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Optimization of the Distance between Two Adjacent Multi-Story Buildings by Calculating the Earthquake Effect in Yogyakarta

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Abstract: Neo Malioboro and Malioboro Suite Hotels are two adjacent multi-story buildings in Yogyakarta with a fairly close distance of 2.5m (Lx) between their structures. Considering that Yogyakarta is an area prone to earthquakes, the relatively close distance between the two hotels has triggered research interest. The research was carried out by taking hotel planning data in the form of structural and architectural drawings modeled in SAP2000.14 to obtain structural behavior toward existing designs such as natural shear periods, base shear, mass participation, and to obtain deviation values between floors (drift ratio) and the center of mass deflection (δ). The largest deviation value of the two hotels in the joint reviewed occurred on the top floor, with the maximum deviation value of 0.440m (δM1) for Neo Malioboro and 0.412m (δM2) for Malioboro Suite. The minimum deflection distance between the two hotels was 0.602m (δMT), resulting in the minimum separation distance for the two hotels of 1.454m. The results revealed that the distance of the two hotels was in a safe condition because it was greater than the required minimum separation distance of 2.5m > 1.454m.

Keywords: center mass deflection, structure separation distance, minimal separation distance

1. Introduction

Yogyakarta is a city with quite a lot of tourist destinations. A day is not enough for foreign tourists to visit Yogyakarta to enjoy tourism. The large number of tourists visiting this city leads to the construction of multi-story hotels. Of the many hotels in Yogyakarta, Neo Malioboro and Malioboro Suite located on Pasar Kembang Street are interesting to investigate. These two hotels are multi-story buildings, with the two edge structures of 2.5m. Given that Yogyakarta is an earthquake-prone area, the researcher wanted to study the optimization of the safe distance between the two hotels in an earthquake. Determining the minimum separation distance between two adjacent buildings can be calculated according to [1], that all parts of the structure must be designed and built to work as an integrated unit to withstand earthquake forces unless a sufficient distance structurally separates them to avoid a damaging impact. The building structure must be positioned at least δM away from the land ownership boundary, the value δM = (Cd. δmax)/Ie. Furthermore, the adjacent building structures must be separated by at least δMT, for the value $\delta MT = \{(\delta M1)^2 + (\delta M2)^2\}^{1/2}$.

Faisal et al. [2] stated that excessive lateral deviation could also cause collisions on two adjacent tall structures. A collision can damage the structure, wherein the structural components or even the structure as a whole loses its ability to withstand the loads it carries. The inter-level deviation determines the service limit performance of building

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structures due to the effects of the earthquake aiming to limit the occurrence of excessive melting of steel and concrete cracking and prevent non-structural damage occupant discomfort (Soelarso et al., 2015).

Azizah et al. (2018) conducted a study entitled study of analysis of the vulnerability level of buildings to earthquakes with a maximum strength of 6.9 MW. This study aimed to: (i) examine the comparison of the deformation value of the building using the analytical loading pattern of the response spectrum and acceleration time history, (ii) determine the effect of earthquake strength and distance on the deformation and drift ratio of buildings, and (iii) evaluate the vulnerability level of buildings in terms of the drift and deformation ratios between earthquake simulations and the earthquake acceleration spectrum on the surface following SNI 1726: 2012. The results discovered that the buildings under study were not susceptible to large earthquakes because the drift ratio and deformation were smaller than those set by [3].

Meanwhile, [4] conducted a comprehensive case study on analysis of the performance of multi-story building structures (hotel building) with dynamic analysis of response spectrums using ETABS software. This study aimed to determine the performance of hotel structures in Semarang based on a variety of response specimens. The analysis results of various response spectrums to the level of performance of the building structure according to ATC-40, in the X-direction and Y-direction, the maximum value of total drift and total in-elastic drift shows that hotel buildings in Semarang are included in the category of Immediate Occupancy (IO) level.

[5] carried out a study entitled evaluation of multi-story building structure performance with time history dynamic analysis using ETABS. The study aimed to evaluate the performance of a multi-story building structure (hotels in the Karanganyar Area) caused by an earthquake. The results disclosed that the greater the PGAMAX, the greater the SaMAX. However, the Sa acceleration (response spectrum) affecting the structural response should be examined in the range 0.2T-1.5T (effective period). It would be a more decisive basis than just seeing the value of the PGAMax acceleration (accelerogram).

In earthquake-resistant building planning, the mechanism for forming plastic hinges must be carried out to determine the building's performance level. The performance level of the building against earthquakes is known as the seismic performance level. The seismic performance level is determined by a pushover procedure, where the additional load is provided repeatedly until the structural components experience plastic hinges or collapse of the structural elements [7]. [8] analyzed the response of flat slab-drop panel system structures in irregular multi-story buildings against earthquake loads. The study aimed to determine an excellent structural model for earthquake forces working using the flat slab-drop panel system. The results uncovered that the value of the stiffness level of a building was inversely proportional to the displacement value.

[9] conducted a study on performance of reinforced concrete frame structures with the addition of perforated infill walls as seismic reinforcement. This research aimed to obtain a model of reinforced concrete frame structure with perforated infill walls (RDP), with and without reinforcement around the hole (lintel) as seismic reinforcement by comparing the behavior and performance of the RDP structure with various hole ratios. The results obtained from the lateral deviation-load diagram obtained from the validation model using the shell element were closer to the laboratory test results diagram than the diagonal strat model.

[10] conducted a study entitled evaluation of the vulnerability of buildings to earthquakes with Rapid Visual Screening (RVS) based on FEMA P 154 aiming to estimate the performance and building level in an earthquake. One of the results disclosed that the vulnerability level of the building was influenced by several factors, in which the more irregular the building (vertical irregularity and plan irregularity), the lower the base score. [11] in evaluation of the physical risks of the Rusunawa building aiming to evaluate the feasibility of the building in an earthquake. One of the results implied that the building must be evaluated in more detail due to the deterioration of the structural components. This study aimed to determine the behavior of the two building structures based on design parameters and the safe distance between two adjacent buildings with different heights.

2. Method

The methods used in this study consisted of data collection, loading and modeling analysis. Primary data were collected directly from related agencies, namely structural and architectural drawings of the two hotels. Then, field data on the distance between the two hotels were obtained from direct measurements. The loading analysis was carried out based on the function of the room or the places in the existing parts of the two hotels. Furthermore, modeling was conducted using SAP2000 software following the planning drawing. Several outputs were issued from the modeling, including mass participation, the period of natural shaking, floor shear forces, the deviation between floors, and the center of mass deviation. From the output, the largest deviation in the two hotels was obtained. After that, the minimum distance from the two hotels was obtained and compared with the existing hotel distance to get a conclusion.

3. Results and Discussion

3.1 Period and Frequency of Structure

The structure period obtained from the SAP 2000 modeling for both hotels exceeded the required period limit calculated based on SNI. The value of the natural vibration period based on the calculation for Neo Malioboro acquired a Tmin of 1.045 and a Tmax of 1.463, while from the modeling, the T was 1.743. Meanwhile, for Malioboro Suite, the value of the natural vibration period obtained a Tmin of 1.404 and a Tmax of 1.965. In terms of modeling, the natural vibration period was 2.014. In theory, the structural period results obtained from these two hotels were less rigid because the modeling's natural vibration period exceeded the required natural vibration period limit.

3.2 Mass Participation

The natural vibration variation of the structure must be analyzed first. The requirement for determining the analysis is to include sufficient variance to produce the mass participation of the combined variants of which the value is at least 90% of the actual mass in each axis of the model response under review. If the mass participation ratio value has not been reached, the building mode must be added until the mass participation is exceeded. The mass participation value has exceeded 90% for Neo Malioboro in the 31st mode and the 35th mode for Malioboro Suite. The building mode did not need to be added because the mass participation of the two hotels has met the permitted conditions.

3.3 Base Share Control

According to SNI 1726 2012 (BSN, 2012), the value of the dynamic shear force response spectrum is greater than 85% of the basic shear force value obtained from the equivalent static analysis. If the value of the dynamic shear force response spectrum is less than 85% of the value of the equivalent static shear, the earthquake coefficient value for the x-direction and y-direction must be multiplied by the new scale factor. The base shear value due to the earthquake load response spectrum is presented in Table 1 and Table 2.

Table 1 - The dynamic base shear value of the spectrum response and static equivalent of the Neo Malioboro Hotel

Direction	Initial Dynamic V (KN)	85% V Static (KN)	Multiplier	Final Dynamic V (KN)	Control	Description
X	5267.781	6781.477	1.4	7303.259	0.929	OK
Y	5568.936	6202.716	1.3	7311.631	0.848	OK

Table 2 - The dynamic base shear value of the spectrum response and static equivalent of the Malioboro Suite Hotel.

Direction	Initial Dynamic V (KN)	85%V Static (KN)	Multiplier	Final Dynamic V (KN)	Control	Description
X	7505.289	7359.610	-	8355.109	0.881	OK
Y	8047.686	10045.571	1.4	10412.717	0.965	OK

Table 1 and Table 2 indicate that the multiplier value of the structure was less than 1, meaning that it has met the requirements, namely the value of the dynamic shear force due to the earthquake load of the spectrum response is greater than 85% of the value of the basic shear force of the equivalent static analysis plan. Therefore, re-analysis was unnecessary, and the output results from SAP2000 could be used.

3.4 Floor Shear Style (Story Shear)

The higher the floor, the smaller the shear force's value because the ground floor supports all the loads above it. The second floor supports the load above it and so on up to the roof. This study discovered that the stiffer the structure, the greater the shift force. The results of the floor shear force are depicted in Fig. 1 and Fig. 2.

3.5 Deviation Between Floor (Drift ratio)

According to SNI 1726 2012 (BSN, 2012), the deviation value between the the design level floor is calculated as the difference in deflection between the center of mass of the upper floor and the ground floor under review. The deviation value between floors was then used to calculate the drift ratio, the ratio between the deviation value between floors, and the height between floors. The deviation output between floors reviewed in this study was based on joint structures on the adjacent building side, as shown in Fig. 3 to Fig. 6. The deviation value between floors and the center of mass deflection are presented in Table 3 and Table 4.

Based on the figure and drift ratio table for the Neo Malioboro Hotel, the value of the deviation ratio generated due to the earthquake response spectrum in the X-direction and all parts of the joint under review were still in the safe category because it was below the specified limit (permitted ratio). Conversely, the Malioboro Suite Hotel had a drift ratio value of 0.092 on the third floor, exceeding the permitted ratio of 0.090 due to the less rigid structure.

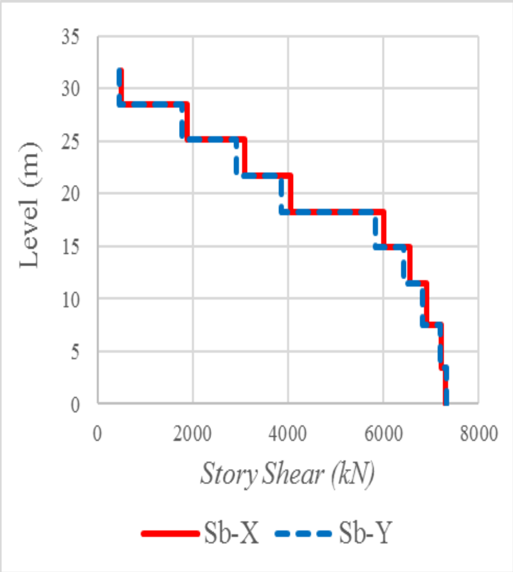

Fig. 1 - The floor shear force of Neo Malioboro Hotel

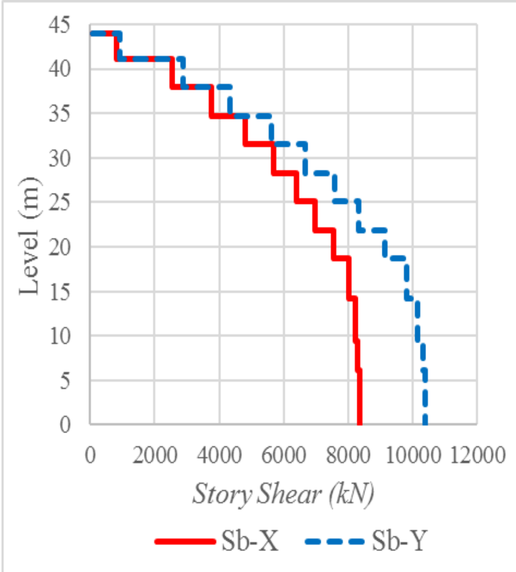

Fig. 2 - The floor shear force of Malioboro Suite Hotel

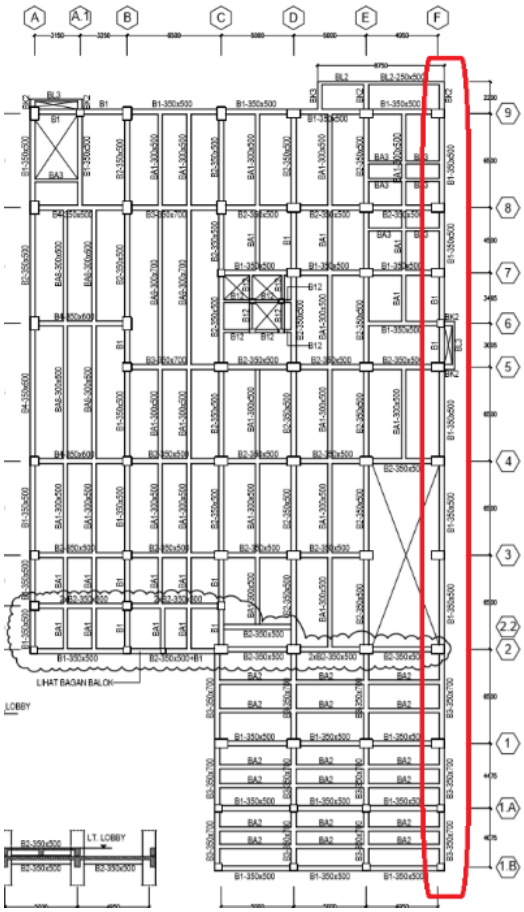

Fig. 3 - The joint location reviewed by Neo Malioboro Hotel from the basement to the 3rd floor

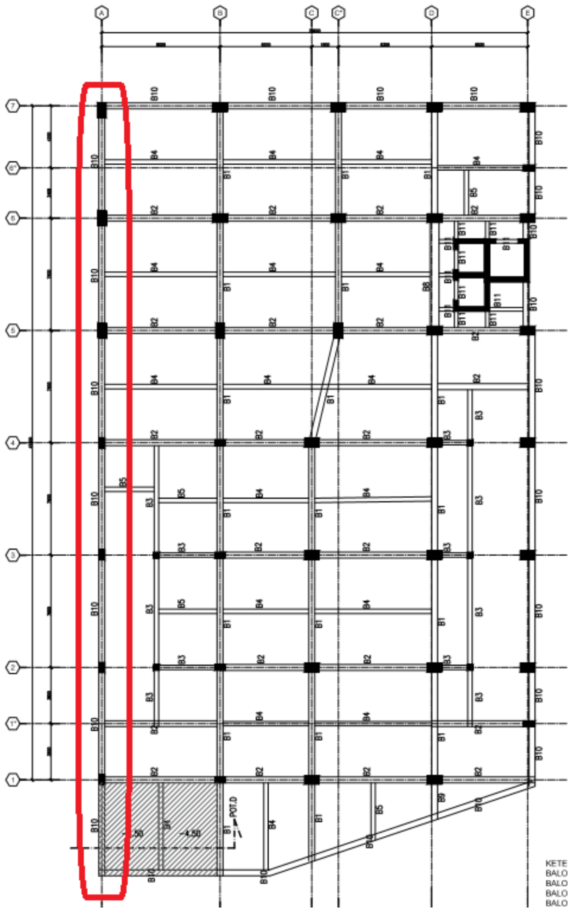

Fig. 4 - The joint location reviewed by Malioboro Suite Hotel from the basement to the 3rd floor

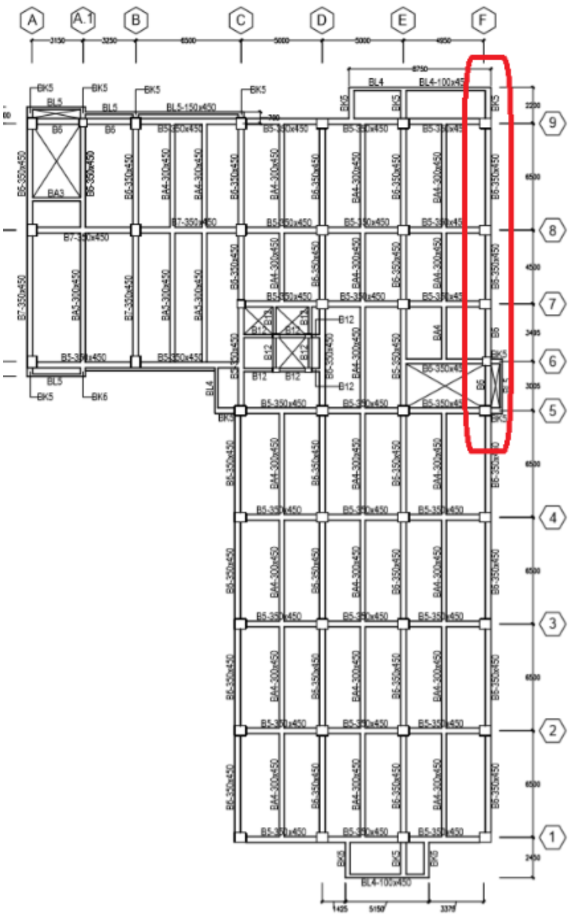

Fig. 5 - The joint location reviewed by Neo Malioboro Hotel from the 5th floor to the roof

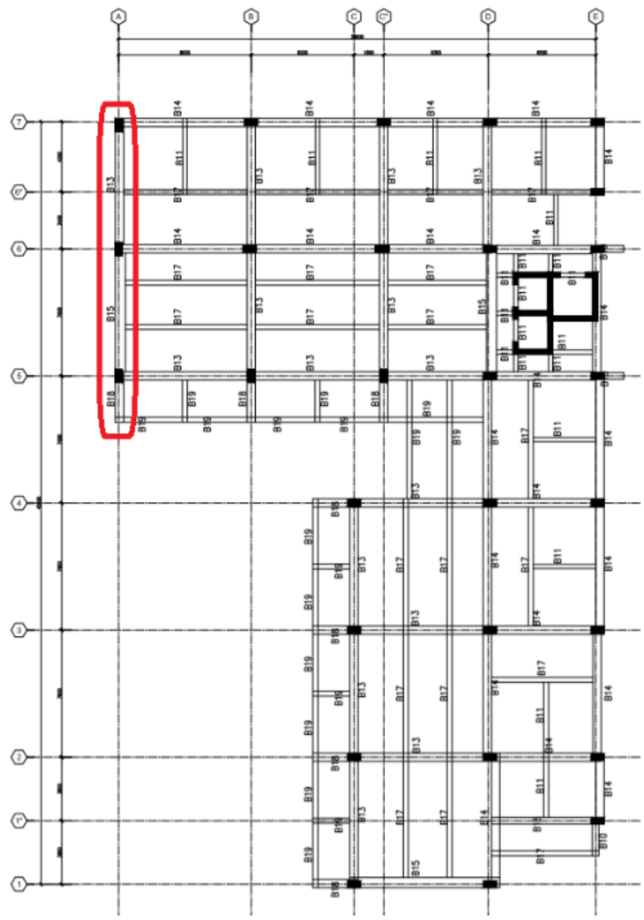

Fig. 6 - The joint location reviewed by Malioboro Suite Hotel from the 4th floor to the roof

Table 3. Deviation value between floors (drift ratio) and the center of mass deflection of Neo Malioboro Hotel Sb-X

Floor	Floor Elevation (m)	Height (m)	Total Deflection (m)	Center of Mass Deflection Rate (m)	Drift Ratio (m)	Drift Limit 2.0%
ROOF	31.70	3.20	0.0800	0.440	0.063	0.064
SKY LOUGE	28.50	3.40	0.0685	0.377	0.041	0.068
8TH FLOOR	25.10	3.40	0.0611	0.336	0.048	0.068
7TH FLOOR	21.70	3.40	0.0523	0.288	0.057	0.068
6TH FLOOR	18.30	3.40	0.0420	0.231	0.062	0.068
5TH FLOOR	14.90	3.40	0.0308	0.169	0.063	0.068
3RD FLOOR	11.50	4.00	0.0193	0.106	0.065	0.080
2ND FLOOR	7.50	4.00	0.0074	0.041	0.036	0.080
LOBBY	3.50	3.50	0.0009	0.005	0.004	0.070
BASEMENT	0.00	0.00	0.0002	0.001	0.001	0.070

Table 4 - Deviation value between floors (drift ratio) and the center of mass deflection of Neo Malioboro Hotel Sb-Y

Floor	Floor Elevation (m)	Height (m)	Total Deflection (m)	Center of Mass Deflection Rate (m)	Drift Ratio (m)	Drift Limit 2.0%
ROOF	31.7	3.2	0.0560	0.308	0.034	0.064
SKY LOUGE	28.5	3.4	0.0498	0.274	0.035	0.068
8TH FLOOR	25.1	3.4	0.0435	0.239	0.037	0.068
7TH FLOOR	21.7	3.4	0.0368	0.202	0.040	0.068
6TH FLOOR	18.3	3.4	0.0296	0.163	0.041	0.068
5TH FLOOR	14.9	3.4	0.0222	0.122	0.041	0.068
3RD FLOOR	11.5	4.0	0.0147	0.081	0.046	0.080
2ND FLOOR	7.5	4.0	0.0063	0.035	0.032	0.080
LOBBY	3.5	3.5	0.0005	0.003	0.002	0.070
BASEMENT	0.0	0.0	0.0002	0.001	0.001	0.070

Table 5 - Deviation value between floors (drift ratio) and the center of mass deflection of Malioboro Suite Hotel Sb-X

Floor	Floor Elevation (m)	Height (m)	Total Deflection (m)	Center of Mass Deflection Rate (m)	Drift Ratio (m)	Drift Limit 2.0%
ROOF	41.10	3.20	0.0749	0.412	0.034	0.064
9TH FLOOR	37.90	3.20	0.0688	0.378	0.039	0.064
8TH FLOOR	34.70	3.20	0.0618	0.340	0.046	0.064
7TH FLOOR	31.50	3.20	0.0535	0.294	0.050	0.064
6TH FLOOR	28.30	3.20	0.0445	0.245	0.050	0.064
5TH FLOOR	25.10	3.20	0.0354	0.195	0.046	0.064
4TH FLOOR	21.90	3.20	0.0270	0.149	0.006	0.064
3RD FLOOR	18.70	4.50	0.0281	0.155	0.092	0.090
2ND FLOOR	14.20	4.80	0.0114	0.063	0.058	0.096
1ST FLOOR	9.40	3.20	0.0009	0.005	0.003	0.064
BASEMENT 1	6.20	3.20	0.0004	0.002	0.001	0.064
BASEMENT 2	3.00	3.00	0.0002	0.001	0.001	0.060
GWT	0.00	0.00		0.000	0.000	0.060

Table 6 - Deviation value between floors (drift ratio) and the center of mass deflection from Malioboro Suite Hotel Sb-Y

Floor	Floor Elevation (m)	Height (m)	Total Deflection (m)	Center of Mass Deflection Rate (m)	Drift Ratio (m)	Drift Limit 2.0%
ROOF	41.1	3.2	0.0735	0.404	0.035	0.064
9TH FLOOR	37.9	3.2	0.0672	0.370	0.034	0.064
8TH FLOOR	34.7	3.2	0.0611	0.336	0.041	0.064
7TH FLOOR	31.5	3.2	0.0536	0.295	0.048	0.064
6TH FLOOR	28.3	3.2	0.0449	0.247	0.051	0.064
5TH FLOOR	25.1	3.2	0.0357	0.196	0.050	0.064
4TH FLOOR	21.9	3.2	0.0266	0.146	0.047	0.064
3RD FLOOR	18.7	4.5	0.0181	0.100	0.061	0.090
2ND FLOOR	14.2	4.8	0.0070	0.039	0.036	0.096
1ST FLOOR	9.4	3.2	0.0005	0.003	0.001	0.064
BASEMENT 1	6.2	3.2	0.0003	0.002	0.001	0.064
BASEMENT 2	3.0	3.0	0.0001	0.001	0.001	0.060
GWT	0.0	0.0		0.000	0.000	0.060

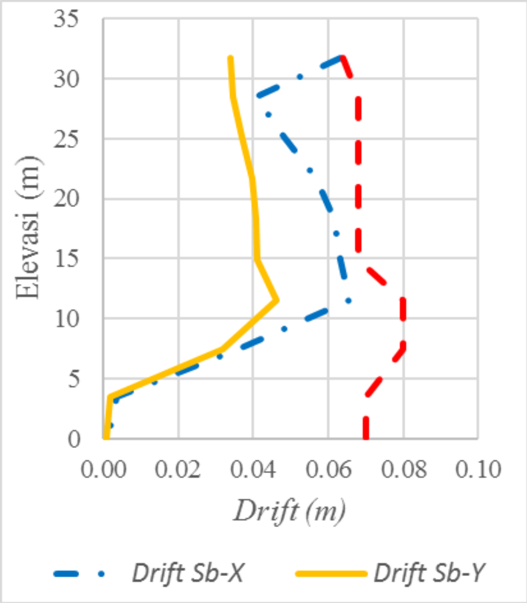

Fig. 7 - Drift ratio of Neo Malioboro Hotel due to earthquake loads in X and Y directions

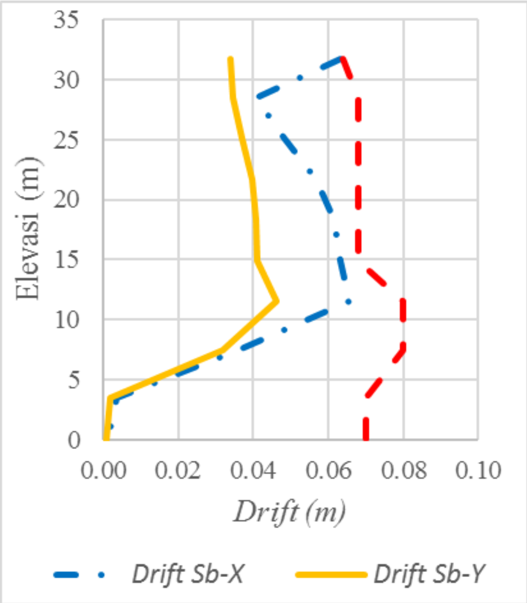

Fig. 8 - Drift ratio of Malioboro Suite Hotel due to earthquake loads in X and Y directions

3.6 Separation Distance between Building Structures

According to BSN (2012), all parts of the structure must be designed and built to work as an integrated unit in resisting earthquake forces unless they are structurally separated by a sufficient distance to avoid damaging collisions. Adjoining building structures must be separated by at least δMT. The manual calculations results disclosed that the minimum deflection distance (δMT) between the two hotels was 0.602m. The largest deviation of the center of mass of the two hotels in the X-direction based on Table 3 and Table 5 occurred on the top floor, namely the roof, with 0.44m for Neo Malioboro, and 0.412m for Malioboro Suite. Accordingly, the minimum distance between the two hotels was 1.454m. Meanwhile, the separation distance between the existing hotel structure was 2.5m. In other words, the distance between the two hotels was safe because the outer structure distance of the building was greater than the minimum limit required, as presented in Fig. 9.

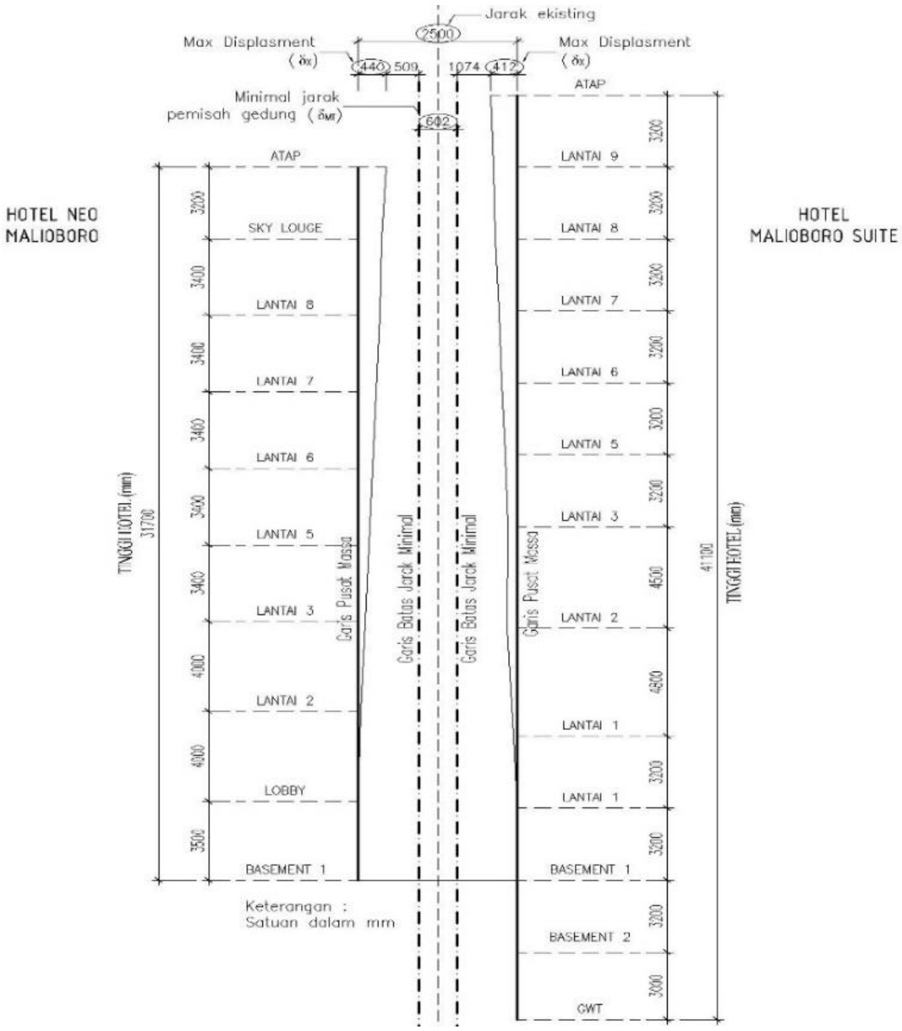

Fig. 9 - The center of mass deflection at the Neo Malioboro Hotel and the Malioboro Suite Hotel due to the maximum combined load of directions

4. Conclusions

The following conclusions were drawn based on the results obtained from the structural design parameters of both Neo Malioboro and Malioboro Suite Hotels:

- The natural vibration period of the structure based on modeling using SAP2000 with existing data obtained for the Neo Malioboro Hotel in the X-direction was 1.635 and 1.258 in the Y-direction. Moreover, the calculations of the natural vibration period for Neo Malioboro were a Tmin value of 1.045 and a Tmax value of 1.463. For Malioboro Suite, the X-direction was 2.014, while the Y-direction was 1.505. The value of the natural vibration period for Malioboro Suite was a Tmin of 1.404 and a Tmax of 1.965. In theory, the value of the natural vibration period of the two hotels obtained based on modeling in SAP2000 with existing data was excluded in the Ta min <T <Ta max requirement, meaning that the structures in both buildings were still too flexible because the T value exceeded the Tmax calculation value.
- The drift ratio for the Neo Malioboro Hotel was still in a safe condition because it did not exceed the permitted ratio. As for the Malioboro Suite Hotel, there was a drift ratio value of 0.092m on the third floor, exceeding the permitted ratio of 0.090m.
- The maximum deflection of the center of mass (deviation) in each building was on the top floor; namely, the roof with 0.440m for Neo Malioboro, and 0.412m for Malioboro Suite.
- The separation distance between the outer structures of Neo Malioboro and Malioboro Suite Hotels was 2.5m. The manual calculations obtained the minimum distance separating the structures of the two hotels of 1.454m. In a nutshell, the distance between the existing structures from the two hotels was still safe in an earthquake in Yogyakarta.

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