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Analysis of the Effect of Bracing on the Performance of Reinforced Concrete Structures in Multi-Storey Buildings

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Abstract

The planning of earthquake-resistant buildings can be done in two ways: either the building is designed to behave elastically during an earthquake or it is designed to behave inelastically during an earthquake. One effort to ensure that a building remains sturdy in the face of an earthquake is by using concentric bracing, which functions as a lateral force restraint on the structure of a construction. This research aims to analyze the effect of using steel profile bracing on the performance of reinforced concrete structures in a three-story building, with Model A representing a building without bracing, Model B with inverted-V bracing, and Model C with cross bracing. Based on data processing and analysis, the results show that the greatest internal forces occurred in the building without bracing, and the moments acting on the beams of the building without bracing were 57.536% larger than those in the building with X-type (cross) bracing and 55.817% larger than those in the building with Inverted-V bracing. The structural performance based on performance-based design for both braced and unbraced buildings was categorized at the immediate occupancy level, as the maximum total drift values obtained for each building were less than 0.01 and the maximum total inelastic drift values were less than 0.005.

Keywords: Multi-story Building, SNI 1726-2019, Bracing, Elastic, Inelastic.

1. Introduction

Earthquakes in Indonesia cause numerous fatalities, physical damage to buildings, and material damage. This situation needs to be minimized, considering that buildings are human habitations. To minimize these losses, it is necessary to design building structures that can withstand the forces caused by earthquakes, thus preventing the building from collapsing until the occupants can escape [6].

One of the areas in Indonesia prone to earthquakes is Padang City. Its direct border with the Indian Ocean makes it one of the most earthquake-prone areas in Indonesia, potentially triggering tsunamis. On September 30, 2009, a 7.6 magnitude earthquake struck, causing extensive damage to high-rise buildings such as hotels, office buildings, shopping centers, and others. To prevent future severe damage from earthquakes, building construction in Padang City requires careful planning.

There are two ways to design earthquake-resistant buildings: either the building is designed to behave elastically during an earthquake, or the building is designed to behave inelastically during an earthquake. The advantage of an elastic structure is that no part of the structure will undergo permanent deformation, but the cross-section of the structural elements used will be much larger. The advantage of an inelastic structure is that certain structural elements will experience yielding or plasticization due to absorbing earthquake energy, and these structural elements will experience plastic deformation, but remain rigid enough to remain standing. So that when a high-intensity earthquake occurs, the building will not experience total collapse . [4]

One of the causes of building collapse is structural instability. When designing a structure, instability is a fundamental factor that must be avoided. This must be considered for various types of building heights. An unstable structure, when subjected to a load, will experience greater deformation than a stable structure. One way to make the structure more stable is to combine the structure with bracing (stiffening elements) [5]. One effort to ensure that buildings remain safe from the impacts caused by earthquakes is to use concentric bracing, which functions as a lateral force retainer that occurs in the structure of a building construction . [1]

Braced frame elements are structural elements placed diagonally on the portal structure, which function to support the portal against lateral loads. [3]. The bracing system can be used to withstand vertical forces such as gravity loads and horizontal forces/lateral forces such as

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earthquakes, so as to prevent excessive shaking of the structure. The use of bracing is also intended so that when an earthquake occurs, the lateral forces that affect the structure are not only resisted by the beam and column elements in the structure but are also resisted by the bracing system. [5].

The use of bracing in multi-story portal structures is considered to increase the stiffness and strength of the building structure, in addition to the use of bracing also tends to be more efficient. Portals with bracing are expected to be earthquake-resistant because bracing has maximum tensile strength. In steel structures, the choice of connection assembly details is a critical factor that cannot be ignored.[2]

Based on the background description above, this study will analyze the effect of using bracing with steel profiles on the performance of reinforced concrete structures in multi-storey buildings using the earthquake spectrum response method. This study will model multi-storey buildings with three different models, namely, model A for buildings without bracing, model B for buildings with Inverted-V bracing, and model C for buildings with Cross or X bracing. So that the results of the study are obtained in the form of a comparison of the ideal bracing form for use in buildings with hospital functions in Padang City.

2. Research methodology

The type of research used to analyze the effect of bracing on the performance of reinforced concrete structures in multi-story buildings is quantitative. The primary data used is as follows.

1. Function of the building : Hospital building
2. Type of structure : Reinforced concrete structure
3. Location : Padang City
4. Soil type : Soft soil

Meanwhile, the secondary data used in this study are as follows:

1. Structural concrete requirements for building structures (SNI 2847:2019)
2. Minimum design loads and related criteria for buildings and other structures (SNI 1727: 2020)
3. Procedures for earthquake resistance planning for building and non-building structures (SNI 1726:2019)
4. Indonesian loading regulations for buildings (PPIUG 1987)
5. Specifications for Structural Steel Buildings (SNI 1729:2020)

2.1. Data Processing Techniques

After the data used to analyze the effect of bracing on the performance of reinforced concrete structures in multi-story buildings was obtained, the data was processed to solve the existing problems and achieve the final objective of this study. The following are the data processing techniques used in this study.

1. Literature Study
   This research is a multi-story building planning study. Three models are compared to determine which building structure performs best under earthquake loads. The models compared are a building with no bracing, an inverted-V bracing, and a cross bracing.

2. Structured Data
   After completing and understanding the literature review, the next step was to determine the structural data. This stage involved comparing the structures of three multi-story building models, with and without bracing. Each of the three buildings has an area of 325 m2 and a height of 20 m (5 stories). Preliminary design was performed for the structural dimensions.

3. Static Loading (Live Load and Dead Load)
   Static loads are permanent loads that work continuously on a structure consisting of live loads and dead loads.

4. Earthquake Loading
   In earthquake loading, the risk category and priority factors of the building will be determined, the seismic design category will be determined, the earthquake load analysis method will be determined, and the lateral force will be calculated.

5. Analysis
   After the earthquake load is calculated, a performance analysis of the structure working on a multi-storey building without bracing and using inverted-V and Cross type bracing will be carried out, which will be assisted by ETABS software.

2.2. Research Flowchart

The following is a flow diagram of the research activities analyzing the effect of the use of bracing on the performance of reinforced concrete structures in multi-storey buildings, as follows.

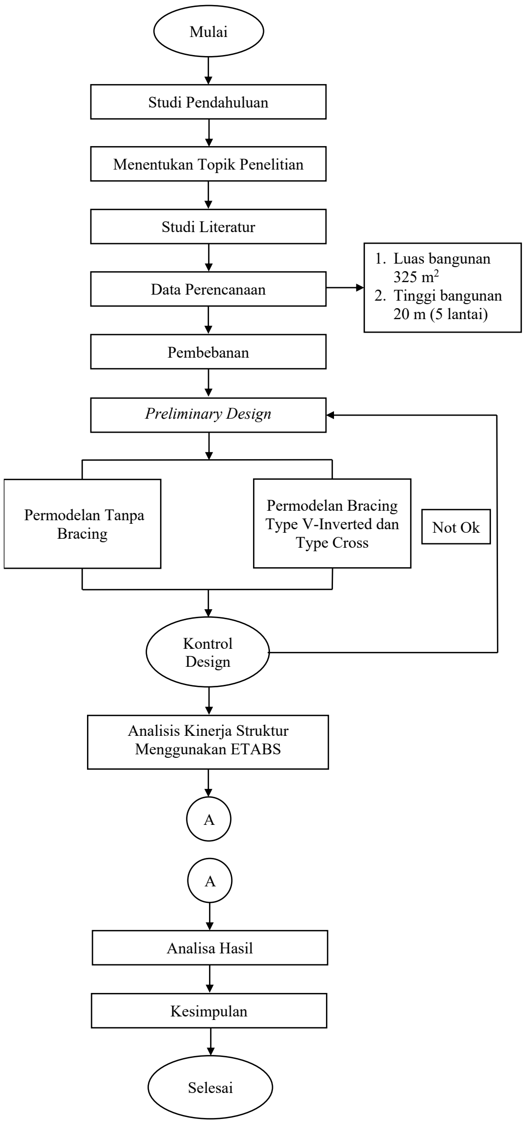

Figure 1. Research Flowchart

3. Results and Discussion

Based on the initial planning dimension data obtained through preliminary design, the structural elements were modeled into a 3D building using ETABS software and analysis was carried out for building control which was modeled using Microsoft Excel.

3.1. Structural Modeling

Structural modeling in ETABS software is carried out in several steps, namely :

1. The grid is created in ETABS according to the building size planning .

2. Input material data based on the planned quality, namely fc' = 25 Mpa or K-300 concrete .

3. Input the dimensions of columns, beams and floor slabs based on the preliminary design data that has been carried out.

4. After inputting the materials and dimensions of the structural elements, modeling is carried out for the three buildings based on the grid that has been created according to the planned building dimensions.

5. Input dead loads, live loads, and earthquake loads according to the collected data. Input load combinations based on SNI 1727-2020 concerning minimum design loads related to building structures.

6. Next, a structural analysis of the building is performed to determine whether the structural elements are adequate. If the control is inadequate, the dimensions of the structural elements are changed and the analysis is repeated.

3.2. Structure Control

After 3D structural modeling is performed using the ETABS program, the structural analysis results must be controlled against certain limits in accordance with SNI 1726:2019 regulations to determine the feasibility of the structural system. The following points must be controlled:

1. Control mass participation
2. Control the structure period
3. Seismic base shear control
4. Control the deviation limits between floors of the structure

From this analysis, the internal forces that occur in each structural element are also taken to check the cross-sectional capacity.

3 . 3. Structural Analysis

1. Analysis of Forces in Beams

Analysis of internal forces in beams is generally performed on each floor of the building. On each floor, the largest internal forces acting on the beams are taken, then a comparison and calculation of the difference ratio between the largest internal forces in the beams acting on each modeled building structure are performed.

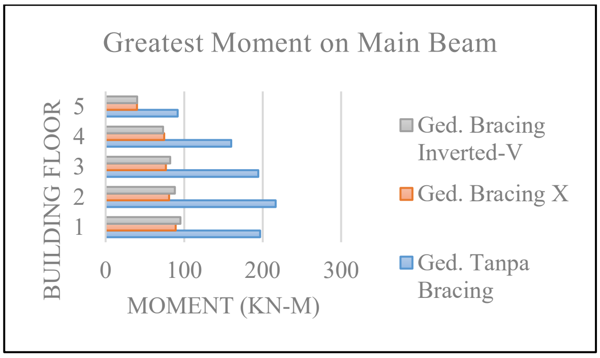

Figure 2. Comparison Graph of the Largest Moments on Beams

2. Analysis of Style in Columns

On each floor of the building, the largest internal forces acting on the columns are taken, then a comparison and calculation of the difference ratio between the largest internal forces on the columns acting on each floor of the modeled building structure is carried out.

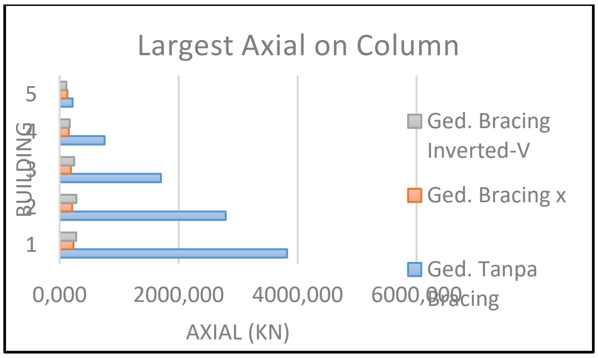

Figure 3. Largest Axial Comparison Graph on Column

Based on the data above, it can be seen that the largest axial force occurs in buildings without bracing with a difference of 79.045% with buildings using inverted-V bracing and 78.868% with buildings using X bracing, this is because buildings without bracing have a greater weight experienced by the columns than buildings using x bracing and inverted-v bracing that are modeled.

In the comparison of the moment in the direction of axis 2, the building without bracing bears a greater moment than the two buildings using bracing with a difference ratio of 96.864% with the building using X bracing which bears a smaller moment in the direction of axis 2 than the building using Inverted-V bracing with a difference of 5.754%.

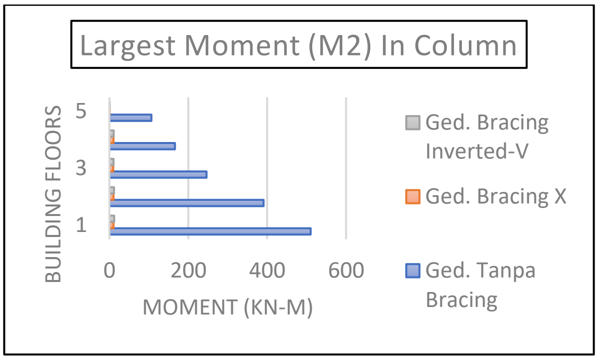

Figure 4. Comparison Graph of the Largest Moment (M2) in the Column

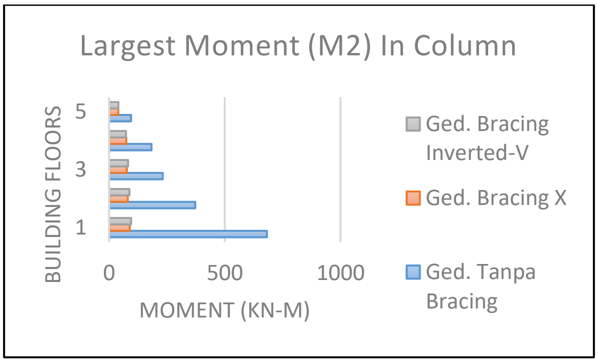

Figure 5. Comparison Graph of the Largest Moment (M3) in the Column

However, at the moment of the 3-axis direction, the building using X-bracing bears almost the same moment as the building using Inverted-V bracing with a difference ratio of only 3.973%. Meanwhile, the building without using bracing bears a greater moment than the building using X-bracing with a difference ratio of 69.881% and 68.952% with the building using Inverted-V bracing.

3. Results and Discussion

A series of research results is arranged in a logical sequence to form a narrative. The content should present facts/data and avoid discussing the results. Tables and figures may be used, but avoid repeatedly describing the same data in figures, tables, and text. Subheadings may be used to clarify the description.

The discussion provides a basic explanation, relationships, and generalizations demonstrated by the results. The description answers the research questions. If any results are questionable, present them objectively.

3.1 . Specification

Use Times New Roman font for all text (except pseudocode) , with the font size as shown. This writing guide has been exemplified. The spacing is *single* , and the text or manuscript uses left-right alignment (*justified*).

3. 4. Comparative Analysis of Structural Performance

Base Shear Comparison

Comparison of base shear or seismic base shear force obtained data that the building without Bracing has the largest base shear force with a difference of 11.903% with the building using X bracing and 10.586% with the building using Inverted-V Bracing. Meanwhile, the building using X Bracing is the building with the smallest base shear force with a difference of 0.057% with the building using Inverted V Bracing.

Table 1. Comparison of *base shear*

	***Base Shear* (kN)**			Selisih TB & BV	Selisih BV & BX	Selisih TB & BX
	TB	BX	BV			
Vx	2903,493	2596,137	2594,655	11,903	0,057	10,586
Vy	2903,493	2596,137	2594,655	11,903	0,057	10,586

**TB : Ged. Tanpa Bracing; BX : Ged. Bracing X; BV : Ged. Bracing V - Inverted*

2. *Displacement Comparison*

In the displacement comparison, the largest deviation occurred in the building without Bracing with a difference of 1.059 mm in the x direction and 1.202 mm in the y direction with the building using Bracing X. While the smallest deviation occurred in the building using Bracing X 0.623 mm in the x direction and 0.725 mm in the y direction with the building using Inverted-V Type Bracing. For buildings without Bracing with buildings using Inverted-V Type Bracing, the difference in deviation that occurred was 0.436 mm in the x direction and 0.477 mm in the y direction.

Table 2. Comparison of X-direction *displacement*

Lantai	***Displacement* (X) (mm)**			Selisih TB & BV	Selisih BV & BX	Selisih TB & BX
	TB	BX	BV			
5	20,725	15,827	16,847	3,878	1,020	4,898
4	13,269	12,7	13,43	-0,161	0,730	0,569
3	9,961	9,864	10,534	-0,573	0,670	0,097
2	6,482	6,534	7,02	-0,538	0,486	-0,052
1	2,741	2,959	3,167	-0,426	0,208	-0,218
Rata-Rata				0,436	0,623	1,059

**TB : Ged. Tanpa Bracing; BX : Ged. Bracing X; BV : Ged. Bracing V - Inverted*

Table 3. Comparison of *displacement* in the Y direction

Lantai	***Displacement* (Y) (mm)**			Selisih TB & BV	Selisih BV & BX	Selisih TB & BX
	TB	BX	BV			
5	23,315	17,34	18,786	4,529	1,446	5,975
4	15,053	14,084	15,168	-0,115	1,084	0,969
3	11,216	10,868	11,788	-0,572	0,920	0,348
2	7,212	7,13	7,762	-0,550	0,632	0,082
1	3,038	3,202	3,471	-0,433	0,269	-0,164
Rata-Rata				0,477	0,725	1,202

**TB : Ged. Tanpa Bracing; BX : Ged. Bracing X; BV : Ged. Bracing V - Inverted*

3. *Drift Ratio* Comparison

The drift ratio comparison is a comparison of the ratio of drift between floors that occurs in buildings using bracing and buildings without bracing, where the ratio in question is the difference in drift between floors in inelastic drift conditions divided by the height distance per floor.

Table 4. Comparison of *drift ratio* in X direction

Lantai	Tinggi Lantai	***Drift Ratio* (X) (%)**		
		TB	BX	BV
5	4000	0,683	0,208	0,228
4	4000	0,303	0,189	0,193
3	4000	0,319	0,222	0,234
2	4000	0,343	0,238	0,257
1	4000	0,251	0,197	0,211

TB : Ged. Tanpa Bracing; BX : Ged. Bracing X; BV : Ged. Bracing V - Inverte

Based on the analysis carried out, the ratio of inter-floor deviation in the x direction in the three modeled buildings is almost the same, but the building without bracing is the building with the largest inter-floor deviation ratio among the three modeled buildings.

Table 4. Comparison of *drift ratio* in Y direction

Lantai	Tinggi Lantai	***Drift Ratio* (X) (%)**		
		TB	BX	BV
5	4000	0,683	0,208	0,228
4	4000	0,303	0,189	0,193
3	4000	0,319	0,222	0,234
2	4000	0,343	0,238	0,257
1	4000	0,251	0,197	0,211

TB : Ged. Tanpa Bracing; BX : Ged. Bracing X; BV : Ged. Bracing V - Inverte

In the ratio of inter-floor deviations in the y direction, the smallest inter-floor deviations occur in buildings using X-type bracing, while the inter-floor deviations in buildings without bracing and buildings using Inverted-V bracing, but on the fifth floor the ratio of inter-floor deviations in buildings without bracing is quite large compared to buildings using Inverted-V type bracing.

4 . ATC 40 Comparison

Table 5. Comparison of Structural Performance Levels Based on ATC 40

Level Kinerja	Arah X	Arah Y
Ged. Tanpa Bracing	*Immediate Occupancy*	*Immediate Occupancy*
Ged. Bracing X	*Immediate Occupancy*	*Immediate Occupancy*
Ged. Bracing Inverted -V	*Immediate Occupancy*	*Immediate Occupancy*

From the table data above, it can be seen that the building without bracing and the building using bracing that has been modeled are included in the immediate occupancy category. This is because the maximum total drift value obtained in each building is smaller than 0.01 and the maximum total inelastic drift value is small from 0.005 in accordance with the structural performance level requirements based on ATC 40. In this category, the condition of the building structure can fully resist the vertical and horizontal base shear forces that occur. Structural damage is very small, the risk of loss of life when damage occurs is very small, and the building can be immediately re-used.

4. Conclusion

The largest internal forces generally occur in buildings without bracing, meaning that the forces acting on buildings without bracing are greater than those on buildings with bracing. Base shear in buildings without bracing is 11.903% greater than buildings using Inverted-V type bracing and 10.586% greater than buildings using X type bracing. 6. In the displacement comparison, the largest deviation occurred in the building without using bracing with a difference of 1.059 mm in the x direction and 1.202 mm in the y direction with the building using type X bracing. Meanwhile, the smallest deviation occurred in the building using type X bracing with a difference ratio of 0.623 mm in the x direction and 0.725 mm in the y direction with the building using inverted-V type bracing. 7. The drift ratio between floors for each building did not show any significant difference. The drift ratio in the X direction was almost the same for each building with an average of 0.379%. However, in the Y direction, buildings using bracing were smaller than buildings without bracing with an average of 0.231% and 0.250%.

3. Further research is needed to analyze the comparative performance of structures in buildings using bracing and buildings without bracing with various bracing forms. The analysis was conducted in accordance with SNI 1726-2019 and SNI 1729-2019, with more complex structural uses and modeling.

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