IJTI (International Journal Of Transportation And Infrastructure)
Available Online @ http://jurnal.narotama.ac.id/index.php/ijti
ISSN : 2597-4769 (ONLINE) ISSN : 2597-4734 (CETAK)

Volume 4 Number 2 March 2021

Study of Behavioral of Vertical Irregular Building Structure by Applying Column Variation Due to Earthquake using Dynamic Analysis

Syafwandi[1], Pawening Esti Pramundi[1], Agyanata Tua Munthe[1], Agung Sumarno[2]
Departement of Civil Engineering, Universitas Mercu Buana, Indonesia[1]
National Research and Innovation Agency[2]
h.syafwandi13@gmail.com, paweningesti@gmail.com, agyanata.umb@gmail.com,
agung_sumarno@mercubuana.ac.id

Abstract

The development of high-rise buildings in Indonesia is now increasingly diverse. The need for increasingly narrow land functions affects the shape of the building which tends to be irregular. Irregularity in the building requires structural planners to build buildings that are safe against earthquakes but also do not forget the aspect of user comfort. In this study, an analysis of the dynamics of earthquakes was carried out in buildings that have vertical geometric irregularities by varying the dimensions and reinforcement of the columns. The behavior of the building structure produces structural responses in the form of base shear, fundamental period, displacement and story drift. Analysis of earthquake using dynamic analysis of response spectrum based on SNI 1726 2019 with the help of ETABS software version 9.7.4. The results of this research indicate that the variation of column dimensions and column reinforcement in buildings with irregular vertical geometry reduces the stiffness of the building thereby reducing the forces in the structure, increasing the fundamental period, reducing the base shear force, increasing the displacement and the story drift.

Keywords:
Vertical Geometric Irregularity, Dynamic Analysis Response Spectrum, Base Shear, Fundamental Period, Displacement, Story Drift.

1. Introduction

Indonesia is a country that is flanked by two oceans and is located in a tectonic plate area. Indonesia's geographical location is at the confluence of four major tectonic plates, namely the Eurasian, Indo-Australian, Pacific and Philippine plates, which is often referred to as the ring of fire or earthquake-prone area. Earthquakes that occur in Indonesia often take lives. However, it is certain that the cause of the death toll was not directly caused by the earthquake, but caused by the damage to the building which caused the collapse of the building and resulted in casualties. With these conditions, the challenges in the construction world in Indonesia are very large, especially in designing earthquake-resistant high-rise buildings.

The development of high-rise buildings in Indonesia is now increasingly diverse. The need for increasingly narrow land functions, affects the shape of the building which tends to be irregular. Irregularity in the building requires structural planners to build buildings that are safe against earthquakes but also do not forget the aspect of user comfort. One type of irregularity in a building is vertical geometric irregularity, where according to SNI 03-1726:2019, vertical geometric irregularity is a building if the horizontal dimension of the seismic force bearing system at any level is more than 130% of the horizontal dimension of the adjacent seismic force resisting system.

Buildings with regular, simple, and symmetrical shapes will behave better against earthquakes than buildings with irregular shapes (Paulay & Priestley, 1992). The irregular shape of the building will be more unstable than the regular building. These irregularities can affect the stiffness of the building to withstand earthquake loads. One of the indicators to see earthquake response is displacement. The displacement resulting from irregular buildings is greater, so the building has a lower strength against earthquake loads (Purba, 2014).

Regardless of the complexity of the earthquake problems that occur, the main task of experts and practitioners, especially those engaged in civil engineering, is to create a new order regarding the design of earthquake-resistant buildings that are even better. Another thing that must be considered in planning earthquake-resistant buildings is to be guided by the latest regulations or standards that apply in Indonesia, SNI 1726:2019 (2019) concerning *Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung*. To review the magnitude of the earthquake load that occurs in the building structure, it can be seen from the factors that influence it. There are several factors, including the mass and stiffness of the structure, soil conditions and the seismic area where the building structure is erected. The mass of the building structure is a very important factor, because the earthquake load is an inertial force that acts on the center of mass, the amount of which is very dependent on the mass of the structure (Indarto et al., 2013).

In this research, we will review the behavior of buildings against earthquakes through changes in mass. One of the ways to reduce the mass of the building is by reducing the dimensions and reinforcement of the column. The analysis method used is the dynamic analysis of the response spectrum. The building being analyzed is the Social Security Tower (SS Tower) which has vertical geometric irregularities in 3 (three) types of columns. The building has a building area of 50,000 m^2, a height of 125.2 meters with 30 stories and 3 basements.

2. Methodology

2.1. Research Method

The research method used in this analysis is a quantitative method, which begins with studying survey data and some literature reviews and then proceed with structural modeling using the ETABS V.9.7.4 software. The calculation of earthquake analysis uses the SNI 1726:2019 concerning *Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung.*

2.2. General Data

Project name : Social Security (SS) Tower
Project location : Jalan Rasuna Said, Kav. 112 Blok B, Setia Budi, Jakarta Selatan
Latitude : -6.20697°
Longitude : 106.82862°

2.3. Technical Data

Object of research : Social Security (SS) Tower
Material properties : Reinforced concrete
Building function : Office
Structure system : Dual System
Soil type : Medium soil
Building area : 50.000 m^2
Structure height : 125,2 m
Number of stories : 30 stories and 3 basement
Drawing data : As planned drawing
Concrete strength : 35 MPa – 45 MPa (Column daand Core Wall)
30 MPa – 35 MPa (Beam and Slab)
Reinforecement yield strength: 400 MPa (Longitudinal)
240 MPa (Transversal)
Concrete Density : 24 kN/m^3

2.4. Gambar Desain Struktur

The following is a picture of the structure design of Social Security (SS) Tower.

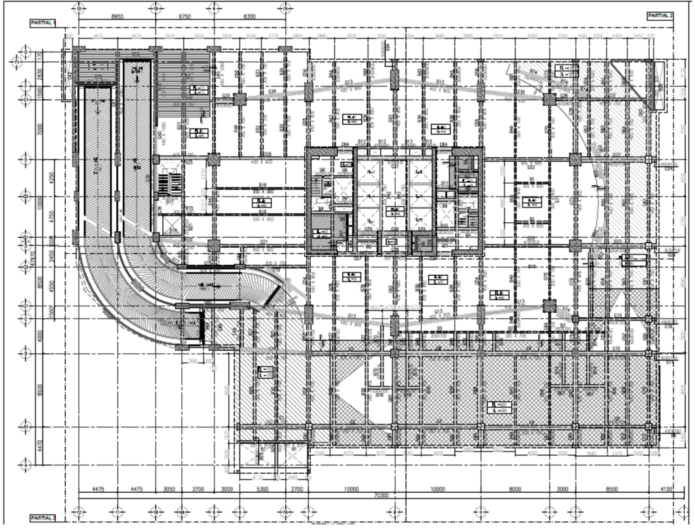

Figure 1. Ground Floor Structure Plan
(Source: Secondary data, 2022)

2.5. Flowchart

The stages of analysis in the calculation of this study are as described in the following figure:

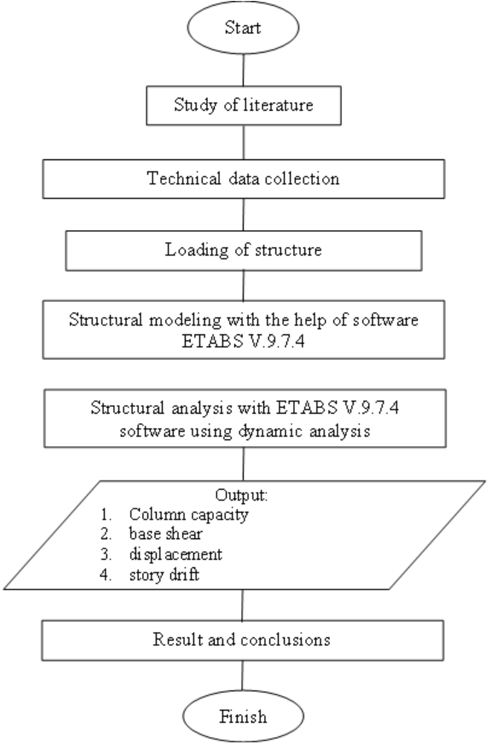

Figure 2. Flowchart
(Source: Author, 2022)

3. Analysis and Result

3.1. Spectra Response Design

Earthquake parameters are determined based on SNI 1726 2019 concerning *Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung* with the following details:

1. The category of building structure is seen from Table 1 of SNI 1726-2019. The Social Security (SS) Tower building which is included in an office building is categorized as a risk II building.
2. The earthquake priority factor (Ie) is seen from Table 2 of SNI 1726-2019. The risk category II building has an earthquake priority factor (Ie) of 1.00.
3. Based on Indonesia's spectral response design data released by Pusat Penelitian dan Pengembangan Permukiman, Kementrian Pekerjaan Umum, the response spectra parameters are obtained as follows:

Table 1. Parameter Response Spectra

Variable	Value
PGA (g)	0,361
S_S (g)	0,686
S_1 (g)	0,300
C_{RS}	0,995
C_{R1}	0,940
F_{PGA} (g)	1,139
F_A	1,251
F_V	1,799
PSA (g)	0,411
S_{MS} (g)	0,858
S_{M1} (g)	0,540
S_{DS} (g)	0,572
S_{D1} (g)	0,360
T_0 (second)	0,126
T_S (second)	0,630

(Source: Pusat Penelitian dan Pengembangan Pemukiman – Kementerian Pekerjaan Umum)

Table 2. Connectivity Fundamental Period, T (second) and Spectral Response Acceleration, SA (g)

T (second)	SA (g)
0	0,229
T_0	0,572
T_S	0,572
$T_S + 0$	0,494
$T_S + 0,5$	0.293
$T_S + 1$	0.208
$T_S + 1,5$	0.162
$T_S + 2$	0.132
$T_S + 2,5$	0.112
$T_S + 3$	0.097
$T_S + 3,1$	0.094
$T_S + 3,2$	0.092
4	0.090

(Source: Pusat Penelitian dan Pengembangan Pemukiman – Kementerian Pekerjaan Umum)

The connectivity between the natural vibration period (T) and SA (g) can be seen in the following spectrum response graph:

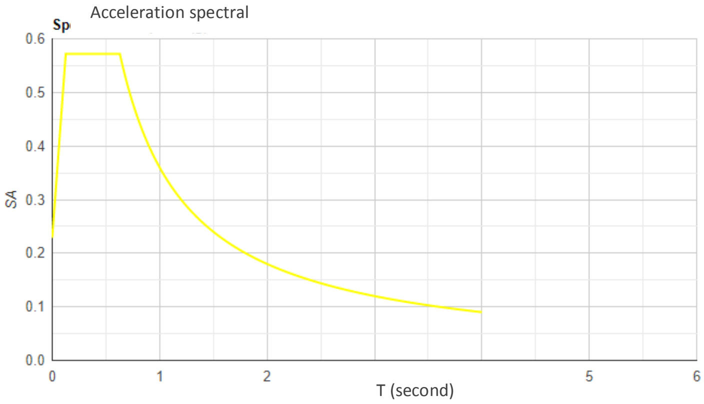

Figure 3. Response Spectrum Graph
(Source: Pusat Penelitian dan Pengembangan Pemukiman – Kementerian Pekerjaan Umum)

1. Seismic design categories are obtained from Table 8 and Table 9 of SNI 1726-2019. Based on the data in point 3, buildings with $S_{DS} \geq 0{,}50$ dan $S_{D1} \geq 0{,}20$ are categorized as type D seismic design categories.
2. Site classification is obtained from Table 5 of SNI 1726-2019. Buildings with N values between 15 and 50 are classified as type D site classification.
3. The response modification coefficient (R) is obtained from Table 12 SNI 1726-2019. Buildings with special moment-bearing reinforced concrete frame structures have a response modification coefficient value (R) of 8.

3.2. Column Capacity

In this research, the column capacity was carried out using pcaColumn software. The columns that are reviewed or varied are the types of columns K5, K7, K8, K22, K23, and K25. Based on the column interaction diagram, the condition of the column from the basement floor to the roof floor is still able to accept all variations of the building because the results of the analysis of all columns are still within the strong line of the plan. The ability of the column to receive axial loads and moments in the building to be analyzed, explains that all column dimensions are feasible to be analyzed based on the parameters of base shear, displacement, and story drift. The results of the analysis prove that the variation of column dimensions given in this study does not result in collapse of the concrete, failure will begin in the steel reinforcement first due to tensile forces, so that the concrete in the column is still strong.

3.3. Base Shear

Based on the results of the ETABS program analysis, the base shear values obtained with various variations of column dimension reduction. The response of the base shear structure is taken from the results of the ETABS program analysis seen from the base reaction.

Table 3. Base Shear Value

Variation	Base Shear (kN) Dynamic Analysis X Direction	Base Shear (kN) Dynamic Analysis Y Direction	Base Shear (kN) Equivalent Static Analysis	Structure Weight (kN)	Fundamental Period (s)
Existing	4112,62	5971,23	3334,280	540050,1	7,288607
Variation 1	4067,31	5893,29	3301,133	535275,6	7,296709
Variation 2	4019,05	5812,28	3266,976	530716,4	7,310197
Variation 3	3974,3	5732,11	3236,099	526820,4	7,325771

(Source: ETABS V9.7.4 software, 2022)

Based on the results that have been obtained, the value of the dynamic base shear of the entire modeling is 100% greater than the calculation of the static earthquake base shear. Therefore, the base shear obtained does not need to be re-evaluated. If we compare the results of the base shear analysis from the X direction and from the Y direction, it will be seen that the change in value is not too significant. However, the base shear value is constantly decreasing accompanied by a decrease in the column dimensions which are treated in variation 1, variation 2, and variation 3. The largest base shear value on the X and Y axes is found in the existing building model. While the lowest base shear value in terms of both the X and Y axes is found in the variation 3 building model.

3.4. Displacement

Displacement that occurs in every condition of the variation of the building is viewed from both directions, namely the X direction and the Y direction. The displacement value is taken from one point that has a continuous column from the basement floor to the roof story, and the point that has the largest displacement value as a sample to see the treatment of the building. The following is the displacement value of each modeling variation for the X direction and the Y direction.

Table 4. Displacement of X Direction

Story	Displacement of X Direction (mm) Existing	Variation 1	Variation 2	Variation 3
Roof Story	195,424	196,190	197,270	197,935
ME Story	192,665	193,424	194,633	195,147
Story 28	188,198	188,872	189,971	190,386
Story 27	183,177	183,764	184,755	185,075
Story 26	177,772	178,271	179,149	179,372
Story 25	173,086	173,520	174,312	174,460
Story 24	168,051	168,416	169,116	169,187
Story 23	162,722	163,026	163,645	163,653
Story 22	157,075	157,320	157,860	157,907
Story 21	151,098	151,289	151,753	152,646
Story 20	144,791	144,931	145,323	146,166
Story 19	138,182	138,276	138,602	139,403
Story 18	131,266	131,318	131,581	132,344
Story 17	124,110	124,132	124,345	125,083
Story 16	116,679	116,689	116,832	117,547
Story 15	109,401	109,570	110,495	110,597
Story 14	101,494	101,544	101,630	102,222
Story 13	93,362	93,597	93,751	94,040
Story 12	85,056	85,982	86,012	86,706
Story 11	76,589	76,713	76,925	77,233
Story 10	67,797	67,919	68,915	69,638
Story 9	59,101	59,329	59,516	60,062
Story 8	50,133	50,672	50,858	51,436

Story 7	40,107	40,360	40,548	41,172
Story 6	30,560	30,624	30,813	31,378
Story 5	23,160	23,340	24,340	24,544
Story 4	17,431	17,626	17,834	18,368
Story 3	12,032	12,049	12,074	13,046
Story 2	7,034	7,068	7,109	7,123
Story 1	1,362	1,433	1,506	1,574
Basement 1	0,209	0,217	0,226	0,234
Basement 2	0,065	0,068	0,070	0,072
Basement 3	0,000	0,000	0,000	0,000

(Source: ETABS V 9.7.4, 2022)

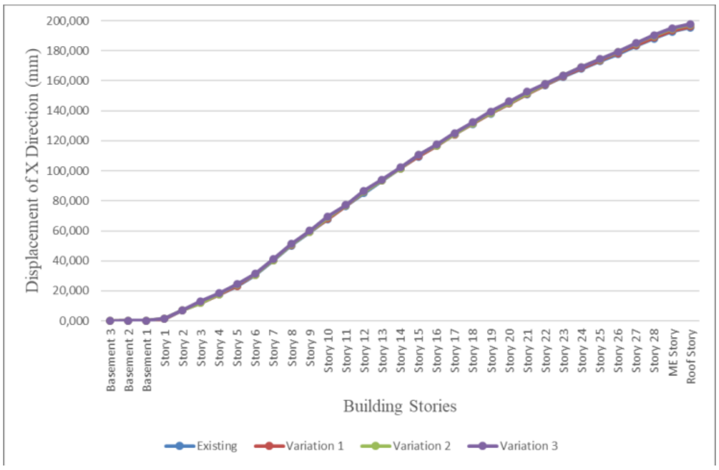

Figure 4. The Graph of X-Direction Displacement All Variations
(Source: Author's analysis, 2022)

Table 5. Displacement of Y Direction

Story	Displacement of Y Direction (mm)			
	Existing	Variation 1	Variation 2	Variation 3
Roof Story	168,149	168,508	168,478	168,834
ME Story	160,515	160,910	160,929	161,312
Story 28	153,054	153,493	153,566	153,981
Story 27	145,474	145,948	146,069	146,512
Story 26	137,923	138,430	138,598	139,065
Story 25	131,623	132,157	132,360	132,847
Story 24	125,318	125,875	126,113	126,617
Story 23	119,048	119,623	119,890	120,405
Story 22	112,799	113,387	113,679	114,204
Story 21	106,583	107,180	107,493	108,023
Story 20	100,406	101,007	101,337	101,868
Story 19	94,277	94,876	95,219	95,746
Story 18	88,187	88,781	89,132	89,653
Story 17	82,165	82,747	83,100	83,610
Story 16	76,189	76,755	77,107	77,602
Story 15	70,557	71,104	71,451	71,928
Story 14	64,695	65,217	65,555	66,009
Story 13	58,893	59,388	59,712	60,141
Story 12	53,181	53,642	53,949	54,349

Story 11	47,556	47,981	48,266	48,634
Story 10	42,054	42,440	42,703	43,038
Story 9	36,766	37,112	37,349	37,647
Story 8	31,657	31,958	32,165	32,424
Story 7	25,687	25,939	26,114	26,332
Story 6	20,115	20,317	20,460	20,634
Story 5	16,030	16,192	16,305	16,444
Story 4	12,637	12,761	12,847	12,952
Story 3	9,509	9,597	9,656	9,731
Story 2	6,652	6,713	6,755	6,808
Story 1	3,401	3,439	3,468	3,501
Basement 1	1,258	1,272	1,282	1,293
Basement 2	0,314	0,319	0,322	0,326
Basement 3	0,000	0,000	0,000	0,000

(Source: ETABS V 9.7.4, 2022)

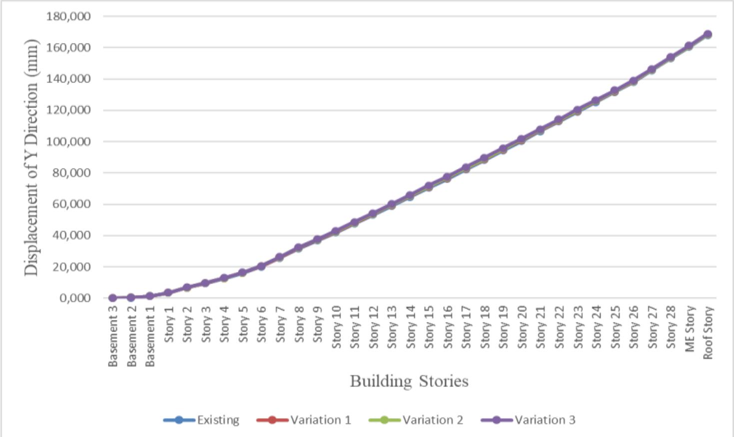

Figure 5. The Graph of Y-Direction Displacement All Variations
(Source: Author's analysis, 2022)

In accordance with SNI 1726 2019, the deviation value for all variations of the X-direction and Y-direction modeling obtained must not exceed the allowable deviation value under review, where the magnitude of the displacement under review should not exceed 0.020 times the building height. This is done to avoid the danger of excessive deviation so that it can cause the building to collapse. Based on the results of the deviation values for all modeling variations in the X and Y directions, they are still in the safe category. The following describes the displacement value for the displacement allowable.

Table 6. Displacement Allowable

Variation	Displacement (mm)		Displacement Allowable (mm)	Result
	X-Direction	Y-Direction		
Existing	195,424	168,149	2748	Safe
Variation 1	196,190	168,508	2748	Safe
Variation 2	197,270	168,478	2748	Safe
Variation 3	197,935	168,834	2748	Safe

(Source: Author’s analysis, 2022)

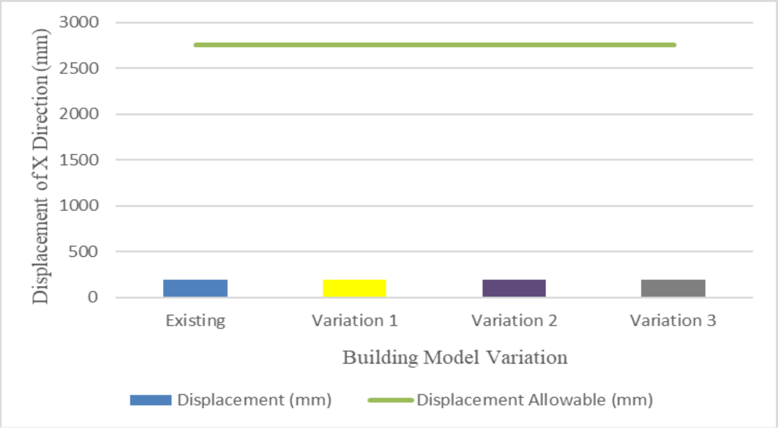

Figure 6. Displacement Allowable of X Direction
(Source: Author's analysis, 2022)

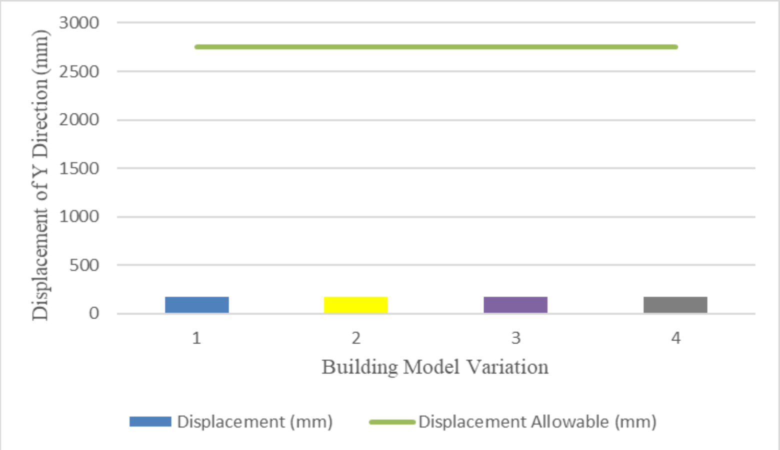

Figure 7. Displacement Allowable of Y Direction
(Source: Author's analysis, 2022)

3.5. Story Drift

Story drift is the deviation between floors measured from the base of the story below. The value of the story drift is taken from the displacement value between stories that has been obtained in the previous sub-chapter. The following is the story drift value that occurs in each condition of the variation of the X-direction and Y-direction buildings.

Table 7. Story Drift of X Direction

Story	Story Drift of X Direction (mm)			
	Existing	Variation 1	Variation 2	Variation 3
Roof Story	2,759	2,767	2,637	2,788
ME Story	4,467	4,552	4,661	4,761
Story 28	5,021	5,107	5,216	5,310
Story 27	5,405	5,493	5,606	5,703
Story 26	4,686	4,751	4,838	4,912
Story 25	5,035	5,105	5,196	5,273
Story 24	5,329	5,390	5,471	5,533
Story 23	5,647	5,706	5,786	5,746
Story 22	5,977	6,032	6,107	5,262
Story 21	6,307	6,358	6,430	6,480
Story 20	6,609	6,655	6,721	6,763
Story 19	6,916	6,958	7,022	7,059
Story 18	7,155	7,186	7,236	7,261
Story 17	7,432	7,443	7,513	7,537

Story 16	7,278	7,119	6,337	6,950
Story 15	7,907	8,027	8,865	8,375
Story 14	8,132	7,947	7,879	8,182
Story 13	8,306	7,614	7,739	7,334
Story 12	8,467	9,269	9,087	9,473
Story 11	8,792	8,794	8,010	7,595
Story 10	8,696	8,590	9,399	9,576
Story 9	8,968	8,657	8,658	8,626
Story 8	10,026	10,312	10,310	10,265
Story 7	9,547	9,736	9,735	9,794
Story 6	7,401	7,284	6,473	6,834
Story 5	5,728	5,714	6,507	6,176
Story 4	5,399	5,577	5,760	5,322
Story 3	4,998	4,981	4,964	5,923
Story 2	5,672	5,635	5,604	5,548
Story 1	1,153	1,216	1,280	1,341
Basement 1	0,145	0,149	0,155	0,162
Basement 2	0,065	0,068	0,070	0,072
Basement 3	0,000	0,000	0,000	0,000

(Source: Author’s analysis, 2022)

Tabel 8. Story Drift Arah Y

Story	Story Drift of Y Direction (mm)			
	Existing	Variation 1	Variation 2	Variation 3
Roof Story	7,633	7,598	7,549	7,522
ME Story	7,461	7,417	7,363	7,331
Story 28	7,580	7,545	7,496	7,469
Story 27	7,551	7,518	7,472	7,447
Story 26	6,300	6,274	6,237	6,218
Story 25	6,305	6,281	6,247	6,230
Story 24	6,270	6,253	6,224	6,212
Story 23	6,250	6,236	6,211	6,202
Story 22	6,216	6,207	6,186	6,181
Story 21	6,177	6,173	6,156	6,155
Story 20	6,129	6,131	6,118	6,121
Story 19	6,090	6,095	6,087	6,093
Story 18	6,022	6,034	6,031	6,043
Story 17	5,977	5,992	5,993	6,008
Story 16	5,632	5,651	5,657	5,675
Story 15	5,862	5,887	5,896	5,918
Story 14	5,801	5,830	5,843	5,869
Story 13	5,713	5,746	5,763	5,792
Story 12	5,625	5,661	5,682	5,714
Story 11	5,502	5,540	5,563	5,596
Story 10	5,288	5,329	5,355	5,391
Story 9	5,110	5,154	5,184	5,223
Story 8	5,970	6,019	6,051	6,092
Story 7	5,572	5,621	5,655	5,698
Story 6	4,085	4,126	4,154	4,190
Story 5	3,393	3,431	3,458	3,492
Story 4	3,128	3,164	3,191	3,222

Story 3	2,858	2,884	2,901	2,923
Story 2	3,251	3,274	3,288	3,307
Story 1	2,143	2,167	2,186	2,208
Basement 1	0,944	0,953	0,959	0,967
Basement 2	0,314	0,319	0,322	0,326
Basement 3	0,000	0,000	0,000	0,000

(Source: Author's analysis, 2022)

4. Conclussion

Based on the results of modeling analysis with variations in column dimensions in buildings that have vertical geometric irregularities, it can be concluded that variations in column dimensions in the behavior of building structures with vertical geometric irregularities will affect building behavior against earthquakes, namely reducing building stiffness. The decrease in building stiffness is seen from the parameter results, increasing the fundamental structure, reducing the base shear, and increasing the displacement.

The difference in the behavior of the irregular structure of the vertical geometry which has varied the dimensions of the column shows that the reduction in mass in the building will cause the stiffness of the building to be smaller. This is evidenced by the existing building as a variation that does not experience a reduction in column dimensions so that the mass of the building does not decrease and has a greater building rigidity when compared to other modeling variations. This is reviewed based on the parameters of base shear, fundamental period, displacement, and story drift.

The variation of the planned column dimension reduction is still within safe limits in accordance with the permitted displacement of SNI 1726 2019 in terms of displacement parameters and story drift.

The value of the base shear in each building model, namely, the existing model in the X direction is 4112.62 kN, while the Y direction is 5971.23 kN. Variation Model 1 in X direction is 4067.31 kN, while the Y direction is 5893.29 kN. Variation Model 2 in X direction is 4019.05 kN, while the Y direction is 5812.28 kN. Variation Model 3 in X direction is 3974.3 kN, while the Y direction is 5732.11 kN. The critical story displacement value is obtained in the Variation model 3 with a displacement value of 195.424 mm in the X direction and 168,834 mm in the Y direction. The largest story drift in the X direction is found in the structure model variation 3 with a story drift value of 10.312 mm and the Y direction in the existing structural model with a value of 7.580 mm.

References

Badan Standardisasi Nasional (BSN). (2019). *SNI 1726:2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*. BSN. https://tekonsipil.sv.ugm.ac.id/wp-content/uploads/sites/938/2020/01/SNI-1726-2019-Persyaratan-Beton-Struktural-Untuk-Bangunan-Gedung.pdf

Indarto, H., A., H. T. C., & Putra, K. C. A. (2013). *Aplikasi SNI Gempa 1726:2012 for Dummies*. Bambang Dewasa File's. https://www.academia.edu/40767178/Aplikasi_SNI_Gempa_1726_

Paulay, T., & Priestley, M. J. N. (1992). *Seismic design of reinforced concrete and masonry buildings*. Wiley. https://www.wiley.com/en-us/Seismic+Design+of+Reinforced+Concrete+and+Masonry+Buildings-p-9780471549154

Purba, H. L. (2014). Analisis Kinerja Struktur pada Bangunan Bertingkat Beraturan dan Ketidak Beraturan Horizontal sesuai SNI 03-1726-2012. *Jurnal Teknik Sipil Dan Lingkungan*, *2*(4), 710–717. https://media.neliti.com/media/publications/212167-analisis-kinerja-struktur-pada-bangunan.pdf