International Journal of Architecture and Urbanism
Journal homepage: https://talenta.usu.ac.id/ijau

Analysis of SCWB Ratio on Collapse Probability of SRPMK Concrete Structures

Syarbaini Lubis*[1], Johannes Tarigan[1], Nursyamsi Nursyamsi[1]

[1]Master of Civil Department, Engineering Faculty, Universitas Sumatera Utara, Medan, 20155, Indonesia

*Corresponding Author: syarbainilubis150@gmail.com

ARTICLE INFO

Article history:
Received 18-9-2024
Revised 21-10-2024
Accepted 5-11-2024
Available online 30-11-2024

E-ISSN: 2622-1640
P-ISSN: 2622-0008

How to cite:
Lubis S, et.al. Analysis of SCWB Ratio on Collapse Probability of SRPMK Concrete Structures. International Journal of Architecture and Urbanism. 2024. 8(3):421-430.

http://doi.org/10.32734/ijau.v8i3.18210

ABSTRACT

The Bank Indonesia Medan Office, built in 1907, is an example of an old building requiring seismic resilience evaluation. This article investigates the impact of the Strong Column-Weak Beam (SCWB) ratio on the collapse probability of SRPMK concrete structures using spectrum response and linear time history analyses. Ground motions from Niigata (Mw 6.63), Tohoku (Mw 9.12), and Miyagi (Mw 7.15) earthquakes were utilized. Findings indicate that the existing structure does not meet seismic resilience standards per SNI 1726:2019 and SNI 2847:2019. Structural modifications are necessary with an SCWB ratio of 1.2 to ensure adequate seismic resistance. The analysis reveals that the largest inter story drift and displacement occur during the Niigata earthquake, while the maximum base shear is recorded in spectrum response analysis. Performance evaluation of the structure shows that the collapse probability remains within the Immediate Occupancy (IO) level. This article underscores the critical role of the SCWB ratio in determining collapse probability and provides recommendations for structural design improvements.

Keywords: erathquake, probability, resilience, SCWB, SRPMK

1. Introduction

The Bank Indonesia Representative Office of North Sumatra Province, which opened on July 30, 1907, underwent enlargement and the construction of a permanent office structure in 1912. Based on this time, it is clear that the building was built by the regulations in effect at the time. The laws governing building and non-building planning have been revised in response to earthquake disasters throughout the year. Therefore, the Bank Indonesia Office Building must be examined using the existing regulations.

The Strong Column-Weak Beam (SCWB) concept is an essential design principle for buildings that are resistant to earthquakes. This principle states that beams should undergo plastic deformation before columns to make a more ductile reaction. This is critical for preventing catastrophic building collapses during seismic occurrences [1] [2] [3].

A special Moment Resisting Frame System (SRPMK) is a type of structure designed to resist earthquake forces by providing high deformation capacity and efficient energy dissipation. In the design of earthquake-resistant buildings, the principle of Strong Column-Weak Beam (SCWB) plays an important role in ensuring that damage occurs in the beam and not in the column, thus avoiding total collapse of the building. SCWB refers to the strength ratio between columns and beams, where columns must have a greater capacity than beams to resist earthquake forces and minimize the risk of structural collapse [4], [5], [6], [7].

The risk of structure collapse rises when the SCWB ratio is not reached, particularly in regions that are prone to earthquakes. Too-low variations in the SCWB ratio can lead to overstressed columns, which raises the risk of structural collapse from lateral pressures during an earthquake. Significant horizontal displacement (inter-story drift) and higher base shear force are two signs of an improper SCWB ratio, which can result in overall structural collapse [8][9][10][11][12].

In addition, evaluation of building performance based on collapse probability is conducted using standards such as ATC-40 and FEMA 356, which classify building damage levels into several categories, including Immediate Occupancy (IO) and Collapse Prevention (CP). Buildings with lower SCWB ratios tend to perform worse, where the probability of collapse increases as the lateral force due to the earthquake increases [13][14].

Given the age of the Bank Indonesia Medan building, it is required to examine its current structural state using updated seismic codes, notably SNI 1726:2019, SNI 2847:2019, and SNI 1727:2020, which are by global standards such as ACI 318.14 [15][16][17]. The inspection will establish whether the building's SCWB ratio, inter-story drift, and foundation shear comply with earthquake resistance standards.

This study will investigate the current structure's Strong Column-Weak Beam (SCWB) ratio, inter-story drift, and seismic base shear. These aspects will be evaluated using the most contemporary Indonesian seismic design guidelines, which incorporate international seismic performance advancements.

2. Method

The methodology utilized in this study is a systematic approach to assessing the seismic performance of the Bank Indonesia Medan building, with an emphasis on the Strong Column-Weak Beam (SCWB) ratio and its effect on the building's collapse likelihood. This section discusses the fundamentals of structural modeling, seismic load analysis, and the methodologies for assessing building performance under various earthquake scenarios.

2.1 Structural modeling

This study will take place in the 10-story Bank Indonesia Medan office, which was built using reinforced concrete. To withstand lateral seismic stresses, the structural system incorporates Special Moment-Resisting Frames (SRPMK) and Special Shear Walls (SDSK). The key design parameters are: Concrete Strength: K-225 kg/cm²; Reinforcement Steel Strength: U32; Seismic Design Coefficients: R=7, Cd=5.5, $\Omega 0$=2.5.

To simulate the building's response to seismic loading, structural modeling was performed using finite element analysis software. The analysis took into consideration the building's material qualities, shape, and site conditions. Fig. 1 (3D image) depicts the building's layout and structural features such as beams and columns.

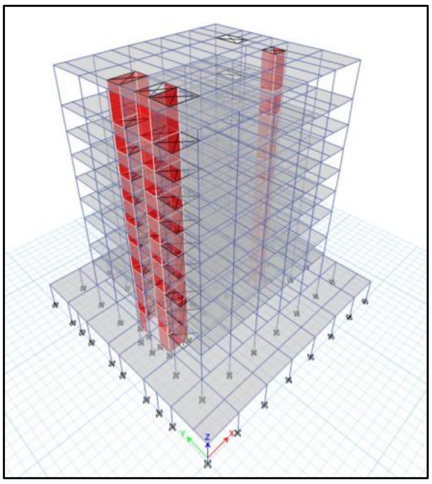
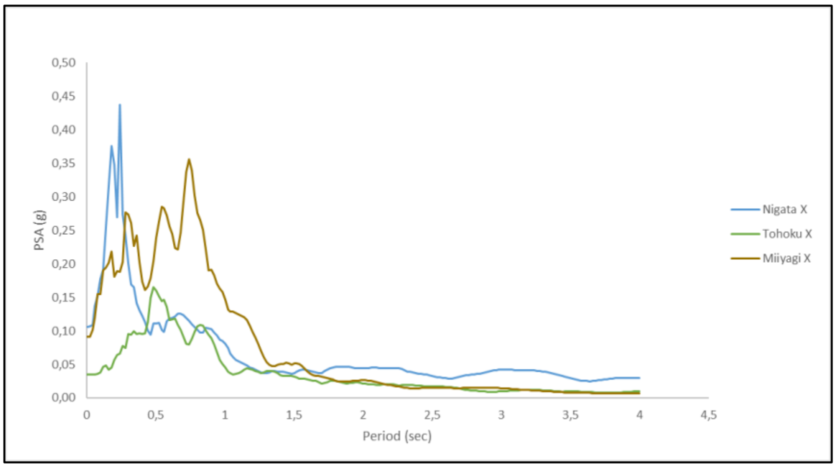


Figure 1 3D view of the building structure

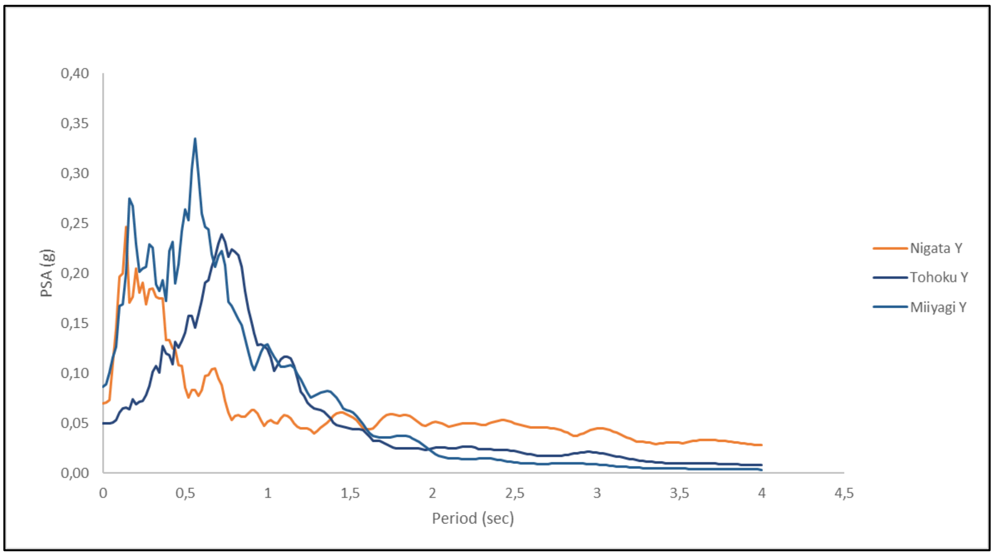
2.2 Seismic Load Analysis

The seismic loads were computed according to SNI 1726:2019 standards, which comprised both response spectrum analysis (RSA) and linear time history analysis (LTHA). The ground motion used is Niigata (Mw. 6.63), Tohoku (Mw. 9.12), and Miyagi (Mw.7.15).

The response spectra were estimated based on SNI recommendations, and the building's seismic performance was assessed for inter-story drifts, base shear, and displacement. The elastic response spectrum (ERS) approach was used to record the building's response to seismic stresses in both the X and Y directions, as shown in Fig. 2 and 3.



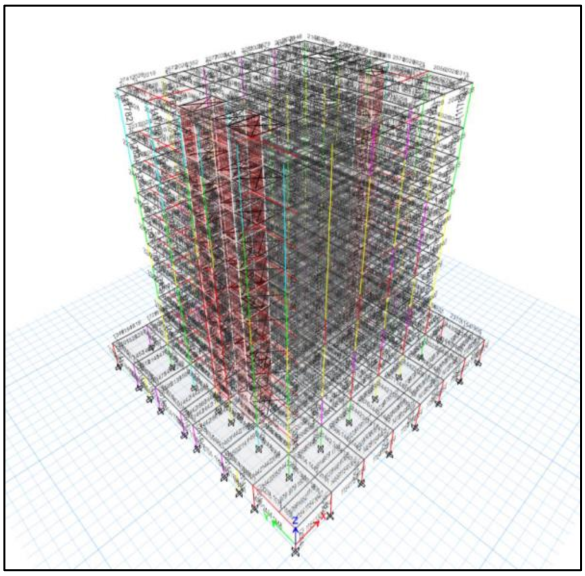
Figures 2 Spectra (ERS) of ground motion in X direction



Figures 3 Spectra (ERS) of ground motion in Y direction

2.3 SCWB Evaluation

The primary objective was to determine the SCWB ratio across different structural components. The SCWB ratio varied between 1.2 and 4.25, and its effect on the building's overall seismic performance was analyzed. Modifications to overstressed elements, particularly beams and columns, were implemented based on the analysis. Fig. 4 shows overstressed beams and columns that required modification.



Figures 4 Beam-column elements are *overstressed*

In addition to analyzing the structural elements, the building was evaluated for torsional irregularities, vertical irregularities (mass), and P-Delta effects under seismic load.

3. Results and Analysis

The analysis evaluates the seismic performance of the existing reinforced concrete structure at Bank Indonesia Medan by examining the strong column-weak beam (SCWB) ratio, inter-story drift, and seismic shear forces. The study incorporates linear response spectrum and time-history analyses using ground motion records from Niigata, Tohoku, and Miyagi earthquakes. The results are discussed based on these parameters.

3.1 Seismic Shear Forces

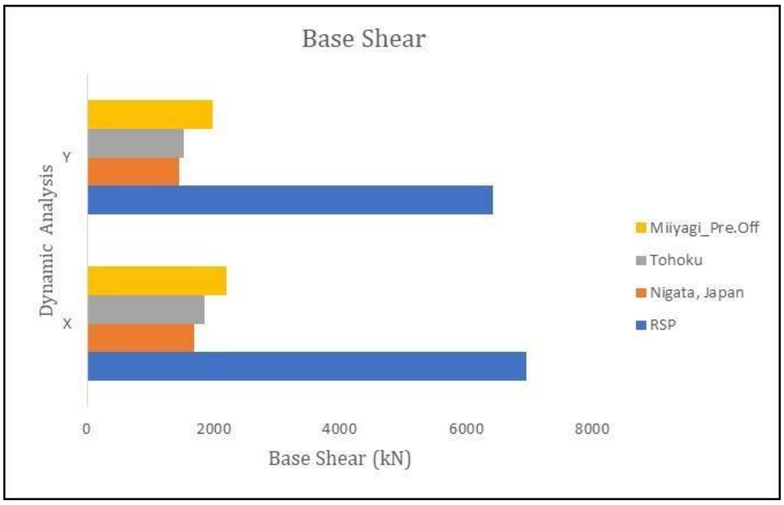
Both the response spectrum and the linear time history technique were used to calculate seismic shear forces. As shown in Table 1, seismic base shear forces in both the X and Y directions were evaluated, and scaling factors were used as needed to meet SNI 1726:2019 standards. The maximum base shear force measured was 6950.42 kN for the response spectrum in the X direction. The minimum was 1699.31 kN for the Niigata earthquake's time-history analysis in the Y direction (see Fig. 5). These values describe the structural response to various ground motion profiles.

3.2 Inter-storey Drift

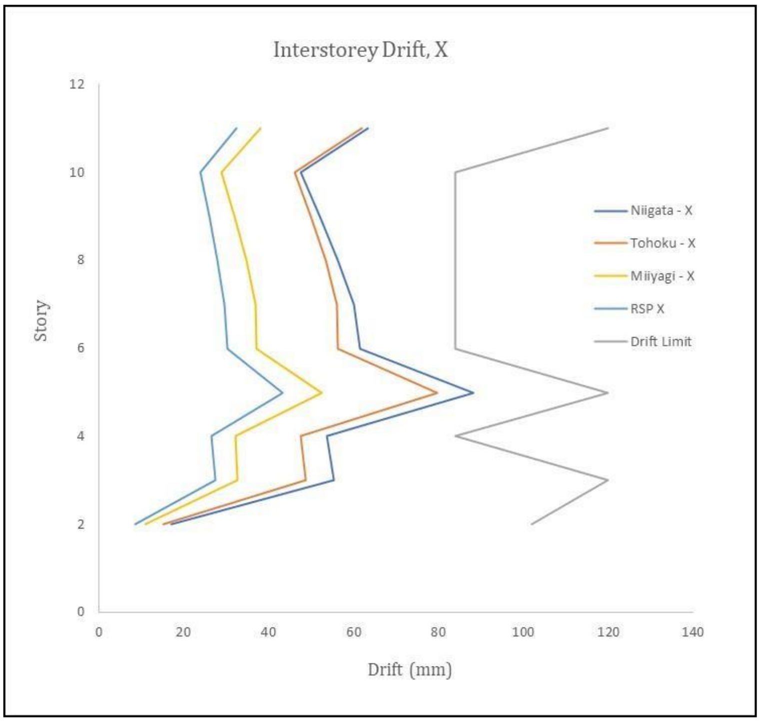
The drift limitations given in SNI 1726:2019 checked the inter-story drift values to ensure that they did not exceed acceptable thresholds. During the Niigata earthquake, the biggest inter-story drift was reported, with values ranging from 88.20 mm to 118.70 mm for various floors of the structure. In contrast, for the city of Medan's response spectrum, the largest drift measured was 44.24 mm, which is still within acceptable limits for immediate occupancy (IO) performance standards (see Figs. 6 and 7).

Table 1 Seismic base shear

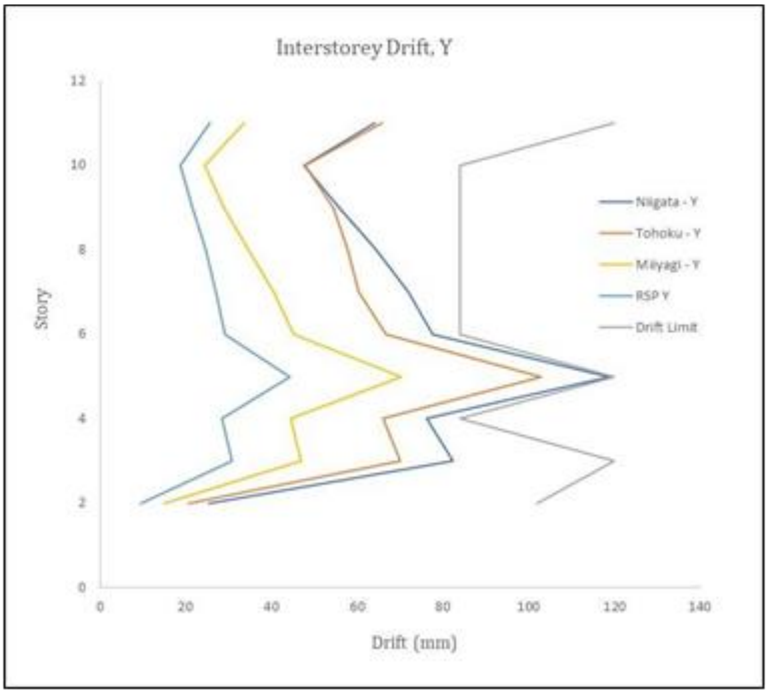
Description	X direction	Y direction
C_s	0,0715	0,0715
W_t (kN)	177176	177176
V_{static} (kN)	12671,08	12671,08



Figures 5 Base shear force



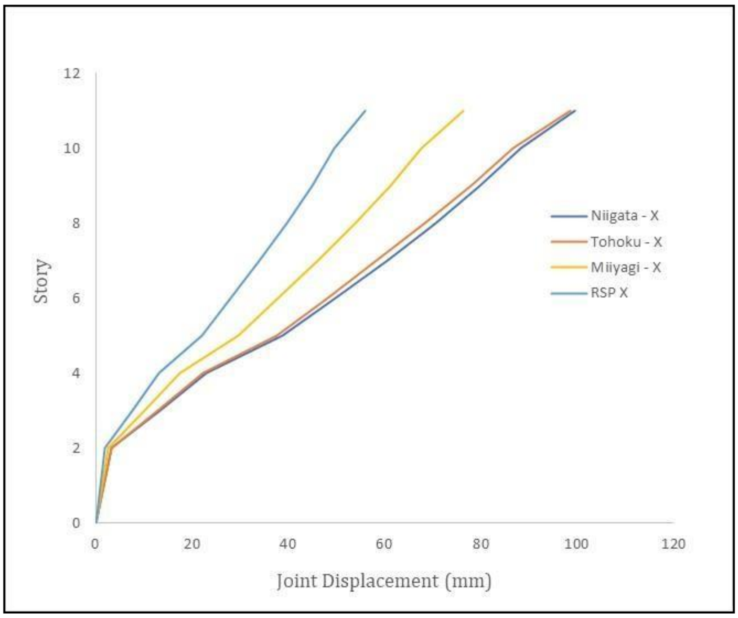
Figures 6 X direction inter-level deviation check



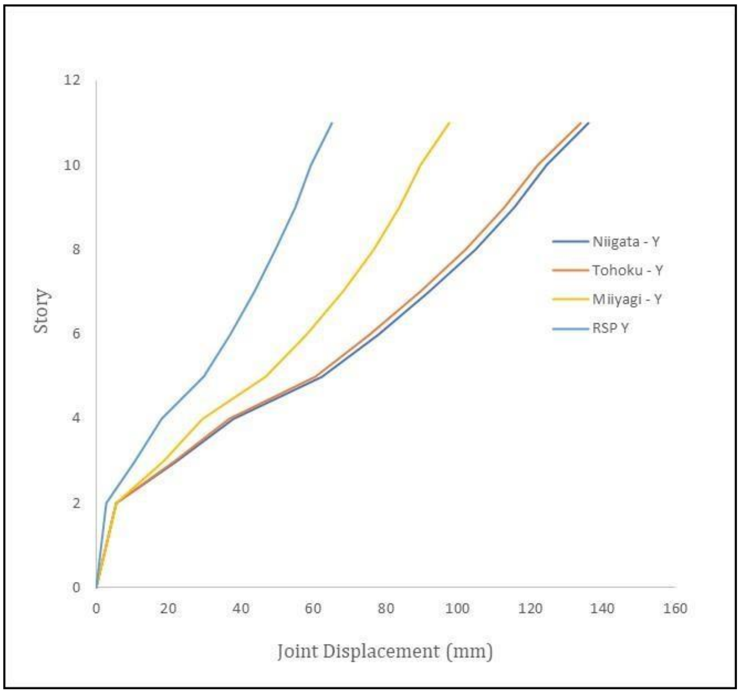
Figures 7 Y direction inter-level deviation check

3.3 Displacement

The combined displacement data for the X and Y axis show the largest displacement during the Niigata earthquake. The maximum displacement in the X direction was 99.44 mm. In the Y direction, it was 136.05 mm, indicating that the structure experiences significant lateral deformation during seismic activity (see Figs. 8 and 9). Despite these displacements, the structure remained structurally sound, demonstrating that the overall design was suitable for seismic loads.



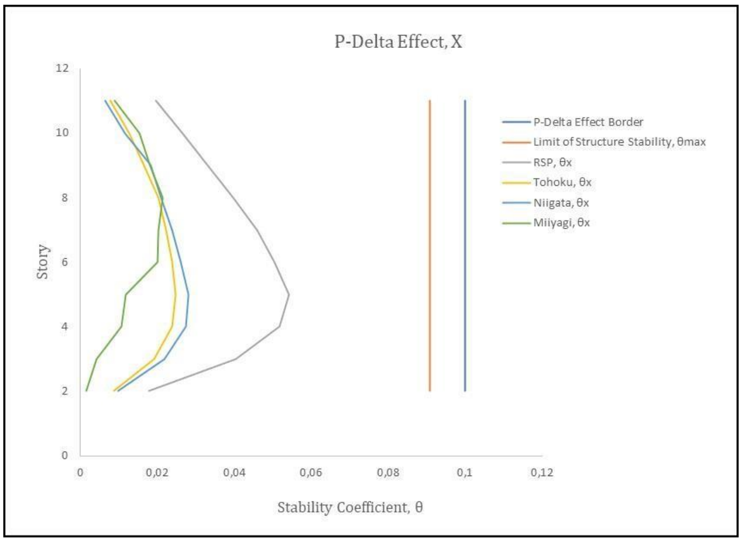
Figures 8 Comparison of *joint displacement* in X direction



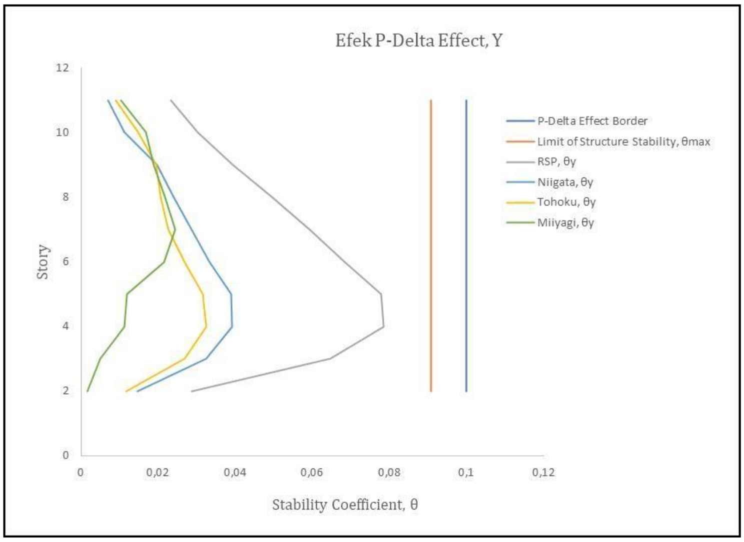
Figures 9 Comparison of *joint displacement* in Y direction

3.4 P-Delta Effects

The P-Delta effect, which accounts for higher moment demands due to lateral displacements, was also studied. According to SNI 1726:2019, the stability coefficient (θ) was found to be within authorized limits (θ < 0.1), indicating that P-Delta influences did not negatively affect the building's structural stability (see Figs. 10 and 11).



Figures 10 X-direction P-Δ effect check



Figures 11 Y-direction P-Δ effect check

3.5 SCWB Ratio and Structural Performance

The SCWB ratio examination discovered that the ratio ranged from 1.2 to 4.25, with some beam-column joints experiencing overstress due to the columns' inadequate strength. This uneven SCWB ratio caused structural issues, particularly in lateral load resistance. To achieve the optimal SCWB ratio and ensure structural compliance with seismic design standards, column size, and material properties should be adjusted.

The building's overall seismic performance was evaluated using the ATC-40 Immediate Occupancy (IO) standards. Despite the large displacements and inter-story drifts, the structure meets the IO performance level, indicating that it can survive seismic shocks without collapsing completely. However, immediate structural repairs are necessary to bring the building up to current seismic resilience standards.

3.6 Discussion

The results highlight that while the existing structure shows some non-compliance with current seismic codes (SNI 1726:2019), particularly in terms of base shear forces and inter-story drift, it maintains immediate occupancy (IO) performance during large seismic events. As recommended, modifications to the SCWB ratio could improve the structural performance by ensuring that the column remains stronger than the beams during plastic hinge formation, thus preventing collapse.

4. Conslussion

The evaluation of the Bank Indonesia Medan building, constructed using outdated seismic design codes, revealed that it does not meet current earthquake resistance standards outlined in SNI 1726:2019 and SNI 2847:2019. The analysis focused on the Strong Column-Weak Beam (SCWB) ratio and its effect on the building's structural performance under seismic loading.

The results showed that the SCWB ratio, which varied between 1.2 and 4.25, significantly determined the building's collapse probability. Many beam-column joints experienced overstress due to insufficient column strength, indicating the need for structural modification to improve the SCWB ratio and prevent premature column failure during seismic events.

Key findings from the analysis of inter-story drift and displacement during ground motions, particularly the Niigata, Tohoku, and Miyagi earthquakes, revealed significant lateral displacements and drifts that exceed allowable limits, further underscoring the building's vulnerability. Maximum base shear values recorded during the response spectrum analysis confirmed that the building is subjected to high seismic forces.

Despite these structural deficiencies, the building's performance level remains within the Immediate Occupancy (IO) category based on the ATC-40 guidelines, meaning the building is still safe but requires urgent structural improvements to comply with modern seismic design standards. Implementing these modifications, especially adjusting the SCWB ratio, will enhance the building's seismic resilience and reduce the probability of collapse in future earthquakes.

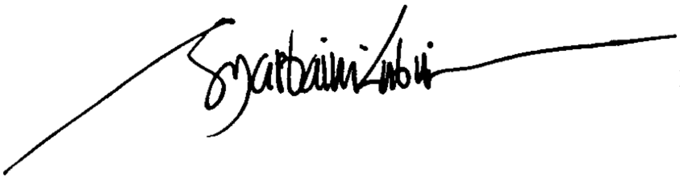
5. Acknowledgements

I conducted this study in collaboration with two more people. We studied the SCWB ratio, inter-story drift, and shear force on existing buildings by national requirements for Indonesia.

6. Conflict of Interest

As confirmed by the authors of the paper, whose names are shown below, there are no conflicts of interest.
Syarbaini Lubis

This form may be photocopied if there are more than ten writers. This declaration is endorsed by the accuracy and correctness of the previously mentioned information:

Author's name	Author's signature	Date
Syarbaini Lubis		18 October 2024

References

[1] X. Nie, S. Zhang, T. Jiang, and T. Yu, "The strong column–weak beam design philosophy in reinforced concrete frame structures: A literature review," Advances in Structural Engineering, vol. 23, no. 16, pp. 3566–3591, Dec. 2020, doi: 10.1177/1369433220933463.

[2] Mr. V. Kadukar, "Study on Literature Review of Strong Column Weak Beam Behavior of Frames," Int J Res Appl Sci Eng Technol, vol. 6, no. 5, pp. 2915–2922, May 2018, doi: 10.22214/ijraset.2018.5476.

[3] M. Ghorbanzadeh and F. Khoshnoudian, “The Effect of Strong Column-Weak Beam Ratio on the Collapse Behaviour of Reinforced Concrete Moment Frames Subjected to Near-Field Earthquakes,” Journal of Earthquake Engineering, vol. 26, no. 8, pp. 4030–4053, Jun. 2022, doi: 10.1080/13632469.2020.1822228.

[4] M. Gong, B. Liu, Z. Zuo, J. Sun, and H. Zhang, “The Influence of the Flexural Strength Ratio of Columns to Beams on the Collapse Capacity of RC Frame Structures,” Buildings, vol. 12, no. 8, p. 1219, Aug. 2022, doi: 10.3390/buildings12081219.

[5] C.-S. Kim, H.-G. Park, and G. T. Truong, “Column-to-beam flexural strength ratio for performance-based design of RC moment frames,” Journal of Building Engineering, vol. 46, p. 103645, Apr. 2022, doi: 10.1016/j.jobe.2021.103645.

[6] G. Maosheng, Z. Zhanxuan, S. Jing, H. Riteng, and Z. Yinan, “Influence of the column-to-beam flexural strength ratio on the failure mode of beam-column connections in RC frames,” Earthquake Engineering and Engineering Vibration, vol. 20, no. 2, pp. 441–452, Apr. 2021, doi: 10.1007/s11803-021-2030-y.

[7] A. Mistri, P. Sarkar, and R. Davis, “Column–beam moment capacity ratio and seismic risk of reinforced concrete frame building,” Proceedings of the Institution of Civil Engineers - Structures and Buildings, vol. 172, no. 3, pp. 189–196, Mar. 2019, doi: 10.1680/jstbu.17.00100.

[8] M. Nahar, K. Islam, and A. M. Billah, “Seismic collapse safety assessment of concrete beam-column joints reinforced with different types of shape memory alloy rebars,” Journal of Building Engineering, vol. 29, p. 101106, May 2020, doi: 10.1016/j.jobe.2019.101106.

[9] H. Kosarzadeh and M. Poursha, “Seismic evaluation of vertically irregular RC frames subjected to mainshock-aftershock sequences of near-fault and far-fault ground motions,” Structures, vol. 49, pp. 1130–1156, Mar. 2023, doi: 10.1016/j.istruc.2023.01.102.

[10] Z. He, Z. Wang, and Y. Zhang, “Collapse safety margin and seismic loss assessment of RC frames with equal material cost,” The Structural Design of Tall and Special Buildings, vol. 27, no. 1, Jan. 2018, doi: 10.1002/tal.1407.

[11] M. F. Gallegos, G. Araya-Letelier, D. Lopez-Garcia, and P. F. Parra, “Collapse Assessment of Mid-Rise RC Dual Wall-Frame Buildings Subjected to Subduction Earthquakes,” Buildings, vol. 13, no. 4, p. 880, Mar. 2023, doi: 10.3390/buildings13040880.

[12] F. Fattahi and S. Gholizadeh, “Seismic fragility assessment of optimally designed steel moment frames,” Eng Struct, vol. 179, pp. 37–51, Jan. 2019, doi: 10.1016/j.engstruct.2018.10.075.

[13] X. Estrella, P. Guindos, and J. L. Almazán, “Ground motions for FEMA P-695 application in subduction zones,” Latin American Journal of Solids and Structures, vol. 16, no. 9, 2019, doi: 10.1590/1679-78255848. International Journal of Architecture and Urbanism Vol. 00, No. 00 (20..) … … 11

[14] B. Ghanbari, M. Fathi, and A. H. Akhaveissy, “Fragility curves for reinforced concrete (RC)/steel vertical hybrid frame structure under mainshock–aftershock sequences,” Journal of Structural Integrity and Maintenance, vol. 8, no. 3, pp. 179–187, Jul. 2023, doi: 10.1080/24705314.2023.2220946.

[15] Badan Standardisasi Nasional, “SNI 1726:2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Nongedung,” 2019.

[16] Badan Standardiasasi Nasional, “SNI 2847:2019: Persyaratan Beton Struktural untuk Bangunan Gedung dan Penjelasan (ACI 318M-14 dan ACI 318RM 14-MOD),” 2019.

[17] Badan Standarisasi Nasional, “SNI 1727:2020: Beban Desain Minimum dan Kriteria Terkait untuk Bangunan Gedung dan Struktur Lain,” Jakarta, 2020.