Comparative study of structural response on multi-story buildings with shear wall and bracing systems

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Abstract. Multi-story buildings are designed to withstand lateral forces against earthquakes. There are several ways to strengthen multi-story building structures. One way is to add a dual system, namely the shear wall or the bracing systems. Shear walls and bracing techniques can resist earthquake forces in vertical and horizontal directions that occur in building structures. This study compares the results of the structural analysis to three structural models. The 10-story of the structural response used in the research includes the story drift, base shear, displacement, and structural behavior due to the earthquake force. Model 1 is a general structure without the shear wall and bracing systems, Model 2 is a structure completed with L-shear walls, and Model 3 is a structure installed with the X-bracing system. The analyses of three Models were carried out by SAP2000 software. The results show that the slightest interstory drift occurs in Model 2, namely 0.041 mm. The decrease in deviation value that arises in Model 2 is 12.6 mm, with 34.35%. In Model 1, the story drift exceeds the allowable limit, so that with such a model, it is not feasible. Therefore, it is necessary to add shear walls or a bracing system.

1. Introduction

Geographically, Indonesia is also a meeting point between 4 plates: the Eurasian, Philippine, Pacific, and Indo-Australian plates. Geographically and geologically, this condition causes the area of Indonesia to be frequently hit by earthquakes. One of the civilian buildings that were greatly affected by the quake was a multi-story building. The impact that occurs due to earthquakes on multi-story buildings is on the structural design of the building. Therefore, in designing the structure of a multi-story building, the structural engineer must pay special attention to the structural model applied in its design to meet the standards set out in the related SNI 1726 [1]. Furthermore, the selection of the structural system must be adjusted to the needs of the building, for example, the function of the building, the location of the building, environmental conditions, history of earthquake disasters, and other essential factors. Therefore, a multi-story building structure should be designed by considering earthquake loads in the design process will provide structural elements to be more vital to withstand these temporary loads and give a sense of security for the occupants [2-5].

To produce the best structural system in a particular building is strongly influenced by many factors, including architectural and functional requirements, labor, fabrication, construction costs, and other technical aspects. Consequently, there are so many problems that it is impossible to solve them in one rule. Concerning this system, ASCE 7 places strict requirements on the types and heights of structural systems that can be used for earthquake-resistant designs, for example, the application of multiple systems [6].

A perfect building design can provide extra strength to withstand earthquake forces by adding a shear wall or bracing system to the main structure [7-8]. Shear walls are not common but structural elements
designed to resist lateral forces caused by an earthquake [9-11]. Shear walls play a constructive role in multi-story buildings. Bracing is a structural element to resist lateral forces. The bracing system is in the form of a typical rod that is attached to the structure frame. When an earthquake occurs, the lateral force received by the structure will be transmitted to this bracing element as an axial force [12]. Various models of bracing systems have been commonly applied in the field for both medium and high-rise buildings as dual systems. The type of tethering is very much influenced directly by many factors: building plans, structural geometry, building location, earthquake area/zone, soil conditions, and others. This paper presents the comparative study of structural responses on three structural Models consisting of a general frame, two dual system models using a combination of L-shear wall and X-bracing systems subjected to simulated earthquake loads [13].

2. Irregularity Buildings and Dual System Structures

2.1. Horizontal Irregularity
According to SNI 1726-2019 [3] article 7.3.3, building structures can be regular and irregular frames. This grouping is based on the configuration of the structure both horizontally and vertically, referring to SNI 1726-2019 Table 13 and SNI 1726-2019 Table 14. Horizontal irregularities can be identified according to the characteristics of the structure, such as irregularity in torsion, inner corner, and diaphragm discontinuity.

Lateral loads can cause torsion on the building when the lateral load tends to rotate the building with vertical direction causes torsional moments. Torque also be caused by torsion occurring in the section perpendicular to the principal axis of the element [14]. Another possibility of torsion occurs when the load center of mass does not coincide with the center of rigidity of the component resulting in eccentricity, affecting the stability of the structure's resistance system. Re-entrant corner irregularity is defined as the two dimensions of the structure plan projection from the internal corner location that is greater than 15% of the dimension of the structure plan in the direction under review. In addition, diaphragm irregularities are identified as a diaphragm that experiences sudden discontinuities or variations in stiffness, including diaphragms that have a cut or open area greater than 50% of the gross diaphragm area closed [3].

2.2. Vertical Irregularity
In general, vertical irregularity can be identified based on mass and vertical geometry irregularities. The mass irregularity is well-defined if the effective mass at any level is more than 150% of the effective mass of the nearby level. In comparison, the vertical geometry irregularity is determined as existing if the horizontal dimension of the seismic force bearing system at any level is more than 130% of the seismic force bearing system's horizontal dimension [3].

2.3 Interstory Drift
According to SNI 1726-2019 article 7.8.6 [3], interstory drift or lateral deflection between design levels (Δ) can be calculated as the difference in the deviation at the center of mass above and below the reviewed level [18]. Therefore, the determination of the interstory drift can be measured in Figure 1 [6].

Several techniques can be adopted to design frame structures to anticipate excessive interstory drift in multi-story buildings, such as using a dual system combined with shear wall and bracing systems [13, 15-16]. In this study, three structural models were proposed to analyze structural responses of a 10-story building under simulated earthquake loads. The study's objective is to compare the proposed models of a dual system in resisting applied loads. Based on the three-dimensional modeling of the three frame models, the analysis was carried out using SAP2000 software to perform the structural performance of each model depending on the configuration of the shear wall or bracing systems. A complete dual system configuration is outlined in Figures 4-6, respectively.
2.4 Dual System

1. Shear wall
States that the dual system combines lateral load-bearing systems in shear walls or bracing frames with a moment-bearing frame system [17-18]. Shear walls play a constructive role in multi-story buildings besides preventing the failure of exterior walls, and shear walls can also help prevent structures from collapsing. The shear wall limitation refers to SNI 2847-2019 in article 14.3.3.1 with a minimum thickness of 140 mm and a wall thickness of at least 1/24 of the most extended beam [3-4]. States that structures with the placement of shear walls in the direction of the earthquake load or along the x and y axes are more robust to withstand lateral loads [3]. The location of shear walls was placed on maintaining symmetry and the central point of the building mass [4]. The optimum placement of shear walls was placed on the outer side of the building and in the x and y axes [5].

2. Bracing
A bracing system is one of the dual systems used in the building to withstand the lateral forces occurred. In a multi-story building, the structure's stiffness needs to be increased by providing an attachment system to the building [17-18]. In practice, there are two groups of bracing systems commonly used to reduce interstory drift, such as a concentric bracing frame (CBF) and an eccentric bracing frame (EBF). Figure 2 presents typical CBF models comprising diagonal braced, inverted V-braced, V-braced, X-braced, and K-braced. Another bracing system of the EBF is shown in Figure 3, consisting of diagonal braced, split-K-braced, and V-braced.

The use of the bracing system is regulated in SNI 1726-2019 article 7.2.2 to provide restrictions of using too many. In addition, the frames in the structure can withstand at least 25 percent of the lateral load [3]. Therefore, choosing the proper form of the bracing system will help to resist the lateral forces efficiently. There are many types of bracing systems depicted in Figures 2 and 3. The most effective bracing system can be selected by conducting research and simulated numerically with various bracing systems such as types Z, X, V, and Λ. A previous study indicates that the building designed with the type X-bracing system has the highest rigidity [6]. Given this reason, the X-bracing was selected and adopted in this study to compare the structural responses on multi-story buildings with a variety of shear wall and bracing systems under simulated vertical and lateral loads.
3. Materials and Methods

3.1 Structural Model

The research object uses a model of reinforced concrete frame structures with horizontal irregularities in the inner corners (Figure 4). The building height is 31.5 meters comprising ten floors, and the level height is 3.5 meters. This study utilizes three structural models described in Table 1 and Figures 4-6.

| Model | Earthquake Resisting Structure                  | Description |
|-------|-----------------------------------------------|-------------|
| 1     | An ordinary frame (without shear wall and bracing) | Figure 4    |
| 2     | Frame with L-shear wall                        | Figure 5    |
| 3     | Frame with X-bracing                           | Figure 6    |

Figure 4 presents a complete building plan used as a basic model of a dual structural system and adopted in the analysis. In the study, the three-dimensional system was adopted to model the building geometry. In each model analysis, the building structure was simulated to withstand the combined loads and the structural performance such as lateral deflection, drift ratio, and interstory drift. Table 2 outlines the building geometry adopted in overall analyses.
Figure 5. Building plans using shear wall shear wall (Model 2)

Figure 6. Building plans using bracing (Model 3)

Table 2. Building geometry

| No  | Parameter                  | Description                  |
|-----|----------------------------|------------------------------|
| 1   | Building function          | Apartment                    |
| 2   | Building location          | Padang                       |
| 3   | Subgrade type              | Medium                       |
| 4   | Number of story            | 10                           |
| 5   | Height between floors      | 3.5 meters                   |
| 6   | Building height            | 31.5 meters                  |
| 7   | Building length X-direction| 50 meters                    |
| 8   | Building length Y-direction| 19 meters                    |
| 9   | Building Area              | 950 m²                       |
| 10  | Structure Type             | RC Structure                 |
| 11  | Structure system           | Dual System                  |
| 12  | Concrete strength          | 25 MPa                       |
| 13  | Concrete beam and Column strength | 27.5 MPa           |
| 14  | Reinforcement steel strength d ≤ 12 mm | 370 MPa            |
| 15  | Reinforcement steel strength d > 12 mm | 420 MPa            |
4. Results and Discussion

4.1 Lateral Deflection
Displacement in the building structure model caused by differences in the stiffener structure used is as follows.

![Figure 7. Lateral deflection in the X-direction](image1)

![Figure 8. Lateral deflection in the Y-direction](image2)

In the analysis results above, the lateral deflections from the three models have a significant difference. This condition is due to Model 2, and Model 3 has lesser lateral deflection than Model 1 (without using shear walls and a bracing system). This condition indicates that using a rigid structure such as a shear wall or a bracing system in this building model reduces the displacement value [1, 9-10]. Therefore, the model with the most optimum displacement value is Model 2, which compares Figures 7 and 8.

4.2 Drift Ratio
Drift ratio is the deviation between floors divided by the floor height in the building. The drift ratio calculation in this study is depicted in Figures 9 and 10.

![Figure 9. Drift ratio in the X-direction](image3)

![Figure 10. Drift ratio in the Y-direction](image4)

The drift ratio shows the nature of the building being analyzed is rigid or flexible. The smaller the drift ratio value, the stiffer the building is designed. Based on the above analysis results, giving a rigid
structure to a building makes the system more rigid. This condition is indicated by the results of the drift ratio Model 1 (without using shear wall and bracing) is more significant than Model 2 and Model 3. On the other hand, Model 2 is an effective stiffener structure compared to the other two Models. Because Models 2 and 3 are added rigidity (shear wall and bracing), the building will automatically be stiffer [7].

4.3 Interstory Drift

The interstory drift is formulated as a displacement between two floors that occurs due to lateral force on a building. According to SNI 1726-2019, the interstory drift (Δ) in a building must not exceed the calculated allowable drift [18]. The calculations between floors are shown in Figures 11 and 12.

Based on the graph above, it can be concluded that the deviation between floors in Model 1 (without using shear wall and bracing) exceeds the permitted limit. It is observed that this research building must be given a stiffener structure so that the deviation between floors does not exceed the permissible limit so that this building is shown a stiffener structure, namely shear wall as in Model 2 or bracing like Model 3. Models 2 and 3 are eligible for the deviation between floors because they do not exceed the permissible limit. The interstory drift in Model 2 is smaller than in Model 3. This result proves that Model 2 is more robust and stiffer than Model 3.

5. Concluding Remarks

1. The lateral deflection with the most effective value is Model 2 (using shear walls) because the analysis results have the slightest difference compared to the other two Models.
2. The comparison of the drift ratio is as follows.
   a. The value of the extreme drift ratio of the three Models is Model 1 (without shear and anchoring walls) of 83%. The optimum drift ratio value occurs in Model 2 (using shear walls) on the same floor, 20%.
   b. In Model 1, there is a significant drift ratio value, so that Model 1 must be strengthened by the addition of structural stiffeners, namely shear walls or bracing systems.
3. The comparison of deviation values between floors is as follows,
   a. The slightest deviation value is found in Model 2 (using shear walls) compared to the others. The decrease in the deviation value in the extreme x-direction between Model 2 (using shear walls) and Model 1 (without using shear walls and bonding systems) is 12.6 mm with a percentage of 34.35% smaller.
   b. Model 1 (without shear walls and a bracing system) does not meet the allowable boundaries between floors, indicating that the building structure needs to be strengthened with shear walls or a bracing system.
References

[1] S Kiemberly, R S Windah, and B D Handono 2018 Response of Multi-storey Building Structure with Variation of Column Stiffness due to Earthquake Based on SNI 03-1726-2012 Civil Static Journal, Vol.6, No.6, Universitas Sam Ratulangi, Manado.

[2] PPURG 1987 Loading Design Guidelines for Houses and Buildings, Publishing Agency Foundation, PU, Jakarta.

[3] Standar Nasional Indonesia 2019 Procedures for design earthquake resistance for building and non-building structures, SNI 1726, Jakarta.

[4] Standar Nasional Indonesia. 2013 Structural concrete requirements for buildings and explanations. SNI 2847. Jakarta.

[5] Standar Nasional Indonesia 2013 Minimum load for designing buildings and other structures, SNI 1727, Jakarta.

[6] F A Charney 2015 Seismic loads guide to the seismic load provisions of ASCE 7-10, the American Society of Civil Engineers, USA.

[7] S G Hutahaeen, Aswandy 2016. Study of the Use of Shear wall and Bracing in High-rise Buildings, Journal of Civil Engineering Department, Itenas Vol.2, No. 4. Bandung.

[8] L Fauziah, M D J Sumajouw, S O Dapas, R S Windah 2013 Effect of shear wall layout and position on the deviation of multi-story reinforced concrete buildings due to earthquake loads, Civil Static Journal, Vol.1 No.7 Juni 2013 (466-472), Universitas Sam Ratulangi, Manado.

[9] H Manalip, E J, Kumaat, F I Runtu 2015 Layout of Shear Walls in Reinforced Concrete Buildings With Pushover Analysis, Media Engineering Scientific Journal Vol. 5 No.1, Universitas Sam Ratulangi, Manado.

[10] G Andalas, Suyadi, H R Husni 2016 Shear wall Layout Analysis on Building Structure Behavior Journal of Civil Engineering Department, Faculty of Engineering, Universitas Lampung.,

[11] A Kurnia, S H Dewi, M Kurniawan 2018 Effect of Shear Wall Position on Structure Performance in Irregular Buildings Using Response Spectrum Method, Scientific Journal, Vol.18, Nomor 1, Universitas Islam Riau, Riau.

[12] D Aryandi, B Herbudiman 2017 The Effect of Bracing Form on the Performance of Reinforced Concrete Structures. Bandung: Jurnal Online Institut Teknologi Nasional.

[13] S Haryono, D Arumningish, D.Purnamawanti 2015 Use of Type X Concentric Bracing Structures to Improve Performance of Multi-story Building Structures Against Lateral Loads Due to Earthquake. Journal of Civil Engineering and Architecture UTP Vol. 16, No. 20, Surakarta.

[14] N K Astariani 2010 Torque effect on building, Ganec Swara, Special edition Vol.4 No.3, Faculty of Engineering, Universitas Ngurah Rai Denpasar, Denpasar,

[15] A A. Mondal, G B Bhaskar, D Telang 2017 Comparing the effectof Earthquake on Shear Wall Building and Non-Shear Wall Building – A Review, International research journal of engineering and technology (IRJET), India

[16] M D P Putra 2018 Comparison of Horizontal "L" Shaped Irregular Building Structures Against the Condition of Rigid Floor Flexuran Floor System, and Sliding Wall System, Universitas Muhammadiyah Sumatera Utara, Medan.

[17] Z A Siddiqi, R Hameed, U Akmal 2014 Comparison of Different Bracing Systems for Tall Buildings, Journals Pak. J. Engg. & Appl. Sci. Vol. 14, Jan., 2014 (p. 17-26), Lahore,

[18] Viswanath K.G, Prakash K.B., dan Anant Desai. 2010. Seismic Analysis of Steel Braced Reinforced Concrete Frames. International Journal of Civil and Structural Engineering Vol. 1, No 1, 2010.

[19] V Suwalka, N Laata, B Nagar 2018 Comparative Study and Modelling of Framed Structure with Shear Wall & Without Shear Wall by Using ETABS, International research journal of engineering and technology (IRJET), Vol.5, Jagannath Gupta Institute of Engineering and Technology, India.