

## STRUCTURAL PERFORMANCE OF 1 WAY AND 2 WAY SETBACK WITH THE SOFT FIRST STORY USING DDBD

### KINERJA STRUKTUR SETBACK 1 ARAH DAN 2 ARAH DENGAN SOFT FIRST STORY MENGGUNAKAN DDBD

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#### ABSTRAK

Struktur bangunan yang tidak beraturan semakin bervariasi, seperti bangunan *setback* dan bangunan tidakberaturan kekakuan tingkat lunak pada lantai pertama bangunan (*soft first story*). Bangunan bertingkat tinggi beresiko terjadinya keruntuhan akibat gempa. Sebagai upaya untuk efisiensi desain tersebut, memerlukan metode *Direct Displacement Based Design* (DDBD). Dalam penelitian ini digunakan metode DDBD menggunakan analisis pushover pada bangunan *soft first story* tanpa *setback*, *setback 1*, dan *2 arah*. Tujuan penelitian ini untuk mendapatkan nilai *displacement*, *story drift*, daktilitas, mekanisme sendi plastis, dan level kinerja menggunakan *software*. Hasil dari penelitian ini menunjukkan bahwa nilai *displacement* bangunan *soft first story* tanpa *setback* lebih kecil dibandingkan bangunan *setback*. Selain itu, besarnya nilai *displacement* dan *story drift* pada bangunan *setback* dengan *soft first story* dipengaruhi oleh kecilnya rasio luasan *setback*. Nilai *displacement* dan *story drift* terbesar pada arah X adalah bangunan *setback 1 arah*, yaitu 0.422 m dan 0.0147 m, sedangkan pada arah Y bangunan *setback 2 arah*, yaitu 0.44 m dan 0.0167 m. Nilai daktilitas aktual yang paling besar adalah bangunan tanpa *setback* dengan *soft first story*. Mekanisme sendi plastis pada ketiga bangunan menunjukkan *strong column weak beam*. Level kinerja struktur pada ketiga bangunan berada pada level *Immediate Occupancy* dimana nilai level kinerja metode FEMA 356 lebih besar dibandingkan metode ATC 40.

**Kata Kunci:** *DDBD; Setback; Soft First Story; Tanpa Setback.*

#### ABSTRACT

*Irregular building structures increasingly varied, such as setback buildings and buildings with soft level stiffness irregularity on the first floor of the building (soft first story). High-rise buildings are at risk of collapse due to earthquakes. Designing efficiency requires a Direct Displacement Based Design (DDBD) method. In this study, the DDBD method uses pushover analysis on soft first-story buildings without a setback, 1-way setback, and 2-way setback. This study aims to obtain the value software's value of displacement, story drift, ductility, plastic hinge response, and performance levels study indicates that the displacement value of the soft first-story building without setback is smaller than the setback building. In addition, the value of displacement and story drift in the setback building with a soft first story is influenced by the small setback area ratio. The highest displacement and story drift values in the X direction are 1-way setback buildings, which are 0.422 m and 0.0147 m, while in the Y-direction, the 2-way setback buildings are 0.44 m and 0.0167 m. The most significant value of actual ductility is a building*

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*without setbacks with a soft first-story. The plastic hinge response in all three buildings shows a strong column weak beam. The level of structural performance in all three buildings is at the level of Immediate Occupancy, where the value of the performance level of the FEMA 356 method is greater than the ATC 40 method.*

**Keywords:** *DDBD; Setback; Soft First Story; Without Setback.*

## INTRODUCTION

BMKG reports that Indonesia has recorded 924 earthquakes between January until September 2019. The quake has often caused infrastructure damage, due to irregular building structures, such as setback buildings and buildings without infill walls on the ground floor (soft story) [1]. Irregular buildings significantly affect the structural response [2].

A setback building is when the top of the building is indented; there are two types: type 1 and 2 [3]. Soft story structures usually receive relatively heavy loads from the above structures and increase the column's lateral deformation and shear forces [1].

Design methods and control for buildings can be performed more efficiently using The Direct Displacement Based Design (DDBD) method than with the Force Based Design (FBD) method, which is often used. [4][5][6][7]. In comparison to the elastic model and the displacement value as the benchmark, the DDBD method produces a more realistic seismic response. [8][9][10].

With the DDBD method, this study provides better earthquake-resistant building design information: the building structural performance without a setback, with a 1-way setback, and with a 2-way setback with a soft first-story. These results consider the performance results based on displacement values, story drift, ductility values, plastic hinge mechanisms, and performance levels based on ATC 40 and FEMA 356 [11] [12].

## METHOD

In the present study, the building is irregularly designed, without a setback (vertical geometric irregularity), and first floor is a soft one (extreme soft stiffness irregularity).

The earthquake location is in Padang area with soft soil types.

This building acts as a hotel and consists of 10 floors, the first-floor with a 6 meters height while the other floor were 3.5 meters tall. The building utilized the Special Moment Frame System.

It has full ductility, and this system should be used in areas with a high level of earthquake risk. The principle of this system, namely strong-column weak-beam, is resistant to shear and has sophisticated details. The advantage of this system is its simple architecture, while The disadvantage is that the details are complex, so it can be challenging to work on [13][14].

## Pushover Analysis

Pushover analysis is a nonlinear static analysis to determine the collapse behavior of a building or structure against an earthquake. Pushover analysis is used as an option in carrying out performance-based earthquake engineering. This happens because the nonlinear static analysis is very accurate when used when there is a fairly large earthquake due to structural plasticization in several places so that the building will change from linear behavior to nonlinear behavior.[15]

In this analysis, the structure is given a static lateral load pattern whose value continues to be increased gradually until the displacement target is obtained from a reference point. In this analysis, the reference point is the point on the roof floor and the maximum deformation that may occur in the structure is determined in advance by the planner. [16]

## Direct Displacement Based Design (DDBD)

DDBD identifies the structure by its stiffness at maximum displacement, and this section outlines a complete method design for DDBD of single degree of freedom (SDOF) structures with a representation of the performance at the peak displacement. [17]

For DDBD of SDOF structure, the lateral design displacement of the frame can be taken

as the maximum lateral frame displacement ( $\Delta_d$ ), that occurs based on the design drift limit chosen, where the maximum lateral frame displacement can be found as shown in Eq. (1) where  $m_i$  is mass at level-i (ton) and  $\Delta_i$  is displacement on floor-I (m). The first-mode response leads to a SDOF system estimate of the roof displacement. [17][18][19]

$$\Delta_d = \frac{\sum_{i=1}^n (m_i \Delta_i^2)}{\sum_{i=1}^n (m_i \Delta_i)} \dots\dots\dots(1)$$

DDBD method use the lateral design displacement to get the ductility design displacement as shown Eq. (2) where is the displacement of melting frame. Then, The basic shear force is obtained by equation and the distribution of the shear force for each floor using the equation.

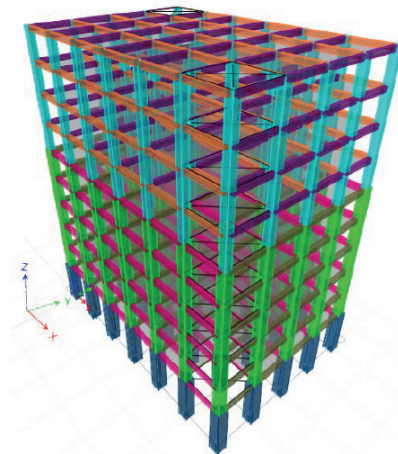
$$\mu \dots\dots\dots(2)$$

In the pushover analysis, a capacity curve is obtained which shows the relationship between the basic shear force and the displacement value, which shows the slope of the curve due to the occurrence of plastic hinges in the column and beam, resulting in a change in the behavior of the structure from being linear to non-linear.

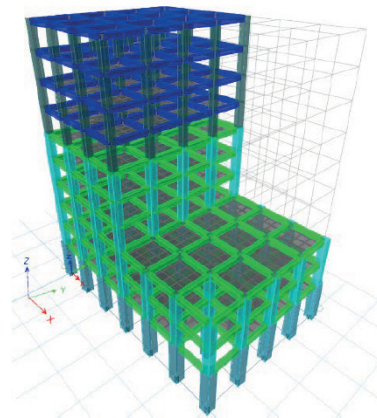
**Design Data**

Building type, A (Figure 1) was a building without setbacks with a soft first story with a building area of 600 m<sup>2</sup>. The building type B (Figure 2) was a 1-way (x-direction) setback building with a soft first-story with a building area of 1-3 floors of 600 m<sup>2</sup> and a building area of 4-10 floors of 300 m<sup>2</sup>. In a type B building, the area setback ratio was 50% by only reducing the x-direction area. The type C building (Figure 3) was a 2-way setback building (x and y direction) with a soft first story with a 50% setback area ratio by reducing the area in the x and y directions.

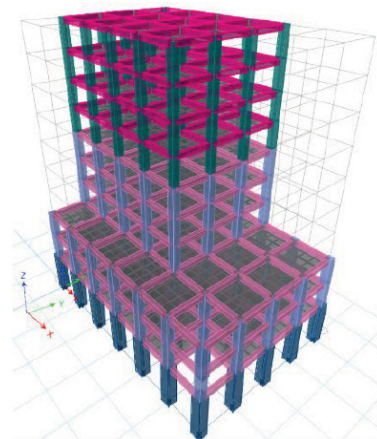
The load for buildings is based on SNI 1727:2013. The dead load used for this analysis is the load of concrete, ceramic, plafond, utilities, partitions, and wall.



**Figure 1.**  
3D Model Building Type A  
Source: Author Analysis (2020).



**Figure 2.**  
3D Model Building Type B  
Source: Author Analysis (2020).



**Figure 3.**  
3D Model Building Type C  
Source: Author Analysis (2020).

From the results of preliminary design calculations, the data obtained in the form of dimensions of structural elements are as follows. The beams' dimensions for floors 1-6 are 400 x 650 mm, and for floors 7-10 are 350 x 550 mm. Column dimensions for floor 1 are 1200 x 1200 mm, floors 2-6 are 900 x 900 mm, and floors 7-10 are 700 x 700 mm. The thickness of the floor slab is 125 mm.

This research method used in this study focused on a measuring displacement values, drifting, ductility, plastic hinge mechanism, and performance levels within buildings without a setback, 1-way, and 2-way setbacks with soft first-floors. In this study, a nonlinear pushover analysis refers to ATC 40 and FEMA 356 using ETABS v.16.2.1. The flow chart in this research method is presented in Figure 4.

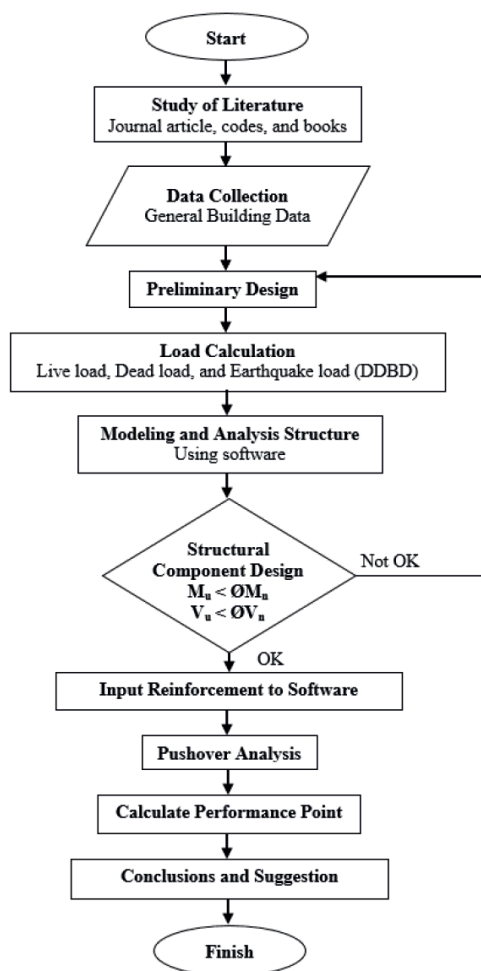


Figure 4.

Flow Chart of the research procedure  
Source: Author Analysis (2020).

Figure 4 showed that the load calculation, modeling in software after the preliminary design was carried out. Structural analysis, after checking the reinforcement, if it was not okay, it just changed in the preliminary design if it was okay to directly input the reinforcement requirements and perform a pushover analysis to determine the performance level of the structure based on ATC - 40 and FEMA 356.

In designing this building, SNI 2847 - 2019, SNI 1726 - 2019, SNI 03 - 1727 - 2013, Applied Technology Council (ATC) - 40 - 1996, and Federal Emergency Management Agency (FEMA) - 356 - 2000 regulations are used.

## RESULTS AND DISCUSSION

### Displacement

The pushover analysis of buildings A, B, and C with the same reinforcement design got the displacement results. Based on design displacement, the location nodal of Building A is at 0.405 m and effective height is 23.79 m. The location nodal of Building B and C is at 0.379 m and effective height is 22.086 m.

In Figure 5, It can see the most significant displacement results in the X direction, building B of 0.422 m. It happened because building B reduced the area in the X direction more in the setback area. In Figure 6, the results of the most significant displacement in the Y direction were building C of 0.44 m. It happened because only building C reduced the area in the Y direction in the setback area. Meanwhile, the most negligible displacement results for building A were in the X and Y directions, which were 0.311 m and 0.324 m.

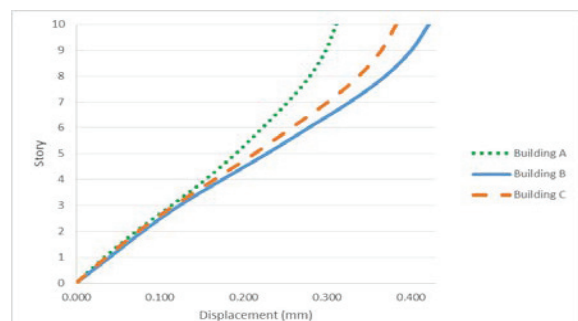
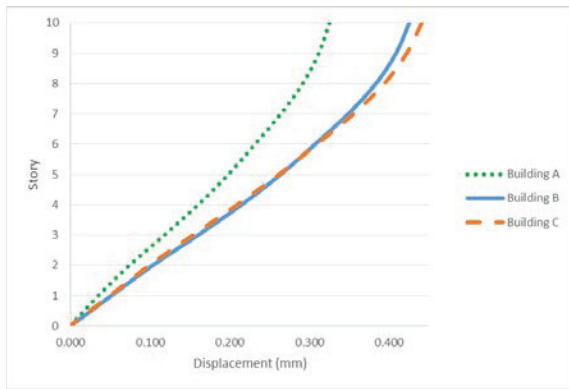


Figure 5.

Displacement of Building A, B, and C in the X Direction

Source: Analysis Data (2020).



**Figure 6.**  
The Building Displacement of A, B, and C in the Y Direction  
Source: Analysis Data (2020)

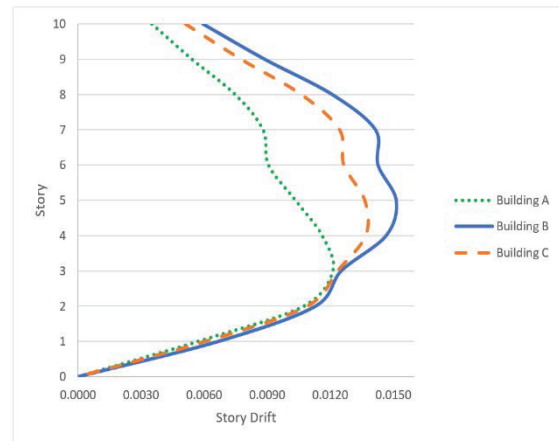
This displacement results followed previous research by Hanan, which states that the most significant displacement is in the soft first story building with a smaller ratio of downstairs to the upper floor [20]. The results of the building displacement without a setback, which has a mass that was almost the same as the setback model, would produce a smaller displacement than the setback building [21].

### Story Drift

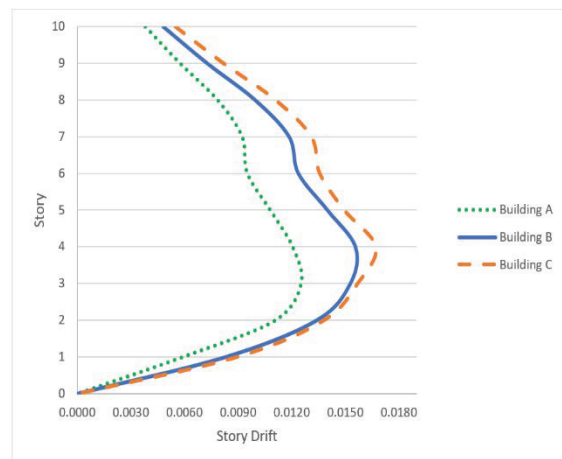
Pushover analysis of buildings A, B, and C with the same reinforcement design got story drift results. In this case, the story drift value increase is quite extreme in the transitional or setback area. In Figure 7, the most considerable story drift results in the X direction on the 4th floor, building B, of 0.0147 m. It happened because building B reduced the setback area in the X direction, more remarkable than buildings A and C. In Figure 8, the most significant story drift results in the Y direction on the 4th floor, building C, of 0.0167 m. It happened because only building C reduced the setback area in the Y direction. Meanwhile, on the 10th floor for building A got the minor story drift results in the X and Y directions, which are 0.0035 m and 0.0038 m. It indicated that building A was stiffer.

The story drift results above were from Hanan and Immanuel's previous research that the most significant story drifts were in

the building with a smaller ratio of the lower floors to the upper floors [20] [22]. The shortest story drift value indicated that the structure was more ductile than the building with a considerable story drift value. It showed that this study was under previous research by Hanan [20].



**Figure 7.**  
Story Drift of Building A, B, and C in The X Direction  
Source: Analysis Data (2020).



**Figure 8.**  
Story Drift of Building A, B, and C in The Y Direction  
Source: Analysis Data (2020).

### Ductility

Pushover analysis of buildings A, B, and C with the same reinforcement design got the actual ductility results. The design ductility is obtained when calculating the basic shear

force design with DDBD. In Table 1, buildings A, B, and C in the X and Y directions using the ATC 40 and FEMA 356 methods show that the actual ductility value is smaller than the design ductility. It is similar to previous research by Utomo et al. and Tajunnisa et al., where the actual ductility value is less than the design ductility value [23] [24].

Table 1 also shows that the FEMA 356 method is closer to the design ductility than the ATC 40 method. In line with Pranata and Wijaya’s FEMA 356 methods, the reality is close to the design ductility results [25].

The actual ductility value results showed that building A has the largest real ductility

value. It is because the transition point’s distance at the time of first yielding ( $\delta_y$ ) was to the ultimate end of the transition ( $\delta_t$ ) is considerable. It indicated that the building was more ductile than buildings B and C, and the greater the actual ductility value, it can slow down the collapse. This result was under previous research that the real ductility value is in a structure with additional stiffness. The design can still maintain sufficient strength and stiffness so that the building remains standing even though it is on the verge of collapse [26] [27].

**Table 1.**  
Ductility Value Results of Analysis Pushover

Methods	Direction	Type of Building	$\delta_y$ (m)	$\delta_t$ (m)	Actual Ductility ( $\mu_s$ )	Design Ductility ( $\mu$ )
<b>ATC 40</b>	X	Building A	0.14	0.277	1.979	2.641
		Building B	0.158	0.246	1.557	2.665
		Building C	0.148	0.249	1.682	2.665
	Y	Building A	0.149	0.284	1.906	2.641
		Building B	0.139	0.251	1.806	2.665
		Building C	0.149	0.259	1.738	2.665
<b>FEMA 356</b>	X	Building A	0.14	0.280	2.000	2.641
		Building B	0.158	0.246	1.557	2.665
		Building C	0.148	0.249	1.682	2.665
	Y	Building A	0.149	0.287	1.926	2.641
		Building B	0.139	0.258	1.856	2.665
		Building C	0.149	0.265	1.779	2.665

Source: Analysis Data (2020).

### Plastic Hinge Mechanism Building A

Figure 9 that the distribution of the plastic hinge of building A at the maximum condition for pushover in X direction was at step 22 due to the push load of 40368,794 kN. In the X-direction pushover, the plastic hinge’s initial location was on the beam in story 3, which is in the 10th step, and as the push load increases, it would gradually rise upward. Furthermore, plastic hinges began to form on the 1st-floor column in the 14th step.

Figure 10 shows the distribution of the plastic hinge of building A at the maximum condition for the Y direction pushover at the 21st step due to the push load of 39680.735 kN. At the Y-direction pushover, the initial location of the plastic hinge occurrence was on the beam in story 3, which is in the 10th step, and as the push load increases, it would gradually rise upward. Furthermore, plastic hinges began to form on the 1st-floor column in the 14th step.

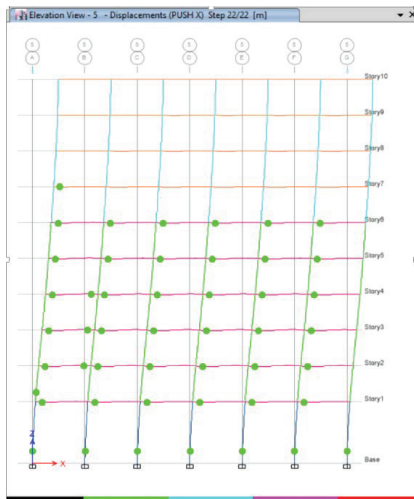


Figure 9.  
Plastic Hinge Mechanisms of Building A in The X Direction  
Source: Analysis Data (2020).

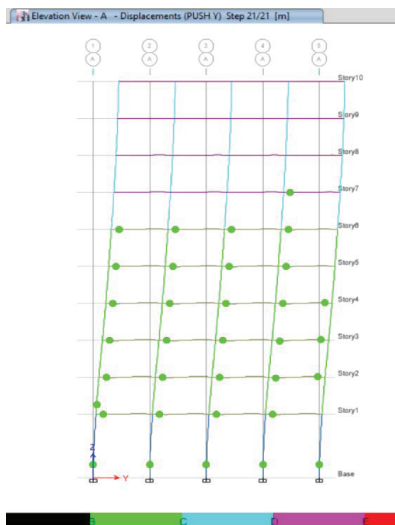


Figure 10.  
Plastic Hinge Mechanisms of Building A in The Y Direction  
Source: Analysis Data (2020)

### Building B

Figure 11, the distribution of the plastic hinge of building B at the maximum condition for pushover in X direction was at step 18 due to the thrust load of 42855.068 kN. In X-direction pushover, the initial location of the plastic hinge was on the beam in story 4, which is in step 5, and along with the increase in the push load, it would gradually rise upward. Furthermore, plastic hinges began to form on the 1st-floor column in the 10th step.

Figure 12 showed the plastic hinge distribution of building B at the top condition for the Y direction pushover at step 19 due to the thrust load of 37909.105 kN. In the Y direction pushover, the plastic hinge occurrence's initial location was on the beam in story 3, which is in the 6th step, and as the push load increases, it would gradually rise upward. Furthermore, plastic hinges began to form on the 1st-floor column in the 9th step.

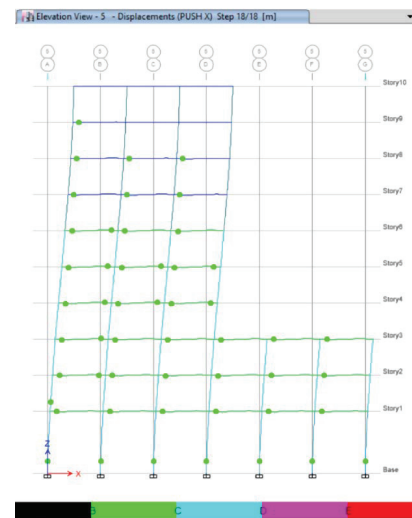


Figure 11.  
Plastic Hinge Mechanisms of Building B in The X Direction  
Source: Analysis Data (2020).

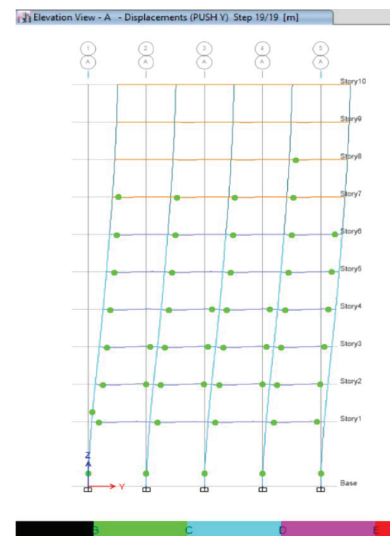
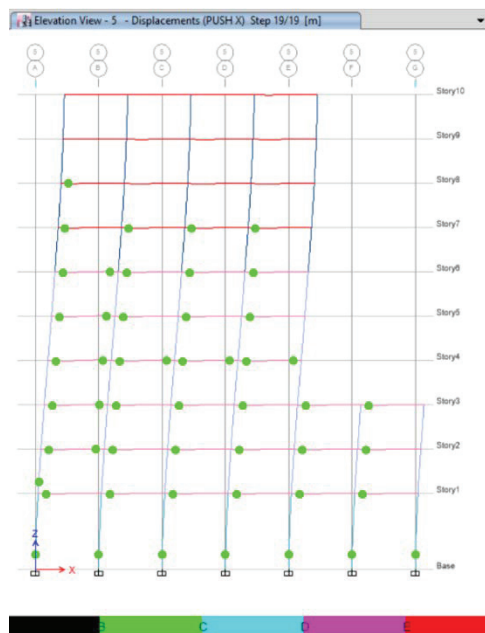


Figure 12.  
Plastic Hinge Mechanisms of Building B in The Y Direction  
Source: Analysis Data (2020).

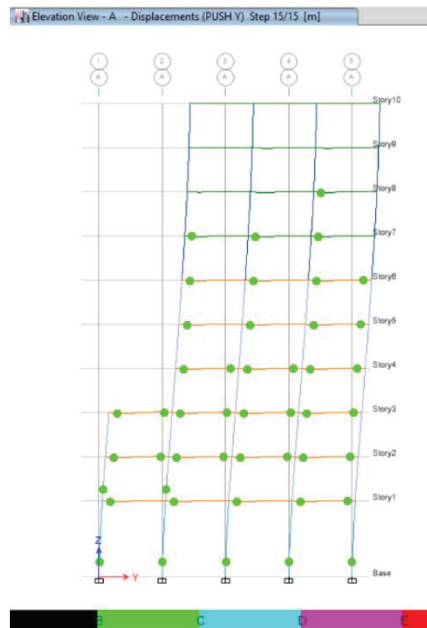
### Building C

Figure 13 shows that the building plastic hinge C distribution in the maximal condition for pushover direction X was in the 19th step due to the push load of 40561.546 kN. In X-direction pushover, the plastic hinge's initial location was on the beam in story 4, which is in step 7, and as the push load increases, it would gradually rise to the top. Furthermore, plastic hinges began to form on the 1st-floor column in the 12th step.



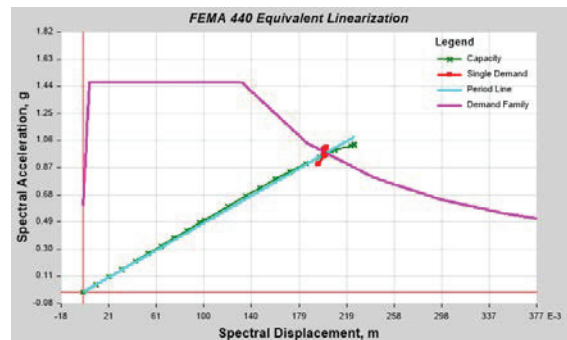
**Figure 13.**  
Plastic Hinge Mechanisms of Building C in The X Direction  
Source: Analysis Data (2020).

Figure 14 showed the plastic hinge building C distribution at the maximum condition for the Y direction pushover at the 15th step due to the thrust load of 39730.546 kN. At the Y-direction pushover, the plastic hinge occurrence's initial location was on the beam in story 3, which is in the 5th step, and as the push load increases, it would gradually rise upward. Furthermore, plastic hinges began to form on the 1st-floor column in step 8.

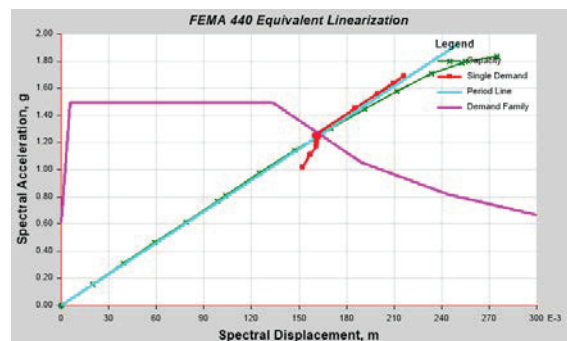


**Figure 14.**  
Plastic Hinge Mechanisms of Building C in The Y Direction  
Source: Analysis Data (2020).

### Performance Level

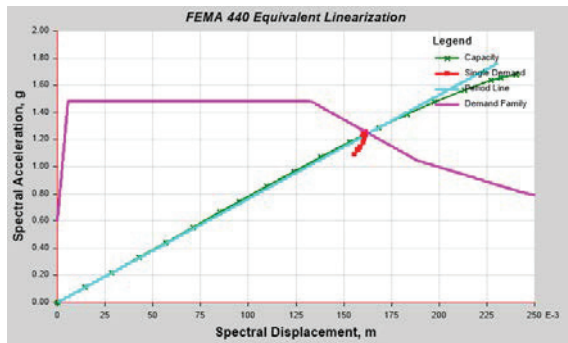


(a)



(b)





(c)

**Figure 15.**

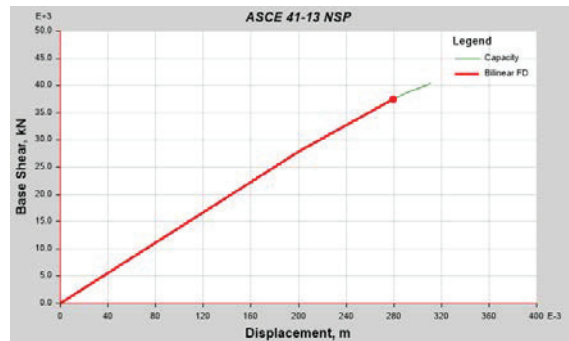
Capacity Spectrum Curve ATC 40  
(a) Building A, (b) Building B, and (c) Building C

Source: Analysis Data (2020).

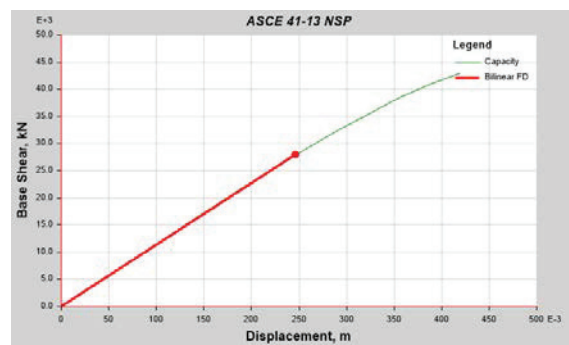
Figure 15 showed the capacity spectrum curve ATC 40 from ETABS v.16.2.1 for buildings A, B, and C. The performance point value obtained is then used to determine the performance level of building A, B, and C with the soft first story in the x and y directions tabled in Table 2. The results of the performance point value from the calculation of the displacement target value are contained in Table 2, divided by the total height floor of 37.5 m. The average performance point value for building A is 0.0075, building B is 0.0067, and building C is 0.0068. The difference between the average performance point values in buildings A, B, and C based on the ATC 40 capacity spectrum is 0.0008. Overall, the performance point values of buildings A, B, and C based on ATC - 40 are close to a minimal difference.

Figure 16 showed the result of the bilinear curve FEMA 356 from ETABS v.16.2.1 for buildings A, B, and C. The result was used to get performance levels. The performance point value obtained is then used to determine the performance level of building A, B, and C with the soft first story in the x and y directions tabled in Table 2. The results of the performance point value from the calculation of the displacement target value are contained in Table 2, divided by the total height floor of 37.5 m. The average performance point value for building A is 0.0076, building

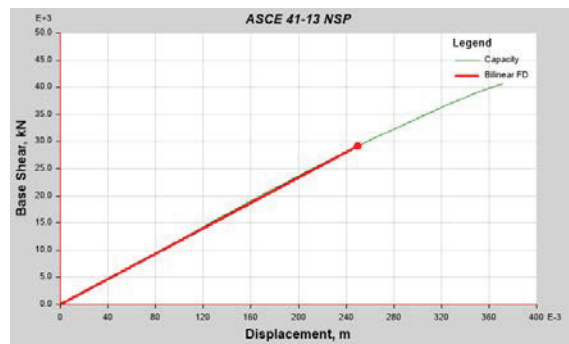
B is 0.0067, and building C is 0.0068. The average performance point value of building A is 0.0009 greater than buildings B and C.



(a)



(b)



(c)

**Figure 16.**

Bilinear Curve FEMA 356  
(a) Building A, (b) Building B, and (c) Building C

Source: Analysis Data (2020).

Based on Figures 15 and 16 were used to get the performance level, and the result shown in Table 2, the structure performance level based on ATC 40 and FEMA 356 for buildings A, B, and C was at the Immediate

Occupancy level. It explained that the building is safe during an earthquake so that the risk of casualties, structural failure, and damage to the building is not so significant that it can be used again. [18].

Table 2 shows that the target value of FEMA 356 displacement got more significant

results in buildings A, B, and C. It is consistent with previous research by Sudarman et al. that FEMA 356 got the most remarkable results in all building types compared to ATC 40, which got more minor results. [28] [29].

**Table 2.**  
Performance Level Results

	Direction	Parameter	Pushover Analysis Result	
			ATC - 40	FEMA - 356
<b>Building A</b>	x-x	Performance Point, $\Delta_m$ (m)	0.277	0.280
		Actual Drift	0.0074	0.0075
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>
	y-y	Performance Point, $\Delta_m$ (m)	0.284	0.287
		Actual Drift	0.0076	0.0077
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>
<b>Building B</b>	x-x	Performance Point, $\Delta_m$ (m)	0.246	0.246
		Actual Drift	0.0066	0.0066
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>
	y-y	Performance Point, $\Delta_m$ (m)	0.251	0.258
		Actual Drift	0.0067	0.0069
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>
<b>Building C</b>	x-x	Performance Point, $\Delta_m$ (m)	0.249	0.249
		Actual Drift	0.0066	0.0066
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>
	y-y	Performance Point, $\Delta_m$ (m)	0.259	0.265
		Actual Drift	0.0069	0.0071
		Performance Level	<i>Immediate Occupancy</i>	<i>Immediate Occupancy</i>

Source: Analysis Data (2020).

**CONCLUSION**

The above research shows that the value of displacement and story drift will be high if the building's reduced floor area gets the biggest. Second, the most negligible story drift results indicate that the building is more ductile than buildings with large story drift values. The ductility results showed that the

FEMA 356 method gave the actual ductility close to the design flexibility results. The more ductile buildings produce the actual ductility value, which can slow down the collapse. Third, in this research, buildings A, B, and C were by the concept of a substantial column weak beam, which is the first yielding occurs in the beam first then the column.

In the plastic hinge mechanism, it can also be seen that building A has more plastic hinge mechanism steps than other models, which indicates that the structure is ductile.

Fourth, the performance level results in this study also obtained immediate occupancy for the ATC 40 and FEMA 356 methods. Furthermore, the conclusion is from the above results, and it can conclude that building A has the best structural performance value compared to other building models. Meanwhile, buildings with a setback area ratio of 50% only differentiate from the setback direction. From the performance results, it can be seen that building C was better than building B. In the X-direction, building C's performance results are better. In the Y-direction, building C has a performance value that the ratio difference is minimal with building B.

The results of this study were consistent with previous research. Still, it can also be examined using the time history method to determine the accuracy of the analysis results and pay more attention to parameters in the pushover analysis process with the software of ETABS.

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