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Comparison Of Pushover Method And Direct Displacement Method In Earthquake Load Analysis With Performance-Based Design Concepts

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ABSTRACT

The development of earthquake-resistant building designs led to developing an analysis method for earthquake loads, one of the performance-based methods. This method uses structural displacement as an approach. The purpose of this analysis method was to guarantee the structure's performance so that it will be able to withstand forces due to earthquake loads. In this paper, an analysis of the design of a building structure was more reliable with applicable regulations in Indonesia and determined building performance based on FEMA 356. The study was carried out using the direct displacement method and the pushover analysis method, with the displacement targets and structure performance levels being compared with each other. Based on these results, it can conclude that the use of the direct displacement method and pushover analysis can produce almost the same displacement target values and structure performance levels. Comparison using pushover analysis design performance targets can be fulfilled so that the Direct Displacement Based Design Method can be used in structures. Where the total displacement value of the x-x (δT) direction is 0.300 m, and the y-y course is 0.115 m.

1. Introduction

With the complexity of the earthquake load problem due to the asymmetrical shape, civil engineering construction experts always try to create a system regarding earthquake-resistant buildings. Several earthquake load analysis methods have been applied using the equivalent static method and the spectrum response method. Earthquake-resistant materials are an alternative, especially materials with high elasticity, such as bamboo [1]. However, the selection of materials still prioritizes building functions. Materials with low ductilities, such as concrete, are still optimally used by paying attention to the work process not to suffer damage

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if they experience bending [2][3].

Various construction materials need to be analyzed to perform structural elements to withstand dead loads and live loads, especially earthquake loads. The magnitude of earthquake load was strongly influenced by the type of soil and rock in which the building, mostly if the building were built on slopes, would be highly threatened by ground motion [4][5][6].

The hazards to earthquake loads were challenging to predict because the earthquake source is very dependent on the distance and depth. It also depends on the spatial conditions that give rise to a safe number at the location to be built [7][8]. Highly recommended analysis of buildings' resistance due to earthquake loads using an equivalent static method or a response spectrum. Specifically, for structure elements with reinforced concrete, the equivalent static method was preferable because reinforced concrete has a massive weight of its own [9].

The performance-based design concept, which adopts structural displacement as its approach, emphasizes the structure's performance during an earthquake response. The level of damage to the building during the earthquake response illustrates how much the structure [10]. Several calculation methods usually carry out Performance-based design, one of which is the Direct Displacement Based Design (DDBD) method, to predict how much the design shear force will be given to the building during an earthquake to achieve the desired structural performance [11].

This study aims to analyze the structure's performance to ensure that it can withstand forces due to earthquake loads. The use analysis begins with planning the building structure design by regulations; SNI 1726: 2012 and SNI 2847: 2013 and building performance categories based on the pushover analysis results at FEMA 356 [12] and carried out The study on the Sanur Village Hotel project with 50 bedrooms, a restaurant, a swimming pool and spa, structural materials with reinforced concrete and materials. Roof using steel.

2. Literature Review

The pushover analysis indicates that the maximum lateral load is 551.601 ton at the 10^{th} step. Base shear (Vt) obtained from the performance point is 477.508 ton, displacement at 6^{th} step was 0,054m > 0.032m (Dt), and structural performance wasn't more than the life safety (LS) limit, the maximum total drift is 0.006, and maximum inelastic drift is 0.004 [13]. Pushover analysis can be a good alternative to non-linear time history analysis if some improvements are made, particularly Soil-Structure Interaction [14]. Due to the earthquake load from masonry, it is necessary to reinforce the columns and support the floor slabs so that the

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structural response results show good performance with the structural elements. But sometimes, the repair options have no relevance at all [15].

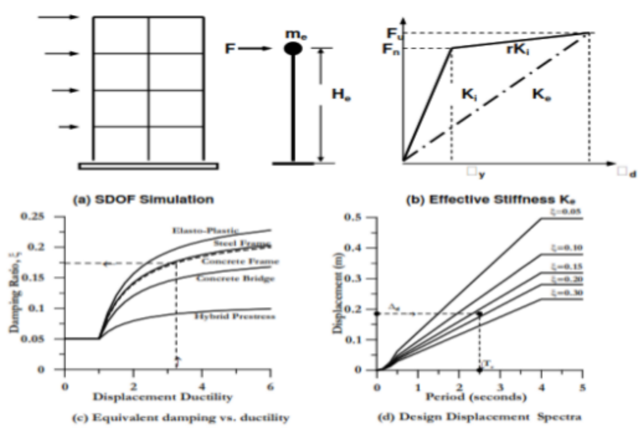
2.1 Structure Performance

The structural performance was the performance of a structure against a planned earthquake [16]. Soil layers and geological conditions greatly influenced the performance to support the construction to be built [17]. It can determine the structural performance level by looking at the structure's damage when a planned earthquake hits it with a specified return period. Therefore it will always relate the level of structural performance to the cost of repairing the building. Load due to vibration followed by high rain intensity causes the soil layer's erosion, especially silt or sand that wasn't dense [18][19].

The building's weight, which includes all the equivalent static loads acting on the construction or part of the building that mimics the effects of ground motion due to the earthquake, will determine its performance. Analysis of buildings in 3 dimensions using the response spectrum analysis method, where the building is subject to the planned earthquake response's acceleration spectrum, was calculated according to the earthquake spectrum response diagram [20].

2.2 Direct Displacement Based Design Method (DDBD)

The ability of a structure to deform in its elastic response is directly related to system stiffness, but for inelastic structures, the relationship will be complicated so that it will depend on the instantaneous displacement as well as the history of displacement during the earthquake response [21][22].



Source : Priestley et al., 2007

Figure 1. Direct Displacement Based Design Concept

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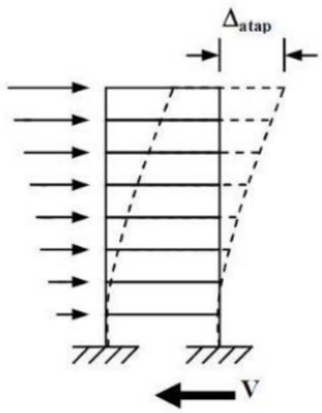
The DDBD method emphasizes displacement value to determine the strength needed by the building against the design earthquake. The fundamental difference between the DDBD method was that the structure would be designed by The Single Degree of Freedom (SDOF) to represent the peak displacement response's performance, not by the first elastic characteristics.

2.3 Static Non-Linear Pushover Analysis

Pushover static analysis was a non-linear static analysis due to the earthquake plan's effect on building structures. It increased the static load acting on the center of the mass on each floor until it caused the building structure's first meeting. The addition of a further load causes a significant change in the elastoplastic shape until it reaches a condition on the verge of collapse [14].



Source : Kholilur, Rosyid R, 2009

Figure 2. Lateral Forces in Pushover Analysis

The capacity curve obtained from pushover analysis illustrates the strength of the structure, which very much dependent on the moment-deformation capability of each structural component. As shown in **Figure 2**, the easiest way to make this curve is by gradually pushing the structure and noting the relationship between the base shear and the roof's displacement due to lateral loads applied to the structure with a specified loading pattern [23].

2.4 Plastic Joint Behavior

The building structure receives an earthquake load at a certain level or condition; a plastic hinge joint will occur on the beams. Plastic joints were a form of beam and column structural elements' inability to withstand internal forces [24][25].

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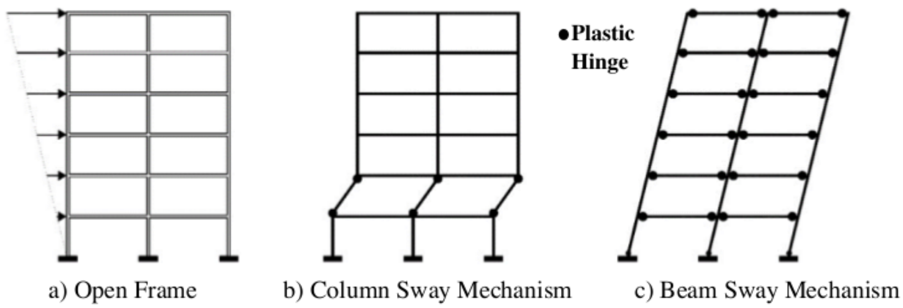
Must design Building structure planning with the strong column and weak beam (SCWB); with this concept, if the building collapses, the beam structure will collapse first while the column will remain standing. Logically, the SCWB principle will cause the structure to sway according to the beam sway mechanism, as shown in **Figure 3**. In SCWB, the beams are deliberately made slightly weaker than the columns. Therefore if exceeded the load level, plastic joints generally occur at the ends of the beam and the lower end of the column at the ground level. These are the places where the detail of the reinforcement was designed and installed properly to become a ductile element [11].



Source : *Widodo, 2012*

Figure 3. Collapsing Mechanism on an Open Frame

The capacity curve provides an overview of the structure's behavior starting from the stage of the building's elastic condition with maximum horizontal irregularity to non-elastic regularity, which was called the structural performance level [26]. Can do the completion of the structural performance evaluation by modifying the linear elastic response of the SDOF system which was equivalent to the coefficient factors C0, C1, C2, and C3 so that the maximum global displacement (elastic and inelastic) obtained which called the "displacement target" [27].

3. Research Method

We carried out the study and analysis method by modeling the structure using ETABS software in 3D, such as plates, beams, and columns, which are then given loads and combined using linear elastic analysis, which then analyzed to get the forces acting on the structural elements. Carried out based on the primary shear force design analysis on the displacement design model based on the Direct Displacement and Response Spectrum method without any loading. The value of the primary shear force on the structure obtained.

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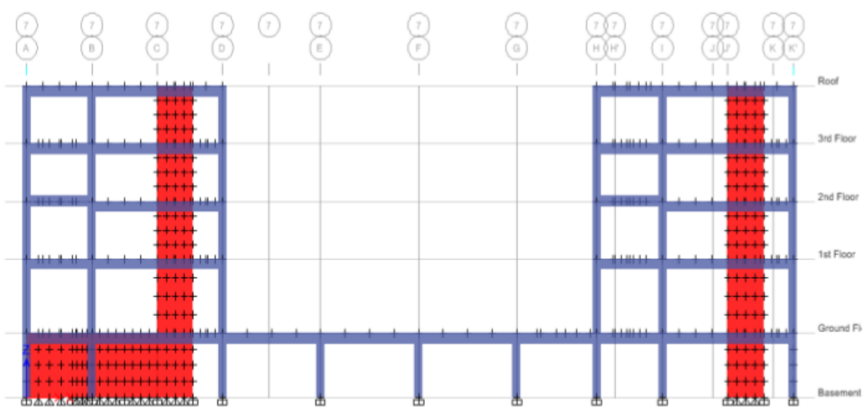
3.1 Structural Modeling

Modeling and structural analysis were performed using ETABSv16 and SPcolumn software. The parameter data in planning are; 1) The function of the building was a hotel; 2) The height of the building is 13.5 meters; 3) Located the planning location was in Sanur, Bali; 4) Soil type is medium soil; 5) Number of floors: one Basement and four Floors; 6) Structural system: Dual System (Frame system and shear walls); 7) The structural material is reinforced concrete; 6) The quality of f'c concrete is 30 MPa; 7) Quality of steel reinforcement: fy = 400 MPa, for Ø ≥ 10 mm, fy = 240 Mpa, for Ø <10 mm.

Carried out The analysis on non-linear static analysis (Pushover analysis) and plastic hinge modeling using the auto hinge already in the ETABS. The frame system was planned as a Special Moment Bearer Frame Structure system (SRPMK). The analysis refers to the applicable Indonesian regulations in planning and analysis; 1) SNI 2847/2013 concerning Structural Concrete Requirements for Buildings; 2) SNI 1727 the Year 2013 concerning Minimum Load for Designing Buildings and Other Structures; 3) SNI 1726 of 2012 concerning Earthquake Resistance Planning Procedures for Building and Non-Building Structures; 4) FEMA 356 the Year 2000 regarding Prestandard And Commentary for The Seismic Rehabilitation Of Buildings.

3.2 Structural Analysis Steps

The process begins with collecting planning data and then modeling, as shown in **Figure 4**, by formulating the initial structure's dimensions, modeling the 3D structure **Figure 5**.



Source : ETABSv16, 2020

Figure 4. Structure modeling

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The steps in overall structural planning were as follows:

1. Collect and determine the data needed in the plan, such as image data, structure data, structure material data, soil data, loading data, and loading combination data.
2. Determine the dimensions and shape of structural elements at the beginning of planning. These include plates, beams, columns, and foundations, which are then controlled following the provisions of SNI 2847: 2013.
3. 3D structural modeling is shown in Figure 5 using the ETABS software, then given a load and combined using linear elastic analysis, then analyzed to obtain internal forces.
4. We plan the displacement design based on the Direct Displacement method and using the Earthquake Response without any loading. The value of the primary shear force on the structure was obtained later.
5. Calculating the loads that burden structural elements such as dead loads, live loads, earthquake loads, and wind loads by SNI 1726: 2012, SNI 1727: 2013 and PPIUG-1983, then combined SNI 1727: 2013.
6. The analysis process was carried out on the ETABS software to find the value of the internal forces that occur in the structure and design the dimensions of structure elements and reinforcement, such as plates, beams, columns, and foundations by the provisions in SNI 2847: 2013.
7. We are creating a case pushover non-linear static curve with a pushover rate-setting scheme, which will later be applied to the structure to obtain the capacity curve's value.
8. To obtain the structure's yield behavior value and the effective lateral stiffness of the structure, the FEMA 356 Control Evaluation will produce a building category at the structural performance level.

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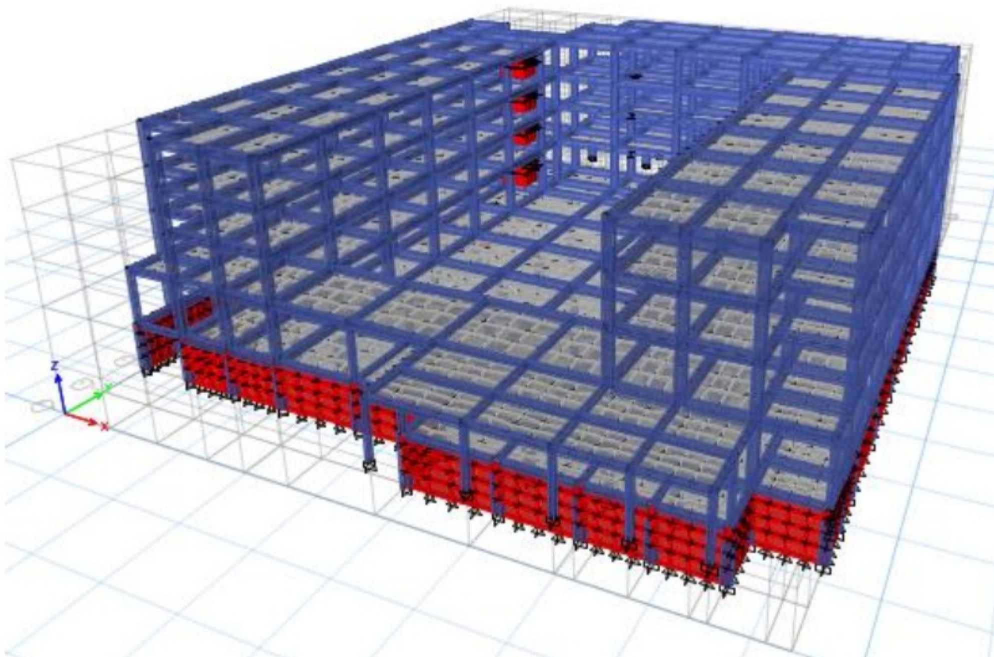

Source : ETABSv16, 2020

Figure 5. 3D View of Building Structure

4. Results and Discussions

4.1 Basic Shear Force Design

The displacement design with the target structure performance level was damage control, so the results of the displacement from the SDOF system are as follows: SDOF x-direction displacement design

$$\Delta dx = \frac{\sum_{i=1}^{n}(m_i {\Delta_i}^2)}{\sum_{i=1}^{n}(m_i \Delta_i)} = 0.157 \text{ m}$$

y-y direction SDOF displacement design

$$\Delta dy = \frac{\sum_{i=1}^{n}(m_i {\Delta_i}^2)}{\sum_{i=1}^{n}(m_i \Delta_i)} = 0.139 \text{ m}$$

The amount of the basic shear force that occurs in the x-x direction and in the y-y direction can be calculated based on the magnitude of the displacement value with the effective stiffness value.

Vbase-x = Ke x Δdx = 9,125.75 kN

Vbase-y = Ke x Δdy = 10,223.36 kN

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4.2 Detailing of Structural Elements

Carried out the detailing of structural elements based on SNI 2847: 2013 regulations with the results as shown in **Table 1**, **Table 2**, **Table 3**, **Table 4**.

Table 1. Reinforcement Details of floor slab and shear wall.

Floor Slab		Shear wall	
Plate thickness`	140 mm	wall thickness	250 mm
Middle reinforcement	Ø10 – 150	Middle reinforcement	D16 – 150
Joint reinforcement	Ø10 – 150	Transversal reinforcement	Ø10 – 200
Share reinforcement	Ø8 – 150	Special bounding element	Not required

Source : Analysis (2020)

Table 2. Beam Reinforcement Details.

BEAM B1		BEAM B2	
Dimension	350/600 mm	Dimension	350/500 mm
Middle reinforcement	2 D22 + 6D19	Middle reinforcement	8 D19
Joint reinforcement	2 D22 + 7D19	Joint reinforcement	8 D19
Torsion reinforcement	2 D16	Torsion Reinforcement	2 D13
Shear Reinforcement	Ø10 – 100, Ø10 – 250	Shear Reinforcement	Ø10 – 85, Ø10 – 200

Source : Analysis (2020)

Tabel 3. Detail Penulangan Kolom.

COLUMN K1		COLUMN K2	
Dimension	500/500 mm	Dimension	400/400 mm
Main reinforcement	16 D22	Main reinforcement	12 D22
Shear Reinforcement	3 Ø13 – 100, 3 Ø13 – 130	Shear Reinforcement	Ø13 – 100, Ø13 – 120

Source : Analysis (2020)

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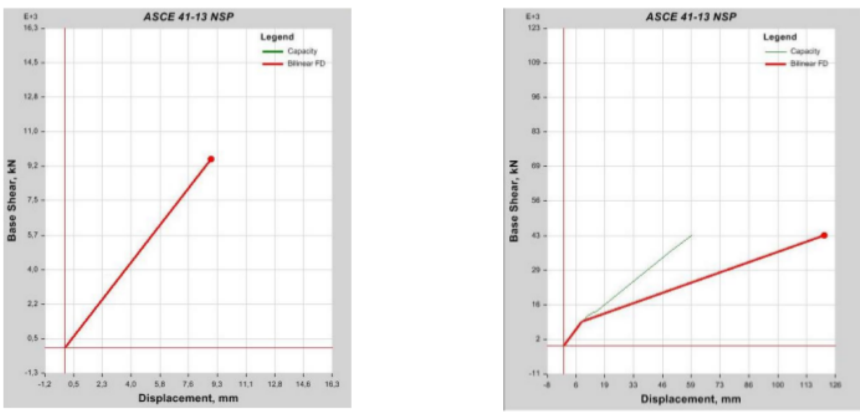
Table 4. Details of Foundation Reinforcement.

Footplate Foundation		Raft Foundation	
Dimension	2000/2000 mm	Dimension	48000/48000 mm
Foundation thickness	400 mm	Foundation thickness	500 mm
Upper Reinforcement	D13 - 200	Upper Reinforcement	D13 - 200
Lower Reinforcement	D19 - 200	Lower Reinforcement	D16 - 200

Source : Analysis (2020)

4.3 Pushover Analysis Based on FEMA356

The results of the pushover analysis carried out with the help of Etabs software obtained a capacity curve, as shown in **Figure 9**:



a. x-x direction

b. y-y direction

Source : ETABSv16, 2020

Figure 6. Bilinier Curve

Based on the pushover analysis curve of Figure 6, made the biliary idealization curve of the capacity curve as a calculation of target displacement. Based on Figure 9 (a), the yield displacement value is 0.009 m, and the shear force at melting, Vy = 8,974.78 kN. Then, calculate the total displacement based on FEMA 356 to obtain the total displacement value, δT of 0.300 m.

Based on the pushover analysis curve, a biliary idealization curve is made from the capacity curve to calculate the target displacement. Based on Figure 9 (b), the yield displacement value is 0.121 m, and the shear force at melting, Vy = 9,126.22 kN. Then proceed with calculating the total displacement based on FEMA 356, so that the total displacement value, δT, is 0.115 m.

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4.4 Comparison of the DDBD Method with FEMA 356

The comparison of the results from the direct displacement method and the pushover analysis method based on FEMA 356 was tabulated as follows:

Table 5. Comparison of the Results of DDBD Plans with FEMA 356

Direction	Parameter	Target DDBD	Pushover FEMA 356
x-x	displacement target	0.157	0.300
	Drift Actual	-	0.0176
	Performance level	Damage Control	Damage Control
y-y	Displacement target	0.139	0.115
	Drift Actual	-	0.0068
	Performance level	Damage Control	Immediate Occupancy

Source : Analysis (2020)

Table 5 shows the value for each direction of the pushover analysis results with the FEMA 356, resulting in a displacement target value almost close to the planned value with DDBD. This means that the overall structure is in the damage control performance category. With the performance level of the damage control design, the structure has reached the design performance target.

5. Conclusion and Suggestion

5.1 Conclusion

Planning and detailing the dimensions of reinforced concrete structural elements used in this structured planning with a performance-based earthquake design concept with the direct displacement method can be meet the conditions of "Strong Column Weak Beam" with the special moment bearer frame structure method. The results of the planned performance of the structure using the direct displacement method with the performance target of the damage control design, by comparison, pushover analysis, the design performance targets can be met so that the direct displacement-based can use design method on structures where the total was based on pushover total displacement values x-x (δT) was 0.300 m, and the y-y direction was 0.115 m.

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5.2 Suggestion

The direct displacement method can be an alternative as a performance-based structure calculation method by observing the structure's behavior from the magnitude of displacement that occurs. Although it can be an alternative method of structural calculation, it takes a longer time to perform calculations than using a force-based method

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