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PERFORMANCE ANALYSIS OF HORIZONTAL IRREGULAR BUILDINGS BASED ON RESPONSE SPECTRUM AND TIME HISTORY METHOD (STUDY CASE: BUILDING MRT HUB DUKUH ATAS JAKARTA)

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Abstract

Indonesia is geographically located in the Pacific ring of fire, especially on Java Island, which has the densest infrastructure and population and is located between the Indo-Australian plate and the Eurasian plate, causing this area to have many active volcanoes and has a high potential for earthquakes. Therefore, it is necessary to pay the planned earthquake load in planning the building structure design to minimize losses due to the earthquake. This study aims to determine the structure's performance against displacement, story drift, and structural stability limits against earthquake loads and to review horizontal structural irregularities based on SNI 1726: 2019 regulations in existing buildings at the Simpang Temu MRT Dukuh Atas Jakarta building. The analysis process was carried out by 3-D building modeling using the ETABS software program, analysis based on time history and sresponse. spectrum Time History analysis uses recorded earthquakes of Kobe Japan, ChiChi Taiwan, and El Centro which match the earthquake response spectrum, the results of the analysis based on the program were carried out to compare the two methods used. Based on the results of the analysis, the building is classified into horizontal irregularities with excessive torque ratio > 1.4, average displacement value from the 2nd to 12th floor in the horizontal direction X exceeds the drift value limit. The results of the instability limit for structural stability against displacement based on the P-Delta effect still meet the structural stability limits so it can be stated that the structure is stable and safe.

Keywords: Horizontal Irregularity, Response Spectrum, Time History, Displacement, Story Drift, P-Delta

Introduction

Indonesia's territory is located on the Pacific Ring of Fire and is located at the confluence of 3 major tectonic plates in the world, so that Indonesia's geographical location provides abundant natural resource potential, but also makes Indonesia a very disaster-prone country, especially earthquakes (Nehe et al., 2021; S. P. Tampubolon et al., 2020; Tjandra, 2017; Triany et al., 2022). Problems caused by earthquakes can be in terms of material, physical and psychological casualties. Therefore, it is necessary to take preventive measures by designing earthquake – resistant building structures to be able to withstand and minimize damage caused by earthquakes, (LE et al., 2019; Samsunan, 2018; S. P. Tampubolon et al., 2022a). Therefore, building and non-building structures in every planning and development must be earthquake resistant, so that if an earthquake occurs the building does not cause major damage (Gonzales, 2022; Hariyanto, 2011; S. P. Tampubolon et al., 2022b; Tatya Putri Utami & Niken Warastuti, 2019). Based on the Indonesian earthquake guide which was inaugurated in 2019 (SNI 1726:2019) Indonesia is divided into several earthquake areas according to their respective risk levels according to the rock acceleration value of each sector. The magnitude of the rock acceleration value is then used as the basic seismic acceleration coefficient in seismic force calculations (Badan Standarisasi Nasional, 2019). The response structure due to seismic forces can be obtained by equivalent static analysis and also dynamic analysis using the method of range response spectra and seismic response time history. Meanwhile, determining the seismic analysis procedure that can be used depends on the seismic design category, the structure of the system itself, dynamic properties, and the regularity of the structure. (Saputra et al., 2021; Yusmar et al., 2021). Therefore, research was carried out on buildings that have irregular structures and different structural dimensions on certain floors and use response spectrum analysis and time history based on SNI 1726:2019 concerning Standards for Earthquake Resistance Planning for Buildings. Several previous studies regarding irregularities in strengthening concrete building structures and building analysis using response spectrum and time history methods have been carried out by several researchers, (Bayyinah & Faimun, 2017a; Rendra et al., 2015). Kharisma in 2022 conducted research on the performance analysis of the structure of the Indonesian University of Education (UPI) using the time history method by taking into account shear forces, displacements, and story drift, (Andriyanto & Setiya Budi, 2014; S. Tampubolon, 2021). The results show that the structure meets the requirements that the structure meets the deviation permit limits, and states that the level of the building structure includes the Immediate Occupancy (IO) level which states that there is no serious damage to the structure (Kharisma, 2022). Taufik in 2021 discussed the earthquake loads of San Fernando, Loma Prieta, and Kobe by adjusting the location of the building, using the SeismoMatch 2021 software. The analysis being reviewed is the fundamental period, the variety of vibrations, and excess torque irregularities. The results of the analysis show that the structure has torsional structural irregularities (Alavi-Dehkordi et al., 2019; Taufik et al., 2021). In research that analyzes area using the dynamic time history analysis method aims to determine the performance of building structures based on their displacements, (Sudarno P Tampubolon, 2021; S. Tampubolon, 2021). The research method used is dynamic response spectrum with ETABS software. The result of the analysis due to the planned earthquake is that the structure is safe and is included in the immediate occupancy category. The results of the analysis due to the actual earthquake were, Elcentro: unsafe structure on Floor 1 – Roof, the structure is in the damage control category, Northridge: structure is not safe on floor 10 and floor roof, but still in the immediate occupancy category, and Mentawai: structure is safe and into the immediate occupancy category. (Anggen et al., 2014). From the results of the research above, it is necessary to analyze the structural performance of buildings that have been completed, (Ibnu Syamsi, 2018; Kimsan & Perceka, 2013; Priyono et al., 2014). While the case study taken is an office building consisting of 12 floors and 2 basements. However, this research only focuses on the upper structure of the building. This building is located in the Jakarta area with earthquake area 4, where in the earthquake area 4 is the building area, SNI 1727:2020 concerning Minimum Design Loads and Related Criteria for Buildings and Other Structures, and SNI 2847:2019, (ACI Committee 318, 2019) concerning structural concrete requirments fot building.

Research Methodology

This research used analysis and simulation method based on dynamic linear analysis of response spectrum and linear time history analysis on the MRT Hub Dukuh Atas Jakarta building using ETABS software. The steps taken in evaluating the structure are collecting data on building plans, modeling building structures, modeling material quality, and modeling structural elements starting from columns, beams, slabs, and roofs into the ETABS software. The loads applied are gravitational loads (dead loads, additional dead loads, and live loads) plus earthquake accelerating loads (planned earthquakes and actual earthquakes). The results of analysis due to planned earthquakes and actual earthquakes are analyzed to determine the performance and level of structural performance as well as the qualifications for horizontal structural irregularities adjusted according to SNI 1726: 2019 regulations, (ACI committee 318, 2011; Mandloi et al., 2017; Nagod, 2017; Rathod & Gupta, 2020; Zhai & Chen, 2020) (Silaban et al., 2023).

Table 1. Building information data

No	Buliding Description	Information
1	Project Name	MRT Transport and Facilities Intersection Building Supporters in the Dukuh Atas Transit Oriented Area, Central Jakarta.
2	Project Address	Juana Street, No.30, District Menteng, Central Jakarta.
3	Building Function	MRT Office, transit oriented, and retail.
4	Building Coordinate	Latitude : 106.82383004089631
		Longitude : -6.201216641221554,
5	Building Area	17,719 m²
6	Building Height	57.7 m
7	Building Type	Concrete Reinforcement
8	Number of Floors	2 floor basement and 12 floor with rooftop.

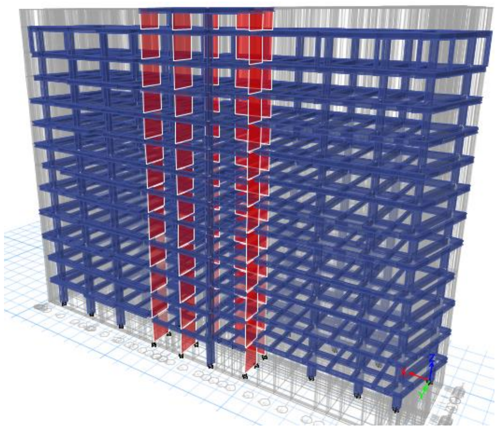

Figure 1. 3-D modeling structure MRT Hub Dukuh Atas Jakarta

Research Results and Discussion

Modeling the loads acting on the analyzed building must be done first so that structural modeling analysis can be carried out (Nie et al., 2020). This aims to determine the response of a structure to the design of a building model in carrying the load received, especially earthquake loads. The following is a discussion of the results of the analysiso or simulation that has been carried out on buildings at MRT Hub Dukuh Atas Jakarta. Gravity load is a load that is affected by the gravitational force of the earth. In building structures and non-buildings, this load is divided into additional dead loads and live loads based on the building filling components and the floor function of the building (Badan Standardisasi Nasional, 2019; SNI 1727, 2020; SNI 2847:2019, 2019).

Table 2. Structure weight

Story	Total Load in X (kN)	Total Load in Y (kN)
Roof	125414.1956	125414.1956
LMR	752751.7552	752751.7552
12	1035716.915	1035716.915
11	1031329.768	1031329.768
10	1043564.45	1043564.45
9	1025408.005	1025408.005
8	1042712.44	1042712.44
7	1050036.706	1050036.706
6	1046337.506	1046337.506
5	1071882.215	1071882.215
4	1132099.58	1132099.58
3	1159839.637	1159839.637
2	1150735.512	1150735.512
1	194517.4918	194517.4918
Total weight	12862346.18	12862346.18

In linear dynamic response spectrum analysis, spectral response parameters must be calculated first by knowing the site coefficient values can be obtained by calculating the RSA Cipta Karya software. Whereas in the dynamic linear analysis of time history, based on SNI 1726, at least 3 recordings of ground motion acceleration due to the earthquake are selected and then the time history graph is matched with the spectral response graph (Bayyinah & Faimun, 2017b; Herucahyo et al., 2015; PuSGen, 2018; Suntoko, 2019).

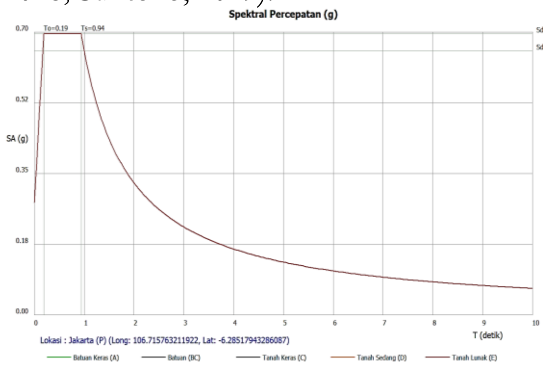

Figure 2. Response spectrum MRT Hub Dukuh Atas Jakarta

Table 3. Earthquake data and structure system

Earthquake Acceleration Data			
Site Class		=	SE (Soft Soil)
Seismic Design Category,	KDS	=	D
Short Period Acceleration Spectral,	S_s	=	0.7975
1 Second Period Spectral Acceleration,	S_1	=	0.3879
Site Coefficient,	F_a	=	1.262
	F_v	=	2.4484
Short Period Design Acceleration,	S_{DS}	=	0.67
1 Second Period Design Acceleration,	S_{D1}	=	0.67
Structural System Parameters			
Earthquake Priority Factor,	I_e	=	1.00
Response Modification Coefficient,	R	=	7
Strong Factor Over System,	Ω_0	=	2.5
Deflection Magnification Factor,	C_d	=	5.5

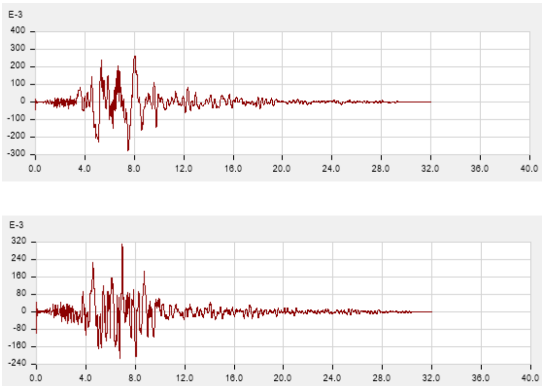

Figure 3. Acceleration earthquake Kobe University Japan (up) X, (down) Y

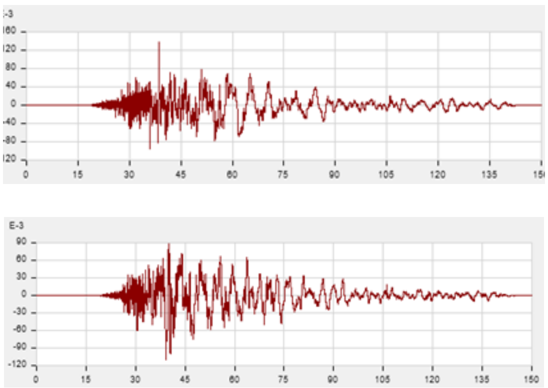

Figure 4. Acceleration earthquake ChiChi Taiwan (up) X, (down) Y

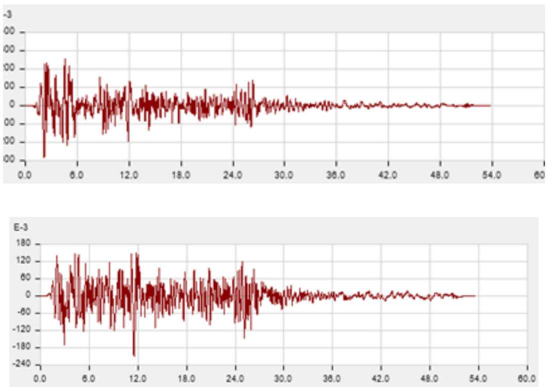

Figure 5. Acceleration earthquake EI centro 1940 (up) X, (down) Y

Based on SNI 1726:2019 the analysis must include a sufficient number of variations to obtain a combined mass participation of 100% of the mass of the structure, but as an alternative, the analysis is permitted to include a minimum number of combined modes of 90% of the actual mass in each orthogonal horizontal direction of the response reviewed by the model.

Table 4. Modal participating mass ratio

Case	Mode	Period	UX	UY
Modal	1	25.345	0.0005	0.3134
Modal	2	21.008	0.0269	0.7257
Modal	3	19.963	0.7458	0.7377
Modal	4	7.377	0.746	0.7615
Modal	5	6.194	0.7469	0.8496
Modal	6	5.753	0.8559	0.8499
Modal	7	4.047	0.8559	0.8544
Modal	8	3.07	0.8559	0.9041
Modal	9	2.85	0.9112	0.9041
Modal	10	2.647	0.9117	0.907
Modal	11	1.859	0.9121	0.9113
Modal	12	1.797	0.9123	0.9365

The results of the ETABS program, it was found that the value of combined mass participation in the number of shape modes 12 shows that the value in the X direction reached 0.9123 (91.23%) and in the Y direction reached 0.9365 (93.65%). These results stated that mass participation could be permitted because it had met the minimum limit of ≥ 90% in the X and Y directions.

Table 5. Structure period control

Structure Period Control				
1 Second Period Design Acceleration,	SD1	=	0.63316	g
Coefficient for Period Limit,	Cu	=	1.4	
	Ct	=	0.0488	
	x	=	0.75	
Building Height (Seismic),	h	=	57.7	m
Period Fundamental Approach,	Ta	= =	Ct × hx 1.02165	sec
Maximum Period,	Tmax	= =	Cu × Ta 1.43031	sec
Analysis Result Period (X),	Tc, X	=	1.808	sec
Analysis Results Period (Y),	Tc, Y	=	1.879	sec

Period use X,	TX	=	1.43031	det
Period use Y,	TY	=	1.43031	det

Based on Table 5, the building under study uses a special moment bearing frame system (SRPMK) with a reinforced concrete frame so that table 4 uses a response modification coefficient (R) = 7. Because the value of the seismic response coefficient and the total weight of the building in the x and y directions are the same, the value of V is 785127.04 kN. Force scaling based on article 7.9.1.4.1 SNI 1726:2019 if the combined response for the base shear force analysis of variance (V dynamics) is less than 100% of the base shear force value (V) calculated using the equivalent static method, then the value of the force scale factor is necessary multiplied by (Vstatic/Vdynamic). Based on the results of analysis calculations, the shear force (base reaction) of static and dynamic earthquakes is presented in table 6.

Table 6. Comparison of static fear shear force (VS) and dynamic shear (VD) values

Base Shear	Static Shear Force (V_S)	Dynamic Shear (V_D), kN			
		Response Spectrum MRT Hub Dukuh Atas	Time History Kobe Univ Japan	Time History ChiChi Taiwan	Time History El Centro (1940)
X	524222.6589	88905.449	33556.1665	32085.55	33262.394
Y	524357.8026	72571.5239	25997.28919	32903.9331	27198.3639

Based on table 6, it is obtained that the comparative value of the dynamic shear force (VD) does not exceed or equal to 100% of the value of the static shear force, therefore it is necessary to scale the force by multiplying the initial scale factor by the scale factor (Vs/VD).

Table 7. shows the style scaling analysis table.
Initial scale factor = (g/(R/Ie) x 1000
New scale factor = initial Fs x Fs (Vs/VD)

The new scale factor will be entered into the ETABS for scaling.

Table 7. Static and dynamic shear forces after scalling

Load Case	Shear Value Comparasion (V_S/V_D)		Initial Scale Factor (mm/s²)	New Scale Factor (mm/s²)	
	X	Y		X	Y
Response Spektrum MRT Hub Dukuh Atas	5,90	7.23	1400,95	8260.571	10122.41
Time History Kobe Japan	15,62	20,17		21885.98	28256.76
Time History Chichi Taiwan	16,34	15,94		22889.11	22325.57
Time History El – Centro 2002	15,76	19,28		22079.28	27008.94

Based on the scaling performed on the values of the static shear force (VS) and the dynamic shear force (VD), the values of the static shear force and dynamic shear force are obtained as shown in Table 6. The story drift

(Δ) needs to be reviewed to determine the level of flexibility in structural performance based on article 7.8.6 SNI 1726:2019, but may not exceed the allowable drift between levels based on article 7.12.1 Table 20 SNI 1726:2019. Figure 7, 8, and 9 shows that the deviation between levels that occurs in the analyzed building is still at a safe point (below the value of the drift limit).

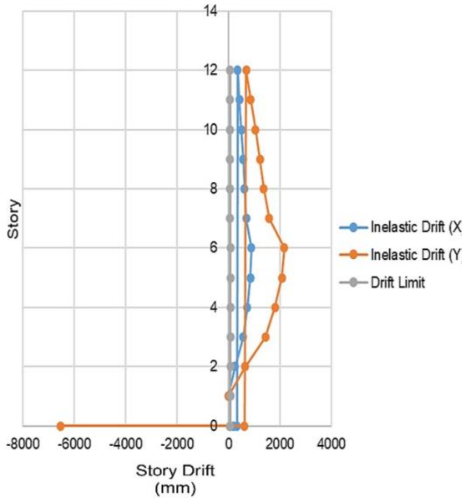

Figure 6. Story drift of earthquake loads response spectrum

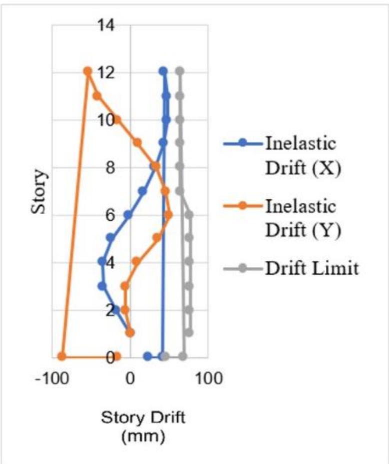

Figure 7. Story drift of earthquake loads Kobe University, Japan

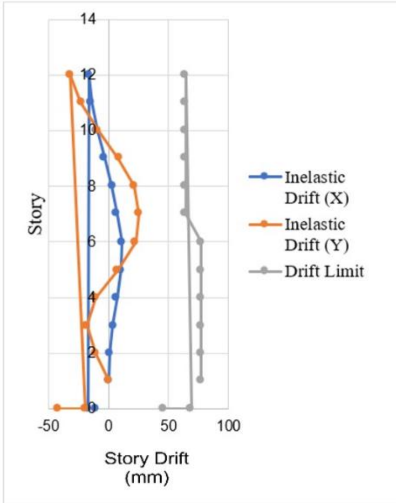

Figure 8. Story drift of earthquake loads ChiChi Taiwan

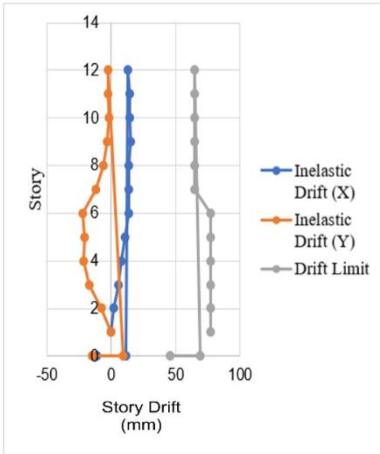

Figure 9. Story drift of earthquake loads EI centro 1940

The effect of P-Delta on story shear and moment, resulting structural element forces and moments, and the drift between stories need to be taken into account to determine the value of the stability coefficient. The stability coefficient (θ) must not exceed θmax, which is determined by 0.5/(β ×Cd) less than or equal to 0.25. If the stability of the structure exceeds the stability limit of the structure, then the structure must be redesigned. Meanwhile, if the stability of the structure exceeds the P-delta effect limit, then the structure must take into account the P-delta effect.

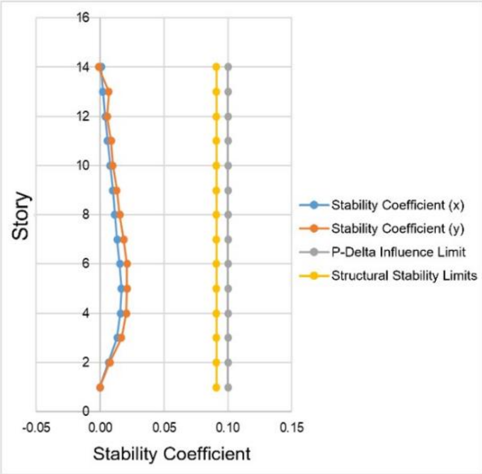

Figure 10. Stability against the influence of P-Delta earthquake response spectrum

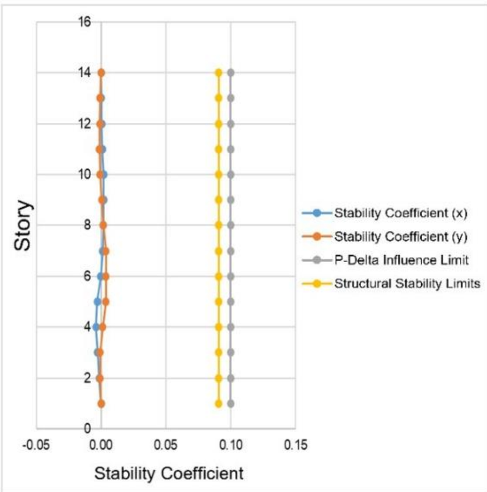

Figure 11. Stability against influence of P-Delta Kobe University Japan earthquake

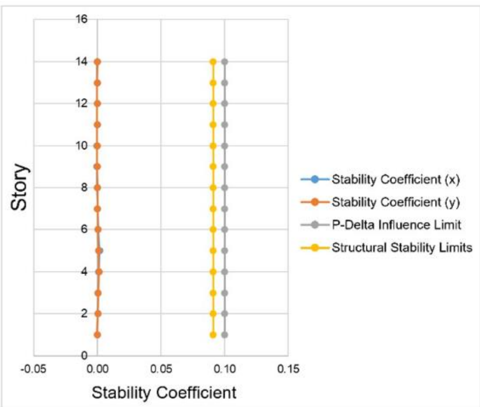

Figure 12. Stability against influence of P-Delta ChiChi Taiwan earthquake

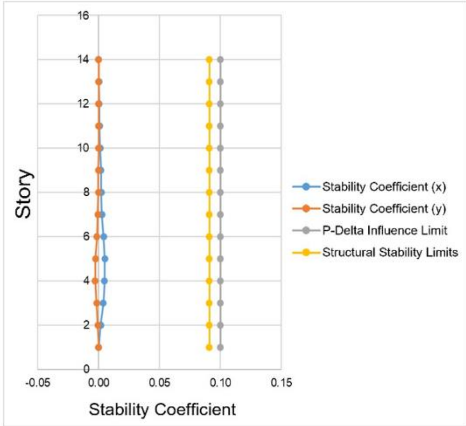

Figure 13. Stability against influence P-Delta EI centro 1940 earthquake

Irregular shapes in the building structure of the MRT Hub Dukuh Atas Jakarta Building, so it is necessary to classify the building based on SNI 1726-2019 while the qualifications for horizontal irregularities buildings are as follows:

1. Torsion irregularities and over-torsions (1a and 1b).
2. Irregularity of the inner angle.
3. Irregularity discontinuity of the diaphragm.
4. Irregulear displacement across the plane.
5. Nonparallel system irregularities.

Story	X		Y	
	$\Delta_{max}/\Delta_{avg}$	Check	$\Delta_{max}/\Delta_{avg}$	Check
Rooftop	1.021	OK	1.16	OK
LMR	1.048	OK	1.528	H.1b
12	1.033	OK	1.451	H.1b
11	1.022	OK	1.43	H.1b
10	1.014	OK	1.447	H.1b
9	1.01	OK	1.467	H.1b
8	1.009	OK	1.475	H.1b
7	1.008	OK	1.496	H.1b
6	1.014	OK	1.536	H.1b
5	1.019	OK	1.561	H.1b
4	1.024	OK	1.58	H.1b
3	1.034	OK	1.624	H.1b
2	1.045	OK	1.671	H.1b
1	0	OK	0	OK

Figure 14. Horizontal irregularity checking 1a and 1b

Based on Figure 10, the average ratio value on each floor is more than 1.4. This shows that the Simpang Temu Jakarta MRT building has type 1b horizontal irregularity.

Next check for irregularities in the inner angle. It is said that if Lx/Px and Ly/Py > 0.15 however, if only one of them has a value > 0.15 it cannot be said to be an irregular inner angle. Checking the structure of the building under study can be seen as described below:

Lx = 69.6 m
Px = 25.675 m
Ly = 13.154 m
Py = 3.454 m
Lx/Px = 0.1890 m
Ly/Py = 0.13 m

Information:
Lx = Overall length of the building
Px = Length of the largest opening
Ly = Overall width of the building
Py = Width of the largest opening

Because Lx/Px is greater than 0.15 and Ly/Py is less than 0.15, it can be said that this building has no internal corner irregularities. The next check is on the irregularity of the diaphragm discontinuity. It is said to be an irregular diaphragm discontinuity if the opening area is >50% of the floor area of the building.

Total floor area = 1742 m2
Largest opening area = 71,534 m2

so, $\frac{\text{Opening Area}}{\text{Total Area}}$

$= \frac{223{,}734}{71{,}534}$

$= 0.041 \quad < 0.5$

This indicates that the building structure does not experience irregular diaphragm discontinuities.

Irregularities due to shifts perpendicular to the plane did not occur in the MRT Hub Dukuh Atas Jakarta under review, because all the shear walls continued from the base to the roof of the building.

Nonparallel system irregularities do not occur in the MRT Hub Dukuh Atas Jakarta Intersection Building under review, because all the shear walls are right on the x and y axes.

Conclusion

Based on the results of analysis that has been carried out, it can be concluded that MRT Hub Dukuh Atas Jakarta Building has a horizontal irregularity of type 1b with maximum delta ratio in the Y direction > 1.4. The time history analysis provides information about the behavior of the structure against vibrations generated through earthquake recorded data every second with the accelelogram recorded values entered, from the results of the analysis carried out also obtained the value of the mass participation ratio in in the x direction it reaches 0.9123 (91.23%) and in the y direction it reaches 0.9365 (93.65%). This result is still permitted because it meets the minimum limit of ≥ 90% in both the x and y directions. In story drift, response spectrum analysis shows that the horizontal structural plane in the x direction has weak stiffness against the influence of earthquake loads when compared to the y direction, however for the time history of the Kobe, Chichi and El – Centro earthquakes still meets the drift limits and the p delta effect there is no need to re-model because it is still safe limits.

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