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Behaviour of Concrete Structures of 5-storey Shopping and Residences Buildings due to Earthquakes using Spectrum Response Analysis

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Abstract. The 5-story building with 20 meters high and is located in Jakarta, a building that functions as a shop and residence. As a high-rise building, earthquake analysis of the building is required to determine the seismic pattern using the response spectrum method. The spectrum response method is used to determine the structural performance and compare static analysis and dynamic analysis based on SNI 1726-2019. Then the results obtained for each frame use a combination of cases (static + seismic), for displacement review, there is the highest drift on the 5th floor of 37.04 mm, and the highest drift value on the 5th floor of 4.57x10^{-3} mm. The internal force in the sample column obtained the same results in story 1 column C1 and C2 of 59.57 kN at Fx, Fy of 4.72 kN and moment of 5.01 kN-m, through a combination (static + seismic). The value of the sample beam on the 3rd floor has the highest value on B1, the Fx value was 4.73x10^{-14} kN, Fy was 9.09 kN, and the moment was 13.88 kN-m.

Keywords: *Displacement, drift, frequency, period, seismic, shear static*

1 Introduction

The construction of multi-storey buildings is the right thing to overcome the lack of available land. The research by Afriandini, et. al in [1], Afrida, et.al in [2], Anisa, et. al in [3], and Harahap, et. al in [4], stated that high-rise buildings have a great risk of earthquake forces because the magnitude of earthquake loads cannot be predicted. It is because the higher a building's lateral forces that occur will be greater. Planning buildings in areas prone to earthquakes requires careful calculations in determining the building design. So that if an earthquake occurs, the building structure can remain strong and collapse will not occur. In the structural analysis process, Hilmi, et. al in [5], Hukama, et. al in [6], Rafsanjani, et. al in [7] indicated that forces are obtained in the form of bending moments, shear forces, and axial forces which will be used to determine the dimensions of the structural elements. These structural elements will be designed so that a strong building structure is produced and is expected to withstand all planned loads, including earthquake loads that cannot be predicted when they occur. Estimation for earthquake loads on buildings can use a seismic design approach which ensures that the intensity of the shaking does not cause any damage to the building so that the structure can be reused after an earthquake.

The research of Silaban, et. al in [8], Hasaballa, et. al in [9] explained that the plan uses boundary conditions that correspond to the intensity of the strongest or expected earthquake at the building site. The use of the Response Spectrum method can be used to determine the intensity of the earthquake, which can be continued to investigate the seismic performance of the building frame in. In this article, an experiment was carried out to determine the seismic performance of frames in educational facility buildings with a height of 5 floors located in Central Jakarta City, DKI Jakarta. The approach uses the Response Spectrum Analysis method using the SAP 2000 V22.0 program.

2 Research Methods

The response Spectrum method is a spectrum that describes the shape of the curve between structure periods (T), with maximum responses based on the damping ratio and certain earthquakes. The maximum response can be the maximum deviation (spectral displacement, SD), maximum speed (spectral velocity, SV), or maximum acceleration (spectral acceleration, SA) of the single degree of freedom (SDOF) structural mass. Spectrum response is a dynamic earthquake analysis that is used to determine the performance of structures in high-rise, irregular buildings, and buildings that require very high precision. By inputting the spectrum response based on the location of the building model and its soil class at https://rsa.buatkarya.pu.go.id/2021/. Then determine the value of bedrock acceleration for a short period (Ss), bedrock acceleration for 1 second (S_1), and the period data according to the spectral response data. Later calculate and input the period and value values in the define functions menu of the spectrum response. Subsequently, add dead, and live loads in the mass source menu, then input static E_x and static E_y values in define-load patterns. Afterwards determine the structural system and system parameters, namely response modification coefficient (R), system strength factor (Ω_0), and deflection magnification factor (C_d) by SNI 1726: 2019 (Earthquake Resistance Planning Procedures for building and non-building structures) then the data is input into static E_x and E_y by clicking modify lateral. Further to add a spectrum response load by copying the static load and naming it Earthquake X and Earthquake Y, then modifying it according to the load case type. Hereinafter to perform a response spectrum analysis run and recalculate the scale factors to adjust the values as correction factors. Furthermore, the spectrum response analysis from the table results obtained after carrying out an analyst run.

3 Frame Details Analysis

This reinforced concrete building plan consists of 5 stories. The shape of the building resembles a rectangle with a main size of 16.50m x 37.25m. This building is located in Jakarta, intended for shops and residential buildings. Analyzed to find out and evaluate how the building will behave seismically, the main parameters that influence this frame analysis are dead, live, and seismic loads. Seismic load calculations are based on a Response Spectrum Approach (RSA) which is used to understand how a building will respond to possible earthquake forces. Three combinations of nodal displacements in the tested frame are as follows:

Load Case 1 is a static load (dead + live)

Load Case 2 is a seismic load

Load Case 3 is (static + seismic) loads

The sections of columns and beams of the frame are shown in Table 1

Table 1 Section of Columns and Beams of the frame Building

Structure Frame	Dimension	
Columns (mm)	450x450	300x300
Beams (mm)	300x500	250x500

selected frame (the critical one) was analyzed using SAP 2000 v22.2.2 program. were calculated the seismic response spectrum parameters, i.e., displacements and stresses. Several parts of the frame were selected to be analysis samples. Some selected frames are shown in Figures 1 and 2, C1 - C2 represent columns, and B1- B2 represent beams.

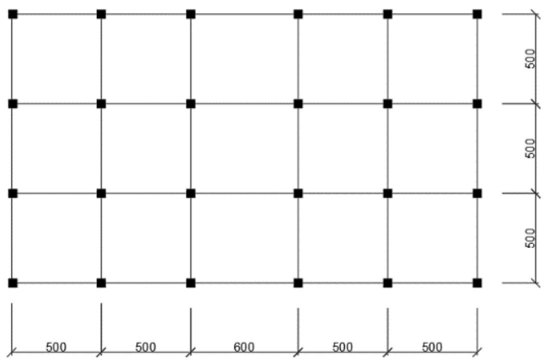

Figure 1 Dimensions of the plan

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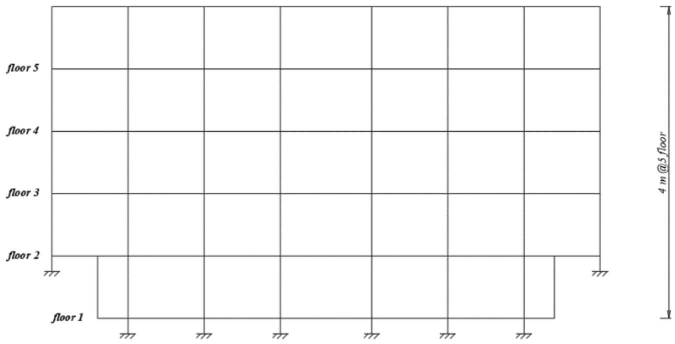


Figure 2 Dimensions of site elevation

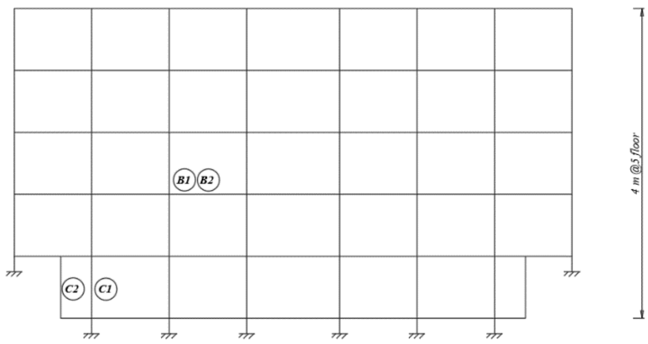


Figure 3 Selected Nodes and Members of the Studied Frame

3.1 Concrete

The concrete used is ready-mix with quality K-175 or K-225. Using steel reinforcement with a diameter of 8 and 10 mm using BJTP 24 (plain) and for reinforcement with a diameter > 13 mm using BJTD 40 (threaded). Weight per unit volume of 2.4 ton/m^3 and 0.24 Mass per Unit Volume. Modulus of Elasticity E is $2x10^6$ ton/m^2, Poisson U is 0.2, Coefficient of thermal expansion A is $9,9x10^{-6}$ m/°C and Shear Modulus G is 8.3 ton-force. The concrete has a compressive strength f'c 25 MPa.

3.2 Profile Steel

The steel used in the construction of this building is profile steel. The profile steel has BJ-37 quality with a maximum yield stress of 2400 kg/cm^2 and a basic stress of 1600 kg/cm^2. The same quality is also used for connection plates. This profile steel has weight per unit volume 7.8 tonf/m^3 and mass per unit volume 0.78 ton/m^3. The modulus of elasticity (E) is $2x10^7$, Poisson (U) 0.3, the coefficient of thermal expansion (A) is $1.17x10^{-5}$ m/ °C, and the shear modulus (G) is $7.69x10^6$ ton-force. The steal has minimum yield stress (F_y) of

$3 x 10^4$ ton/m^2, minimum tensile stress (Fu) of $3.7 x 10^4$ ton/m^2, expected yield stress (F_{ye}) of 3.3 $x 10^4$ ton/m^2, and expected tensile stress (F_{ue}) of 4.12 $x 10^4$ ton/m^2.

3.3 Reinforce Steel

This structure uses two types of reinforced steel BJTP 24 (plain) and BJTD 40 (deform), BJTP 24 has modulus of elasticity (E) $2.04 x 10^7$ ton/m^2, coefficient of thermal expansion (A) $1.17 x 10^{-5}$ m/ ^oC, minimum yield stress (Fy) $3 x 10^4$ ton/m^2, minimum tensile stress (Fu) $4.5 x 10^4$ ton/m^2, expected yield stress (Fye) $3.3 x 10^4$ ton/m^2, expected tensile stress (Fue) $4.95 x 10^4$ ton/m^2. Then BJTP 24 has a modulus of elasticity (E) 2.04 $x 10^7$ ton/m^2, Coefficient of thermal expansion (A) $1.17 x 10^{-5}$ m/^oC, minimum yield stress (Fy) $2.4 x 10^4$ ton/m^2, minimum tensile stress (Fu) $3.6 x 10^4$ ton/m^2, expected yield stress (Fye) $2.64 x 10^4$ ton/m^2, and expected tensile stress (Fue) 3.96 $x 10^4$ ton/m^2.

3.4 Bolt

For high-strength bolted steel structure connections (High Strength Bolt-HSB) with quality A325 and minimum yield stress of 6350 kg/cm^2.

3.5 Welding

The quality of welding steel used is a minimum yield strength of 2400 kg/cm^2.

3.6 Pretension Wire

The tendons used are ASTM A416Gr270 standard with a modulus of elasticity (E) 2.01 $x 10^7$ ton/m^2, coefficient of thermal expansion (A) $1.17 x 10^{-5}$ m/ ^oC, minimum yield stress (Fy) $1.72 x 10^5$ ton/m^2, minimum tensile stress (Fu) $1.89 x 10^5$ ton/m^2, and tendon ASTM A615Gr60 standards with a modulus of elasticity (E) $2.03 x 10^7$ ton/m^2, coefficient of thermal expansion (A) $1.17 x 10^{-5}$ m/ ^oC, minimum yield stress (Fy) $4.21 x 10^{-4}$ ton/m^2, minimum tensile stress (Fu) 6.32 $x 10^{-4}$ ton/m^2, expected yield stress (Fye) $4.64 x 10^{-4}$ ton/m^2, and expected tensile stress (Fue) 6.96 $x 10^{-4}$ ton/m^2.

4 Analysis Result

The result of nodal displacement of the study frame obtained in Table 2 with three load combinations (live + dead load, earthquake load, static load) on a 5-storey building, which is based on the resultant obtained from the first load, namely dead + live load of the building, the second load namely the earthquake load of the building, and the third load namely the static load of the building.

Table 2 Nodal Displacement of the Studied Frame

Story	Node	L/C	Horizontal X (mm)	Vertical Y (mm)	Horizontal Z (mm)	Resultant (mm)
5	600	Dead + Live	-0.135	-3.066	-3.348	-3.202
		Seismic load	18.992	23.650	0.870	42.642
		Static + seismic	37.040	40.111	1.490	77.151
4	471	Dead + Live	-0.083	-2.186	-2.727	-2.269
		Seismic load	16.457	20.595	1.473	37.053
		Static + seismic	31.989	34.851	2.449	66.840
3	329	Dead + Live	-0.044	-1.277	-2.451	-1.321
		Seismic load	11.820	15.139	2.010	26.960
		Static + seismic	22.899	25.623	3.277	48.522
2	173	Dead + Live	-0.013	-0.480	-2.201	-0.493
		Seismic load	5.665	7.913	2.370	13.579
		Static + seismic	10.963	13.552	3.801	24.516
1	153	Dead + Live	-0.013	-0.504	-1.203	-0.518
		Seismic load	5.665	7.917	2.403	13.583
		Static + seismic	10.963	14.911	4.401	25.875

4.1 Story Drift

In Table 3, the story drift structure with static + seismic in node 1, the resultant is 18.30 mm and the drift is $45.7x10^{-4}$ mm, in node 2 the resultant is 24.51 mm and in drift $36.08x10^{-4}$ mm, node 3 the resultant is 48.52 mm and drift $39.44x10^{-4}$ mm, node 4 the resultant is 66.84 mm and drift is $27.41x10^{-4}$ mm, and node 5 the resultant is 77.15 mm and drift $31.64x10^{-4}$ mm.

Table 3 Final Displacement and Drift acquisition data

Story	L/C	Resultant (mm)	Drift mm
1	Static + seismic	18.300	0.004575
2	Static + seismic	24.516	0.003608
3	Static + seismic	48.522	0.003944
4	Static + seismic	66.840	0.002741
5	Static + seismic	77.151	0.003164

4.2 Internal Force Column

Based on the values that have been obtained for the force in the column through a combination of load cases on the columns selected in Table 4, the largest force on the frame that has been taken as an analysis sample is obtained. The force in the horizontal column (Fx) has the same force value in story 1 C1 and C2 with the case combination (static + seismic) of 59.57 kN. Then in the vertical direction (Fy) using the combination of cases (static + seismic) in columns C1 and C2 story of 4.72 kN. In the moment section in story 5 columns C1 and C2 with a combination (static + seismic) of 5.04 kN-m.

Table 4 Internal Force of the Column

Story	L/C	Columns	Fx (kN)	Fy (kN)	Mz (kN-m)
1	Live + Dead	C1	-1814.472	27.897	-1.306
		C2	-155.04	-5.061	2.606
	Seismic Loads	C1	43.845	26.43	34.448
		C2	59.577	4.728	5.004
	Static + Seismic	C1	59.577	4.728	5.004
		C2	59.577	4.728	5.004

4.3 Internal Force Beam

Based on the values that have been obtained for the force in the column through a combination of load cases on the columns selected in Table 5, the largest force on the frame that has been taken as an analysis sample is obtained. The force in the horizontal column (Fx) has the same force value in story 1 C1 and C2 with the case combination (static + seismic) of 59.58 kN. Then in the vertical direction (Fy) using the combination of cases (static + seismic) in columns C1 and C2 story of 4.73 kN. In the moment section in storey 5 columns C1 and C2 with a combination (static + seismic) of 5.01 kN-m.

Table 5 Internal Force of the Beam

Story	L/C	Beam	Fx (kN)	Fy (kN)	Mz (kN-m)
3	Live + Dead	B1	0	78.76	0.87
		B2	0	17.45	48.05
	Seismic Load	B1	4.73×10^{-14}	9.09	13.89
		B2	0	6.42	9.78
	Static + Seismic	B1	4.73×10^{-14}	9.09	13.89
		B2	0	6.42	9.78

The value of the force in the beam was obtained using 3 case combinations, where samples were taken from beams B1 and B2 on the 3rd floor, which based on the Fx force, has the highest internal force value in B1 with the combination (static + seismic) 4.74×10^{-14} kN. For the Fy force, the highest value was obtained on the 3rd floor of beam B1 with a combination (static + seismic) of 9.09 kN. And the highest moment was on the 3rd floor of beam B1 with a combination (static + seismic) of 13.89 kN-m.

4.4 Base Shear

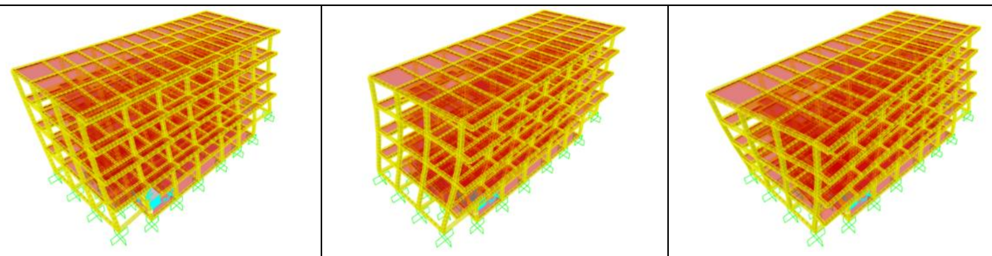
In the base shear calculation through running that has been carried out in Table 6, the comparison value between the static load and the seismic load is obtained, in the x direction the static value is -1.08x10^6 kN and the dynamic value is 1.09x10^6 kN so that the static and dynamic ratio is 0.99 which is equivalent to 1, at In the y direction, the static value is -9.97x10^5 kN and the dynamic value is 9.99x10^5 kN, so the comparison value between the static load and the seismic load is 0.99. Therefore, the basic shear value in this building model has met the value requirements based on SNI 1726-2019 which refers to a dynamic V value ≥ 0.85 V static, as a control value requirement for the final spectrum value.

Table 6 Base Shear

Name	Value (kN)	Factored	Total
Elx (static)	1.08x10^6 kN		0.994
Rsx (dynamic)	1.09x10^6 kN	1087851 / 1093935	
Ely (static)	9.97x10^5 kN		0.998
Rsy (dynamic)	9.99 x10^5 kN	997745 / 999679	

4.5 Mode Shape

By evaluating and attaching free vibration mode shapes to characterize displacement patterns, mode shapes in Figure 4 describe the configuration in which a structure will naturally move. In this method, structures are analyzed based on their vibration modes, which are the natural response of the structure to dynamic excitations such as earthquakes or strong winds.



Mode shape 1 | Mode shape 2 | Mode shape 3

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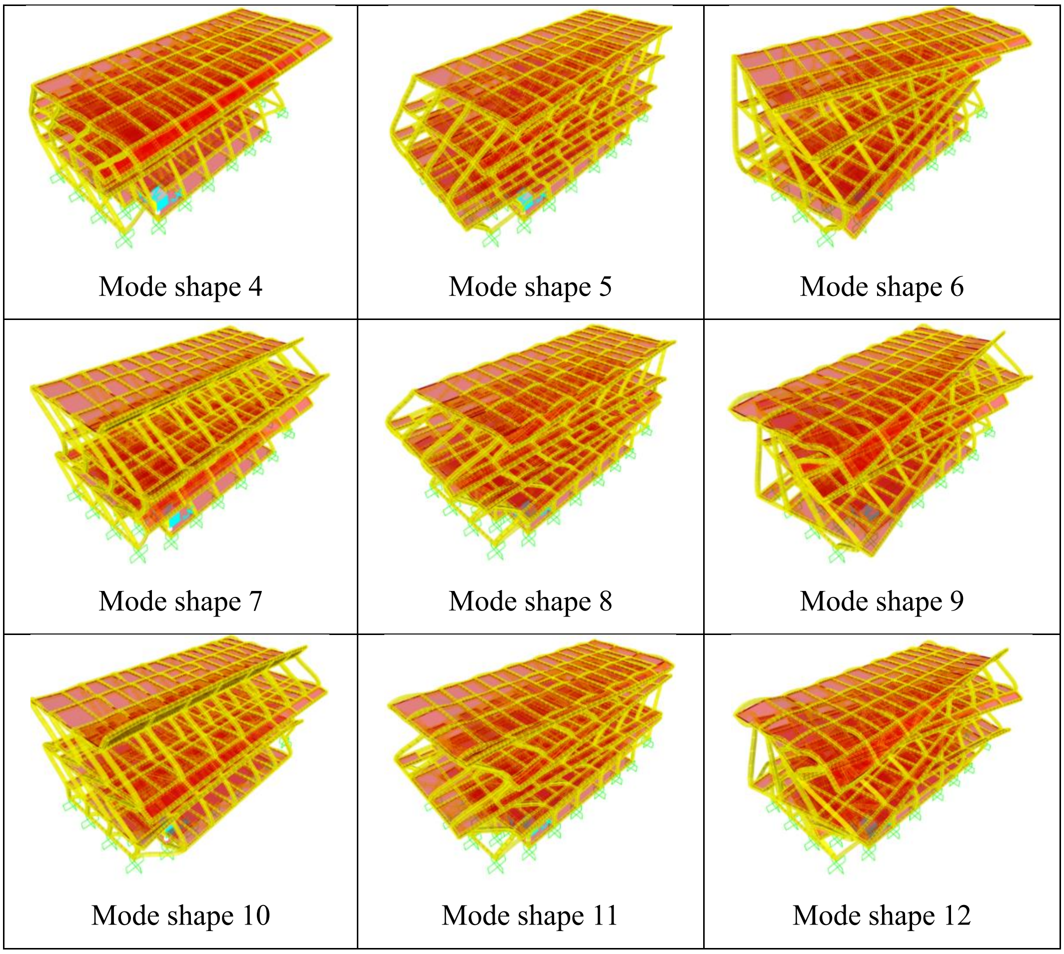

Figure 4. Mode shape

4.6 Modal Results and Period

In Table 7, the model result and period of the values obtained are compared with the building analysis mode. In the period compared with the mode, the initial period value is 0.93 seconds in mode shape 1 and continues to decrease in the period until mode shape 12 where the period is 0.11 seconds. Then for frequency, the value obtained is the opposite of the period, at this frequency the frequency value is compared with the mode shape, the value increases from mode shape 1 to mode shape 12. In mode shape 1 the frequency value is 1.07 Hz and continues to increase up to mode shape 12 with a value of 9.38 Hz. For the Circular Frequency value, it is found that the value continues to increase from mode shape 1 to mode shape 12, from mode shape 1 of 6.72 rad/s to mode shape 12 of 58.97 rad/s. and the eigenvalue continues to increase from mode shape 1 of 45.24 rad^2/s^2 to mode shape 12 of 3478.37 rad^2/s^2.

Table 7 Modal Result and Period

Output Case	Step Type	Step Num	Period	Frequency	Circ Freq	Eigenvalue
		Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
ACASE1	Mode	1	0.934	1.070	6.726	45.244
ACASE1	Mode	2	0.856	1.167	7.333	53.785
ACASE1	Mode	3	0.791	1.263	7.938	63.013
ACASE1	Mode	4	0.301	3.318	20.850	434.737
ACASE1	Mode	5	0.276	3.618	22.737	516.973
ACASE1	Mode	6	0.254	3.927	24.679	609.087
ACASE1	Mode	7	0.174	5.721	35.949	1292.400
ACASE1	Mode	8	0.160	6.227	39.128	1531.033
ACASE1	Mode	9	0.146	6.805	42.759	1828.413
ACASE1	Mode	10	0.125	7.966	50.055	2505.553
ACASE1	Mode	11	0.117	8.489	53.340	2845.251
ACASE1	Mode	12	0.106	9.386	58.977	3478.374

4.7 Mode Shape Vs Period

Based on the Mode vs Period in Figure 5, it is found that the greater the mode, the period value will continue to decrease in seconds. In mode 1 the period value is the largest, namely 0.934 seconds, in mode 2 it drops to 0.856 seconds, in mode 3 it drops to 0.791 seconds, in mode 4 it drops drastically to 0.301 seconds, in mode 5 it drops to 0.276 seconds, in mode 6 down to 0.254 seconds, in mode 7 down to 0.174 seconds, in mode 8 down to 0.160 seconds, in mode 9 down to 0.146 seconds, in mode 10 down to 0.125 seconds, in mode 11 down to 0.117 seconds, finally in mode 12 it drops to 0.106 seconds and becomes the smallest period value.

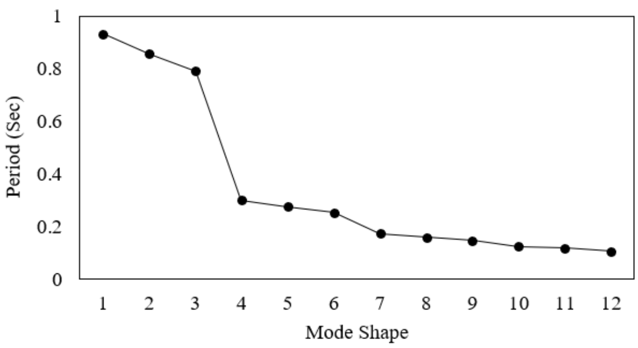

Figure 5 Mode shape vs Period

4.8 Mode shape vs Frequency

Based on the Mode vs Frequency in Figure 6, it is found that the greater the mode, the higher the Hertz value. In mode 1 the lowest frequency value is 1.07 Hertz, in mode 2 it

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increases to 1.16 Hertz, in mode 3 it increases to 1.26 Hertz, in mode 4 it increases drastically to 3.31 Hertz, in mode 5 it increases to 3.61 Hertz, in mode 6 it increases to 3.92 Hertz, in mode 7 it experiences a drastic increase to 5.72 Hertz, in mode 8 it increases to 6.22 Hertz, in mode 9 it experiences a drastic increase to 6.80 Hertz, in mode 10 it experiences a drastic increase to 7.96 Hertz, in mode 11 it increases to 8.489Hertz. Finally, in mode 12 it rises to 9.38 Hertz and becomes the highest frequency value.

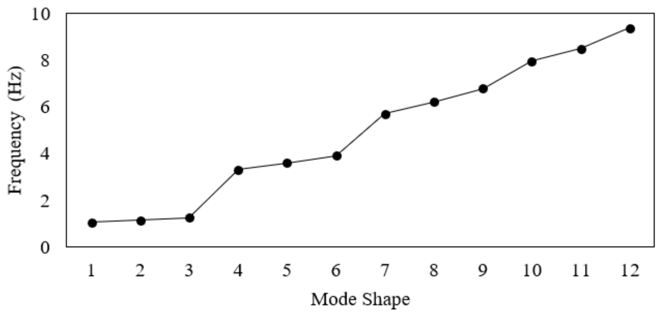

Figure 6 Mode vs Frequency Chart

5 Conclusion

Based on the results of analysis using the spectrum response method of shop buildings and 5-storey residences located in Jakarta, changes in the structure of the building were obtained at each point, whereas in the calculations using the acceleration of the horizontal shift from the earthquake with medium peak ground acceleration (PGA) with the total vibration time for 8 seconds. Several points of the building structure were selected as samples to determine the response and changes.

The force moment on beams and columns due to static loads shows a value that is greater than the value caused by earthquake loads. The final Displacement data obtained with Load combination (Static + Seismic) continues to increase from floor 1 to floor 5. Then the drift decreases from floor 1 to floor 2, then rises slightly on floor 3 before dropping again on floor 4 and rising again on floor 5. Then according to the analysis results obtained on floors 1 to floor 5, they have met the standards for drift values.

Comparison of the basic shear stress produces almost the same results between x and y. Then, for the comparison between mode and period, the value continues to decrease, while the frequency value increases compared to the mode.

Reference

[1] Afriandini, B., Sari, C. A., & Suksmono, A. K., *Comparison of Seismic Base Shear Forces on Java Island Using the Spectrum Response Method*. Jurnal RAB Construction Research (Jurnal RACIC), pp. 140-151, Dec. 2022.

[2] Afrida, I., Wahyuningtyas, W. T., & Krisnamurti., *Resilience Analysis of Surabaya Apartment Buildings Using the Spectrum Response Method*., Berkala Sainstek, **8**(4), pp. 132-139, 2020.

[3] Annisa, A., Oka, I. M., & Turu'allo, G., *Comparison of Planned Earthquake Loads from Analysis Results Using the Equivalent Static Method and Spectrum Response Based on SNI 1726-2012*. Jurnal Sains dan Teknologi Tadulako, pp. 34-50, 2020.

[4] Harahap, M. F., & Fauzan, M., *Dynamic Behavior of the Metro Galaxy Park Apartment Structure against Earthquake Loads*., Jurnal Teknik Sipil dan Lingkungan, pp. 195-206, 2019.

[5] Hilmi, M., Erizal, & Febrita, J., *Analysis of Structural Performance in Multi-Storey Buildings using the Spectrum Response Analysis Method Based on SNI 1726:2019*. Jurnal Teknik Sipil dan Lingkungan, pp. 143-158, 2021.

[6] Hukama, R. D., & Erizal, *Analysis of Structural Strength in an 8 Floor Building Based on Spectrum Response SNI 03-1726-2019 Using SAP 2000*. Jurnal Teknik Sipil dan Lingkungan, pp. 127-136, 2023.

[7] Rafsanjani, A., & Kurnia, F., *Analysis of Building Strength Against Earthquake Forces Using the Linear Response Spectrum Method*. Jurnal Artesis, pp. 52-57, 2021.

[8] Silaban, G. T., Tampubolon, S. P., Mulyani, A. S., & Felestin., *Performance Evaluation of High-rise Buildings with Response Spectrum Analysis and Time History Analysis*. Jurnal Ilmu Pengetahuan dan Teknologi, pp. 84-95, 2023.

[9] Hasaballa, A. E., Adam, F. M., Ismaeil., M. A., *Seismic Analysis of a Reinforced Concrete Building by Response Spectrum Method*. IOSR Journal of Engineering (IOSRJEN), pp. 1-9, 2013.