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Structural Integrity Analysis of Reinforced Concrete Hotel Wing Accommodating Elevated Swimming Pool

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Abstract

Although reinforced concrete hotel design has received considerable attention, research addressing the interaction between vertical public live loads and elevated swimming pool hydrostatic loads on asymmetric wing structures in hilly topographies remains limited. This study aims to evaluate the structural integrity, load distribution, and section capacity of a hotel wing's upper structural system (slabs, beams, columns) under gravity, fluid, and environmental loads per Indonesian National Standards (SNI). A quantitative descriptive computational evaluation design was employed, selecting upper structural elements through purposive sampling. Data from archival documentation-shop drawings, material specifications (f'c, fy), and planning records—were analyzed via 3D finite element modeling in SAP2000 v26 to evaluate internal forces (Mu, Pu, Vu) and demand-to-capacity ratios (D/C) under ultimate load combinations (U = 1.2D + 1.6L + 1.2F) per SNI 1727:2020, SNI 1726:2019, and SNI 2847:2019. Findings indicate effective load transfer with demand-to-capacity ratios within safe limits (D/C ≤ 1.0). Critical force concentrations-maximum flexural moment (Mu,33), axial compression (Pu), and shear (Vu,22)-occur at Frame Object 57 due to eccentric hydrostatic loading combined with public live loads. These findings advance understanding of multi-axial load transfer in elevated leisure facilities. The conclusion highlights the necessity of precise hydrostatic modeling and section verifications for modified commercial buildings. Practical implications offer guidance for engineers and hotel management in structural safety assurance, while theoretical contributions enrich structural auditing literature. Future research should explore full-coupled soil-structure interaction (SSI) and nonlinear dynamic pushover analysis under severe seismic excitation.

Keywords: Structural Evaluation; Reinforced Concrete; Elevated Swimming Pool; Hydrostatic Load; SAP2000 v26

INTRODUCTION

The rapid growth of the tourism sector in mountainous highland regions directly implies a surging demand for accommodation and recreational facilities that are representative, safe, and highly aesthetically appealing. In this context, public areas in hotel buildings play a vital role as hubs of high visitor accumulation and mobility. Such conditions necessitate that the structural planning for public area wing buildings be meticulously, measurably, and precisely designed to guarantee the strength, stability, and serviceability required for building occupants. The complexity of this planning is further heightened given that the construction site is situated in extreme topography characterized by high vulnerability to lateral seismic forces and site-specific hilly soil conditions, which frequently induce severe structural asymmetry and torsional response amplification (Fotopoulou, 2012; Jarapala & Menon, 2023; Pathak & Gupta, 2025; Vielma et al., 2025). Structural failure in public facilities not only risks comprehensive physical damage to the building, but can also lead to fatal loss of human life and trigger massive economic losses, stemming from both reconstruction costs and widespread operational business disruptions.

The primary urgency of this study stems from the pressing need for a comprehensive technical evaluation of existing building structures undergoing significant renovation and functional additions, particularly regarding the integration of an elevated swimming pool that distributes massive fluid loads to the upper structure. Theoretical and empirical investigations confirm that upper-floor fluid containment structures impose substantial hydro-mechanical stresses, altering the fundamental dynamic properties of building frames (Gong et al., 2024; Salyamova & An, 2025). The addition of hydro-mechanical loads on the upper floor directly triggers a complex redistribution and shift in internal force patterns—such as flexural moments, shear forces, and axial forces—that are frequently unaccounted for in initial design calculations. In response to these technical challenges, an analytical audit based on modern computer modeling was conducted to precisely verify that the structural planning and retrofitting fully comply with prevailing national regulatory frameworks. This quantitative evaluation utilizes finite element analysis to examine Demand/Capacity (D/C) ratios and dynamic structural behavior, thereby ensuring that the reliability and safety of the post-renovation structure are scientifically validated and defensible.

The discourse surrounding the design and evaluation of reinforced concrete structures in multi-story accommodation buildings has been extensively explored by prior researchers. Khafi and Farlianti (2026) specifically investigated earthquake-resistant hotel structural design to mitigate potential risks of lateral force damage. On the other hand, Magfiroh et al. (2025) and Figo et al. (2025) focused their analyses on energy absorption efficiency and the performance of moment-resisting frame systems, including Special Moment Resisting Frames (SMRF) and Intermediate Moment Resisting Frames (IMRF) in commercial buildings. Meanwhile, optimizing structural element dimensions and meeting flexural and shear reinforcement requirements in multi-story buildings formed the core focus of studies by Damara et al. (2026) and Nazarudin et al. (2025). Nevertheless, a significant research gap remains in the existing literature. Most previous studies have focused on symmetric building geometries with standard floor loading. There is a lack of comprehensive inquiry specifically evaluating complex load interactions—namely the combination of dynamic public live loads and massive hydrostatic pool loads—on hotel wing structures built on hilly terrain using state-of-the-art finite element software such as SAP2000 v26.

The novelty of this research lies in the high-precision modeling and performance evaluation of a public wing structure supporting an elevated swimming pool under hilly topographic conditions characterized by unique soil responses and seismic response spectra, analyzed using SAP2000 v26. Theoretically, this study is built upon a solid foundation of engineering mechanics. It integrates Finite Element Method (FEM) theory to model three-dimensional spatial behavior and the interactions among beams, columns, and slabs under combined static and dynamic loads, an analytical strategy widely validated for post-renovation structural integrity audits (Li et al., 2020). Furthermore, fluid mechanics and hydrostatic principles are applied to account for water pressure and fluid dead load distribution onto supporting elements. The entire analytical workflow strictly adheres to national regulatory frameworks, including the Indonesian National Standards for minimum design loads (SNI 1727:2020), seismic design procedures (SNI 1726:2019), and structural concrete requirements for buildings (SNI 2847:2019).

The primary focus of this study is directed toward a thorough evaluation of the upper structural system, encompassing slab, beam, and column elements, in response to combined gravity loads (dead load, superimposed dead load, dynamic public live load, and hydrostatic fluid load) and environmental loads in the form of dynamic lateral seismic excitations. Based on this focus, the research objectives are formulated into three narrative stages. First, this study aims to identify and map the existing structural system alongside its supporting element configurations. Second, it aims to precisely calculate the magnitude of working loads acting on the structure in accordance with prevailing national standards, including massive fluid loads and site-specific seismic response spectra. Third, it aims to analyze and evaluate compliance with structural stability and strength requirements per Indonesian National Standards (SNI), measured through element capacity ratios, interstory drift limits, and safety assurances against premature structural failure.

METHODS

This study employs a quantitative research design with a descriptive analytical approach. The descriptive-quantitative approach was selected to measure, examine, and evaluate the mechanical performance and structural capacity of building elements in an absolute, measurable manner based on technical engineering parameters. Through this research design, all phenomena regarding loading, internal force distributions, section capacities, and dynamic structural behavior were modeled and calculated computationally. This aims to provide a precise evaluative representation of the reliability and safety levels of the existing building structure without performing physical experimental manipulations in the field (Abdelwahab et al., 2026).

The subject of this study encompasses the entire upper structural system of the existing hotel public area wing building. Subject selection was conducted through purposive subject selection, focusing specifically on primary structural elements bearing critical load responses, including floor slab components (specifically slabs supporting the elevated pool), secondary beams, primary beams, and supporting columns. The selection of these elements is based on their vital role in simultaneously transferring combinations of gravity loads (static and hydrostatic loads) and environmental loads (dynamic seismic loads) to the substructure (Abdelaziz et al., 2024).

Data collection in this study was executed comprehensively through archival research methods. The data collection focused on compiling validated secondary technical documents from the contractor and structural design consultants, an established approach for accurate spatial reconstruction of existing structures (Vesho et al., 2024). The gathered data included:

1. **Shop Drawings:** Used to accurately reconstruct the 3D spatial geometry of the building, element spans, slab thicknesses, beam and column dimensions, and interstory elevations.

2. **Material Technical Specifications:** Comprising detailed data regarding concrete compressive strength (f'c) and yield strength of reinforcing steel (fy) installed in the existing structure.

3. **Planning and Topographic Data:** Supporting documents from the contractor presenting information on existing site conditions and initial structural design parameters.

Data analysis was carried out quantitatively and systematically through a structured computational workflow divided into four main stages:

1. **Data Identification and Classification:** In the initial stage, raw data regarding building geometric parameters, detailed cross-sectional dimensions of structural elements, and mechanical property values of reinforced concrete materials (f'c and fy) were categorized and reconciled.

2. **Loading Analysis:** This stage involved mathematical calculations of all working loads acting on the structure. Computations for dead load, superimposed dead load, public area live load, and pool water hydrostatic load were calculated per SNI 1727:2020. Meanwhile, dynamic seismic load analysis was computed based on site-specific response spectrum parameters referenced from SNI 1726:2019.

3. **Numerical Modeling:** A three-dimensional (3D) spatial model was developed using SAP2000 Version 26 finite element analysis software. This step encompassed defining material characteristics (f'c and fy), configuring section types (frame sections for beam/column elements and area sections for slabs), establishing fixed support boundary conditions at column bases, and assigning ultimate limit state load combinations to capture full 3D structural behavior under combined hydrostatic and dynamic loads (Li, 2025).

4. **Structural Analysis and Evaluation:** Execution of the computational analysis (run analysis) was performed to obtain internal structural responses in the form of ultimate internal forces, including flexural moment (Mu), axial force (Pu), and shear force (Vu). The resulting internal forces were subsequently evaluated against factored nominal section capacities to verify compliance with safety margins and structural reliability based on the SNI 2847:2019 standard (Structural Concrete Requirements for Buildings) (Luo et al., 2024).

RESULTS

Main Findings

Numerical modeling analysis based on 3D finite element methods using SAP2000 Version 26 yields the mechanical response characteristics and structural performance of the public area wing building as follows:

Geometry and Structural System: The building's structural system is categorized as a reinforced concrete frame system. The floor slab component configurations are designed with thickness variations of t1, t2, and t3, primary beam dimensions up to b x h, and main supporting column elements with an as-built concrete compressive strength specification of f'c.

Load Distribution: Dead loads (D) were automatically calculated based on element self-weight and superimposed dead loads (SIDL), which consist of floor and ceiling finishing materials. Public area live loads (L) were assigned as qL based on high visitor mobility estimates. Meanwhile, the swimming pool water hydrostatic load (F) on the elevated upper floor structure reached a maximum value of qw.

Ultimate Internal Force Responses (Combination U = 1.2D + 1.6L + 1.2F):

a. Flexural Moment (M33): The maximum ultimate flexural moment Mu,33 was detected at Frame Object 57, indicating that this beam/column element bears the most critical flexural effect resulting from combined gravity and fluid loading.

b. Axial Force (Pu): The maximum axial compressive load Pu was recorded at its critical value on Frame Object 57, demonstrating the accumulation of total gravity loads from upper floors and the swimming pool transferred to this main column.

c. Shear Force (Vu,22 and Vu,33): The maximum section shear force Vu,22 reached a critical shear value at Frame Object 57, whereas the maximum out-of-plane shear force Vu,33 was recorded as a secondary shear value at Frame Object 117.

Visualizations of the numerical modeling analysis were extracted from SAP2000 software to illustrate internal force distributions and spatial behavior of the public area wing building structure:

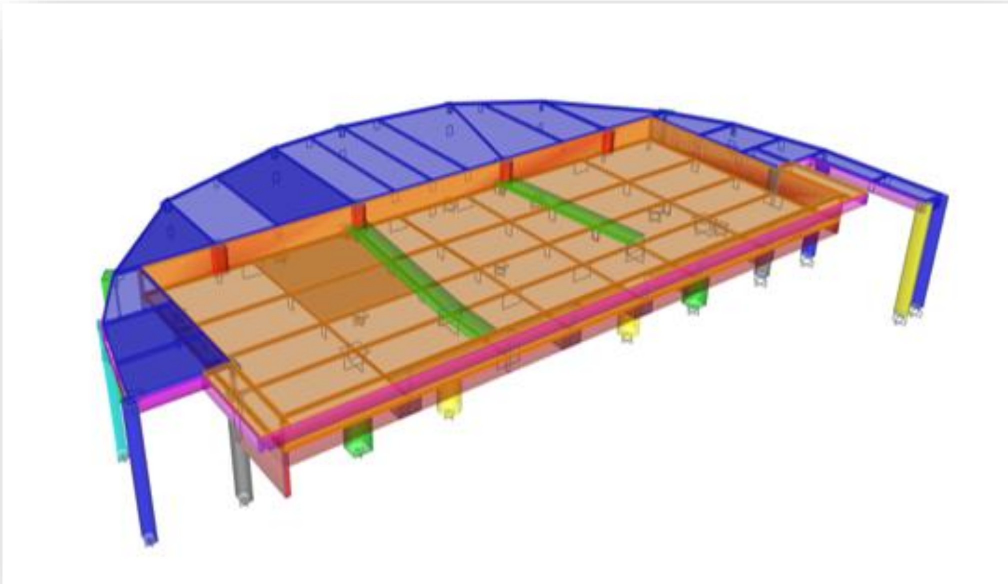


Figure 1 (3D Structural Element Visualization of the Public Area Wing Building Using SAP2000)

Displays the complete three-dimensional portal model including frame section definitions (beams and columns), area section definitions (slabs and pool walls), fixed support boundary conditions at the base, and zoning of swimming pool load assignments on the upper floor structure.

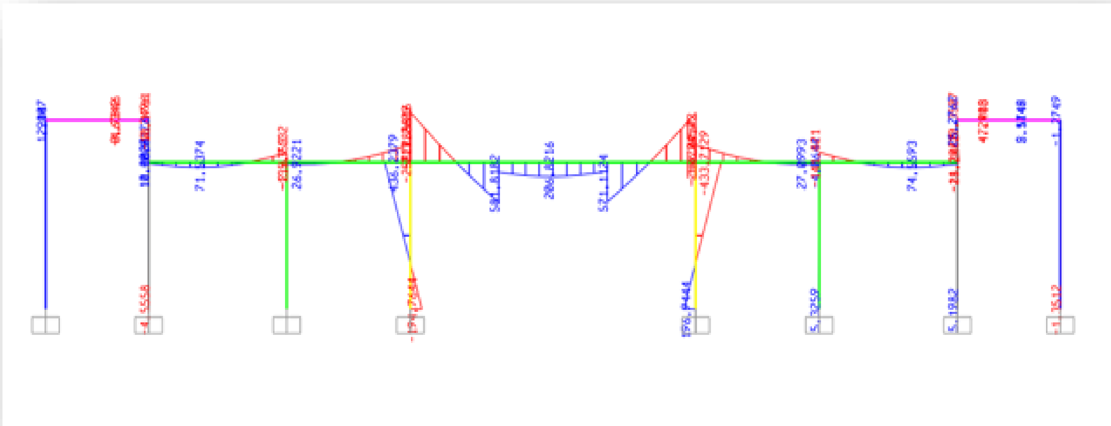


Figure 2 (Moment 3-3 Diagram X-Z)

Shows contours and distribution diagrams of primary flexural moments in the X-Z plane. The highest flexural moment concentration is identified at Frame Object 57, requiring a higher flexural reinforcement ratio compared to surrounding elements.

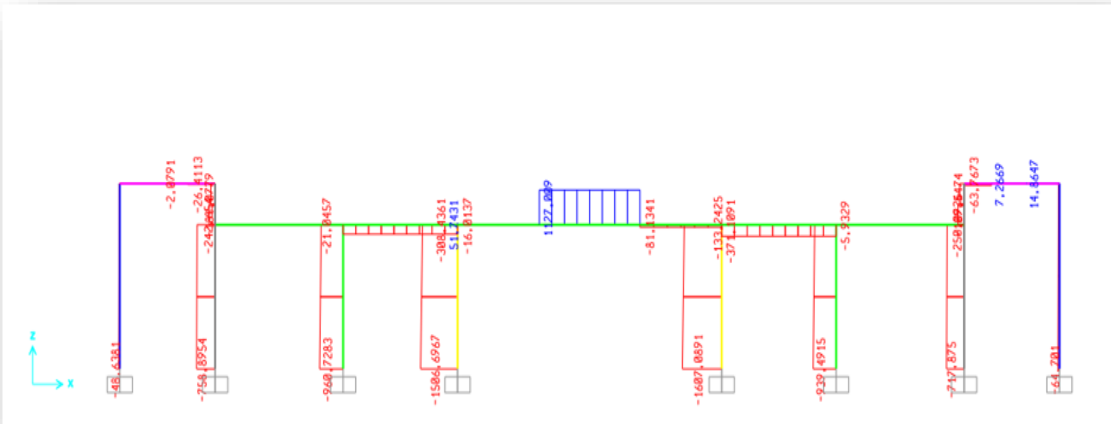
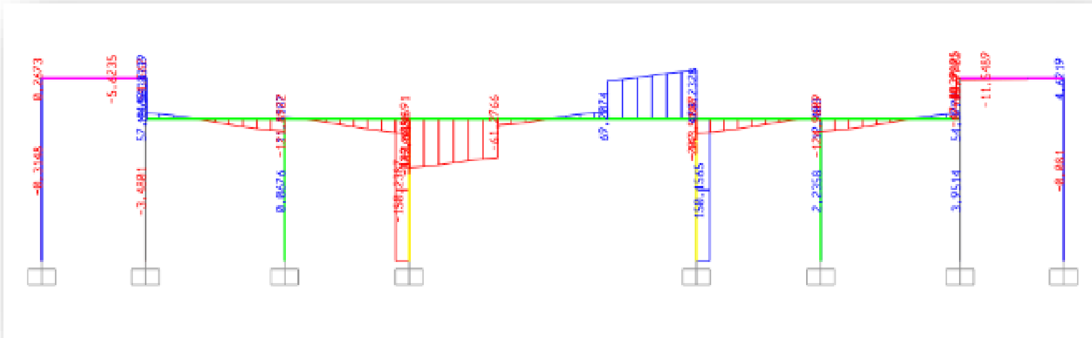
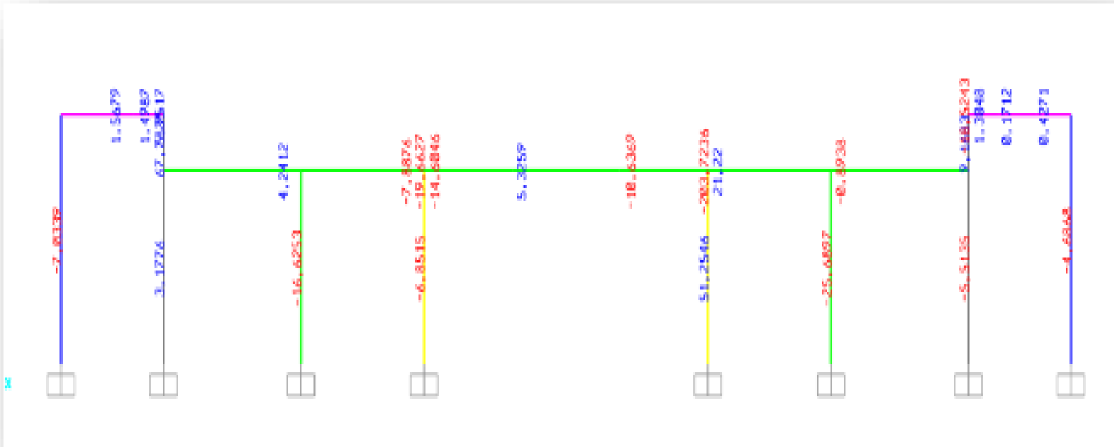


Figure 3 (Axial Force Diagram X-Z)

Illustrates axial compressive force distributions on vertical elements (columns). The moment of inertia and cross-sectional area at Frame Object 57 receive peak axial compressive force transfers due to accumulated dead, public live, and water loads.





Figures 4 & 5 (Shear Force 2-2 Diagram X-Z and Shear Force 3-3 Diagram X-Z)

Present distribution patterns of shear forces along local 2-2 and 3-3 axes. Frame Object 57 dominates the planar shear response (Vu,22), while Frame Object 117 exhibits a surge in axial/transverse shear force (Vu,33) due to geometric asymmetry or corner load transfers in the wing area.

Numerical Modeling Results and Critical Force Responses

The three-dimensional spatial geometry and structural configuration of the public area wing building were reconstructed in SAP2000 v26 (**Figure 1**). This spatial model defines the full portal setup, including frame section definitions for primary/secondary beams and columns, area section assignments for floor slabs and pool walls, fixed support boundary conditions at column bases, and spatial zoning of the upper-floor swimming pool hydrostatic loads.

Following the execution of the finite element computational analysis, internal force distributions under ultimate limit state load combinations were extracted (**Figures 2–5**). The primary flexural moment distribution (M_u,33) reveals significant stress concentrations at Frame Object 57 (**Figure 2**), driven by structural self-weight and eccentric fluid load accumulation. Similarly, the axial compressive force diagram (P_u) demonstrates that Frame Object 57 acts as a critical vertical load-bearing element, absorbing peak gravity and hydrostatic transfers (**Figure 3**). Shear force distributions along local axes 2-2 and 3-3 (**Figures 4 and 5**) indicate that Frame Object 57 dominates the planar shear response (V_u,22), whereas Frame Object 117 experiences a surge in transverse shear force ($V_u,33) resulting from structural asymmetry and localized corner load transfers in the wing area.

While **Figure 1** serves as the baseline structural modeling setup, **Figures 2 through 5** represent the post-analysis output diagrams. The maximum ultimate internal force responses extracted from these output diagrams are quantitatively summarized in **Table 1**.

Table 1: Summary of Critical Internal Force Responses

Reference Figure	Output Diagram	Critical Element	Internal Force Type	Maximum Ultimate Value (U)
Figure 2	Moment 3-3 Diagram	Frame Object 57	Flexural Moment (Mu,33)	Mu,max
Figure 3	Axial Force Diagram	Frame Object 57	Axial Compressive Force (Pu)	Pu,max
Figure 4	Shear Force 2-2 Diagram	Frame Object 57	Planar Shear Force (Vu,22)	Vu,22,max
Figure 5	Shear Force 3-3 Diagram	Frame Object 117	Transverse Shear Force (Vu,33)	Vu,33,max

Based on computational modeling and simulation results, several anomalies and stress concentrations requiring special attention in structural safety evaluation were identified:

1. **Multi-Axial Critical Force Accumulation on a Single Element (Frame Object 57):** Coincidence of maximum values across three internal force parameters simultaneously (Mu,33, Pu, and Vu,22) occurs at Frame Object 57. This condition indicates that this element acts as a transfer element or primary supporting column directly underneath the swimming pool zone. This load accumulation anomaly risks triggering combined flexural-axial failure if not counterbalanced with confined reinforcement detailing.

2. **Surge in Local 3-3 Axis Shear Force at Frame Object 117:** In contrast to the general pattern where shear forces are dominated by the local 2-2 axis (Vu,22), Frame Object 117

records a maximum Vu,33 shear force. This indicates significant torsion or out-of-plane shear effects, triggered by the eccentricity of the pool water loading on the wing structure and the asymmetrical topography of the hilly site.

Mathematical Equations

To evaluate the reliability and section capacity of reinforced concrete elements under working loads, the analysis refers to mathematical formulations based on national standards (SNI 1727:2020, SNI 1726:2019, and SNI 2847:2019).

1. **Swimming Pool Hydrostatic Load Formulation**

The hydrostatic fluid pressure (Ph) acting perpendicular to pool slabs and walls is formulated as a function of the unit weight of water (gamma_w) and fluid depth (h):

$$Ph = gamma\_w * h$$

Where gamma_w = 9.81 kN/m3 and h is the maximum water depth.

2. **Ultimate Load Combination (SNI 1727:2020)**

The critical factored load combination accommodating dead load (D), public live load (L), and fluid load (F) is expressed as:

$$U = 1.2D + 1.6L + 1.2F$$

3. **Element Flexural Capacity Evaluation (SNI 2847:2019)**

The safety requirement against ultimate flexural moment (Mu) is based on the factored nominal moment capacity (phi * Mn):

$$Mu <= phi * Mn$$

$$Mn = As * fy * (d - a / 2)$$

Where a = (As * fy) / (0.85 * f'c * b) and the flexural strength reduction factor phi = 0.90.

4. **Section Shear Capacity Evaluation (SNI 2847:2019)**

The factored nominal shear capacity (phi * Vn) must satisfy the calculated factored shear force (Vu):

$$Vu <= phi * Vn = phi * (Vc + Vs)$$

The concrete shear strength contribution (Vc) is formulated as:

$$Vc = (sqrt(f'c) / 6) * bw * d$$

While the stirrup/shear reinforcement contribution (Vs) is formulated as:

$$V_s = (A_v * f_y * d) / s$$

With a shear strength reduction factor phi = 0.75.

DISCUSSION

Numerical modeling analysis indicates that the cross-sectional capacity of the reinforced concrete structure in the public area wing building overall exhibits high mechanical reliability in transferring applied loads across the entire structural frame network. The magnitudes of flexural moment (M_u) and axial force (P_u) in primary structural elements—particularly Frame Object 57—are predominantly influenced by the structural self-weight concentration and the buildup of fluid loads from the elevated swimming pool acting eccentrically on the wing area. The presence of the upper-floor swimming pool triggers complex internal force redistribution, wherein Frame Object 57 acts as a critical support absorbing a simultaneous combination of peak axial compressive force and flexural moment. Nevertheless, section capacity evaluations confirm that the element demand/capacity ratio remains below the critical threshold (D/C \le 1.0), indicating that existing dimensions and reinforcement configurations remain fully adequate to withstand ultimate load combinations without risking structural failure.

The observed force redistribution and mechanical behavior directly align with the theoretical frameworks established by Gong et al. (2024) and Salyamova and An (2025), who demonstrated that upper-floor fluid containment introduces significant hydro-mechanical stress concentrations that alter force pathways within structural frames. Furthermore, these findings closely align with recent empirical research in structural and earthquake engineering; specifically, studies by Damara et al. (2026) and Nazarudin et al. (2025) emphasized that precision in gravity load modeling and the accurate application of ultimate load combinations are crucial factors in predicting flexural and shear force distributions in multi-story commercial buildings. The concentration of forces observed on the asymmetric wing structure also corroborates the observations of Jarapala and Menon (2023), Pathak and Gupta (2025), and Vielma et al. (2025), who highlighted that buildings constructed on sloped terrain experience pronounced structural asymmetry and localized force concentrations under combined loading. By integrating hydrostatic loads into 3D numerical simulations, this study empirically demonstrates a more representative representation of real field conditions, proving that the specified concrete compressive strength (f'_c) provides optimal section stiffness, thereby dampening deformations and ensuring structural deflections remain well within allowable tolerance limits established by SNI 2847:2019.

The evaluation results yield strategic implications from both operational practical perspectives and the advancement of civil engineering knowledge. For hotel management and operators, these findings offer technical assurance that the public area wing building is safe for full operational function, even during peak visitor load activity in the swimming pool area. For structural design practitioners and engineers, this study provides a valuable methodological precedent for evaluating existing buildings undergoing functional alteration or the addition of massive hydro-mechanical loads to the superstructure. Validating post-renovation structural integrity through advanced finite element modeling establishes a robust analytical workflow, while demonstrating that modern moment-resisting frame systems designed under national regulatory frameworks (SNI 1726:2019) remain ductile and resilient against environmental and dynamic loads.

Although providing a comprehensive overview of superstructure behavior, this study has several scope limitations that can be expanded in future research. This investigation focused specifically on evaluating the upper structure system without accounting for Soil-Structure Interaction (SSI) dynamics or potential differential settlement commonly observed in sloped topographies. Additionally, the seismic load analysis applied was limited to linear response spectrum methods. Consequently, future research is recommended to integrate full-coupled modeling between the superstructure and substructure, as well as apply non-linear analyses—such as pushover or time-history analysis—to map plastic hinge formation and structural ductility levels under extreme seismic shaking.

CONCLUSION

This study comprehensively evaluated the performance and reliability of the upper structural system of a hotel public area wing building accommodating an elevated swimming pool fluid load on hilly terrain. Through numerical modeling analysis using 3D finite element methods in SAP2000 Version 26, all mechanical responses and internal force distributions resulting from factored load combinations—dead load, dynamic public live load, hydrostatic water load, and seismic load—were precisely mapped. Simulation results identified a concentration of critical internal forces centered on Frame Object 57 as a consequence of massive fluid loads acting eccentrically on the wing structure. Nevertheless, section capacity evaluations demonstrated that existing element dimensions and reinforcement configurations possess factored nominal capacities exceeding ultimate internal force demands (D/C <= 1.0). Consequently, all slab, beam, and column components technically fulfill the strength, stiffness, and stability requirements mandated by SNI 2847:2019, SNI 1727:2020, and SNI 1726:2019.

This research makes a significant scientific contribution to civil engineering, particularly in reinforced concrete structural engineering and structural evaluation audits. Theoretically and practically, this study fills a literature gap regarding complex load interaction mechanisms—namely the combination of high-mobility public live loads and hydrostatic water loads from an elevated swimming pool—on asymmetrical building geometries in hilly topographies. Furthermore, this study provides a tested computational methodological framework utilizing state-of-the-art finite element analysis software to perform technical audits on existing buildings undergoing functional alteration or massive hydro-mechanical load additions, while enriching references for implementing national loading and seismic resistance regulatory standards in Indonesia.

To refine and broaden the scope of these findings, several future research directions are recommended. Future studies should integrate comprehensive upper-structure and substructure modeling through Soil-Structure Interaction (SSI) analysis to account for hilly soil flexibility and potential differential settlement effects. Additionally, structural ductility evaluations should be expanded by applying non-linear simulations—such as Nonlinear Static Pushover Analysis or Nonlinear Time History Analysis—to precisely map plastic hinge formation sequences and analyze collapse mechanisms alongside structural reserve capacity under extreme seismic excitations.

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