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COMPARATIVE REVIEW OF PRECAST AND CAST-IN-SITU REINFORCED CONCRETE STRUCTURES UNDER FLEXURAL LOADING

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ABSTRACT

This paper provides a comprehensive review comparing the flexural performance of precast and cast-in-situ reinforced concrete structures. The study focuses on parameters such as flexural strength, ductility, crack propagation, connection behavior, and serviceability. While precast systems offer advantages in construction speed, quality control, and material efficiency, their performance largely depends on connection behavior. Recent advancements, including Ultra-High Performance Concrete (UHPC), Engineered Cementitious Composites (ECC), and mechanical splicing, have notably enhanced the strength and ductility of precast systems. These developments allow precast elements to achieve or even surpass the performance of monolithic concrete. The paper also reviews experimental studies and design approaches, highlighting future research directions related to durability, fatigue resistance, and life-cycle performance of precast structures.

KEYWORDS: Precast concrete; Cast-in-situ concrete; Flexural behavior; UHPC joints; Ductility; Structural performance.

1. INTRODUCTION

Reinforced concrete (RC) remains the most widely used structural material in global infrastructure due to its versatility, strength, and cost efficiency [1–3]. Traditional CIS RC construction involves on-site casting, curing, and formwork, offering monolithic continuity and seamless stress transfer under load. Precast concrete (PCa) systems, on the other hand, transfer most of the production process to a factory-controlled environment, providing enhanced quality control and accelerated construction schedules [4–6]. The growing emphasis on industrialized and modular construction has driven the adoption of precast technology, especially in multi-story buildings, bridges, and transportation infrastructure. Despite these advantages, the performance of precast systems under flexural loading is significantly influenced by connection detailing and interface integrity [7]. The discontinuity at joints remains a primary structural challenge, affecting ductility, crack propagation, and overall serviceability [8–9]. In CIS RC systems, continuous casting ensures uniform stress distribution and reliable ductile behavior during flexure. Conversely, precast systems rely on mechanical, welded, or grouted joints to replicate monolithic action. The efficiency of these connections determines the structure's ability to resist bending moments, transfer shear forces, and maintain stiffness [10–12].

Modern precast elements are often designed using high-performance materials such as Ultra-High Performance Concrete (UHPC) and Engineered Cementitious Composites (ECC), which offer enhanced strength, durability, and energy absorption capacity [13–15]. These materials exhibit higher tensile strain capacities and reduced crack widths, resulting in superior post-yield behavior. When combined with mechanical splicing or post-tensioning techniques, UHPC and ECC connections can achieve monolithic-like flexural performance [16–18]. Factory-controlled production environments ensure consistent curing conditions and dimensional precision, reducing variability in mechanical properties. However, the in-situ connection zones, often cast under uncontrolled site conditions, may exhibit weaker bonding or increased permeability. This hybrid nature of PCa structures—partly factory-produced and partly on-site assembled—necessitates rigorous evaluation of flexural behavior under both short- and long-term loading conditions [19–20].

Flexural performance is governed by parameters such as moment capacity, stiffness, crack width, and ductility. In CIS RC beams, flexural response is characterized by gradual yielding and distributed cracking, offering predictable post-elastic behavior. Precast systems, by contrast, may experience localized cracking at joint interfaces if not properly detailed. Recent studies have demonstrated significant improvements in the flexural performance of precast joints through advanced materials and detailing techniques. For example, UHPC joint grouting has been shown to enhance moment transfer and delay crack initiation. ECC-based connections exhibit multiple fine cracks and superior ductility under cyclic bending loads[21]. Mechanical connectors and post-tensioned reinforcement have further improved continuity across joint interfaces, resulting in flexural strength exceeding that of equivalent CIS beams.

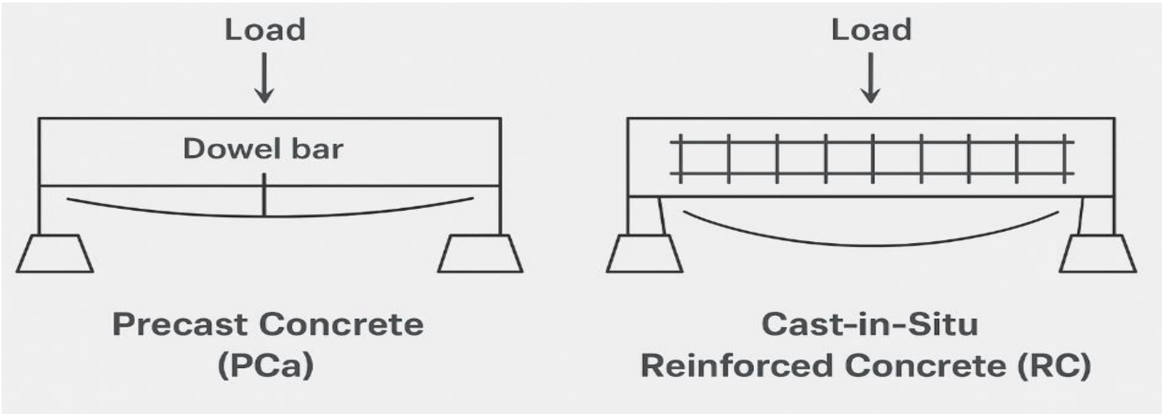

Fig. 1: Flexural loading under PCC and RCC.

Finite element analyses have also validated experimental findings, providing insights into stress redistribution and the influence of joint stiffness on global deformation patterns. These modeling studies confirm that optimized detailing—such as adequate reinforcement anchorage, confinement, and grout confinement—can mitigate performance discrepancies between PCa and CIS systems under flexure. Serviceability under flexural loads encompasses deflection limits, crack width control, and stiffness degradation. Precast structures, due to their high-quality production, exhibit improved short-term stiffness. However, long-term issues such as fatigue, differential shrinkage, and interface corrosion remain critical. Durability is strongly linked to concrete permeability and joint quality. Precast elements typically display superior resistance to chloride ingress and carbonation due to effective curing and low water-cement ratios. Nevertheless, the joint regions—particularly those exposed to aggressive environments—demand special attention to ensure durability parity with monolithic sections. Integration of supplementary cementitious materials (SCMs) such as fly ash, silica fume, and ground granulated blast furnace slag (GGBS) in both precast and CIS systems can enhance durability while reducing carbon emissions. Sustainable alternatives, including stone cutting powder (SCP) as a partial cement replacement, have shown potential to improve mechanical strength and long-term performance, aligning structural innovation with environmental responsibility.

2. Literature Review Methodology

2.1 Literature Search and Review Framework

An extensive review of literature was conducted through leading databases such as ScienceDirect, MDPI, and ResearchGate, covering studies published between 2015 and 2025. Search keywords included *precast flexural behavior*, *beam-to-beam connections*, *UHPC joint performance*, and *mechanical splicing in precast concrete*. Research works that presented experimental results, finite element (FE) modeling, or analytical assessments of precast and cast-in-situ reinforced concrete systems were shortlisted. Priority was given to studies focusing on flexural performance, connection detailing, and the role of advanced materials such as Ultra-High Performance Concrete (UHPC) and Engineered Cementitious Composites (ECC) [1–4]. The selected studies were categorized according to specimen type (beam, slab, frame, composite system), joint configuration (wet, dry, hybrid), joint material (normal concrete, UHPC, epoxy, grout), and failure characteristics (flexural yielding, bond failure, interface slip). Meta-analysis revealed significant progress in understanding flexural mechanisms in precast systems, yet highlighted that joint continuity remains the critical factor governing ductility and serviceability[5–7].

2.2 Fundamental Differences Affecting Flexural Behaviour

2.2.1 Continuity and Load Path

The load path continuity is a primary distinction between cast-in-situ (CIS) and precast (PCa) systems. In CIS reinforced concrete, both concrete and reinforcement are cast monolithically, ensuring full continuity in section and reinforcement anchorage. The typical flexural response follows a well-defined pattern—initial elastic behavior, crack initiation, reinforcement yielding, and eventual compression failure—culminating in high ductility and energy dissipation capacity[8,9].

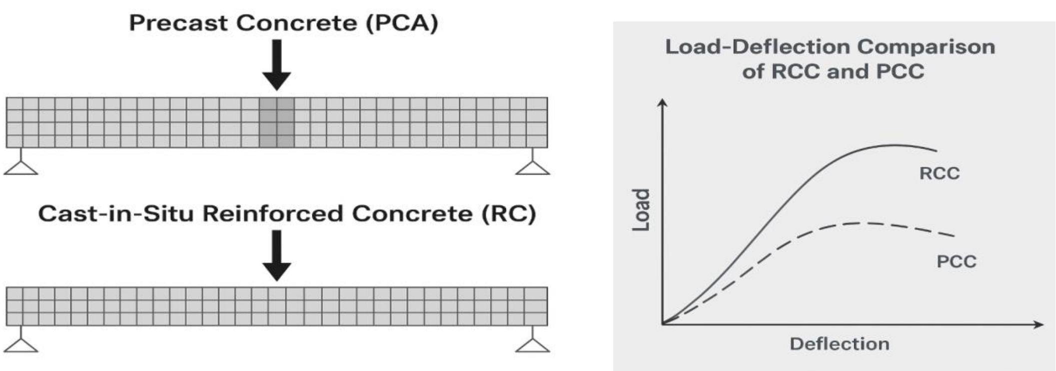

Fig. 2: load-deflection comparison.

In precast concrete systems, however, the structural continuity is achieved through on-site connections rather than monolithic casting. The transfer of moment and shear across these interfaces depends on the mechanical performance of joints, including couplers, sleeves, grouted ducts, or infill concrete. As noted by Kim et al. [10] and Aalami et al. [11], even minor imperfections in joint alignment or inadequate confinement can lead to local slip, delayed stiffness mobilization, and reduced ultimate moment. Finite element studies have confirmed that discontinuity at joints modifies stress distribution along the span, introducing stress concentrations at connection zones [12]. Consequently, while individual precast modules may exhibit high material strength, the global system stiffness and ductility are often governed by the weakest joint. When the joint achieves full moment transfer—such as through UHPC infill or full-depth shear keys—the flexural behavior of the precast system approaches that of monolithic CIS concrete [13].

2.2.2 Material Quality and Curing Conditions

Factory-controlled production offers several advantages in material uniformity and curing efficiency for precast components. Controlled temperature, vibration, and moisture conditions enable optimized hydration and early-age strength gain, resulting in higher modulus of elasticity and reduced microcracking [14]. These improvements enhance both flexural rigidity and fatigue resistance. However, the heterogeneity at the joint interface—arising from different casting ages and curing conditions—introduces zones of differential shrinkage and bond weakness. Studies by Hwang and Kim [15] observed that mismatch in curing between precast and in-situ joint materials can produce localized stress concentrations that accelerate crack initiation under repeated flexural loads. Furthermore, differential moisture content can influence long-term creep and shrinkage compatibility, potentially leading to serviceability issues over time.

2.2.3 Joint and Connection Behaviour

The connection region remains the most influential parameter in determining flexural performance. Various jointing techniques have been developed, including mechanical couplers, post-tensioned joints, wet connections using UHPC infill, and hybrid mechanical-grouted systems [16]. Experimental programs have demonstrated that the use of UHPC or ECC infill significantly enhances bond strength and mitigates slip at reinforcement interfaces, allowing the joint to behave nearly monolithically [17]. In contrast, dry joints without sufficient confinement tend to exhibit brittle shear slip and early joint debonding. Studies involving mechanical sleeve couplers and headed bars report improved strain compatibility and energy absorption under cyclic loading [18]. Moreover, numerical investigations using ABAQUS and ANSYS have highlighted that local joint geometry, including shear key depth, bar embedment length, and joint width, directly affects flexural stiffness and ultimate moment capacity [19]. Proper detailing to ensure sufficient overlap length, confinement reinforcement, and grout strength is crucial to achieving desired ductility and serviceability limits.

2.2.4 Serviceability under Flexural Loading

Serviceability criteria such as deflection, crack width, and stiffness degradation serve as practical indicators of structural performance under working loads. In monolithic CIS beams, the predictable stiffness behavior arises from uniform strain distribution across the section. Precast systems, however, depend on composite action across the joints. If full moment continuity is not achieved, partial composite action can lead to excessive deflection and early cracking [20]. Comparative experimental studies by Zhang et al. [21] and others revealed that beams with wet UHPC joints maintained near-monolithic deflection patterns, whereas dry or ungrouted joints experienced up to 30–40% higher midspan deflection under equivalent loads. Crack widths at the interface are typically wider than those in monolithic beams, emphasizing the need for high bond strength and adequate reinforcement anchorage in the joint zone. The comparative review of flexural performance between precast and cast-in-situ RC systems underscores the central importance of connection design. While material advancements and factory-controlled production have enhanced the intrinsic quality of precast elements, joint continuity and interface performance remain the governing factors in achieving equivalent or superior flexural behavior.

3. Summary of Experimental Findings

3.1 Flexural Capacity and Ultimate Behaviour

The flexural performance of precast concrete elements has been a focus of research due to its critical role in ensuring structural safety and serviceability. Numerous experimental studies have compared precast versus cast-in-situ (CIS) reinforced concrete (RC) beams and slabs under flexural loading to assess ultimate strength, ductility, and failure mechanisms. The overarching trend from the literature indicates that well-designed precast elements can achieve flexural performance approaching that of monolithic cast-in-situ systems, provided the joints and connections are appropriately detailed. An early investigation, titled An

Experimental Study on the Flexural Behavior of Precast Concrete Modular Beam Systems Using Inserted Steel Plates, reported that a precast modular beam system attained roughly 80% of the ultimate flexural capacity of a monolithic cast-in-situ beam. Interestingly, the precast system exhibited a ductility approximately 1.3 times higher than its monolithic counterpart. This enhancement in ductility, despite slightly lower capacity, highlights one of the intrinsic advantages of precast modular systems: the ability to sustain large deformations without immediate catastrophic failure, provided the joints are designed to transfer moments efficiently.

Similarly, studies on prefabricated concrete slabs with various reinforcement configurations at seams have observed that while these systems may show slightly reduced flexural bearing capacity compared to fully cast-in-situ slabs, their deformability and ductility are generally superior. The increased ductility is attributed to controlled cracking at joints and seam regions, which allows redistribution of stresses across the slab before ultimate failure occurs. Such behaviour is especially relevant in applications like long-span floors, bridge decks, and modular construction, where flexibility and crack control are critical for durability and occupant comfort. Full-scale tests of precast concrete deck panels with cast-in-place toppings, as reported in Flexure Shear Behavior of Precast Concrete Deck Panels with Cast-in-Place Concrete Topping, demonstrated composite action between precast and cast-in-place layers under large displacements. Notably, these studies observed that the ultimate failure involved flexure-shear cracks through both precast and cast layers, effectively behaving as a single monolithic slab. The absence of significant horizontal shear slip between the topping and precast panels contributed to this performance. These findings indicate that, with proper connection detailing, precast systems can achieve moment capacities and crack patterns comparable to traditional cast-in-situ systems. Other experimental works reinforce the conclusion that the moment capacity of precast systems is highly dependent on joint quality. Precast elements with carefully designed mechanical connectors, grouted sleeves, or post-tensioned splices exhibit flexural strengths approaching or matching those of monolithic RC beams. In cases where joints are suboptimal, premature failure may occur, reducing effective capacity and potentially altering the intended failure mode. Therefore, joint design and detailing remain the most critical factors in achieving comparable flexural performance in precast versus cast-in-situ elements.

3.2 Serviceability (Cracking, Stiffness, and Deflection)

While ultimate strength is important, serviceability under working loads is equally critical for structural performance. Serviceability criteria include initial stiffness, cracking load, deflection under service loads, and crack widths. Experimental results consistently indicate that precast elements often exhibit slightly higher initial cracking loads due to improved concrete quality achieved under factory-controlled casting conditions. High-quality precast concrete has lower porosity, fewer microcracks, and more uniform curing, which contribute to higher modulus of elasticity and initial stiffness. However, the presence of joints in precast systems can reduce the effective stiffness under service loads. For instance, the study on precast modular beams reported marginally lower initial stiffness compared to monolithic beams due to seam effects, despite the improved ductility. This suggests that joints, while necessary for modularity and constructability, act as local flexibility points that may influence deflection behaviour. Similarly, studies on precast ultrahigh-performance concrete (UHPC) elements combined with cast-in-place UHPC topping observed very low bond strength at untreated interfaces (1.06 MPa). Application of surface treatments, such as EPE foam fiber exposure, significantly enhanced interface strength to ~4.68 MPa, illustrating that interface engineering is critical in controlling cracking and deflection in precast systems.

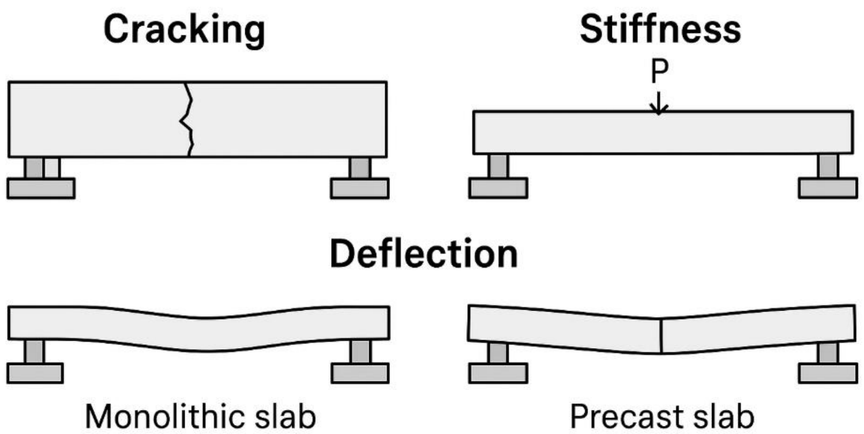

Fig. 3: Cracking, Stiffness comparison in precast and RCC.

Additionally, prefabricated slabs often display crack patterns that are more widely spaced but with larger widths compared to monolithic slabs. This phenomenon results from the ability of joints to accommodate limited movement and redistribute stresses. Although such behaviour increases deformability, it can potentially compromise serviceability if deflections exceed permissible limits or if crack widths become unacceptable for durability. Consequently, proper detailing, reinforcement at seams, and the use of mechanical connectors or post-tensioning techniques are necessary to ensure serviceability performance comparable to cast-in-situ elements.

3.3 Ductility and Failure Mode

Ductility is a critical parameter in structural design, particularly for seismic resilience and load redistribution. Cast-in-situ RC beams generally exhibit ductile behaviour characterized by yielding of tensile reinforcement, followed by concrete crushing in the compression zone and large deflections prior to collapse. Precast systems, however, present more complex ductility behaviour because their ultimate performance is strongly influenced by joint configuration. If the joint strength is lower than the member span, precast beams may fail prematurely by shear slip, interface debonding, or bond failure. Such failures are typically brittle or semi-brittle, reducing warning before collapse. For example, in Experimental Study on Flexural Behaviour of Prefabricated Concrete Beams with Double Grouted Sleeves, precast beams exhibited lower first-cracking loads than cast-in-situ references, but in some configurations, ductility improved, with maximum crack widths 41.2% and 28.6% larger than reference beams under three- and four-point bending tests, respectively. These results highlight that while ultimate capacity may approach that of cast-in-situ beams, the failure mode in precast systems can be substantially different if joint detailing is inadequate. Moreover, the incorporation of enhanced joint detailing—such as grouted sleeves, mechanical splices, or post-tensioned tendons—can significantly improve ductility and prevent brittle failure. Precast elements with carefully engineered joints often display plastic hinges away from the joint, mimicking the ductile failure observed in monolithic beams. This behaviour underscores the importance of joint design not only for strength but also for predictable and safe failure mechanisms.

3.4 Effects of Advanced Materials and Joint Enhancements

Recent experimental research has increasingly focused on advanced materials and joint enhancement techniques to bridge the performance gap between precast and monolithic systems. The use of ultrahigh-performance concrete (UHPC), engineered cementitious composites (ECC), fiber-reinforced concrete (FRC), and high-strength mechanical connectors has shown significant promise. These innovations aim to improve the bond, shear transfer, and flexural response at joints, thereby enhancing overall structural performance. For instance, Zhang et al. investigated precast prestressed concrete beams reinforced with fibers and reported that the addition of 0.6% fiber content increased the cracking load by ~40% and the ultimate flexural capacity by ~20%. Similarly, engineered interfaces with roughened surfaces, epoxy bonding, or embedded shear connectors have been shown to mitigate premature joint slip and increase energy absorption under cyclic loading. The integration of such materials and detailing strategies narrows the gap between precast and cast-in-situ systems, allowing modular construction to achieve both high strength and ductility.

In addition, hybrid approaches combining UHPC or ECC at joint regions with conventional precast concrete in spans have been explored. This strategy leverages the superior mechanical properties of advanced materials at critical connections while maintaining cost-effectiveness in less critical regions. Experimental studies indicate that such hybrid systems not only improve ultimate flexural capacity but also enhance serviceability by reducing deflections and controlling crack widths. In conclusion, experimental research consistently demonstrates that precast concrete systems can achieve comparable flexural capacity, ductility, and serviceability to cast-in-situ RC structures when joints are carefully designed and advanced materials are employed. While precast elements may initially display lower stiffness or slightly reduced cracking loads due to joint flexibility, proper interface treatment, reinforcement detailing, and fiber integration can mitigate these effects. Therefore, modern precast concrete construction, supported by rigorous experimental validation, offers a viable alternative to traditional cast-in-situ construction, providing benefits in quality, speed, and sustainability without compromising structural performance.

4. DISCUSSION

4.1 Understanding the Differences

Recent studies suggest that the key factor distinguishing precast concrete from traditional cast-in-situ systems lies in the behaviour of the joint region. In essence, the joint acts as the linchpin for structural performance. Where connections are poorly detailed – with insufficient splice lengths, weak grout, inadequate shear keys or dowels, or improper curing – the effects are clear: the beam’s stiffness drops, cracking occurs earlier, and overall ductility suffers. In contrast, carefully engineered joints can elevate precast systems to rival monolithic cast-in-situ beams in both moment capacity and flexural resilience. Techniques such as mechanical connectors, ultra-high-performance concrete (UHPC) grout, keying mechanisms, and continuous reinforcement are central to achieving this high performance.

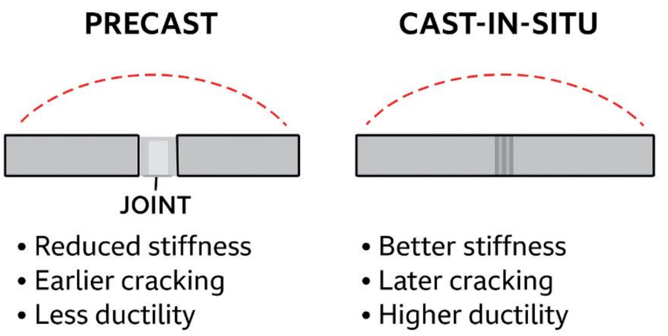

Fig. 4: Joint effect and flexural strength comparison in precast and RCC.

Quality control is another significant differentiator. Precast elements, manufactured in factory-controlled environments, benefit from higher-strength concrete and superior compaction. Yet, this advantage can be eroded during on-site assembly if joints are misaligned, improperly grouted, or inadequately cured. Cast-in-situ concrete avoids this problem through its continuous pouring, although it remains susceptible to variability in site conditions such as temperature, workmanship, and material handling.

4.2 Implications for Design and Construction

For modern construction projects that prioritise speed, repeatability, and modularity – such as large-scale residential blocks or repeated-span bridges – precast systems are particularly appealing. But the success of these systems hinges on careful attention to joint detailing. Engineers are urged to treat the joint region not merely as a connection, but as a "critical section" requiring dedicated analysis in flexural design. Serviceability checks, including deflection and cracking assessments, must account for potential reductions in stiffness at the joint. Material selection also plays a pivotal role. Even if the precast modules themselves are of high quality, the interface must be compatible in terms of strength, shrinkage, and elastic modulus. Innovative, sustainable materials – such as fly ash, stone cutting powder, or other cement replacements – introduce additional variables that require careful consideration to ensure the interface performs adequately under load. Codes and design guidelines, historically focused on monolithic behaviour, must evolve to include explicit provisions for precast joint performance under flexure.

4.3 Life-Cycle and Durability Considerations

Precast construction often provides tangible durability benefits: controlled curing, reduced exposure to adverse weather, and consistent concrete cover. Yet the joint remains a potential weak spot, susceptible to stress concentrations, differential shrinkage, and fatigue under cyclic loading. These effects can manifest as long-term reductions in stiffness, higher deflections, or cracking, impacting the structure’s service life. Life-cycle cost analysis should therefore incorporate potential maintenance or repair needs at joints, including issues such as corrosion of mechanical couplers, shrinkage-induced cracking, or fatigue under repeated loading. For research exploring cement replacement with industrial by-products, understanding the interaction between sustainable materials and joint behaviour in precast systems presents a promising area for further investigation, bridging the gap between innovation and practical structural performance.

5. Extended Literature Summary Table

Recent studies have systematically investigated the flexural performance of precast concrete members with various joint and splice configurations, highlighting the critical role of connection detailing on structural behaviour. In 2019, Kim and Lee examined spliced post-tensioned box girders with sleeve and shear-key joints, reporting flexural failures primarily at the joint regions due to stress concentration. Chin et al. (2020) explored precast decks connected with headed GFRP rebars and UHPC infill, demonstrating enhanced cracking load and deflection capacity compared to conventional connections. The 2021 study on modular precast beams using inserted steel plates revealed that joint detailing significantly influenced stiffness and deflection, with failure occurring in bending at the module interfaces. In 2022, segmental beams made of high-strength and ultra-high-performance fiber concrete connected by shear keys exhibited improved flexural and shear performance at the joints. Hamoda et al. (2023) showed that intermediate connections filled with UHPECC enhanced ultimate load by 13–29% and increased energy absorption by 75–184%, with flexural failure occurring at the connection. The 2024 study on precast concrete-filled steel tubes demonstrated that joint fillers such as ECC and UHFRC substantially improved cracking resistance, stiffness, and energy absorption, emphasizing the importance of joint design and material selection in achieving optimal ductility and structural integrity.

Table 1: literature review on precast vs cast-in-situ flexural behavior.

Year	Title of the article	Specimen geometry / Joint / Splice type & materials	Key results (flexural load, cracking, ductility)	Failure mode
2019	Structural Behavior of Spliced Post-Tensioned Girders with Precast Box Segments (Kim M.S., Lee Y.H.) 2019.	Precast post-tensioned box-girders, spliced joints between segments (sleeves + shear keys)	Experimental results: evaluated crack pattern, max load, displacement/ductility for spliced vs monolithic.	Flexural failure; joint stress-concentration noted.
2020	Flexural Behavior of a Precast Concrete Deck Connected with Headed GFRP Rebars and UHPC (Chin W.J. et al.) 2020.	Precast concrete deck panels connected via headed GFRP rebars and UHPC infill joint	Improved flexural behaviour of deck with this joint type: better cracking load, deflection compared to conventional.	Flexural failure of deck; connection held well.
2021	An Experimental Study on the Flexural Behavior of Precast Concrete Modular Beam Systems Using Inserted Steel Plates (Korea) 2021.	Precast concrete modular beam systems (modules joined using inserted steel plates)	The joint system studied: influence on flexural behaviour (deflection, cracking) of precast modules with joint detail.	Flexural failure (beam bending) with joint detail influencing stiffness/deflection.
2022	Behavior of Precast Segmental Beams Made of High-strength Concrete and Ultra-high Performance Fiber Concrete Connected by Shear Keys Technique (Arabian J. Science & Engineering, 2022)	Precast segmental beams, HSC + UHPFC connected by shear-key joints	The shear-key joint with UHPFC improved performance: under direct shear and flexural influence; enhanced joint behaviour under flexure/shear.	Combined flexural-shear failure at the joint region.
2023	Flexural Behavior of Precast Rectangular Reinforced Concrete Beams with Intermediate Connection Filled with High-Performance Concrete (Hamoda A. et al.) 2023.	Precast rectangular RC beams with an intermediate connection (various shapes) filled with NC, ECC, UHPECC, RECC	The intermediate connection with UHPECC infill increased ultimate load by 13-29 % and energy absorption by 75-184 %.	Flexural failure; connection geometry & infill type influenced ductility.
2024	Flexural behavior of precast concrete-filled steel tubes connected with high-performance concrete joints (Abadel A.A. et al., Materials Science-Poland 2024)	Precast concrete-filled steel tube (CFST) columns subjected to flexural loading; joints filled with ECC and UHFRC; varying development lengths (150-300 mm)	ECC and UHFRC joints improved cracking resistance and ultimate capacity: UHFRC connection 17 % improvement vs control. Doubling development length of ECC improved cracking ultimate force and stiffness.	Flexural failure of slender CFST columns with joint filler influencing behaviour.

6. Prospects and Proposed Actions

1. Standardized flexural testing protocols

Develop unified test methods to assess flexural behavior in precast joints, enabling consistent comparison and reliable design evaluation.

2. Long-term durability and fatigue studies

Examine joint performance under repeated loads and environmental effects to understand stiffness degradation over time.

3. Sustainable and compatible materials

Investigate eco-friendly materials like fly ash and stone-cutting powder for use in precast joints without compromising strength.

4. Life-cycle and cost analysis

Compare precast and cast-in-situ systems in terms of cost, construction time, serviceability, and long-term maintenance.

5. Design code integration and Hybrid structural systems

Update national design standards to include flexural behavior, stiffness reduction, and serviceability criteria for precast systems. Explore combined precast–cast-in-place methods to enhance flexural performance, deflection control, and structural efficiency.

7. CONCLUSIONS

Precast reinforced concrete is rapidly closing the performance gap with traditional cast-in-situ systems, especially when advanced joint detailing and modern materials such as UHPC, ECC, and fiber reinforcements are applied. The key factor that still distinguishes the two lies in the joint or splice region. If poorly executed, it can lead to stiffness reduction, slippage, earlier cracking, and lower ductility. In contrast, well-designed joints can deliver flexural behavior nearly identical to monolithic concrete. For engineers and researchers attention should extend beyond ultimate strength to serviceability and long-term durability, particularly in how joints perform under real-life conditions.

From an academic standpoint, incorporating these concepts into teaching across subjects like Highway Engineering, Structural Design, and Materials can help students understand how detailing impacts structural behavior. Finally, with growing interest in sustainable concrete technology, exploring partial cement replacement using stone-cutting powder, fly ash, and other industrial by-products in precast systems could offer an eco-efficient pathway for future construction, marrying sustainability with structural performance.

Data Availability Statement: All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request the review presented in this paper.

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