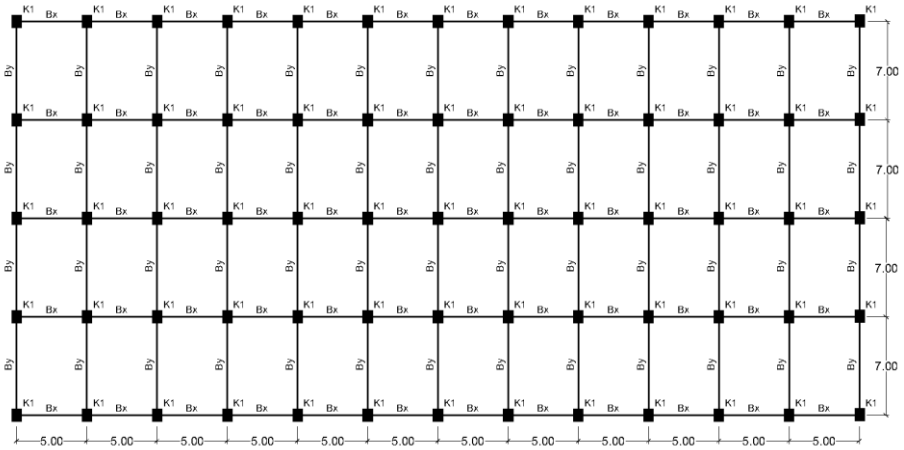
Lampiran 3 Verifikasi Perhitungan Manual dan MATLAB

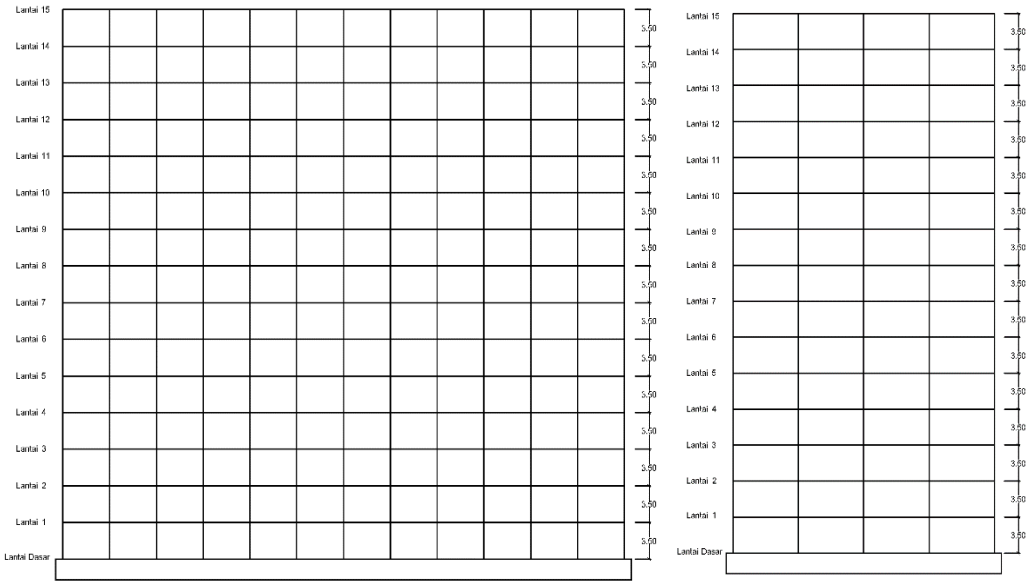
VERIFIKASI PERHITUNGAN MANUAL (MS EXCEL 2016) DAN MATLAB R2013a

A. Data Struktur

Struktur yang digunakan merupakan struktur bangunan reguler berbentuk pipih dengan jumlah lantai 15 lantai yang di bawahnya terdapat fondasi jenis *mat foundations* yang dapat dilihat pada Gambar L-3.1 berikut ini.



a. Denah Bangunan Reguler



b. Tampak X-Z c. Tampak Y-Z

Gambar L-3.1 Model Struktur

Analisis perhitungan berupa massa struktur, kekakuan struktur atas, kekakuan dan redaman interaksi tanah dengan fondasi, massa tingkat dasar, dan momen inersia polar telah dihitung pada BAB 5 dengan hasil sebagai berikut ini.

Tabel 1 Nilai Kekakuan Interaksi Tanah dengan Fondasi

Pemodelan	Kekakuan Horizontal (kg/cm)		Kekakuan Rotasi (kg/rad)	
	Arah X	Arah Y	Arah X	Arah Y
Fondasi	18793479,6177	20731974,5904	2,1946E+14	6,4379E+13
Jepit	1,8793E+18	2,0732E+18	2,1946E+25	6,4379E+24

Tabel 2 Nilai Redaman Interaksi Tanah dengan Fondasi

Pemodelan	Redaman Horizontal (kg dt/cm)		Redaman Rotasi (kg dt/rad)	
	Arah X	Arah Y	Arah X	Arah Y
Fondasi	858113,8620	812799,0672	4,4530E+12	1,1467E+12
Jepit	8,5811E+16	8,1280E+16	4,4530E+23	1,1467E+23

Tabel 3 Nilai Massa, Kekakuan, dan Tinggi Lantai Struktur Atas

Lantai	Massa (M) (kg dt²/cm)	Kekakuan Arah X (K) (kg/cm)	Kekakuan Arah Y (K) (kg/cm)	Tinggi Sampai Lantai Dasar (H) (cm)
0	9380,7360	I_G = 1,44601E+11		0
1	1911,2581	4471097,743	6834859,158	350
2	1911,2581	3222376,317	4170093,894	700
3	1911,2581	3222376,317	4170093,894	1050
4	1911,2581	3222376,317	4170093,894	1400
5	1911,2581	3222376,317	4170093,894	1750
6	1911,2581	3222376,317	4170093,894	2100
7	1911,2581	3222376,317	4170093,894	2450
8	1911,2581	3222376,317	4170093,894	2800
9	1911,2581	3222376,317	4170093,894	3150
10	1911,2581	3222376,317	4170093,894	3500
11	1911,2581	3222376,317	4170093,894	3850
12	1911,2581	3222376,317	4170093,894	4200
13	1911,2581	3222376,317	4170093,894	4550
14	1911,2581	3222376,317	4170093,894	4900
15/Atap	1067,4679	3197041,485	4124638,995	5250

B. Perhitungan Manual

Perhitungan manual mengambil contoh pada perhitungan respon dinamik bangunan dengan rotasi arah x pada pembebanan dominan arah x menggunakan gempa dengan frekuensi rendah (Gempa Duzce). Nilai simpangan netto, sudut rotasi, simpangan rotasi, simpangan total, *interstorey drift ratio*, gaya horizontal tingkat, gaya geser tingkat, dan momen guling dicari menggunakan persamaan iterasi *β-Newmark*. Langkah perhitungannya akan dijelaskan sebagai berikut ini.

1. Mencari Nilai ω Melalui Persamaan *Eigenproblem*

$$[M] = \begin{bmatrix} m1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & m2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & m3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & m4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & m6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & m7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & m8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m10 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m11 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m12 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m13 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m14 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m15 \end{bmatrix}$$

$$[M] = \begin{bmatrix} 1911,3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1911,3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1911,26 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1067,47 \end{bmatrix}$$

Matriks massa dibagi dengan unit massa dengan nilai unit massa M = 1911,2581 sehingga akan diperoleh matriks massa:

$$[M] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0{,}55852 \end{bmatrix}$$

Menyusun matriks kekakuan sebagai berikut.

$$[K] = \begin{bmatrix} k1+k2 & -k2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -k2 & k2+k3 & -k3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k3 & k3+k4 & -k4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -k4 & k4+k5 & -k5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -k5 & k5+k6 & -k6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -k6 & k6+k7 & -k7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -k7 & k7+k8 & -k8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -k8 & k8+k9 & -k9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k9 & k9+k10 & -k10 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k10 & k10+k11 & -k11 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k11 & k11+k12 & -k12 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k12 & k12+k13 & -k13 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k13 & k13+k14 & -k14 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k14 & k14+k15 & -k15 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k15 & k15 \end{bmatrix}$$

$$[K] = \begin{bmatrix} 7693474 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6419418 & -3197041 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3197041 & 3197041 \end{bmatrix}$$

Matriks kekakuan dibagi dengan unit kekakuan dengan nilai unit kekakuan K = 6444752,6346 sehingga akan diperoleh matriks kekakuan:

$$[K] = \begin{bmatrix}
1{,}194 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1 & -0{,}5 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 0{,}996 & -0{,}496 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}496 & 0{,}496
\end{bmatrix}$$

Setelah didapatkan matriks massa dan matriks kekakuan struktur atas, maka disusun persamaan eigen problem seperti pada persamaan 3.38.

$$\{[K] - \omega^2[M]\}\{\phi\}_i = 0$$

$$\begin{bmatrix} 1{,}194-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 0{,}966-\omega^2 & -0{,}496 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}496 & 0{,}496-0{,}559\omega^2 & 0 \end{bmatrix} \begin{bmatrix} \varphi 1 \\ \varphi 2 \\ \varphi 3 \\ \varphi 4 \\ \varphi 5 \\ \varphi 6 \\ \varphi 7 \\ \varphi 8 \\ \varphi 9 \\ \varphi 10 \\ \varphi 11 \\ \varphi 12 \\ \varphi 13 \\ \varphi 14 \\ \varphi 15 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Penyelesaian persamaan di atas menggunakan persamaan 3.42 dan akan menghasilkan nilai ω dengan persamaan: $|[K] - \omega^2[M]| = 0$

$$\begin{bmatrix} 1{,}194-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 1-\omega^2 & -0{,}5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}5 & 0{,}966-\omega^2 & -0{,}496 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0{,}496 & 0{,}496-0{,}559\omega^2 & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Penyelesaian persamaan di atas akan menghasilkan nilai ω sebagai berikut.

ω_1 = 4,3619915 rad/dt

ω_2 = 13,034989 rad/dt

ω_3 = 21,555685 rad/dt

ω_4 = 29,824716 rad/dt

ω_5 = 37,745971 rad/dt

ω_6 = 45,227875 rad/dt

ω_7 = 52,184681 rad/dt

ω_8 = 58,537799 rad/dt

ω_9 = 64,217217 rad/dt

ω_{10} = 69,163128 rad/dt

ω_{11} = 73,327911 rad/dt

ω_{12} = 76,678661 rad/dt

ω_{13} = 79,200644 rad/dt

ω_{14} = 80,903534 rad/dt

ω_{15} = 81,838597 rad/dt

2. Mencari Matriks Redaman

Matriks redaman dicari menggunakan metode *mass and stifness proportional damping* dengan menentukan beberapa nilai sebagai berikut ini.

- Mode ke 1

  ω_j = 4,3619915 rad/dt

  ξ_j = 5 %

- Mode ke 2

  ω_i = 13,034989 rad/dt

  ξ_i = 5 %

a. Mencari Nilai β

$$\beta = \frac{2(\xi_j \omega_j - \xi_i \omega_i)}{\omega_j{}^2 - \omega_i{}^2}$$

$$= \frac{2(0{,}05\ x\ 4{,}3619915 - 0{,}05\ x\ 13{,}034989)}{4{,}3619915^2 - 13{,}034989^2}$$

= 0,0057748124

b. Mencari Nilai α

α $= 2\xi_j \omega_j - \beta\omega_j^2$

$= (2 \times 0{,}05 \times 4{,}3619915) - (0{,}0057748124 \times 4{,}3619915^2)$

$= 0{,}326829772$

Selanjutnya, matriks redaman struktur atas dicari menggunakan persamaan 3.24 yaitu $[C] = a[M] + \beta[K]$

α [M] = 0,326829772

1911,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1911,3	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1911,26	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1911,26	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1911,26	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1911,26	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1911,26	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1911,26	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1911,26	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1911,26	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1911,26	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1911,26	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1911,26	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1911,26	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1067,47

α [M] =

624,7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	624,7	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	624,7	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	624,7	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	624,7	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	624,7	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	624,7	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	624,7	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	624,7	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	624,7	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	624,7	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	624,7	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	624,7	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	624,7	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	348,9

β [K] = 0,005748124

7693474	-3222376	0	0	0	0	0	0	0	0	0	0	0	0	0
-3222376	6444753	-3222376	0	0	0	0	0	0	0	0	0	0	0	0
0	-3222376	6444753	-3222376	0	0	0	0	0	0	0	0	0	0	0
0	0	-3222376	6444753	-3222376	0	0	0	0	0	0	0	0	0	0
0	0	0	-3222376	6444753	-3222376	0	0	0	0	0	0	0	0	0
0	0	0	0	-3222376	6444753	-3222376	0	0	0	0	0	0	0	0
0	0	0	0	0	-3222376	6444753	-3222376	0	0	0	0	0	0	0
0	0	0	0	0	0	-3222376	6444753	-3222376	0	0	0	0	0	0
0	0	0	0	0	0	0	-3222376	6444753	-3222376	0	0	0	0	0
0	0	0	0	0	0	0	0	-3222376	6444753	-3222376	0	0	0	0
0	0	0	0	0	0	0	0	0	-3222376	6444753	-3222376	0	0	0
0	0	0	0	0	0	0	0	0	0	-3222376	6444753	-3222376	0	0
0	0	0	0	0	0	0	0	0	0	0	-3222376	6444753	-3222376	0
0	0	0	0	0	0	0	0	0	0	0	0	-3222376	6419418	-3197041
0	0	0	0	0	0	0	0	0	0	0	0	0	-3197041	3197041

$$\beta\,[K] = \begin{bmatrix}
44223 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 37045 & -18523 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18523 & 36900 & -18377 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18377 & 18377
\end{bmatrix}$$

dengan $[C] = a[M] + \beta[K]$ maka didapat matriks redaman struktur atas [C] sebagai berikut.

$$[C] = \begin{bmatrix}
44847,7 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37524,3 & -18377,0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18377,0 & 18725,9
\end{bmatrix}$$

3. Menyusun Matriks Massa, Kekakuan, dan Redaman Struktur Bangunan dengan Fondasi

   Matriks massa dan kekakuan bangunan beserta fondasi disusun berdasarkan persamaan 3.79 dan matriks redaman bangunan beserta fondasi disusun berdasarkan persamaan 3.83 kemudian persamaan penyelesaian untuk mendapatkan respon dinamik bangunan menggunakan persamaan 3.78.

[M] =

m1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	m1	m1.h1
0	m2	0	0	0	0	0	0	0	0	0	0	0	0	0	m2	m2.h2
0	0	m3	0	0	0	0	0	0	0	0	0	0	0	0	m3	m3.h3
0	0	0	m4	0	0	0	0	0	0	0	0	0	0	0	m4	m4.h4
0	0	0	0	m5	0	0	0	0	0	0	0	0	0	0	m5	m5.h5
0	0	0	0	0	m6	0	0	0	0	0	0	0	0	0	m6	m6.h6
0	0	0	0	0	0	m7	0	0	0	0	0	0	0	0	m7	m7.h7
0	0	0	0	0	0	0	m8	0	0	0	0	0	0	0	m8	m8.h8
0	0	0	0	0	0	0	0	m9	0	0	0	0	0	0	m9	m9.h9
0	0	0	0	0	0	0	0	0	m10	0	0	0	0	0	m10	m10.h10
0	0	0	0	0	0	0	0	0	0	m11	0	0	0	0	m11	m11.h11
0	0	0	0	0	0	0	0	0	0	0	m12	0	0	0	m12	m12.h12
0	0	0	0	0	0	0	0	0	0	0	0	m13	0	0	m13	m13.h13
0	0	0	0	0	0	0	0	0	0	0	0	0	m14	0	m14	m14.h14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	m15	m15	m15.h15
m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14	m15	Σmi dengan i 0-15	Σmi.hi dengan i 1-15
m1.h1	m2.h2	m3.h3	m4.h4	m5.h5	m6.h6	m7.h7	m8.h8	m9.h9	m10.h10	m11.h11	m12.h12	m13.h13	m14.h14	m15.h15	Σmi.hi dengan i 1-15	Σmi.hi² + IG dengan i 1-15

[M] =

1911,3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1911,3	668940
0	1911,3	0	0	0	0	0	0	0	0	0	0	0	0	0	1911,3	1337881
0	0	1911,3	0	0	0	0	0	0	0	0	0	0	0	0	1911,3	2006821
0	0	0	1911,3	0	0	0	0	0	0	0	0	0	0	0	1911,3	2675761
0	0	0	0	1911,3	0	0	0	0	0	0	0	0	0	0	1911,3	3344702
0	0	0	0	0	1911,3	0	0	0	0	0	0	0	0	0	1911,3	4013642
0	0	0	0	0	0	1911,3	0	0	0	0	0	0	0	0	1911,3	4682582
0	0	0	0	0	0	0	1911,3	0	0	0	0	0	0	0	1911,3	5351523
0	0	0	0	0	0	0	0	1911,3	0	0	0	0	0	0	1911,3	6020463
0	0	0	0	0	0	0	0	0	1911,3	0	0	0	0	0	1911,3	6689403
0	0	0	0	0	0	0	0	0	0	1911,3	0	0	0	0	1911,3	7358344
0	0	0	0	0	0	0	0	0	0	0	1911,3	0	0	0	1911,3	8027284
0	0	0	0	0	0	0	0	0	0	0	0	1911,3	0	0	1911,3	8696224
0	0	0	0	0	0	0	0	0	0	0	0	0	1911,3	0	1911,3	9365165
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1067,5	1067,5	5604206
1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1911,3	1067,5	37205,8	75842940
668940	1337881	2006821	2675761	3344702	4013642	4682582	5351523	6020463	6689403	7358344	8027284	8696224	9365165	5604206	75842940	4,12E+11

$$[K] = \begin{bmatrix}
k1 + k2 & -k2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-k2 & k2 + k3 & -k3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -k3 & k3 + k4 & -k4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -k4 & k4 + k5 & -k5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -k5 & k5 + k6 & -k6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -k6 & k6 + k7 & -k7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -k7 & k7 + k8 & -k8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -k8 & k8 + k9 & -k9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -k9 & k9 + k10 & -k10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k10 & k10 + k11 & -k11 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k11 & k11 + k12 & -k12 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k12 & k12 + k13 & -k13 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k13 & k13 + k14 & -k14 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k14 & k14 + k15 & -k15 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k15 & k15 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & kh & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & kr
\end{bmatrix}$$

$$[K] = \begin{bmatrix}
7693474 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6419418 & -3197041 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3197041 & 3197041 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18793479,62 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2,195E+14 & 0
\end{bmatrix}$$

$$[C] = \begin{bmatrix}
c1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & c2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & c3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & c4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & c5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & c6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & c7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & c8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c11 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c12 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c13 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c14 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & c15 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & ch & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & cr
\end{bmatrix}$$

$$[C] = \begin{bmatrix}
44847,7 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37669,9 & -18522,6 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18522,6 & 37524,3 & -18377,0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18377,0 & 18725,9 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 858113,86 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4,453E+12 & 0
\end{bmatrix}$$

4. Menghitung Konstanta $\hat{k}$, a, dan b

Nilai γ dan β perlu ditentukan terlebih dahulu untuk menghitung nilai-nilai konstanta dalam iterasi metode *β-Newmark*. Pada penelitian ini, nilai γ dan β yang digunakan adalah γ = 0,5 dan β = 0,25 sehingga jalannya iterasi mengikuti prinsip *Constant Average Acceleration*.

a. Menghitung nilai $\hat{k}$

Nilai $\hat{k}$ dihitung berdasarkan persamaan 3.92, yaitu $\hat{k} = \left\{[K] + \frac{\gamma}{\beta\,\Delta t}\,[C] + \frac{1}{\beta\,(\Delta t)^2}\,[M]\right\}$

Δt = 0,01 dt

$\frac{\gamma}{\beta\,\Delta t} = \frac{0{,}5}{0{,}25\,x\,0{,}01} = 200$

$\frac{1}{\beta\,(\Delta t)^2} = \frac{1}{0{,}25\,(0{,}01)^2} = 40000$

maka didapat nilai $\hat{k}$

K^ =

93113336	-6926900	0	0	0	0	0	0	0	0	0	0	0	0	0	76450323	2,68E+10
-6926900	90429054	-6926900	0	0	0	0	0	0	0	0	0	0	0	0	76450323	5,35E+10
0	-6926900	90429054	-6926900	0	0	0	0	0	0	0	0	0	0	0	76450323	8,03E+10
0	0	-6926900	90429054	-6926900	0	0	0	0	0	0	0	0	0	0	76450323	1,07E+11
0	0	0	-6926900	90429054	-6926900	0	0	0	0	0	0	0	0	0	76450323	1,34E+11
0	0	0	0	-6926900	90429054	-6926900	0	0	0	0	0	0	0	0	76450323	1,61E+11
0	0	0	0	0	-6926900	90429054	-6926900	0	0	0	0	0	0	0	76450323	1,87E+11
0	0	0	0	0	0	-6926900	90429054	-6926900	0	0	0	0	0	0	76450323	2,14E+11
0	0	0	0	0	0	0	-6926900	90429054	-6926900	0	0	0	0	0	76450323	2,41E+11
0	0	0	0	0	0	0	0	-6926900	90429054	-6926900	0	0	0	0	76450323	2,68E+11
0	0	0	0	0	0	0	0	0	-6926900	90429054	-6926900	0	0	0	76450323	2,94E+11
0	0	0	0	0	0	0	0	0	0	-6926900	90429054	-6926900	0	0	76450323	3,21E+11
0	0	0	0	0	0	0	0	0	0	0	-6926900	90429054	-6926900	0	76450323	3,48E+11
0	0	0	0	0	0	0	0	0	0	0	0	-6926900	90374593	-6872440	76450323	3,75E+11
0	0	0	0	0	0	0	0	0	0	0	0	0	-6872440	49640931	42698716	2,24E+11
76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	76450323	42698716	1,68E+09	3,03E+12
2,68E+10	5,35E+10	8,03E+10	1,07E+11	1,34E+11	1,61E+11	1,87E+11	2,14E+11	2,41E+11	2,68E+11	2,94E+11	3,21E+11	3,48E+11	3,75E+11	2,24E+11	3,03E+12	1,76E+16

kemudian mencari nilai $\hat{k}^{-1}$. Nilai ini merupakan inverse dari matriks $\hat{k}$ yang nilainya memiliki hasil sebagai berikut

K^-1 =

1,2E-08	2,4E-09	1,7E-09	1,6E-09	1,6E-09	1,6E-09	1,7E-09	1,7E-09	1,7E-09	1,7E-09	1,7E-09	1,7E-09	1,8E-09	1,8E-09	1,8E-09	-1,6E-09	-4,7E-14
2,4E-09	1,3E-08	2,7E-09	1,9E-09	1,9E-09	1,9E-09	2,0E-09	2,0E-09	2,0E-09	2,1E-09	2,1E-09	2,1E-09	2,2E-09	2,2E-09	2,2E-09	-1,7E-09	-9,9E-14
1,7E-09	2,7E-09	1,3E-08	2,8E-09	2,1E-09	2,0E-09	2,1E-09	2,1E-09	2,2E-09	2,2E-09	2,3E-09	2,4E-09	2,4E-09	2,5E-09	2,5E-09	-1,7E-09	-1,5E-13
1,6E-09	1,9E-09	2,8E-09	1,3E-08	2,9E-09	2,2E-09	2,2E-09	2,3E-09	2,4E-09	2,4E-09	2,5E-09	2,6E-09	2,6E-09	2,7E-09	2,8E-09	-1,7E-09	-2,0E-13
1,6E-09	1,9E-09	2,1E-09	2,9E-09	1,3E-08	3,1E-09	2,4E-09	2,4E-09	2,5E-09	2,6E-09	2,7E-09	2,8E-09	2,9E-09	3,0E-09	3,0E-09	-1,7E-09	-2,5E-13
1,6E-09	1,9E-09	2,0E-09	2,2E-09	3,1E-09	1,4E-08	3,3E-09	2,6E-09	2,7E-09	2,8E-09	2,9E-09	3,0E-09	3,1E-09	3,2E-09	3,3E-09	-1,7E-09	-3,0E-13
1,7E-09	2,0E-09	2,1E-09	2,2E-09	2,4E-09	3,3E-09	1,4E-08	3,6E-09	2,9E-09	3,0E-09	3,1E-09	3,2E-09	3,3E-09	3,4E-09	3,5E-09	-1,7E-09	-3,5E-13
1,7E-09	2,0E-09	2,1E-09	2,3E-09	2,4E-09	2,6E-09	3,6E-09	1,4E-08	3,9E-09	3,2E-09	3,3E-09	3,4E-09	3,5E-09	3,7E-09	3,8E-09	-1,7E-09	-4,0E-13
1,7E-09	2,0E-09	2,2E-09	2,4E-09	2,5E-09	2,7E-09	2,9E-09	3,9E-09	1,4E-08	4,2E-09	3,5E-09	3,6E-09	3,8E-09	3,9E-09	4,1E-09	-1,7E-09	-4,5E-13
1,7E-09	2,1E-09	2,2E-09	2,4E-09	2,6E-09	2,8E-09	3,0E-09	3,2E-09	4,2E-09	1,5E-08	4,5E-09	3,9E-09	4,0E-09	4,2E-09	4,3E-09	-1,7E-09	-5,0E-13
1,7E-09	2,1E-09	2,3E-09	2,5E-09	2,7E-09	2,9E-09	3,1E-09	3,3E-09	3,5E-09	4,5E-09	1,5E-08	4,9E-09	4,3E-09	4,4E-09	4,6E-09	-1,7E-09	-5,5E-13
1,7E-09	2,1E-09	2,4E-09	2,6E-09	2,8E-09	3,0E-09	3,2E-09	3,4E-09	3,6E-09	3,9E-09	4,9E-09	1,5E-08	5,3E-09	4,7E-09	4,9E-09	-1,7E-09	-6,0E-13
1,8E-09	2,2E-09	2,4E-09	2,6E-09	2,9E-09	3,1E-09	3,3E-09	3,5E-09	3,8E-09	4,0E-09	4,3E-09	5,3E-09	1,6E-08	5,8E-09	5,2E-09	-1,7E-09	-6,5E-13
1,8E-09	2,2E-09	2,5E-09	2,7E-09	3,0E-09	3,2E-09	3,4E-09	3,7E-09	3,9E-09	4,2E-09	4,4E-09	4,7E-09	5,8E-09	1,6E-08	6,9E-09	-1,7E-09	-7,0E-13
1,8E-09	2,2E-09	2,5E-09	2,8E-09	3,0E-09	3,3E-09	3,5E-09	3,8E-09	4,1E-09	4,3E-09	4,6E-09	4,9E-09	5,2E-09	6,9E-09	2,6E-08	-1,7E-09	-7,5E-13
-1,6E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	-1,7E-09	1,7E-09	-2,1E-15
-4,7E-14	-9,9E-14	-1,5E-13	-2,0E-13	-2,5E-13	-3,0E-13	-3,5E-13	-4,0E-13	-4,5E-13	-5,0E-13	-5,5E-13	-6,0E-13	-6,5E-13	-7,0E-13	-7,5E-13	-2,1E-15	1,4E-16

b. Menghitung nilai a

Nilai a dihitung berdasarkan persamaan 3.95, yaitu $a = \left(\frac{1}{\beta\,\Delta t}\,[M] + \frac{\gamma}{\beta}\,[C]\right)$

$\Delta t = 0{,}01$ dt

$\frac{1}{\beta\,\Delta t} = \frac{1}{0{,}25\,x\,0{,}01} = 400$

$\frac{\gamma}{\beta} = \frac{0{,}5}{0{,}25} = 2$

maka didapat nilai a

a =

854198,6	-37045,2	0	0	0	0	0	0	0	0	0	0	0	0	0	764503	2,7E+08
-37045,2	839843	-37045,2	0	0	0	0	0	0	0	0	0	0	0	0	764503	5,4E+08
0	-37045,2	839843	-37045,2	0	0	0	0	0	0	0	0	0	0	0	764503	8E+08
0	0	-37045,2	839843	-37045,2	0	0	0	0	0	0	0	0	0	0	764503	1,1E+09
0	0	0	-37045,2	839843	-37045,2	0	0	0	0	0	0	0	0	0	764503	1,3E+09
0	0	0	0	-37045,2	839843	-37045,2	0	0	0	0	0	0	0	0	764503	1,6E+09
0	0	0	0	0	-37045,2	839843	-37045,2	0	0	0	0	0	0	0	764503	1,9E+09
0	0	0	0	0	0	-37045,2	839843	-37045,2	0	0	0	0	0	0	764503	2,1E+09
0	0	0	0	0	0	0	-37045,2	839843	-37045,2	0	0	0	0	0	764503	2,4E+09
0	0	0	0	0	0	0	0	-37045,2	839843	-37045,2	0	0	0	0	764503	2,7E+09
0	0	0	0	0	0	0	0	0	-37045,2	839843	-37045,2	0	0	0	764503	2,9E+09
0	0	0	0	0	0	0	0	0	0	-37045,2	839843	-37045,2	0	0	764503	3,2E+09
0	0	0	0	0	0	0	0	0	0	0	-37045,2	839843	-37045,2	0	764503	3,5E+09
0	0	0	0	0	0	0	0	0	0	0	0	-37045,2	839551,8	-36754	764503	3,7E+09
0	0	0	0	0	0	0	0	0	0	0	0	0	-36754	464439	426987	2,2E+09
764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	764503,2	426987	1,7E+07	3E+10
2,68E+08	5,35E+08	8,03E+08	1,07E+09	1,34E+09	1,61E+09	1,87E+09	2,14E+09	2,41E+09	2,68E+09	2,94E+09	3,21E+09	3,48E+09	3,75E+09	2,2E+09	3E+10	1,7E+14

c. Menghitung nilai b

Nilai b dihitung berdasarkan persamaan 3.95, yaitu $b = \left\{\frac{1}{2\beta}\ [M]\ +\ \Delta t\ \left(\frac{\gamma}{2\beta} - 1\right)\ [C]\right\}$

$\Delta t = 0{,}01$ dt

$\frac{1}{2\beta} = \frac{1}{2\ x\ 0{,}25} = 2$

$\frac{\gamma}{2\beta} - 1 = \frac{0{,}5}{2\ x\ 0{,}25} - 1 = 0$

sehingga persamaan tersebut menjadi $b = \{2\ [M]\}$, maka didapat nilai b

b =

3822,516	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3822,516	1337881
0	3822,516	0	0	0	0	0	0	0	0	0	0	0	0	0	3822,516	2675761
0	0	3822,516	0	0	0	0	0	0	0	0	0	0	0	0	3822,516	4013642
0	0	0	3822,516	0	0	0	0	0	0	0	0	0	0	0	3822,516	5351523
0	0	0	0	3822,516	0	0	0	0	0	0	0	0	0	0	3822,516	6689403
0	0	0	0	0	3822,516	0	0	0	0	0	0	0	0	0	3822,516	8027284
0	0	0	0	0	0	3822,516	0	0	0	0	0	0	0	0	3822,516	9365165
0	0	0	0	0	0	0	3822,516	0	0	0	0	0	0	0	3822,516	10703045
0	0	0	0	0	0	0	0	3822,516	0	0	0	0	0	0	3822,516	12040926
0	0	0	0	0	0	0	0	0	3822,516	0	0	0	0	0	3822,516	13378806
0	0	0	0	0	0	0	0	0	0	3822,516	0	0	0	0	3822,516	14716687
0	0	0	0	0	0	0	0	0	0	0	3822,516	0	0	0	3822,516	16054568
0	0	0	0	0	0	0	0	0	0	0	0	3822,516	0	0	3822,516	17392448
0	0	0	0	0	0	0	0	0	0	0	0	0	3822,516	0	3822,516	18730329
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2134,936	2134,936	11208413
3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	3822,516	2134,936	74411,634	151685880
1337881	2675761	4013642	5351523	6689403	8027284	9365165	10703045	12040926	13378806	14716687	16054568	17392448	18730329	11208413	151685880	8,233E+11

5. Perhitungan Respon Dinamik Struktur Metode *β-Newmark*

Beban gempa yang digunakan adalah Gempa Duzce (frekuensi rendah) dimana nilai percepatan arah x (*East-West*) yang telah dinormalisasi adalah sebagai berikut.

t = 0 detik $\ddot{y}_{b0} = 0$ cm/dt²

t = 0,01 detik $\ddot{y}_{b1}$ = -0,000373832g atau -0,366728972 cm/dt²

t = 0,02 detik $\ddot{y}_{b2}$ = -0,000373832g atau -0,366728972 cm/dt²

a. Iterasi 1 (Saat t = 0,01 detik)

Kondisi awal diketahui

Simpangan awal (y_0) = 0

Kecepatan awal ($\dot{y}_0$) = 0

Percepatan awal ($\ddot{y}_0$) = 0

1) Menghitung $\Delta\hat{p}_0$

$$\Delta p_0 = (\ddot{y}_{b1} - \ddot{y}_{b0}) \begin{bmatrix} m1 \\ m2 \\ m3 \\ m4 \\ m5 \\ m6 \\ m7 \\ m8 \\ m9 \\ m10 \\ m11 \\ m12 \\ m13 \\ m14 \\ m15 \\ \Sigma mi \text{ dengan i } 0\text{-}15 \\ \Sigma mi.hi \text{ dengan i } 1\text{-}15 \end{bmatrix}$$

$$\Delta p_0 = (-0{,}366728972 - 0) \begin{bmatrix} 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1067{,}46789 \\ 37205{,}81676 \\ 75842940{,}24 \end{bmatrix} = \begin{bmatrix} -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -391{,}4714019 \\ -13644{,}45093 \\ -27813803{,}51 \end{bmatrix}$$

$$\Delta\hat{p}_0 = \Delta p_0 + a\,\dot{y}_i + b\,\ddot{y}_i = \begin{bmatrix} -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -700{,}9137047 \\ -391{,}4714019 \\ -13644{,}45093 \\ -27813803{,}51 \end{bmatrix}$$

2) Menghitung pertambahan simpangan (Δy_0)

$$\Delta y_0 = \hat{k}^{-1}\ x\ \Delta\hat{p}_0 = \begin{bmatrix} -2{,}71039E\text{-}06 \\ -2{,}99902E\text{-}06 \\ -3{,}0201E\text{-}06 \\ -3{,}02056E\text{-}06 \\ -3{,}01944E\text{-}06 \\ -3{,}0182E\text{-}06 \\ -3{,}01694E\text{-}06 \\ -3{,}01569E\text{-}06 \\ -3{,}01443E\text{-}06 \\ -3{,}01318E\text{-}06 \\ -3{,}01192E\text{-}06 \\ -3{,}01067E\text{-}06 \\ -3{,}00941E\text{-}06 \\ -3{,}00817E\text{-}06 \\ -3{,}00708E\text{-}06 \\ -6{,}13755E\text{-}06 \\ -3{,}59124E\text{-}12 \end{bmatrix}$$

3) Menghitung pertambahan kecepatan ($\Delta\dot{y}_0$)

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

$$= \frac{0{,}5}{0{,}25\ x\ 0{,}01} \begin{bmatrix} -2{,}71039E\text{-}06 \\ -2{,}99902E\text{-}06 \\ -3{,}0201E\text{-}06 \\ -3{,}02056E\text{-}06 \\ -3{,}01944E\text{-}06 \\ -3{,}0182E\text{-}06 \\ -3{,}01694E\text{-}06 \\ -3{,}01569E\text{-}06 \\ -3{,}01443E\text{-}06 \\ -3{,}01318E\text{-}06 \\ -3{,}01192E\text{-}06 \\ -3{,}01067E\text{-}06 \\ -3{,}00941E\text{-}06 \\ -3{,}00817E\text{-}06 \\ -3{,}00708E\text{-}06 \\ -6{,}13755E\text{-}06 \\ -3{,}59124E\text{-}12 \end{bmatrix} - 0 + 0 = \begin{bmatrix} -0{,}000542078 \\ -0{,}000599803 \\ -0{,}000604019 \\ -0{,}000604113 \\ -0{,}000603888 \\ -0{,}000603639 \\ -0{,}000603388 \\ -0{,}000603137 \\ -0{,}000602886 \\ -0{,}000602636 \\ -0{,}000602385 \\ -0{,}000602134 \\ -0{,}000601883 \\ -0{,}000601634 \\ -0{,}000601416 \\ -0{,}001227511 \\ -7{,}18248E\text{-}10 \end{bmatrix}$$

4) Menghitung pertambahan percepatan ($\Delta\ddot{y}_0$)

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

$$= \frac{1}{0{,}25\;x\;(0{,}01)^2} \begin{bmatrix} -2{,}71039E\text{-}06 \\ -2{,}99902E\text{-}06 \\ -3{,}0201E\text{-}06 \\ -3{,}02056E\text{-}06 \\ -3{,}01944E\text{-}06 \\ -3{,}0182E\text{-}06 \\ -3{,}01694E\text{-}06 \\ -3{,}01569E\text{-}06 \\ -3{,}01443E\text{-}06 \\ -3{,}01318E\text{-}06 \\ -3{,}01192E\text{-}06 \\ -3{,}01067E\text{-}06 \\ -3{,}00941E\text{-}06 \\ -3{,}00817E\text{-}06 \\ -3{,}00708E\text{-}06 \\ -6{,}13755E\text{-}06 \\ -3{,}59124E\text{-}12 \end{bmatrix} - 0 - 0 = \begin{bmatrix} -0{,}108415639 \\ -0{,}119960601 \\ -0{,}120803873 \\ -0{,}120822524 \\ -0{,}120777634 \\ -0{,}120727847 \\ -0{,}120677683 \\ -0{,}120627491 \\ -0{,}120577295 \\ -0{,}1205271 \\ -0{,}120476905 \\ -0{,}120426713 \\ -0{,}120376558 \\ -0{,}120326887 \\ -0{,}120283151 \\ -0{,}245502139 \\ -1{,}4365E\text{-}07 \end{bmatrix}$$

5) Menghitung simpangan (y_1)

$$y_1 = y_0 + \Delta y_0 = \begin{bmatrix} -2{,}71039E\text{-}06 \\ -2{,}99902E\text{-}06 \\ -3{,}0201E\text{-}06 \\ -3{,}02056E\text{-}06 \\ -3{,}01944E\text{-}06 \\ -3{,}0182E\text{-}06 \\ -3{,}01694E\text{-}06 \\ -3{,}01569E\text{-}06 \\ -3{,}01443E\text{-}06 \\ -3{,}01318E\text{-}06 \\ -3{,}01192E\text{-}06 \\ -3{,}01067E\text{-}06 \\ -3{,}00941E\text{-}06 \\ -3{,}00817E\text{-}06 \\ -3{,}00708E\text{-}06 \\ -6{,}13755E\text{-}06 \\ -3{,}59124E\text{-}12 \end{bmatrix}$$

6) Menghitung kecepatan ($\dot{y}_1$)

$$\dot{y}_1 = \dot{y}_0 + \Delta\dot{y}_0 = \begin{bmatrix} -0{,}000542078 \\ -0{,}000599803 \\ -0{,}000604019 \\ -0{,}000604113 \\ -0{,}000603888 \\ -0{,}000603639 \\ -0{,}000603388 \\ -0{,}000603137 \\ -0{,}000602886 \\ -0{,}000602636 \\ -0{,}000602385 \\ -0{,}000602134 \\ -0{,}000601883 \\ -0{,}000601634 \\ -0{,}000601416 \\ -0{,}001227511 \\ -7{,}18248E\text{-}10 \end{bmatrix}$$

7) Menghitung percepatan ($\ddot{y}_1$)

$$\ddot{y}_1 = \ddot{y}_0 + \Delta\ddot{y}_0 = \begin{bmatrix} -0{,}108415639 \\ -0{,}119960601 \\ -0{,}120803873 \\ -0{,}120822524 \\ -0{,}120777634 \\ -0{,}120727847 \\ -0{,}120677683 \\ -0{,}120627491 \\ -0{,}120577295 \\ -0{,}1205271 \\ -0{,}120476905 \\ -0{,}120426713 \\ -0{,}120376558 \\ -0{,}120326887 \\ -0{,}120283151 \\ -0{,}245502139 \\ -1{,}4365E\text{-}07 \end{bmatrix}$$

8) Menghitung simpangan netto (y_n)

Simpangan netto dapat dilihat pada hasil simpangan di atas. Simpangan netto lantai 1 berada pada baris ke 1 sampai dengan simpangan netto lantai 15 berada pada baris ke 15 dan simpangan pada fondasi berada pada baris ke 16.

a) Lantai 1, y_{n1} = -2,71039 x 10^{-6} cm

b) Lantai 2, y_{n2} = -2,99902 x 10^{-6} cm

c) Lantai 3, y_{n3} = -3,02056 x 10^{-6} cm

d) Lantai 0/fondasi, y_{n0} = -6,13755 x 10^{-6} cm

dan seterusnya.

9) Menghitung sudut rotasi fondasi (θ)

Sudut rotasi fondasi terletak pada hasil simpangan di atas pada baris ke 17.

θ = -3,59124 x 10^{-12} radian = -2,05763 x 10^{-10} °

10) Menghitung simpangan rotasi (y_r)

$y_{ri} = h_i \tan \theta$

a) Lantai 1, y_{r1} = 350 x tan (-2,05763 x 10^{-10})
= -1,25693 x 10^{-9} cm

b) Lantai 2, y_{r2} = 700 x tan (-2,05763 x 10^{-10})
= -2,51387 x 10^{-9} cm

c) Lantai 3, y_{r3} = 1050 x tan (-2,05763 x 10^{-10})
= -3,7708 x 10^{-9} cm

dan seterusnya.

11) Menghitung simpangan total (y_t)

$y_{ti} = y_0 + y_{ni} + y_{ri}$

a) Lantai 1, y_{t1} = -6,13755 x 10^{-6} + -2,71039 x 10^{-6} + -1,25693 x 10^{-9}

= -8,8492 x 10^{-6} cm

b) Lantai 2, y_{t2} = -6,13755 x 10^{-6} + -2,99902 x 10^{-6} + -2,51387 x 10^{-9}

= -9,13908 x 10^{-6} cm

c) Lantai 3, y_{t3} = -6,13755 x 10^{-6} + -3,0201 x 10^{-6} + -3,7708 x 10^{-9}

= -9,16142 x 10^{-6} cm

dan seterusnya.

12) Menghitung *interstorey drift ratio* (*DR*)

$$DR_i = \left[\frac{y_{ni} - y_{ni-1}}{\Delta hi}\right] \text{ x } 100\%$$

a) Lantai 1, DR_1 $= \left[\frac{-2{,}71039 \text{ x } 10^{-6} - 0}{350}\right]$ x 100%

= 7,74397 x 10^{-7} %

b) Lantai 2, DR_2 $= \left[\frac{-2{,}99902 \text{ x } 10^{-6} + 2{,}71039 \text{ x } 10^{-6}}{350}\right]$ x 100%

= 8,2464 x 10^{-8} %

c) Lantai 3, DR_3 $= \left[\frac{-3{,}0201 \text{ x } 10^{-6} + 2{,}99902 \text{ x } 10^{-6}}{350}\right]$ x 100%

= 6,02337 x 10^{-9} %

dan seterusnya.

13) Menghitung gaya horizontal tingkat (F)

$F_i = k_i \, x \, y_{ni}$

$$F = \begin{bmatrix}
7693474 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6419418 & -3197041 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3197041 & 3197041
\end{bmatrix}
\begin{bmatrix}
-2{,}71039E\text{-}06 \\
-2{,}99902E\text{-}06 \\
-3{,}0201E\text{-}06 \\
-3{,}02056E\text{-}06 \\
-3{,}01944E\text{-}06 \\
-3{,}0182E\text{-}06 \\
-3{,}01694E\text{-}06 \\
-3{,}01569E\text{-}06 \\
-3{,}01443E\text{-}06 \\
-3{,}01318E\text{-}06 \\
-3{,}01192E\text{-}06 \\
-3{,}01067E\text{-}06 \\
-3{,}00941E\text{-}06 \\
-3{,}00817E\text{-}06 \\
-3{,}00708E\text{-}06
\end{bmatrix}$$

$$F = \begin{bmatrix} -11{,}18836763 \\ -0{,}862121857 \\ -0{,}066430968 \\ -0{,}005118851 \\ -0{,}000394434 \\ -3{,}03932E\text{-}05 \\ -2{,}34195E\text{-}06 \\ -1{,}80353E\text{-}07 \\ -1{,}25316E\text{-}08 \\ 1{,}67628E\text{-}08 \\ 2{,}31358E\text{-}07 \\ 3{,}00357E\text{-}06 \\ 3{,}89795E\text{-}05 \\ 0{,}000505865 \\ 0{,}003495606 \end{bmatrix}$$

Gaya horizontal tingkat dapat dilihat pada hasil di atas. Gaya horizontal tingkat 1 berada pada baris ke 1 sampai dengan gaya horizontal tingkat 15 berada pada baris ke 15.

a) Lantai 1, F_1 = -11,18836763 kg
b) Lantai 2, F_2 = -0,862121857 kg
c) Lantai 3, F_3 = -0,066430968 kg

dan seterusnya.

14) Menghitung gaya geser tingkat (V)

$V = \sum_{i=1}^{n} F_i$

a) Lantai 1, V_1 = $F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$
= -12,11842297 kg

b) Lantai 2, V_2 = $F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$
= -10,930055336 kg

c) Lantai 3, V_3 = $F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$

= -0,06793348 kg

dan seterusnya.

15) Menghitung momen guling (M)

$M_i = \sum_{i=1}^{n} F_i h_i$

a) Lantai dasar/fondasi

M_0 = (F_1 x H_1 + F_2 x H_2 + F_3 x H_3 + F_4 x H_4 + F_5 x H_5 + F_6 x H_6 + F_7 x H_7 + F_8 x H_8 + F_9 x H_9 + F_{10} x H_{10} + F_{11} x H_{11} + F_{12} x H_{12} + F_{13} x H_{13} + F_{14} x H_{14} + F_{15} x H_{15}) / 100

= -45,76071656 kg.m

b) Lantai 1

M_1 = (F_2 x H_2 + F_3 x H_3 + F_4 x H_4 + F_5 x H_5 + F_6 x H_6 + F_7 x H_7 + F_8 x H_8 + F_9 x H_9 + F_{10} x H_{10} + F_{11} x H_{11} + F_{12} x H_{12} + F_{13} x H_{13} + F_{14} x H_{14} + F_{15} x H_{15}) /100

= -6,601429846 kg.m

c) Lantai 2

M_2 = (F_3 x H_3 + F_4 x H_4 + F_5 x H_5 + F_6 x H_6 + F_7 x H_7 + F_8 x H_8 + F_9 x H_9 + F_{10} x H_{10} + F_{11} x H_{11} + F_{12} x H_{12} + F_{13} x H_{13} + F_{14} x H_{14} + F_{15} x H_{15}) / 100

= -0,566576848 kg.m

dan seterusnya.

b. Iterasi 2 (Saat t = 0,02 detik)

Kondisi awal diketahui dari perhitungan iterasi sebelumnya.

y_1 = [-0,108415639; -0,119960601; -0,120803873; -0,120822524; -0,120777634; -0,120727847; -0,120677683; -0,120627491; -0,120577295; -0,1205271; -0,120476905; -0,120426713; -0,120376558; -0,120326887; -0,120283151; -0,245502139; -1,4365E-07]

$\dot{y}_1$ = [-2,71039E-06; -2,99902E-06; -3,0201E-06; -3,02056E-06; -3,01944E-06; -3,0182E-06; -3,01694E-06; -3,01569E-06; -3,01443E-06; -3,01318E-06; -3,01192E-06; -3,01067E-06; -3,00941E-06; -3,00817E-06; -3,00708E-06; -6,13755E-06; -3,59124E-12]

$\ddot{y}_1$ = [-0,000542078; -0,000599803; -0,000604019; -0,000604113; -0,000603888; -0,000603639; -0,000603388; -0,000603137; -0,000602886; -0,000602636; -0,000602385; -0,000602134; -0,000601883; -0,000601634; -0,000601416; -0,001227511; -7,18248E-10]

1) Menghitung $\Delta\hat{p}_1$

$$\Delta p_1 = (\ddot{y}_{b2} - \ddot{y}_{b1}) \begin{bmatrix} m1 \\ m2 \\ m3 \\ m4 \\ m5 \\ m6 \\ m7 \\ m8 \\ m9 \\ m10 \\ m11 \\ m12 \\ m13 \\ m14 \\ m15 \\ \Sigma mi \text{ dengan } i\ 0\text{-}15 \\ \Sigma mi.hi \text{ dengan } i\ 1\text{-}15 \end{bmatrix}$$

$$\Delta p_1 = (-0{,}366728972 - -0{,}366728972) \begin{bmatrix} 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1911{,}258063 \\ 1067{,}46789 \\ 37205{,}81676 \\ 75842940{,}24 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta\hat{p}_1 = \Delta p_1 + a\ \dot{y}_i + b\ \ddot{y}_i = \begin{bmatrix} -2732{,}499274 \\ -2797{,}474757 \\ -2802{,}481745 \\ -2802{,}867849 \\ -2802{,}897889 \\ -2802{,}900493 \\ -2802{,}900984 \\ -2802{,}901311 \\ -2802{,}901625 \\ -2802{,}901939 \\ -2802{,}902254 \\ -2802{,}902585 \\ -2802{,}903125 \\ -2802{,}906376 \\ -1565{,}487983 \\ -52009{,}73189 \\ -111245664{,}8 \end{bmatrix}$$

2) Menghitung pertambahan simpangan (Δy_1)

$$\Delta y_1 = \hat{k}^{-1}\, x\, \Delta\hat{p}_1 = \begin{bmatrix} -1{,}39288E\text{-}05 \\ -1{,}61366E\text{-}05 \\ -1{,}63542E\text{-}05 \\ -1{,}63668E\text{-}05 \\ -1{,}63596E\text{-}05 \\ -1{,}63505E\text{-}05 \\ -1{,}63413E\text{-}05 \\ -1{,}63321E\text{-}05 \\ -1{,}63228E\text{-}05 \\ -1{,}63136E\text{-}05 \\ -1{,}63043E\text{-}05 \\ -1{,}62951E\text{-}05 \\ -1{,}62859E\text{-}05 \\ -1{,}62768E\text{-}05 \\ -1{,}62691E\text{-}05 \\ -2{,}02302E\text{-}05 \\ -2{,}64558E\text{-}11 \end{bmatrix}$$

3) Menghitung pertambahan kecepatan ($\Delta \dot{y}_1$)

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

$$= \begin{bmatrix} -0{,}001701612 \\ -0{,}002027719 \\ -0{,}00206281 \\ -0{,}002065135 \\ -0{,}002064138 \\ -0{,}002062824 \\ -0{,}002061481 \\ -0{,}002060135 \\ -0{,}002058789 \\ -0{,}002057443 \\ -0{,}002056097 \\ -0{,}002054751 \\ -0{,}002053407 \\ -0{,}002052088 \\ -0{,}002050991 \\ -0{,}001591024 \\ -3{,}85466E\text{-}09 \end{bmatrix}$$

4) Menghitung pertambahan percepatan ($\Delta \ddot{y}_1$)

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

$$= \begin{bmatrix} -0{,}123491093 \\ -0{,}165622531 \\ -0{,}170954242 \\ -0{,}171381943 \\ -0{,}171272384 \\ -0{,}171109145 \\ -0{,}170940824 \\ -0{,}170772038 \\ -0{,}17060321 \\ -0{,}17043438 \\ -0{,}170265552 \\ -0{,}170096761 \\ -0{,}169928359 \\ -0{,}169763775 \\ -0{,}169631973 \\ 0{,}172799526 \\ -4{,}83632E\text{-}07 \end{bmatrix}$$

5) Menghitung simpangan (y_2)

$$y_2 = y_1 + \Delta y_1 = \begin{bmatrix} -2{,}71039E\text{-}06 \\ -2{,}99902E\text{-}06 \\ -3{,}0201E\text{-}06 \\ -3{,}02056E\text{-}06 \\ -3{,}01944E\text{-}06 \\ -3{,}0182E\text{-}06 \\ -3{,}01694E\text{-}06 \\ -3{,}01569E\text{-}06 \\ -3{,}01443E\text{-}06 \\ -3{,}01318E\text{-}06 \\ -3{,}01192E\text{-}06 \\ -3{,}01067E\text{-}06 \\ -3{,}00941E\text{-}06 \\ -3{,}00817E\text{-}06 \\ -3{,}00708E\text{-}06 \\ -6{,}13755E\text{-}06 \\ -3{,}59124E\text{-}12 \end{bmatrix} + \begin{bmatrix} -1{,}39288E\text{-}05 \\ -1{,}61366E\text{-}05 \\ -1{,}63542E\text{-}05 \\ -1{,}63668E\text{-}05 \\ -1{,}63596E\text{-}05 \\ -1{,}63505E\text{-}05 \\ -1{,}63413E\text{-}05 \\ -1{,}63321E\text{-}05 \\ -1{,}63228E\text{-}05 \\ -1{,}63136E\text{-}05 \\ -1{,}63043E\text{-}05 \\ -1{,}62951E\text{-}05 \\ -1{,}62859E\text{-}05 \\ -1{,}62768E\text{-}05 \\ -1{,}62691E\text{-}05 \\ -2{,}02302E\text{-}05 \\ -2{,}64558E\text{-}11 \end{bmatrix} = \begin{bmatrix} -1{,}66392E\text{-}05 \\ -1{,}91356E\text{-}05 \\ -1{,}93743E\text{-}05 \\ -1{,}93874E\text{-}05 \\ -1{,}9379E\text{-}05 \\ -1{,}93687E\text{-}05 \\ -1{,}93582E\text{-}05 \\ -1{,}93477E\text{-}05 \\ -1{,}93372E\text{-}05 \\ -1{,}93267E\text{-}05 \\ -1{,}93163E\text{-}05 \\ -1{,}93058E\text{-}05 \\ -1{,}92953E\text{-}05 \\ -1{,}9285E\text{-}05 \\ -1{,}92762E\text{-}05 \\ -2{,}63678E\text{-}05 \\ -3{,}0047E\text{-}11 \end{bmatrix}$$

6) Menghitung kecepatan ($\dot{y}_2$)

$$\dot{y}_2 = \dot{y}_1 + \Delta\dot{y}_1 = \begin{bmatrix} -0{,}000542078 \\ -0{,}000599803 \\ -0{,}000604019 \\ -0{,}000604113 \\ -0{,}000603888 \\ -0{,}000603639 \\ -0{,}000603388 \\ -0{,}000603137 \\ -0{,}000602886 \\ -0{,}000602636 \\ -0{,}000602385 \\ -0{,}000602134 \\ -0{,}000601883 \\ -0{,}000601634 \\ -0{,}000601416 \\ -0{,}001227511 \\ -7{,}18248E\text{-}10 \end{bmatrix} + \begin{bmatrix} -0{,}001701612 \\ -0{,}002027719 \\ -0{,}00206281 \\ -0{,}002065135 \\ -0{,}002064138 \\ -0{,}002062824 \\ -0{,}002061481 \\ -0{,}002060135 \\ -0{,}002058789 \\ -0{,}002057443 \\ -0{,}002056097 \\ -0{,}002054751 \\ -0{,}002053407 \\ -0{,}002052088 \\ -0{,}002050991 \\ -0{,}001591024 \\ -3{,}85466E\text{-}09 \end{bmatrix} = \begin{bmatrix} -0{,}00224369 \\ -0{,}002627522 \\ -0{,}002666829 \\ -0{,}002669248 \\ -0{,}002668026 \\ -0{,}002666463 \\ -0{,}002664869 \\ -0{,}002663273 \\ -0{,}002661675 \\ -0{,}002660078 \\ -0{,}002658481 \\ -0{,}002656885 \\ -0{,}00265529 \\ -0{,}002653722 \\ -0{,}002652407 \\ -0{,}002818534 \\ -4{,}57291E\text{-}09 \end{bmatrix}$$

7) Menghitung percepatan ($\ddot{y}_2$)

$$\ddot{y}_2 = \ddot{y}_1 + \Delta\ddot{y}_1 = \begin{bmatrix} -0{,}108415639 \\ -0{,}119960601 \\ -0{,}120803873 \\ -0{,}120822524 \\ -0{,}120777634 \\ -0{,}120727847 \\ -0{,}120677683 \\ -0{,}120627491 \\ -0{,}120577295 \\ -0{,}1205271 \\ -0{,}120476905 \\ -0{,}120426713 \\ -0{,}120376558 \\ -0{,}120326887 \\ -0{,}120283151 \\ -0{,}245502139 \\ -1{,}4365E\text{-}07 \end{bmatrix} + \begin{bmatrix} -0{,}123491093 \\ -0{,}165622531 \\ -0{,}170954242 \\ -0{,}171381943 \\ -0{,}171272384 \\ -0{,}171109145 \\ -0{,}170940824 \\ -0{,}170772038 \\ -0{,}17060321 \\ -0{,}17043438 \\ -0{,}170265552 \\ -0{,}170096761 \\ -0{,}169928359 \\ -0{,}169763775 \\ -0{,}169631973 \\ 0{,}172799526 \\ -4{,}83632E\text{-}07 \end{bmatrix} = \begin{bmatrix} -0{,}231906732 \\ -0{,}285583132 \\ -0{,}291758115 \\ -0{,}292204467 \\ -0{,}292050018 \\ -0{,}291836993 \\ -0{,}291618507 \\ -0{,}291399528 \\ -0{,}291180506 \\ -0{,}29096148 \\ -0{,}290742457 \\ -0{,}290523474 \\ -0{,}290304917 \\ -0{,}290090662 \\ -0{,}289915124 \\ -0{,}072702613 \\ -6{,}27282E\text{-}07 \end{bmatrix}$$

8) Menghitung simpangan netto (y_n)

Simpangan netto dapat dilihat pada hasil simpangan di atas. Simpangan netto lantai 1 berada pada baris ke 1 sampai dengan simpangan netto lantai 15 berada pada baris ke 15 dan simpangan pada fondasi berada pada baris ke 16.

e) Lantai 1, y_{n1} = $-1{,}66392 \times 10^{-5}$ cm

f) Lantai 2, y_{n2} = $-1{,}91356 \times 10^{-5}$ cm

g) Lantai 3, y_{n3} = $-1{,}93743 \times 10^{-5}$ cm

h) Lantai 0/fondasi, y_{n0} = $-2{,}63678 \times 10^{-5}$ cm

dan seterusnya.

9) Menghitung sudut rotasi fondasi (θ)

Sudut rotasi fondasi terletak pada hasil simpangan di atas pada baris ke 17.

$\theta = -3{,}0047 \times 10^{-11}$ radian = $-1{,}72157 \times 10^{-9}$ °

10) Menghitung simpangan rotasi (y_r)

$y_{ri} = h_i \tan \theta$

d) Lantai 1, y_{r1} = $350 \times \tan(-1{,}72157 \times 10^{-9})$

= $-1{,}05165 \times 10^{-8}$ cm

e) Lantai 2, y_{r2} = $700 \times \tan(-1{,}72157 \times 10^{-9})$

= $-2{,}10329 \times 10^{-8}$ cm

f) Lantai 3, y_{r3} = $1050 \times \tan(-1{,}72157 \times 10^{-9})$

= $-3{,}15494 \times 10^{-8}$ cm

dan seterusnya.

11) Menghitung simpangan total (y_t)

$y_{ti} = y_0 + y_{ni} + y_{ri}$

d) Lantai 1, y_{t1} = $-2{,}63678 \times 10^{-5} + -1{,}66392 \times 10^{-5} + -1{,}05165 \times 10^{-8}$

= $-4{,}30175 \times 10^{-5}$ cm

e) Lantai 2, y_{t2} = $-2{,}63678 \times 10^{-5} + -1{,}91356 \times 10^{-5} + -2{,}10329 \times 10^{-8}$

= $-4{,}55245 \times 10^{-5}$ cm

f) Lantai 3, y_{t3} = $-2{,}63678 \times 10^{-5} + -1{,}93743 \times 10^{-5} + -3{,}15494 \times 10^{-8}$

= $-4{,}57737 \times 10^{-5}$ cm

dan seterusnya.

12) Menghitung *interstorey drift ratio* (*DR*)

$DR_i = \left[\frac{y_{ni} - y_{ni-1}}{\Delta hi}\right]$ x 100%

d) Lantai 1, $DR_1 = \left[\frac{-1{,}66392 \times 10^{-5} - 0}{350}\right]$ x 100%

$= 4{,}75407 \times 10^{-6}$ %

e) Lantai 2, $DR_2 = \left[\frac{-1{,}91356 \times 10^{-5} + 1{,}66392 \times 10^{-5}}{350}\right]$ x 100%

$= 5{,}46733 \times 10^{-6}$ %

f) Lantai 3, $DR_3 = \left[\frac{-1{,}93743 \times 10^{-5} + 1{,}91356 \times 10^{-5}}{350}\right]$ x 100%

$= 5{,}53553 \times 10^{-6}$ %

dan seterusnya.

13) Menghitung gaya horizontal tingkat (F)

$F_i = k_i \, x \, y_{ni}$

$$F = \begin{bmatrix} 7693474 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6444753 & -3222376 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3222376 & 6419418 & -3197041 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3197041 & 3197041 \end{bmatrix} \begin{bmatrix} -1{,}66392E\text{-}05 \\ -1{,}91356E\text{-}05 \\ -1{,}93743E\text{-}05 \\ -1{,}93874E\text{-}05 \\ -1{,}9379E\text{-}05 \\ -1{,}93687E\text{-}05 \\ -1{,}93582E\text{-}05 \\ -1{,}93477E\text{-}05 \\ -1{,}93372E\text{-}05 \\ -1{,}93267E\text{-}05 \\ -1{,}93163E\text{-}05 \\ -1{,}93058E\text{-}05 \\ -1{,}92953E\text{-}05 \\ -1{,}9285E\text{-}05 \\ -1{,}92762E\text{-}05 \end{bmatrix}$$

$$F = \begin{bmatrix} -66{,}35127306 \\ -7{,}275173542 \\ -0{,}727218947 \\ -0{,}06887563 \\ -0{,}006296586 \\ -0{,}00056142 \\ -4{,}91344E\text{-}05 \\ -4{,}23603E\text{-}06 \\ -3{,}29992E\text{-}07 \\ 3{,}33602E\text{-}07 \\ 4{,}14261E\text{-}06 \\ 4{,}62608E\text{-}05 \\ 0{,}00050259 \\ 0{,}005253605 \\ 0{,}028012483 \end{bmatrix}$$

Gaya horizontal tingkat dapat dilihat pada hasil di atas. Gaya horizontal tingkat 1 berada pada baris ke 1 sampai dengan gaya horizontal tingkat 15 berada pada baris ke 15.

d) Lantai 1, F_1 = -66,35127306 kg

e) Lantai 2, F_2 = -7,275173542 kg

f) Lantai 3, F_3 = -0,727218947 kg

dan seterusnya.

14) Menghitung gaya geser tingkat (V)

$V = \sum_{i=1}^{n} F_i$

d) Lantai 1, V_1 = $F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$

= -74,39563347 kg

e) Lantai 2, V_2 = $F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$

= -8,04436041 kg

f) Lantai 3, V_3 = $F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + F_{11} + F_{12} + F_{13} + F_{14} + F_{15}$

= -0,769186868 kg

dan seterusnya.

15) Menghitung momen guling (M)

$M_i = \sum_{i=1}^{n} F_i h_i$

d) Lantai dasar/fondasi

M_0 = $(F_1 \times H_1 + F_2 \times H_2 + F_3 \times H_3 + F_4 \times H_4 + F_5 \times H_5 + F_6 \times H_6 + F_7 \times H_7 + F_8 \times H_8 + F_9 \times H_9 + F_{10} \times H_{10} + F_{11} \times H_{11} + F_{12} \times H_{12} + F_{13} \times H_{13} + F_{14} \times H_{14} + F_{15} \times H_{15}) / 100$

= -290,1259772 kg.m

e) Lantai 1

M_1 = $(F_2 \times H_2 + F_3 \times H_3 + F_4 \times H_4 + F_5 \times H_5 + F_6 \times H_6 + F_7 \times H_7 + F_8 \times H_8 + F_9 \times H_9 + F_{10} \times H_{10} + F_{11} \times H_{11} + F_{12} \times H_{12} + F_{13} \times H_{13} + F_{14} \times H_{14} + F_{15} \times H_{15}) /100$

= -57,89652145 kg.m

f) Lantai 2

M_2 = (F_3 x H_3 + F_4 x H_4 + F_5 x H_5 + F_6 x H_6 + F_7 x H_7 + F_8 x H_8 + F_9 x H_9 + F_{10} x H_{10} + F_{11} x H_{11} + F_{12} x H_{12} + F_{13} x H_{13} + F_{14} x H_{14} + F_{15} x H_{15}) / 100

= -6,970306656 kg.m

dan seterusnya.

6. Perhitungan Resultan Respon Struktur

Resultan respon struktur dihitung dengan persamaan seperti biasa, yakni R = $\sqrt{x^2 + y^2}$ dengan nilai x adalah respon struktur pada arah x dan y adalah respon struktur pada arah y. Respon struktur tersebut mencakup seluruh respon struktur yang dicari seperti perhitungan di atas, yaitu simpangan netto, sudut rotasi, simpangan rotasi, simpangan total, *interstorey drift ratio*, gaya horizontal tingkat, gaya geser tingkat, dan momen guling.

C. Verifikasi Hasil Perhitungan Manual dan Program MATLAB R2013a

Nilai verifikasi ini diambil dari hasil respon struktur yang terjadi pada detik ke 0,01 dan detik ke 0,02 seperti pada contoh perhitungan sebelumnya.

1. Detik ke 0,01

Tabel 4 Perbandingan Simpangan Netto Manual dan MATLAB R2013a detik ke 0,01

Lantai	Simpangan Netto (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-6,13755E-06	-6,13755E-06	4,96004E-07
1	-2,71039E-06	-2,71039E-06	2,57496E-05
2	-2,99902E-06	-2,99901E-06	4,87425E-05
3	-3,0201E-06	-3,02009E-06	7,31738E-05
4	-3,02056E-06	-3,02056E-06	9,78899E-05
5	-3,01944E-06	-3,01944E-06	0,00012266
6	-3,0182E-06	-3,01819E-06	0,000147454
7	-3,01694E-06	-3,01694E-06	0,000172269
8	-3,01569E-06	-3,01568E-06	0,000197105
9	-3,01443E-06	-3,01443E-06	0,000221961
10	-3,01318E-06	-3,01317E-06	0,000246838
11	-3,01192E-06	-3,01191E-06	0,000271736
12	-3,01067E-06	-3,01066E-06	0,000296653
13	-3,00941E-06	-3,0094E-06	0,000321572
14	-3,00817E-06	-3,00816E-06	0,000346272
15	-3,00708E-06	-3,00707E-06	0,000368037

Tabel 5 Perbandingan Sudut Rotasi Manual dan MATLAB R2013a detik ke 0,01

Lantai	Sudut Rotasi (rad)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-3,59124E-12	-3,59338E-12	0,059512085

Tabel 6 Perbandingan Simpangan Rotasi Manual dan MATLAB R2013a detik ke 0,01

Lantai	Simpangan Rotasi (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-1,25693E-09	-1,25768E-09	0,059512085
2	-2,51387E-09	-2,51536E-09	0,059512085
3	-3,7708E-09	-3,77304E-09	0,059512085
4	-5,02773E-09	-5,03073E-09	0,059512085
5	-6,28467E-09	-6,28841E-09	0,059512085
6	-7,5416E-09	-7,54609E-09	0,059512085
7	-8,79853E-09	-8,80377E-09	0,059512085
8	-1,00555E-08	-1,00615E-08	0,059512085
9	-1,13124E-08	-1,13191E-08	0,059512085
10	-1,25693E-08	-1,25768E-08	0,059512085
11	-1,38263E-08	-1,38345E-08	0,059512085
12	-1,50832E-08	-1,50922E-08	0,059512085
13	-1,63401E-08	-1,63499E-08	0,059512085
14	-1,75971E-08	-1,76075E-08	0,059512085
15	-1,8854E-08	-1,88652E-08	0,059512085

Tabel 7 Perbandingan Simpangan Total Manual dan MATLAB R2013a detik ke 0,01

Lantai	Simpangan Total (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-6,13755E-06	-6,13755E-06	4,96004E-07
1	-8,8492E-06	-8,8492E-06	2,22271E-07
2	-9,13908E-06	-9,13908E-06	4,17608E-08
3	-9,16142E-06	-9,16142E-06	4,06192E-08
4	-9,16314E-06	-9,16314E-06	5,2825E-08
5	-9,16328E-06	-9,16328E-06	6,60564E-08
6	-9,16329E-06	-9,16329E-06	7,93694E-08
7	-9,16329E-06	-9,16329E-06	9,26852E-08
8	-9,1633E-06	-9,1633E-06	1,06005E-07
9	-9,1633E-06	-9,1633E-06	1,19323E-07
10	-9,1633E-06	-9,1633E-06	1,32645E-07
11	-9,1633E-06	-9,1633E-06	1,46001E-07
12	-9,1633E-06	-9,1633E-06	1,59825E-07
13	-9,16331E-06	-9,16331E-06	1,79702E-07
14	-9,16332E-06	-9,16332E-06	2,78141E-07
15	-9,16349E-06	-9,16349E-06	1,34028E-06

Tabel 8 Perbandingan *Interstorey Drift* Manual dan MATLAB R2013a detik ke 0,01

Lantai	*Interstorey Drift Ratio* (%)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-7,74397E-07	-7,74397E-07	2,57496E-05
2	-8,2464E-08	-8,24638E-08	0,000264663
3	-6,02337E-09	-6,02316E-09	0,003548666
4	-1,33221E-10	-1,33008E-10	0,160186457
5	3,20645E-10	3,20859E-10	0,066545691
6	3,55618E-10	3,55832E-10	0,06000075
7	3,58313E-10	3,58526E-10	0,059549471
8	3,58521E-10	3,58734E-10	0,059514955
9	3,58537E-10	3,5875E-10	0,05951231
10	3,58538E-10	3,58751E-10	0,059512095
11	3,58536E-10	3,5875E-10	0,059512094
12	3,58516E-10	3,58729E-10	0,059512084
13	3,58249E-10	3,58463E-10	0,059512082
14	3,54793E-10	3,55004E-10	0,059512086
15	3,12397E-10	3,12582E-10	0,059512084

Tabel 9 Perbandingan Gaya Hor Tingkat Manual dan MATLAB R2013a detik ke 0,01

Lantai	Gaya Horizontal Tingkat (kg)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-11,18836763	-11,18836697	5,88951E-06
2	-0,862121857	-0,862121806	5,88967E-06
3	-0,066430968	-0,066430964	5,89067E-06
4	-0,005118851	-0,005118851	5,8771E-06
5	-0,000394434	-0,000394434	6,06674E-06
6	-3,03932E-05	-3,03932E-05	2,61838E-06
7	-2,34195E-06	-2,34195E-06	4,39928E-05
8	-1,80353E-07	-1,80354E-07	0,000199941
9	-1,25316E-08	-1,25304E-08	0,009639035
10	1,67628E-08	1,67729E-08	0,059745823
11	2,31358E-07	2,31496E-07	0,059699946
12	3,00357E-06	3,00536E-06	0,05951374
13	3,89795E-05	3,90027E-05	0,059511755
14	0,000505865	0,000506166	0,059512098
15	0,003495606	0,003497686	0,059512084

Tabel 10 Perbandingan Gaya Geser Tkt Manual dan MATLAB R2013a detik ke 0,01

Lantai	Gaya Geser Tingkat (kg)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-12,11842297	-12,11841985	2,57496E-05
2	-0,930055336	-0,930052875	0,000264663
3	-0,06793348	-0,067931069	0,003548666
4	-0,001502511	-0,001500104	0,160186457
5	0,00361634	0,003618747	0,066545691
6	0,004010774	0,004013181	0,06000075
7	0,004041167	0,004043574	0,059549471
8	0,004043509	0,004045916	0,059514955
9	0,00404369	0,004046096	0,05951231
10	0,004043702	0,004046109	0,059512095
11	0,004043685	0,004046092	0,059512094
12	0,004043454	0,00404586	0,059512084
13	0,004040451	0,004042855	0,059512083
14	0,004001471	0,004003852	0,059512086
15	0,003495606	0,003497686	0,059512084

Tabel 11 Perbandingan Momen Guling Manual dan MATLAB R2013a detik ke 0,01

Lantai	Momen Guling (kg.m)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-45,76071656	-45,76058875	0,000279304
1	-6,601429846	-6,601304341	0,001901181
2	-0,566576848	-0,566451698	0,022088738
3	0,13094832	0,131073429	0,095540431
4	0,202612238	0,202737342	0,061745716
5	0,209514834	0,209639938	0,059711265
6	0,210153091	0,210278195	0,059529908
7	0,210210469	0,210335573	0,059513647
8	0,210215519	0,210340623	0,059512222
9	0,210215914	0,210341017	0,059512092
10	0,210215327	0,21034043	0,059512092
11	0,21020642	0,210331518	0,059512084
12	0,21008027	0,210205293	0,059512083
13	0,208306702	0,208430669	0,059512086
14	0,183519325	0,183628541	0,059512084
15	0	0	0

2. Detik ke 0,02

Tabel 12 Perbandingan Simpangan Netto Manual dan MATLAB R2013a detik ke 0,02

Lantai	Simpangan Netto (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-2,63678E-05	-2,63678E-05	1,10095E-06
1	-1,66392E-05	-1,66392E-05	3,28979E-05
2	-1,91356E-05	-1,91356E-05	6,05921E-05
3	-1,93743E-05	-1,93743E-05	9,06471E-05
4	-1,93874E-05	-1,93873E-05	0,00012129
5	-1,9379E-05	-1,9379E-05	0,000152053
6	-1,93687E-05	-1,93687E-05	0,00018286
7	-1,93582E-05	-1,93582E-05	0,000213701
8	-1,93477E-05	-1,93477E-05	0,000244577
9	-1,93372E-05	-1,93372E-05	0,000275485
10	-1,93267E-05	-1,93267E-05	0,000306428
11	-1,93163E-05	-1,93162E-05	0,000337403
12	-1,93058E-05	-1,93057E-05	0,000368408
13	-1,92953E-05	-1,92952E-05	0,000399404
14	-1,9285E-05	-1,92849E-05	0,000429963
15	-1,92762E-05	-1,92761E-05	0,000455878

Tabel 13 Perbandingan Sudut Rotasi Manual dan MATLAB R2013a detik ke 0,02

Lantai	Sudut Rotasi (rad)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-3,0047E-11	-3,0064E-11	0,056705309

Tabel 14 Perbandingan Simpangan Rotasi Manual dan MATLAB R2013a detik ke 0,02

Lantai	Simpangan Rotasi (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-1,05165E-08	-1,05224E-08	0,056705309
2	-2,10329E-08	-2,10448E-08	0,056705309
3	-3,15494E-08	-3,15672E-08	0,056705309
4	-4,20658E-08	-4,20897E-08	0,056705309
5	-5,25823E-08	-5,26121E-08	0,056705309
6	-6,30987E-08	-6,31345E-08	0,056705309
7	-7,36152E-08	-7,36569E-08	0,056705309
8	-8,41316E-08	-8,41793E-08	0,056705309
9	-9,46481E-08	-9,47017E-08	0,056705309
10	-1,05165E-07	-1,05224E-07	0,056705309
11	-1,15681E-07	-1,15747E-07	0,056705309
12	-1,26197E-07	-1,26269E-07	0,056705309
13	-1,36714E-07	-1,36791E-07	0,056705309
14	-1,4723E-07	-1,47314E-07	0,056705309
15	-1,57747E-07	-1,57836E-07	0,056705309

Tabel 15 Perbandingan Simpangan Total Manual dan MATLAB R2013a detik ke 0,02

Lantai	Simpangan Total (cm)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-5,27356E-05	-2,63678E-05	50,00000055
1	-4,30175E-05	-4,30175E-05	4,62892E-07
2	-4,55245E-05	-4,55245E-05	9,17859E-08
3	-4,57737E-05	-4,57737E-05	8,21196E-08
4	-4,57972E-05	-4,57972E-05	1,05336E-07
5	-4,57994E-05	-4,57994E-05	1,31596E-07
6	-4,57996E-05	-4,57996E-05	1,58135E-07
7	-4,57996E-05	-4,57996E-05	1,84693E-07
8	-4,57996E-05	-4,57996E-05	2,11257E-07
9	-4,57997E-05	-4,57997E-05	2,37821E-07
10	-4,57997E-05	-4,57997E-05	2,644E-07
11	-4,57997E-05	-4,57997E-05	2,91119E-07
12	-4,57997E-05	-4,57997E-05	3,19475E-07
13	-4,57998E-05	-4,57998E-05	3,66007E-07
14	-4,58E-05	-4,58E-05	6,08999E-07
15	-4,58017E-05	-4,58017E-05	2,80475E-06

Tabel 16 Perbandingan *Interstorey Drift* Manual dan MATLAB R2013a detik ke 0,02

Lantai	*Interstorey Drift Ratio* (%)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-4,75407E-06	-4,75406E-06	3,28979E-05
2	-7,13259E-07	-7,13257E-07	0,000245181
3	-6,82005E-08	-6,81988E-08	0,002500016
4	-3,72112E-09	-3,71941E-09	0,045706222
5	2,38579E-09	2,38749E-09	0,071271446
6	2,94408E-09	2,94578E-09	0,057754901
7	2,99386E-09	2,99556E-09	0,056794533
8	2,99822E-09	2,99992E-09	0,056711979
9	2,99859E-09	3,00029E-09	0,056704879
10	2,99862E-09	3,00032E-09	0,056704262
11	2,99859E-09	3,00029E-09	0,056704208
12	2,99823E-09	2,99993E-09	0,05670401
13	2,99412E-09	2,99582E-09	0,05670225
14	2,94956E-09	2,95123E-09	0,056687319
15	2,50343E-09	2,50485E-09	0,056581626

Tabel 17 Perbandingan Gaya Hor Tingkat Manual dan MATLAB R2013a detik ke 0,02

Lantai	Gaya Horizontal Tingkat (kg)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-66,35127306	-66,35126831	7,16091E-06
2	-7,275173542	-7,275173048	6,78316E-06
3	-0,727218947	-0,727218899	6,57917E-06
4	-0,06887563	-0,068875626	6,44294E-06
5	-0,006296586	-0,006296585	6,44676E-06
6	-0,00056142	-0,00056142	4,90553E-06
7	-4,91344E-05	-4,91344E-05	2,03035E-05
8	-4,23603E-06	-4,23603E-06	3,10315E-05
9	-3,29992E-07	-3,29971E-07	0,006552218
10	3,33602E-07	3,3381E-07	0,062195497
11	4,14261E-06	4,14503E-06	0,058313836
12	4,62608E-05	4,62877E-05	0,057988828
13	0,00050259	0,00050288	0,057690518
14	0,005253605	0,005256613	0,057250882
15	0,028012483	0,028028333	0,056581626

Tabel 18 Perbandingan Gaya Geser Tkt Manual dan MATLAB R2013a detik ke 0,02

Lantai	Gaya Geser Tingkat (kg)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
1	-74,39563347	-74,395609	3,28979E-05
2	-8,04436041	-8,044340687	0,000245181
3	-0,769186868	-0,769167638	0,002500016
4	-0,041967921	-0,041948739	0,045706222
5	0,026907709	0,026926887	0,071271446
6	0,033204295	0,033223472	0,057754901
7	0,033765715	0,033784892	0,056794533
8	0,033814849	0,033834026	0,056711979
9	0,033819085	0,033838262	0,056704879
10	0,033819415	0,033838592	0,056704262
11	0,033819082	0,033838258	0,056704208
12	0,033814939	0,033834113	0,05670401
13	0,033768678	0,033787826	0,05670225
14	0,033266088	0,033284946	0,056687319
15	0,028012483	0,028028333	0,056581626

Tabel 19 Perbandingan Momen Guling Manual dan MATLAB R2013a detik ke 0,02

Lantai	Momen Guling (kg.m)		Ketelitian (%)
	Manual (Ms Excel)	MATLAB R2013a	
0	-290,1259772	-290,1249626	0,000349702
1	-57,89652145	-57,8955235	0,001723673
2	-6,970306656	-6,969312164	0,014267555
3	0,665492285	0,666486275	0,149361609
4	1,62975111	1,630745038	0,060986481
5	1,739941358	1,740935278	0,057123807
6	1,751731177	1,752725097	0,056739309
7	1,75293497	1,75392889	0,056700331
8	1,753053579	1,754047499	0,056696497
9	1,753063974	1,754057893	0,056696122
10	1,753052298	1,75404621	0,056696085
11	1,752892807	1,753886626	0,056695938
12	1,750949852	1,751942545	0,056694503
13	1,728082008	1,729061507	0,056681323
14	1,470655363	1,471487483	0,056581626
15	0	0	0