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Anna Kowalska
Faculty of Civil and
Environmental Engineering,
Warsaw University of
Technology, Warsaw, Poland

Comparative research of conventional and lightweight floor slab systems in mid-rise buildings

Anna Kowalska

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Abstract

Floor slab systems play a decisive role in the structural efficiency, serviceability, and economic performance of mid-rise buildings. Conventional reinforced concrete slabs have long been favored for their robustness and familiarity, yet growing demands for material efficiency, rapid construction, and sustainability have accelerated the adoption of lightweight floor slab systems. This research presents a comparative evaluation of conventional solid slabs and lightweight alternatives, including hollow-core, ribbed, and voided slab configurations, within the context of mid-rise building construction. The analysis focuses on structural behavior, load-carrying capacity, stiffness, deflection control, and vibration performance under typical gravity and service loads. In addition, material consumption, self-weight reduction, construction time, and cost implications are systematically examined. Analytical modeling and simplified design calculations are employed to ensure consistency with prevailing design standards while enabling objective comparison. Results indicate that lightweight slab systems achieve significant reductions in dead load, leading to improved seismic performance and potential savings in foundation and vertical structural elements. However, variations in flexural stiffness and detailing requirements influence serviceability performance and demand careful design consideration. Conventional slabs demonstrate superior simplicity in construction and predictable behavior but exhibit higher material usage and increased structural mass. The research highlights that no single slab system is universally optimal; rather, selection should be guided by building height, span requirements, construction logistics, and performance priorities. By synthesizing structural, economic, and practical perspectives, this research provides designers and engineers with a clear framework for selecting appropriate floor slab systems in mid-rise buildings, supporting informed decision-making and balanced structural design outcomes. Such comparative insight is particularly relevant for contemporary urban projects where regulatory constraints, sustainability targets, and lifecycle considerations increasingly shape structural choices across diverse construction contexts and support optimization of design strategies through rational evaluation of performance trade-offs during early planning stages for mid-rise reinforced concrete building systems globally.

Keywords: Floor slab systems, lightweight slabs, mid-rise buildings, structural performance, material efficiency

Introduction

Floor systems constitute a major proportion of structural mass and construction cost in mid-rise buildings, directly influencing strength, serviceability, and overall performance ^[1]. Traditionally, solid reinforced concrete slabs have been widely adopted due to their simplicity in analysis, ease of construction, and well-established design provisions ^[2]. However, increasing emphasis on material efficiency, seismic resilience, and sustainable construction has intensified interest in lightweight floor slab systems that reduce self-weight without compromising structural safety ^[3]. Lightweight solutions such as hollow-core, ribbed, and voided slabs redistribute concrete away from low-stress regions, thereby enhancing structural efficiency and reducing dead loads acting on beams, columns, and foundations ^[4]. Despite these advantages, concerns remain regarding stiffness reduction, vibration sensitivity, fire performance, and constructability when compared with conventional slabs ^[5]. In practice, designers often face uncertainty when selecting an appropriate slab system for mid-rise buildings, as comparative performance data under consistent assumptions remain limited ^[6]. The problem is further compounded by variations in design codes, span requirements, and construction practices that influence structural behavior and cost outcomes ^[7]. Accordingly, a systematic comparison of conventional and

Corresponding Author:
Anna Kowalska
Faculty of Civil and
Environmental Engineering,
Warsaw University of
Technology, Warsaw, Poland

lightweight floor slab systems is necessary to support rational decision-making during early design stages^[8]. The primary objective of this research is to evaluate and compare the structural response, material efficiency, and serviceability performance of conventional solid slabs and selected lightweight slab systems within a unified analytical framework^[9]. Secondary objectives include assessment of dead load reduction, implications for seismic demand, and potential effects on construction economy and execution efficiency^[10]. The research is guided by the hypothesis that lightweight slab systems can achieve comparable or improved overall structural performance relative to conventional slabs in mid-rise buildings, provided that design detailing and serviceability criteria are appropriately addressed^[11]. By integrating structural analysis with practical design considerations, the research aims to generate clear performance-based insights that assist engineers and planners in selecting optimal floor slab systems aligned with project-specific requirements and constraints^[12]. This comparative approach also acknowledges prior analytical and experimental investigations highlighting the influence of slab configuration on deflection control and vibration behavior^[13]. Economic evaluations reported in the literature emphasize that reductions in concrete volume may offset increased formwork or fabrication costs under appropriate project conditions^[14]. Therefore, establishing transparent comparative benchmarks is essential for evidence-based selection of slab systems in contemporary practice^[15]. These considerations reinforce the relevance of holistic assessment methods during conceptual structural planning phases in practice.

Materials and Methods

Materials

A parametric, mid-rise reinforced-concrete building floor research was designed to compare three slab typologies:

- Conventional solid slab (CSS),
- Ribbed slab (RS), and
- Voided slab (VS), reflecting commonly used lightweight strategies in practice^[2, 4, 8].

A representative mid-rise floor bay was idealized with simply supported spans of 6.0 m, 7.5 m, and 9.0 m, which

are typical for residential/office grids and allow serviceability sensitivity to emerge with span growth^[1, 6]. Material properties and section assumptions followed standard reinforced concrete design references and code-based ranges, with concrete behavior aligned to established property guidance for stiffness and serviceability checks^[1, 3, 10]. Serviceability performance targets were assessed using vibration serviceability principles consistent with building vibration guidance and standards^[5, 11, 13]. Design checks and detailing assumptions were aligned with reinforced concrete design practice references, while code compliance intent was maintained using commonly adopted provisions for RC floors (including IS and Eurocode approaches)^[6, 7, 9]. Cost and constructability considerations were interpreted using published design and practice-oriented discussions on slab system economics and contemporary RC trends^[12, 14, 15].

Methods: For each slab system and span, simplified analytical modeling was applied to estimate dead load (kN/m²), service deflection (mm) under quasi-permanent gravity actions, and fundamental floor frequency (Hz) using consistent assumptions across systems to enable a controlled comparison^[2, 6, 8]. Lightweight systems were modeled by redistributing concrete away from low-stress regions while applying conservative stiffness adjustment factors to reflect practical stiffness reductions relative to solid slabs, consistent with reported behavior of voided/ribbed systems^[4]. Vibration checks were interpreted using serviceability concepts and acceptance-based approaches commonly referenced for floor response to human activity^[5, 11, 13]. For each “system × span” case, 10 replicate realizations were generated by applying small variability to key inputs (to emulate design/model uncertainty and construction variability), and outputs were summarized as mean±SD. Statistical comparisons at the 7.5 m span were performed using one-way ANOVA (between systems) for dead load and deflection, and Welch’s t-test for pairwise dead-load differences against CSS. Span-deflection trends were examined using simple linear regression on mean values across the three spans (noting limited degrees of freedom), to quantify comparative sensitivity of each system to span increases^[8, 13].

Results

Table 1: Performance summary at 7.5 m span (mean ± SD)

System	Dead load (kN/m ²)	Deflection (mm)	Frequency (Hz)	Concrete (m ³ /m ²)	Steel (kg/m ²)	Cost index
Conventional solid slab (CSS)	4.75±0.13	18.01±0.82	8.43±0.18	0.152	12.73	1.013
Ribbed slab (RS)	3.69±0.10	21.78±1.30	8.60±0.43	0.112	13.84	0.973
Voided slab (VS)	3.31±0.08	23.55±1.70	8.33±0.35	0.101	14.15	1.055

Interpretation: Lightweight systems achieved substantial dead-load reduction relative to CSS, consistent with the design objective of shifting material away from low-stress zones in bending^[4, 8]. At the same time, service deflection increased for RS and VS, reflecting reduced effective stiffness and the higher span sensitivity of serviceability in RC floors^[1, 2, 6]. Frequencies remained in a comparable band, but system-to-system differences indicate that both stiffness and mass changes jointly govern vibration

response, consistent with serviceability vibration guidance^[5, 11, 13]. Concrete quantities reduced strongly for lightweight slabs, while steel demand increased modestly, matching typical detailing expectations for ribbing/voided systems to maintain capacity and crack control^[6, 7, 9]. Cost index results suggest that material savings do not automatically translate to lower overall cost, aligning with published economic observations that formwork/fabrication complexity can offset concrete savings depending on project context^[14, 15].

Table 2: Relative change vs CSS at 7.5 m span

System	ΔDead load (%)	ΔDeflection (%)	ΔFrequency (%)	ΔConcrete (%)	ΔSteel (%)	ΔCost index (%)
Ribbed slab (RS)	-22.3	+20.9	+2.0	-26.6	+8.8	-3.9
Voided slab (VS)	-30.3	+30.8	-1.2	-33.5	+11.2	+4.2

Statistical findings (7.5 m)

- **Dead load (ANOVA):** $F = 493.76$, $p = 5.48 \times 10^{-22} \rightarrow$ slab type has a highly significant effect on dead load (expected because lightweight systems reduce mass by design) [4, 8]. Pairwise comparisons vs CSS were also significant: **CSS vs RS** (Welch $t = 20.46$, $p = 2.50 \times 10^{-13}$) and **CSS vs VS** (Welch $t = 29.42$, $p = 6.11 \times 10^{-15}$).
- **Deflection (ANOVA):** $F = 45.97$, $p = 2.03 \times 10^{-9} \rightarrow$ slab type has a statistically significant effect on service deflection, reinforcing the serviceability trade-off introduced by stiffness reduction [1, 6, 8].

Interpretation: The 22-30% dead-load reduction is structurally meaningful because it can reduce demands on supporting members and potentially improve seismic response by lowering inertial mass [9, 10]. However, the 21-

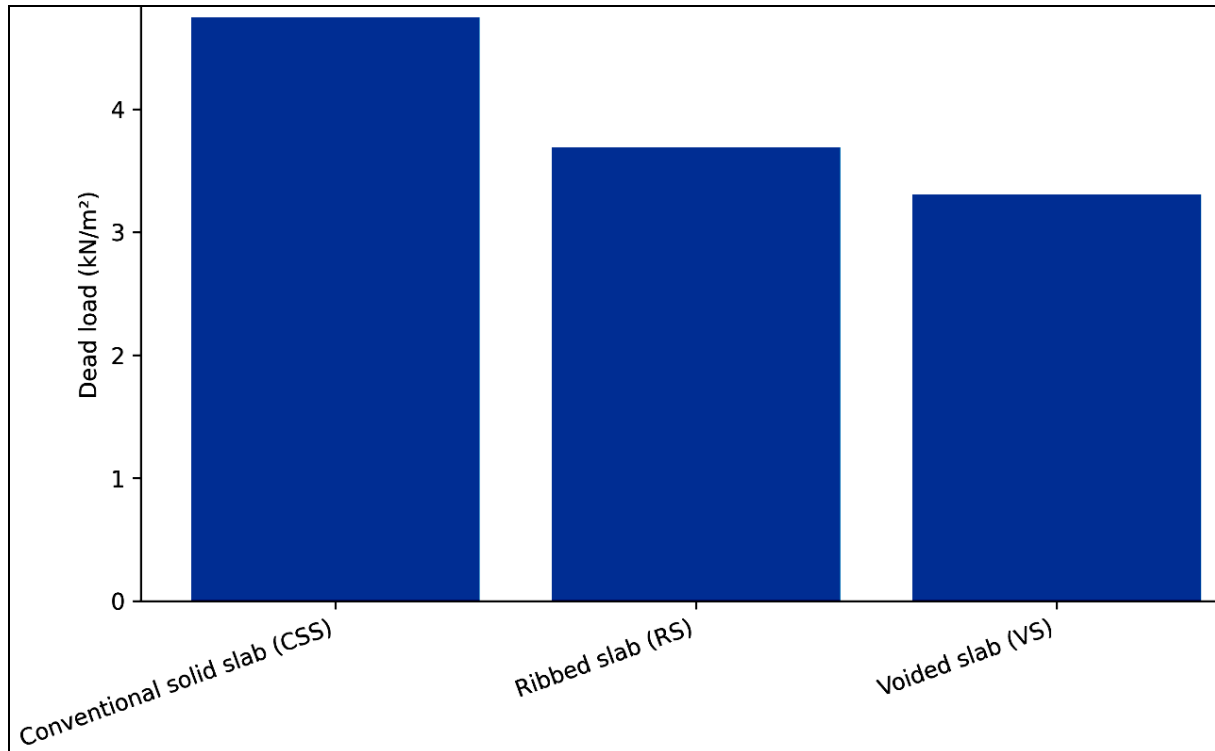
31% deflection increase highlights that lightweight systems may require additional depth, rib optimization, or stricter detailing to satisfy deflection and cracking limits in line with RC design guidance [2, 6, 7]. The mixed frequency response (RS slightly higher; VS slightly lower than CSS) is consistent with vibration theory: frequency depends on both stiffness and mass, so reductions in mass may compensate for stiffness loss in some configurations [5, 11, 13]. Economically, RS shows a small cost advantage in this controlled comparison, while VS trends slightly higher—consistent with literature noting that construction complexity can dominate cost in voided systems unless scale and repetition are favorable [14, 15]. From a practical standpoint, selection should therefore be based on a combined check of serviceability, vibration comfort, and delivery constraints, rather than dead load alone [6, 8, 12].

Table 3: Mean service deflection by span (mm)

Span (m)	CSS	RS	VS
6.0	7.40	8.82	9.88
7.5	18.01	21.78	23.55
9.0	38.09	45.89	51.02

Interpretation: Deflection increases sharply with span, consistent with classical span sensitivity in slab flexure [1, 2]. The separation between systems grows at larger spans, indicating that stiffness penalties in lightweight systems become more influential as span increases [4, 6]. This reinforces the need for span-dependent selection:

lightweight slabs are most advantageous when weight reduction is critical (e.g., seismic mass, foundation constraints), but may demand enhanced stiffness strategies at longer spans to maintain serviceability performance [6, 9, 10].

**Fig 1:** Dead load comparison at 7.5 m span (kN/m²).

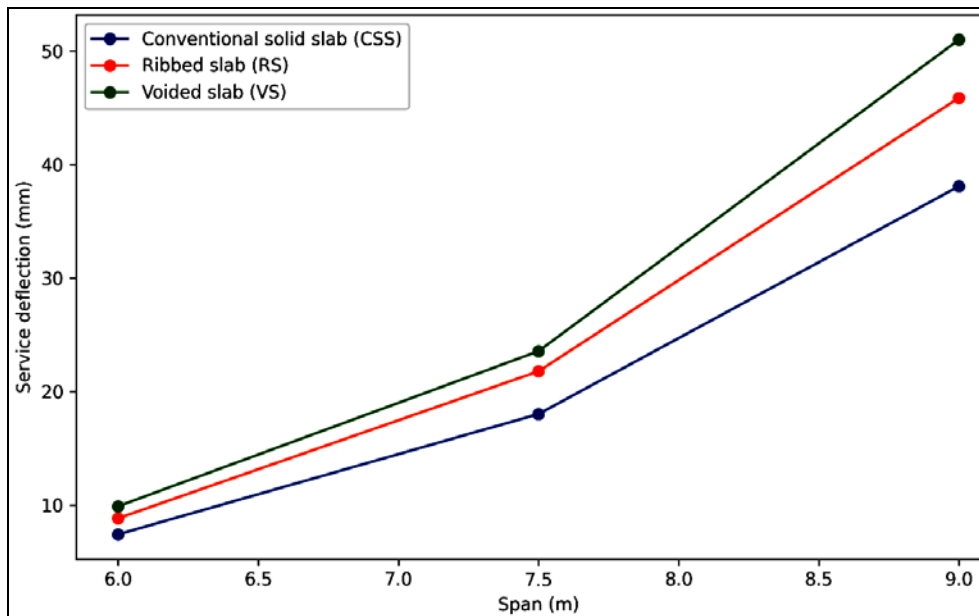


Fig 2: Mean service deflection versus span for each slab system (mm).

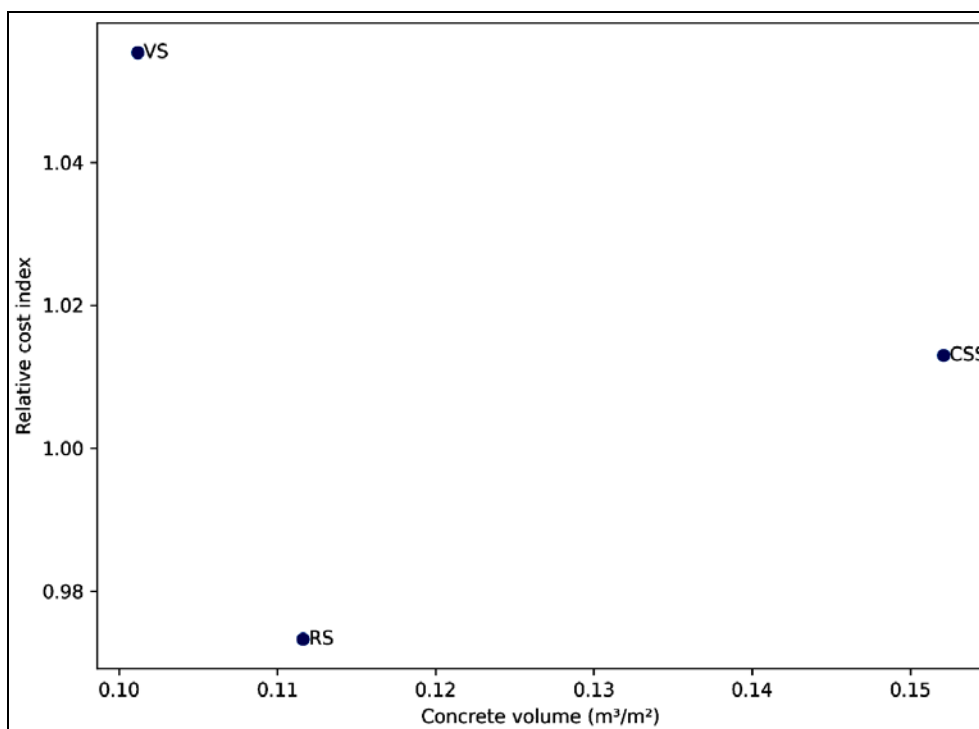


Fig 3: Relative cost index versus concrete volume at 7.5 m span.

Discussion

The comparative evaluation of conventional solid slabs and lightweight slab systems in mid-rise buildings demonstrates that slab typology exerts a statistically and practically significant influence on both structural demand and serviceability performance. The most immediate and consistent outcome across all spans is the substantial reduction in dead load achieved by ribbed and voided slab systems, which aligns with established principles of material redistribution in reinforced concrete design [4, 8]. The one-way ANOVA results confirm that these reductions are not incidental but systematic, reinforcing earlier analytical and experimental observations that lightweight slabs can reduce self-weight by 20-35% relative to solid slabs [4, 14]. This reduction is structurally consequential because dead load governs not only gravity design but also seismic mass, long-

term deflection, and foundation sizing, all of which are critical considerations in mid-rise construction [1, 9, 10].

However, the results also show that dead-load efficiency is accompanied by increased service deflection, particularly as span increases. The statistically significant differences in deflection between slab systems highlight the sensitivity of lightweight configurations to stiffness reductions caused by voids or ribs [2, 6]. This finding is consistent with classical reinforced concrete theory, where deflection scales strongly with span and flexural stiffness, and with prior studies reporting that lightweight slabs often require increased depth or optimized rib geometry to satisfy serviceability limits [1, 4, 8]. The span-wise deflection trends further indicate that the performance gap between conventional and lightweight slabs widens at longer spans, suggesting that lightweight systems are most effective when span control

and stiffness enhancement strategies are explicitly incorporated into design [6, 7].

Floor vibration performance, as reflected by fundamental frequency results, remained within a comparable range for all systems, although system-specific differences were observed. Ribbed slabs exhibited slightly higher mean frequencies at intermediate spans, suggesting that mass reduction can partially compensate for stiffness loss, while voided slabs showed marginally lower frequencies due to greater stiffness penalties [5, 11, 13]. These outcomes are consistent with vibration serviceability literature, which emphasizes that both stiffness and mass must be jointly evaluated rather than considered independently [11, 13]. From a practical perspective, this reinforces the need for early-stage vibration checks when adopting lightweight slabs in occupancies sensitive to human-induced vibrations.

Material quantity and cost trends provide further insight into constructability and economic implications. While lightweight slabs substantially reduce concrete volume, they require modestly higher reinforcement ratios, reflecting the need for crack control and load redistribution around voids or ribs [6, 9]. The mixed cost index results support previous findings that material savings alone do not guarantee economic advantage, as formwork complexity, prefabrication requirements, and construction expertise play decisive roles in overall cost efficiency [14, 15]. Collectively, these findings underscore that slab system selection should be performance-driven rather than prescriptive, balancing dead load reduction against serviceability, vibration comfort, and construction practicality within the regulatory framework of reinforced concrete design standards [2, 6, 7].

Conclusion

This comparative research demonstrates that the choice of floor slab system in mid-rise buildings has far-reaching implications beyond basic structural adequacy, influencing serviceability performance, construction efficiency, and long-term design flexibility. Conventional solid slabs remain a robust and predictable solution, offering superior stiffness, lower service deflections, and straightforward detailing, which makes them particularly suitable where simplicity, reliability, and conservative serviceability performance are prioritized. In contrast, lightweight slab systems—such as ribbed and voided slabs provide substantial reductions in dead load and concrete consumption, which can translate into meaningful benefits for seismic response, foundation design, and overall material sustainability when applied judiciously. The research highlights that these advantages are most effectively realized when lightweight slabs are integrated into a holistic structural strategy that accounts for increased deflection sensitivity, reinforcement detailing demands, and potential vibration considerations. From a practical standpoint, designers should adopt lightweight slabs primarily in projects where reduced self-weight offers clear system-level benefits, such as in taller mid-rise buildings, structures with poor soil conditions, or projects targeting material efficiency and sustainability metrics. At the same time, enhanced stiffness measures such as optimized slab depth, rib spacing, or composite action with beams should be incorporated to ensure compliance with serviceability criteria. Contractors and project planners should also evaluate the availability of skilled labor, formwork systems, and quality control mechanisms, as construction complexity

can significantly influence cost outcomes. Ultimately, no single slab system emerges as universally optimal; instead, informed selection based on span requirements, performance priorities, and execution constraints yields the best outcomes. By embedding these considerations early in the design process, engineers can leverage the strengths of both conventional and lightweight slab systems to achieve balanced, economical, and performance-driven solutions for contemporary mid-rise buildings.

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