BENTANG (ft)					
		50	66	82	98.5	115	131.5
1	B_{eff} (in)	120	120	120	120	120	120
2	B_m (in)	92.46621	92.46621	92.46621	92.46621	92.46621	92.46621
3	A_s (in2)	462.3311	462.3311	462.3311	462.3311	462.3311	462.3311
4	H (in)	32	37	45	55	61	69
5	B (in)	16	16	22	24	25	29
6	b'/b	0.3	0.3	0.3	0.3	0.2	0.2
7	t/h	0.1	0.2	0.1	0.1	0.2	0.2
8	A_c	0.44	0.58	0.44	0.44	0.52	0.52
9	C_b	0.5	0.5	0.5	0.5	0.5	0.5
10	C_t	0.5	0.5	0.5	0.5	0.5	0.5
11	I	0.0535	0.0707	0.0535	0.0535	0.0689	0.0689
12	r^2	0.121	0.122	0.121	0.121	0.132	0.132
13	% S_a	-9.98	-9.49	-7.21	-17.91	-39.11	-48.32
14	% S_b	4.85	5.29	7.26	-2	-20.34	-28.31
		Beban					
15	W_{sd} (lb/in)	40.13	40.13	40.13	40.13	40.13	40.13
16	W_{csd} (lb/in)	12.2	12.2	12.2	12.2	12.2	12.2
17	W_l (lb/in)	51.37	51.37	51.37	51.37	51.37	51.37
18	W_d (lb/in)	19.56	29.81	37.8	50.42	68.84	89.01
19	W_d taksir	20	30	40	55	70	90
20	M_{sd} (lb.in)	1805981	3146741	4857366	7008831	9553637	12491790
21	M_{csd} (lb.in)	549018.1	956609.2	1476639	2130685	2904306	3797504
22	M_l (lb.in)	2311655	4027828	6217428	8971303	12222222	15989490
23	M_d (lb.in)	879999.9	2336994	4576523	8804791	1.64E+07	2.77E+07
24	M_t (lb.in)	5546654	1.05E+07	1.71E+07	2.69E+07	4.10E+07	6.00E+07
25	n kabel	10	16	20	26	36	46
		Saat transfer pada kedua macam kontruksi					
26	F_{TI} (psi)	200.7984	200.7984	200.7984	200.7984	200.7984	200.7984
27	F_{CI} (psi)	-2688	-2688	-2688	-2688	-2688	-2688
28	f_{ti} (psi)	-749.46	-792.01	-733.44	-701.87	-899.82	-1044.58
29	f_{bi} (psi)	-1816.23	-1897.37	-1920.37	-1885.59	-1724.14	-1548.26

Saat layan pada kontruksi tanpa perancah sebelum menjadi komposit							
30	F_{TS} (psi)	480	480	480	480	480	480
31	F_{CS} (psi)	-2880	-2880	-2880	-2880	-2880	-2880
32	f_{t2} (psi)	-1730.14	-1803.71	-1797.75	-1690.43	-1720.8	-1811.57
33	f_{b2} (psi)	-322.42	-350.99	-325.29	-379.54	-378.37	-262.71
Saat layan pada kontruksi tanpa perancah setelah menjadi komposit							
34	f_{tc} (psi)	-2033.03	-2196.88	-2250.85	-2168.17	-2218.41	-3330.9
35	f_{bc} (psi)	683.77	689.08	770.3627	635.37	530.77	588.71
Saat layan pada kontruksi dengan perancah sebelum menjadi komposit							
36	f_{t2} (psi)	-699.96	-787.719	-778.77	-788.18	-975.52	-1135.55
37	f_{b2} (psi)	-1352.59	-1366.99	-1344.28	-1281.79	-1123.65	-938.73
Saat layan pada kontruksi dengan perancah setelah menjadi komposit							
38	f_{tc} (psi)	-1194.09	-1429.1	-1517.92	-1567.52	-1787.28	-1982.75
39	f_{bc} (psi)	288.818	344.39	443.08	373.86	359.44	450.2
Momen dan gaya geser							
40	W_u (lb/in)	187.97	202.32	213.53	231.18	256.97	285.22
41	M_u (lb.in)	8458812	1.59E+07	2.58E+07	4.04E+07	6.12E+07	8.88E+07
42	M_{n1} (lb.in)	9398680	1.76E+07	2.87E+07	4.49E+07	6.80E+07	9.86E+07
43	M_{n2} (lb.in)	1.11E+07	2.10E+07	3.26E+07	5.29E+07	8.16E+07	1.17E+08
44	V_{u1} (lb)	56392.08	80120.15	105058.4	136626.9	177307.5	225034.9
45	V_{n1} (lb)	66343.62	94258.99	123598.1	160737.5	208597	264746.9
46	V_{nh} (lb)	384000	506880	810497,7	1052803	1380000	1493329
47	V_c (lb)	97838.4	115790.4	198706.2	270626.4	210375	274403.8
48	$V_{c\,min}$ (lb)	20928	24768	42504	57888	45000	58696
49	$V_{c\,max}$ (lb)	52320.01	61920.01	106260	144720	112500	146740
50	V_{c2} (lb)	26160	30960	53130.01	72360	56250	73370
51	A_{v1} (in2)	0.178	0.26	0.25	0.27	0.43	0.48
52	A_{v2} (in2)	9.60E-02	9.60E-02	0.132	1.44E-01	0.1	0.116
53	$A_{vf\,tot}$ (in2)	1.07E+01	1.45E+01	2.25E+01	2.92E+01	3.83E+01	4.15E+01
54	$A_{vf\,min}$(in2)	4	5.28	9.02	11.82	14.38	19.07
Tata letak tendon							
55	K_b (in)	4.13	5.9	7.82	10.49	13.26	15.62
56	K_t (in)	13.74	15.74	18.91	22.28	24.23	25.61
57	e_1 (in)	19.86	22.4	29.22	34.29	36.09	40.78
58	e_2 (in)	13.82	15.34	19.96	23.1	23.75	26.68
59	e_3 (in)	4.13	5.9	7.82	10.49	13.26	15.62
60	e_4 (in)	16.78	20.79	26.83	33.996	39.97	46.45
61	e_5 (in)	16.02	19.53	24.85	31.07	36.04	41.24
62	e_6 (in)	13.74	15.74	18.91	22.28	24.23	25.61
63	e_e (in)	4.8	4.92	5.55	5.9	5.48	4.99

Lendutan							
64	a_1 (in)	-0.59	-1.04	-1.48	-1.86	-2.18	-2.58
65	a_2 (in)	-0.47	-0.83	-1.18	-1.49	-1.74	-2.06
66	a_3 (in)	0.26	0.58	0.94	1.32	1.82	2.51
67	a_4 (in)	0.53	0.79	1	1.05	1.06	1.13
68	a_5 (in)	0.3	0.51	0.72	0.83	0.97	1.12
69	a_6 (in)	0.18	0.31	0.43	0.5	0.59	0.67
lendutan pada kontruksi tanpa perancah							
70	a_t (in)	0.62	1.06	1.48	1.71	2.12	2.7
lendutan pada kontruksi dengan perancah							
71	a_t (in)	0.28	0.58	0.91	1.16	1.64	2.24
72	$a_{t\,ijin}$ (in)	1.67	2.2	2.73	3.28	3.83	4.38

Tabel 4.2 Hasil perhitungan kontruksi balok komposit beton prategang tanpa perancah

No	NOTASI	PANJANG BENTANG (ft)					
		50	66	82	98.5	115	131.5
1	B_{eff} (in)	120	120	120	120	120	120
2	B_m (in)	92.46621	92.46621	92.46621	92.46621	92.46621	92.46621
3	A_s (in2)	462.3311	462.3311	462.3311	462.3311	462.3311	462.3311
4	H (in)	32	38	45	55	61	69
5	B (in)	16	16	22	24	25	32
6	b'/b	0.4	0.4	0.2	0.2	0.3	0.2
7	t/h	0.1	0.2	0.2	0.2	0.2	0.2
8	A_c	0.52	0.64	0.52	0.52	0.58	0.52
9	C_b	0.5	0.5	0.5	0.5	0.5	0.5
10	C_t	0.5	0.5	0.5	0.5	0.5	0.5
11	I	0.0577	0.0725	0.0689	0.0689	0.0707	0.0689
12	r^2	0.111	0.113	0.132	0.132	0.122	0.132
13	% S_a	-17.53	-17.35	-36.84	-50.54	-40.3586	-65.78
14	% S_b	-1.67	-1.52	-18.38	-30.23	-21.4216	-43.42
Beban							
15	W_{sd} (lb/in)	40.13	40.13	40.13	40.13	40.13	40.13
16	W_{csd} (lb/in)	12.2	12.2	12.2	12.2	12.2	12.2

17	W_l (lb/in)	51.37	51.37	51.37	51.37	51.37	51.37
18	W_d (lb/in)	23.11	33.78	44.69	59.58	76.77951	99.666
19	W_d taksir	25	35	45	60	80	100
20	M_{sd} (lb.in)	1805981	3146741	4857366	7008831	9553637	12491790
21	M_{csd} (lb.in)	549018.1	956609.2	1476639	2130685	2904306	3797504
22	M_l (lb.in)	2311655	4027828	6217428	8971303	12222222	15989490
23	M_d (lb.in)	1040000	2648448	5408617	1.04E+07	1.83E+07	3.10E+07
24	M_t (lb.in)	5706654	1.08E+07	1.80E+07	2.85E+07	4.30E+07	6.33E+07
25	n kabel	12	18	24	30	40	50
Saat transfer pada kedua macam kontruksi							
26	F_{TI} (psi)	200.7984	200.7984	200.7984	200.7984	200.7984	200.7984
27	F_{CI} (psi)	-2688	-2688	-2688	-2688	-2688	-2688
28	f_{ti} (psi)	-706.65	-687.51	-782.36	-759.14	-874.43	-1026.24
29	f_{bi} (psi)	-1898.52	-1986.21	-1912.27	-1767.08	-1739.48	-1490.84
Saat layan pada kontruksi tanpa perancah sebelum menjadi komposit							
30	F_{TS} (psi)	480	480	480	480	480	480
31	F_{CS} (psi)	-2880	-2880	-2880	-2880	-2880	-2880
32	f_{t2} (psi)	-1630.51	-1647.43	-1593.33	-1515.92	-1703.75	-1711.54
33	f_{b2} (psi)	-453.62	-491.56	-562.385	-505.06	-387.371	-302.121
Saat layan pada kontruksi tanpa perancah setelah menjadi komposit							
34	f_{tc} (psi)	-1928.04	-2026	-2007.21	-1948.1	-2202.93	-2197.23
35	f_{bc} (psi)	437.65	450.59	344.2524	332.26	476.414	456.7651
Saat layan pada kontruksi dengan perancah sebelum menjadi komposit							
36	f_{t2} (psi)	-675.33	-708.12	-802.093	-815.34	-977.448	-1116.32
37	f_{b2} (psi)	-1408.81	-1430.86	-1353.62	-1205.64	-1113.68	-897.135
Saat layan pada kontruksi dengan perancah setelah menjadi komposit							
38	f_{tc} (psi)	-1160.69	-1325.7	-1477.27	-1520.35	-1791.76	-1908.84
39	f_{bc} (psi)	45.1	106.08	125.3926	160.29	295.4271	340.8463
Momen dan gaya geser							
40	W_u (lb/in)	192.95	207.88	223.1583	244.01	268.0872	300.1292
41	M_u (lb.in)	8682812	1.63E+07	2.70E+07	4.24E+07	6.38E+07	9.34E+07
42	M_{n1} (lb.in)	9647569	1.81E+07	3.00E+07	4.73E+07	7.09E+07	1.04E+08
43	M_{n2} (lb.in)	1.33E+07	2.42E+07	3.90E+07	6.08E+07	9.04E+07	1.29E+08
44	V_{u1} (lb)	57885.42	82322.35	109793.9	144211.4	184980.1	236801.9
45	V_{n1} (lb)	68100.49	96849.81	129169.3	169660.4	217623.7	278590.5
46	V_{nh} (lb)	384000	506880	865920	1134720	1380000	1493329
47	V_c (lb)	130451.2	159174.4	132470.8	180417.6	315562.5	307577.6
48	$V_{c\,min}$ (lb)	27904	34048	28336	38592	67500.01	65792
49	$V_{c\,max}$ (lb)	69760	85120	70840	96480.01	168750	164480
50	V_{c2} (lb)	34880	42560	35420	48240.01	84375.01	82240

51	A_{v1} (in2)	0.185	0.25	0.364005	0.39	0.3913	0.494134
52	A_{v2} (in2)	0.128	0.128	0.088	9.60E-02	0.15	0.128
53	$A_{vf\,tot}$ (in2)	1.07E+01	1.41E+01	2.41E+01	3.15E+01	3.83E+01	41.48
54	$A_{vf\,min}$(in2)	4	5.28	9.02	11.82	14.375	21.04
Tata letak tendon							
55	K_t (in)	4.41	6.21	8.684991	11.54	13.00784	16.1899
56	K_b (in)	13.2	15.46	19.02503	22.36	22.5092	25.296
57	e_1 (in)	16.16	19.69	23.68499	29.57	33.44973	38.56874
58	e_2 (in)	11.02	13.21	15.5906	19.29	21.83534	24.87911
59	e_3 (in)	4.41	6.21	8.684991	11.54	13.00784	16.1899
60	e_4 (in)	16.2	20.55	26.82292	34.36	38.32007	46.7652
61	e_5 (in)	15.45	19.28	24.87344	31.36	34.36735	41.39802
62	e_6 (in)	13.2	15.46	19.02503	22.36	22.5092	25.296
63	e_c (in)	4.4	4.6	5.170017	5.41	4.750681	4.55328
Lendutan							
64	a_1 (in)	-0.65	-1.08	-1.36257	-1.65	-2.319	-2.4536
65	a_2 (in)	-0.51	-0.87	-1.09005	-1.32	-1.855	-1.9629
66	a_3 (in)	0.28	0.6	0.866086	1.21	1.981923	2.436326
67	a_4 (in)	0.49	0.71	0.777814	0.81	1.035957	0.981039
68	a_5 (in)	0.28	0.46	0.612005	0.71	0.941767	1.003034
69	a_6 (in)	0.17	0.28	0.368786	0.43	0.56716	0.603967
lendutan pada kontruksi tanpa perancah							
70	a_t (in)	0.54	0.899	1.165851	1.41	2.104412	2.457484
lendutan pada kontruksi dengan perancah							
71	a_t (in)	0.22	0.47	0.756824	1.02	1.635614	2.080412
72	$a_{t\,ijin}$ (in)	1.67	2.2	2.7333	3.28	3.833	4.3833