LOGIC
Journal of Engineering Design and Technology
Vol. 20 No. 1 March 2020; p. 6 - 12

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs.pnb.ac.id/index.php/LOGIC

DIRECT DISPLACEMENT BASED DESIGN AND CAPACITY SPECTRUM METHOD FOR SPECIAL MOMENT RESISTING FRAME

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Abstract. In designing seismic-resistant buildings, it is commonly used Forced-Based Design method. The concept of the Force-Based Design (FBD) method is based on an elastic analysis of the structure and indirectly shows the performance level of the structure towards the effects of the seismic forces. Therefore, it is required an approach that capable of analyzing and evaluating the performance of the inelastic structural response; it is called Performance-Based Design method. This paper uses two methods of Performance-Based Design, there are Direct Displacement-Based Design and Capacity Spectrum Method, by using pushover analysis. The objectives of the research are to analyze and compare performance level of the building in inelastic condition by using these two methods. The structural model reinforced concrete special moment frames. Seismic design code that used in this study is SNI 1726:2012. The reviewed parameter values are displacement and story drift values, estimated plastic hinge response, and performance level of the building from two methods. As the results, all the parameter values of DDBD analysis are more significant than CSM. DDBD produces the drift and displacement values of 0.668 m with the rebar ratio is more significant than 1.00. Meanwhile, the CSM produces the drift and displacement values of 0.501 m with the rebar ratio of 1.00. The failure mechanism of both methods indicates the strong column weak beam where the beams should fail prior to the columns. The structure performance level which refers to ATC-40 indicate that both DDBD method and CSM method are in Damage Control level despite displacement target of the two methods are different which is DDBD produces displacement target of 0.376 m while CSM produces the value of 0.345 m.

Keywords : Building Performance; Capacity Spectrum Method; Direct Displacement-Based Design

1. INTRODUCTION

Earthquake is one of the phenomena potentially to cause considerable damage [1]. If the structure of the building is designed does not take into account when it is planning, maybe collapse when exposed to earthquake loads. One of the systems that can resist lateral loads is the special moment-resisting frame. Building with the special moment-resisting frame consists of column, beam, and beam-column joints. The building with special moment resisting frame is designed in detail for flexural, axial, and shear forces that occur when a building experience shocks due to an earthquake [2]. Loads on buildings with special moment-resisting frame are borne by the frame bearing the moments through a flexible mechanism [3].

At present, commonly used Force Based Design methods for designing earthquake-resistant structures. This concept is based on an analysis of elastic structures and indirectly shows the effects of the seismic forces to the building [4]. This concept triggers the development of the alternative methods for seismic design, called Performance-Based Design. The concept of Performance-Based Design is that the structural components are analyzed in stages so that it can provide a non-linear (inelastic) behavior of the structure when it first experiences structural failure [4]. This method produces more realistic seismic response analysis compared to elastic models [5].

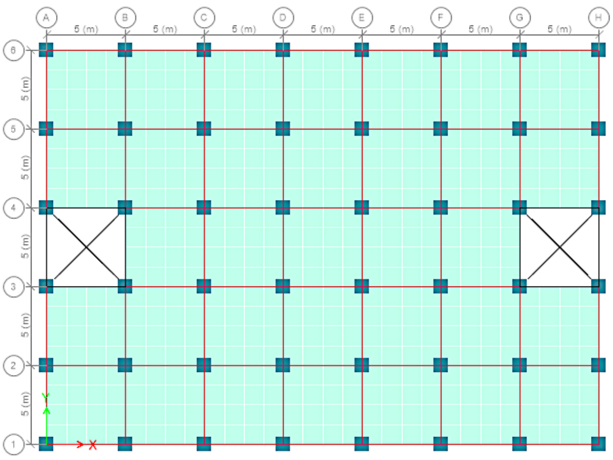
According to Priestley, there are three methods in Performance-Based Design, namely The Capacity Spectrum Approach, The N2 Method, and Direct Displacement Based Design [6]. The Direct Displacement Based Design (DDBD) emphasizes the displacement value as a reference in determining the building strength needed to withstand design earthquake loads [7]. This concept can also give an idea of how the structure's performance against earthquakes occurs [4] while the Capacity Spectrum Method (CSM) method can be known the structure performance points obtained from the intersection between the capacity spectrum curve and the demand spectrum.

There have been several studies analyzing the differences of these methods, including Purba [4] which compared the use of CSM and DDBD methods but on a dual system regular building structure. Therefore, this study is intended to compare the structural performance of the two methods in buildings with special moment-resisting frame systems using pushover analysis. Pushover analysis is used to determine the behavior of the building [8]. This research was conducted to get the value of displacement and story drift value in the structure, to get the value of the reinforcement ratio of both methods, to get the failure mechanism of the structure, and to get the level performance in both methods.

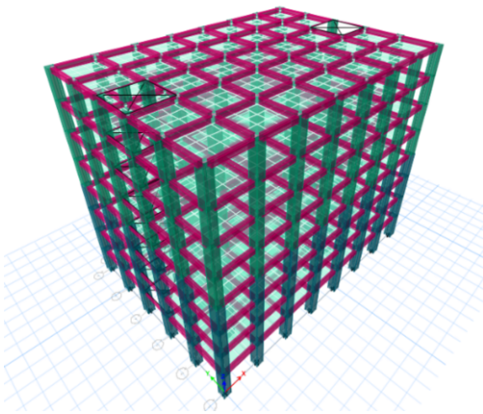
2. METHODS

The structural model used is a special moment resisting frame system with a typical floor plan (Figure 1). The building is assumed to function as an 8-story office building located in Malang city area with soft soil type. The building was designed with two different methods, namely Direct Displacement Based Design (DDBD) and Capacity Spectrum Method (CSM). Although designed with different methods, the floor plan, dimensions of the structures are the same. In buildings designed using the DDBD method, the targeted performance level is the Life Safety condition. Then the building performance is calculated based on FEMA 356 and ATC-40.

The quality of material used is concrete grade 30 MPa and reinforcing steel grade 400 MPa. The objects in this study are only part of the upper structure. The analysis was performed using pushover analysis with the help of software. The earthquake design regulations used to refer to SNI 1726: 2012.



(a)



(b)

Figure 1. (a) Floor plan of the building, (b) building form

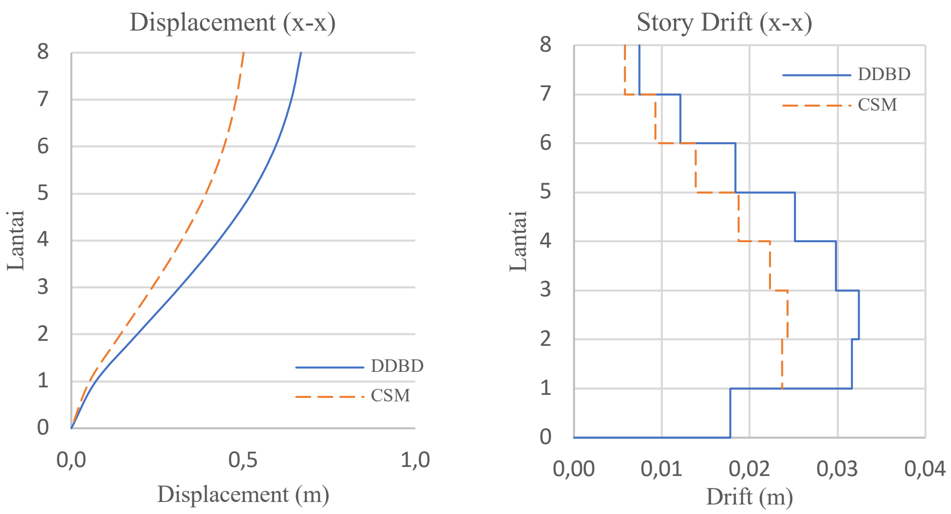
3. RESULTS AND DISCUSSION

3.1. Displacement and Story Drift Value

Dimensions of the calculated structural elements in the preliminary design are presented in Table 1. The structural elements in buildings using the DDBD and CSM methods have the same dimensions, but with different reinforcement details according to the internal forces produced on each element. From the results of the pushover conducted with the help of software, the results obtained in the form of displacement values and story drift in each method contained in Figure 2 and Figure 3.

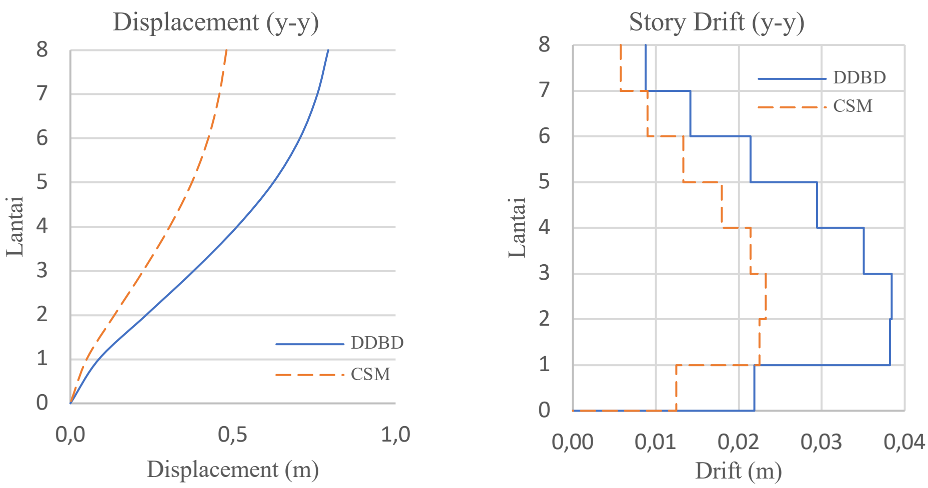
Table 1. Dimensions of the structural elements

Structural Elements	b (mm)	h (mm)	L (mm)
Beam	400	550	5000
Column (Story 1-4)	900	900	3800
Column (Story 5-8)	800	800	3800



(a) (b)

Figure 2. (a) displacement and (b) story drift dir x-x



(a) (b)

Figure 3. (a) displacement and (b) story drift dir y-y

3.2. Reinforcement Ratios

In getting reinforcement ratios, reinforcement area values are required for each structural element, which is the beam and column in both methods. Comparison of the value of the beam reinforcement ratio can be seen in Table 2 and Table 3, while for the column reinforcement ratio can be seen in Table 4. The amount of reinforcement area mounted on the CSM method is assumed to be 1.00 as a reference in the ratio of reinforcement ratio.

Table 2. Reinforcement ratio of beam dir x-x (400 x 550)

Method	I-end and J-end		Middle	
	Reinforcement area installed (mm²)	The ratio of reinforcement area to CSM	Reinforcement area installed	The ratio of reinforcement area to CSM
CSM	1701.172	1.00	850.586	1.00
DDBD	2268.230	1.33	1134.115	1.33

Table 3. Reinforcement ratio of beam dir y-y (400 x 550)

Method	I-end and J-end		Middle	
	Reinforcement area installed (mm²)	The ratio of reinforcement area to CSM	Reinforcement area installed (mm²)	The ratio of reinforcement area to CSM
CSM	1984.701	1.00	850.586	1.00
DDBD	2551.759	1.29	1134.115	1.33

Table 4. Reinforcement ratio of column

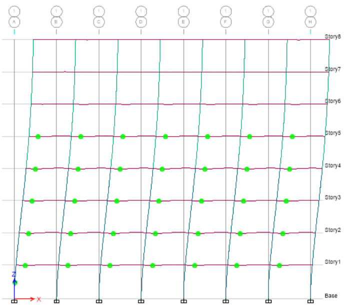
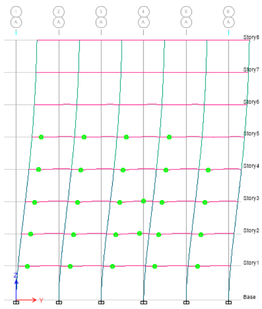
Method	Column Story 1-4 (900x900)		Column Story 5-8 (800x800)	
	Reinforcement area installed (mm²)	The ratio of reinforcement area to CSM	Reinforcement area installed (mm²)	The ratio of reinforcement area to CSM
CSM	15714.29	1.00	11785.71	1.00
DDBD	21607.14	1.30	17678.57	1.50

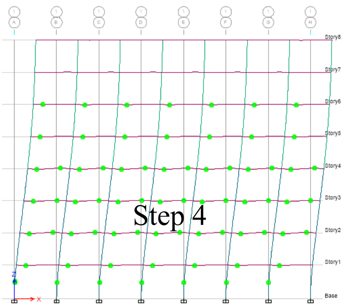
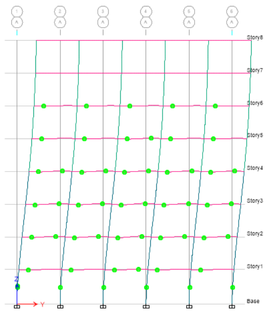
A large number of area reinforcement installed depends on the moment on each element of the structure. The higher the moment, the more reinforcement needed. Tables 2, 3, and 4 show that the DDBD method has more significant reinforcement are than the CSM method.

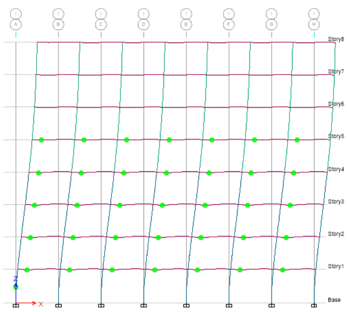
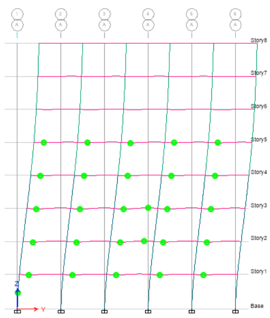
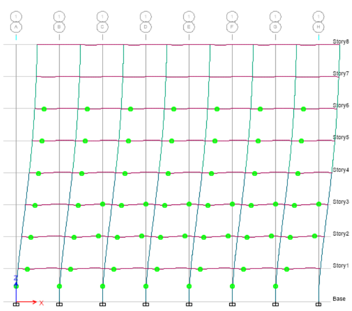
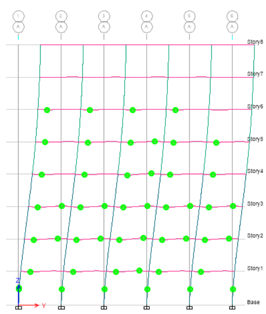
3.3. Failure Mechanism

Table 5 shows the process of the occurrence of plastic joints in the DDBD and CSM method of building structures which were carried out by pushover analysis. In both buildings, the process of plastic joints is expected, which is under the Strong Column-Weak Beam system where the plastic joints start on the beam structure elements first then followed by the column section. The building collapse mechanism also shows a suitable mechanism, namely beam-sway mechanism, because the plastic hinge in the column only occurs in the bottom column.

Table 5. Mechanism for plastic hinge collapse

Method	Direct Displacement Based Design	
Direction	Dir x-x	Dir y-y
	 Step 3	 Step 4

Method	Direct Displacement Based Design	
Direction	Dir x-x	Dir y-y
	 Step 4	 Step 6

Method	Capacity Spectrum Method	
Direction	Dir x-x	Dir y-y
	 Step 3	 Step 3
	 Step 4	 Step 4

3.4. Structure Performance

From the results of pushover conducted using the software, we will get the total displacement value, which can later determine the level of performance in each method. In the DDBD method, pushover is performed on software with the FEMA 356 method reference and produces a binary pushover curve with parameters which are then calculated based on the reference on FEMA 356. In the x-x direction, the displacement target is 0.376 m, and the y-y direction is 0.384 m. Furthermore, to determine the level of performance, the total displacement, according to ATC-40, can be calculated.

$$\text{X-x dir} = \frac{D_T}{H_{Tot}} = \frac{0.376}{30.6} = 0.0122$$

$$\text{Y-y dir} = \frac{D_T}{H_{Tot}} = \frac{0.384}{30.6} = 0.0125$$

Based on ATC-40, the total displacement of x-direction is 0.0122, and the y-direction of 0.0125 is included in the Damage Control performance level.

In the CSM method, the displacement target value is obtained in software using ATC-40 with the value in the x-direction of 0.345 m and the y-direction of 0.352 m. The level of performance in the structure can be calculated as follows.

$$\text{X-x dir} = \frac{D_T}{H_{Tot}} = \frac{0.345}{30.6} = 0.0112$$

$$\text{Y-y dir} = \frac{D_T}{H_{Tot}} = \frac{0.352}{30.6} = 0.0115$$

Based on ATC-40, the x-direction and y-direction are categorized as Damage Control performance levels. The performance level in both DDBD and CSM methods shows the results of damage control with a target value that is not much different. The level of performance on damage control, according to ATC-40, is a building with a level of performance that is still able to withstand earthquakes that occur, and the risk of human casualties is minimal. In the DDBD method, with the level of life safety plan performance and damage control performance categories obtained, the structure has not yet reached the design performance target but has approached the design performance value with a higher level of performance.

4. CONCLUSION

In this research, it has been explained about the results of the analysis in the Direct Displacement Based Design (DDBD) and Capacity Spectrum Method (CSM) methods in buildings with special moment-resisting frame systems. It can be concluded that.

1. The value of story drift and displacement in the DDBD method is higher than in the CSM method.
2. Design using the DDBD method produces more wasteful buildings because the reinforcement ratio in the DDBD method is more significant when compared to the reinforcement ratio in CSM. However, the more excellent reinforcement ratio in the DDBD method makes the building safer than the CSM method.
3. The failure mechanism by using these two different methods results in the same collapse pattern, namely the plastic hinge first occurs in the structural elements of the beam then the column, which means the building complies with the Strong Column-Weak Beam system. The failure mechanism is also following a suitable collapse mechanism, the beam - sway mechanism.
4. Designing using the DDBD and CSM methods shows the level of Damage Control. In the DDBD method, with the level of performance of the Life Safety plan and the performance category obtained by Damage Control, the structure has not yet reached the design performance target but has approached the design performance value with a higher level of performance.

5. ACKNOWLEDGEMENT

The author is grateful to P3M of Politeknik Negeri Jakarta for funding this research through the BTAM program.

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