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LAMPIRAN 1 (Desain Penampang Kolom)

1. Desain Penampang Kolom

Penampang kolom :

B = 300 mm

H = 300 mm

d = 275 mm

d_s = 25 mm

f'_c = 25 MPa

f_y = 474 MPa

E_s = 200000 MPa

Regangan tarik baja tulangan pada saat leleh (ε_y) :

$$\varepsilon_y = \frac{f_y}{E_s}$$

$$= \frac{473,744}{200000}$$

$$= 0,00237$$

Luas penampang bruto kolom (A_g) :

A_g = B.H

= 300.300

= 90000 mm^2

Luas tulangan terpasang (A_{st}) :

A_{st} = $n.0,25.\pi.D^2$

= $8.0,25.\pi.13^2$

= 1061,32 mm^2

Persyaratan :

Berdasarkan SNI 2847-2019 Pasal 10.6.1 tulangan longitudinal terpasang harus lebih besar dari $0,01.A_g$ dan lebih kecil dari $0,08.A_g$:

$0{,}01.A_g \leq A_{st} \leq 0{,}08.A_g$

$900 \leq 1061{,}32 \leq 7200 \rightarrow$ Syarat terpenuhi

Inersia penampang bruto :

$$I_g = \frac{1}{12} b.h^3$$

$$= \frac{1}{12} 300.300^3$$

$$= 675000000 \text{ mm}^4$$

Nilai momen inersia penampang kolom harus dihitung berdasarkan ketentuan dalam SNI 2847-2019 Pasal 6.6.3.1.1 dengan persamaan :

$$I = 0{,}70.I_g$$

$$= 0{,}70.675000000$$

$$= 472500000 \text{ mm}^4$$

Radius girasi (r) :

$$r = \sqrt{\frac{I}{A_g}}$$

$$= \sqrt{\frac{472500000}{90000}}$$

$$= 72{,}46$$

Persyaratan kelangsingan :

Berdasarkan SNI 2847-2019 Pasal 6.2.5 pengaruh kelangsingan boleh diabaikan apabila memenuhi persyaratan :

$\frac{k.l_u}{r} \leq 40$ dimana faktor panjang efektif (k) = 0,5 (SNI 2847:2019 Gbr.R.6.2.5b)

$\frac{0{,}5.1465}{72{,}46} = 10{,}075 \leq 40 \rightarrow$ Syarat terpenuhi sebagai kolom pendek

2. Tinjauan Beban Sentris

P_0 = $0{,}85.f'_c.(A_g - A_{st}) + A_{st}.f_y$

= $[0{,}85.25.(90000 - 1061{,}858) + 1061{,}858.\ 473{,}744].10^{-3}$

= 2392,985 kN

$\phi.P_0$ = 0,65.2392,985

= 1555,440 kN

Kapasitas aksial maksimum :

$P_{n\ max}$ = $0{,}80.P_0$

= 0,80.2392,985

= 1914,388 kN

3. Tinjauan Kondisi Tekan Menentukan ($c > c_b$)

Lebar efektif (d) :

d = $h - d_s$

= 300 – 25

= 275 mm

Jarak antara garis netral dan tepi serat beton tekan pada kondisi regangan seimbang (c_b) :

$$c_b = \frac{600.d}{600 + f_y} = \frac{600.275}{600 + 473{,}744} = 153{,}668 \text{ mm}$$

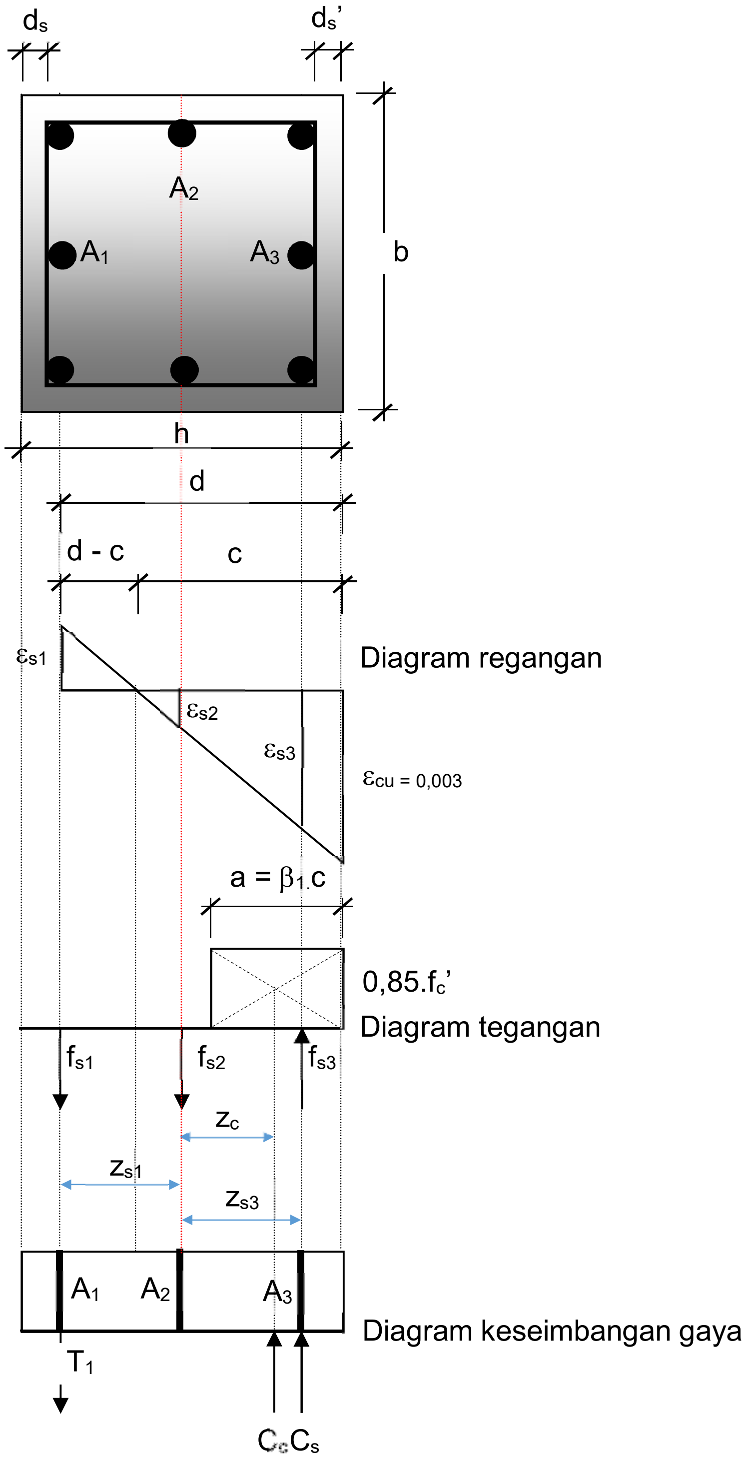
c = 200 mm

Tinggi blok tegangan beton tekan ekivalen (a) :

a = $\beta_1.c$

= 0,85.200

= 170 mm



Gambar L1. Diagram regangan, tegangan dan keseimbangan gaya kondisi tekan menentukan

Regangan dan tegangan pada setiap baris baja tulangan :

$$\varepsilon_{s1} = \frac{d - c}{c}.\varepsilon_c$$

$$= \frac{275 - 200}{200}.0{,}003$$

$$= 0{,}00113 < \varepsilon_y \rightarrow \text{OK}$$

$$\varepsilon_{s2} = \frac{[c - (d - c)] - (d - c)}{c}.\varepsilon_c$$

$$= \frac{[200 - (275 - 200)] - (275 - 200)}{200}.0{,}003$$

$$= 0{,}00075 < \varepsilon_y \rightarrow \text{OK}$$

$$\varepsilon_{s3} = \frac{c - d_s'}{c}.\varepsilon_c$$

$$= \frac{200 - 25}{200}.0{,}003$$

$$= 0{,}00263 > \varepsilon_y \rightarrow \text{OK}$$

$f_{s1} = \varepsilon_{s1}.E_s.10^{-3} = 0{,}225$ kN/mm^2

$f_{s2} = \varepsilon_{s2}.E_s.10^{-3} = 0{,}150$ kN/mm^2

$f_{s3} = f_y.10^{-3} = 0{,}474$ kN/mm^2

Gaya-gaya internal yang bekerja :

$-T_s$	=	$A_{s1}.f_{s1}$	=	398,197.0,225	=	-89,594 kN
C_{s2}	=	$A_{s2}.f_{s2}$	=	265,465.0,150	=	39,820 kN
C_c	=	$0{,}85.f'_c.a.b$	=	0,85.25.170.300	=	1083,750 kN
C_{s3}	=	$A_{s3}.f_{s3}$	=	398,197.0,474	=	188,643 kN
P_n	=	$-T_s + C_{s2} + C_c + C_{s3}$			=	1222,619 kN

Lengan momen akibat gaya-gaya internal :

$-z_{s1}$ = $(h/2) - d_s$ = $(0,300/2) - 0,025$ = $-0,125$ m

z_{s2} = $(h/2) - (h/2)$ = $(0,300/2) - (0,30/2)$ = $0,000$ m

z_c = $(h/2) - (a/2)$ = $(0,300 - 0,170)/2$ = $0,065$ m

z_{s3} = $(h/2) - d_s'$ = $(0,300/2) - 0,025$ = $0,125$ m

Momen akibat gaya-gaya internal :

M_{Ts} = $-T_s.z_{s1}$ = $-89,594.-0,125$ = 11,199 kN.m

M_{Cs2} = $C_{s2}.z_{s2}$ = $39,820.0$ = 0,000 kN.m

M_{Cc} = $C_c.z_c$ = $1083,750.0,065$ = 70,440 kN.m

M_{Cs3} = $C_s.z_{s3}$ = $188,643.0,125$ = 23,580 kN.m

M_n = $M_{Ts} + M_{Cs2} + M_{Cc} + M_{Cs3}$ = 105,223 kN.m

Eksentrisitas dalam kondisi tekan menentukan (e) :

$$e = \frac{M_n}{P_n} = \frac{105,223}{1222,619} = 0,0861 \text{ m} = 86 \text{ mm}$$

Gaya aksial dan momen nominal untuk kondisi kuat nominal (P_n dan M_n) :

P_n = 1222,619 kN

M_n = 105,223 kN.m

Gaya aksial dan momen nominal untuk kondisi kuat rencana ($\phi.P_n$ dan $\phi.M_n$) :

$\phi.P_n$ = 0,65.1222,619 = 794,702 kN

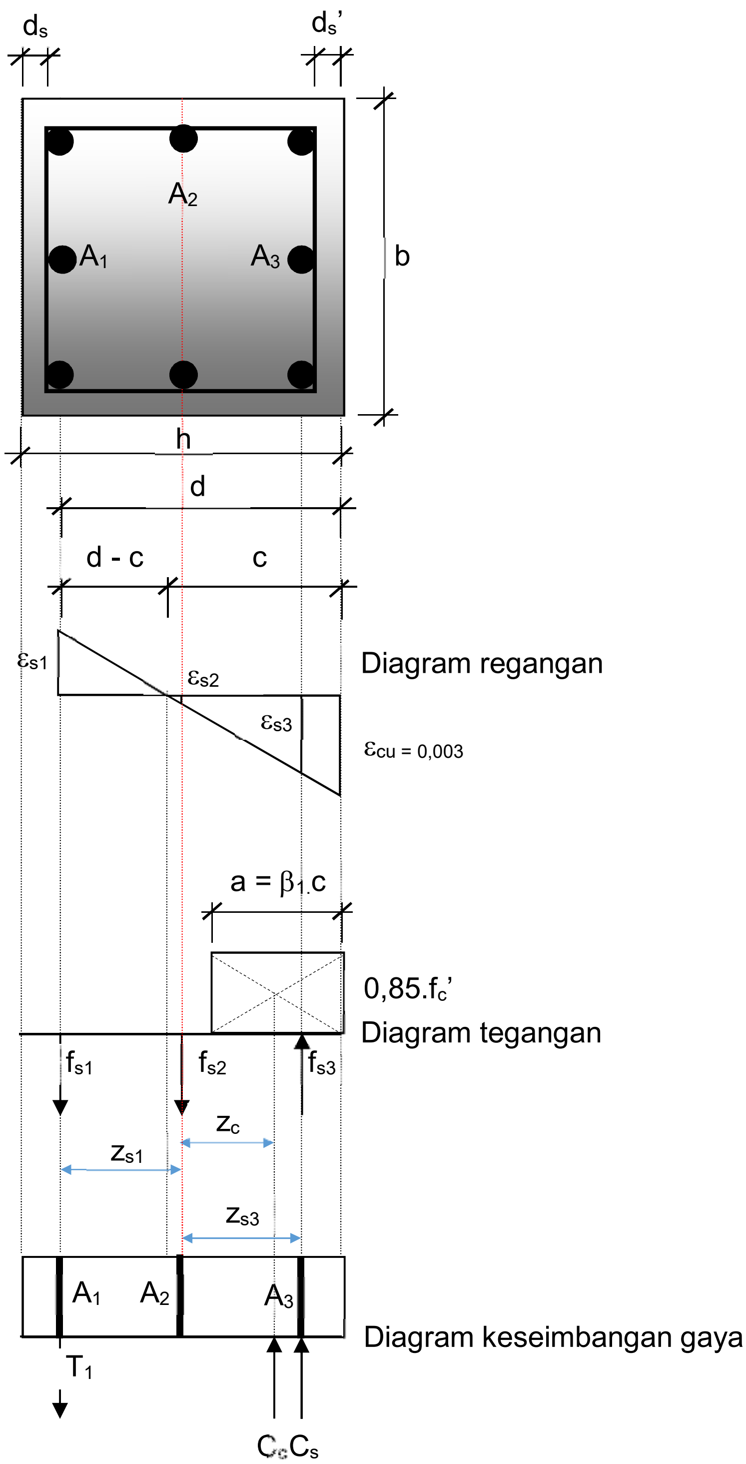
$\phi.M_n$ = 0,65.105,223 = 68,395 kN.m

4. Tinjauan Kondisi Seimbang ($c = c_b$)

d = 275 mm

$$c_b = \frac{600.d}{600 + f_y} = \frac{600.275}{600 + 474} = 154 \text{ mm}$$

c = c_b



Gambar L2. Diagram regangan, tegangan dan keseimbangan gaya kondisi seimbang

$a_b = \beta_1.c_b$

$= 131$ mm

Regangan dan tegangan pada setiap baris baja tulangan :

$\varepsilon_{s1} = \frac{d-c}{c}.\varepsilon_c'$

$= \frac{275-154}{154}.0{,}003$

$= 0{,}00237 \;=\; \varepsilon_y \rightarrow$ OK

$\varepsilon_{s2} = \frac{(0{,}5.h)-d_s-(d-c)}{c}.\varepsilon_c'$

$= \frac{(0{,}5.300)-25-(275-154)}{154}.0{,}003$

$= 0{,}00007 \;<\; \varepsilon_y \rightarrow$ OK

$\varepsilon_{s3} = \frac{c-d_s'}{c}.\varepsilon_c'$

$= \frac{154-25}{154}.0{,}003$

$= 0{,}00251 \;>\; \varepsilon_y \rightarrow$ OK

$f_{s1} = \varepsilon_{s1}.E_s.10^{-3} = 0{,}474$ kN/mm^2

$f_{s2} = \varepsilon_{s2}.E_s.10^{-3} = 0{,}014$ kN/mm^2

$f_{s3} = f_y.10^{-3} = 0{,}474$ kN/mm^2

Gaya-gaya internal yang bekerja :

$-T_s$	=	$A_{s1}.f_{s1}$	=	398,197.0,474	=	-188,643 kN
C_{s2}	=	$A_{s2}.f_{s2}$	=	265,465.0,014	=	3,802 kN
C_c	=	$0{,}85.f'_c.a.b$	=	0,85.25.131.300	=	832,688 kN
C_{s3}	=	$A_{s3}.f_{s3}$	=	398,197.0,474	=	188,643 kN
P_{nb}	=	$-T_s + C_{s2} + C_c + C_{s3}$			=	836,490 kN

Lengan momen akibat gaya-gaya internal :

$-z_{s1}$ = $(h/2) - d_s$ = $(0{,}300/2) - 0{,}025$ = $-0{,}125$ m

z_{s2} = $(h/2) - (h/2)$ = $(0{,}300/2) - (0{,}3/2)$ = $0{,}000$ m

z_c = $(h/2) - (a/2)$ = $(0{,}300 - 0{,}170)/2$ = $0{,}085$ m

z_{s3} = $(h/2) - d_s'$ = $(0{,}300/2) - 0{,}025$ = $0{,}125$ m

Momen akibat gaya-gaya internal :

M_{Ts} = $-T_s.z_{s1}$ = $-188{,}643.-0{,}125$ = 23,580 kN.m

M_{Cs2} = $C_{s2}.z_{s2}$ = $3{,}802.0$ = 0,000 kN.m

M_{Cc} = $C_c.z_c$ = $832{,}688.0{,}085$ = 70,521 kN.m

M_{Cs3} = $C_s.z_{s3}$ = $188{,}643.0{,}125$ = 23,580 kN.m

M_{nb} = $M_{Ts} + M_{Cs2} + M_{Cc} + M_{Cs3}$ = 117,682 kN.m

Eksentrisitas dalam kondisi seimbang menentukan (e_b) :

$$e_b = \frac{M_{nb}}{P_{nb}} = \frac{117{,}682}{836{,}490} = 0{,}141 \text{ m} = 141 \text{ mm}$$

Gaya aksial dan momen nominal untuk kondisi kuat nominal (P_n dan M_n) :

P_{nb} = 836,490 kN

M_{nb} = 117,682 kN.m

Gaya aksial dan momen nominal untuk kondisi kuat rencana ($\phi.P_n$ dan $\phi.M_n$) :

$\phi.P_n$ = 0,65.836,490 = 543,718 kN

$\phi.M_n$ = 0,65.117,682 = 76,493 kN.m

5. Tinjauan Kondisi Tarik Menentukan ($c < c_b$)

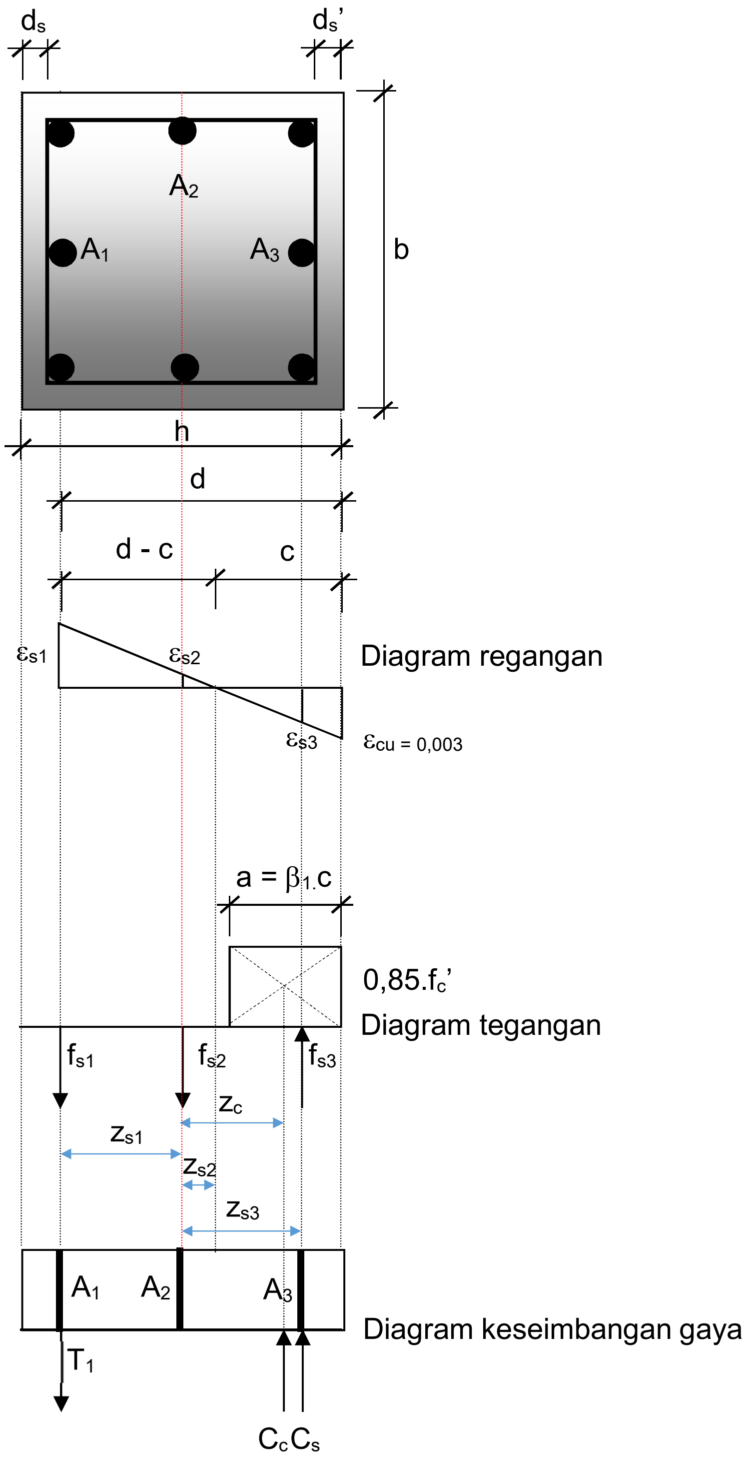
d = 275 mm

$$c_b = \frac{600.d}{600 + f_y} = \frac{600.275}{600 + 473{,}744} = 154 \text{ mm}$$

c = 100 mm

$$a = \beta_1.c$$

$$= 85 \text{ mm}$$



Gambar L3. Diagram regangan, tegangan dan keseimbangan gaya kondisi tarik

Regangan dan tegangan pada setiap baris baja tulangan :

$\varepsilon_{s1} \quad = \quad \dfrac{d - c}{c}.\varepsilon_c'$

$\quad = \quad \dfrac{275 - 100}{100}.0{,}003$

$\quad = \quad 0{,}00525 \quad > \quad \varepsilon_y \rightarrow \quad \text{OK}$

$\varepsilon_{s2} \quad = \quad \dfrac{(d - c) - (0{,}5.h - d_s)}{c}.\varepsilon_c'$

$\quad = \quad \dfrac{(275 - 100) - (0{,}5.300 - 25)}{100}.0{,}003$

$\quad = \quad 0{,}00150 \quad < \quad \varepsilon_y \rightarrow \quad \text{OK}$

$\varepsilon_{s3} \quad = \quad \dfrac{c - d_s'}{c}.\varepsilon_c'$

$\quad = \quad \dfrac{100 - 25}{100}.0{,}003$

$\quad = \quad 0{,}00300 \quad > \quad \varepsilon_y \rightarrow \quad \text{OK}$

f_{s1}	=	$f_y.10^{-3}$	=	0,474 kN/mm^2
f_{s2}	=	$\varepsilon_{s2}.E_s.10^{-3}$	=	0,300 kN/mm^2
f_{s3}	=	$f_y.10^{-3}$	=	0,474 kN/mm^2

Gaya-gaya internal yang bekerja :

$-T_s$	=	$A_{s1}.f_{s1}$	=	398,197.0,474	=	-188,643 kN
C_{s2}	=	$A_{s2}.f_{s2}$	=	265,465.0,300	=	79,639 kN
C_c	=	$0{,}85.f'_c.a.b$	=	0,85.25.100.300	=	541,875 kN
C_{s3}	=	$A_{s3}.f_{s3}$	=	398,197.0,474	=	188,643 kN
P_n	=	$-T_s + C_{s2} + C_c + C_{s3}$			=	621,514 kN

Lengan momen akibat gaya-gaya internal :

$-z_{s1}$	=	$(h/2) - d_s$	=	(0,300/2) – 0,025	=	-0,125 m
z_{s2}	=	$(h/2) - (h/2)$	=	(0,300/2) – (0,30/2)	=	0,000 m

z_c = (h/2) – (a/2) = (0,300 – 0,100)/2 = 0,108 m

z_{s3} = (h/2) – d_s' = (0,300/2) – 0,025 = 0,125 m

Momen akibat gaya-gaya internal :

M_{Ts}	= $-T_s.z_{s1}$	=	-188,643.-0,125	=	23,580 kN.m
M_{Cs2}	= $C_{s2}.z_{s2}$	=	79,639.0	=	0,000 kN.m
M_{Cc}	= $C_c.z_c$	=	541,875.0,108	=	58,252 kN.m
M_{Cs3}	= $C_s.z_{s3}$	=	188,643.0,125	=	23,580 kN.m
M_n	= $M_{Ts} + M_{Cs2} + M_{Cc} + M_{Cs3}$			=	105,412 kN.m

Eksentrisitas dalam kondisi seimbang menentukan (e) :

$$e = \frac{M_n}{P_n} = \frac{105,412}{621,514} = 0,170 \text{ m} = 170 \text{ mm}$$

Gaya aksial dan momen nominal untuk kondisi kuat nominal (P_n dan M_n) :

P_n = 621,514 kN

M_n = 105,412 kN.m

Gaya aksial dan momen nominal untuk kondisi kuat rencana ($\phi.P_n$ dan $\phi.M_n$) :

$\phi.P_n$ = 0,65.621,514 = 403,394 kN

$\phi.M_n$ = 0,65.105,412 = 68,518 kN.m

Batas struktur boleh dianggap hanya menahan momen lentur pada kondisi :

$P_{u\phi}$ = 0,10.f'$_c$.b.h

= $(0,10.25.300.300).10^{-3}$

= 225,000 kN

$P_{u\phi}$ = $\phi.P_{nb}$

= 0,65.836,490

= 543,718 kN

Digunakan nilai terkecil.

6. Tinjauan keadaan P = 0

Dalam kondisi ini perhitungan dilakukan seperti pada balok, dimana hal ini disebabkan oleh luas tulangan tekan (A_3) yang terpasang sama dengan luas tulangan tarik (A_1), sehingga tulangan tekan pasti belum leleh.

Menentukan nilai a, a_{min} dan a_{maks} :

$$a = \frac{(A_s - A').f_y}{0,85.f'_c.b} = \frac{(1061,858 - 398,197).474}{0,85.25.300} = 49,319 \text{ mm}$$

$$a_{min} = \frac{600.\beta_1.d_s'}{600 - f_y} = \frac{600.0,85.25}{600 - 474} = 100,985 \text{ mm}$$

$$a_{max} = \frac{600.\beta_1.d_d}{600 + f_y} = \frac{600.0,85.275}{600 + 474} = 130,618 \text{ mm}$$

Syarat :

$a_{min} < a < a_{maks}$

$100,985 > 49,319 < 130,618$

Syarat di atas tidak terpenuhi, nilai $a < a_{min}$, sehingga tulangan tekan belum leleh dan nilai a baru harus dihitung ulang, sebagai berikut :

$$p = \frac{600.A_3 - A_1.f_y}{1,7.f'_c.b} = \frac{600.398,197 - 398,197.474}{1,7.25.300} = 3,943$$

$$q = \frac{600.\beta_1.d_s'.A_3}{0,85.f'_c.b} = \frac{600.0,85.25.398,197}{0,85.25.300} = 796,394$$

Nilai a baru :

$$a = \sqrt{p^2 + q} - p = \sqrt{3,943^2 + 796,394} - 3,943 = 24,551 \text{ mm}$$

$$f'_s = \frac{a - \beta_1.d_s'}{a}.600 = \frac{24,551 - 0,85.25}{24,551}.600 = 80,683 \text{ MPa}$$

$M_{nc} = 0,85.f'_c.a.b.(d – 0,5.a)$

$= [0,85.25.24,551.300 – (275 – 0,5.24,551)].10^{-6}$

$= 41,120$ kN.m

M_{ns} = $A_1.f_s'.(d - d_s')$

= $[398,197.80,683.(275 - 25)].10^{-6}$

= 8,032 kN.m

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

= 41,120 + 8,032

= 49,152 kN.m

M_r = $\phi.M_n$

ϕ = 0,65 $\rightarrow$ M_r = 0,65.49,152

= 31,949 kN.m

ϕ = 0,80 $\rightarrow$ M_r = 0,80.49,152

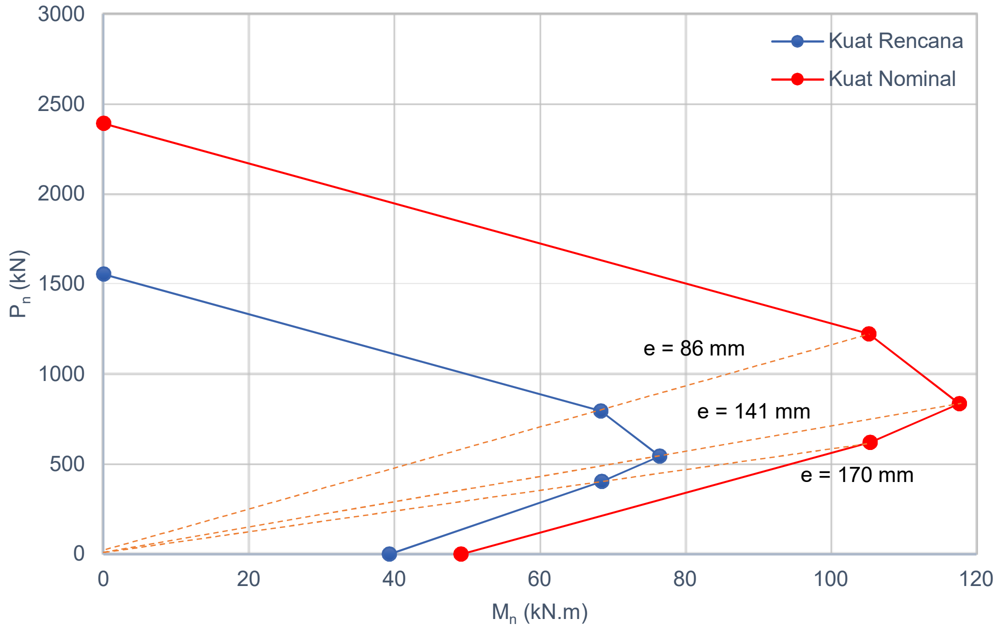
= 39,322 kN.m

Selanjutnya nilai kuat rencana dan nilai kuat nominal dari hasil perhitungan di atas disajikan dalam Tabel L1 di bawah ini.

Tabel L1. Kuat rencana dan kuat nominal kolom

Kondisi	Kuat Rencana		Kuat Nominal	
	$\phi.M_n$ (kN.m)	$\phi.P_n$ (kN)	M_n (kN.m)	P_n (kN)
Aksial sentris	0	1555,440	0	2392,985
Tekan	68,395	794,702	105,223	1222,619
Seimbang	76,493	543,718	117,682	836,490
Tarik	68,518	403,394	105,412	621,514
Lentur murni	39,322	0	49,152	0

Selain itu, nilai-nilai dalam tabel di atas, dapat dibuat dalam bentuk diagram interaksi seperti disajikan pada Gambar L4 di bawah ini.

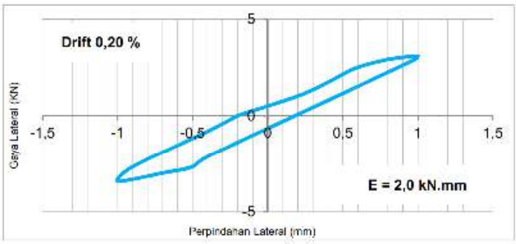


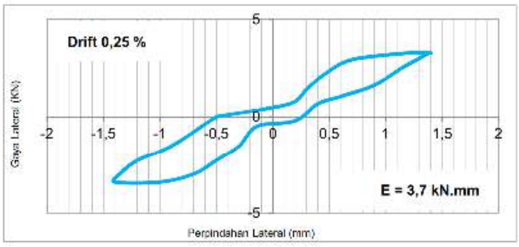
Gambar L4. Diagram interaksi penampang kolom

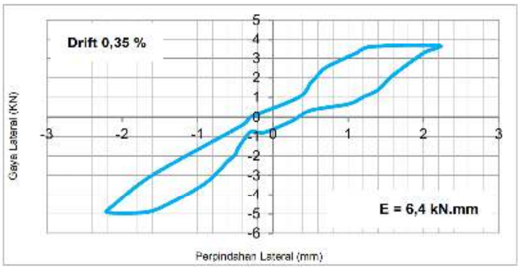
LAMPIRAN 2 (Pembebanan Siklik)

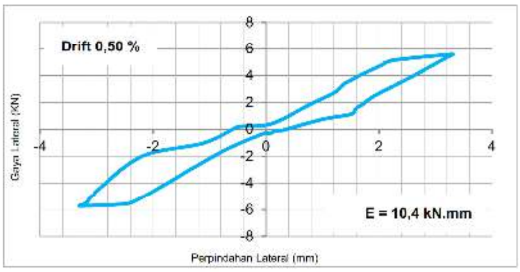
No	Ratio Simpangan (Δ/h)	Tinggi Benda Uji h (mm)	Besar Simpangan Δ (mm)	Simpangan Rata-rata Δ (mm)	Beban				Ket
					Dorong (kN)	Titik Seimbang	Tarik (kN)	Titik Seimbang	
1	0,20%	1460	2,92	1,46					
1	0,20%	1460	2,92	1,46					
1	0,20%	1460	2,92	1,46					
2	0,25%	1460	3,65	1,83					
2	0,25%	1460	3,65	1,83					
2	0,25%	1460	3,65	1,83					
3	0,35%	1460	5,11	2,56					
3	0,35%	1460	5,11	2,56					
3	0,35%	1460	5,11	2,56					
4	0,50%	1460	7,30	3,65					
4	0,50%	1460	7,30	3,65					
4	0,50%	1460	7,30	3,65					
5	0,75%	1460	10,95	5,48					
5	0,75%	1460	10,95	5,48					
5	0,75%	1460	10,95	5,48					
6	1,00%	1460	14,60	7,30					
6	1,00%	1460	14,60	7,30					
6	1,00%	1460	14,60	7,30					
7	1,40%	1460	20,44	10,22					
7	1,40%	1460	20,44	10,22					
7	1,40%	1460	20,44	10,22					
8	1,75%	1460	25,55	12,78					
8	1,75%	1460	25,55	12,78					
8	1,75%	1460	25,55	12,78					
9	2,20%	1460	32,12	16,06					
9	2,20%	1460	32,12	16,06					
9	2,20%	1460	32,12	16,06					
10	2,75%	1460	40,15	20,08					
10	2,75%	1460	40,15	20,08					
10	2,75%	1460	40,15	20,08					
11	3,50%	1460	51,10	25,55					
11	3,50%	1460	51,10	25,55					
11	3,50%	1460	51,10	25,55					
12	4,48%	1460	65,41	32,70					
12	4,48%	1460	65,41	32,70					
12	4,48%	1460	65,41	32,70					
13	5,73%	1460	83,72	41,86					
13	5,73%	1460	83,72	41,86					
13	5,73%	1460	83,72	41,86					

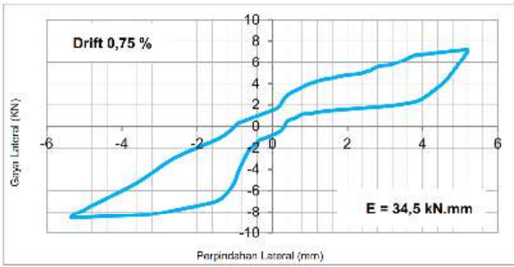
LAMPIRAN 3 (Kurva Disipasi Energi Spesimen Kolom Kontrol)

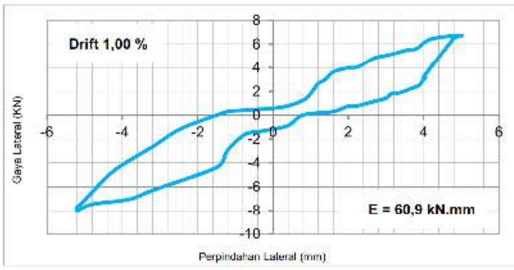


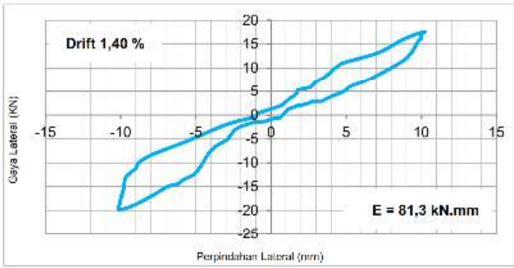


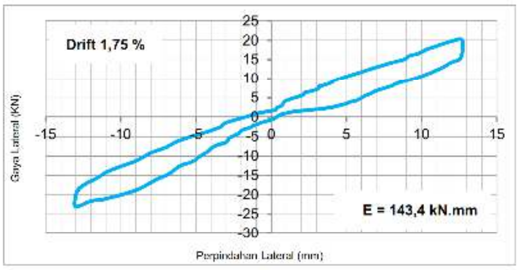


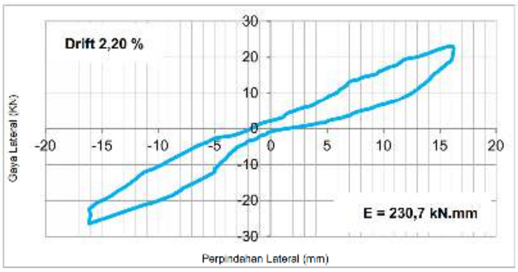


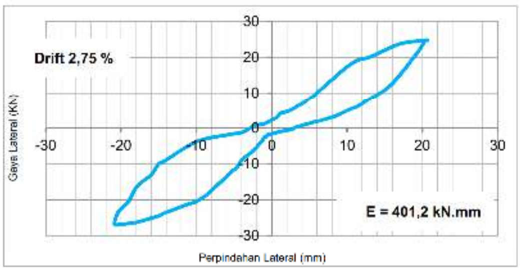


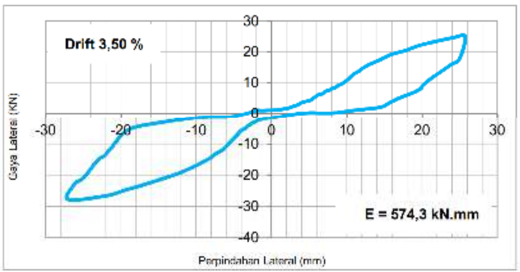




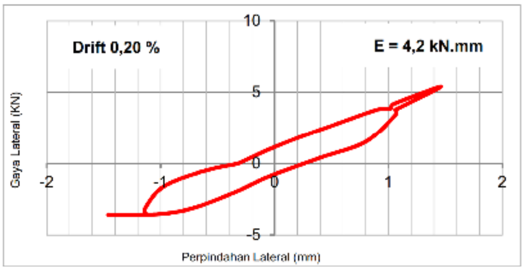


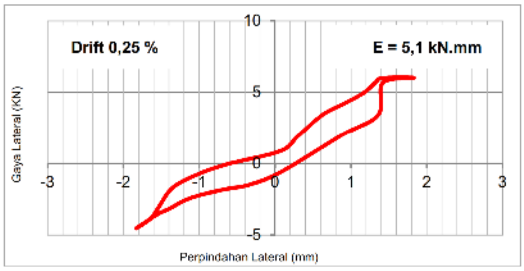


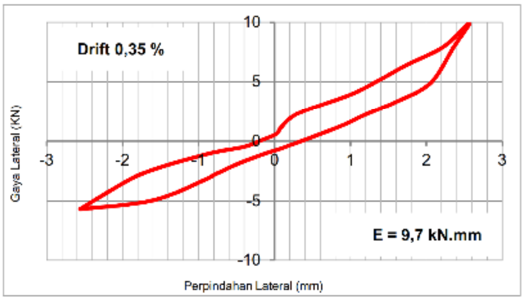


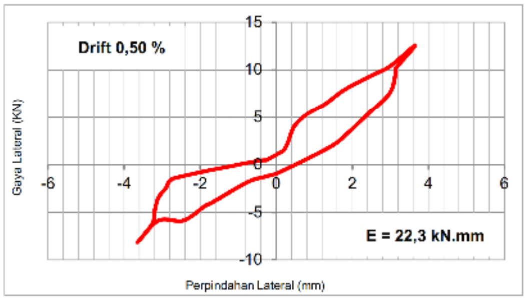


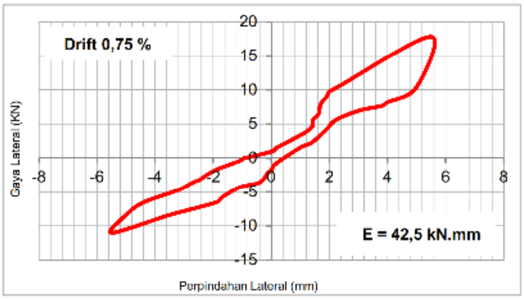
LAMPIRAN 4 (Kurva Disipasi Energi Spesimen Kolom Retrofit 01)

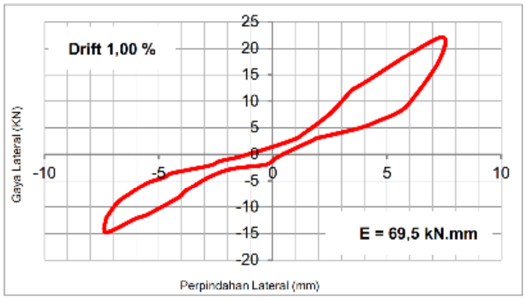


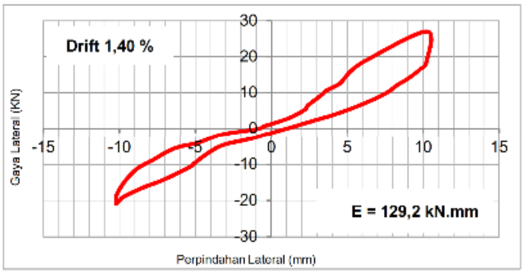


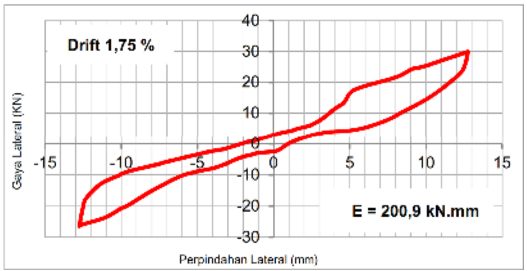


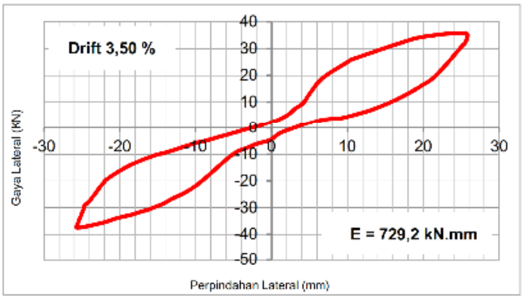


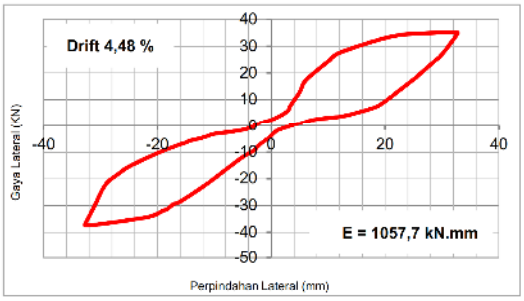


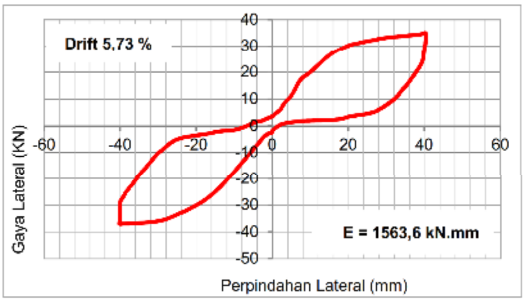




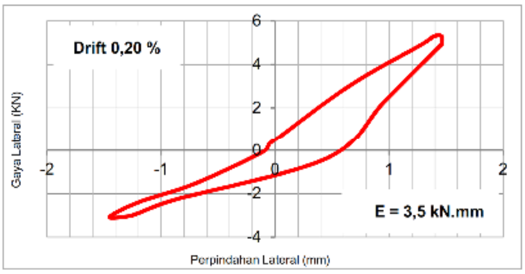


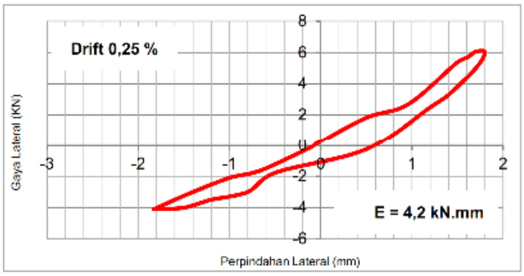

Drift 3,50 %
E = 729,2 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)

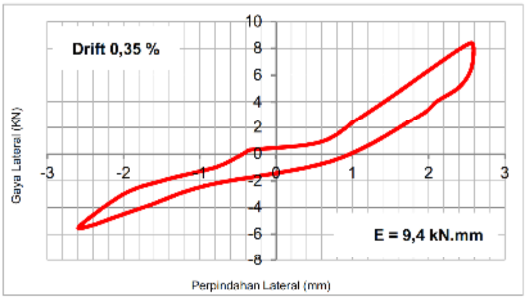

Drift 4,48 %
E = 1057,7 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)

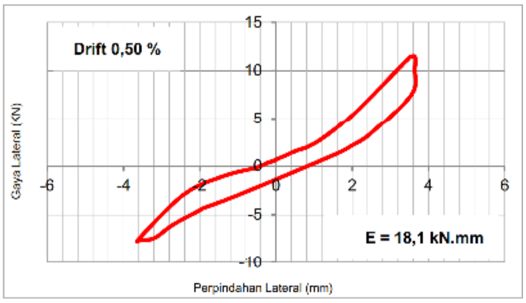

Drift 5,73 %
E = 1563,6 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)

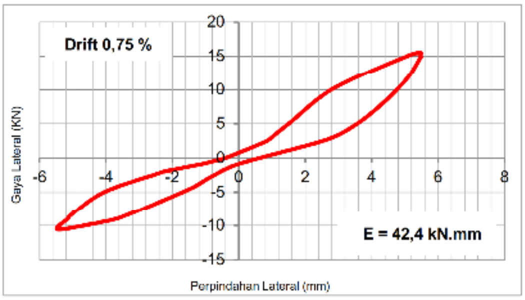
LAMPIRAN 5 (Kurva Disipasi Energi Spesimen Kolom Retrofit 02)

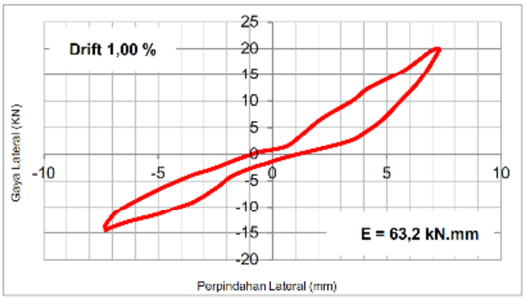


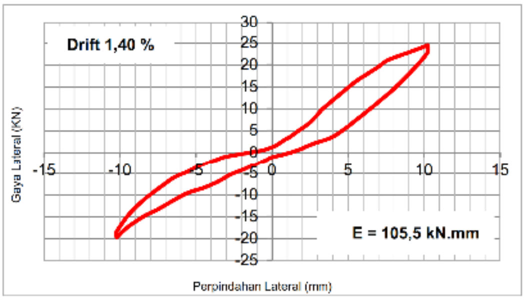


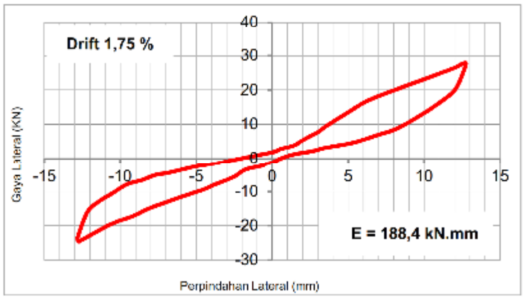


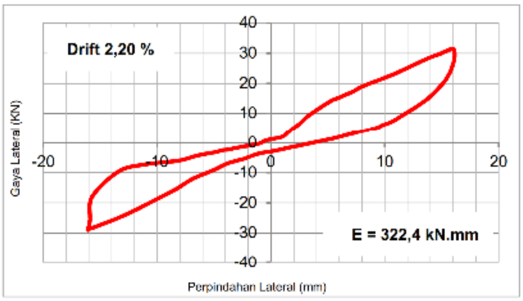


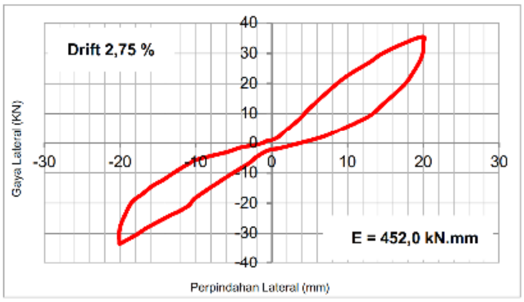


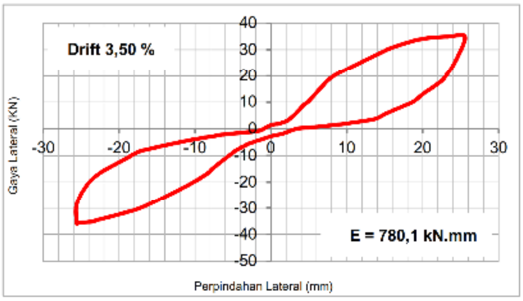


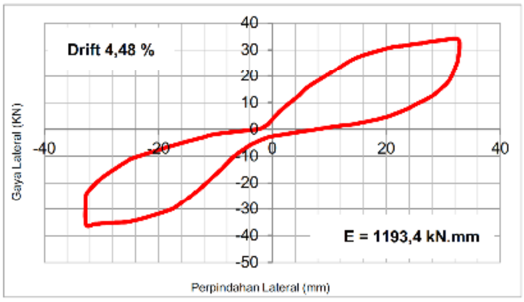


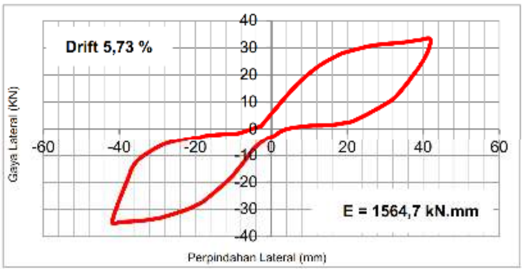



Drift 2,20 %
E = 322,4 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)


Drift 2,75 %
E = 452,0 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)


Drift 3,50 %
E = 780,1 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)


Drift 4,48 %
E = 1193,4 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)


Drift 5,73 %
E = 1564,7 kN.mm
Gaya Lateral (KN)
Perpindahan Lateral (mm)

LAMPIRAN 6 (Foto Dokumentasi Penelitian)

Perakitan Tulangan

Perakitan Bekesting

Pemasangan *Strain Gauge*

	
Persiapan Pengecoran	Persiapan Pengecoran
	
Mobilisasi Adukan Beton	Uji Slump

<table>
<tr><td></td><td></td></tr>
<tr><td>Pengecoran Spesimen</td><td>Pemadatan Adukan Beton</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Pengecoran foot plate spesimen</td></tr>
</table>

Pengecoran kolom

	
Perawatan Spesimen	Perawatan Spesimen
	
Perawatan spesimen	Pemasangan tulangan *wire mesh*

Pemasangan bekesting retrofit

Pengecoran retrofit

Setting up pengujian

Pengujian spesimen