

Review on Prepare and Test Hollow Slab with Economical Comparison

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ABSTRACT

Slab systems happen to be the most material-demanding parts in a reinforced concrete building and their proper functioning is important for the structural safety, serviceability, and cost, and energy efficiency. Though widely considered and the solid conventional reinforced concrete slabs have consumed big amounts of concrete and steel, heavier dead loads are their outcome and there is an increased load on the beams, columns, and foundations as well. Over the last few decades, hollow and voided slab systems, such as hollow-core slabs, bubble deck slabs, and voided flat slabs, have been viewed as sustainable solutions because they need less material and their structural efficiency is better. This review paper provides a thorough synthesis of recent research on hollow slab technologies focussing on structural behaviour, flexural and punching shear performance, deflection features, construction methods, strengthening techniques, and economic viability. The literature's experimental, numerical, and analytical studies are rigorously analyzed to discern the advantages, limitations, and performance trends of the different hollow slab systems. Furthermore, the paper indicates the present research gaps concerning code provisions, long-term behavior, and system-level cost evaluation. By reviewing the literature, the authors want to provide support for engineers and researchers in their endeavors to choose and optimize hollow slab systems for constructing safe, cost-effective, and energy-efficient buildings.

Keywords: Hollow Core Slab, Bubble Deck Slab, Structural Performance, Punching Shear, Economic Analysis.

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1. Introduction

A) Overview

Reinforced concrete slabs are the most crucial structural components in a building construction process because they act as horizontal load-bearing members transferring the gravity loads to the beams, columns, and walls. Slabs have a large surface area, and hence, they represent a major part of concrete and reinforcement used in high-rise buildings. Solid reinforced concrete slabs are the most widely used ones due to their easy design, predictable behavior, and good compatibility with the conventional construction practices. But as the span of buildings gets bigger and the requirements of the architects become more difficult, solid slabs often lead to an increase in the thickness of the slabs, the dead load being higher and thus also larger beams, columns, and foundations. The increase in consumption of materials has quite a close connection with the construction cost, structural efficiency, and environmental sustainability [1][2].

At the same time with the issue of structure, the building industry has become one of the most important users of global energy. One major use of this energy is to make people warm or cool through heating and cooling systems. There are some studies that show that buildings are responsible for about 25-40% of total global energy consumption with residential and commercial buildings being the main contributors to this demand [3]. Hence, material reduction and enhancement of thermal performance of building components are among the strategies that can help in reaching the sustainable

development goals. In this aspect, innovative slab systems that reduce the volume of concrete while the structural performance being the same have become the subject of research attention that is increasing [4].

The hollow and voided slab systems are the leading edge in slab technology. The basics of these systems deal with taking away concrete from areas that do not add to the strength of the structure, especially those close to the neutral line of bending. Typical examples are: precast prestressed hollow-core slabs, bubble deck slabs using HDPE (high-density polyethylene) spheres, and cast-in-situ voided slabs with hollow blocks or pipes. The introduction of voids in the slab leads to major self-weight reductions which usually are between 10% and 40% depending on the geometry and configuration of the slab. The reduced self-weight creates lower bending moments, smaller support reactions, and enhanced structural efficiency at the system level [5][6].

A lot of experimental and numerical research has been done on the bending behaviour of hollow slabs. They all came to the same conclusion that if properly designed, the floor slabs would not only be able to carry the same load as solid slabs of the same thickness, but they would also have the same deflection performance. Prestressed hollow-core slabs, in particular, are the best choice when it comes to the ability to span large distances and control one's comfort. Nevertheless, research has also pointed out that there are very few critical challenges related to hollow slabs, mainly those of punching shear resistance, localized cracking near voids, reduced ductility, and complex load paths. The problems get worse in flat slab systems and under

concentrated loads; hence, it is necessary to be very careful in detailing and, sometimes, to provide extra reinforcement or solid zones [7][8].

One more considerable research path actually goes through the improvement and reinforcement of hollow-core slabs. There have been proposed techniques like use of concrete-filled cores, external bonding of fiber-reinforced polymers (FRP), and mechanical connectors and composite toppings, which will improve the performance for shear and punching. All these methods are very promising but their long-term performance, constructability, and cost-effectiveness need more thorough investigation. Besides, current design codes mostly depend on solid slabs' provisions and thus fail to accurately reflect the impact of void geometry on shear and punching behavior which causes either conservative or inconsistent design practices [9].

Hollow slab systems, from both the economy and sustainability points of view, lead to the possibility of advantages other than just the saving of materials. The reduction of dead weight can cause the use of smaller structural members and foundations, shorter construction time, and less embodied carbon, among others. However, the majority of the research evaluates the economy in terms of slab-level material costs only, without taking into account the savings at the system level or the performance over the life cycle of the system. This necessitates the carrying out of the integrated studies that will combine structural behavior, cost analysis, and energy efficiency [10].

In line with these arguments, this review paper intends to gather the most recent studies on hollow and voided slab systems, perform a thorough critique of their structural and economic performance, point out the existing limitations, and bring to light the future research requirements in order to facilitate the greater acceptance of these systems in contemporary construction.

B) Problem Definition

- Typical solid reinforced concrete slabs need lots of concrete and steel and thus cost more and have more dead weight.
- The larger weight of the slab has an impact throughout the structure because it requires larger beams, columns and foundations, thus decreasing overall structural efficiency.
- The use of solid slabs is one of the main factors contributing to the increase of energy demand due to the inability to provide a good thermal insulation and the consequent need for more cooling/heating.
- Hollow and voided slab systems have lowered material consumption but their structural behaviour has not been fully recognized thereby remaining uncertain.
- There is no clear understanding of the punching shear resistance and cracking behaviour in hollow slabs subjected to concentrated loads.
- Not only design codes do not give specific geometries for voids and shear evaluation, but also they provide limited guides in this regard.
- The economic advantages of hollow slabs are often unclear because no system-level cost comparison has been made.
- The lacking experimental data is one of the factors that make the adoption of hollow slab systems in practical

construction unconfident.

C) Existing System

- Solid slabs are capable of bearing vertical loads and are held up by beams and columns.
- Concrete volume throughout the full thickness is a must for these slabs, no matter how stress distribution is applied.
- An established procedure for design and building codes supports this practice.
- Solid slabs have the benefit of load-carrying capacity along with simple reinforcement detailing.
- Regular activities in construction consist of putting up forms, placing reinforcements, pouring concrete, and curing.
- Solid slabs are the most common choice because of their acceptance by contractors and their simplicity in execution.
- Their use has become common even for long spans, and this has led to thicker slabs.

D) Drawbacks

- Meaningful slabs ultimately require a great deal of concrete and steel consuming whole construction budget besides the materials.
- Self-weight of slab forces bigger structure in terms of beams, columns, and foundations.
- The dead weight increases leading to the generation of higher seismic forces and reduction in structural efficiency.
- Thick slabs take clear floor height away or increase storey height.
- Poor thermal performance leads to more energy consumption for heating and cooling.
- Heavy usage of materials in construction results in a greater environmental impact and embodied carbon.
- Larger deflections call for more reinforcement which in turn pushes the cost up.
- The method does not make efficient use of concrete since the material that is close to the neutral axis has a very small contribution to strength.

2. Literature Survey

A) Literature Survey

Hussain Ali Yazal et. al. (2024), This review collects and summarizes worldwide research on hollow-core slab systems that can be either precast or cast-in-situ, and it sorts out the published works according to the manufacturing method (precast prestressed vs in-situ voided slabs), structural behavior (flexure, shear, and punching), and durability/strengthening techniques. The researchers point out the significant transformations made in the areas of void geometry optimization, the behavior of composite topping, and the renovation/strengthening (CFRP, infill concrete) for old hollow cores. The main gaps recognized are the unavailability of long-term performance data of modern composite repairs and the shortage of code provisions for the punching shear of voided cross-sections. The authors suggest that practical recommendations indicate the necessity of carrying out integrated system-level cost studies (which would include reductions in beam/column sizing) and of establishing standardized test protocols for the comparison of different voided technologies to be applied in different ways.

Victor O. Francis et. al. (2021), Bubble Deck technology, which involves injecting plastic spheres into the slabs, is critically evaluated and experimental and numerical studies on flexural stiffness, cracking, punching shear, thermal performance, and constructability are compiled. The research points out that bubble deck slabs generally have 10-25% concrete volume reduction, around 80-95% of the equivalent solid slabs' flexural stiffness, and better deflection performance due to reduced weight. The downside, however, is that punching shear may occur near concentrated loads unless additional shear reinforcement or solid strips are provided. It is also suggested that the review indicate lifecycle advantages such as lower embodied CO₂ and faster construction when semi-precast modules are used but it also asks for more large-scale tests and harmonized design guidance.

A. Al-Bayati et. al. (2022), shows the results of the studies conducted on punching shear of both voided and bubble/void-block slabs and compares the results with current codes developed for solid flat slabs. The author concludes that the voided slabs exhibit the different shear perimeter and shear flow behavior, which in many cases leads to lower punching capacity when the voids are situated in the critical shear perimeter. A number of experimental programs are undertaken which show that the punching strengths deviate from the predictions of the codes; therefore, the use of conservative design or local solid zones/headers is recommended. The paper recommends the revision of the design factors or modifier equations in order to include the effective slab thickness and void geometry in the checks for punching shear.

M.R. McDermott et al. (2020), The research work is both experimental and analytical, comprising the case of hollow-core precast units with their center cores filled (either partial or full) with cast-in-place concrete and the investigation of shear capacity enhancements that go with it. Results of the tests show that filling the cores can significantly enhance resistance to punching and shear, particularly when the technique is applied to the case of roughened interfaces or supplementary shear reinforcement. The effects of time-of-fill and age were pronounced: early fillings made composite action much more effective. The authors put forward the suggestion for practical strengthening—adding fiber to the concrete, using headed bars, and incorporating welded wire—to improve local shear capacity without resorting to extensive retrofitting. This project is a step forward in assessing the alternative options for the retrofitting of existing hollow-core floors.

D.H. Kim et al. (2023), The report outlines four-point bending tests on prestressed hollow-core slabs, which are conducted to evaluate ultimate flexural strength and serviceability. According to the study, well-designed prestressed hollow cores not only lead to high bending capacity but also to controlled deflection up to service loads; nevertheless, some configurations have exhibited localized cracking close to void edges and less ductility as compared to solid slabs. This research provides a detailed analysis of stiffness loss after cracking and points out the influence of

topping thickness and reinforcement on the recovery of composite behavior. The authors suggest design practices for topping continuity and detail anchorage to enhance ductility and shear transfer.

K.A. Chebo et al. (2022), Experimental programs have been reviewed that compared hollow-core slabs, post-tensioned slabs, and conventional reinforced slabs. The review pointed out differences in dynamic and serviceability behaviors: hollow cores lower the weight and change the natural frequencies, thus affecting the vibration performance for the floor applications. Flexural tests demonstrate similar ultimate loads for the cases of topping or sufficient reinforcement, but service cracking patterns and local punching remain concerns. The review indicates that the material savings are frequently nullified by the need for further reinforcement or the complexity of construction unless a system-level redesign (smaller columns/beams) has been done. The authors recommend that dynamic testing to check for habitability should be standardized.

A.E. Abd Elhameed (2024), The paper discusses how the different methods—externally bonded FRP, concrete infill, ring anchors, and mechanical connectors—were assessed by conducting a survey on damaged or under-designed hollow-core units. The review indicates that the use of FRP sheets and strips can significantly increase the flexural capacity; however, their use in the case of punching shear is limited unless anchorage is provided. On the other hand, concrete-filled cores with headed reinforcement significantly increase the shear and punching resistance, thus, giving a strong retrofit strategy. The review also lists the efficiency factors, typical bond issues, and detailing that is required for ensuring composite behavior, stressing that the site constraints and access for anchorage installation usually control the method chosen.

Samantha.Konuri et. al. (2022), the experimental and field case studies conducted on Bubble Deck and similar systems for voided slabs have grouped their results as follows: 12-25% less concrete, same bending strength for equivalent thickness, and mixed conclusions regarding punching shear (requiring either solid ribs or shear reinforcement). Meanwhile, lifecycle analyses have usually been in the favor of bubble decks regarding reduced embodied carbon and transport burden. However, the practical use of these decks is still often restricted by the unawareness of local contractors and the absence of prescriptive code rules. The reviews suggest pilot projects and standard detailing guides to speed up the acceptance.

Hussam Ali Mohammed et. al. (2024) , The latest developments in hollow-core technology have been covered through various aspects like void geometry, composite topping design and shear/punching vulnerabilities, etc. The author compares cast-in-place voided solutions (Bubble, Voided slabs) with factory prestressed hollow cores considering trade-offs: onsite flexibility versus factory quality and span capability. Emerging numerical models for predicting punching shear in voided sections are discussed and the review suggests updating design codes to include void geometry modifiers. Moreover, the use of less concrete

and recycled void formers is expected to lead to significant sustainability benefits.

R. Ingeli et al. (2025), the review of voided slabs (bubble deck, voided flat slabs) discussed their thermal and hygrothermal effects on building energy performance. The results of the study indicate that voids in concrete slabs improve the thermal resistance and consequently enhance the buffering of diurnal temperature when the arrangement of voids is done to prevent thermal bridging; however, this is not the case with the slabs that are thinner and have larger voids since they will lose their thermal mass affecting passive cooling/heating strategies. The review has strongly recommended the need for integrated design whereby the three parameters of structural, thermal and acoustic performance are optimized simultaneously, further indicating that voided slabs would then be able to form part of the energy-efficient building envelopes provided topping and insulation detailing of the right types are done.

B) Literature Summary

- Hollow-core and voided slabs are said to cut down the use of concrete by 20-40% according to the recent studies, and this is one of the biggest factors that contribute to the reduction of the dead load.
- The flexural performance of hollow slabs is usually considered to be on the same level with that of solid slabs as long as proper reinforcement or prestressing is applied in the design.
- The punching shear strength is often lower in hollow slabs due to the lesser amount of concrete surrounding the critical shear zones; hence, the researchers suggest the use of solid strips or enhanced shear reinforcement.
- Bubble Deck slabs are able to retain 80-95% of the flexural strength of solid slabs, however, they exhibit different patterns of cracking around the voids.
- Prestressed hollow-core slabs have the ability to carry larger loads and span longer distances than traditional slabs, however, this comes at the expense of reduced ductility.
- Concrete-filled-core strengthening can lead to a significant improvement in both shear and punching performance of hollow-core units.
- Studies on thermal and acoustic properties have shown that voided slabs offer better insulation because of their lighter weight.
- According to economic analyses, hollow slabs are a good option economically when the percent of the void is high or when the redesign of the structural system results in lower loads on beams and foundations.

C) Research Gap

- Very few experimental investigations carried out on full-size hollow and voided slabs, particularly under the combined flexure-shear loading.
- Most of the research is directed towards the flexural strength, but the punching shear behavior of hollow slabs is not yet completely comprehended and lacks a unified approach to design.
- The present codes do not outline the specific requirements for the geometries of the voids, their distances, or the detailing of shear zones in hollow/voided slabs.
- Only a handful of studies have looked at the long-term

performance of hollow slabs in terms of creep, shrinkage, fatigue, and durability when subjected to real service conditions.

- Cost comparisons are usually based on the material costs of the slab only, while the system-level savings (beams, columns, foundations) are barely touched upon.
- Very little research is done on the thermal, acoustic, and vibration performance of hollow slabs in contemporary buildings.
- Research attempting to combine experimental, numerical, and economic analyses into a single decision-making model is still limited.

3. Research Methodology

A) Criteria for selecting this study

- The slab systems chosen must fulfill structural safety standards under dead, live, and service loads.
- Both solid and hollow slabs are designed for equal span, loading, and support conditions to guarantee just comparison.
- Concrete grade, type of reinforcement, and curing conditions are kept the same for all specimens.
- Slab thickness and void geometry are selected according to practical construction feasibility.
- Flexural strength, deflection, cracking pattern, and ultimate load capacity are the criteria for performance evaluation.
- Punching shear behavior at the supports is meticulously monitored.
- Material consumption is expressed in terms of concrete volume and steel quantity.
- The economic evaluation comprises material, labor, and formwork costs.
- The sustainability aspects like dead load reduction and energy efficiency are included.

B) Method of analysis

- Identify slab configurations for analysis: conventional solid slab and hollow slab with void formers.
- Define geometric parameters such as span length, slab thickness, and void arrangement based on design standards.
- Apply identical loading conditions including dead load, live load, and self-weight for both slab types.
- Perform analytical design for flexure and shear using relevant code provisions.
- Calculate reinforcement requirements and check serviceability criteria such as deflection and crack width.
- Prepare numerical or spreadsheet-based calculations to estimate bending moments and shear forces.
- Conduct experimental load testing to obtain load-deflection behaviour and cracking patterns.
- Compare analytical predictions with experimental results to validate structural behaviour.
- Evaluate material quantities including concrete volume, reinforcement weight, and void material usage.
- Perform cost analysis based on calculated quantities and compare economic efficiency.

C) Comparison and Analysis

Table 1: Comparison and Analysis from Literatures

Sr. No.	Structural Performance (Flexure & Deflection)	Shear / Punching Behaviour	Material & Weight Reduction	Economic / Practical Implications
1	Comparable flexural behaviour to solid slabs with proper topping	Punching shear design not fully addressed in codes	Significant reduction to optimized void geometry	Recommends system-level cost evaluation
2	Maintains 80–95% stiffness; good deflection control	Punching critical near concentrated loads	10–25% concrete reduction	Faster construction, lower CO ₂ , needs design guidelines
3	Flexural behaviour acceptable	Reduced punching capacity due to void interference	Moderate material savings	Requires conservative design and solid zones
4	Improved stiffness with filled cores	Significant increase in shear and punching resistance	Slight increase in material but safer	Effective retrofit solution for existing slabs
5	High flexural capacity with prestressing	Local cracking reduces ductility	Reduced slab thickness and weight	Suitable for long spans; needs precise detailing
6	Ultimate load similar to solid slabs	Service cracking and punching concerns	Lower mass affects dynamic response	Requires system redesign for true economy
7	FRP improves flexural strength	Limited punching improvement without anchors	No major weight reduction	Practical strengthening for deficient slabs
8	Comparable bending strength	Punching behaviour inconsistent	12–25% concrete saving	Adoption limited by lack of code provisions
9	Adequate flexural performance	Punching vulnerability near void zones	Reduced concrete with sustainability	Calls for updated design models

			lity benefits	
10	Structural behaviour maintained	Not shear-dominant focus	Reduced mass improves insulation	Supports energy-efficient building design.

4. Discussion

A) Methodology for future research directions

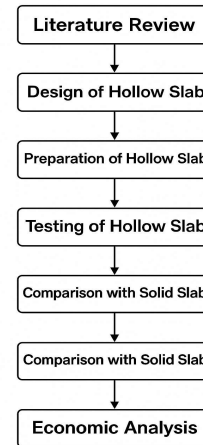


Fig. 1. Flow Diagram of system

- The principal mechanism of hollow slabs is the removal of non-structural concrete from the middle of the slab, where it does not contribute significantly to the load-bearing capacity, thus maintaining the same strength axial deflection.
- The slabs are made by placing hollow blocks or void formers in a way that creates cavities either longitudinally or bi-axially and consequently reducing the total dead load without sacrificing the bending performance.
- The layers of concrete on the upper and lower sides, along with the steel reinforcement, behave like a flanged beam resisting compression (on top) and tension (at the bottom) due to applied loads.
- The reduction in self-weight results in a drop in the bending moments and shear forces in the beams and columns that support the structure, thus making the whole structure more efficient.
- Like in the case of solid slabs, tensile forces are taken by the reinforcing bars or prestressing tendons whereas the concrete in the compressive zone resists the compressive stresses.
- The placement of voids is done in such a way that they do not disrupt the load paths, which in turn guarantees that the slab acts structurally as an equivalent solid section of reduced thickness.
- In the case of prestressed hollow-core slabs, the prestressing tendons are responsible for the creation of compressive stresses which in turn leads to the increase of span capacity and the decrease of cracking.
- The loading of the slab is such that it transfers the loads to the supports through a combination of flexural and shear resistance while the localized solid areas are responsible for

the punching shear that occurs near the columns.

- All in all, the whole system reaches a point where less material is used, but the structure still performs really well, and money is saved.

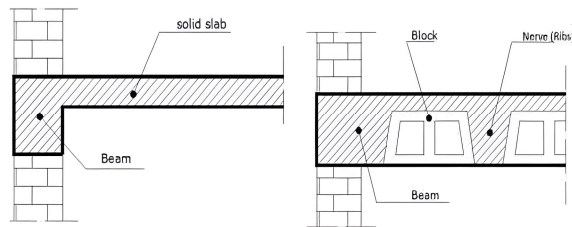


Figure 2. Solid Slab and hollow block slab

- Slabs are premium concrete consumers since they support vertical loads mainly, and the continuing increase in building spans brings about the need for thicker slabs, larger columns, and better foundations which in turn elevate material cost and usage.
- A solid slab heavyweight also has an impact on the structural deflection control requirements which in turn means more steel reinforcements and concrete are going to be used.
- Energy demand all over the world for heating and cooling is increasing; among the total energy usage the buildings consume 25–40% mainly due to the need for thermal comfort.
- The world according to Gervásio is moving to a more sustainable building envelop by reducing material and energy consumption, as he who favors energy-efficient structural systems points out.

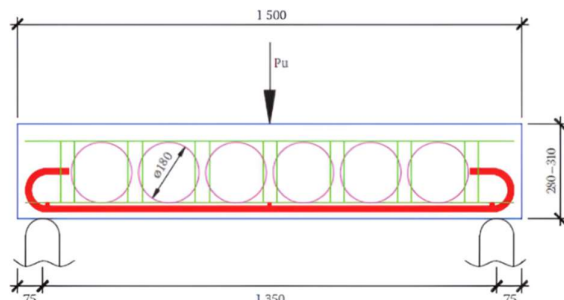


Figure 3. Experimental setup

- Hollow Core Slabs (HCS) provide thermal insulation and at the same time keep the concrete to a minimum in the critical areas for flexural strength and thus offer significant thermal benefits.
- The outcome of the research proves that voided slabs lower the weight and deflection of slabs, thereby getting the latter improved in terms of span capability and still holding the same structural behaviour.
- Research indicated that steel fibers addition (1–2%) caused deflection reduction in voided slabs, while hollow-core slabs accomplished 43% weight savings and bubble slabs, on the other hand, 18% when compared to solid slabs.

5. Conclusion And Future Prospective

The present article has given an extensive overview of the latest works concerning the hollow and voided slab systems, including the hollow core slabs, the bubble deck slabs, and

other voided slab technologies as compared to traditional solid slabs. The reviewed studies assert that hollow slabs can cut down on concrete usage and weight to a large extent while still providing the necessary bending strength and being suitable for use if they are properly designed. Nevertheless, punching shear, cracking around the voids, and loss of ductility are still major problems, especially when the loading is concentrated. On the other hand, the use of concrete-filled cores, fiber-reinforced polymers, and composite toppings has led to considerable gains in the resistance to shear and punching. From the economic and environmental standpoint, hollow slabs are a very promising option, particularly when one takes into account the overall reduction of beams, columns, and foundations. Yet, the review points out the necessity for new design codes, uniform testing methods, and prolonged performance evaluations to facilitate the broader and safer incorporation of hollow slab systems in contemporary construction.

References

- [1] Al-Furat Al-Awsat Technical University, "State of the Art Review on Hollow Core Slabs," Technical Journal, Zien Journals, 2024.
- [2] V. O. Francis, "Bubble Deck Slab System: A Review on Design and Performance," International Journal, 2021. [Online]. Available: ResearchGate.
- [3] A. Al-Bayati, "Punching Shear Strength of Voided Slab: Literature Review and Code Evaluation," EJ UOWASIT Conference Proceedings, 2022. [Online]. Available: ejuow.uowasit.edu.iq.
- [4] M. R. McDermott et al., "Shear Capacity of Hollow-Core Slabs with Concrete-Filled Cores," PCI Journal, Precast/Prestressed Concrete Institute, 2020.
- [5] D. H. Kim et al., "Evaluation of Flexural Behavior of Prestressed Concrete Hollow-Core Slabs," Buildings, MDPI, vol. XX, no. X, 2023.
- [6] K. A. Chebo et al., "Experimental Investigation on the Structural Performance of Hollow Core Slabs," PMC, 2022.
- [7] A. E. Abd Elhameed, "Strengthening of Hollow-Core Precast Prestressed Elements: A Review," Heliyon, Taylor & Francis Online, 2024.
- [8] V. O. Francis et al., "Review on Bubble Deck Technology," IJSRET / IJSTR Journals, 2019–2022.
- [9] Al-Mussaib Technical College, "State of the Art Review on Hollow Core Slabs," ResearchGate Preprint, 2024.
- [10] R. Ingeli et al., "Enhancement of the Thermal Performance of Voided Slabs," Energy & Built Environment, Elsevier, 2025.
- [11] J. Newman, B. S. Choo, and P. Owens, Advanced Concrete Technology: Processes. Oxford, U.K.: Elsevier Ltd., 2003.
- [12] M. F. Junaid et al., "Lightweight concrete from a perspective of sustainable reuse of waste byproducts," Constr. Build. Mater., vol. 319, 2022, doi: 10.1016/j.conbuildmat.2021.126061.
- [13] A. M. Neville and J. J. Brooks, Concrete Technology, 2nd ed. London, U.K.: Prentice Hall, Pearson Education, 2010.
- [14] M. F. Junaid et al., "Lightweight concrete from a perspective of sustainable reuse of waste byproducts,"

- Constr. Build. Mater., vol. 319, 2022, doi: 10.1016/j.conbuildmat.2021.126061.
- [15] S. K. Adhikary and Z. Rudzionis, "Influence of expanded glass aggregate size, aerogel and binding materials volume on the properties of lightweight concrete," *Materials Today: Proceedings*, vol. 32, pp. 712–718, 2020.
- [16] S. Abdulhussein and A. Alfeehan, "Mechanical properties of structural aerated lightweight concrete reinforced with iron lathing waste," *J. Eng. Sustainable Development*, vol. 25, 2021, doi: 10.1061/jsdeag.0003070.
- [17] N. M. Zamzani, A. O. Mydin, and A. N. Abdul Ghani, "Experimental investigation on engineering properties of lightweight foamed concrete with coconut fiber addition," *MATEC Web Conf.*, vol. 250, pp. 1–8, 2018.
- [18] A. Thakur and S. Kumar, "Mechanical properties and development of lightweight concrete using autoclaved aerated concrete with aluminum powder," *Materials Today: Proceedings*, vol. 56, pp. 3734–3739, 2022.
- [19] A. Khan, M. Baluch, and A. Al-Gadhib, "Repair and strengthening of reinforced concrete structures using CFRP plates," in *Proc. Int. Bhurban Conf. Applied Sciences and Technology*, Pakistan, vol. 26, no. 2, 2004.
- [20] ACI 318-14: Building Code Requirements for Structural Concrete, American Concrete Institute, USA, 2014.
- [21] BS 1881-116: Method for Determination of Compressive Strength of Concrete Cubes, British Standards Institution, London, U.K., 2000.
- [22] ASTM C496-04: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, USA, 2004.