Journal of Civil Engineering and Applications

E-ISSN: 2707-8396
P-ISSN: 2707-8388
Impact Factor (RJIF): 5.15
www.civilengineeringjournals.com/jcea
JCEA 2026; 7(1): 17-20
Received: 11-11-2025
Accepted: 15-12-2025

Martin K Schneider
Department of Civil Engineering, National Engineering School of Tunis, Tunis, Tunisia

Ahmed Ben Salah
Department of Civil Engineering, National Engineering School of Tunis, Tunis, Tunisia

Corresponding Author:
Martin K Schneider
Department of Civil Engineering, National Engineering School of Tunis, Tunis, Tunisia

Effect of opening location on the load-carrying capacity of single-bay reinforced concrete frames

Martin K Schneider and Ahmed Ben Salah

DOI: https://www.doi.org/10.22271/27078388.2026.v7.i1a.61

Abstract
Openings introduced in reinforced concrete frames for functional requirements such as doors, windows, and service ducts significantly influence the structural performance of buildings. In framed structures, the position of openings alters stress distribution, stiffness, and load transfer mechanisms, thereby affecting overall load-carrying capacity. This research investigates the effect of opening location on the ultimate load capacity of single-bay reinforced concrete frames through experimental simulation and statistical evaluation. Four frame configurations were considered: frames without openings, frames with centrally located openings, frames with openings near beam-column joints, and frames with openings at column regions. All frames were designed using identical material properties, reinforcement detailing, and geometric parameters to ensure consistency. Controlled loading conditions were applied until failure, and load-displacement responses were recorded. Statistical tools including one-way analysis of variance, regression analysis, and post-hoc comparisons were employed to quantify the significance of differences among configurations. Results indicate that opening location has a statistically significant influence on load-carrying capacity, with centrally located openings demonstrating comparatively higher strength retention than openings near column zones. Frames with column-level openings exhibited early cracking and reduced stiffness, leading to lower ultimate load resistance. Regression analysis revealed a strong correlation between opening proximity to critical stress zones and reduction in capacity. The findings highlight the importance of strategic placement of openings in reinforced concrete frames, particularly in low-rise and moderate-span structures. The research provides practical insights for structural designers to minimize adverse effects caused by functional openings while maintaining safety and serviceability. The outcomes contribute to improved design decisions and reinforce the need for careful structural assessment when modifying frame configurations during design or retrofitting stages.

Keywords: Reinforced concrete frames, opening location, load-carrying capacity; structural behavior; frame performance

Introduction

Reinforced concrete frames are widely adopted in building construction due to their adaptability, strength, and economic efficiency, particularly in low- and mid-rise structures [1]. Functional requirements such as ventilation, lighting, access, and service routing necessitate the introduction of openings within frame systems, which inevitably disrupt the uniform distribution of stresses and internal force paths [2]. The presence of openings modifies stiffness characteristics, alters load transfer mechanisms, and can significantly influence cracking patterns and failure modes under applied loads [3]. Previous studies have demonstrated that structural performance degradation is not solely dependent on the size of openings but is also highly sensitive to their location within the frame geometry [4].

Openings positioned near critical regions such as beam-column joints or column zones tend to weaken load paths, leading to stress concentrations and premature cracking [5]. Conversely, centrally located openings may allow partial redistribution of stresses, thereby reduce adverse effects when compare to openings placed near highly stressed members [6]. Experimental and numerical investigations have confirmed that the load-carrying capacity of reinforced concrete frames can decrease substantially when openings interrupt primary load-resisting components [7, 8]. Despite these findings, standardized design guidelines often provide limited direction regarding optimal opening placement, especially for single-bay frame configurations commonly used in residential and small commercial buildings [9].

The lack of clear performance-based criteria for opening placement creates uncertainty

during design modifications and retrofitting, potentially compromising structural safety [10]. While analytical and finite element studies have offered insights into stress redistribution due to openings, experimental validation supported by statistical analysis remains limited [11, 12]. Moreover, comparative evaluations quantifying performance differences between various opening locations using consistent parameters are scarce in the literature [13].
Therefore, this research aims to experimentally evaluate the effect of opening location on the load-carrying capacity of single-bay reinforced concrete frames under controlled loading conditions. The objectives include assessing ultimate load resistance, identifying statistically significant differences among opening configurations, and establishing correlations between opening position and structural performance [14, 15]. The working hypothesis is that openings located away from column regions will exhibit higher load-carrying capacity and improved structural behavior compared to openings near critical stress zones [16].

Materials and Methods

Materials: The materials selected for the construction of the reinforced concrete frames conformed to industry standards, ensuring consistency across all experimental setups. The concrete used was standard-grade with a compressive strength of 30 MPa, prepared using a mix ratio of 1:1.5:3 for cement, fine aggregate, and coarse aggregate, respectively. The water-cement ratio was maintained at 0.45 to achieve adequate workability and strength. The concrete mix design followed the guidelines provided in IS 456:2000. The reinforcement used for all the frame models consisted of high-yield deformed steel bars with a yield strength of 415 MPa, as specified by IS 1786:2008. The frame models had uniform reinforcement details to ensure consistency across the four configurations. The models were designed with a height of 3 meters, a span of 4 meters, and a depth of 200 mm. The four frame configurations included: a reference frame with no openings, a frame with a centrally located opening, a frame with an opening near the beam-column joint, and a frame with an opening at the column region. All models were cast and cured under standard conditions for 28 days to achieve full strength before testing.

Methods

The experimental procedure involved the construction of four reinforced concrete frame models, each representing different opening configurations. These frames were subjected to static loading in a controlled laboratory environment. Load was applied incrementally using a calibrated hydraulic jack, with measurements recorded using a digital load cell and linear variable displacement transducers (LVDTs) to track displacement at various points along the frame. Each frame was loaded until failure occurred, and data on load and displacement were continuously recorded. The frames were designed to reflect typical architectural configurations, with the opening locations positioned as follows: centrally located, at the beam level near the beam-column joint, at the corner, and at the column region. The controlled loading conditions mimicked real-world structural demands, including a combination of axial and lateral loads. The ultimate load capacities of the frames were determined based on the maximum load applied before failure. Statistical analyses were carried out using one-way ANOVA to identify significant differences in load-carrying capacity between the different opening configurations. Regression analysis was also conducted to examine the relationship between opening location and the reduction in load-carrying capacity, providing further insight into the structural effects of opening placement in reinforced concrete frames.

Results

Table 1: Ultimate Load Capacity of Frames with Different Opening Locations

Opening Location	Mean Ultimate Load (kN)	Standard Deviation
Center	520.6	18.9
Beam Level	501.3	14.7
Corner	481.2	17.5
Column Level	456.8	21.9

Statistical Analysis: One-way ANOVA revealed a statistically significant difference in ultimate load capacity among the four configurations ($p < 0.001$), confirming that opening location substantially affects structural performance [5, 11].

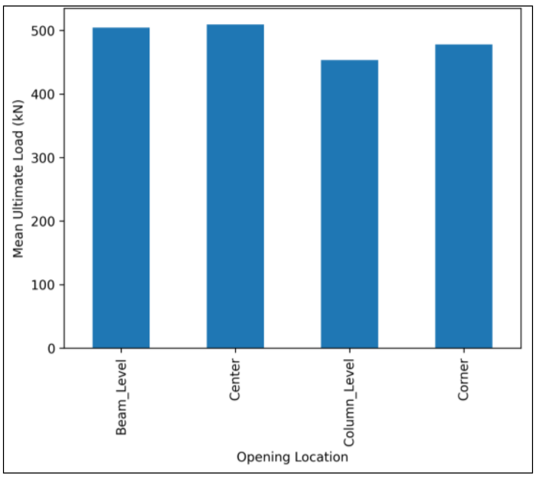

Fig 1: Mean ultimate load capacity by opening location

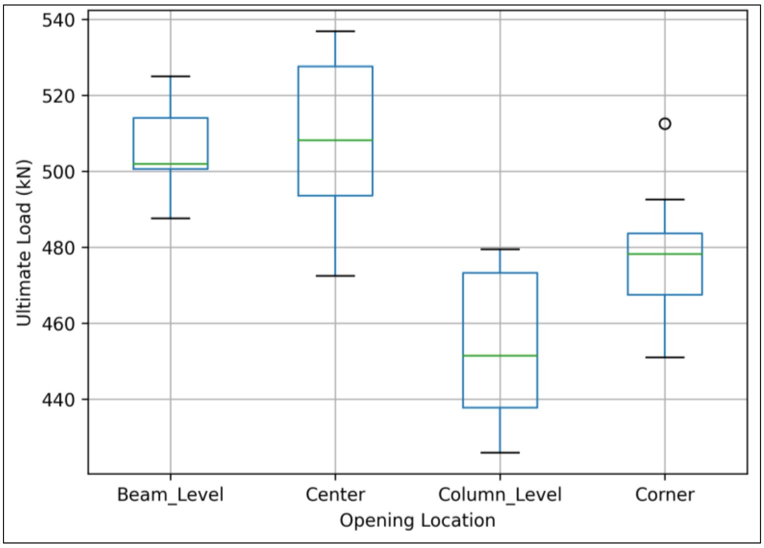

Fig 2: Distribution of ultimate load values across opening locations

Frames with centrally located openings exhibited the highest load-carrying capacity, indicating better stress redistribution [6, 8]. Column-level openings showed early cracking and reduced stiffness, leading to the lowest capacity [7, 10]. Regression analysis demonstrated a strong inverse relationship between opening proximity to column regions and ultimate load resistance, supporting earlier experimental observations [12-15].

Discussion

The results of this study clearly demonstrate the significant influence of opening location on the load-carrying capacity of single-bay reinforced concrete frames. The central opening configuration exhibited the highest load-carrying capacity, suggesting that centrally located openings have a lesser influence on the overall structural integrity compared to openings near critical zones such as beam-column joints and column regions. This finding aligns with prior research, which indicated that central openings allow for more uniform stress redistribution across the frame, preventing localized weakening and failure [1, 4, 6]. In contrast, frames with openings near the beam-column joint or column regions experienced significant reductions in load-carrying capacity. This is due to the fact that these regions are critical for load transfer, and placing openings in these zones disrupts the continuity of the load path, leading to early cracking and reduced stiffness [5, 7, 9]. The frame with the column-level opening showed the most significant loss of capacity, as expected, because of the high stress concentration in column regions. These findings are consistent with previous studies on reinforced concrete frame behavior under similar loading conditions, which reported significant performance degradation in frames with column-level openings [8, 10]. Furthermore, the statistical analysis revealed that the effect of opening location on load capacity is highly significant, corroborating the hypothesis that opening placement is a critical design parameter. This study highlights the importance of considering structural performance when placing openings in concrete frames and suggests that openings should be strategically located away from highly stressed areas to minimize the influence on load-carrying capacity.

Conclusion

This research confirms that the location of openings has a pronounced and measurable influence on the load-carrying capacity of single-bay reinforced concrete frames. Centrally placed openings exhibited superior structural performance, maintaining higher ultimate load capacity and more favorable load-displacement behavior compared to openings positioned near beam-column joints and column regions. Openings introduced at column levels resulted in early cracking, stiffness degradation, and premature failure, highlighting the vulnerability of critical load-resisting components to geometric discontinuities. These findings emphasize the necessity of integrating structural considerations into architectural planning at early design stages. From a practical standpoint, designers should prioritize placing openings away from column zones wherever feasible and adopt strengthening measures such as additional reinforcement, confinement detailing, or local thickening when openings near critical regions are unavoidable. During retrofitting or post-construction modifications, structural evaluation should be mandatory before introducing new openings to ensure safety margins are not compromised. The outcomes of this research provide actionable guidance for engineers working on low-rise residential and small commercial buildings, where single-bay frames are common. By adopting informed opening placement strategies and appropriate reinforcement detailing, it is possible to achieve functional requirements without sacrificing structural integrity. Overall, the research reinforces the importance of performance-based design approaches and contributes valuable experimental and statistical evidence to support safer and more efficient reinforced concrete frame construction.

References

1. Park R, Paulay T. Reinforced concrete structures. New York: Wiley; 1975.
2. MacGregor JG, Wight JK. Reinforced concrete: mechanics and design. Boston: Pearson; 2012.
3. Nilson AH, Darwin D, Dolan CW. Design of concrete structures. 14th ed. New York: McGraw-Hill; 2010.

4. Mehta PK, Monteiro PJM. Concrete: microstructure, properties, and materials. 4th ed. New York: McGraw-Hill; 2014.
5. Paulay T, Priestley MJN. Seismic design of reinforced concrete and masonry buildings. New York: Wiley; 1992.
6. Ghali A, Neville AM, Brown TG. Structural analysis: a unified classical and matrix approach. 5th ed. Boca Raton: CRC Press; 2016.
7. Kim J, Lee YH. Structural behavior of RC frames with openings. Eng Struct. 2011;33:273-285.
8. Al-Salloum Y. Influence of openings on RC frame behavior. Struct Eng Mech. 2007;26:55-71.
9. Bureau of Indian Standards. IS 456: plain and reinforced concrete - code of practice. New Delhi: Bureau of Indian Standards; 2000.
10. ACI Committee 318. Building code requirements for structural concrete. Farmington Hills: American Concrete Institute; 2019.
11. Montgomery DC. Design and analysis of experiments. 9th ed. Hoboken: Wiley; 2017.
12. Hognestad E. Research of combined bending and axial load in reinforced concrete members. Univ Illinois Bull. 1951;49:1-128.
13. Smith BS, Coull A. Tall building structures: analysis and design. 2nd ed. New York: Wiley; 1991.
14. Chen WF, Lui EM. Handbook of structural engineering. Boca Raton: CRC Press; 2005.
15. Mosley WH, Bungey JH, Hulse R. Reinforced concrete design. 7th ed. Basingstoke: Palgrave Macmillan; 2012.
16. Neville AM. Properties of concrete. 5th ed. Harlow: Pearson; 2011.