



General Concept and Structural Behavior of Reinforced Concrete Wide Beams: A Review

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ABSTRACT

This paper presents a comprehensive review of experimental and numerical studies on the structural behavior of reinforced concrete wide beams, defined by a width-to-effective depth ratio (b/d) of 2 or greater. The synthesis of findings from investigations over the past two decades reveals that wide beams exhibit fundamentally different responses to loading compared to conventional narrow beams, particularly in shear distribution, crack propagation, and failure mechanisms. Key findings indicate that reinforced concrete wide beams demonstrate an inherent extra shear resistance of 30-40% beyond first cracking, a beneficial characteristic underestimated by current design codes including ACI 318 and Eurocode 2. The review confirms that properly designed web reinforcement, including stirrups, hybrid steel-FRP configurations, and polypropylene fibers, substantially enhances shear strength, ductility, and crack control, with fibers capable of completely substituting minimum stirrups. Additionally, horizontal openings introduce stress concentrations requiring special detailing. The findings emphasize the critical need for revised code provisions that account for width effects and modern reinforcement strategies in wide beam applications.


1. Introduction

Reinforced concrete (RC) beams are key load-carrying elements in building systems, transferring slab actions to columns and walls and contributing to global stiffness and serviceability [1]. In modern practice, wide RC beams, whose width exceeds or is comparable to their depth are frequently adopted to minimize floor-to-floor height, alleviate reinforcement congestion, and simplify formwork, while maintaining adequate flexural and shear capacities when properly detailed [2]. Some codes take $b/d > 2$ or depth \leq slab depth; threshold depth ranges from 150–700 mm across codes [2], [3], [4].

Wide beams, in contrast to conventional narrow beams, engage more directly with slab actions and exhibit a unique distribution of stresses across their breadth [5]. This has initiated continuous experimental and analytical investigations into their behavior and design specifications [6]. Foundational theses and studies highlight the impact of load/support width and reinforcement distribution on the shear and flexural behavior of wide members, along with the possibility of adapting or extending code provisions to address these geometries [7]. Alongside geometric strategies, material innovation has gained traction in aggressive or serviceability-sensitive environments. Glass

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Fiber Reinforced Polymer (GFRP) bars offer corrosion resistance, reduced maintenance demands, and electromagnetic neutrality, albeit with distinct stress–strain response, bond characteristics, and crack-control implications compared to steel [8]. When GFRP is used in wide beams, designers must re-examine stiffness, cracking patterns, and ultimate capacity to reconcile serviceability targets with safety margins. Moreover, practical floor systems often require functional openings (e.g., for services or penetrations) within beam webs. Horizontal openings introduce local stress redistributions, potential stress concentrations, and modified crack trajectories that can interact with the flexural response [9], [10]. Consequently, the combined configuration—wide RC beams reinforced with GFRP and incorporating horizontal openings—merits a focused assessment to establish rational detailing, quantify performance trade-offs, and clarify the limits of applicability relative to conventional practice.

In design practice, wide reinforced concrete beams are generally governed by standard beam provisions, notwithstanding differences in their geometry and stress distribution [2]. ACI 318-19 [11] provides flexural and shear design equations primarily intended for slender beams, but it does not offer specific guidance for wide sections. Eurocode 2 (EN 1992-1-1:2004) [12] includes beam width in shear checks; however, it does not specifically address cases where the beam width significantly exceeds its depth, as seen in wide beams. The British Standard BS 8110 (1997) [13] outlines general shear design provisions; however, it assumes that the support width is equal to the beam width, a condition that may not accurately represent situations involving wide beams on narrower columns.

The introduction of non-metallic reinforcement, such as GFRP bars, highlights the existing gaps in codes. The ACI 440.1R-17 [14] design guide pertains to GFRP-reinforced members, with a primary emphasis on conventional rectangular beams and slabs. This design guide presents formulas for flexural strength, serviceability, and crack width control; however, it does not explicitly address wide beam geometries or the

existence of openings. Eurocode 2 lacks specific provisions for FRP reinforcement, necessitating reliance on national annexes or guidelines established by research institutions for designers. This inconsistency among design standards shows why further experimental and analytical research is needed to generate dependable data that can inform future revisions of codes of practice.

1.1 Background of Wide Beams

Wide RC beams are structural elements that possess a larger width compared to their depth, typically used in flat slab systems or long-span floor structures. These beams are designed to support slab loads efficiently over wide areas while also reducing the number of required formworks and columns [15]. According to standard design criteria, a beam is often considered “wide” when its width b is greater than or equal to twice its effective depth d , as shown in Figure 1 and as follow [3]:

$$b / d \geq 2 \quad (\text{Eq.1})$$

This proportion allows wide beams to behave differently from conventional narrow beams, particularly in terms of shear distribution and flexural stiffness. The load transfer is more spread out across the width, and cracks may propagate more irregularly, especially when discontinuities such as openings or voids are introduced [16].

Moreover, the flexural behavior of a wide beam can be estimated using classical beam theory. The flexural stiffness EI plays a significant role in determining the beam’s deflection under bending, where:

$$\delta = PL^3 / 48EI \quad (\text{Eq. 2})$$

$$M = PL / 4 \quad (\text{Eq. 3})$$

In the context of wide beams with openings or internal voids, these formulas must be applied cautiously, as such discontinuities cause stress concentrations and potential reductions in moment capacity. The effective depth d_{eff} is often reduced near the openings, and the flexural stiffness EI may be compromised [17].

Despite the increasing use of wide RC beams in modern structural systems, current design codes such as ACI 318-19 [18] and Eurocode 2 [12] do not provide specific provisions for dealing with horizontal openings or internal voids in such beams. Their recommendations focus primarily on conventional narrow beams, with limited guidance on how discontinuities like voids or service openings influence structural performance [19].

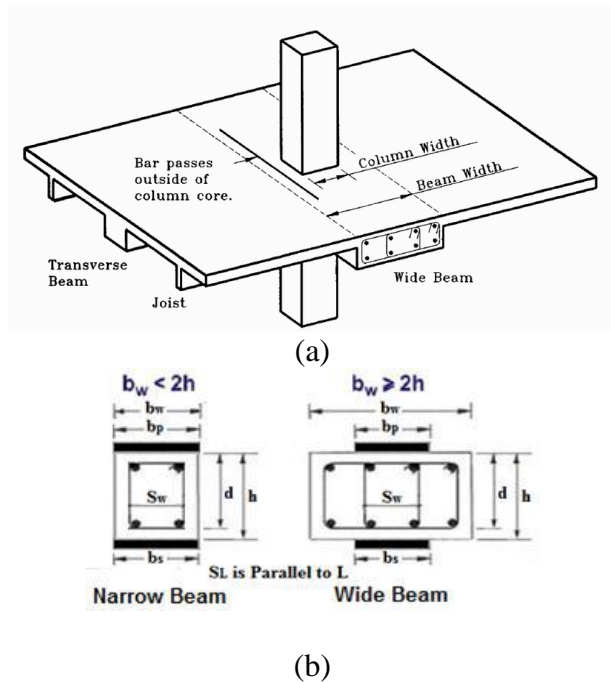


Figure 1. Concrete wide beam: a) Wide beam integrated in slab system; b) Wide and Narrow beam [20]

2. Previous Studies

A multitude of scholars have thoroughly investigated the capability of wide concrete beams. Experimental studies involve evaluating numerous wide beams with differences in specific properties in certain instances. In contrast, the others are theoretical in estimating wide beam capacity by proposing specific theories and equations for computing their capacity, and comparisons were conducted with those accepted by some codes. Because of the enormous number of these studies, their review needs to be a substantial part of this study.

2.1 Experimental Studies

Sherwood et al. (2007) [21] analyzed the structural performance of wide RC beams using various reinforcing methods, including GFRP bars and traditional steel. Eight broad beams subjected to four-point bending. All beams had uniform dimensions of 2500 mm in length, 600 mm in breadth, and 300 mm in depth. The main variables were the type of longitudinal reinforcement (steel, GFRP, and hybrid containing both), reinforcement ratio, and stirrup spacing. The results demonstrated that beams with hybrid reinforcement outperformed those reinforced solely with GFRP, offering an optimal equilibrium between strength and ductility. Beams fully reinforced with GFRP showed earlier cracking and more brittle failure, while steel-reinforced beams displayed enhanced ductility. Hybrid beams demonstrate enhanced rigidity and load-bearing capacity, devoid of the limitations associated with each material.

The research also indicated that the inclusion of GFRP bars in wide concrete beams may lead to a decrease in ductility and stiffness, particularly following the onset of cracking. The hybrid configuration results in markedly enhanced performance of the beams. Hybrid beams demonstrate an optimal equilibrium between strength and flexibility, resulting in improved fracture distribution and load-bearing capacity. The results demonstrate that hybrid reinforcement significantly improves the flexural performance of wide beams, offering corrosion resistance and structural efficiency.

Said and Elrakib (2013) [22] studied the effects of stirrups on the shear strength and ductility of reinforced concrete broad beams. The subject of an experimental investigation. A total of nine different reinforced concrete beams were subjected to four-point loads to investigate the effects of varying stirrup amounts, spacing, and steel grades. The dimensions of each beam were identical (1750 mm × 700 mm × 250 mm) as shown in Figure 2. The concrete had a compressive strength of 29 MPa, and the longitudinal reinforcement was constant in all specimens. The variable parameter was the stirrup configuration: one control specimen was without stirrups, whereas the other eight beams had stirrups of Ø6, Ø8, and Ø10 mm, with

spacings of 100, 150, and 200 mm. The experimental results showed that increasing the stirrup amount and using higher steel grades significantly improved shear strength and ductility. The beam with $\text{Ø}10$ stirrups at 100 mm intervals demonstrated a 106% enhancement in ultimate load capacity and absorbed 40 times more energy than the control specimen. The study concluded that web reinforcement is crucial for improving broad beams, and these effects are little covered by design standards.

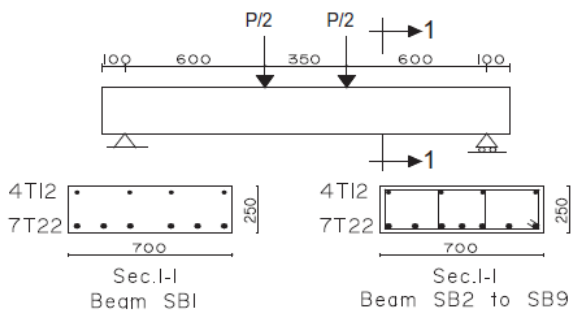


Figure 2. Set up and details of the beams [22]

A comparison of empirical results with projections from five international codes (**ECP 203-2007** [23], **ACI 318** [24], **AASHTO** [25], **CSA** [26], and **Eurocode EN 1992** [27]) indicates that the Egyptian code dramatically underrepresents the role of stirrups, especially at increased reinforcement ratios. The authors propose amending the ECP standards to more precisely reflect the actual effects of web reinforcement. The findings validated that web reinforcement using vertical stirrups substantially enhances the shear strength and ductility of broad beams. The increase in shear capacity varied from 32% to 132%, with the most significant improvement seen in the beam strengthened with $\text{Ø}10$ stirrups at 100 mm intervals. The study demonstrated that reducing stirrup spacing and using higher-grade steel improved energy dissipation and post-peak ductility. The energy absorbed by the most reinforced specimen was 40 times more than that of the control specimen. The findings robustly advocate for the incorporation of shear-reinforcing mandates in design specifications for broad beams. In the comparison of the experimental conclusions with five prominent international codes, it was shown that the

Egyptian code significantly underrepresents the role of web reinforcement. The report advocates for the revision of ECP regulations to account for the real impact of stirrups.

Al et al. (2013) [28] explored the use of external steel plates as an alternative to conventional shear reinforcement in broad concrete beams. Four beams, each with dimensions of 1800 mm in length, 560 mm in width, and 215 mm in depth, underwent single-point loading tests. The primary variable investigated was the integration of 4 mm thick steel "gagger" plates, which were configured as either solid or perforated, positioned vertically within the shear zone. A solitary beam functioned as a control, lacking supplementary support.

The evaluations encompassed analyses of cracking behavior, load capacity, deflection, and strain. Beams incorporating plates demonstrated enhanced shear resistance, postponing crack initiation and elevating ultimate capacity to a range of 420 kN to 620 kN. Crack widths were reduced notably, reaching a minimum of 0.12 mm; however, the failure mode shifted to diagonal compression. Enhancements in strength and energy absorption did not alleviate the occurrence of brittle failure, which is linked to the low shear span-to-depth ratio ($a/d = 0.31$).

The research shows that the integration of vertical steel plates in broad beams significantly enhances shear performance, especially in situations where conventional stirrups are difficult to use. The plates boosted load-bearing capability and enhanced crack management. However, they also created a failure mode marked by heightened brittleness, affected by diagonal compression. The results underscore the importance of shear span and plate arrangement in the design of broad beams, suggesting that steel plates may serve as efficient shear reinforcement in certain construction scenarios.

El-Sayed et al., (2014) [29] investigated the long-term behavior of wide shallow RC beams strengthened with externally bonded carbon fiber reinforced polymer (CFRP) plates to evaluate deflection and cracking performance under sustained loading conditions. The study included

five full-scale wide beams (5300 mm × 500 mm × 250 mm) as shown in Figure 4, where two beams were tested under short-term static loading and three beams were subjected to sustained loading for 600 days. Among these, three beams were strengthened with CFRP plates bonded to the tension face, while two beams served as control specimens. The experimental variables included the presence of CFRP reinforcement and different sustained load levels. The results showed that CFRP strengthening significantly enhanced the short-term behavior, increasing the ultimate load capacity by about 77% and reducing immediate deflection and crack width by approximately 40–50%. However, the improvement in long-term performance was limited, as reductions in long-term deflection and crack width were only about 13–14%. It was also observed that increasing the sustained load level led to higher immediate and long-term deflections, with a more significant effect on the immediate response. The study further demonstrated that long-term behavior is primarily governed by concrete creep rather than CFRP reinforcement. Consequently, CFRP strengthening is highly effective in improving the initial stiffness and cracking behavior of wide beams but has a limited role in mitigating long-term deflection. For wide beam applications, the findings emphasize the importance of considering creep effects in design, as external CFRP reinforcement mainly enhances short-term performance while long-term serviceability remains controlled by concrete properties.

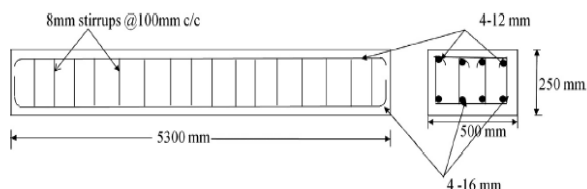


Figure 4. Details of tested beams

TAPAN (2014) [30] examined the structural performance of six reinforced concrete wide beams that were enhanced with lattice girders in comparison to conventional longitudinal reinforcement methods. Each beam exhibited a span of 2250 mm and underwent testing through

mid-span loading. Type I beams were enhanced with prefabricated lattice girders consisting of Ø12 bars and Ø5.5 diagonal elements, whereas Type II beams utilized solely Ø12 bars. The average strength of the concrete was measured at 46.57 MPa. Both types exhibited comparable stiffness prior to cracking; however, following the onset of cracking, the lattice girder beams demonstrated a greater load capacity while experiencing reduced deflection. Type I beams achieved an average ultimate load of 116.27 kN, in contrast to 80.71 kN for Type II, and exhibited reduced mid-span deflection. The failure observed in both instances was flexural. However, the lattice beams exhibited more refined cracking patterns and superior strain distribution.

Lattice girders have significantly enhanced the flexural strength, stiffness, and crack control of wide beams compared to traditional reinforcement methods. The ultimate load exhibited an increase of approximately 45%, accompanied by significant decreases in both deflection and crack width. Their truss-like mechanism notably improved post-cracking performance while reducing bond-slip effects. The research shows that using lattice girders is a strong method to boost the structural integrity of reinforced concrete wide beams, especially in precast or semi-precast applications. The performance of existing broad beams, specifically improving strength and serviceability while reducing the need for section enlargement.

Lotfy et al. (2014) [31] studied the effect of web reinforcement on the shear behavior of shallow wide reinforced concrete beams. Ten beams (300×200 mm cross-section, 1280 mm span) were tested in two groups. Each group had one control specimen without stirrups and four with various web reinforcement configurations. Parameters included stirrup spacing, number of branches, and shear span-to-depth ratio ($a/d = 2, 3, 4, 5$) as shown in Figure 5. All beams had consistent longitudinal reinforcement and concrete compressive strength of 25 MPa. The experimental findings revealed that increasing web reinforcement improved shear strength, ductility, and delayed failure modes.

The study confirmed that adding vertical stirrups greatly enhances the shear capacity and ductility of shallow wide beams. A higher web reinforcement ratio leads to increased ultimate shear strength and transitions the failure mode from brittle shear failure to a more ductile flexure-shear failure. Beams with smaller stirrup spacing develop steeper crack angles and more distributed cracking, whereas those with wider spacing show fewer but wider cracks. The shear capacity also increases with more stirrup branches, even when the overall reinforcement ratio stays the same. Furthermore, increasing the shear span-to-depth ratio (a/d) decreases shear strength. These findings emphasize the inadequacy of design codes that ignore the role of web reinforcement in such beams and suggest revisiting the Egyptian Code provisions for better accuracy and safety.

consisted of six wide beam specimens with dimensions of 1820 mm length, 750 mm width, and 250 mm depth, tested as beam–column systems. The variables included different shear reinforcement types such as no reinforcement, vertical stirrups, independent bent-up bars, mid-depth horizontal bars, and a combination of stirrups with bent-up bars, as well as variation in longitudinal reinforcement distribution. The results showed that independent bent-up bars significantly enhanced shear capacity by about 51% compared to the control specimen and provided higher ductility, while mid-depth horizontal bars increased shear strength moderately but reduced ductility. Stirrups improved shear resistance effectively, and the combination of stirrups with bent-up bars achieved the highest load capacity and more ductile failure behavior. It was also observed that concentrating longitudinal reinforcement in the column band increased the ultimate load compared to uniformly distributed reinforcement. The study concluded that independent bent-up bars can be considered an efficient alternative to conventional stirrups in wide beams, especially when combined with stirrups to achieve optimal performance. For wide beams, the findings highlight that shear capacity and failure mode are strongly influenced by reinforcement configuration, and hybrid reinforcement systems provide superior strength and ductility, making them suitable for practical design applications.

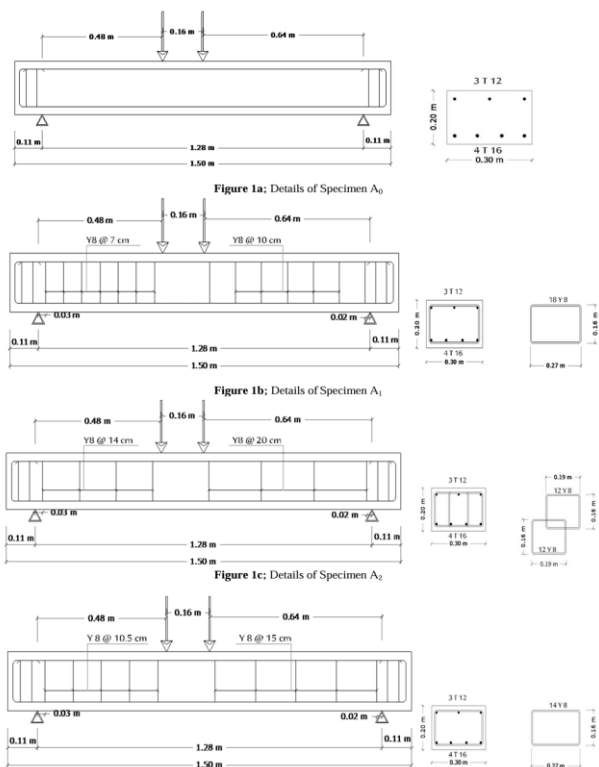


Figure 5. Specimens details [31]

In 2015, **Yasouj et al.** [32] investigated the shear behavior of reinforced concrete wide beams with different types and arrangements of shear reinforcement to identify effective and practical reinforcement techniques for improving shear capacity. The experimental program

Conforti et al. (2015) [33] investigated the shear behavior of wide-shallow beams made with polypropylene fiber reinforced concrete beam (PFRC) to evaluate the influence of the width-to-effective depth ratio and the potential of using PP fibers as a substitute for minimum shear reinforcement. The experimental program consisted of fourteen full-scale wide-shallow beam specimens, all with a length of 3000 mm and a shear span-to-depth ratio (a/d) of 2.5. The primary variables included the beam width (ranging from 430 mm to 890 mm, resulting in width-to-effective depth ratios (b/d) of 2 and 3) as shown in Figure 6, the concrete type (plain concrete (PC) vs. PFRC with 13 kg/m³ of crimped PP fibers), and the presence of

minimum conventional shear reinforcement (stirrups). The beams were designed to represent geometries common in residential buildings and were tested under a four-point loading system. The results showed that plain concrete wide-shallow beams with a b/d ratio between 2 and 3 exhibited a significant extra shear resistance of about 30-40% beyond the first shear cracking load, a behavior not typically observed in narrower beams and generally disregarded by design codes like EC2 [27], ACI 318-11 [34], and MC2010 [35].

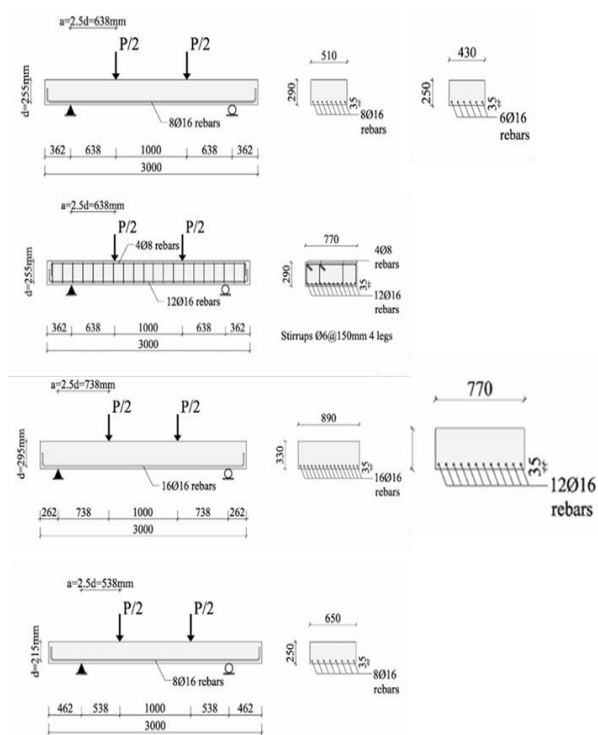


Figure 6. Displacement energy of tested specimens [33]

It was found that the addition of 1.45% volume fraction of specifically developed polypropylene fibers completely altered the failure mode from brittle shear failure to ductile flexural failure, achieving the full flexural capacity of the beams. Furthermore, the PFRC beams demonstrated substantially higher ductility (an increase of 132% compared to beams with minimum shear reinforcement) and developed finer, more closely spaced cracks, with crack spacing reduced by about 40%. The study concluded that properly designed PFRC can be a valuable structural material for wide-shallow beams, effectively serving as a complete substitute for minimum conventional shear reinforcement. For

wide-shallow beams, the findings highlight that their inherent shear capacity is underestimated by current standards, and that the use of high-performance PP fibres not only enhances strength and ductility but also significantly improves durability through superior crack control, making them a promising alternative for practical design applications.

In 2017, Abass and Hassan [36] investigated the flexural improvement of reinforced concrete wide beams using externally bonded carbon fiber-reinforced polymer (CFRP) sheets of varying widths. Four beams with identical dimensions (2000 mm in length, 550 mm in width, and 250 mm in depth) underwent four-point loading testing. One beam functioned as a control without reinforcement. However, the remaining three were externally reinforced with CFRP sheets spanning 30%, 60%, and 100% of the bottom width, respectively. All beams were intentionally under-reinforced to facilitate flexural failure, and the concrete had a compressive strength of 30 MPa. The results indicated that all reinforced beams exceeded the control group in terms of ultimate load and fracture management. The beam with 60% CFRP coverage exhibited the ideal balance of increased capacity (+29%) and ductility, while the fully covered beam achieved the highest load (+31%) but showed a little decrease in ductility. The reinforcement also changed the failure mode from flexural to shear, with CFRP rupture seen in some specimens.

The experimental findings unequivocally illustrated the efficacy of externally bonded CFRP sheets are used to improving the flexural performance of reinforced concrete broad beams. The reinforcement resulted in notable enhancements in ultimate load capacity, with increases reaching 31% relative to the control beam. Moreover, the use of CFRP resulted in diminished fracture widths, limited strain in both steel and concrete, and enhanced the overall stiffness of the structural element. The beam reinforced with 60% CFRP width demonstrated the most effective equilibrium of strength and ductility among all designs evaluated. The fully enclosed beam demonstrated increased strength, though it showed a minor decrease in ductility,

indicating a compromise between load-bearing capacity and deformation characteristics. The application of CFRP sheets transformed the failure mode in some instances from pure flexural failure to shear-dominated failure, due to increased section strength. The findings indicate that CFRP reinforcement effectively enhances the performance of existing broad beams, specifically improving strength and serviceability while reducing the need for section enlargement.

Abass et al. (2018) [37] investigated the shear behavior of nine simply supported reinforced concrete wide beams ($1200 \times 220 \times 110$ mm) strengthened with externally bonded steel plates applied along the shear zone as shown in Figure 7. The main parameters were plating ratio (0%, 33%, 55%), shear span to depth ratio ($a/d = 2.5$ and 4.2), and concrete strength type (normal strength concrete (NSC) and high strength concrete (HSC)). All beams were reinforced longitudinally without stirrups. Steel plates were glued to the beam sides using epoxy adhesive and varied in spacing depending on the desired plating ratio. The beams were tested under monotonic two-point loading while recording shear cracking load (P_{cr}), ultimate shear strength (P_u), load-deflection behavior, and crack patterns.

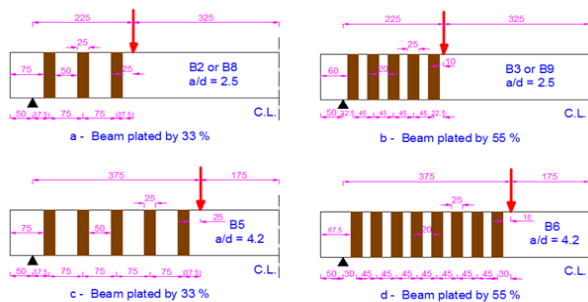


Figure 7. Details of steel plates [37]

All tested beams failed in the diagonal shear mode. Adding steel plates significantly improved both shear cracking capacity and ultimate load, especially at higher plating ratios and lower compressive strengths. For example, at 55% plating and $a/d = 4.2$ (NSC), the maximum increase in P_{cr} was 29% and P_u was 33%. Plates also changed crack patterns and reduced their widths. The a/d ratio negatively impacted both P_{cr} and P_u , with up to 31%

reduction in cracking load and 18% in ultimate load for non-plated beams. However, this reduction was mitigated by higher plating ratios. The application of HSC improved beam performance overall; however, the advantage decreased with an increase in the plating ratio. Steel plates exhibited minimal influence on the initial load-deflection response but contributed to increased stiffness in subsequent phases as shown in Figure 8. Partial debonding of plates occurred before yielding in certain instances, especially in beams with elevated plating ratios.

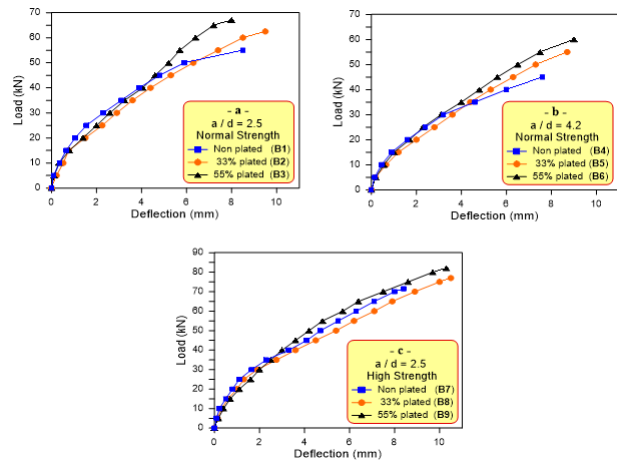


Figure 8. Effect of the plating ratio on load-deflection response [37]

Mohamed et al. (2020) [38] examined the effectiveness of externally bonded Strain-Hardening Cementitious Composites (SHCC) in improving the shear performance of shallow, wide reinforced concrete beams. Eleven beams measuring 1500 mm in span, 500 mm in width, and 170 mm in depth were tested under single-point loading as depicted in Figure 9. The main parameters analyzed included SHCC jacket thickness (25 mm and 40 mm), jacketing configuration (two-sided or U-shaped), and variations in shear reinforcement (with or without internal and embedded external stirrups). The specimens were divided into three groups to assess how jacketing type and reinforcement setup affected shear capacity and failure mode. Measurements of load, deflection, cracking behavior, and reinforcement strain were recorded. The findings confirmed that SHCC jacketing, especially in U-shaped form, notably enhanced shear strength and ductility,

particularly when combined with stirrups embedded within the jacket.

SHCC jacketing markedly improved the shear performance of wide concrete beams. Beams with U-shaped SHCC jackets exhibited enhanced load capacity and ductility relative to those featuring flat-side jacketing as shown in load deflection curve. The addition of stirrups in the SHCC layer markedly enhanced shear resistance. Failure modes shifted from brittle shear to a more ductile flexural-shear behavior. The established design codes have not accurately accounted for the observed shear strength. The authors propose revised predictive equations that consider SHCC grade, jacketing type, and beam geometry.

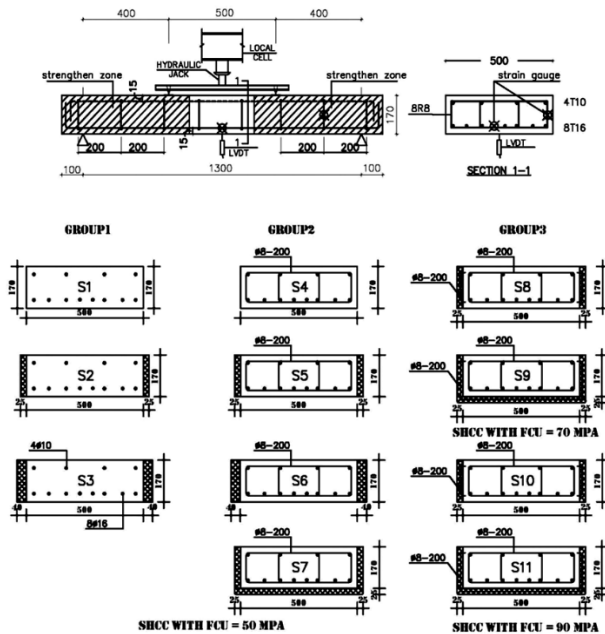


Figure 9. Details tested beams and instrumentation [38]

Sultan (2020) [39] examined the behavior of nine high-strength concrete wide beams (1200×220×110 mm) under combined bending and torsion. Key variables included the torque-to-moment ratio (T/M) and the ratios of longitudinal (ρ_L) and transverse reinforcement (ρ_t). Beams were grouped based on T/M values (0, 0.5, and 1.5). Higher torsion ratios led to earlier cracking, lower ultimate moment, and a shift in failure mode toward torsional. Increasing ρ_L improved flexural capacity significantly, while increasing ρ_t had a more noticeable effect

under torsional loading. Figure 10 shows the load application on specimen.

The findings indicated that torsion markedly diminishes the flexural strength of broad beams and alters the cracking pattern and failure mechanism. Beams with increased longitudinal reinforcement provide enhanced strength and stiffness, but transverse reinforcement significantly influences performance under torsional stress. A refined model was proposed to accurately predict the ultimate moment capacity. The research underscores the significance of including torsion in the design of edge beams and recommends the modification of design methodologies for high-strength concrete broad beams subjected to combined loads.

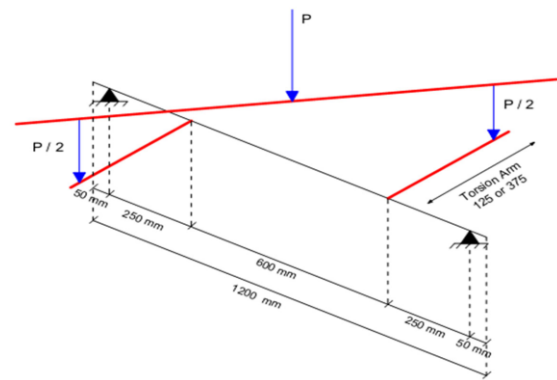


Figure 10. Load application on the specimen [39]

In 2021, **MAWLOOD et al.** [40] investigates the shear behavior of wide shallow beams made with high-performance and self-compacting concrete (HSC and SCC). Seven beams with varying width-to-height ratios (from 0.67 to 3.0), shear reinforcement ratios (0 to 0.222%), and carbon fiber content (0 to 0.53%) were tested. The objective was to examine the impact of these characteristics on shear strength and to assess the precision of ACI 318-14 [41] and Eurocode 2 [27] standards when applied to these beams. The beams were engineered to fail under shear, and the impacts of carbon fiber, stirrups, and shape were examined, the test setup is detailed in Figure 11.

The study revealed that broad beams with elevated b/h ratios exhibit reduced shear

capacity, particularly in the absence of transverse reinforcement. The incorporation of stirrups markedly enhanced ductility and load-bearing capability, whereas carbon fibers facilitated energy absorption, although with a little reduction in compressive strength. The study revealed that the criteria of ACI 318-14 [41] and Eurocode 2 [27] often underestimate shear strength in large high-performance concrete beams.

codes. Beams without shear reinforcement still developed diagonal shear cracks, and failure was typically brittle. Most international codes, including ACI [18], EC2 [27], and JSCE [42], either underestimated or overestimated shear strength in wide beams. The study concluded that current design provisions are not fully adequate for predicting the shear capacity of wide beams without stirrups. It recommends refining existing equations or proposing new models that better account for width effects in wide beam behavior.

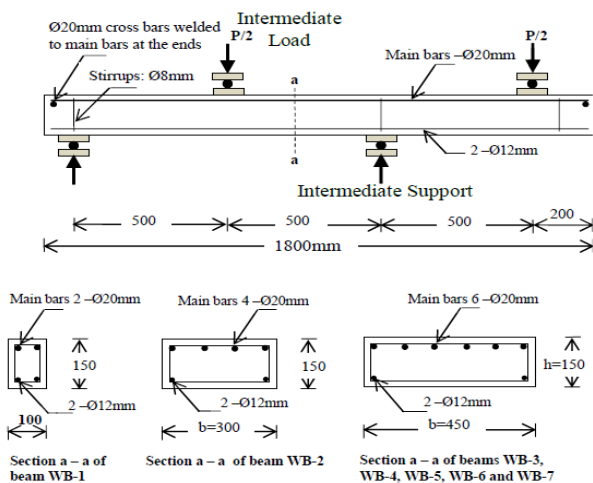


Figure 11. Sections and instrumentation

A modified shear equation was presented and validated against experimental results, producing more accurate predictions for certain beam combinations. The authors recommend that enhanced code equations include width effects in shallow wide beams.

Abduljabar and Abbas (2021) [15] examined the behavior of broad reinforced concrete beams devoid of shear reinforcement. A total of 23 simply supported beams were studied and tested, measuring 1700 mm in length, 400 mm in breadth, and 200 mm in depth. The variables included the shear span-to-depth ratio (a/d), concrete compressive strength, and beam width. The objective was to comprehend the impact of these factors on shear strength without the presence of stirrups. The research further juxtaposed experimental findings with forecasts from prominent worldwide standards.

The findings revealed that beam width significantly affects shear strength. As the width increased, the shear capacity decreased relative to the calculated values from existing design

Mohammed et al, (2023) [43] examined the flexural performance of wide reinforced concrete beams that utilize GFRP (Glass Fiber Reinforced Polymer) bars instead of conventional steel reinforcement. Five simply supported beams were subjected to testing under four-point loading—all beams measured 2,400 mm in length, 500 mm in width, and 250 mm in depth. One beam was fully reinforced with steel and acted as the control. In contrast, the other four beams featured various GFRP bar configurations, either completely replacing steel in tension zones or incorporating GFRP in both tension and compression areas. The findings indicated that GFRP-reinforced beams excelled in load-carrying capacity and crack management. They exhibited reduced post-cracking stiffness and demonstrated more noticeable and earlier crack formation than the steel-reinforced beam. The failure mode was primarily flexural, though the GFRP specimens exhibited somewhat more brittle traits.

This research demonstrates that GFRP bars can effectively substitute steel reinforcement in large reinforced concrete beams, especially in corrosive environments. GFRP-reinforced beams experienced a slight decrease in stiffness after cracking compared to the steel-reinforced control beam, but they still exhibited adequate flexural performance. Nonetheless, the overall load capacity was still deemed acceptable, and the primary failure mode was flexural, accompanied by some indications of brittleness. The results indicate that GFRP reinforcement is effective in the flexural areas of wide beams, particularly in settings where long-term durability is prioritized over ductility.

2.2 Numerical and Experimental Studies

Abass and Hassan (2019) [44] examined the effectiveness of externally bonded CFRP sheets in enhancing shear reinforcement for wide concrete beams that do not contain internal stirrups. Four beams, measuring 1800×400×200 mm, underwent testing under two-point loads. The experiment included a control beam, two beams with vertical and inclined CFRP U-wraps, and one beam employing conventional stirrups. The primary variables included the orientation of the CFRP and its juxtaposition with internal steel reinforcement. The results demonstrated that inclined CFRP wrapping provided superior shear strength and ductility compared to vertical CFRP, although it was still less effective than stirrups.

The findings indicated that externally affixed CFRP sheets may improve the shear capacity of wide beams, especially when placed in an angled configuration. The inclined CFRP beam demonstrated about a 20% enhancement in ultimate load, while the vertical CFRP beam exhibited an improvement of around 7%. Conventional stirrups had the greatest shear strength; however, inclined CFRP demonstrated encouraging outcomes, presenting enhanced ductility and decreased deflection. The results indicate that CFRP may function as an effective alternative for shear strengthening in wide beams, particularly in retrofit scenarios where internal reinforcement is impractical.

In 2024, **Badawy et al.** [45] studied the Flexural behavior of high strength concrete wide beams reinforced by hybrid modern composite bars, either wholly composite or a mix of the two, were used to reinforce wide beams of high-strength concrete in this experimental inquiry. The beams were then put through flexural tests. We built and tested six beams under four-point loading conditions. Consistent with one another, all of the specimens were 2100 mm in length, 600 mm in width, and 250 mm in depth as shown in Figure 12. Three beams in the first set were tension-face reinforced using locally made ribbed-surface basalt fiber-reinforced polymer (BFRP) bars, glass fiber-reinforced polymer (GFRP) bars, or standard steel. The

second group included three hybrid-reinforced beams: one with steel and GFRP, one with steel and BFRP, and one with a combination of all three (steel, GFRP, and BFRP). The main variables studied were the type and configuration of longitudinal reinforcement. All beams were tested until failure, and key parameters such as crack propagation, failure mode, ultimate load, and load-deflection behavior were recorded to evaluate the.

The flexural strength of the GFRP-reinforced beam was 41% higher than that of the steel-reinforced beam, while that of the BFRP-fully reinforced beam was 43% higher. On the other hand, these beams were more brittle and shattered earlier and more widely. The flexural capacity of the hybrid-reinforced beams showed considerable improvement: 26% for the steel + GFRP beam, 30% for the steel + BFRP beam, and 41% for the beam reinforced with steel, GFRP, and BFRP combined. Additionally, the beams showed improved crack management and more ductile failure modes. Based on the findings, wide beams in flexural applications benefit from hybrid reinforcement, which combines the best features of conventional and composite bars to create an ideal combination of strength and ductility.

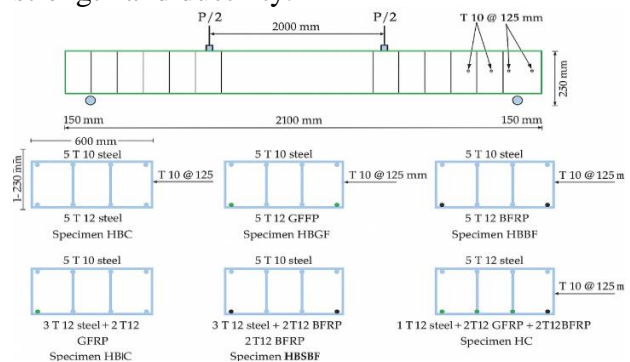


Figure 12. Details and reinforcement of Specimens

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Mahmoud et al. (2024) [3] examined the flexural performance of broad reinforced concrete beams constructed using self-compacting concrete (SCC) and reinforced with glass fiber-reinforced polymer (GFRP) bars. Six beams, each sized 2100×600×250 mm, were subjected to four-point bending tests. The reinforcement configuration included complete GFRP, hybrid GFRP-steel, and conventional steel reinforcement. The main objective was to evaluate the efficacy of GFRP bars in improving flexural strength, ductility, and fracture behavior in comparison to traditional steel.

The findings demonstrated that GFRP bars can be used effectively in wide beams, showing higher flexural strength than steel reinforcement in some configurations. However, beams with full GFRP bars showed wider and more distributed cracking and reduced ductility. Hybrid reinforcement improved ductility while maintaining strength. The study concluded that GFRP is a promising alternative to steel in corrosive environments, but hybrid systems are more practical for structural balance. The behavior of SCC with GFRP was generally stable, and crack widths remained within acceptable limits. The results support the use of GFRP in structural applications, with consideration for serviceability and deformation control.

3. Conclusions

Based on the extensive review of experimental and numerical studies, this paper systematically examined the structural characteristics of reinforced concrete wide beams. The following conclusions are drawn from the comprehensive analysis of the literature:

- Wide reinforced concrete beams ($b/d \geq 2$) exhibit fundamentally different structural behavior compared to conventional narrow beams, particularly in terms of shear distribution, crack propagation, and stress distribution across their width.
- Existing design codes (ACI 318, Eurocode 2, BS 8110) lack specific provisions for wide beam geometries and generally underestimate their shear capacity, as they do not account for the unique width-related effects.
- RC wide beams with width-to-effective depth ratios (b/d) between 2 and 3 demonstrate a significant extra shear resistance of approximately 30-40% beyond the first shear cracking load—a beneficial characteristic not typically observed in narrower beams.
- Properly designed web reinforcement, including stirrups, independent bent-up bars, and hybrid configurations, substantially enhances shear strength (by 32% to 132%), ductility, and energy dissipation in wide beams compared to un-reinforced specimens.
- Combining traditional steel with composite bars (GFRP or BFRP) in hybrid reinforcement systems provides an optimal balance between strength (26-41% increase) and ductility, overcoming the brittleness issues associated with fully FRP-reinforced beams.
- Horizontal openings in wide beams introduce local stress concentrations, modify crack trajectories, and reduce effective depth, requiring special detailing considerations that current codes do not adequately address.
- There is a critical need to revise existing design provisions (particularly the Egyptian code ECP 203) to better account for width effects, the actual contribution of web reinforcement, and the performance of modern materials in wide beam applications.

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