Advancing Concrete Design: Shear Capacity in Wide Beams with Shallow Depths

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Abstract

Beams with shallow depths are commonly referred to as wide beams, shallow beams, or banded beams. These terms are essentially interchangeable. They are frequently incorporated into ribbed slabs to simplify the construction process. However, the role of web reinforcement in enhancing the shear capacity of such beams remains uncertain. Design codes and guidelines for concrete design have largely overlooked this aspect. The purpose of the study was to provide a comprehensive overview of this topic, identify areas that had not been adequately studied, and to identify opportunities for further research. The following methods were used: seven code provisions and a wide range of earlier research papers were gathered, investigated, categorized, and indexed based on various parameters, methodologies employed, recorded observations, and concluded outcomes. As a result, there is a significant scarcity of both theoretical research employing finite element analysis (FEM) and predictive models (mathematical or AI-based) concerning shear capacity, as well as the impact of creep and cyclic loading, particularly in beams with web openings.

Keywords: *Shear Capacity; Wide Beams; Code Provisions; Shallow Beams.*

1. Introduction

The constant drive for new and creative designs in architecture has always challenged structural engineers to find new solutions and systems to meet these challenges. Architectural engineers have always prioritized clear heights and unobstructed lines of sight as fundamental aspects [1] [2]. One of the solutions that has emerged in recent years is the use of reinforced concrete shallow wide beams. However, as the popularity of wide beams has increased, concerns regarding their ductility, failure modes, and load capacity have also surfaced.

Shallow wide beams are characterized by having a width that exceeds twice its depth [3]. Several researchers have shown that the shear resistance of wide beams differs from that of conventional dropped (or projected) beams.

In other words, structural engineers are constantly being challenged to come up with new and innovative ways to design buildings that are both aesthetically pleasing and structurally sound [4] [5]. Shallow wide beams are one solution that has emerged in recent years, but there are some concerns about their safety and reliability.

2. Objective

The main goal of this study is to collect and organize all of the existing data about the shear capacity of wide beams into a single framework, in order to identify any gaps in the research on this topic. The methodology used involved gathering data from a variety of sources, including design provisions and earlier published research, and then sorting, investigating, and categorizing the data. Next, the data is mapped based on a variety of factors, including the methodologies used, the findings observed, and the conclusions drawn. This mapping process will visually depict areas that have not been adequately studied, as well as areas that have received excessive attention in this field. Figure 1 demonstrates the framework of the research, including the parameters being considered.

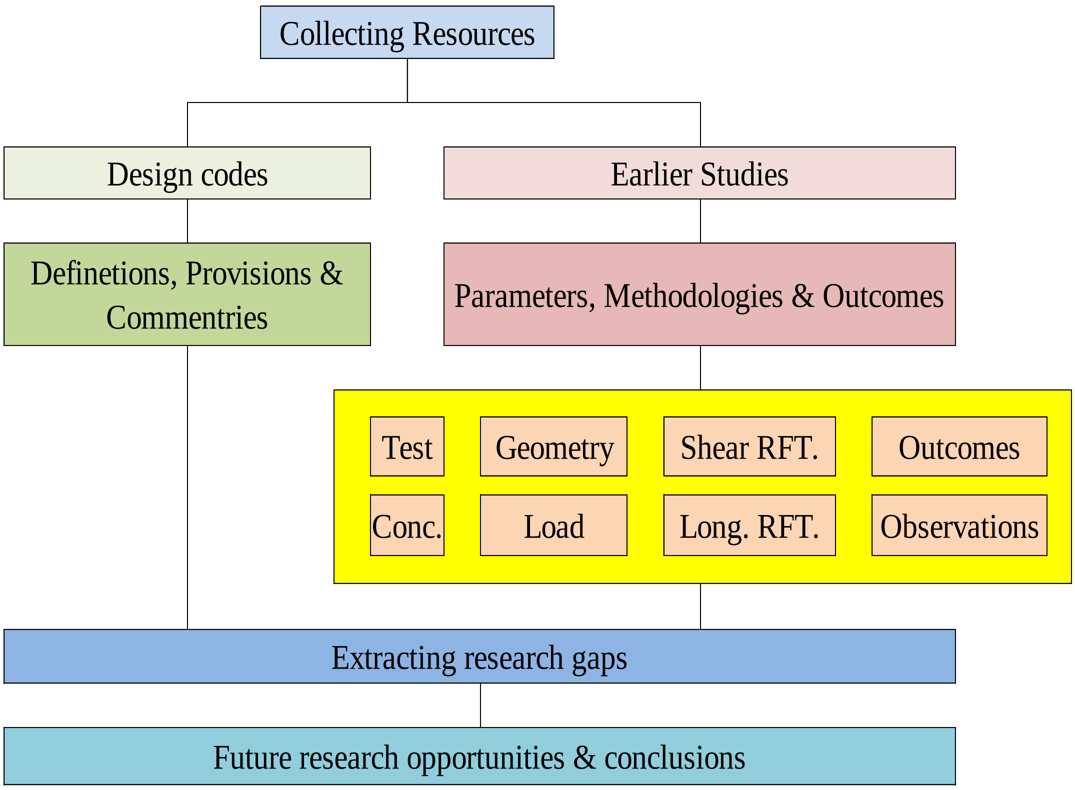


Fig. 1 Framework of current study

3. Design Codes Provisions

Different codes of practice have addressed the challenge of reinforcing wide beams to withstand shear in varying ways, and some codes have not tackled the issue at all. For instance, the American standard ACI 314-2019 classifies beams with a depth equal to or less than 10 inches (25.4 cm) as shallow, exempting them from the minimum shear reinforcement requirement for wide beams [6]. The code's commentary suggests considering shear reinforcement design for specific types of wide beams, a viewpoint echoed by researchers such as Lubell et al. (2004) [7], and Soliman et al. (2023) [8] [9].

In contrast, the European Code EN 1992-1-1:2004 does not obviously rule out shear reinforcement in wide beams. While it notes the insignificance of shear reinforcement in solid slabs, hollow block slabs, and flat slabs, it emphasizes meeting minimum reinforcement requirements using standard equations for shear reinforcement in beams [10].

The Japanese code, Standard Specifications for Concrete Structures "Design," doesn't specifically address shallow wide beams. However, it stipulates that even if a member doesn't necessitate shear reinforcement, the code mandates providing minimum shear reinforcement [11]. The Canadian standard CSA A23.3-04 shares similarity with the American code ACI 314-2019 but requires a minimum depth of 75 cm for mandating reinforcement, offering a more lenient criterion (C. S., 2004)[12].

Moreover, the Chinese standard GB 50010-2010 [13], elements with a depth less than 15 cm are exempt from the requirement of stirrups or minimum stirrups, as outlined by The Ministry of Construction of the People’s Republic of China in 2010. This demonstrates the code's stance on stirrup necessity, particularly in relatively shallow members.

Similarly, the Saudi code "SBC304c" refers to research on stirrup spacing concerning the behavior of shallow wide beams. However, the code does not explicitly designate a minimum stipulation for stirrups or provide a clear definition of a wide beam in this specific context, as indicated by the Saudi Building Code National Committee Saudi Building Code in 2007 [14].

In the context of the Egyptian code "ECP 203-2017," its treatment of shallow wide beams is succinct but instructive. The code explicitly states that members with a depth less than 25 cm do not necessitate shear reinforcement, aligning with the specifications laid out in ECP 203 in 2018. This provision offers a clear guideline for the shear reinforcement requirements in shallow wide beams as outlined by the Egyptian code [15].

4. Earlier Studies

The guidance provided by various codes of practice, as discussed earlier, seems somewhat inadequate when considering the crucial aspect of shear resistance in beams. This is particularly significant in the context of design considerations related to factors like ductility, mode of failure, and prioritizing safety. To address this substantial concern, researchers have delved into comprehensive investigations on the shear resistance of wide beams, considering various parameters. These parameters were categorized as follows:

a) Concrete-related Parameters (Figure 2):

- Characteristic concrete strength

- Concrete type, including ultra-high performance, self-compacting, and lightweight concrete.

b) Beam Geometry-related Parameters (Figure 3):

- Width of beam to depth ratio

- Width of beam to support width ratio

- Shear span to beam depth ratio

- Presence of web openings.

c) Longitudinal Reinforcement-related Parameters (Figure 4):

- Material of tension reinforcement

- Tension reinforcement ratio (As/Ac)

- Material of compression reinforcement

- Compression reinforcement ratio (As'/Ac).

d) Shear Reinforcement-related Parameters (Figure 4):

- Material of shear reinforcement

- Shear reinforcement ratio (Ash/Ac)

- Direction of shear reinforcement

- Longitudinal shear reinforcement spacing and transversal shear reinforcement spacing as well

- Yield stress of shear reinforcement (fy).

e) Loading Type-related Parameters (Figure 5):

- Short-term monotonic load

- Long-term monotonic load

- Cyclic load.

f) Testing Type-related Parameters (Figure 6):

- Experimental testing in a controlled laboratory environment

- Numerical testing using finite element method (FEM) models.

g) Test Observations-related Parameters (Figure 7):

- Shear strength

- Beam-column joint strength

- Failure modes

- Stiffness
- Ductility
- Dissipated energy.

h) Test Outcomes-related Parameters (Figure 8):

- Quantitative outcomes, like formulas or AI models.
- Qualitative outcomes, i.e., conclusions drawn from the study.

Fig. 2 Considered special concrete types.

In a study focusing on the shear performance of wide beams, six specimens were tested, employing Glass Fiber Reinforced Polymer (GFRP) plates as shear reinforcement. The specimens, sharing identical dimensions and longitudinal reinforcement, varied only in the transverse spacing between the GFRP plates. Notably, the study observed an enhancement in the shear performance of the wide beams as the spacing between the GFRP plates decreased, reaching optimal improvement at 1.16 times the effective depth [16].

Another investigation in 2013 involved nine reinforced concrete wide beam specimens subjected to shear testing. Among them, one lacked shear reinforcement, while the remaining eight exhibited diverse configurations of shear reinforcement, including variations in steel rebar diameter and longitudinal spacing between stirrups. The findings revealed a remarkable increase of up to 132% in the shear capacity of reinforced concrete wide beams, particularly with maximum shear reinforcement and minimum longitudinal spacing, indicating improved ductility [17].

Exploring different shear reinforcement strategies, the study employed Strain Hardening Cementitious Composites (SHCC) jackets to enhance the shear behavior of reinforced concrete wide beams. The eleven specimens were divided into three groups, each implementing distinct reinforcement and jacketing techniques. The results not only showcased improved shear behavior but also highlighted an enhanced ultimate load capacity of the beams, emphasizing the effectiveness of various shear reinforcement configurations in conjunction with SHCC [18].

In an examination involving nine wide shallow beam specimens of varying thicknesses, transverse shear reinforcement (stirrups) was employed. The study revealed that beam thicknesses of 250 mm and above demonstrated the most effective utilization of stirrups, while thicknesses below 250 mm also exhibited improvement, albeit to a lesser extent compared to the thicker beams [19].

In a study featuring sixteen wide beam specimens, steel plates with holes were employed instead of conventional stirrups to assess their impact on overall beam capacity. The use of hole-stirrups resulted in a minimal 5% difference compared to conventional stirrups, indicating a comparable effect on the beams' performance [20].

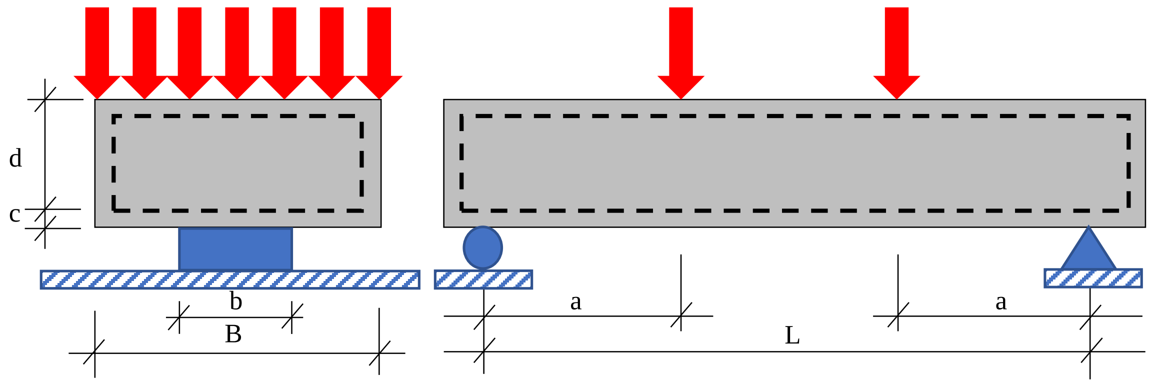


Fig. 3 The parameters considered for the geometry.

In the study spearheaded by Al-Azab, an array of stirrup configurations and concrete mixes were systematically examined in multiple wide beam specimens, delving into the intricate interplay between various factors influencing shear behavior. The study found that the transverse spacing of stirrups had a minimal impact on shear behavior, while an increased number of stirrup branches positively influenced shear behavior. The experimental programs were validated using a finite element model, demonstrating alignment with the guidelines of the Egyptian code of practice (ECP-203) [21] [22].

In a separate study, wide beam specimens were cast and tested with varying support conditions. The findings revealed that narrower supports, relative to the beam width, led to reduced shear and flexural capacity due to variations in shear stresses manifesting as cracks [23].

An extensive experimental program on full-scale reinforced concrete wide beams aimed to compare and enhance Eurocode 2 and ACI-318. Different stirrup configurations were employed to improve the specimens' behavior, resulting in a proposed formula for enhanced shear capacity. The study concluded that ACI-318 was more conservative than Eurocode 2 [24]. Taking a different approach, El Ansary tested nine reinforced concrete wide beam specimens with various stirrup configurations, including spiral reinforcement. Spiral reinforcement was found to increase ductility but also led to more extensive cracking compared to standard shear reinforcement [25].

In the research conducted by Taha and Abbas, four reinforced concrete wide beam specimens were tested with varying stirrup spacing (0.75d, 0.8d, and 1d). Emphasizing the pivotal role of stirrup configuration in governing the structural performance of wide beams, it was concluded that an increase in stirrup spacing led to a decrease in shear capacity and an increase in deflection [26].

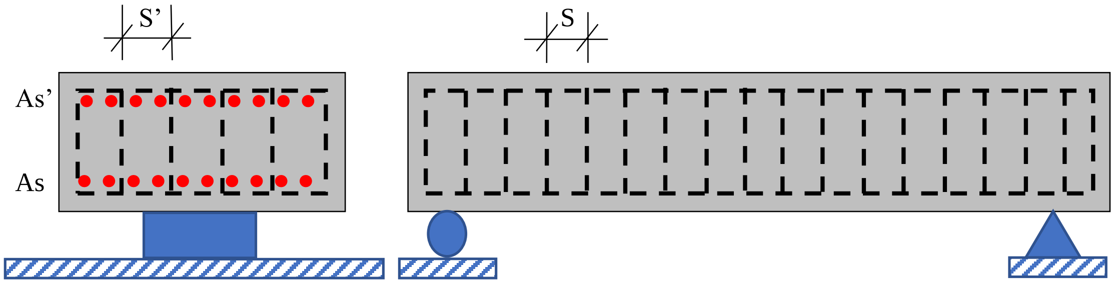


Fig. 4 The considered reinforcement parameters

Conforti conducted experiments on fourteen reinforced concrete (RC) wide beams reinforced with polypropylene fibers, aiming to assess the optimal shear behavior of such beams in relation to the width-to-depth ratio and the use of stirrups. Results indicated that a width-to-depth ratio between 2 to 3 led to a notable enhancement of shear capacity and behavior by 30% to 40%. The high tensile strength of polypropylene fibers shifted the failure mode from shear to flexure, improving the ductility of shallow beams. Additionally, utilizing a volume fraction of 1.45% for the fibers could potentially replace the minimum stirrups typically required for shear reinforcement in wide beams [27].

In another study, Moubarak and co-authors tested thirteen concrete wide beams, implementing both external and internal fasteners as shear reinforcement. These fasteners were positioned both vertically and inclined. The inclusion of these fasteners significantly increased the shear capacity of the wide shallow concrete beams, altering the failure mode from shear to flexure. The utilization of external and internal fasteners resulted in a substantial enhancement of beam capacity by 32% to 72%. Notably, steel plates at the shear span outperformed steel angles, reducing shear cracks and improving beam ductility. Inclined fasteners demonstrated no significant difference compared to their vertical counterparts [28].

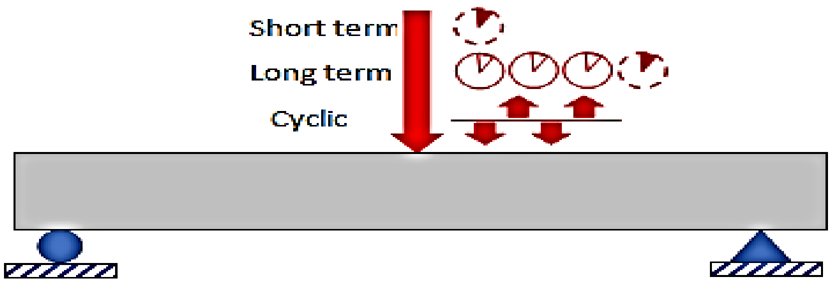


Fig. 5 The considered loading types

In a comprehensive study involving five full-scale shallow beams, an ordinary four-point load test was applied to two of the specimens, yielding insightful findings. The results indicated that the incorporation of carbon fiber plates contributed to a reduction in immediate deflection and crack openings. However, it was notable that this intervention did not exert a significant influence on long-term deflection and crack openings, underscoring the nuanced impact of carbon fiber plates on the structural behavior of shallow beams [29].

In a comparative analysis, conventional T beams were compared against hidden shallow beams embedded in slabs to evaluate the efficacy of shallow beams in meeting architectural demands. The investigation involved testing fourteen concrete beam specimens under a four-point load. Notably, the study observed that as the depth of wide beams increased, their behavior tended to converge toward that of ordinary beams, offering valuable insights into the structural characteristics and architectural considerations associated with these beam types [30].

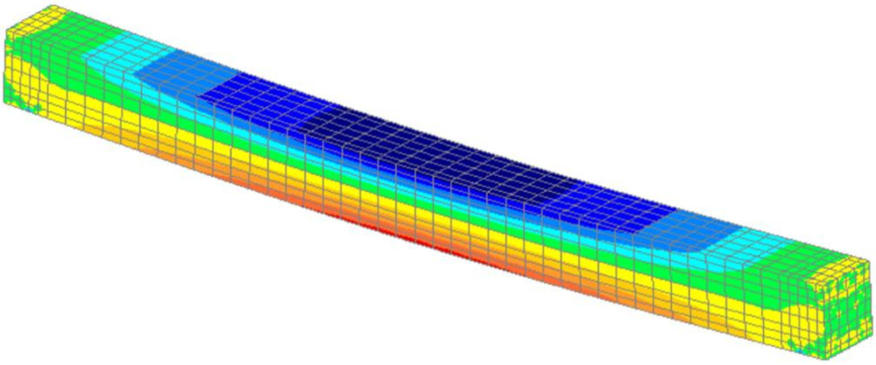
In a separate study conducted in 2020, Alluqmani delved into the safety aspects of reinforced concrete shallow wide beams, testing two specimens designed in accordance with Eurocode EC2 and the Saudi code of practice SBC 304, respectively. The objective was to ascertain which code led to a safer failure for reinforced concrete shallow wide beams. The findings indicated that SBC 304 emerged as the safer code compared to EC2. Additionally, the study identified optimal design parameters, revealing that the most effective stirrup location was at 0.56 times the effective depth, with a longitudinal spacing of 0.6 times the effective depth between stirrups being deemed the most effective configuration [31].

The use of carbon fiber reinforced polymers (CFRP) for strengthening reinforced concrete shallow beams was investigated. Thirteen specimens with variations in CFRP plate dimensions, steel reinforcement, and beam thickness and width were tested. The study focused on the occurrence of sudden debonding at failure after an intermediate crack. It was found that parameters like CFRP plate dimensions and beam dimensions did not impact sudden debonding, except for increased compressive strength, which delayed debonding without preventing it [32].

In 2021, researchers examined seven specimens of wide reinforced shallow beams subjected to eccentric loading. Changes in longitudinal reinforcement ratio, eccentricity, and stirrup spacing were studied. The study concluded that increasing eccentricity decreased the load capacity of the beam and decreasing the longitudinal spacing between stirrups significantly affected crack control [33].

Kim and their research team investigated eighteen specimens of reinforced concrete shallow beams with the goal of improving the shear capacity equation. Steel plates with openings were used instead of stirrups to enhance shear behavior. The study found that when the transverse spacing of the plates exceeded 1.1 times the depth, it had no impact on shear behavior or crack control [34].

(a)



(b)

Fig. 6 Testing setups, a) experimental, b) theoretical (FEM)

Examining reinforced concrete shallow wide beams, the study subjected five specimens to testing to investigate the influence of short glass fiber polymers on shear behavior and failure. The use of shear reinforcement, particularly with a preferred percentage of 1% for short glass fiber in the mix, had a notable effect on shear capacity. Additionally, the inclusion of short glass fibers enhanced the ductility of the beams [35].

Conducting a rigorous investigation, Conforti examined fifteen specimens of reinforced concrete shallow beams, specifically comparing those with and without transverse steel reinforcement for shear resistance. As revealed by the study, the presence of shear reinforcement did not exert a significant influence on the initiation of the first shear crack. However, the study highlighted a consequential outcome, indicating that specimens with shear reinforcement demonstrated a notable enhancement, exhibiting a 20-25% increased resistance to shear after the occurrence of the initial shear crack in comparison to those without transverse stirrups. The observed mode of failure was identified as being influenced by the width and effective depth of the beams, providing valuable insights into the complex interplay of factors affecting shear behavior in reinforced concrete shallow beams [36].

While research on wide beams in torsion remains limited, a noteworthy study delved into this aspect by subjecting nine specimens of high strength reinforced concrete wide beams to both bending and torsion tests. The primary variable under scrutiny was the torque to bending moment ratio, as detailed in the study on the behavior of high-strength reinforced concrete wide beams under felxural and torsion effects in 2020.

The findings unveiled a distinct trend, revealing that an increase in the torque to bending moment ratio corresponded to a reduction in the flexural capacity of the wide beams. The alteration in the torque to bending moment ratio resulted in a significant increase in the occurrence of inclined cracks along the span of the high-strength reinforced concrete wide beams, highlighting the complex interaction between torsional and flexural effects [37].

A comparison was made between two specimens of reinforced concrete beam-column joints, one with a wide beam and the other with a conventional beam. Quasi-static cyclic loading was applied to assess the performance of the beam-column joints. While both specimens exhibited similar deformation capacity, the conventional beam specimen outperformed the wide beam specimen in terms of initial crack density and approaching the designed capacity of the beams [38].

The study by Al-Harmani and co-authors aimed to assess the influence of basalt fiber-reinforced concrete slabs on the overall shear capacity of the specimens. The percentage of basalt fiber reinforcement ranged from 0.792% to 1.27%, transitioning from plain concrete to basalt macro fiber concrete. The basalt macro fiber concrete had no significant effect on the flexural behavior or compressive strength of the slabs but increased their shear capacity by approximately 16.7% [39].

Sixteen specimens of one-way FRP concrete slabs, using glass and carbon fibers with different cross-sections, were tested to study shear resistance mechanisms. Glass fiber polymers led to desired ductile failure, while carbon fibers resulted in brittle failure [40].

The use of engineered cementitious composite (ECC) to replace stirrups in reinforced concrete beams was investigated. Comparing specimens with ECC coatings of 20 mm and 40 mm thickness to those using stirrups, it was concluded that a 20 mm ECC thickness provided optimal shear resistance, while 40 mm thickness had a positive impact but was not as effective as the 20 mm thickness [41].

Reactive powder concrete (RPC) offers potential enhancements to the mechanical and physical properties of concrete elements. Eighteen specimens of RPC beams without stirrups were manufactured and tested for shear resistance, using ten different RPC mixtures with varying compressive strengths. Increasing the volume fraction of RPC had a significant impact on shear capacity, with increases of up to 132% depending on the volume fraction [42].

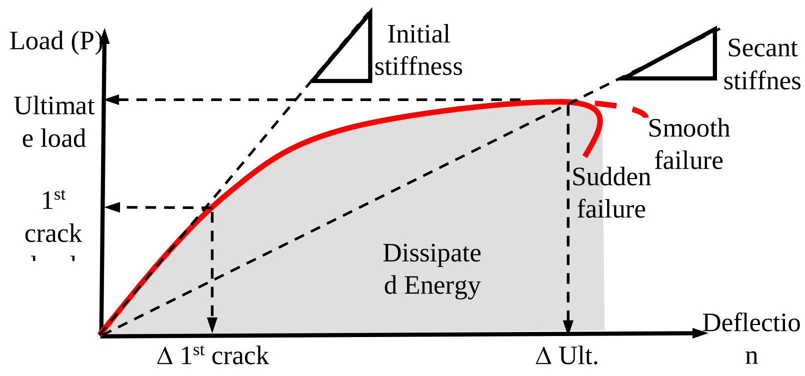


Fig. 7 The considered observations

Ebid conducted a comprehensive study collecting experimental test results on concrete beams reinforced with FRP bars, both with and without FRP web reinforcement. The database covered a wide range of width-to-depth ratios, encompassing both wide and projected beams. Utilizing the Genetic Programming technique, the study developed a unified equation for shear capacity, considering factors such as width-to-depth ratio, shear span-to-depth, modular, and reinforcement ratios. The resulting equation demonstrated superior accuracy compared to international design codes and previous research efforts [43] [44].

A study on reinforced concrete shallow beams with various openings along their span revealed that increasing opening lengths led to decreased stiffness, shear capacity, deformation, and flexural capacity of the beams [45].

In 1992, a study focused on beam-column specimens subjected to cyclic loads aimed to address the absence of code guidelines for narrow wide beams. The research team proposed detailing improvements that enhanced the capacity of the specimens to resist seismic loads [46].

In a 2013 study, researchers investigated the behavior of one-way slabs under shear conditions. The study involved testing the slabs and revealed that increasing transverse reinforcement did not significantly impact the overall load capacity. However, it did influence crack patterns and modes of failure in the slabs [47].

With the increasing prevalence of reinforced concrete wide beams in diverse building structures, an Iraqi research team, led by Fadhil and Abbass in 2022, conducted a comprehensive review. Their study focused on evaluating the influence of geometric, material, reinforcement, and monotonic loading parameters on crucial aspects such as shear capacity, failure modes, stiffness, and ductility of wide beams [48].

Tests on column-wide beam joint specimens under gravity load, with varying widths and reinforcement distributions, showed that concentrated reinforcement at the joint area increased shear capacity by 24%. Further investigation is needed to explore the effects of increasing column width on controlling diagonal cracks at the connection area [49].

The shear failure of RC one-way slabs is often overlooked by design codes. A comparative study using widely used codes worldwide found that the French national annex guidelines closely aligned with experimental results, while Eurocode 2 and ACI 318-14 significantly underestimated the phenomena [50].

The dataset consisting of 279 records served as the foundation for the development of two predictive models aimed at assessing the shear capacity of wide beams without web reinforcement. The first model used nonlinear regression, while the second model employed an Artificial Neural Network (ANN). Both models outperformed design codes, with the ANN model achieving higher accuracy than the regression model [51].

Another research effort focused on shear reinforcement for wide beams, an aspect often overlooked by international design codes. Ten specimens of reinforced concrete wide beams were tested, considering shear reinforcement ratio, shear span-to-depth ratio, and stirrup spacing. The results demonstrated that increased web reinforcement led to greater ductility, improved shear and flexural capacity, and enhanced crack control [52].

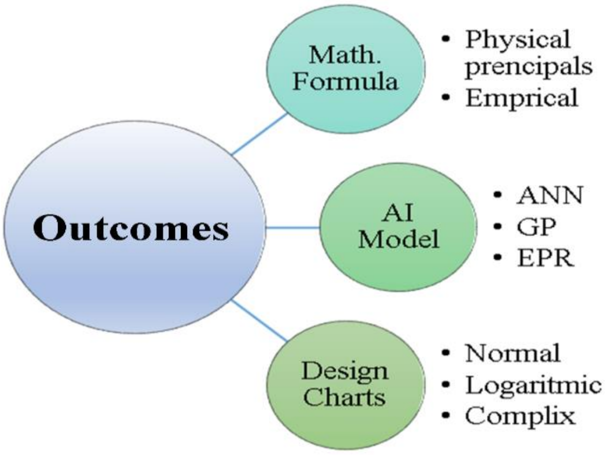


Fig. 8 Classifications of quantitative outcomes

Lantsoght and her research team have played a pivotal role in advancing the comprehension of shear strength in reinforced concrete wide beams and one-way slabs through their extensive investigations.

In a study conducted by Lantsoght and her team, eight specimens of reinforced concrete slabs were subjected to testing, with variations in parameters such as reinforcement, slab width, loading position, and support type. The results revealed that the compressive strength of the concrete did not significantly influence the shear capacity. However, a noteworthy observation was made that decreasing the distance of the load to the supports led to an increase in the shear capacity of the specimens [53].

Another investigation by the same research team involved testing eight slab specimens under different load combinations. The study compared the obtained results with the guidelines of the Eurocode (EN 1991-2:2003). The findings from this study suggested that the minimum effective shear width should be approximately four times the depth, and a new reduction factor for concentrated loads near the supports was proposed [47].

In a more recent effort, the researchers compiled a comprehensive database consisting of 170 shear test results for wide beams without web reinforcement, considering various loading conditions. This extensive database was employed to assess the existing provisions of design codes and previously developed shear models. The study provided valuable insights into the shear performance of wide beams, contributing to a better understanding of their behavior under different loading conditions [54].

5. Results and discussions

The review of seven design codes and forty research works has revealed several gaps and limitations in the existing provisions for the shear capacity of wide beams. The identified gaps are discussed below:

1. Lack of Unified Definition for Wide Beams:

- One prevalent gap across most design codes is the absence of an accurate and unified definition for wide (or shallow) beams. The definition of what constitutes a wide beam varies among codes, leading to ambiguity and inconsistency in design and analysis.

2. Neglect of Web Reinforcement Contribution:

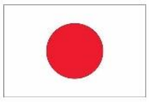
- Design codes generally overlook the contribution of web reinforcement in the shear capacity of wide beams. While some codes suggest the use of a minimum amount of web reinforcement in wide beams, it is primarily to fulfill requirements unrelated to shear capacity, such as fire resistance and ductility.

3. Inconsistencies in Code Provisions:

- There are inconsistencies among design codes in terms of shear capacity provisions for wide beams. This lack of uniformity can lead to confusion and may result in varying levels of safety in structural design.

Table 1 provides a summary of the shear capacity provisions for wide beams in the considered design codes, highlighting the identified gaps. Addressing these gaps is crucial for developing accurate and reliable design guidelines for wide beams, ensuring the safety and efficiency of reinforced concrete structures.

Table 1: Summary for the provisions of considered design codes

	Design Code	Provision	Gaps
	ACI 314-2019	It is not required to satisfy the minimum shear reinforcement for members with thickness less than 25 cm, however, using shear reinforcement is advised.	- The absence of a universally accepted definition for shallow (or wide) beams creates ambiguity in design codes, necessitating a more precise criterion considering structural behavior. - the overlooked contribution of shear reinforcement in wide beams and the varied objectives behind minimum shear reinforcement requirements underscore the need for a nuanced and context-specific approach in code provisions.
	EN 1992-1-1:2004	While the impact of shear reinforcement is deemed insignificant, adherence to the minimum shear reinforcement requirements is essential for structural integrity and safety compliance.	
	SPCS-2007	Shallow beams are not defined; however, the minimum shear reinforcement must be used.	
	CSA A23.3-04	While it is not mandatory to meet the minimum shear reinforcement criteria for members with a depth shallower than 75 cm, it is recommended to incorporate shear reinforcement for enhanced structural performance.	
	GB 50010-2010	For members with a depth less than 15 cm, satisfying the minimum shear reinforcement is not a mandatory requirement.	
	SBC304c	It has no definition or minimum shear reinforcement for shallow beams.	
	ECP 203-2017	Members with a thickness less than 25 cm are not obligated to meet the minimum shear reinforcement requirements.	

The analysis of the collected previous research on the shear capacity of wide beams involved sorting and classifying the studies based on considered parameters, methodologies used, recorded observations, and obtained outcomes, as illustrated in Figure 9. The quick evaluation score provided in the last column offers an overview of the research scope, regardless of its contribution. Meanwhile, the bottom row displays the frequency at which each parameter or scope was addressed.

The average score among the forty selected research papers was 11 out of 32, with a maximum value of 19 and a minimum of 6. This indicates that, on average, most papers covered approximately 33% of the parameters within this topic, which is considered reasonable. However, the values in the bottom row indicate a wide range of variability among the parameters. Some parameters were addressed only once, while others were addressed in the majority of the research, with an average of 14 addressing times. This bottom row highlights the gaps in previous research, with certain parameters being addressed less than seven times, which is less than half of the average compared to other parameters.

Parameters related to FRP in longitudinal and web reinforcement, as well as beam-column joint strength, were addressed in only three to five research papers. Furthermore, only four research papers presented prediction models, including two mathematical formulas and two AI models. In delving into the various parameters affecting wide beam behavior, it's worth noting that aspects like web openings, compression reinforcement, inclined ties, long-term loading, cyclic loading, and dissipated energy as a measure of damage have been investigated in only one or two research papers, highlighting a gap in the existing body of research.

Notably, the majority of the research heavily relied on experimental programs, with only three research papers incorporating FEM models alongside experimental work. This analysis emphasizes the need for more comprehensive and diversified research efforts to fill the identified gaps in understanding the shear capacity of wide beams.

		Year													
		1992	2002	2011	2013	2014	2015	2016	2018	2019	2020	2021	2022	2023	**Sum**
Concrete	Fcu	0	1	1	1	0	0	0	2	2	2	2	1	0	12
	Non-conventional concrete	0	0	0	0	0	1	1	0	1	2	1	1	0	7
Geometry	Beam width / Beam depth	1	0	0	2	0	1	0	2	3	1	2	2	0	14
	Beam width / Col width	0	0	1	2	0	0	0	0	2	0	1	1	0	7
	Shear span / beam depth	0	0	1	2	1	0	0	2	2	0	2	1	0	11
	Web openings	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Long. RFT.	Ten. RFT - Steel	1	1	1	5	1	3	0	4	5	6	4	4	1	36
	Ten. RFT - FRP	0	0	0	0	1	1	1	0	0	0	1	1	0	5
	Ten. RFT - As/Ac	0	0	0	1	0	1	1	1	1	3	3	2	0	13
	Comp.. RFT - Steel	1	1	1	5	1	3	0	2	5	4	3	4	1	31
	Comp. RFT - FRP	0	0	0	0	0	0	1	0	0	1	2	1	0	5
	Comp. RFT - As/Ac	0	0	0	0	0	0	0	0	0	1	1	0	0	2
Shear RFT.	Ties - Steel	1	1	0	3	1	3	0	2	4	3	3	3	1	25
	Ties - FRP	0	0	0	0	0	0	0	1	0	1	1	0	0	3
	Inclined ties	0	0	0	0	0	0	0	0	0	0	0	1	0	1
	Ties -Fy	0	0	0	0	0	0	0	0	0	0	1	2	0	3
	Ties - As/Ac	0	1	0	1	1	1	0	1	3	4	5	3	0	20
	Ties - Long. Spacing	0	1	0	1	1	1	0	0	3	1	4	3	1	16
	Ties - Trans. Spacing	0	1	0	0	1	1	0	1	3	1	1	3	0	12
Load	Monotonic load	0	1	1	5	2	2	1	4	5	5	5	5	1	37
	Long term loading	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	Cyclic load	1	0	0	0	0	1	0	0	0	0	0	0	0	2
Test	Experimental	1	1	1	5	2	3	1	3	5	6	3	5	1	37
	Numerical FEM	0	0	0	0	0	0	0	1	0	0	1	1	0	3
Observations	Shear strength	0	1	1	3	0	2	1	4	5	6	5	5	1	34
	Beam-column joint strength	1	0	0	1	0	1	0	0	1	0	0	0	0	4
	Failure modes	1	1	1	3	0	3	1	2	5	6	4	5	0	32
	Stiffness	0	0	0	2	2	1	0	1	3	2	2	3	1	17
	Ductility	1	0	0	1	0	2	1	1	0	0	0	2	0	8
	Dissipated Energy	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Outcomes	Mathematical or AI model	0	1	0	0	0	0	0	1	1	0	1	0	0	4
	Recommendations	1	1	1	5	2	3	1	4	5	6	5	5	1	40
	Score	10	13	10	48	17	35	10	39	64	61	63	65	9	

Fig. 9 Mapping for the collected research with respect to considered parameters, methodologies, observations and outcomes along with publication year

6. Conclusions

The research findings on the shear capacity of wide beams have led to several key observations and recommendations:

Key Findings:

1. Lack of Unified Definition:

- There is not globally accepted or unified definition for wide or shallow beams, with varying depth criteria and width-to-depth ratios among design codes.

2. Overlooked Contribution of Web Reinforcement:

- Despite research indicating significant enhancements in shear capacity with web reinforcement, design codes have largely overlooked this contribution.

3. Minimum Web Reinforcement for Non-Shear Reasons:

- Some design codes include provisions for minimum web reinforcement in wide beams, primarily to address fire resistance and ductility, rather than enhancing shear strength.

4. Identified Research Gaps:

- Research gaps include the shear capacity of wide beams with FRP longitudinal and web reinforcement, consideration of web openings or inclined ties, and the effects of creep or cyclic loading.

5. Shortage of Predictive Models:

- There is a significant shortage of Finite Element Method (FEM) models and predictive models (mathematical or AI-based) for assessing the shear capacity of wide beams.

Recommendations:

1. Refine Definition of Wide Beams:

- Develop a more precise and comprehensive definition for wide/shallow beams based on their structural behavior rather than relying solely on dimensional criteria.

2. Develop Predictive Models:

- Create accurate predictive models for the shear capacity of wide beams, employing mathematical or machine learning techniques. These models can eventually be incorporated into design codes.

3. Address Research Gaps:

- Conduct further experimental and numerical research to investigate the shear capacity of wide beams, specifically addressing the identified research gaps.

Implementing these recommendations will contribute to a more nuanced understanding of wide beam behavior, leading to improved design practices and potentially influencing updates to design codes in this area.

Abbreviation

Fcu : Characteristic compressive strength of concrete after 28 days.

Fy: Yield strength of the reinforced steel.

As : Tension steel reinforcement in the wide beams.

As' : Compression steel reinforcement in the wide beams.

B : Width of the cross section of the wide beams.

b : Width of the support of the wide beams.

Ac : Cross sectional area of the wide beams.

L : Length of the wide beams.

d: Effective depth of the wide beams.

a: Shear span of the wide beam.

c: Concrete cover of the wide beams.

S: Longitudinal spacing between the stirrups of the wide beams.

S': Transverse spacing between the legs of the stirrups of the wide beams.

FRP: Fiber reinforced polymers.

GFRP: Glass fiber reinforced polymers.

SHCC: Strain hardening cementations compositions.

CFRP: Carbon fiber reinforced polymers.

Competing Interests

The authors declare that they have no competing interests.

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