Lampiran 4 Verifikasi

1. Menentukan Kelas Situs Tanah

Kedalaman (m)	Tebal (m)	NSPT	Ň = tebal/NSPT
0	0	0	0.00
2	2	27	0.07
4	2	25	0.08
6	2	27	0.07
8	2	43	0.05
10	2	32	0.06
12	2	40	0.05
14	2	12	0.17
16	2	22	0.09
18	2	60	0.03
20	2	60	0.03
22	2	60	0.03
24	2	60	0.03
26	2	57	0.03

$\Sigma\check{N}$ = 0,00 + 0,07 + 0,08 + 0,07 + 0,05 + 0,06 + 0,05 + 0,17 + 0,09 + 0,03 + 0,03 + 0,03 + 0,03 + 0,04

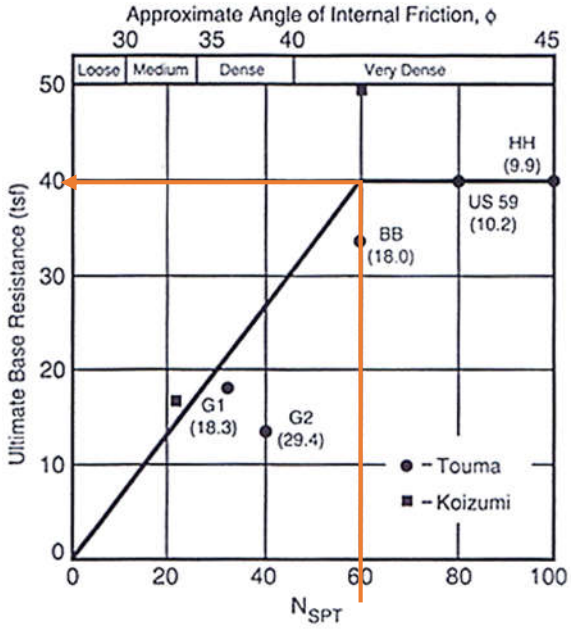
= 0,81

$\bar{N} = \frac{30}{\sum \check{N}}$ = 30/0,81 = 36,89

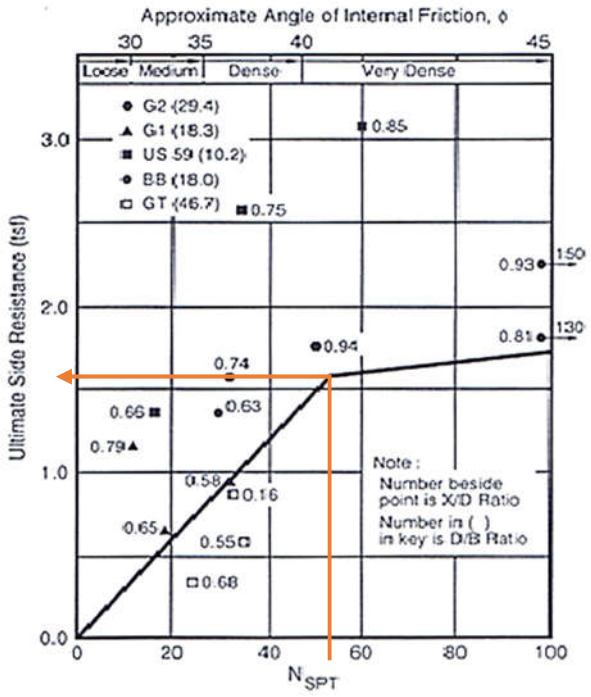
Karena 15 < $\bar{N}$ = 36,89 < 50 maka termasuk tanah sedang

2. Mencari Daya Dukung Fondasi

Pondasi di pasang sampai kedalaman 20m



qp = (NSPT rata-rata/60) x 40 (dari grafik)



fs = (NSPT rata-rata/53) x 1,6 (dari grafik)

Kedalaman	Tebal	NSPT	NSPT rata-rata	qp		fs	
m	m			t/sf	t/m^2	t/sf	t/m^2
0	0	0	0	0	0	0	0
2	2	27	13.5	9	96.88	0.41	4.39
4	2	25	26	17.33	186.57	0.78	8.45
6	2	27	26	17.33	186.57	0.78	8.45
8	2	43	35	23.33	251.16	1.06	11.37
10	2	32	37.5	25	269.10	1.13	12.19
12	2	40	36	24	258.33	1.09	11.70
14	2	12	26	17.33	186.57	0.78	8.45
16	2	22	17	11.33	121.99	0.51	5.52
18	2	18	20	13.33	143.52	0.60	6.50
20	2	60	39	26	279.86	1.18	12.67

Diameter dipakai antara 0,4 m, 0,8 m, 1 m dan 1,2 m

Luas penampang tiang (A) $= \frac{1}{4}.\pi.D^2$

Keliling tiang (K) $= \pi.D$

Notasi	Diameter Tiang (m)			
	0.4	0.8	1	1.2
A (m^2)	0.13	0.50	0.79	1.13
K (m)	1.26	2.51	3.14	3.77

Luas selimut tiang per segmen = Keliling tiang x Tebal

Kedalaman (m)	Tebal (m)	Keliling Tiang			
		1,26	2,51	3,14	3,77
0	0	2,51	5,03	6,28	7,54
2	2	2,51	5,03	6,28	7,54
4	2	2,51	5,03	6,28	7,54
6	2	2,51	5,03	6,28	7,54
8	2	2,51	5,03	6,28	7,54
10	2	2,51	5,03	6,28	7,54
12	2	2,51	5,03	6,28	7,54
14	2	2,51	5,03	6,28	7,54
16	2	2,51	5,03	6,28	7,54
18	2	2,51	5,03	6,28	7,54
20	2	2,51	5,03	6,28	7,54

fs tiang per segmen = fs x Luas selimut tiang per segmen

Kedalaman	Tebal	fs	Diameter Tiang				Diameter Tiang			
			0,4	0,8	1	1,2	0,4	0,8	1	1,2
m	m	t/m²	Luas Selimut Tiang per Segmen				fs Tiang per Segmen			
0	0	0	0	0	0	0	0	0	0	0
2	2	4.39	2,51	2,51	5,03	6,28	11,03	22,05	27,56	33,08
4	2	8.45	2,51	2,51	5,03	6,28	21,23	42,47	53,08	63,70
6	2	8.45	2,51	2,51	5,03	6,28	21,23	42,47	53,08	63,70
8	2	11.37	2,51	2,51	5,03	6,28	28,58	57,17	71,46	85,75
10	2	12.19	2,51	2,51	5,03	6,28	30,63	61,25	76,56	91,88
12	2	11.70	2,51	2,51	5,03	6,28	29,40	58,80	73,50	88,20
14	2	8.45	2,51	2,51	5,03	6,28	21,23	42,47	53,08	63,70
16	2	5.52	2,51	2,51	5,03	6,28	13,88	27,77	34,71	41,65
18	2	6.50	2,51	2,51	5,03	6,28	16,33	32,67	40,83	49,00
20	2	12.67	2,51	2,51	5,03	6,28	31,85	63,70	79,63	95,55

Qst = $\sum fs$

Qp = qp di ujung pondasi.Luas penampang tiang

Qu = Qst + Qp

Qall = $\frac{Qu}{SF}$

Notasi	Diameter Tiang			
	0,4	0,8	1	0,4
Qst (ton)	225,40	450,81	563,51	676,21
Qp (ton)	35,17	140,67	219,80	316,52
Qu (ton)	260,57	591,48	783,31	992,73
SF	3	3	3	3
Qall (ton)	86,86	197,16	261,10	330,91

3. Mencari Jumlah Tiang

Dari data ETABS di dapat nilai :

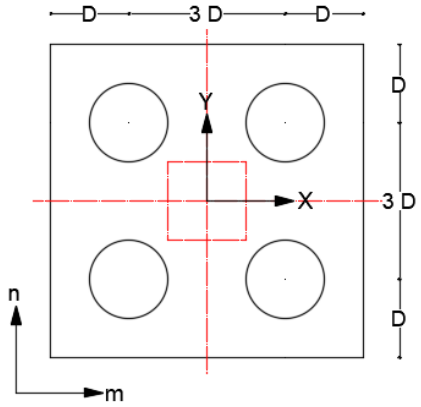
Pd = 255.71 ton

Pl = 0 ton

Digunakan tiang diameter 0,4 m

Jumlah tiang = $\frac{P_d + P_l}{Pall} = \frac{189,56}{86,86} = 2,18$ buah $\approx$ 4 buah untuk OF

Jumlah tiang = $\frac{P_d + P_l}{Pall} = \frac{192,571}{86,86} = 2,22$ buah $\approx$ 4 buah untuk BrX

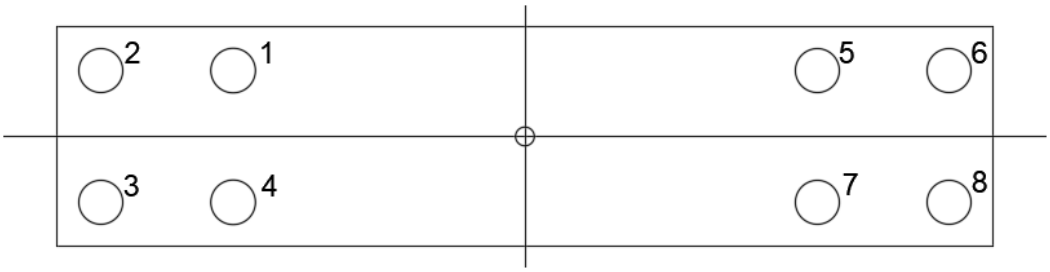


m = 2 buah

n = 2 buah

Jarak antar tiang (s) = 3d = 3 x 0,4 = 1,2 m

4. Mencari Dimensi *Pile Cap*



Panjang *pile cap* = (2x1d) + (2x3d) + 5,3 = (2x0,4) + (6x0,4) + 5,3 = 8,5 m

Lebar *pile cap* = 1d + 3d + 1d = (1 x 0,4) + (3 x 0,4) + (1 x 0,4) = 2 m

Tinggi *pile cap* = 2d = 2 x 0,4 = 0,8 m

5. Mencari Massa *Pile Cap*

Volume *pile cap* = Panjang *pile cap* x Lebar *pile cap* x Tinggi *pile cap*

= 8,5 x 2 x 0,8 = 13,6 m^3

Berat jenis = 2400 kg/m^3 (beton bertulang)

Berat *pile cap* (W) = Volume *pile cap* x Berat jenis

= 13,6 x 2400 = 32640 kg

$m_0 = \frac{W}{g} = \frac{32640}{9,81} = 3327,22 \ \frac{kg.dt^2}{m}$

6. Mencari Nilai G (modulus geser tanah)

Data tanah yang digunakan

Lapisan Tanah	Kedalaman	Deskripsi Tanah	γ_{sat}	γ_w	e	PI	OCR	Kohesi	θ
	m		kg/m^3	kg/m^3		%		kg/m^2	derajat
1	6	Pasir	1828	1800	0,4	5	1	300	33
2	12	Lanau	1957	1800	0,6	20	1	360	26
3	17	Lanau	1820	1800	0,6	21	1	220	26
4	20	Lempung	1960	1800	0,6	25	1	370	20
5	24	Pasir	1895	1800	0,4	5	1	200	40
6	26	Pasir	1895	1800	0,4	3	1	200	34

Plasticity Index (PI)	k
0	0
20	0,18
40	0,3
60	0,41
80	0,48
100	0,5

Muka air tanah berada di kedalaman -0,8 m.

$\bar{\sigma}_v = h.\gamma$

$= \frac{0,8*1800}{10^4} = 0,144 \text{ kg/cm}^2$

$\bar{\sigma}_h = k_0.\bar{\sigma}_v$

$$= (1-\sin\phi)\bar{\sigma}_v$$

$$= (1-\sin(33))*0{,}144 = 0{,}066 \text{ kg/cm}^2$$

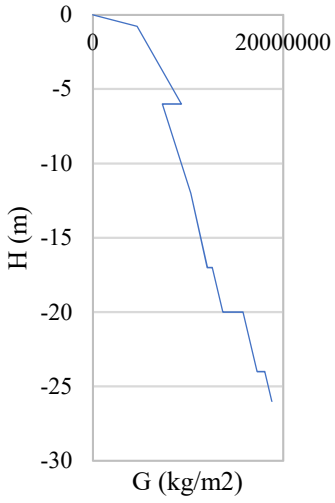
$$\bar{\sigma}_0 = \frac{\bar{\sigma}_v + 2\bar{\sigma}_h}{3}$$

$$= \frac{0{,}144 + 2*0{,}066}{3} = 0{,}092 \text{ kg/cm}^2$$

$$G = 326.OCR^k \frac{(2{,}973-e)^2}{(1+e)} \bar{\sigma}_0^{0{,}5}$$

$$= 326.1^{0{,}086} \frac{(2{,}973-0{,}4)^2}{(1+0{,}4)} 0{,}092^{0{,}5} = 465{,}774 \text{ kg/cm}^2 = 4657739{,}27 \text{ kg/m}^2$$

El.	e	PI	OCR	ϕ	K_0	γ_{sat} (kg/m3)	γ_w (kg/m3)	σv	σh	$\bar{\sigma}_0$	k	G (kg/cm2)	G (kg/m2)	G x h
0	0.4	5	1	33	0.455361	1828	1800	0	0	0	0.08602381	0	0	0
-0.8	0.4	5	1	33	0.455361	1828	1800	0.144	0.065572	0.091715	0.08602381	465.7739268	4657739.268	3726191.41
-0.8	0.4	5	1	33	0.455361	1828	1800	0.144	0.065572	0.091715	0.08602381	465.7739268	4657739.268	0
-6	0.4	5	1	33	0.455361	1828	1800	0.57456	0.261632	0.365941	0.08602381	930.3826901	9303826.901	48379899.9
-6	0.6	20	1	26	0.561629	1957	1800	0.57456	0.322689	0.406646	0.1612381	729.7981036	7297981.036	0
-12	0.6	20	1	26	0.561629	1957	1800	1.14876	0.645177	0.813038	0.1612381	1031.928695	10319286.95	61915721.7
-12	0.6	21	1	26	0.561629	1820	1800	1.14876	0.645177	0.813038	0.16625238	1031.928695	10319286.95	0
-17	0.6	21	1	26	0.561629	1820	1800	1.55876	0.875445	1.103216	0.16625238	1202.055896	12020558.96	60102794.8
-17	0.6	25	1	20	0.65798	1960	1800	1.55876	1.025633	1.203342	0.18630952	1255.419322	12554193.22	0
-20	0.6	25	1	20	0.65798	1960	1800	1.84676	1.215131	1.425674	0.18630952	1366.483563	13664835.63	40994506.9
-20	0.4	5	1	40	0.357212	1895	1800	1.84676	0.659686	1.055377	0.08602381	1580.009256	15800092.56	0
-24	0.4	5	1	40	0.357212	1895	1800	2.20476	0.787568	1.259965	0.08602381	1726.374697	17263746.97	69054987.9
-24	0.4	3	1	34	0.440807	1895	1800	2.20476	0.971874	1.382836	0.07599524	1808.594203	18085942.03	0
-26	0.4	3	1	34	0.440807	1895	1800	2.38376	1.050778	1.495106	0.07599524	1880.579674	18805796.74	37611593.5
													sum	321785696
													ekuivalen	12376372.9



Hasil ekuivalen didapatkan dari

G = (1/26)*321785696 = 12376372.92 kg/m^2

7. Mencari Kekakuan dan Redaman Interaksi antara Fondasi dengan Tanah

Data tiang dan *pile cap*

f'c = 30 Mpa

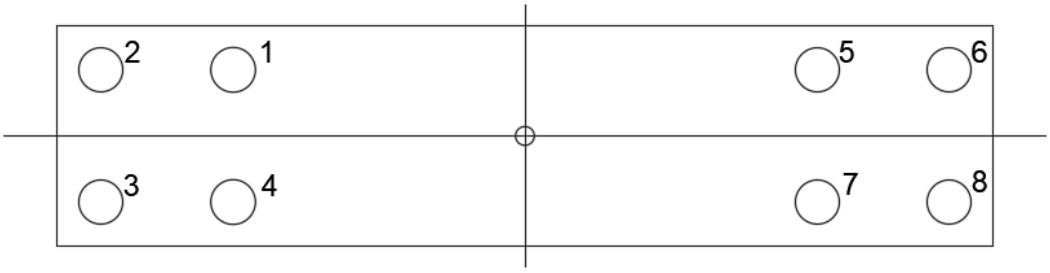
Jumlah tiang = 8 buah

Panjang tiang = 20 m

Dia. tiang = 0,4 m

m = 4 buah

n = 2 buah



Mod. elas. tiang (E_p) = $4700*\sqrt{f'c}$ = $4700*\sqrt{30}$

= 25742,9602 MPa

= 2625781941 kg/m^2

Inersia tiang (I_p) = (1/64) x π x D^2 = (1/64) x π x 0,4^2

= 0,001256637 m^4

Panjang *pile cap* = 8,5 m

Lebar *pile cap* = 2 m

Tinggi *pile cap* = 0,8 m

h *pile cap* dlm tanah = 0,7 m (asumsi 10 cm di bawah muka tanah)

G tanah = 12376372,92 kg/m^2

γ sat = 1828 kg/m^3

ν = 0,4

ro tiang = 0,2 m

ro *pile cap* = 2,326213246 m

Sh1 = 4,1

Sh2 = 10,6

Sr1 = 2,5

Sr2 = 1,8

a. Kekakuan dan Redaman Vertikal

$V_s = \sqrt{\frac{G_s g}{\gamma_{sat}}} = \sqrt{\frac{12376372,92*9,81}{1828}} = 257,7170203$ m/dt

$\frac{E_p}{G_s} = \frac{2625781941}{12376372,92} = 212.1608614$

$\frac{L}{r_0} = \frac{20}{0,2} = 100$

Didapat nilai konstanta f_{v1} dan f_{v2} dari grafik.

$f_{v1} = 0,0635$

$f_{v2} = 0,0975$

$k_v^1 = \frac{E_p A}{r_0} f_{v1} = \frac{2625781941*\left(\frac{1}{4}*\pi*0,4^2\right)}{0,2}*0,0635 = 104777789,2$ kg/m

$c_v^1 = \frac{E_p A}{V_s} f_{v2} = \frac{2625781941*\left(\frac{1}{4}*\pi*0,4^2\right)}{257,7170203}*0,0975 = 124774,3739$ kgdt/m

b. Kekakuan dan Redaman Horizontal

$V_s = \sqrt{\frac{G_s g}{\gamma_{sat}}} = \sqrt{\frac{12376372,92*9,81}{1828}} = 257,7170203$ m/dt

$\frac{E_p}{G_s} = \frac{2625781941}{12376372,92} = 212,1608614$

Didapat nilai konstanta f_{h1} dan f_{h2} dari tabel.

$f_{h1} = 0,0726$

$f_{h2} = 0,1717$

1. Tiang tunggal

$k_h^1 = \frac{E_p I_p}{r_0^3} f_{h1} = \frac{2625781941*0,001256637}{0,2^3}0,0726 = 29944368,23$ kg/m

$c_h^1 = \frac{E_p I_p}{r_0^2 V_s} f_{h2} = \frac{2625781941*0,001256637}{0,2^2*257,7170203}*0,1717 = 54958.60789$ kgdt/m

2. Kelompok tiang

$$K_R = \frac{E_p I_p}{2G(1+\upsilon)_{soil} L^4} = \frac{2625781941*0,001256637}{2*12376372,92*(1+0,4)*20^4} = 5.9511\text{E-}07 \text{ kg/m}$$

αL didapat dari grafik.

No Pile	S/(2r0)	αL
1	0	1
2,4	3	0,5
3	4,25	0,375
5	13,25	0
6	16,25	0
7	13,575	0
8	16,525	0

$$\sum \alpha L = 1*1 + 2*0,5 + 1*0,375 + 1*0 + 1*0 + 1*0 = 2,375$$

$$k_h^g = \frac{\sum k_h^1}{\sum \alpha L} = \frac{8*29944368,23}{2,375} = 100865240,4 \text{ kg/m}$$

$$c_h^g = \frac{\sum c_h^1}{\sum \alpha L} = \frac{8*58154,0098}{2,375} = 185123,7318 \text{ kgdt/m}$$

3. *Pile cap*

$$k_h^f = G_s h S_{h1} = 12376372,92*0,7*4,1 = 35520190,29 \text{ kg/m}$$

$$c_h^f = hr_0 S_{h2} \sqrt{G_s \rho_s} = 0,7*2,33*10,6\sqrt{\frac{12376372,92*9,81}{1828}} = 828903 \text{ kgdt/m}$$

4. Total

$$k_h = 100865240,4 + 35520190,29 = 136385430,7 \text{ kg/m}$$

$$c_h = 185123,7318 + 828903 = 1014026,739 \text{ kgdt/m}$$

c. Kekakuan dan Redaman Rotasi

$V_s = \sqrt{\frac{G_s g}{\gamma_{sat}}} = \sqrt{\frac{12376372,92 * 9,81}{1828}} = 257,7170203$ m/dt

$\frac{E_p}{G_s} = \frac{2625781941}{12376372,92} = 212,1608614$

Didapat nilai konstanta f_{hr1}, f_{hr2}, f_{r1} dan f_{r2} dari tabel.

f_{hr1} = -0,1365

f_{hr2} = -0,1896

f_{r1} = 0,5336

f_{r2} = 0,3377

1. Tiang tunggal

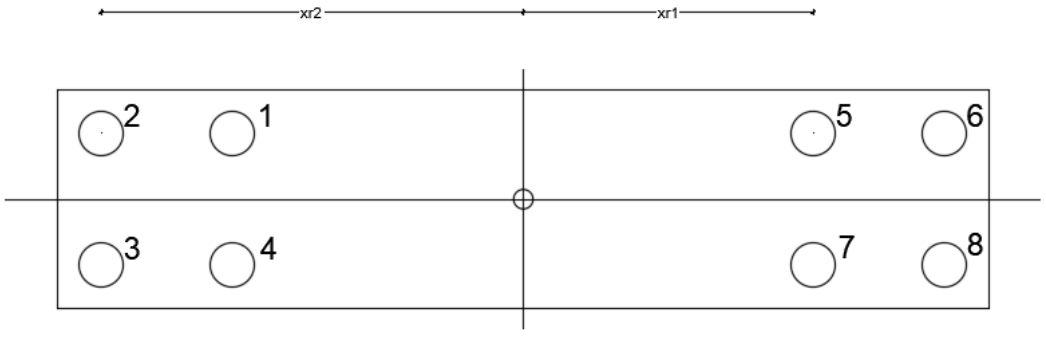
$k_{hr}^1 = \frac{E_p I_p}{r_0^2} f_{hr1} = \frac{2625781941 * 0,001256637}{0,2^2} * (-0,1365) =$ -11260072,4 kg

$c_{hr}^1 = \frac{E_p I_p}{r_0 V_s} f_{hr2} = \frac{2625781941 * 0,001256637}{0,2 * 257,7170203} (-0,1896) =$ -12137,63 kgdt

$k_r^1 = \frac{E_p I_p}{r_0} f_{r1} = \frac{2625781941 * 0,001256637}{0,2} * 0,5336 =$ 8803479,278 kgm

$c_r^1 = \frac{E_p I_p}{V_s} f_{r2} = \frac{2625781941 * 0,001256637}{257,7170203} * 0,3377 =$ 4323,709 kgmdt

2. Kelompok tiang



x_{r1} = 2,65 m

x_{r1} = 3,85 m

$$k_r^g = \sum_1^n \left[k_r^1 + k_v^1 x_r^2 + k_h^1 z_c^2 - 2 z_c k_{hr}^1 \right]$$

$$= \begin{matrix} 8*8803479 + 4*104777789,2*(2,65^2 + 3,85^2) \\ +8*29944368,23*\left(\frac{0,8}{2}\right)^2 - 8*2*0,8*(-11260072,4) \end{matrix}$$

$$= 9336304311 \text{ kgm}$$

$$c_r^g = \sum_1^n \left[c_r^1 + c_v^1 x_r^2 + c_h^1 z_c^2 - 2 z_c c_{hr}^1 \right]$$

$$= \begin{matrix} 8*4323,709 + 4*124774,3739*(2,65^2 + 3,85^2) \\ +8*54958.60789*\left(\frac{0,8}{2}\right)^2 - 8*2*0,8*(-12137,63) \end{matrix}$$

$$= 11085402.29 \text{ kgmdt}$$

3. *Pile cap*

$$\delta = \frac{h}{r_0} = \frac{0,7}{2,32} = 0,3$$

$$k_r^f = G_s.r_0^2.h.\overline{S}_{r1} + G_s.r_0^2.h.\overline{S}_{h1}\left[\left(\frac{\delta^2}{3}\right) + \left(\frac{z_c}{r_0}\right)^2 - \delta\left(\frac{z_c}{r_0}\right)\right]$$

$$= \begin{matrix} 12376372,92*2,32^2*0,7*2,5 + 12376372,92*2,32^2*0,7*4,1* \\ \left[\left(\frac{0,3^2}{3}\right) + \left(\frac{0,8}{2,32}\right)^2 - 0,3\left(\frac{0,8}{2,32}\right)\right] \end{matrix}$$

$$= 118739983.5 \text{ kgm}$$

$$c_r^f = \delta.r_0^4\sqrt{\frac{G_s\gamma_s}{g}}.\left\{\overline{S}_{r2} + \overline{S}_{h2}\left[\left(\frac{\delta^2}{3}\right) + \left(\frac{z_c}{r_0}\right)^2 - \delta\left(\frac{z_c}{r_0}\right)\right]\right\}$$

$$= \begin{matrix} 0,3*2,32^4\sqrt{\frac{12376372,92*1828}{9,81}}* \\ \left\{2,5 + 1,8\left[\left(\frac{0,3^2}{3}\right) + \left(\frac{0,8}{2,32}\right)^2 - 0,3\left(\frac{0,8}{1,13}\right)\right]\right\} \end{matrix}$$

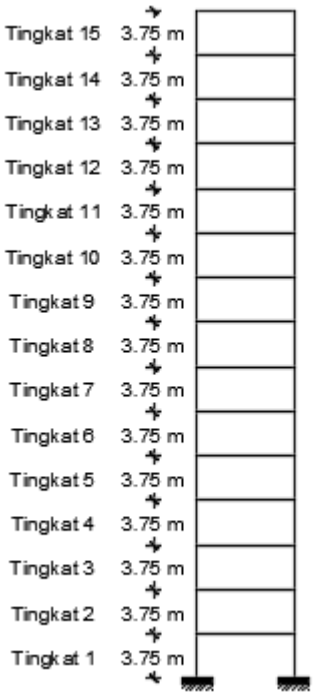
= 797593,6084 kgmdt

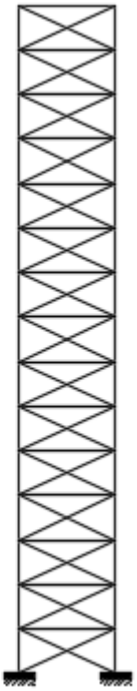
4. Total

k_r = 9336304311 + 118739983.5 = 9455044295kgm/rad

c_r = 11085402.29 + 797593,6084 = 11882995.95kgmdt/rad

7. Menghitung Massa dan Kekakuan





No	Elemen Struktur	Lantai	Profil Baja	Berat (kg/m)	Luas (m^2)	Inersia (m^4)
1	Balok	1-5	W14X53	78.87268882	0.010064496	0.000225181
2	Balok	6-10	W14X53	78.87268882	0.010064496	0.000225181
3	Balok	11-15	W14X26	38.69226244	0.00496128	0.000101977
4	Kolom	1-5	W14X370	550.6206578	0.07032244	0.002264299
5	Kolom	6-10	W14X311	462.8189853	0.058967624	0.001802282
6	Kolom	11-15	W14X211	314.0025913	0.03999992	0.001107176
7	*Bracing*	1-5	W8X21	31.25144274	0.003974186	3.13422E-05
8	*Bracing*	6-10	W8X18	26.78695092	0.003393542	2.57647E-05
9	*Bracing*	11-15	W8X15	22.3224591	0.00286451	1.99791E-05

Tabel 4.3 Beban Merata Struktur 15 Tingkat

Tingkat	Beban Merata (kg/m)
	Balok 6.5 m
1-14	3427

Data :

Modulus elastis baja (E_{baja}) = 200000 MPa

= 20400000000 kg/m^2

Tinggi tiap lantai = 3,75 m

Lebar tengah = 6,5 m

Panjang *bracing* tipe X = $\sqrt{6,5^2 + 3,75^2}$ = 7,50 m

α brX = 0.523278322 rad

= 29.98163937 degrees

Percepatan gravitasi (g) = 9,81 m/s^2

a. Open Frame

$$m = \frac{W}{g}$$

$M_{1\text{-}5}$ = (2*550,6206578*3,75 + 1*78,87268882*6,5 + 6,5*3427)/9,81

= 2743,92 kgdt^2/m

$M_{6\text{-}10}$ = (2*462.8189853*3,75 + 1*78,87268882*6,5 + 6,5*3427)/9,81

= 2676,79 kgdt^2/m

$M_{11\text{-}15}$ = (2*314.0025913*3,75 + 1*38.69226244*6,5 + 6,5*3427)/9,81

= 2536,39 kgdt^2/m

$$K = \frac{12.E.I}{h^3},\ K_b = \frac{H}{u} = \frac{A.E}{L}\cos^2(\alpha)$$

$K_{1\text{-}5}$ = $\frac{12 * 20400000000 * 0,002264299}{3,75^3}$ = 21022355,31 kg/m

$K_{6\text{-}10}$ = $\frac{12 * 20400000000 * 0,001802282}{3,75^3}$ = 16732867,37 kg/m

$$K_{11\text{-}15} = \frac{12 * 20400000000 * 0,001107176}{3,75^3} = 10279313,44 \text{ kg/m}$$

b. Bracing X

$$m = \frac{W}{g}$$

$M_{1\text{-}5} = 2743.92 + (2*7,5*31,25144274)/9,81 = 2791,73 \text{ kgdt}^2/\text{m}$

$M_{6\text{-}10} = 2676.79 + (2*7,5*26,78695092)/9,81 = 2717,77 \text{ kgdt}^2/\text{m}$

$M_{11\text{-}15} = 2536.39 + (2*7,5*22,3224591)/9,81 = 2570,54 \text{ kgdt}^2/\text{m}$

$$Kb_{1\text{-}5} = 21022355,31 + \frac{0,003974186*20400000000}{7,5}\cos^2(29,98163937)$$

$$= 29128191,33 \text{ kg/m}$$

$$Kb_{6\text{-}10} = 16732867,37 + \frac{0,003393542*20400000000}{7,5}\cos^2(29,98163937)$$

$$= 23654409,17 \text{ kg/m}$$

$$Kb_{11\text{-}15} = 10279313,44 + \frac{0,00286451*20400000000}{7,5}\cos^2(29,98163937)$$

$$= 16121831,61 \text{ kg/m}$$

7. Mencari Nilai Frekuensi Sudut (ω)

a. Open Frame

$$[M] = \begin{bmatrix}
m_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & m_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & m_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & m_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & m_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & m_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & m_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & m_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_9 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{10} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{11} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{12} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{13} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{14} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{15}
\end{bmatrix}$$

$$[M] = \begin{bmatrix}
2743.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2743.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 2743.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2743.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2743.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2676.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 2676.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2676.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2676.79 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2676.79 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2536.39 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2536.39 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2536.39 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2536.39 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2536.39
\end{bmatrix}$$

$$[K] = \begin{bmatrix}
k_1+k_2 & -k_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-k_2 & k_2+k_3 & -k_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -k_3 & k_3+k_4 & -k_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -k_4 & k_4+k_5 & -k_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -k_5 & k_5+k_6 & -k_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -k_6 & k_6+k_7 & -k_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -k_7 & k_7+k_8 & -k_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -k_8 & k_8+k_9 & -k_9 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_9 & k_9+k_{10} & -k_{10} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{10} & k_{10}+k_{11} & -k_{11} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{11} & k_{11}+k_{12} & -k_{12} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{12} & k_{12}+k_{13} & -k_{13} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{13} & k_{13}+k_{14} & -k_{14} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{14} & k_{14}+k_{15} & -k_{15} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{15} & k_{15}
\end{bmatrix}$$

$$[K] = \begin{bmatrix}
42044710.6 & -21022355.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-21022355 & 42044710.63 & -21022355 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -21022355.3 & 42044710.6 & -21022355 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -21022355 & 42044710.6 & -21022355 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -21022355 & 37755222.7 & -16732867 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -16732867 & 33465734.7 & -16732867 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -16732867 & 33465734.7 & -16732867 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -16732867 & 33465734.7 & -16732867 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -16732867 & 33465734.7 & -16732867.4 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16732867 & 27012180.82 & -10279313 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10279313.4 & 20558626.9 & -10279313 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10279313 & 20558626.9 & -10279313 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10279313 & 20558626.9 & -10279313 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10279313 & 20558626.9 & -10279313.4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10279313 & 10279313.44
\end{bmatrix}$$

Konversi m = 1000

Konversi k = 1000000

Maka menjadi,

[M] =

2.74	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2.74	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2.74	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	2.74	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2.74	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	2.68	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	2.68	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2.68	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	2.68	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	2.68	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2.54	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2.54	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	2.54	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	2.54	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54

[K] =

42.04	-21.02	0	0	0	0	0	0	0	0	0	0	0	0	0
-21.02	42.04	-21.02	0	0	0	0	0	0	0	0	0	0	0	0
0	-21.02	42.04	-21.02	0	0	0	0	0	0	0	0	0	0	0
0	0	-21.02	42.04	-21.02	0	0	0	0	0	0	0	0	0	0
0	0	0	-21.02	37.76	-16.73	0	0	0	0	0	0	0	0	0
0	0	0	0	-16.73	33.47	-16.73	0	0	0	0	0	0	0	0
0	0	0	0	0	-16.73	33.47	-16.73	0	0	0	0	0	0	0
0	0	0	0	0	0	-16.73	33.47	-16.73	0	0	0	0	0	0
0	0	0	0	0	0	0	-16.73	33.47	-16.73	0	0	0	0	0
0	0	0	0	0	0	0	0	-16.73	27.01	-10.28	0	0	0	0
0	0	0	0	0	0	0	0	0	-10.28	20.56	-10.28	0	0	0
0	0	0	0	0	0	0	0	0	0	-10.28	20.56	-10.28	0	0
0	0	0	0	0	0	0	0	0	0	0	-10.28	20.56	-10.28	0
0	0	0	0	0	0	0	0	0	0	0	0	-10.28	20.56	-10.28
0	0	0	0	0	0	0	0	0	0	0	0	0	-10.28	10.28

$|[K] - \omega 2\ [M]| = 0$

Apabila di ambil notasi $\lambda = \omega^2/(k/m)$, maka didapat,

$21{,}02235531 + (-379{,}4063527)\ \lambda + 1322{,}120434\ \lambda^2 + (-1832{,}430664)\ \lambda^3 + 1325{,}803547\ \lambda^4 + (-574{,}8451209)\ \lambda^5 + 161{,}7881198\ \lambda^6 + (-31{,}03923754)\ \lambda^7 + 4{,}181023547\ \lambda^8 + (-0{,}401612593)\ \lambda^9 + 0{,}027606177\ \lambda^{10} + (-0{,}001345688)\ \lambda^{11} + 4{,}53538E\text{-}05\ \lambda^{12} + (-1{,}00353E\text{-}06)\ \lambda^{13} + 1{,}30977E\text{-}08\ \lambda^{14} + (-7{,}6315E\text{-}11)\ \lambda^{15} = 0$

$\omega = (\lambda^*(k/m))^{0.5}$

Mode	λ	f (λ)	ω (rad/dt)	T (dt)
1	0.07158131	0.0000	8.46	0.74
2	0.5000598	0.0000	22.36	0.28
3	1.3946115	0.0000	37.34	0.17
4	2.71011	0.0000	52.06	0.12
5	4.3157727	0.0000	65.69	0.10
6	6.3276595	0.0000	79.55	0.08
7	8.1047589	0.0000	90.03	0.07
8	10.6420251	0.0000	103.16	0.06
9	12.4130224	0.0000	111.41	0.06
10	14.6913534	0.0000	121.21	0.05
11	15.7795256	0.0000	125.62	0.05
12	19.0316157	0.0000	137.96	0.05
13	22.52897226	0.0000	150.10	0.04
14	24.39934786	-0.0001	156.20	0.04
15	28.71526641	0.0021	169.46	0.04

Massa	Mode ke-														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Nilai λ														
	0.0715813	0.5000598	1.3946115	2.71011	4.31577	6.32766	8.10476	10.642	12.413	14.6914	15.7795	19.0316	22.529	24.3993	28.7153
	Koordinat Mode Shape														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1.990656937	1.934730307	1.817970043	1.64626621	1.436689	1.17409	0.942136	0.610963	0.379805	0.082429	-0.0596	-0.48408	-0.94057	-1.18469	-1.74802
3	2.962715042	2.743181362	2.305015077	1.71019244	1.064075	0.378487	-0.11238	-0.62672	-0.85575	-0.99321	-0.99645	-0.76567	-0.11533	0.403502	2.055591
4	3.907092314	3.372585813	2.372478315	1.16916583	0.092056	-0.72971	-1.04801	-0.99387	-0.70482	-0.1643	0.118995	0.854722	1.049046	0.706668	-1.8452
5	4.814965377	3.781862624	2.008079427	0.21456575	-0.93182	-1.23523	-0.87499	0.019508	0.588052	0.979662	0.989355	0.351916	-0.87136	-1.24069	1.169864
6	5.899053777	3.98593901	1.091031742	-1.08010303	-1.5587	-0.58863	0.50529	1.25862	1.015358	0.056732	-0.47721	-1.37807	-0.06492	1.27686	-0.55085
7	6.915592075	3.871157918	-0.06942383	-1.90650204	-1.10945	0.653816	1.230446	0.355024	-0.57357	-0.99953	-0.73916	1.087514	0.975498	-1.18945	0.258853
8	7.852939884	3.446701328	-1.21439103	-1.90635281	0.105766	1.234436	0.360286	-1.15297	-1.02354	0.293309	0.864737	0.242134	-1.49978	0.986913	-0.12052
9	8.700363629	2.746523888	-2.08842903	-1.07972003	1.247964	0.565501	-0.977	-0.69812	0.55897	0.896812	0.285797	-1.34043	1.43016	-0.68886	0.053726
10	9.448159454	1.826636693	-2.496541	0.21501646	1.528564	-0.67586	-1.04757	0.945233	1.031512	-0.60738	-1.01458	1.157979	-0.7942	0.324129	-0.01883
11	10.4893208	0.091364703	-2.25421831	2.17087076	0.267452	-1.58292	1.048472	1.000844	-1.53355	-0.73228	1.037621	-0.51394	0.244259	-0.08634	0.003858
12	11.34521453	-1.655180634	-1.23618146	2.67503671	-1.27847	-0.01851	1.04775	-1.57165	0.598473	1.797366	-0.95022	0.227596	-0.07511	0.022996	-0.00079
13	12.00072342	-3.197495828	0.207246066	1.39037225	-1.46294	1.574799	-1.04829	-0.01716	0.897449	-2.18854	0.761671	-0.09966	0.023042	-0.00612	0.000159
14	12.44426955	-4.345277025	1.579356762	-0.82405147	-0.08952	0.709324	-1.04793	1.582393	-1.55235	1.759122	-0.49205	0.04109	-0.0069	0.001599	-1.9E-05
15	12.66801878	-4.956901302	2.407984426	-2.48742169	1.379234	-1.26364	1.048111	-0.97325	0.752518	-0.67013	0.17005	-0.01112	0.00151	-0.00029	-0.00011

b. Bracing X

$$[M] = \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & m_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{10} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{11} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{13} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{14} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{15} \end{bmatrix}$$

$$[M] = \begin{bmatrix}
2791.73 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2791.73 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 2791.73 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2791.73 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2791.73 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2717.77 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 2717.77 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2717.77 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2717.77 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2717.77 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2570.54 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2570.54 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2570.54 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2570.54 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2570.54
\end{bmatrix}$$

$$[K] = \begin{bmatrix}
k_1+k_2 & -k_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-k_2 & k_2+k_3 & -k_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -k_3 & k_3+k_4 & -k_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -k_4 & k_4+k_5 & -k_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -k_5 & k_5+k_6 & -k_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -k_6 & k_6+k_7 & -k_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -k_7 & k_7+k_8 & -k_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -k_8 & k_8+k_9 & -k_9 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_9 & k_9+k_{10} & -k_{10} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{10} & k_{10}+k_{11} & -k_{11} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{11} & k_{11}+k_{12} & -k_{12} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{12} & k_{12}+k_{13} & -k_{13} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{13} & k_{13}+k_{14} & -k_{14} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{14} & k_{14}+k_{15} & -k_{15} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{15} & k_{15}
\end{bmatrix}$$

$$[K] = \begin{bmatrix}
58256382.7 & -29128191.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-29128191 & 58256382.66 & -29128191 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -29128191.3 & 58256382.7 & -29128191 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -29128191 & 58256382.7 & -29128191 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -29128191 & 52782600.5 & -23654409 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -23654409 & 47308818.3 & -23654409 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -23654409 & 47308818.3 & -23654409 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -23654409 & 47308818.3 & -23654409 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -23654409 & 47308818.3 & -23654409.2 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -23654409 & 39776240.78 & -16121832 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16121831.6 & 32243663.2 & -16121832 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16121832 & 32243663.2 & -16121832 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16121832 & 32243663.2 & -16121832 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16121832 & 32243663.2 & -16121831.6 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16121832 & 16121831.61
\end{bmatrix}$$

Konversi m = 1000

Konversi k = 1000000

Maka menjadi,

$$[M] = \begin{bmatrix}
2.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 2.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2.79 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2.72 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 2.72 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.72 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.72 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.72 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.57 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.57 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.57 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.57 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.57
\end{bmatrix}$$

[K] =

58.26	-29.13	0	0	0	0	0	0	0	0	0	0	0	0	0
-29.13	58.26	-29.13	0	0	0	0	0	0	0	0	0	0	0	0
0	-29.13	58.26	-29.13	0	0	0	0	0	0	0	0	0	0	0
0	0	-29.13	58.26	-29.13	0	0	0	0	0	0	0	0	0	0
0	0	0	-29.13	52.78	-23.65	0	0	0	0	0	0	0	0	0
0	0	0	0	-23.65	47.31	-23.65	0	0	0	0	0	0	0	0
0	0	0	0	0	-23.65	47.31	-23.65	0	0	0	0	0	0	0
0	0	0	0	0	0	-23.65	47.31	-23.65	0	0	0	0	0	0
0	0	0	0	0	0	0	-23.65	47.31	-23.65	0	0	0	0	0
0	0	0	0	0	0	0	0	-23.65	39.78	-16.12	0	0	0	0
0	0	0	0	0	0	0	0	0	-16.12	32.24	-16.12	0	0	0
0	0	0	0	0	0	0	0	0	0	-16.12	32.24	-16.12	0	0
0	0	0	0	0	0	0	0	0	0	0	-16.12	32.24	-16.12	0
0	0	0	0	0	0	0	0	0	0	0	0	-16.12	32.24	-16.12
0	0	0	0	0	0	0	0	0	0	0	0	0	-16.12	16.12

$|[K] - \omega 2\ [M]| = 0$

Apabila di ambil notasi $\lambda = \omega^2/(k/m)$, maka didapat,

$29{,}12819133 + (-373{,}0838385)\ \lambda + 900{,}9664972\ \lambda^2 + (-865{,}160053)\ \lambda^3 + 433{,}8376735\ \lambda^4 + (-130{,}4678827)\ \lambda^5 + 25{,}49420405\ \lambda^6 + (-3{,}399968711)\ \lambda^7 + 0{,}318805963\ \lambda^8 + (-0{,}021351219)\ \lambda^9 + 0{,}001025087\ \lambda^{10} + (-3{,}49684E\text{-}05)\ \lambda^{11} + 8{,}26457E\text{-}07\ \lambda^{12} + (-1{,}28517E\text{-}08)\ \lambda^{13} + 1{,}1815E\text{-}10\ \lambda^{14} + (-4{,}86038E\text{-}13)\ \lambda^{15} = 0$

Dengan $\omega = (\lambda*(k/m))^{0.5}$

Mode	λ	f (λ)	ω (rad/dt)	T (dt)
1	0.10003	-0.0001	10.00	0.63
2	0.72997	0.0001	27.02	0.23
3	2.0014	0.0008	44.74	0.14
4	3.95035	-0.0001	62.85	0.10
5	6.2262	-0.0004	78.91	0.08
6	9.1298	0.0005	95.55	0.07
7	11.84437	-0.0001	108.83	0.06
8	15.3937	0.0009	124.07	0.05
9	18.307	-0.0002	135.30	0.05
10	21.35242	0.0002	146.12	0.04
11	23.39022	0.0001	152.94	0.04
12	26.628985	-0.0001	163.18	0.04
13	31.1733237	-0.0002	176.56	0.04
14	33.6999406	-0.0004	183.58	0.03
15	39.159342	0.0005	197.89	0.03

Massa	Mode ke-														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Nilai λ														
	0.10003	0.72997	2.0014	3.95035	6.2262	9.1298	11.8444	15.3937	18.307	21.3524	23.3902	26.629	31.1733	33.6999	39.1593
	Koordinat Mode Shape														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1.99041284	1.930037597	1.808180126	1.62138721	1.403263	1.124974	0.864802	0.524624	0.245405	-0.04648	-0.24179	-0.5522	-0.98774	-1.2299	-1.75314
3	2.961743274	2.725045125	2.269515367	1.62889648	0.969148	0.265566	-0.25212	-0.72477	-0.93978	-0.99784	-0.94154	-0.69508	-0.02437	0.51265	2.07351
4	3.904679001	3.329401949	2.295512457	1.01968471	-0.04329	-0.82622	-1.08283	-0.90486	-0.47603	0.092853	0.469436	0.936018	1.011811	0.599391	-1.88202
5	4.810179945	3.70082581	1.881184636	0.02440727	-1.0299	-1.19504	-0.68432	0.250061	0.822956	0.993524	0.828037	0.178211	-0.97504	-1.24984	1.225933
6	5.868432128	3.83936543	0.926627413	-1.21256308	-1.48802	-0.36154	0.763018	1.217925	0.644442	-0.40111	-1.01622	-1.31504	0.165626	1.444015	-0.61274
7	6.859238768	3.655898013	-0.24100846	-1.89918109	-0.88167	0.851205	1.171995	0.031696	-0.88958	-0.81171	-0.12947	1.215118	0.713074	-1.45329	0.305445
8	7.771212583	3.165810948	-1.35322426	-1.72380786	0.355391	1.171063	-0.01395	-1.21059	-0.55248	0.769044	1.105217	0.027576	-1.29346	1.276471	-0.15063
9	8.593872312	2.410207766	-2.15426516	-0.76604095	1.338217	0.262513	-1.18091	-0.31176	0.946695	0.463112	-0.63027	-1.24434	1.332742	-0.93621	0.071003
10	9.317763176	1.4524608	-2.4599312	0.53941296	1.363738	-0.9214	-0.74082	1.13847	0.454605	-0.97897	-0.67196	1.290842	-0.81448	0.476061	-0.02682
11	10.22275312	-0.131507109	-2.07845632	2.09559609	-0.03019	-1.24037	1.384078	0.311925	-1.67038	0.428993	1.916447	-0.78411	0.315229	-0.15634	0.006717
12	10.96469754	-1.700168902	-1.03371878	2.33184008	-1.39415	0.246271	0.895112	-1.28022	1.080404	0.37643	-2.64245	0.470159	-0.12189	0.051328	-0.00168
13	11.53176294	-3.070947992	0.340891982	1.0993435	-1.37408	1.374416	-1.2843	0.26987	0.677532	-0.9577	2.65354	-0.2718	0.046833	-0.0168	0.000418
14	11.91490506	-4.084299365	1.606719642	-0.82558925	0.010081	0.501823	-1.03828	1.157582	-1.70303	0.968696	-1.94672	0.140264	-0.01723	0.005345	-9.1E-05
15	12.10801305	-4.622279029	2.359821997	-2.23051359	1.384239	-1.10127	1.168553	-0.79593	0.88748	-0.40287	0.713226	-0.04321	0.004331	-0.00123	-4E-05

8. Metode *β*-Newmark

Dalam verifikasi ini hanya di tunjukan untuk *open frame* dikarenakan caranya sama.

$\beta = 2*(5\%*8{,}46 - 5\%*22{,}36) / ((8{,}46)^2 - (22{,}36)^2) = 0{,}003244374$

$\alpha = 2*5\%*8{,}46 - 0{,}003244374*(8{,}46)^2 = 0{,}613820873$

Rumus di bawah ini menggunakan 3 tingkat, tetapi konsep untuk 15 tingkat hampir sama.

$$\begin{bmatrix} m_1 & 0 & 0 & m_1 & m_1h_1 \\ 0 & m_2 & 0 & m_2 & m_2h_2 \\ 0 & 0 & m_3 & m_3 & m_3h_3 \\ m_1 & m_2 & m_3 & m_0+m_1+m_2+m_3 & m_1h_1+m_2h_2+m_3h_3 \\ m_1h_1 & m_2h_2 & m_3h_3 & m_1h_1+m_2h_2+m_3h_3 & I_G+m_1h_1^2+m_2h_2^2+m_3h_3^2 \end{bmatrix}$$

$$\begin{Bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \\ \ddot{y}_3 \\ \ddot{y}_0 \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} c_1 & 0 & 0 & 0 & 0 \\ 0 & c_2 & 0 & 0 & 0 \\ 0 & 0 & c_3 & 0 & 0 \\ 0 & 0 & 0 & c_h & 0 \\ 0 & 0 & 0 & 0 & c_r \end{bmatrix} \begin{Bmatrix} \dot{y}_1 \\ \dot{y}_2 \\ \dot{y}_3 \\ \dot{y}_0 \\ \dot{\theta} \end{Bmatrix} + \begin{bmatrix} k_1+k_2 & -k_2 & 0 & 0 & 0 \\ -k_2 & k_2+k_3 & -k_3 & 0 & 0 \\ 0 & -k_3 & k_3 & 0 & 0 \\ 0 & 0 & 0 & k_h & 0 \\ 0 & 0 & 0 & 0 & k_r \end{bmatrix}$$

$$\begin{Bmatrix} y_1 \\ y_2 \\ y_3 \\ y_0 \\ \theta \end{Bmatrix} = -\begin{Bmatrix} m_1\ddot{y}_b \\ m_2\ddot{y}_b \\ m_3\ddot{y}_b \\ (m_0+m_1+m_2+m_3)\ddot{y}_b \\ (m_1h_1+m_2h_2+m_3h_3)\ddot{y}_b \end{Bmatrix}$$

Nilai C didapatkan dari *mass and stiffness damping*.

$$r_0 = \sqrt[4]{\frac{BL^3}{3\pi}} = \sqrt[4]{\frac{2*8,5^3}{3\pi}} = 3,378733294 \text{ m}$$

$$I_G = m\left(\frac{r_0^2}{4}+\frac{h^2}{3}\right)$$

$$= (m_0 + m_1 + m_2 + m_3 + m_4 + m_5 + m_6 + m_7 + m_8 + m_9 + m_{10} + m_{11} + m_{12} + m_{13} + m_{14} + m_{15}) * \left(\frac{r_0^2}{4}+\frac{h^2}{3}\right)$$

$$= 43112,72*\left(\frac{3,378733294^2}{4}+\frac{0,8^2}{3}\right) = 132239,35 \text{ kgmdt}^2$$

[M] =

2743.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2743.92	10289.68938
0	2743.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2743.92	20579.37875
0	0	2743.92	0	0	0	0	0	0	0	0	0	0	0	0	0	2743.92	30869.06813
0	0	0	2743.92	0	0	0	0	0	0	0	0	0	0	0	0	2743.92	41158.75751
0	0	0	0	2743.92	0	0	0	0	0	0	0	0	0	0	0	2743.92	51448.44689
0	0	0	0	0	2676.79	0	0	0	0	0	0	0	0	0	0	2676.79	60227.78639
0	0	0	0	0	0	2676.79	0	0	0	0	0	0	0	0	0	2676.79	70265.75079
0	0	0	0	0	0	0	2676.79	0	0	0	0	0	0	0	0	2676.79	80303.71519
0	0	0	0	0	0	0	0	2676.79	0	0	0	0	0	0	0	2676.79	90341.67959
0	0	0	0	0	0	0	0	0	2676.79	0	0	0	0	0	0	2676.79	100379.644
0	0	0	0	0	0	0	0	0	0	2536.39	0	0	0	0	0	2536.39	104626.2273
0	0	0	0	0	0	0	0	0	0	0	2536.39	0	0	0	0	2536.39	114137.7025
0	0	0	0	0	0	0	0	0	0	0	0	2536.39	0	0	0	2536.39	123649.1777
0	0	0	0	0	0	0	0	0	0	0	0	0	2536.39	0	0	2536.39	133160.6529
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2536.39	0	2536.39	142672.1281
2743.917167	2743.917167	2743.917167	2743.917167	2743.917167	2676.790506	2676.790506	2676.790506	2676.790506	2676.790506	2536.393388	2536.393388	2536.393388	2536.393388	2536.393388	2536.393388	43112.722435841	1174109.805
10289.68938	20579.37875	30869.06813	41158.75751	51448.44689	60227.78639	70265.75079	80303.71519	90341.67959	100379.644	104626.2273	114137.7025	123649.1777	133160.6529	142672.1281	1174109.805	45172636.11	

[K] =

42044710.63	-21022355.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-21022355.3	42044710.63	-21022355.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-21022355.3	42044710.63	-21022355.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	-21022355.3	42044710.63	-21022355.31	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	-21022355.3	33755222.69	-16732867.37	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-16732867.37	33465734.75	-16732867.37	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	-16732867.37	33465734.75	-16732867.4	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	-16732867.37	33465734.75	-16732867.37	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-16732867.4	33465734.75	-16732867.37	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	-16732867.37	27012180.82	-10279313.44	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	-10279313.44	20558626.89	-10279313.44	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	-10279313.44	20558626.89	-10279313.44	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-10279313.44	20558626.89	-10279313.44	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-10279313.44	20558626.89	-10279313.44	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	-10279313.44	10279313.44	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.36E+08	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.46E+09	0

[C] =

138093.0232	-68204.3748	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-68204.3748	138093.0232	-68204.3748	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-68204.3748	138093.0232	-68204.3748	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	-68204.3748	138093.0232	-68204.37476	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	-68204.3748	124176.3217	-54287.67329	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-54287.67329	110218.4165	-54287.67329	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	-54287.67329	110218.4165	-54287.6733	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	-54287.67329	110218.4165	-54287.67329	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-54287.6733	110218.4165	-54287.67329	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	-54287.67329	89280.67642	-33349.93325	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	-33349.93325	68256.7577	-33349.93325	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	-33349.93325	68256.7577	-33349.93325	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-33349.93325	68256.7577	-33349.93325	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-33349.93325	68256.7577	-33349.93325	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	-33349.93325	34906.82445	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1014026.739	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11882995.9	0

$\Delta t = 0{,}01$, $\gamma = 0{,}5$, dan $\beta = 0{,}25$.

$$\hat{k} = [K] + \frac{\gamma}{\beta * \Delta t}[C] + \frac{1}{\beta * (\Delta t)^2}[M]$$

k̂ =

1794200001.9	-34663230.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1097566686.7	41158757 5.1
-34663230.3	1794200001.9	-34663230.3	0	0	0	0	0	0	0	0	0	0	0	0	0	1097566686.7	8231751 50.2
0	-34663230.3	1794200001.9	-34663230.3	0	0	0	0	0	0	0	0	0	0	0	0	1097566686.7	1234762725
0	0	-34663230.3	1794200001.9	-34663230.27	0	0	0	0	0	0	0	0	0	0	0	1097566686.7	1646350800
0	0	0	-34663230.3	172347173.7	-27590402.03	0	0	0	0	0	0	0	0	0	0	1097566686.7	2057937875
0	0	0	0	-27590402.03	162581038.3	-27590402.03	0	0	0	0	0	0	0	0	0	1070716203	2409111456
0	0	0	0	0	-27590402.03	162581038.3	-27590402	0	0	0	0	0	0	0	0	1070716203	2810630032
0	0	0	0	0	0	-27590402.03	162581038.3	-27590402.03	0	0	0	0	0	0	0	1070716203	3212148608
0	0	0	0	0	0	0	-27590402	162581038.3	-27590402.03	0	0	0	0	0	0	1070716203	3613667184
0	0	0	0	0	0	0	0	-27590402.03	151999936.4	-16949300.09	0	0	0	0	0	1070716203	4015185760
0	0	0	0	0	0	0	0	0	-16949300.09	135665714	-16949300.09	0	0	0	0	1014557355	4185049091
0	0	0	0	0	0	0	0	0	0	-16949300.09	135665714	-16949300.09	0	0	0	1014557355	4565508099
0	0	0	0	0	0	0	0	0	0	0	-16949300.09	135665714	-16949300.09	0	0	1014557355	4945967108
0	0	0	0	0	0	0	0	0	0	0	0	-16949300.09	135665714	-16949300.09	0	1014557355	5326426116
0	0	0	0	0	0	0	0	0	0	0	0	0	-16949300.09	118716413.9	0	1014557355	5706885124
1097566686.7	1097566686.7	1097566686.7	1097566686.7	1097566686.7	1070716203	1070716203	1070716203	1070716203	1070716203	1014557355	1014557355	1014557355	1014557355	1014557355	1014557355	2063699676	4696439202
41158757 5.1	8231751 50.2	1234762725	1646350300	2057937875	2409111456	2810630032	3212148608	3613667184	4015185760	4185049091	4565508099	4945967108	5326426116	5706885124	4696439202	2063699676	4696439202

$$a = \frac{1}{\beta * \Delta t}[M] + \frac{\gamma}{\beta}[C]$$

a =

1373752.913	-136408.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1097566.867	4115875.751
-136408.75	1373752.913	-136408.75	0	0	0	0	0	0	0	0	0	0	0	0	0	1097566.867	8231751.502
0	-136408.75	1373752.913	-136408.75	0	0	0	0	0	0	0	0	0	0	0	0	1097566.867	12347627.25
0	0	-136408.75	1373752.913	-136408.7495	0	0	0	0	0	0	0	0	0	0	0	1097566.867	16463503
0	0	0	-136408.75	1345919.51	-108575.3466	0	0	0	0	0	0	0	0	0	0	1097566.867	20579378.75
0	0	0	0	-108575.3466	1291153.035	-108575.3466	0	0	0	0	0	0	0	0	0	1070716.203	24091114.56
0	0	0	0	0	-108575.3466	1291153.035	-108575.347	0	0	0	0	0	0	0	0	1070716.203	28106300.32
0	0	0	0	0	0	-108575.3466	1291153.035	-108575.3466	0	0	0	0	0	0	0	1070716.203	32121486.08
0	0	0	0	0	0	0	-108575.347	1291153.035	-108575.3466	0	0	0	0	0	0	1070716.203	36136671.84
0	0	0	0	0	0	0	0	-108575.3466	1249277.555	-66699.86649	0	0	0	0	0	1070716.203	40151857.6
0	0	0	0	0	0	0	0	0	-66699.86649	1151070.871	-66699.86649	0	0	0	0	1014557.355	41850490.91
0	0	0	0	0	0	0	0	0	0	-66699.86649	1151070.871	-66699.86649	0	0	0	1014557.355	45655080.99
0	0	0	0	0	0	0	0	0	0	0	-66699.86649	1151070.871	-66699.86649	0	0	1014557.355	49459671.08
0	0	0	0	0	0	0	0	0	0	0	0	-66699.86649	1151070.871	-66699.86649	0	1014557.355	53264261.16
0	0	0	0	0	0	0	0	0	0	0	0	0	-66699.86649	1084371.004	0	1014557.355	57068851.24
1097566.867	1097566.867	1097566.867	1097566.867	1097566.867	1070716.203	1070716.203	1070716.203	1070716.203	1070716.203	1014557.355	1014557.355	1014557.355	1014557.355	1014557.355	1014557.355	1927314.245	468643922
4115875.751	8231751.502	12347627.25	16463503	20579378.75	24091114.56	28106300.32	32121486.08	36136671.84	40151857.6	41850490.91	45655080.99	49459671.08	53264261.16	57068851.24	468643922	1809282 0434	468643922

$$b = \frac{1}{2 * \beta}[M] + \Delta t * \left(\frac{\gamma}{2 * \beta} - 1\right)[C]$$

b =

5487.834335	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5487.834335	20579.37875
0	5487.834335	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5487.834335	41158.75751
0	0	5487.834335	0	0	0	0	0	0	0	0	0	0	0	0	0	5487.834335	61738.13626
0	0	0	5487.834335	0	0	0	0	0	0	0	0	0	0	0	0	5487.834335	82317.51502
0	0	0	0	5487.834335	0	0	0	0	0	0	0	0	0	0	0	5487.834335	102896.8938
0	0	0	0	0	5353.581013	0	0	0	0	0	0	0	0	0	0	5353.581013	120455.5728
0	0	0	0	0	0	5353.581013	0	0	0	0	0	0	0	0	0	5353.581013	140531.5016
0	0	0	0	0	0	0	5353.581013	0	0	0	0	0	0	0	0	5353.581013	160607.4304
0	0	0	0	0	0	0	0	5353.581013	0	0	0	0	0	0	0	5353.581013	180683.3592
0	0	0	0	0	0	0	0	0	5353.581013	0	0	0	0	0	0	5353.581013	200759.288
0	0	0	0	0	0	0	0	0	0	5072.786777	0	0	0	0	0	5072.786777	209252.4545
0	0	0	0	0	0	0	0	0	0	0	5072.786777	0	0	0	0	5072.786777	228275.405
0	0	0	0	0	0	0	0	0	0	0	0	5072.786777	0	0	0	5072.786777	247298.3554
0	0	0	0	0	0	0	0	0	0	0	0	0	5072.786777	0	0	5072.786777	266321.3058
0	0	0	0	0	0	0	0	0	0	0	0	0	0	5072.786777	0	5072.786777	285344.2562
5487.834335	5487.834335	5487.834335	5487.834335	5487.834335	5353.581013	5353.581013	5353.581013	5353.581013	5353.581013	5072.786777	5072.786777	5072.786777	5072.786777	5072.786777	5072.786777	86225.44487	2348219.61
20579.37875	41158.75751	61738.13626	82317.51502	102896.8938	120455.5728	140531.5016	160607.4304	180683.3592	200759.288	209252.4545	228275.405	247298.3554	266321.3058	285344.2562	2348219.61	90345722.22	

Perhitungan pembebanan gempa menggunakan gempa EL Centro frekuensi Rendah dengan percepatan gempa sebagai berikut,

Untuk selang waktu 0,01 detik = -0,006548837 m/dt^2

Untuk selang waktu 0,02 detik = -0.013097674 m/dt^2

1. Step ke 1 (0,01 detik)

Kondisi pertama diketahui $y_0 = 0, \dot{y}_0 = 0, \ddot{y}_0 = 0$

$$\Delta p = (\ddot{y}b_1 - \ddot{y}b_0)\begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ m_0 + m_1 + m_2 + m_3 \\ m_1h_1 + m_2h_2 + m_3h_3 \end{bmatrix}$$

Rumus di atas untuk 3 tingkat, sedangkan untuk 15 tingkat sama konsepnya.

Δp_1 (kg)	Δp_2 (kg)	Δp_3 (kg)	Δp_4 (kg)	Δp_5 (kg)	Δp_6 (kg)	Δp_7 (kg)	Δp_8 (kg)	Δp_9 (kg)	Δp_{10} (kg)	Δp_{11} (kg)	Δp_{12} (kg)	Δp_{13} (kg)	Δp_{14} (kg)	Δp_{15} (kg)	Δp_{16} (kg)	Δp_{17} (kgm)
-17.9695	-17.9695	-17.9695	-17.9695	-17.9695	-17.5299	-17.5299	-17.5299	-17.5299	-17.5299	-16.6104	-16.6104	-16.6104	-16.6104	-16.6104	-282.338	-7689.05

a. Menghitung pertambahan pembebanan

$$\Delta\hat{p} = \Delta p_0 + a * \dot{y}_0 + b * \ddot{y}_0$$

$\Delta\hat{p}_1$ (kg)	$\Delta\hat{p}_2$ (kg)	$\Delta\hat{p}_3$ (kg)	$\Delta\hat{p}_4$ (kg)	$\Delta\hat{p}_5$ (kg)	$\Delta\hat{p}_6$ (kg)	$\Delta\hat{p}_7$ (kg)	$\Delta\hat{p}_8$ (kg)	$\Delta\hat{p}_9$ (kg)	$\Delta\hat{p}_{10}$ (kg)	$\Delta\hat{p}_{11}$ (kg)	$\Delta\hat{p}_{12}$ (kg)	$\Delta\hat{p}_{13}$ (kg)	$\Delta\hat{p}_{14}$ (kg)	$\Delta\hat{p}_{15}$ (kg)	$\Delta\hat{p}_{16}$ (kg)	$\Delta\hat{p}_{17}$ (kgm)
-17.9695	-17.9695	-17.9695	-17.9695	-17.9695	-17.5299	-17.5299	-17.5299	-17.5299	-17.5299	-16.6104	-16.6104	-16.6104	-16.6104	-16.6104	-282.338	-7689.05

b. Menghitung pertambahan simpangan

$$\Delta y_0 = \hat{k}^{-1} * \Delta \hat{p}$$

Δy_1 (m)	Δy_2 (m)	Δy_3 (m)	Δy_4 (m)	Δy_5 (m)	Δy_6 (m)	Δy_7 (m)	Δy_8 (m)	Δy_9 (m)	Δy_{10} (m)	Δy_{11} (m)	Δy_{12} (m)	Δy_{13} (m)	Δy_{14} (m)	Δy_{15} (m)	Δy_{16} (m)	Δy_{17} (rad)
-8.41E-08	-9.78E-08	-9.735E-08	-9.408E-08	-9.035E-08	-8.622E-08	-8.219E-08	-7.818E-08	-7.421E-08	-7.044E-08	-6.617E-08	-6.213E-08	-5.812E-08	-5.417E-08	-5.066E-08	-5.31E-08	-1.073E-09

c. Menghitung pertambahan kecepatan

$$\Delta \dot{y}_0 = \frac{\gamma}{\beta * \Delta t} \Delta y_0 - \frac{\gamma}{\beta} \dot{y}_0 + \Delta t * \left(1 - \frac{\gamma}{2 * \beta}\right) \ddot{y}_0$$

$\Delta \dot{y}_1$ (m)	$\Delta \dot{y}_2$ (m)	$\Delta \dot{y}_3$ (m)	$\Delta \dot{y}_4$ (m)	$\Delta \dot{y}_5$ (m)	$\Delta \dot{y}_6$ (m)	$\Delta \dot{y}_7$ (m)	$\Delta \dot{y}_8$ (m)	$\Delta \dot{y}_9$ (m)	$\Delta \dot{y}_{10}$ (m)	$\Delta \dot{y}_{11}$ (m)	$\Delta \dot{y}_{12}$ (m)	$\Delta \dot{y}_{13}$ (m)	$\Delta \dot{y}_{14}$ (m)	$\Delta \dot{y}_{15}$ (m)	$\Delta \dot{y}_{16}$ (m)	$\Delta \dot{y}_{17}$ (m)
-1.682E-05	-1.956E-05	-1.947E-05	-1.882E-05	-1.807E-05	-1.724E-05	-1.644E-05	-1.564E-05	-1.484E-05	-1.409E-05	-1.323E-05	-1.243E-05	-1.162E-05	-1.083E-05	-1.013E-05	-1.062E-05	-2.147E-07

d. Menghitung pertambahan percepatan

$$\Delta \ddot{y}_0 = \frac{1}{\beta * \Delta t^2} \Delta y_0 - \frac{1}{\beta * \Delta t} \dot{y}_0 - \frac{1}{2 * \beta} \ddot{y}_0$$

$\Delta \ddot{y}_1$ (m)	$\Delta \ddot{y}_2$ (m)	$\Delta \ddot{y}_3$ (m)	$\Delta \ddot{y}_4$ (m)	$\Delta \ddot{y}_5$ (m)	$\Delta \ddot{y}_6$ (m)	$\Delta \ddot{y}_7$ (m)	$\Delta \ddot{y}_8$ (m)	$\Delta \ddot{y}_9$ (m)	$\Delta \ddot{y}_{10}$ (m)	$\Delta \ddot{y}_{11}$ (m)	$\Delta \ddot{y}_{12}$ (m)	$\Delta \ddot{y}_{13}$ (m)	$\Delta \ddot{y}_{14}$ (m)	$\Delta \ddot{y}_{15}$ (m)	$\Delta \ddot{y}_{16}$ (m)	$\Delta \ddot{y}_{17}$ (m)
-0.003364	-0.0039119	-0.003894	-0.0037632	-0.0036141	-0.0034489	-0.0032877	-0.0031273	-0.0029684	-0.0028176	-0.0026468	-0.002485	-0.0023246	-0.0021667	-0.0020265	-0.0021242	-4.294E-05

e. Menghitung simpangan

$$\Delta y_1 = y_0 + \Delta y_0$$

y_1 (m)	y_2 (m)	y_3 (m)	y_4 (m)	y_5 (m)	y_6 (m)	y_7 (m)	y_8 (m)	y_9 (m)	y_{10} (m)	y_{11} (m)	y_{12} (m)	y_{13} (m)	y_{14} (m)	y_{15} (m)	y_{16} (m)	y_{17} (rad)
-8.4099E-08	-9.7798E-08	-9.735E-08	-9.4081E-08	-9.0352E-08	-8.6223E-08	-8.2191E-08	-7.8182E-08	-7.4211E-08	-7.044E-08	-6.617E-08	-6.2125E-08	-5.8116E-08	-5.4167E-08	-5.0663E-08	-5.3104E-08	-1.0735E-09

f. Menghitung kecepatan

$$\Delta \dot{y}_1 = \dot{y}_0 + \Delta \dot{y}_0$$

$\dot{y}_1$ (m)	$\dot{y}_2$ (m)	$\dot{y}_3$ (m)	$\dot{y}_4$ (m)	$\dot{y}5$ (m)	$\dot{y}_6$ (m)	$\dot{y}_7$ (m)	$\dot{y}_8$ (m)	$\dot{y}_9$ (m)	$\dot{y}_{10}$ (m)	$\dot{y}_{11}$ (m)	$\dot{y}_{12}$ (m)	$\dot{y}_{13}$ (m)	$\dot{y}_{14}$ (m)	$\dot{y}_{15}$ (m)	$\dot{y}_{16}$ (m)	$\dot{y}_{17}$ (m)
-1.7E-05	-2E-05	-1.9E-05	-1.9E-05	-1.8E-05	-1.7E-05	-1.6E-05	-1.6E-05	-1.5E-05	-1.4E-05	-1.3E-05	-1.2E-05	-1.2E-05	-1.1E-05	-1E-05	-1.1E-05	-2.1E-07

g. Menghitung percepatan

$$\Delta\ddot{y}_1 = \ddot{y}_0 + \Delta\ddot{y}_0$$

$\ddot{y}_1$ (m)	$\ddot{y}_2$ (m)	$\ddot{y}_3$ (m)	$\ddot{y}_4$ (m)	$\ddot{y}_5$ (m)	$\ddot{y}_6$ (m)	$\ddot{y}_7$ (m)	$\ddot{y}_8$ (m)	$\ddot{y}_9$ (m)	$\ddot{y}_{10}$ (m)	$\ddot{y}_{11}$ (m)	$\ddot{y}_{12}$ (m)	$\ddot{y}_{13}$ (m)	$\ddot{y}_{14}$ (m)	$\ddot{y}_{15}$ (m)	$\ddot{y}_{16}$ (m)	$\ddot{y}_{17}$ (m)
-0.00336	-0.00391	-0.00389	-0.00376	-0.00361	-0.00345	-0.00329	-0.00313	-0.00297	-0.00282	-0.00265	-0.00249	-0.00232	-0.00217	-0.00203	-0.00212	-4.3E-05

h. Menghitung simpangan relatif/neto

SN 0 (m)	SN 1 (m)	SN 2 (m)	SN 3 (m)	SN 4 (m)	SN 5 (m)	SN 6 (m)	SN 7 (m)	SN 8 (m)	SN 9 (m)	SN 10 (m)	SN 11 (m)	SN 12 (m)	SN 13 (m)	SN 14 (m)	SN 15 (m)
-5.31042E-08	-8.4099E-08	-9.7798E-08	-9.735E-08	-9.4081E-08	-9.0352E-08	-8.6223E-08	-8.2191E-08	-7.8182E-08	-7.4211E-08	-7.044E-08	-6.617E-08	-6.2125E-08	-5.8116E-08	-5.4167E-08	-5.0663E-08

i. Menghitung sudut rotasi fondasi

ϕ = -1.07349E-09 rad

j. Menghitung simpangan rotasi

$$y = h * \tan(\phi)$$

SR 1 (m)	SR 2 (m)	SR 3 (m)	SR 4 (m)	SR 5 (m)	SR 6 (m)	SR 7 (m)	SR 8 (m)	SR 9 (m)	SR 10 (m)	SR 11 (m)	SR 12 (m)	SR 13 (m)	SR 14 (m)	SR 15 (m)
-4.0256E-09	-8.0512E-09	-1.2077E-08	-1.6102E-08	-2.0128E-08	-2.4154E-08	-2.8179E-08	-3.2205E-08	-3.623E-08	-4.0256E-08	-4.4281E-08	-4.8307E-08	-5.2333E-08	-5.6358E-08	-6.0384E-08

k. Menghitung simpangan total

Simpangan total merupakan jumlah dari simpangan relatif fondasi ditambah simpangan realtif ditambah simpangan rotasi.

ST 0 (m)	ST 1 (m)	ST 2 (m)	ST 3 (m)	ST 4 (m)	ST 5 (m)	ST 6 (m)	ST 7 (m)	ST 8 (m)	ST 9 (m)	ST 10 (m)	ST 11 (m)	ST 12 (m)	ST 13 (m)	ST 14 (m)	ST 15 (m)
-5.3104E-08	-1.41229E-07	-1.58953E-07	-1.62531E-07	-1.63287E-07	-1.63584E-07	-1.63481E-07	-1.63475E-07	-1.63491E-07	-1.63545E-07	-1.638E-07	-1.63556E-07	-1.63536E-07	-1.63553E-07	-1.63629E-07	-1.64151E-07

l. Menghitung drift ratio

$$yy(t) = \frac{y_j(t) - y_{j-1}(t)}{H} * 100\%$$

Drift ratio simpangan relatif

DR 1 (%)	DR 2 (%)	DR 3 (%)	DR 4 (%)	DR 5 (%)	DR 6 (%)	DR 7 (%)	DR 8 (%)	DR 9 (%)	DR 10 (%)	DR 11 (%)	DR 12 (%)	DR 13 (%)	DR 14 (%)	DR 15 (%)
-2.2426E-06	-3.653E-07	1.19E-08	8.72E-08	9.94E-08	1.1E-07	1.08E-07	1.07E-07	1.06E-07	1.01E-07	1.14E-07	1.08E-07	1.07E-07	1.05E-07	9.34E-08

Drift ratio simpangan total

DR 1 (%)	DR 2 (%)	DR 3 (%)	DR 4 (%)	DR 5 (%)	DR 6 (%)	DR 7 (%)	DR 8 (%)	DR 9 (%)	DR 10 (%)	DR 11 (%)	DR 12 (%)	DR 13 (%)	DR 14 (%)	DR 15 (%)
-3.76611E-06	-4.72644E-07	-9.5E-08	-2E-08	-7.9E-09	2.73E-09	1.74E-10	-4.3E-10	-1.4E-09	-6.8E-09	6.53E-09	5.14E-10	-4.4E-10	-2E-09	-1.4E-08

m. Menghitung gaya horizontal

$$F_j(t) = y_j(t) * K_j$$

FH 1 (kg)	FH 2 (kg)	FH 3 (kg)	FH 4 (kg)	FH 5 (kg)	FH 6 (kg)	FH 7 (kg)	FH 8 (kg)	FH 9 (kg)	FH 10 (kg)	FH 11 (kg)	FH 12 (kg)	FH 13 (kg)	FH 14 (kg)	FH 15 (kg)
-1.47999	-0.29739	-0.05932	-0.00966	0.009317	0.001607099	0.000380589	0.000635582	0.003364687	0.019191394	0.002317723	0.000366727	0.000617635	0.004576953	0.036017246

n. Menghitung gaya geser

$$V(t) = \sum_{j=1}^{n} F(t)$$

V 1 (kg)	V 2 (kg)	V 3 (kg)	V 4 (kg)	V 5 (kg)	V 6 (kg)	V 7 (kg)	V 8 (kg)	V 9 (kg)	V 10 (kg)	V 11 (kg)	V 12 (kg)	V 13 (kg)	V 14 (kg)	V 15 (kg)
-1.767964	-0.287976	0.0094121	0.0687327	0.0783931	0.069075634	0.067468535	0.06708795	0.066452364	0.063087678	0.043896284	0.041578561	0.041211834	0.040594198	0.036017246

o. Menghitung momen guling

$$M_g = F_j(t) * H$$

MG 0 (kgm)	MG 1 (kgm)	MG 2 (kgm)	MG 3 (kgm)	MG 4 (kgm)	MG 5 (kgm)	MG 6 (kgm)	MG 7 (kgm)	MG 8 (kgm)	MG 9 (kgm)	MG 10 (kgm)	MG 11 (kgm)	MG 12 (kgm)	MG 13 (kgm)	MG 14 (kgm)	MG 15 (kgm)
-5.1109942	1.51887009	2.59878056	2.56348517	2.30573762	2.011763549	1.752729921	1.499722914	1.248143113	0.998946747	0.762367956	0.597756893	0.441837291	0.287292915	0.135064671	0

2. Step ke 2 (0,02 detik)

$$\Delta p = (\ddot{y}b_2 - \ddot{y}b_1)\begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ m_0 + m_1 + m_2 + m_3 \\ m_1 h_1 + m_2 h_2 + m_3 h_3 \end{bmatrix}$$

Rumus di atas untuk 3 tingkat, sedangkan untuk 15 tingkat sama konsepnya.

Δp_1 (kg)	Δp_2 (kg)	Δp_3 (kg)	Δp_4 (kg)	Δp_5 (kg)	Δp_6 (kg)	Δp_7 (kg)	Δp_8 (kg)	Δp_9 (kg)	Δp_{10} (kg)	Δp_{11} (kg)	Δp_{12} (kg)	Δp_{13} (kg)	Δp_{14} (kg)	Δp_{15} (kg)	Δp_{16} (kg)	Δp_{17} (kgm)
-17.9695	-17.9695	-17.9695	-17.9695	-17.9695	-17.5299	-17.5299	-17.5299	-17.5299	-17.5299	-16.6104	-16.6104	-16.6104	-16.6104	-16.6104	-282.338	-7689.05

a. Menghitung pertambahan pembebanan

$$\Delta\hat{p} = \Delta p_1 + a * \dot{y}_1 + b * \ddot{y}_1$$

$\Delta\hat{p}_1$ (kg)	$\Delta\hat{p}_2$ (kg)	$\Delta\hat{p}_3$ (kg)	$\Delta\hat{p}_4$ (kg)	$\Delta\hat{p}_5$ (kg)	$\Delta\hat{p}_6$ (kg)	$\Delta\hat{p}_7$ (kg)	$\Delta\hat{p}_8$ (kg)	$\Delta\hat{p}_9$ (kg)	$\Delta\hat{p}_{10}$ (kg)	$\Delta\hat{p}_{11}$ (kg)	$\Delta\hat{p}_{12}$ (kg)	$\Delta\hat{p}_{13}$ (kg)	$\Delta\hat{p}_{14}$ (kg)	$\Delta\hat{p}_{15}$ (kg)	$\Delta\hat{p}_{16}$ (kg)	$\Delta\hat{p}_{17}$ (kgm)
-81.9501	-88.206	-89.4675	-89.7328	-89.8358	-87.6012	-87.5973	-87.6013	-87.6184	-87.7047	-83.0232	-83.0154	-83.0192	-83.0427	-83.2114	-1361.18	-38399.6

b. Menghitung pertambahan simpangan

$$\Delta y_1 = \hat{k}^{-1} * \Delta\hat{p}$$

Δy_1 (m)	Δy_2 (m)	Δy_3 (m)	Δy_4 (m)	Δy_5 (m)	Δy_6 (m)	Δy_7 (m)	Δy_8 (m)	Δy_9 (m)	Δy_{10} (m)	Δy_{11} (m)	Δy_{12} (m)	Δy_{13} (m)	Δy_{14} (m)	Δy_{15} (m)	Δy_{16} (m)	Δy_{17} (rad)
-4.363E-07	-5.432E-07	-5.538E-07	-5.391E-07	-5.189E-07	-4.95E-07	-4.716E-07	-4.485E-07	-4.256E-07	-4.043E-07	-3.79E-07	-3.554E-07	-3.322E-07	-3.097E-07	-2.907E-07	-1.817E-07	-6.224E-09

c. Menghitung pertambahan kecepatan

$$\Delta\dot{y}_1 = \frac{\gamma}{\beta * \Delta t}\Delta y_1 - \frac{\gamma}{\beta}\dot{y}_1 + \Delta t * \left(1 - \frac{\gamma}{2 * \beta}\right)\ddot{y}_1$$

$\Delta\dot{y}_1$ (m)	$\Delta\dot{y}_2$ (m)	$\Delta\dot{y}_3$ (m)	$\Delta\dot{y}_4$ (m)	$\Delta\dot{y}_5$ (m)	$\Delta\dot{y}_6$ (m)	$\Delta\dot{y}_7$ (m)	$\Delta\dot{y}_8$ (m)	$\Delta\dot{y}_9$ (m)	$\Delta\dot{y}_{10}$ (m)	$\Delta\dot{y}_{11}$ (m)	$\Delta\dot{y}_{12}$ (m)	$\Delta\dot{y}_{13}$ (m)	$\Delta\dot{y}_{14}$ (m)	$\Delta\dot{y}_{15}$ (m)	$\Delta\dot{y}_{16}$ (m)	$\Delta\dot{y}_{17}$ (m)
-5.361E-05	-6.952E-05	-7.181E-05	-7.019E-05	-6.764E-05	-6.452E-05	-6.145E-05	-5.842E-05	-5.544E-05	-5.268E-05	-4.933E-05	-4.624E-05	-4.32E-05	-4.027E-05	-3.787E-05	-1.51E-05	-8.155E-07

d. Menghitung pertambahan percepatan

$$\Delta\ddot{y}_1 = \frac{1}{\beta * \Delta t^2}\Delta y_1 - \frac{1}{\beta * \Delta t}\dot{y}_1 - \frac{1}{2 * \beta}\ddot{y}_1$$

$\Delta\ddot{y}_1$ (m)	$\Delta\ddot{y}_2$ (m)	$\Delta\ddot{y}_3$ (m)	$\Delta\ddot{y}_4$ (m)	$\Delta\ddot{y}_5$ (m)	$\Delta\ddot{y}_6$ (m)	$\Delta\ddot{y}_7$ (m)	$\Delta\ddot{y}_8$ (m)	$\Delta\ddot{y}_9$ (m)	$\Delta\ddot{y}_{10}$ (m)	$\Delta\ddot{y}_{11}$ (m)	$\Delta\ddot{y}_{12}$ (m)	$\Delta\ddot{y}_{13}$ (m)	$\Delta\ddot{y}_{14}$ (m)	$\Delta\ddot{y}_{15}$ (m)	$\Delta\ddot{y}_{16}$ (m)	$\Delta\ddot{y}_{17}$ (m)
-0.003995	-0.0060799	-0.0065746	-0.0065113	-0.0062996	-0.0060054	-0.0057152	-0.0054292	-0.0051516	-0.0049008	-0.0045729	-0.0042773	-0.0039912	-0.0037207	-0.0035202	0.00122925	-7.722E-05

e. Menghitung simpangan

$$\Delta y_2 = y_1 + \Delta y_1$$

y_1 (m)	y_2 (m)	y_3 (m)	y_4 (m)	y_5 (m)	y_6 (m)	y_7 (m)	y_8 (m)	y_9 (m)	y_{10} (m)	y_{11} (m)	y_{12} (m)	y_{13} (m)	y_{14} (m)	y_{15} (m)	y_{16} (m)	y_{17} (rad)
-5.2037E-07	-6.4099E-07	-6.5111E-07	-6.3318E-07	-6.0925E-07	-5.8125E-07	-5.5384E-07	-5.2664E-07	-4.9984E-07	-4.7472E-07	-4.4517E-07	-4.1756E-07	-3.9036E-07	-3.6385E-07	-3.4132E-07	-2.3479E-07	-7.2979E-09

f. Menghitung kecepatan

$$\Delta\dot{y}_2 = \dot{y}_1 + \Delta\dot{y}_1$$

$\dot{y}_1$ (m)	$\dot{y}_2$ (m)	$\dot{y}_3$ (m)	$\dot{y}_4$ (m)	$\dot{y}$5 (m)	$\dot{y}_6$ (m)	$\dot{y}_7$ (m)	$\dot{y}_8$ (m)	$\dot{y}_9$ (m)	$\dot{y}_{10}$ (m)	$\dot{y}_{11}$ (m)	$\dot{y}_{12}$ (m)	$\dot{y}_{13}$ (m)	$\dot{y}_{14}$ (m)	$\dot{y}_{15}$ (m)	$\dot{y}_{16}$ (m)	$\dot{y}_{17}$ (m)
-7E-05	-8.9E-05	-9.1E-05	-8.9E-05	-8.6E-05	-8.2E-05	-7.8E-05	-7.4E-05	-7E-05	-6.7E-05	-6.3E-05	-5.9E-05	-5.5E-05	-5.1E-05	-4.8E-05	-2.6E-05	-1E-06

g. Menghitung percepatan

$$\Delta\ddot{y}_2 = \ddot{y}_1 + \Delta\ddot{y}_1$$

$\ddot{y}_1$ (m)	$\ddot{y}_2$ (m)	$\ddot{y}_3$ (m)	$\ddot{y}_4$ (m)	$\ddot{y}_5$ (m)	$\ddot{y}_6$ (m)	$\ddot{y}_7$ (m)	$\ddot{y}_8$ (m)	$\ddot{y}_9$ (m)	$\ddot{y}_{10}$ (m)	$\ddot{y}_{11}$ (m)	$\ddot{y}_{12}$ (m)	$\ddot{y}_{13}$ (m)	$\ddot{y}_{14}$ (m)	$\ddot{y}_{15}$ (m)	$\ddot{y}_{16}$ (m)	$\ddot{y}_{17}$ (m)
-0.00736	-0.00999	-0.01047	-0.01027	-0.00991	-0.00945	-0.009	-0.00856	-0.00812	-0.00772	-0.00722	-0.00676	-0.00632	-0.00589	-0.00555	-0.00089	-0.00012

h. Menghitung simpangan relatif/neto

SN 0 (m)	SN 1 (m)	SN 2 (m)	SN 3 (m)	SN 4 (m)	SN 5 (m)	SN 6 (m)	SN 7 (m)	SN 8 (m)	SN 9 (m)	SN 10 (m)	SN 11 (m)	SN 12 (m)	SN 13 (m)	SN 14 (m)	SN 15 (m)
-2.34789E-07	-5.2037E-07	-6.4099E-07	-6.5111E-07	-6.3318E-07	-6.0925E-07	-5.8125E-07	-5.5384E-07	-5.2664E-07	-4.9984E-07	-4.7472E-07	-4.4517E-07	-4.1756E-07	-3.9036E-07	-3.6385E-07	-3.4132E-07

i. Menghitung sudut rotasi fondasi

ϕ = -7.29786E-09 rad

j. Menghitung simpangan rotasi

$$y = h * \tan(\phi)$$

SR 1 (m)	SR 2 (m)	SR 3 (m)	SR 4 (m)	SR 5 (m)	SR 6 (m)	SR 7 (m)	SR 8 (m)	SR 9 (m)	SR 10 (m)	SR 11 (m)	SR 12 (m)	SR 13 (m)	SR 14 (m)	SR 15 (m)
-2.7367E-08	-5.4734E-08	-8.2101E-08	-1.0947E-07	-1.3683E-07	-1.642E-07	-1.9157E-07	-2.1894E-07	-2.463E-07	-2.7367E-07	-3.0104E-07	-3.284E-07	-3.5577E-07	-3.8314E-07	-4.105E-07

k. Menghitung simpangan total

Simpangan total merupakan jumlah dari simpangan relatif fondasi ditambah simpangan realtif ditambah simpangan rotasi.

ST 0 (m)	ST 1 (m)	ST 2 (m)	ST 3 (m)	ST 4 (m)	ST 5 (m)	ST 6 (m)	ST 7 (m)	ST 8 (m)	ST 9 (m)	ST 10 (m)	ST 11 (m)	ST 12 (m)	ST 13 (m)	ST 14 (m)	ST 15 (m)
-2.34796-07	-7.82526E-07	-9.3051E-07	-9.68005E-07	-9.77442E-07	-9.80872E-07	-9.80242E-07	-9.80196E-07	-9.80364E-07	-9.80934E-07	-9.83181E-07	-9.80998E-07	-9.80751E-07	-9.80919E-07	-9.81779E-07	-9.86612E-07

l. Menghitung drift ratio

$$yy(t) = \frac{y_j(t) - y_{j-1}(t)}{H} * 100\%$$

Drift ratio simpangan relatif

DR 1 (%)	DR 2 (%)	DR 3 (%)	DR 4 (%)	DR 5 (%)	DR 6 (%)	DR 7 (%)	DR 8 (%)	DR 9 (%)	DR 10 (%)	DR 11 (%)	DR 12 (%)	DR 13 (%)	DR 14 (%)	DR 15 (%)
-1.3877E-05	-3.2164E-06	-2.7E-07	4.78E-07	6.38E-07	7.47E-07	7.31E-07	7.25E-07	7.15E-07	6.7E-07	7.88E-07	7.36E-07	7.25E-07	7.07E-07	6.01E-07

Drift ratio simpangan total

DR 1 (%)	DR 2 (%)	DR 3 (%)	DR 4 (%)	DR 5 (%)	DR 6 (%)	DR 7 (%)	DR 8 (%)	DR 9 (%)	DR 10 (%)	DR 11 (%)	DR 12 (%)	DR 13 (%)	DR 14 (%)	DR 15 (%)
-2.08674E-05	-3.94622E-06	-1E-06	-2.5E-07	-9.1E-08	1.68E-08	1.24E-09	-4.5E-09	-1.5E-08	-6E-08	5.82E-08	6.58E-09	-4.5E-09	-2.3E-08	-1.3E-07

m. Menghitung gaya horizontal

$$F_j(t) = y_j(t) * K_j$$

FH 1 (kg)	FH 2 (kg)	FH 3 (kg)	FH 4 (kg)	FH 5 (kg)	FH 6 (kg)	FH 7 (kg)	FH 8 (kg)	FH 9 (kg)	FH 10 (kg)	FH 11 (kg)	FH 12 (kg)	FH 13 (kg)	FH 14 (kg)	FH 15 (kg)
-8.40376	-2.32271	-0.58986	-0.12626	0.034722	0.009764199	0.003603374	0.006718351	0.028051577	0.116578467	0.019908203	0.004258919	0.007119939	0.040838317	0.231631634

n. Menghitung gaya geser

$$V(t) = \sum_{j=1}^{n} F(t)$$

V 1 (kg)	V 2 (kg)	V 3 (kg)	V 4 (kg)	V 5 (kg)	V 6 (kg)	V 7 (kg)	V 8 (kg)	V 9 (kg)	V 10 (kg)	V 11 (kg)	V 12 (kg)	V 13 (kg)	V 14 (kg)	V 15 (kg)
-10.9394	-2.535637	-0.212924	0.3769351	0.5031946	0.468472981	0.458708782	0.45510541	0.448387057	0.42033548	0.303757013	0.283848809	0.27958989	0.272469951	0.231631634

o. Menghitung momen guling

$$M_g = F_j(t) * H$$

MG 0 (kgm)	MG 1 (kgm)	MG 2 (kgm)	MG 3 (kgm)	MG 4 (kgm)	MG 5 (kgm)	MG 6 (kgm)	MG 7 (kgm)	MG 8 (kgm)	MG 9 (kgm)	MG 10 (kgm)	MG 11 (kgm)	MG 12 (kgm)	MG 13 (kgm)	MG 14 (kgm)	MG 15 (kgm)
-34.445721	6.57703249	16.085673	16.8841377	15.470631	13.58365127	11.82687759	10.10671966	8.400074377	6.718622913	5.142364863	4.003276065	2.93884303	1.890380942	0.868618627	0

Untuk detik selanjutnya caranya sama.