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Seismic Performance Evaluation Of Building Structures Modified With Special Concentrically Braced Frames (SCBF)

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ABSTRACT

The Concentrically Braced Frame (CBF) system utilizes diagonal steel bracing members to enhance structural stiffness and dissipate seismic energy, thereby reducing potential damage to primary structural elements. CBF systems are classified into Special Concentrically Braced Frames (SCBF) and Ordinary Concentrically Braced Frames (OCBF), which are applied in high and moderate-to-low seismic regions, respectively. This study evaluates the modification of an existing 13-story hotel building into an SCBF system in accordance with the latest Indonesian seismic design provisions. The research methodology includes a literature review on SCBF design principles and the most recent SNI standards, preliminary design, numerical modeling, and dynamic analysis using SAP2000. The structural behavior parameters evaluated in this study include mass participation, fundamental period (time period), and interstory drift. The results indicate that both the existing structure with a Dual System (SMRF and shear wall) and the SCBF-modified structure satisfy the minimum 90% mass participation requirement specified in SNI 1726:2019, with the SCBF system achieving this criterion using fewer vibration modes. However, the evaluation of the fundamental period shows that the existing structure remains within the allowable code limits, whereas the SCBF-modified structure exceeds the maximum permitted fundamental period, indicating increased structural flexibility and insufficient lateral stiffness. In terms of interstory drift performance, both structural systems comply with the drift limits specified in SNI 1726:2019; nevertheless, the Dual System demonstrates superior lateral deformation control compared to the SCBF system.

Therefore, it can be concluded that the structural modification using the SCBF system in this study was not successful in replacing or outperforming the existing Dual System. Although the SCBF configuration meets certain code requirements, it does not provide adequate lateral stiffness nor improved seismic performance compared to the original structural system.



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1. Introduction

Indonesia's geographical location places the country in a region with a high vulnerability to natural hazards, particularly earthquakes [1][2][3]. Steel structures are considered an effective seismic-resistant building system due to their high strength and ductility [4], allowing them to absorb significant energy and reduce the risk of collapse [5][6]. To enhance resistance to shear forces, steel building structures require additional supporting elements, such as bracing [7]. In braced systems, beams and columns are designed primarily to resist vertical loads, under the assumption that bracing elements carry the entire lateral force demand [8][9][10]. The seismic frame design concept assigns the link element as the component intended to yield or sustain damage first, while the beams, columns, and bracing members are expected to remain in the elastic range throughout earthquake loading [11]. There are two braced frame systems commonly used in practice, Concentric Braced Frames (CBF) and Eccentric Braced Frames (EBF) in which bracing members dissipate energy through repeated cycles of buckling and plastic hinging [12][13][14]. Concentric Braced Frame System (CBF) dan Eccentric Braced Frame System (EBF). The CBF system consists of several configuration types, including X-type, two-story X-type, V-type, inverted-V type, K-type, Z-type, and diagonal bracing [2][15].

The Centrally Braced Frame (CBF) system is a steel framing configuration in which diagonal bracing provides stiffness and dissipates seismic energy, thereby reducing potential damage to beams and columns [16][17]. The CBF system is currently one of the most commonly used steel structural options for resisting earthquake forces due to its ease of design and effectiveness in limiting lateral building displacement. Over the past several decades, numerous studies have examined the seismic response and design development of CBF systems [12][18], in addition, the system offers several advantages, one of which is the ease of installation and repair in the event of damage [19]. CBF systems are generally utilized in low- to mid-rise steel buildings, employing bracing configurations such as X-bracing, two-story X-bracing, or chevron bracing. However, current CBF design practices are typically based on conventional calculation methods that tend to apply uniform material configurations without considering the distribution of strength demand across individual structural regions. Consequently, this approach may result in excessive material usage in non-critical areas or potential failure in zones that should be more adequately reinforced. The implementation of optimization techniques in the structural design process therefore represents a strategic opportunity to develop building systems that are more efficient and material-saving [20]. The performance of a Centrally Braced Frame (CBF) system is governed by the bracing elements, which function as connectors between columns, enabling the structural system to behave similarly to a truss [21]. In multi-story buildings, the use of Concentric Braced Frame (CBF) systems requires an optimization-based design approach to maximize their performance in resisting lateral loads while simultaneously minimizing material demand [22].

CBF systems are classified into two types: Special Centrally Braced Frames (SCBF) and Ordinary Centrally Braced Frames (OCBF). The primary distinction between the two lies in the seismic hazard level at the building site. SCBFs are implemented in regions with high seismic risk, whereas OCBFs are used in areas with lower seismicity [23]. SCBF is designed to maintain structural capacity when undergoing large inelastic deformations through controlled yielding and failure mechanisms, including brace buckling in compression and tension during loading [24]. In an SCBF system, the bracing elements function as the primary components in absorbing seismic energy and contribute significantly to the structural performance even as it enters nonlinear conditions [25]. The Special Centrally Braced Frame (SCBF) system is designed to undergo significant inelastic deformation when subjected to seismic loading. SCBF provides a higher level of ductility [26].

The existing building was originally planned and constructed in 2015, during which the design process still referred to the applicable SNI codes and technical regulations at that time, which had not yet undergone significant revisions. With advancements in structural design standards, particularly those related to seismic loading requirements and seismic performance criteria, the existing building may no longer fully comply with the latest provisions. This condition establishes the need for re-evaluation using current standards, such as SNI 1726:2019, to determine the adequacy of the original design and identify the structural modifications necessary to improve the building's resistance and safety against present-day earthquake loads. In this study, a structural was carried out for an 13-story hotel building using a Special Centrally Braced Frame (SCBF) system. The building has a total height of 49.5 meters and employs an inverted-V bracing configuration, selected for its ability to control lateral displacement while effectively dissipating seismic energy. The structural design refers to current Indonesian national

standards, namely SNI 03-1726-2019 on Earthquake Resistant Design for Buildings and Non-Buildings, SNI 03-1729-2020 on Steel Structure Design, and SNI 1727-2020 on Building and Residential Load Requirements. Based on these three standards, structural optimization was performed to develop an SCBF design that satisfies the required strength, ductility, and seismic performance criteria while achieving optimal material efficiency.

The existing building was designed and constructed in 2015 in accordance with the structural design standards applicable at that time. Since then, structural design regulations in Indonesia have undergone significant revisions, particularly concerning seismic loading provisions and structural performance criteria in SNI 1726:2019, as well as the steel design standard SNI 1729:2020 and the loading requirements specified in SNI 1727:2020. These regulatory updates may result in the existing structural design no longer fully complying with the latest requirements, especially in terms of seismic capacity, ductility, and lateral drift control. On the other hand, previous studies have generally focused either on evaluating the performance of existing buildings based on updated standards or on designing earthquake-resistant structural systems for new buildings. However, studies that specifically integrate the re-evaluation of an existing building with structural system modification into a Special Centrically Braced Frame (SCBF) system in accordance with the latest SNI standards remain limited. Furthermore, comprehensive investigations on the implementation of preliminary SCBF design as an alternative strengthening or modification strategy for buildings originally designed with different structural systems are still relatively scarce. Therefore, a research gap exists in the need to evaluate the compliance of existing building structures with the latest seismic standards and to investigate structural system modification using SCBF through a preliminary design approach. This study aims to address this gap by conducting structural modeling and analysis of a 13-story hotel building modified using the Special Centrically Braced Frame (SCBF) system in accordance with SNI 1726:2019, SNI 1729:2020, and SNI 1727:2020, in order to achieve a structural design that satisfies strength, ductility, and enhanced seismic performance requirements.

2. Research Method

This research method begins with a literature study covering the fundamental concepts of the Special Centrically Braced Frame (SCBF) system, design provisions in relevant SNI standards, and previous studies related to the topic. This stage establishes a strong theoretical foundation for the planning and analysis of earthquake-resistant steel structures. Subsequently, data collection on the existing building is carried out, including architectural information, structural dimensions, and soil characteristics from the project site, which serve as the basis for determining seismic parameters and site classification. Based on this information, a preliminary design is conducted to determine the initial SCBF configuration, size the structural elements, and generate the initial geometric model of the building. The next step involves structural modeling using finite element-based structural analysis software (SAP 2000). The model incorporates gravity loads, seismic loads, and other design load combinations in accordance with applicable SNI standards. The developed model is then analyzed to evaluate the structural behavior, including inter-story drifts, internal member forces, energy dissipation capacity, and plastic hinge formation mechanisms. This stage is followed by a control and verification process to ensure that the structure satisfies strength requirements, ductility demands, and design limits specified in the SNI codes. The final stage involves interpreting the analysis results to assess the effectiveness of the SCBF design. The research flowchart is presented in Figure 1.

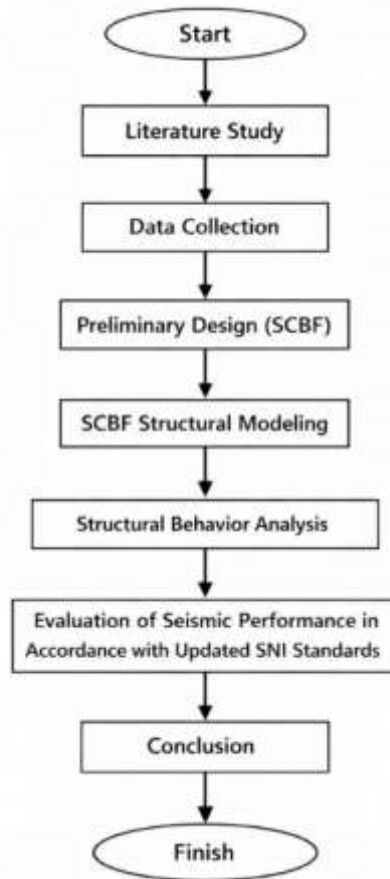


Figure 1. Research Flowchart

3. Structural Modelling and Data Description

This section discusses the existing data that forms the foundation of the research, including the initial structural conditions and environmental characteristics that influence building performance. It then presents a preliminary assessment comparing the current condition with the proposed new structural system intended to enhance performance. This section also outlines the structural modeling process using appropriate analytical tools, including the assumptions, parameters, and limitations applied in the analysis. In addition, it describes the structural behavior control methods used to monitor, evaluate, and optimize the building’s response to loading, ensuring that the overall system functions effectively, safely, and efficiently.

3.1 Existing Data

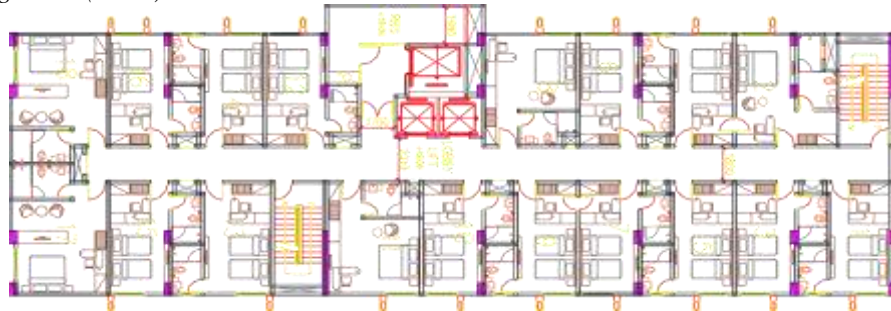
This section presents the existing data used as the foundation of the research, including drawings of the current structure, building specifications, and details of structural dimensions and elements already present in the field. Furthermore, a preliminary assessment is outlined, comparing the existing conditions with the concept and revised structural system proposed in this study. The specifications of the existing building are summarized as follows, while the dimensions of structural members and the existing structural model are shown in Table 1, Figure 1, and Figure 2.

Building Name	: Hotel P
Building Location	: Surabaya
Building Height	: 49.5 m
Design Year	: 2015
Operational Date	: January 2017
Building Function	: Residential/Occupancy
Structural System	: Reinforced Concrete Structure
Site Soil Classification	: Soft Soil (SE)
Seismic Structural System	: Dual System
	(Special Moment Resisting Frame and Special Ductile Shear Wall)

Table 1. Dimensions of Existing Beam and Column Element.

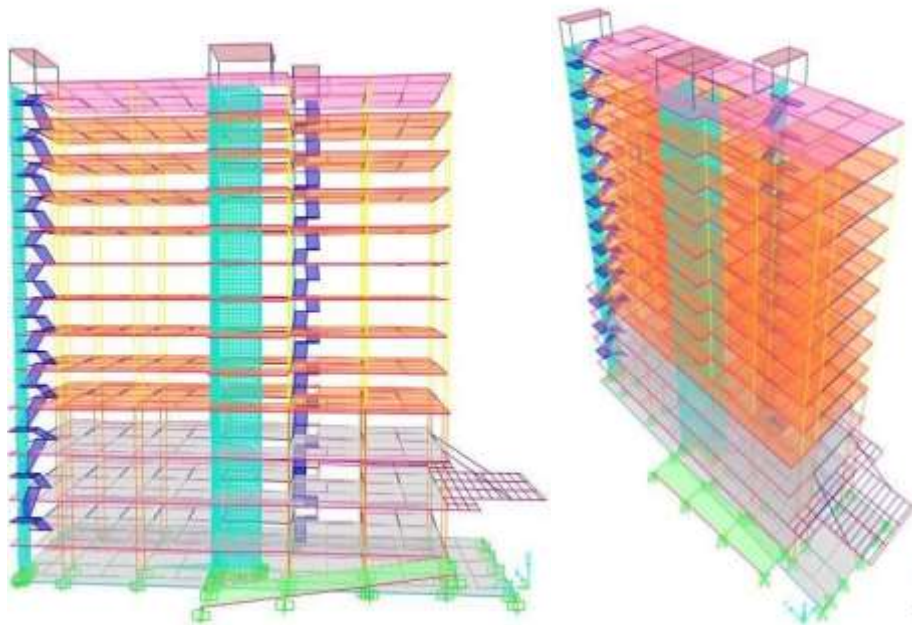
Element	Dimension
Beam	B1 (400x600)
	B2 (300x450)
	B3 (350x450/600)
	B4 (300x500)
	BT1 (250x400)
	SL1 (500x700)
	SL2 (400x600)
	BS1 (500x700)
	BS2 (400x600)
	BR1 (400x600)
BR2 (300x500)	
Column	K1 (800x450)
	K2 (700x400)
	K3 (400x400)

Source : Existing Data (2017)



Source : Existing Data (2017)

Figure 1. Floor Plan of P Hotel Building, Surabaya.



Source : Existing Data (2017)

Figure 2. 3D Modeling of the Existing Building.

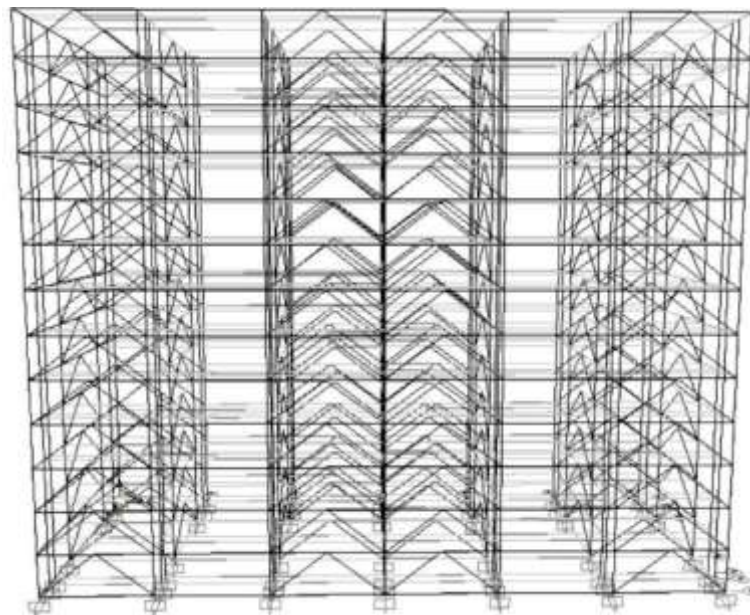
3.2 Preliminary Design and Three-Dimensional Modeling

In this study, a preliminary design was conducted using a new structural system, namely the Special Concentrically Braced Frame (SCBF), as an effort to modify and enhance the performance of the existing building. The initial design phase aimed to evaluate the effectiveness of implementing the SCBF system in increasing the structural capacity, particularly in resisting lateral earthquake loads and minimizing structural deformation. This preliminary design includes a reassessment of the main structural configuration, determination of bracing placement, and evaluation of additional strengthening requirements based on the existing building condition. The structural modeling and loading process were subsequently carried out using a three-dimensional (3D) structural modeling application, which enables both visual and analytical interpretation of changes in structural configuration, bracing layout, and the estimated response of the building under dead loads, live loads, and seismic loads. The outcomes of this stage provide an initial overview of necessary adjustments and strengthening measures for the structural system and serve as a basis for further analytical modeling in the subsequent phases of the study. In this study, the preliminary design stage was carried out using a rule-of-thumb approach (empirical preliminary sizing), which is commonly applied in the initial planning of steel structures prior to detailed analysis and verification in accordance with the applicable design standards. The preliminary profile dimensions for the modified design are presented in Table 2 and Figure 3.

Table 2. Preliminary Design.

Element	L (mm)	H (mm)	Cross Section Profile
Column	8000	400	HB 400.400.21.21
Primary Beam	8000	400	IWF 400.300.9.14
Bracing	6000	300	IWF 300.200.8.12
Secondary Beam	5000	200	IWF 200.200.10.16

Source : Research Data (2025)



Source : Research Data (2025)
Figure 3. SCBF Building 3D Model.

3.3 Structural Behavior Analysis

At the final stage of the analysis, following structural modeling and load application, this study carried out an evaluation of structural behavior control based on the requirements of SNI 1726:2019. The primary parameters reviewed include natural period and modal mass participation. The structural response of the modified building with the SCBF system was then compared to that of the existing building without modification. The comparison revealed significant differences in structural behavior, including increased stiffness, reduced inter-story drift, and improved structural capacity against seismic loads. Accordingly, the results provide a quantitative assessment of the effectiveness of the proposed structural system in enhancing the seismic performance of the building.

4. Results and Discussions

4.1 Mass Participation

Based on SNI 1726:2019 Section 7.9.1.1, the structural mass participation is required to reach 100% of the total building mass. However, in a modal analysis, the standard allows a cumulative modal mass participation of at least 90%, provided that the load transfer mechanism within the structure is assumed to be effectively distributed to the primary structural elements. Thus, a structural model achieving $\geq 90\%$ mass participation is still considered compliant with the dynamic performance requirements specified in the code. Based on the existing building model, the mass participation values reached 91.3% in the X-direction at the 18th mode and 90.4% in the Y-direction at the 14th mode. Meanwhile, the results of the modified SCBF building show that cumulative mass participation reached 94.5% in the X-direction and 90.7% in the Y-direction, both achieved by the 7th mode. These findings confirm that the modal mass participation distribution satisfies the minimum required threshold of at least 90% of the total structural mass accommodated through a combination of vibration modes. This result demonstrates that the modified structural system exhibits a more efficient dynamic response in transferring loads and mobilizing structural mass compared to the existing condition.

4.2 Time Period

Table 3. Time Period.

Step	Period (s)	
	Dual System (SMRF and Shearwall)	SCBF
1	2.168377	2.61255
2	1.850824	2.230306
3	1.740107	1.801296
4	0.627397	1.34322
5	0.548321	1.212825
6	0.501719	1.034016
7	0.329728	0.736731
8	0.275906	0.683932
9	0.263996	0.683613
10	0.256458	0.683584
11	0.236848	0.683371
12	0.230286	0.680583
13	0.225967	0.65935
14	0.222114	0.659165
15	0.221116	0.658585

Source : Research Data (2025)

The fundamental period of the structure was obtained through dynamic analysis based on a three-dimensional structural model. This period value was then used as one of the key parameters for evaluating the seismic performance of the building. In this study, two structural conditions were analyzed: the existing building utilizing a dual system consisting of a Special Moment Resisting Frame (SMRF) combined with Structural Shear Walls (SDS), and the modified building implementing a Special Concentrically Braced Frame (SCBF) system. A comparison of the fundamental period values between these two conditions provides insight into changes in stiffness and dynamic response resulting from the proposed modification, where a decrease or increase in the structural period may indicate an enhancement in stiffness or flexibility in resisting seismic loads. The corresponding structural period results are presented in Table 3.

Referring to SNI 1726:2019, the fundamental period of the structure in the principal direction can be estimated using the following equation:

$$T_a = C_t \cdot h^x$$

SNI 1726-2019 specifies the following limits:

1. Minimum Period

$$T_{min} = 0.2 T_a$$

2. Maximum Period

$$T_{max} = C_u T_a$$

Thus, the calculation of the fundamental period for the existing building (Dual System) is as follows.

$$C_t = 0.0466$$

$$x = 0.90$$

$$h = 49.5 \text{ m}$$

$$T_a = 0.0466 \times (49.5)^{0.9} = 1.56 \text{ s}$$

$$T_{min} = 0.2 \times 1.56 = 0.31 \text{ s}$$

$$T_{max} = 1.4 \times 1.56 = 2.18 \text{ s}$$

Meanwhile, the calculated fundamental period for the modified building (SCBF system) is as follows.

$$C_t = 0.0731$$

$$x = 0.75$$

$$T_a = 0.0731 \times (49.5)^{0.75} = 1.364 \text{ s}$$

$$T_{min} = 0.2 \times 1.36 = 0.272 \text{ s}$$

$$T_{max} = 1.4 \times 1.36 = 1.9 \text{ s}$$

The analysis results indicate that the fundamental period of the existing building is 2.168 seconds, which falls within the allowable range specified in SNI 1726:2019 (between 0.31 seconds and 2.18 seconds). This confirms that the dynamic response of the existing structure satisfies the current standard, although the value lies very close to the upper limit and reflects a relatively flexible structural behavior. In contrast, the modified building utilizing the SCBF system yields a structural period of 2.613 seconds, which exceeds the prescribed maximum limit of 1.90 seconds. This result suggests that the SCBF configuration, as modeled in this study, produces a more flexible system and does not yet provide sufficient lateral stiffness to meet the seismic performance requirements mandated by the standard. These findings imply that the existing system is more compliant with regulatory criteria, while the modified SCBF system requires additional refinement to reduce the period and restore compliance within the permitted range.

4.3 Interstory Drift

Based on the provisions of SNI 1726:2019, which specifies the seismic design procedures for building and non-building structures, interstory drift is used as one of the primary parameters for evaluating structural performance under seismic loading. For buildings employing a Special Moment Resisting Frame combined with shear walls (dual system), as well as a Special Concentrically Braced Frame system, the maximum allowable interstory drift is limited to $0.02 h_{sx}$, where h_{sx} represents the story to-story height. In this study, the story height of the building is designed to be 4 meters, resulting in a maximum permissible interstory drift of 0.08 m (80 mm). This limit is used as a reference criterion in evaluating the results of the structural response analysis under seismic loading. The structure is considered to satisfy the interstory drift performance requirements if the calculated drift values, for both the dual system (SMRF–shear wall) and the SCBF system, do not exceed the limits specified in SNI 1726:2019. The comparison results of interstory drift for structure using dual system and SCBF system are presented in Table 4.

Table 4. Interstory Drift

Story	Interstory Drift			
	x		y	
	Dual System	SCBF	Dual System	SCBF
1	1.003	1.279	0.838	0.001
2	2.793	13.964	1.758	5.502
3	5.861	30.745	3.611	11.654
4	8.968	41.481	8.458	16.534
5	11.939	51.920	12.037	18.691
6	14.761	56.837	15.008	22.162
7	17.389	54.054	17.830	18.266
8	19.78	54.835	20.458	28.201
9	21.892	52.742	22.849	23.827
10	23.685	57.497	24.961	22.672
11	25.123	55.770	26.754	24.394
12	26.189	65.390	28.192	21.192
13	26.341	46.486	29.221	22.737

Based on the interstory drift analysis results, a comparison of structural behavior was obtained between the building with a Dual System (Special Moment Resisting Frame combined with shear walls) and the building with a Special Concentrically Braced Frame (SCBF) system in the X and Y directions. In general, the building with the Dual System exhibits smaller and more uniformly distributed story drift values across almost all levels compared to the building with the SCBF system, in both the X and Y directions. This indicates that the combination of a special moment-resisting frame and shear walls provides greater lateral stiffness, thereby effectively limiting structural deformations under seismic loading. In the X direction, the drift values of the Dual System increase gradually from the lower to the upper stories, with a maximum value of approximately 26.34 at Story 13. In contrast, the SCBF system shows significantly larger drift values, with a sharp increase beginning at Story 2 and reaching a maximum value of approximately 65.39 at Story 12. This difference suggests that although the SCBF system has good energy dissipation capacity, its overall lateral stiffness is relatively lower than that of systems incorporating shear walls. In the Y direction, the Dual System demonstrates superior performance, with relatively small and consistent drift values, reaching approximately 29.22 at Story 13. Conversely, the SCBF system exhibits considerable fluctuations in drift values, with a maximum of about 28.20 at Story 8 and other high values occurring at intermediate stories. This behavior indicates a concentration of deformation at certain levels due to the structural mechanism of the braced frame system.

5. Conclusion and Suggestion

5.1 Conclusion

Based on the numerical modeling and dynamic analysis, both the existing structure and the structure modified with the SCBF system satisfy the minimum 90% mass participation requirement specified in SNI 1726:2019, with the SCBF configuration demonstrating higher efficiency by achieving this requirement using fewer vibration modes. Despite this improvement in mass participation, the fundamental period evaluation indicates that the existing building remains within the allowable limits, whereas the SCBF-modified structure exceeds the maximum permitted fundamental period, reflecting increased structural flexibility and insufficient lateral stiffness. Consequently, although the existing system continues to comply with the current code provisions, the application of the SCBF system requires further design refinement to satisfy the fundamental period limitations prescribed by the standards. In terms of interstory drift performance, both the dual system and the SCBF system comply with the drift limits specified in SNI 1726:2019. However, based on the story drift analysis results, it can be concluded that the building with a Dual System (SMRF and shear wall) demonstrates better lateral deformation performance compared to the building with an SCBF system. The Dual System is more effective in controlling interstory drift, thereby providing higher levels of structural safety, occupant comfort, and seismic performance.

Based on the numerical modeling and dynamic analysis, both the existing structure and the structure modified with the SCBF system satisfy the minimum 90% mass participation requirement specified in SNI 1726:2019, with the SCBF configuration demonstrating higher efficiency by achieving this requirement using fewer vibration modes. However, the evaluation of the fundamental period indicates that while the existing building remains within the allowable limits, the SCBF-modified structure exceeds the maximum permitted fundamental period. This result reflects increased structural flexibility and insufficient lateral stiffness in the modified system. Although both the Dual System (SMRF and shear wall) and the SCBF system comply with the interstory drift limits specified in SNI 1726:2019, the story drift analysis shows that the Dual System provides superior lateral deformation control compared to the SCBF system. The Dual System demonstrates better stiffness characteristics, resulting in improved structural stability, occupant comfort, and overall seismic performance. Therefore, it can be concluded that the structural modification using the SCBF system in this study was not successful in replacing or outperforming the existing Dual System. Despite meeting certain code requirements, the SCBF configuration did not achieve adequate lateral stiffness nor superior seismic performance compared to the original structural system. Consequently, the existing Dual System remains the more effective and appropriate structural solution for the building under the current SNI provisions.

5.2 Suggestion

Based on the dynamic analysis results, which indicate that the SCBF system has not yet provided adequate lateral stiffness, further evaluation and design optimization are required before the system can

be recommended as a replacement for the existing structural configuration. Adjustments may include increasing the number of bracing members, modifying bracing placement and configuration, or enhancing the size and material strength of structural elements responsible for resisting lateral forces. In addition, future studies are recommended to investigate the influence of alternative seismic-resisting systems, including combinations of SCBF with shear walls or Special Moment Resisting Frames, to achieve an optimal configuration that meets the prescribed period limits while improving the overall seismic performance of the building.

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