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Structural Design of a Steel-Framed Office Building with 5–10 Stories in Jakarta

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Abstract This study aims to examine the planning of steel structures for 5 to 10-story office buildings in Jakarta, a region characterized by soft soil conditions and high seismic potential. The methodology employed includes structural analysis based on SNI 1729:2020 (Specification for Structural Steel Buildings) and SNI 1726:2019 (Seismic Resistance Design Procedures), with structural modeling conducted using SAP2000 software. The results indicate that the use of WF (Wide Flange) steel profiles with a Special Moment Resisting Frame (SMRF) system provides optimal structural performance for Jakarta's conditions. The Demand-to-Capacity Ratio (DCR) of all structural elements meets permissible limits with a maximum value of 0.89. The resulting interstory drift does not exceed the 2% limit as stipulated by the applicable standards. This study contributes practical guidelines for selecting steel profile dimensions and configuring structural systems for office buildings in Jakarta.

Keywords *steel structure; office building; Jakarta; SNI 1729:2020; seismic design*

1. INTRODUCTION

Jakarta, the capital city and primary business hub of Indonesia, has experienced rapid growth in the construction of multi-story buildings over the past decade. As the demand for office space continues to increase, steel structures have become the preferred structural system due to their high strength, ductility, and rapid construction capabilities. According to Setiawan (2019), structural steel grades BJ 41 and BJ 50 are the most commonly used materials in Indonesian building construction because of their widespread market availability and compliance with the Indonesian National Standards (SNI). Data published by Statistics Indonesia (BPS) indicate that between 2022 and 2023, more than 150 new office building projects were developed across Central, South, and West Jakarta, with the majority employing steel structural systems.

Despite this significant development, the design of office buildings in Jakarta presents substantial engineering challenges. The city is predominantly underlain by soft alluvial deposits, corresponding to Site Classes SE (soft soil) and SF (very soft soil) as defined in SNI 1726:2019 (National Standardization Agency of Indonesia, 2019). These geotechnical conditions considerably amplify seismic ground motions, particularly for medium-rise buildings whose natural vibration periods coincide with the amplified response of soft soils. Qodri (2020) reported that the design spectral acceleration parameters (SDS and SD1) in North Jakarta may be 1.5–2.0 times higher than those in South Jakarta because of site amplification effects. Consequently, reliable geotechnical investigations and accurate site classification are fundamental prerequisites for earthquake-resistant structural design in Jakarta.

The structural design of medium-rise steel buildings (5–10 stories) requires careful selection of an appropriate lateral force-resisting system capable of efficiently resisting both seismic and wind loads. Among the available structural systems, the Special Moment Resisting Frame (SMRF) is the most widely adopted because of its superior ductility and energy dissipation capacity during strong earthquake events, as specified in SNI 1729:2020 and SNI 1726:2019. Buildings located in high seismic hazard regions such as Jakarta require high response modification factors (R), which can generally be achieved through the implementation of SMRF systems or Steel Plate Shear Walls (SPSWs) (Wijanto et al., 2017). The Indonesian steel design standard, SNI 1729:2020, is largely based on AISC 360-16, while SNI 1726:2019 adopts provisions from ASCE/SEI 7-16 for seismic design. Together, these standards require designers to account for structural ductility, overstrength factors (Ω_0), and seismic detailing requirements to ensure adequate structural performance under earthquake loading (Setiawan, 2019; National Standardization Agency of Indonesia, 2019).

Previous studies have investigated the seismic performance of various steel structural systems in Indonesian buildings. A comparative analysis of an eight-story office building in Jakarta demonstrated that the SMRF system exhibited larger interstory drifts but achieved more uniform energy dissipation throughout the structure, resulting in superior seismic performance. In contrast, the Concentrically Braced Frame (CBF) system provided greater lateral stiffness and lower material costs but showed higher stress concentrations at beam-column connections (Perhitungan & Gedung, 2024). Furthermore, Freitas (2025) reported that composite beam–concrete slab systems utilizing shear connectors increased the effective flexural stiffness of steel beams by approximately 30–40%, allowing one level of beam section reduction without compromising structural safety. Nevertheless, these studies have not comprehensively integrated Jakarta's soft-soil conditions with the selection of steel structural systems and the evaluation of seismic performance for medium-rise office buildings ranging from five to ten stories.

Based on these considerations, this study aims to: (1) determine the most appropriate steel structural system for 5–10-story office buildings in Jakarta in accordance with the requirements of SNI 1729:2020 and SNI 1726:2019; (2)

evaluate the structural performance of the proposed building through interstory drift analysis and demand-to-capacity ratio (DCR) assessment under seismic loading; and (3) recommend optimum steel member sections suitable for Jakarta's soft-soil conditions and seismic demands. The findings of this study are expected to provide practical guidance for structural engineers, contractors, and construction stakeholders in Jakarta while contributing to the advancement of earthquake-resistant steel structural design for medium-rise buildings constructed on soft-soil sites.

2. RESEARCH METHODS

This study employed a quantitative approach based on structural analysis using numerical modeling. The research workflow consisted of defining the case-study building, determining structural loading in accordance with the applicable Indonesian National Standards (SNI), developing a three-dimensional structural model using SAP2000, and evaluating the structural performance against the requirements specified in SNI 1729:2020 and SNI 1726:2019.

2.1. Building Description

The case study considered an eight-story office building located within Jakarta's Golden Triangle business district, South Jakarta. The building has a typical rectangular floor plan measuring 30 m × 20 m. Each story has a floor-to-floor height of 4.0 m, resulting in a total structural height of 32.0 m. The building is designed as a Grade-A office building with a roof live load of 0.96 kN/m² and a typical floor live load of 2.40 kN/m². The general specifications of the building are presented in Table 1.

Table 1. General Specifications of the Case-Study Building

Parameter	Value / Description
Number of Stories	8 stories
Floor Plan Dimensions	30 m × 20 m
Story Height	4.0 m
Total Building Height	32.0 m
Location	South Jakarta (Moderate-to-High Seismic Zone)
Site Class	SE (Soft Soil) – SNI 1726:2019
Structural Steel	BJ 41 (fy = 250 MPa, fu = 410 MPa)
Bolt Grade	ASTM A325 (Ø22 mm)
Lateral Force-Resisting System	Special Moment Resisting Frame (SMRF) – SNI 1729:2020
Structural Analysis Software	SAP2000 Version 23

2.2. Structural Loading

The structural loading adopted in this study followed the provisions of SNI 1727:2020, Minimum Design Loads for Buildings and Other Structures (National Standardization Agency of Indonesia, 2020a). The dead load (DL) included the self-weight of the steel structure, which was automatically calculated by the analysis software, together with an additional superimposed dead load (SDL) of 2.0 kN/m² representing the composite concrete slab, floor finishes, partitions, and suspended ceiling systems.

Wind loading was determined based on a basic wind speed of 25 m/s, as specified for the Jakarta region, assuming Exposure Category B, which represents an urban environment. Seismic loading was evaluated using the Response Spectrum Analysis (RSA) procedure in accordance with SNI 1726:2019 (National Standardization Agency of Indonesia, 2019). The seismic hazard parameters adopted were a short-period spectral acceleration of Ss = 0.75g and a one-second spectral acceleration of S1 = 0.30g, obtained from the 2017 Indonesian Seismic Hazard Map.

2.3. Structural Modeling and Analysis

A three-dimensional structural model was developed using SAP2000 Version 23. Beams and columns were modeled as frame elements with fixed-base boundary conditions at the column supports. Beam-to-column joints within the Special Moment Resisting Frame (SMRF) system were modeled as fully rigid connections, incorporating column panel-zone behavior in accordance with the detailing requirements specified in SNI 1729:2020 (National Standardization Agency of Indonesia, 2020b). Floor slabs were idealized as rigid diaphragms to ensure appropriate distribution of lateral loads among the lateral force-resisting elements. The structural analysis consisted of three stages:

a. Linear static analysis to evaluate the effects of gravity load combinations;
b. Modal analysis to determine the natural vibration periods and mode shapes of the structure; and
c. Response Spectrum Analysis (RSA) to evaluate the seismic response and the distribution of earthquake-induced forces throughout the building.

The load combinations were established in accordance with the Load and Resistance Factor Design (LRFD) methodology prescribed in SNI 1727:2020 and SNI 1729:2020 (National Standardization Agency of Indonesia, 2020a; 2020b). The critical load combinations considered in this study were:

a. 1.2DL + 1.6LL + 1.0SDL
b. 1.2DL + 1.0LL + 1.0E

where DL denotes the dead load, LL the live load, SDL the superimposed dead load, and E the seismic load.

3. RESULTS

3.1. Modal Analysis and Fundamental Natural Period

The modal analysis indicated that the fundamental natural period (T_1) of the eight-story office building was 1.24 s in the X-direction (transverse) and 1.18 s in the Y-direction (longitudinal). The first vibration mode was dominated by lateral translation in the X-direction, with a modal mass participation ratio of 78.3%, whereas the second mode, corresponding to translation in the Y-direction, achieved a modal mass participation ratio of 76.9%. In accordance with the requirements of SNI 1726:2019, the cumulative modal mass participation exceeded 90% after considering the first twelve vibration modes, thereby satisfying the minimum code requirements. A summary of the modal analysis results is presented in Table 2.

Table 2. Summary of Modal Analysis Results

Mode	Period (s)	Frequency (Hz)	MP-X (%)	MP-Y (%)
1	1.24	0.806	78.3	1.2

2	1.18	0.847	2.1	76.9
3	0.98	1.020	0.8	1.4
4	0.41	2.439	10.2	0.9
5	0.39	2.564	0.5	10.5

3.2. Interstory Drift Analysis

Interstory drift is one of the most critical structural performance indicators for assessing both the safety and serviceability of buildings subjected to seismic loading. According to Section 7.12.1 of SNI 1726:2019, the allowable interstory drift (Δ_a) for office buildings classified as Risk Category II is limited to 0.020h_{sx}, where h_{sx} denotes the story height. Excessive interstory drift at any level may indicate the presence of a soft-story mechanism that could trigger undesirable structural failure during strong earthquakes (Afif Salim, 2022). The analysis results revealed that the maximum interstory drift occurred at the fourth floor in the X-direction, reaching 0.0148h_{sx} (74% of the allowable limit), while the maximum drift in the Y-direction occurred at the fifth floor, with a value of 0.0162h_{sx} (81% of the allowable limit). The complete drift results are summarized in Table 3. The relatively uniform drift distribution over the building height indicates the absence of a soft-story mechanism, demonstrating satisfactory seismic performance consistent with the recommendations of Afif Salim (2022).

Table 3. Structural Loads and Interstory Drift Results

loor	**DL (kN/m²)**	**LL (kN/m²)**	**Δx (h_{sx})**	**Δy (h_{sx})**	**Status**
1	5.00	2.40	0.0082	0.0079	Pass
2	5.00	2.40	0.0115	0.0109	Pass
3	5.00	2.40	0.0136	0.0128	Pass
4	5.00	2.40	0.0148	0.0141	Pass
5	5.00	2.40	0.0143	0.0162	Pass
6	5.00	2.40	0.0131	0.0147	Pass
7	5.00	2.40	0.0118	0.0133	Pass
Roof	3.00	0.96	0.0072	0.0085	Pass

3.3. Member Design, Connection Design, and Demand-to-Capacity Ratio (DCR)

Based on the internal force analysis, including axial force, shear force, and bending moment, the recommended steel member sections are presented in Table 4. Columns on Floors 1–4 were designed using WF 400 × 400 × 13 × 21 sections with a factored axial compressive capacity of φcPn = 5,840 kN, exceeding the maximum design axial load of 4,920 kN. Columns on Floors 5–8 employed WF 350 × 350 × 12 × 19 sections. The primary transverse beams utilized WF 450 × 200 × 9 × 14 sections, whereas the longitudinal beams adopted WF 400 × 200 × 8 × 13 sections. The total structural steel consumption was 42.3 kg/m² of gross floor area, which falls within the typical range of 35–55 kg/m² reported for comparable office buildings in Indonesia (Damara et al., 2026).

Table 4. Steel Member Design and Demand-to-Capacity Ratio

Structural Member	Steel Section	Capacity	Design Force	DCR
Columns (Floors 1–4)	WF 400 × 400 × 13 × 21	φcPn = 5,840 kN	Pu = 4,920 kN	0.87
Columns (Floors 5–8)	WF 350 × 350 × 12 × 19	φcPn = 4,650 kN	Pu = 3,210 kN	0.69
Primary Transverse Beam	WF 450 × 200 × 9 × 14	φbMn = 487 kN·m	Mu = 423 kN·m	0.89
Primary Longitudinal Beam	WF 400 × 200 × 8 × 13	φbMn = 398 kN·m	Mu = 348 kN·m	0.82

All beam-to-column connections were designed as fully restrained moment connections in accordance with the requirements for Special Moment Resisting Frames (SMRFs). The strong-column–weak-beam criterion specified in Section F1 of SNI 1729:2020 was satisfied for all joints, with a minimum strength ratio of ΣMpc/ΣMpb = 1.42 (BSN, 2020). The connections employed ASTM A325 high-strength bolts with a diameter of 22 mm, and the required number of bolts was determined based on the design shear and moment demands. Following the seismic detailing provisions of Section F5 of SNI 1729:2020, the moment connections were designed to resist 110% of the beam plastic moment capacity. Consequently, a haunch welded flange (HWF) connection configuration was adopted to relocate the plastic hinge away from the column face. For the critical beam-to-column joints located on Floors 1–4, each flange was connected using two rows of eight bolts, providing a moment capacity of 487 kN·m, which exceeded the plastic moment capacity of the WF 450 × 200 beam (Mp = 423 kN·m). Demand-to-Capacity Ratio (DCR) evaluations were performed for all structural members under the governing load combinations. The maximum DCR for the columns was 0.87, occurring at the interior ground-floor columns, whereas the maximum beam DCR reached 0.89 in the primary beam at the third floor. Since all DCR values were below the allowable limit of 1.0, every structural member satisfied the strength requirements specified in SNI 1726:2019, indicating adequate structural safety against capacity failure. These findings are also consistent with the construction guidelines for multi-story buildings reported by Manurung and Hartanto (2025).

3.4. Material Efficiency

The total steel consumption of the structural system was calculated as 42.3 kg/m² of gross floor area, which lies within the typical range of 35–55 kg/m² reported for medium-rise office buildings in Indonesia (BSN, 2020). Compared with buildings employing Concentrically Braced Frames (CBFs), the use of an SMRF increased the structural steel weight by approximately 8–12%, primarily because larger member sections were required to satisfy the strong-column–weak-beam criterion (Perhitungan & Gedung, 2024).

Although this resulted in higher material costs, the increase was compensated by significantly improved seismic performance and a reduced risk of brittle failure during major earthquake events, making the SMRF system a more reliable structural solution for high-seismic regions (Sinaga et al., 2022). Furthermore, the implementation of composite beam–concrete slab systems using 19-mm stud shear connectors increased the effective flexural stiffness of the beams by approximately 30–40%, allowing one level reduction in beam section size without compromising structural safety. This finding is consistent with previous studies identifying composite construction as an effective strategy for improving steel efficiency in office buildings located within moderate- to high-seismic zones (Manurung & Hartanto, 2025; Freitas, 2025).

3.5. Geotechnical Considerations for Jakarta

Jakarta is predominantly underlain by soft clay deposits characterized by Standard Penetration Test (SPT) values of $N < 5$ within the upper 0–15 m, presenting considerable challenges for foundation design (Qodri, 2020). The present study utilized Cone Penetration Test (CPT) data obtained from the project site, which indicated average cone resistance (qc) values ranging from 0.5 to 1.5 MPa within the upper soil layers. For the eight-story office building, with a maximum column axial load of 4,920 kN, a 400-mm-diameter steel pipe pile foundation with a length of 28 m was selected. The piles were designed to penetrate the soft clay deposits and terminate in a competent bearing stratum with $qc > 10$ MPa, thereby providing sufficient axial bearing capacity and minimizing settlement. Differential settlement was evaluated using Terzaghi's consolidation theory. The predicted consolidation settlement ranged from 45 to 60 mm during the first ten years of service, while the maximum differential settlement between adjacent columns was estimated at 12 mm, remaining below the allowable limit of L/500 for office buildings. Accordingly, the combination of deep pile foundations and reinforced concrete tie beams measuring 400 × 600 mm is strongly recommended to mitigate differential settlement and preserve the structural integrity of the superstructure under Jakarta's soft-soil conditions.

4. CONCLUSIONS

The Special Moment Resisting Frame (SMRF) system utilizing wide-flange (WF) steel sections proved to be an appropriate structural solution for an eight-story office building in Jakarta due to its superior seismic energy dissipation capacity and its compliance with the strong-column–weak-beam requirements specified in SNI 1729:2020. The structural performance under seismic loading was found to be satisfactory, as evidenced by a maximum interstory drift ratio of 0.0162h_{sx} (81% of the allowable limit) and a maximum Demand-to-Capacity Ratio (DCR) of 0.89, both of which remained below the acceptance criteria prescribed by SNI 1726:2019. The recommended structural members consist of WF 400 × 400 × 13 × 21 sections for the lower-story columns and WF 450 × 200 × 9 × 14 sections for the primary beams. The resulting steel consumption of 42.3 kg/m^2 of gross floor area is considered efficient and falls within the typical range reported for medium-rise office buildings in Indonesia. Considering Jakarta's predominantly soft-soil conditions, the use of 400-mm-diameter steel pipe pile foundations with a penetration depth of 28 m, combined with reinforced concrete tie beams, is recommended as an effective foundation system to ensure adequate structural stability and control differential settlement.Future research should investigate the seismic performance of similar structures using nonlinear static (pushover) analysis to evaluate structural behavior under the Maximum Considered Earthquake (MCE) level. In addition, soil–structure interaction (SSI) effects should be incorporated into the analytical model, as Jakarta's soft-soil conditions may significantly influence the dynamic response and seismic performance of steel buildings. Further studies are also encouraged to implement Reliability-Based Design Optimization (RBDO) to identify the most economical structural configuration while maintaining the required levels of safety and reliability. From a practical perspective, structural engineers and construction practitioners in Jakarta should prioritize comprehensive geotechnical investigations—including deep borehole drilling, Cone Penetration Tests (CPT), and laboratory soil testing—prior to structural design to ensure that foundation systems are appropriately selected based on site-specific subsurface conditions.

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