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Structural Analysis of Reinforced Concrete Building Based on Capacity Ratio Using ETABS

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Abstract

This study aims to evaluate the structural performance of a reinforced concrete building through numerical modeling using ETABS. The analysis focuses on the distribution of internal forces and the capacity ratio of structural elements under ultimate load combinations based on the LRFD method. The case study is the upper structure of the BBPSDMP Kominfo Office Building in Makassar. The results indicate that the maximum axial force occurs in the first-floor column, reflecting the accumulation of vertical loads from the upper levels. The evaluation of structural capacity shows that the maximum capacity ratio reaches 0.977, which is still below the allowable limit of 1.0, indicating that all structural elements satisfy the design requirements. However, elements with ratios approaching unity, particularly columns at the lower levels, are identified as critical components that govern the structural performance. This study demonstrates that numerical analysis using ETABS is effective in identifying both the distribution of internal forces and critical structural elements. The findings provide practical insights for structural evaluation and design optimization of reinforced concrete buildings to ensure safety and reliability.

Keywords: Structural analysis, Internal forces, Capacity ratio, Reinforced concrete building, ETABS

1. Introduction

The rapid development of high-rise buildings in urban areas necessitates the use of accurate and efficient structural analysis methods. Planning is a critical stage in the design of building structures to ensure that they meet functional, aesthetic, and economic criteria [1][2][3]. Reinforced concrete high-rise buildings are susceptible to failure if not properly designed; therefore, comprehensive planning is required by considering aspects of strength, serviceability, safety, and durability [4][5][6].

Along with advancements in science and technology in the field of civil engineering, the use of structural analysis software has become increasingly important to facilitate the design process and improve the accuracy of design outcomes [7]. One of the most widely used software packages is ETABS, developed by CSI, which serves as a tool for structural analysis and building design [8]. With the aid of ETABS, structural design can be carried out more efficiently and accurately, resulting in safe and economical designs [9].

Various previous studies have employed finite element–based modeling using software such as ETABS to analyze the behavior of building structures. Studies on building interaction (pounding) indicate that this phenomenon can significantly increase axial forces, bending moments, and deformations, and therefore must be carefully considered during the structural modeling stage [10]. Other studies examining the use of damping systems, such as fluid viscous dampers, demonstrate that ETABS-based analysis approaches are capable of comprehensively evaluating structural performance parameters, including displacement, inter-story drift, and base shear, and further emphasize that the configuration of structural elements strongly influences building response [11]. In addition, research on the effect of accidental eccentricity in response spectrum analysis shows that differences in analytical methods can result in significant variations in structural response, highlighting that appropriate modeling is a key factor in obtaining representative results [12]. Studies related to structural systems and strengthening methods also indicate that variations in element configurations, such as shear walls and slab systems, directly affect deformation and force distribution within the structure [13]. However, these studies are generally limited to presenting analysis results without thoroughly linking them to the performance of structural elements, particularly in terms of strength ratios and the identification of critical elements. This condition indicates a gap between numerical analysis results and comprehensive structural safety evaluation.

Building structures are generally divided into superstructures, which are the components located above ground level, including columns, beams, floor slabs, and roofs (SNI 2847:2013) [14][15][16]. Each structural element plays an essential role: columns function to transfer vertical loads to the foundation, beams act as flexural elements that resist and distribute moments, and floor slabs serve as horizontal partitions between levels supported by beams and columns (SNI T-15-1991-03) [17][18][19].

In building design, it is essential to consider loading concepts, including vertical loads (dead and live loads) as well as lateral loads such as earthquakes and wind [20][21][22]. The design process must adhere to applicable standards, such as SNI 1726:2019 for seismic resistance [23] and SNI 1727:2019 for load combinations [24], to ensure that the structure can safely withstand various loading conditions.

Based on the importance of these planning aspects, a re-analysis of the building superstructure was conducted using ETABS software for the BBPSDMP Kominfo Office Building in Makassar. This analysis is expected to produce a structural design that satisfies safety, efficiency, and reliability requirements in accordance with applicable standards.

2. Methods

Research Type

This study employs a numerical analysis approach based on three-dimensional structural modeling using ETABS software. The object of this study is the superstructure of the BBPSDMP Kominfo Office Building located in Makassar, modeled based on the design drawings (shop drawings).

Research Procedure

The research procedure begins with the collection of structural data, including element dimensions, structural configuration, and material specifications. The building structure is modeled in three dimensions using frame elements for beams and columns, and shell elements for floor slabs. The boundary conditions at the base of the structure are assumed to be fixed supports, and the floor diaphragm system is modeled as a rigid diaphragm.

The loads applied to the structure include dead loads and live loads in accordance with the provisions of SNI 1727:2020. Structural analysis is performed by considering load combinations based on reinforced concrete design requirements as specified in SNI 2847:2019. The load combinations used are ultimate load combinations intended to evaluate the capacity of structural elements.

Description of the Research Object

The object of this study is the superstructure of a reinforced concrete office building located in Makassar. The structural modeling is carried out based on design data (shop drawings), which include geometric configuration, dimensions of structural elements, and the structural system employed.

The three-dimensional structural model of the building is presented in Figure 1, illustrating the arrangement of structural elements, including columns, beams, slabs, as well as the overall foundation system.

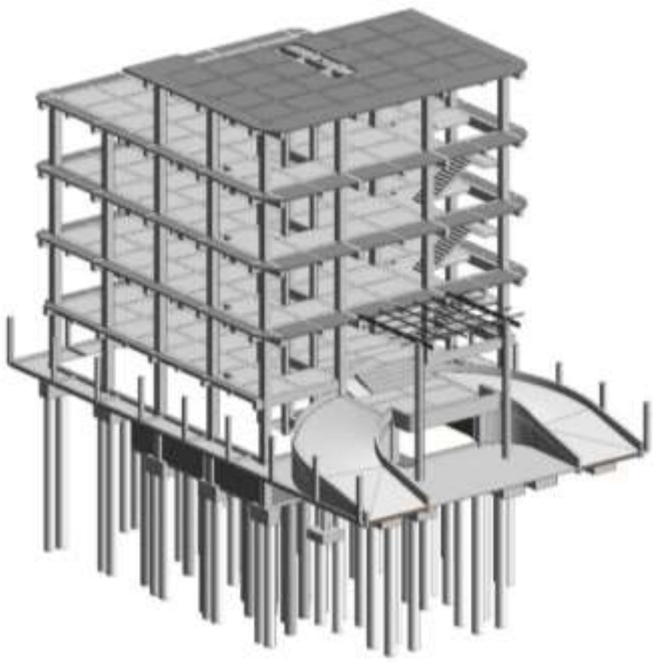

Figure 1. Three-dimensional structural model of the building

Building Parameters and Material Properties

The primary building parameters used in the structural modeling include the building geometry based on the shop drawings. The structural system employed is a reinforced concrete frame system. The material properties consist of a design concrete strength of 25 MPa and reinforcing steel strengths of 280 MPa and 420 MPa.

Structural Modeling Using ETABS

Structural analysis was conducted using ETABS software. The structure was modeled in three dimensions, where beams and columns were represented as frame elements, while floor slabs were modeled as shell elements.

The support conditions at the base of the structure were assumed to be fixed supports, and each floor was modeled as a rigid diaphragm to represent the distribution of lateral loads.

The typical floor plan used in the structural modeling is shown in Figure 2, illustrating the grid system and the distribution of structural elements.

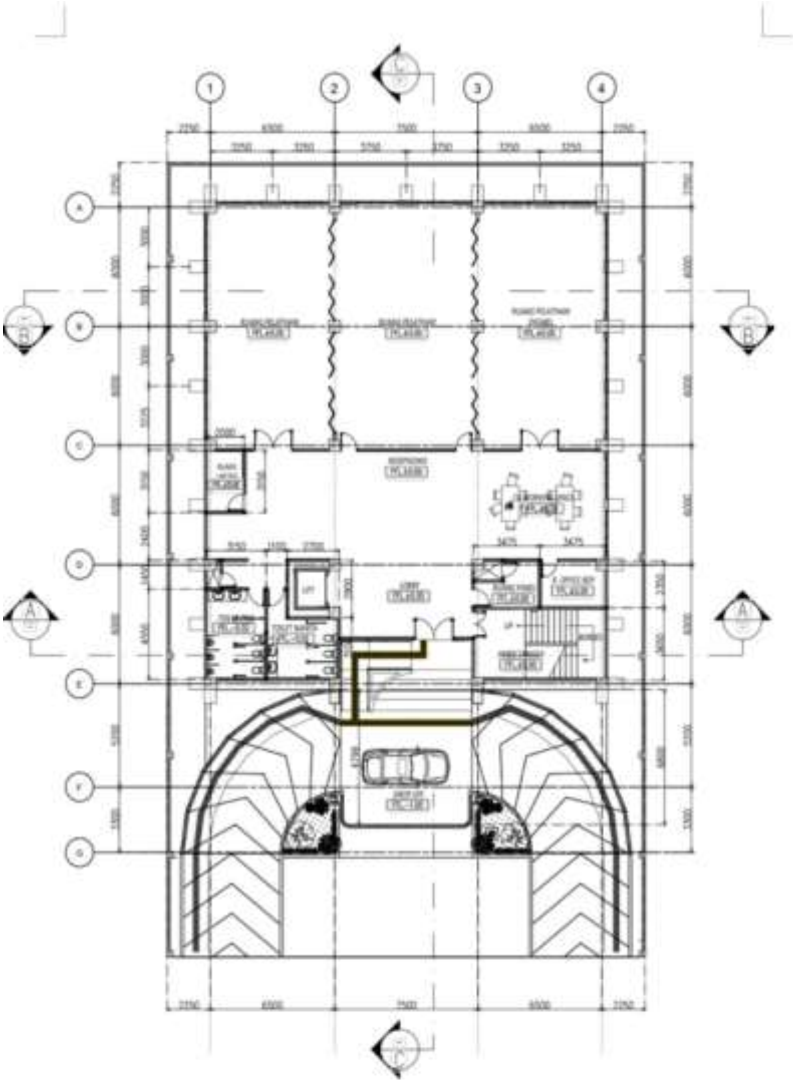

Figure 2. Typical floor structural plan

Loading and Load Combinations

The loads applied to the structure include dead loads and live loads in accordance with the provisions of SNI 1727:2020. In addition, seismic loads were also considered in the analysis using the dynamic response spectrum method in accordance with SNI 1726:2019.

The structural response parameters evaluated include the natural vibration period, base shear, and the distribution of lateral forces at each floor level. The load combinations used refer to the reinforced concrete design provisions specified in SNI 2847:2019 to assess the ultimate condition of the structure.

Additional load combinations were introduced to account for seismic effects, including combinations involving vertical seismic load (Ev) and horizontal seismic load (Eh). The value of Ev is influenced by the design response spectrum parameter (SDS) obtained from Puskim, while the value of Eh is influenced by the redundancy factor (ρ) derived from seismic analysis. Based on loading direction provisions—namely, 100% of the load applied in one direction and 30% in the perpendicular direction—a total of 16 load combinations were obtained and used in the structural analysis, as presented in Table 1.

Structural Evaluation Parameters

The results of the structural analysis consist of internal forces, including axial forces, shear forces, and bending moments in each structural element. In addition, an evaluation of the capacity ratio of structural elements was conducted, which is defined as the ratio between the internal forces obtained from the analysis and the capacity of the element.

A structural element is considered safe if its capacity ratio is less than or equal to one. Critical elements within the structure are identified based on the maximum capacity ratio obtained from the analysis results.

Table 1. Load combinations

No.		DL	SDL	LL	Lr	R	WLx	WLy	Eqx	Eqy
1	1.1	1.40	1.40							
2	2.1	1.20	1.20	1.60	0.50					
	2.2	1.20	1.20	1.60		0.50				
3	3.1	1.20	1.20	1.00	1.60					
	3.2	1.20	1.20		1.60		0.50			
	3.3	1.20	1.20		1.60			0.50		
	3.4	1.20	1.20		1.60		0.38	0.38		
	3.5	1.20	1.20	1.00		1.60				
	3.6	1.20	1.20			1.60	0.50			
	3.7	1.20	1.20			1.60		0.50		
	3.8	1.20	1.20			1.60	0.38	0.38		
4	4.1	1.20	1.20	1.00	0.50		1.00			
	4.2	1.20	1.20	1.00	0.50			1.00		
	4.3	1.20	1.20	1.00	0.50		0.75	0.75		
	4.4	1.20	1.20	1.00		0.50	1.00			
	4.5	1.20	1.20	1.00		0.50		1.00		
	4.6	1.20	1.20	1.00		0.50	0.75	0.75		
5	5.1	0.90	0.90				1.00			
	5.2	0.90	0.90					1.00		
	5.3	0.90	0.90				0.75	0.75		
6	6.1	1.27	1.27	1.00					1.30	0.39
	6.2	1.27	1.27	1.00					1.30	-0.39
	6.3	1.27	1.27	1.00					-1.30	0.39
	6.4	1.27	1.27	1.00					-1.30	-0.39
	6.5	1.27	1.27	1.00					0.39	1.30
	6.6	1.27	1.27	1.00					-0.39	1.30
	6.7	1.27	1.27	1.00					0.39	-1.30
	6.8	1.27	1.27	1.00					-0.39	-1.30
7	7.1	0.79	0.79						1.30	0.39
	7.2	0.79	0.79						1.30	-0.39
	7.3	0.79	0.79						-1.30	0.39
	7.4	0.79	0.79						-1.30	-0.39
	7.5	0.79	0.79						0.39	1.30
	7.6	0.79	0.79						-0.39	1.30
	7.7	0.79	0.79						0.39	-1.30
	7.8	0.79	0.79						-0.39	-1.30

Vertical Configuration of the Structure

The vertical configuration of the building under study is presented in Figure 3, illustrating the arrangement of primary structural elements, including columns, beams, floor slabs, and the foundation system within a cross-sectional view. The building consists of multiple stories with varying interstory heights, where columns function as the main vertical load-bearing elements transferring loads to the foundation, while beams act as horizontal members distributing loads from the slabs to the columns. This structural configuration serves as the basis for the three-dimensional modeling in ETABS, ensuring that the geometric representation and structural system accurately reflect the actual building conditions.

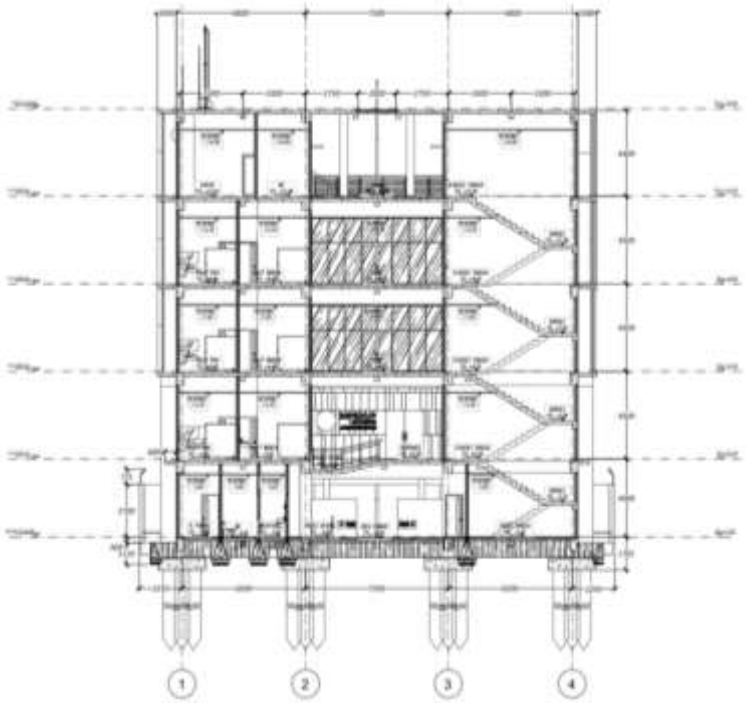

Figure 3. Vertical section of the building structure

3. Results and Discussion

Structural Response Analysis

The results of the structural analysis using ETABS indicate that the building's structural response is influenced by the applied load combinations, including both gravity loads and seismic loads. Structural response parameters such as base shear and the distribution of lateral forces demonstrate that the structure performs in a stable manner in resisting the applied loads.

The distribution of lateral forces within the structure shows a tendency for forces to increase toward the lower floors, indicating that structural elements at the base level experience the highest loads due to the accumulation of loads from the upper floors. This behavior is consistent with the general response of multi-story buildings, where lower-level elements serve as the primary components in resisting the overall structural loads.

Internal Forces in Structural Elements

The results of the internal force analysis indicate that structural elements are subjected to a combination of axial forces, bending moments, and shear forces due to the applied loading conditions. A summary of the internal force analysis results for column and beam elements is presented in Table 2.

Table 2. Maximum internal forces of structural elements

Floor	Column Axial (kN)	Column Moment (kN.m)	Beam Moment (kN.m)
1	-3270.56	-248.18	-313.45
2	-2759.11	-188.27	-372.22
3	-2217.66	-135.34	-335.64
4	-1668.74	-84.39	-245.86
Roof	-1144.77	-124.56	-457.38

Based on these results, the maximum axial force occurs in the main column at the first floor, with a value of −3270.5565 kN, accompanied by a bending moment of −248.1813 kN.m. Thus, ground-level columns act as the primary load-bearing elements in the structural system.

The magnitude of the axial force in the ground-floor columns is attributed to the accumulation of loads from all upper floors, resulting in greater compressive forces compared to other structural elements. Meanwhile, internal force distribution in beam elements varies depending on span length and structural configuration, which influence load transfer to the columns.

In addition, the analysis results indicate that the maximum bending moments in beam elements vary across different floors. Based on Table 2, the largest moment in the beams occurs at the roof level, with a value of −457.38 kN.m, followed by the second floor with −372.22 kN.m. The magnitude of the bending moment in beams is influenced by span length and the distribution of loads acting on the floor slabs, which are subsequently transferred to the beams.

The relatively large moment observed in the roof beams indicates that these elements carry significant loads, particularly due to the combination of roof live loads and the effects of lateral loads. Meanwhile, variations in moment values across other floors reflect differences in load distribution and structural configuration at each level.

The distribution of moments in structural elements is illustrated in Figure 4, which shows the bending moment patterns in beams and columns. It can be observed that the maximum moment values tend to occur at the mid-span of beams, indicating regions with the highest bending stresses due to gravity loads. In addition, negative moments are observed at support regions, reflecting restrained conditions at beam–column connections.

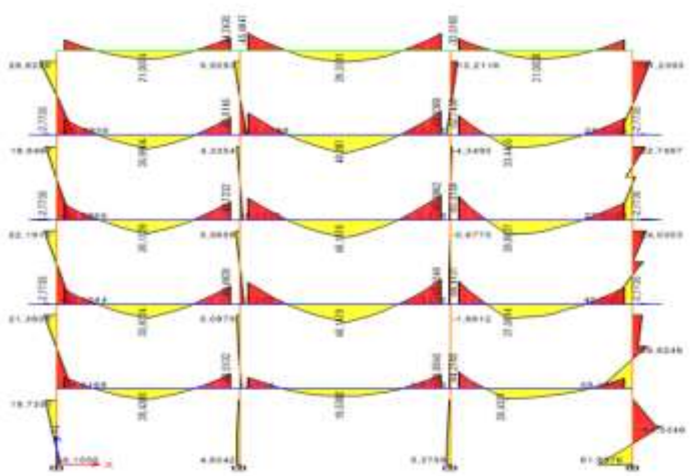

Figure 4. Bending moment distribution (M3-3) in structural elements

These results are consistent with previous studies, which indicate that the maximum axial force in multi-story building structures generally occurs in ground-floor columns due to the accumulation of loads from the upper floors [25][26].

Evaluation of Structural Element Capacity

The structural performance evaluation was conducted based on the capacity ratio of structural elements, defined as the ratio between the internal forces obtained from the analysis and the capacity of the structural elements. An element is considered safe if the ratio does not exceed the allowable limit, i.e., ≤ 1.

Based on the analysis results, the maximum capacity ratio obtained was 0.977, derived from the comparison between the factored ultimate load (Ru) of 1204.8111 and the nominal capacity of the element (Rn) of −1232.6631. This value indicates that all structural elements remain within safe limits under the applied loading conditions.

However, a capacity ratio approaching the maximum allowable limit suggests that certain structural elements are operating under near-critical conditions, thus requiring careful attention during the design evaluation process.

A ratio value close to unity indicates that the element is performing near its capacity, as also reported in previous studies on the performance evaluation of reinforced concrete structural elements [27].

Identification of Critical Elements

The three-dimensional distribution of structural element capacity ratios is shown in Figure 5, illustrating the level of capacity utilization for each structural element based on the analysis conducted using ETABS. The variation in colors across the structural elements represents the magnitude of the capacity ratio, where colors approaching red indicate higher ratio values, while green to blue colors represent elements operating well below their capacity. It can be observed that column elements at the ground floor tend to exhibit higher capacity ratio values compared to those at upper floors, indicating that these elements carry the greatest loads due to the accumulation of vertical loads and the influence of lateral loads. Nevertheless, all structural elements remain within safe limits, as the capacity ratios do not exceed one, indicating that the structural capacity is sufficient to resist the applied loads. This distribution pattern also reinforces the quantitative analysis results presented earlier, where ground-floor column elements were identified as the most critical components within the structural system.

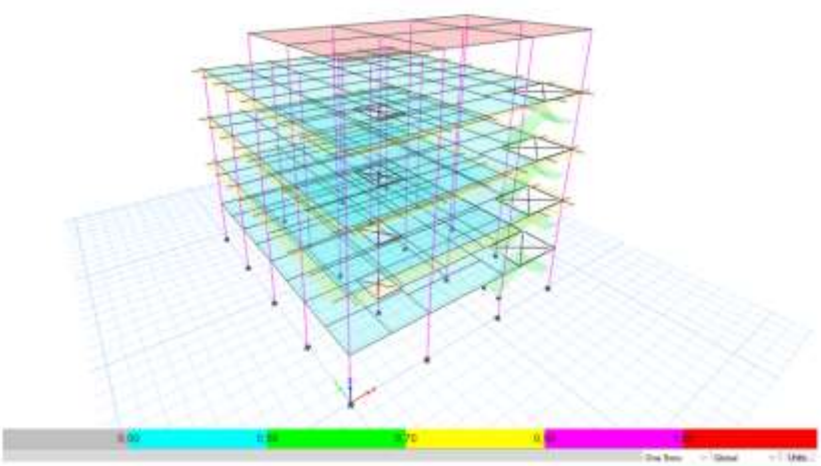

Figure 5. Three-dimensional distribution of capacity ratios in structural elements

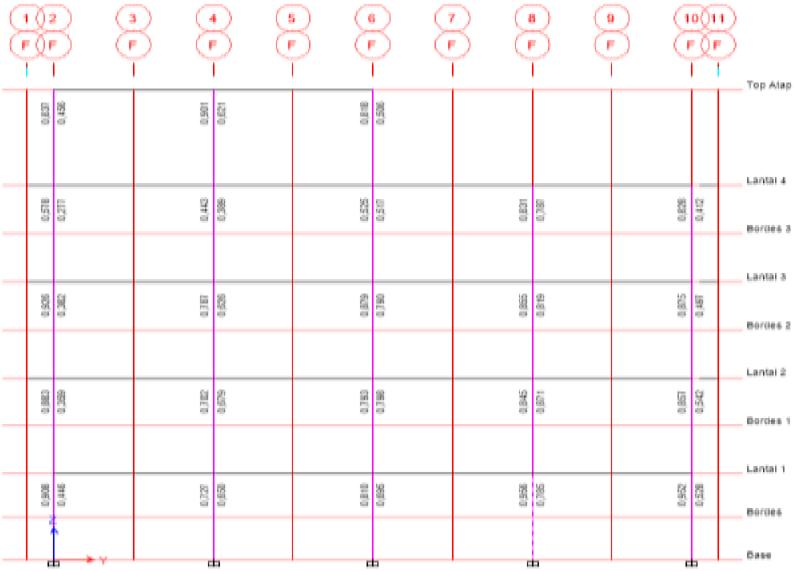

Figure 6. Maximum capacity ratio of the structure

The distribution of maximum capacity ratio values for each structural element is presented in greater detail in Figure 6. The figure illustrates the variation in capacity ratio values of column elements on each floor based on the structural grid positions. The maximum capacity ratio occurs in the main column C34 on the first floor, resulting from load combination 7.8, namely 0.9D − Ev + Eh. This near-limit ratio indicates that the column is operating optimally in resisting the applied loads, particularly due to the significant contribution of seismic loading to the internal forces within the structure.

Furthermore, the high ratio value in this column is attributed to its location at the ground floor, where it must support the accumulation of loads from the upper floors, including loads from beams, slabs, and the roof. This condition causes the column to experience greater internal forces compared to other structural elements.

Although the capacity ratio approaches the maximum allowable limit, it remains below unity, indicating that the structural element still has sufficient capacity to resist the applied factored ultimate loads. Therefore, the overall building structure can be considered safe and compliant with the prescribed design criteria. However, structural elements with high capacity ratios, such as the main column C34 on the first floor, require particular attention during the design evaluation process to enhance structural reliability and long-term performance.

These findings are consistent with previous studies indicating that ground-floor column elements are the most critical components in multi-story building structures, as they are subjected to the greatest combination of vertical and lateral loads [25][28].

4. Conclusions

Based on the results of the structural analysis using ETABS, the distribution of internal forces in structural elements shows a tendency to increase in ground-floor columns due to the accumulation of loads from the upper floors. The maximum axial force and bending moment were identified in the main column on the first floor, indicating that this element plays a dominant role in resisting the overall structural loads.

The structural performance evaluation based on capacity ratios indicates that the maximum ratio value of 0.977 remains below the allowable limit, and therefore all structural elements are considered safe under the applied ultimate load combinations. However, the ratio value approaching the allowable limit suggests that certain elements, particularly ground-floor columns, are in near-critical conditions and represent the most influential components affecting the structural reliability.

The results of this study confirm that numerical modeling–based analysis using ETABS is not only capable of identifying the distribution of internal forces but also effective in determining critical structural elements through a capacity ratio approach. These findings contribute to the evaluation of reinforced concrete building performance, particularly in supporting a more reliable and performance-based structural design process.

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