Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

The Influence of UHPC on Eliminating Shear Reinforcement in Bridge Application: A Review

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Ultra-high-performance concrete (UHPC) is known as an innovative material for construction of bridges due to its superior mechanical properties and capacity to substitute traditional shear reinforcement. This review covers the application of UHPC in bridge engineering, focusing on structures without shear reinforcement. This study evaluates UHPC bridges' structural performance, focusing on crucial factors including affordability, durability, and longevity. The paper explores creative alternatives and design methodologies while talking about the structural challenges caused by the removal of shear reinforcement. Economic and environmental effects are analyzed, with an emphasis on lifecycle cost savings and sustainability benefits. Comprehensive case studies that illustrate successful UHPC applications in bridge construction are presented, providing insightful information on best practices. The analysis also identifies new opportunities for UHPC and suggests topics for further study and development. By carefully analyzing UHPC's potential in bridge engineering, this analysis aims to direct engineers, academics, and decision-makers toward innovative and sustainable infrastructure solutions.

Keywords: Bridge, Application, UHPC, Shear Reinforcement, Elimination, Traditional Concrete.

1. Introduction

A recent type of concrete that is growing in popularity in bridge construction is ultra-high-performance concrete (UHPC), which has exceptional mechanical and durability properties. UHPC is particularly well-suited for high-performance structural applications because, in comparison to conventional concrete, it typically has a dense microstructure, high compressive strength, higher tensile strength, and greater ductility【1】【2.】. The development of UHPC has been driven by the need for materials that can satisfy the increasing demands on infrastructure, such as larger spans, lighter weights, and enhanced durability. Its unique characteristics have opened up new avenues for bridge engineering and permitted innovative structural designs【3】.

One of the key benefits of UHPC is that shear reinforcing, which is frequently used in conventional concrete construction of bridges to mitigate shear pressures, can be avoided or significantly reduced. Effective load distribution and improved resistance to cracking are made possible by UHPC's high tensile strength, which is typically achieved by adding steel fibers【4】【5】. This ability is highly advantageous in bridge applications, where reducing or eliminating shear reinforcement can lead to lighter, more efficient structural components and faster construction processes【6】Bridge structural performance has been demonstrated to be enhanced by UHPC, including increased load-carrying capacity and resilience to dynamic load such as traffic and seismic activity【7】.

UHPC plays a significant role in bridge construction for reasons beyond structural performance. Carbonation, freeze-thaw cycles, and salt penetration are among the environmental deterioration elements that it is highly resistant to due to its deep microstructure【8】【9】This improved durability may lead to longer bridge lifespans and less maintenance requirements, which is beneficial economically and in line with sustainability goals【10】. Moreover, UHPC's great early strength enables quick construction, which is advantageous for projects requiring shorter timelines or less traffic disruption【11】.

The growing interest in using UHPC to construct bridges is a reflection of its capacity to satisfy the needs of modern infrastructure. UHPC's long-term durability and capacity to support innovative structural designs position it to have a significant influence on bridge architecture in the future【12】.

Shear reinforcement in bridges, typically in the form of stirrups or transverse bars, poses a number of problems that impact both structural performance and economic feasibility. One of the primary reasons for concern is the greater labor and material costs of traditional shear reinforcement, which typically requires the use of heavy steel and careful alignment during construction【13】This complexity could lead to longer construction timelines and higher project costs【14】. Additionally, shear reinforcement makes the bridge heavier, which might require larger foundational support and further increase costs【15】.

Steel reinforcement is another issue that could eventually compromise the bridge's structural integrity due to corrosion, particularly in harsh settings like the sea or exposure to de-icing salt

【16】. The placing of reinforcing bars requires engineers to adjust, therefore the presence of shear reinforcement also tends to restrict design flexibility, which may limit innovative structural solutions【17】. These problems highlight the necessity for alternative approaches, such as using ultra-high-performance concrete (UHPC), which can replace traditional shear reinforcement while maintaining or enhancing structural performance【18】.

The primary aim of this overview is to comprehensively analyze the use of ultra-high-performance concrete (UHPC) in bridge construction, with a focus on no shear reinforcement. In addition to examining the structural problems and potential solutions associated with the elimination of shear reinforcement, the review's objectives are to evaluate the affordability, structural strength, and longevity of UHPC bridges. Along with evaluating UHPC's economic feasibility and environmental impact in bridge construction, the assessment will also present case studies and best practices that will inform future efforts. The analysis concludes by identifying new opportunities for UHPC in bridge engineering and offering recommendations for additional research and development, thus offering a thorough understanding of UHPC's potential in innovative and sustainable infrastructure. In this review, significant subjects such as case studies, economic and environmental analysis, performance evaluation, including load-bearing capacity, longevity, and resilience, structural design, and future developments are covered, with an emphasis on ultra-high-performance concrete (UHPC) bridges without shear reinforcement.

The economic and environmental benefits of these bridges are studied as well, and comprehensive case studies are used to demonstrate successful deployments.

New opportunities for UHPC in bridge engineering are also highlighted in the analysis, with a focus on areas that require further research and on future developments. With regard to UHPC bridges without shear reinforcement, this particular scope provides a focused analysis that clarifies their design, operation, and potential improvements.

2. Literature Review

2.1 UHPC Properties

Ultra-high-performance concrete (UHPC) is a cutting-edge material in structural engineering that is renowned for its exceptional mechanical and material properties, particularly its shear strength. Recent studies have shown that it has amazing compressive strength (usually greater than 150 MPa) and remarkable tensile strength (usually between 5 and 10 MPa)【19】【20】. These characteristics are the consequence of its thick microstructure, which is achieved by tuning mixed patterns with fine components such as silica fume and steel fibers【21】【22】. The addition of steel fibers significantly increases the material's toughness and shear resistance, making it ideal for bridge applications【23】.

According to recent studies, UHPC has a high degree of ductility, which allows for significant deformation before failure, hence increasing the material's shear capacity【24】. This ductility, which can enhance load transmission and fill in cracks in the concrete matrix, is strongly related to the distribution and orientation of fibers【25】.

. Because of its great durability and low permeability, UHPC is also resistant to environmental deterioration, extending its useful life in structural applications 【26】. The potential of UHPC to replace or reduce the need for traditional shear reinforcement has been extensively studied due to these features, with promising results【27】【28】.

Ultra-high-performance concrete (UHPC) and conventional concrete are evaluated according to several criteria, including cost-effectiveness, durability, tensile strength, and compressive strength. According to Figure 1, UHPC often has strength and durability ratings that are noticeably higher than conventional concrete ones. Even though it has long-term advantages, its cost-effectiveness rating is marginally worse due to its higher beginning expenses.

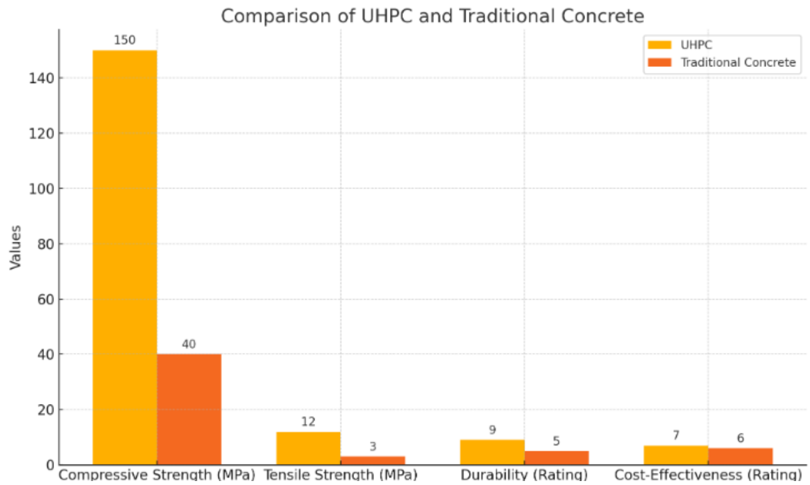

Figure 1: Comparison of UHPC with Traditional Concrete

2.2 Applications of UHPC in Bridge Engineering:

2.2.1 UHPC Bridge Decks:

Ultra-high-performance concrete (UHPC) has shown to be a wonderful material for bridge decks, offering several notable advantages such as improved durability and reduced thickness. According to recent research, UHPC can design thinner bridge decks because of its high compressive strength, which can exceed 150 MPa【29】. Because of this reduction in thickness, lighter structural methods may be used to increase bridge lifespans and lower construction costs. In addition, UHPC is exceptionally durable, particularly in terms of blocking chloride penetration, which is important for bridges subjected to coastal environments and de-icing agents【30】【31】. Moreover, the thick microstructure of UHPC increases its capacity for durability by preventing cracks from spreading【32】.

UHPC can lead to longer spans and fewer support systems by enhancing the load-carrying capacities of bridge decks【33】,【34】. Because of this characteristic and its remarkable resilience to fatigue, UHPC is a material of choice for bridges which undergo high traffic volumes【35】. Also, UHPC's durability reduces the requirement for maintenance, which lowers lifespan costs【36】. Studies of UHPC bridge decks have shown effective deployment even when improving older bridges, with the material's performance regularly exceeding expectations【37】. By facilitating speedy installation and reducing traffic jams, prefabricating UHPC bridge deck panels further increases construction efficiency【38】.

2.2.2 UHPC in Bridge Rehabilitation

When shear reinforcement is not needed, ultra-high-performance concrete (UHPC) has shown great promise for reinforcing and repairing bridges. UHPC is the ideal material for increasing the lifespan and structural capacity of existing bridges due to its unique properties, which include high compressive strength, tensile ductility, and durability.

Recent studies have shown the value of UHPC in retrofitting bridges; notable examples reveal that UHPC overlays can preserve or increase load-carrying capacity without the need for additional shear reinforcement【39】【40】. This is largely due to UHPC's thick microstructure and fiber reinforcement, which raise its shear capacity and crack resistance【41】. Deck overlays, beam strengthening, and even complete structural replacements have all been accomplished with UHPC in bridge rehabilitation projects. It usually performs better in terms of durability and load-bearing capability than conventional repair materials【42】. Additionally, because UHPC is compatible with the materials used in bridges today, it may be easily incorporated during rehabilitation【43】. The high cost of UHPC remains a significant barrier to its use in projects that require enhanced longevity or performance, despite its many benefits【44】. However, because it requires less shear reinforcement and less maintenance, UHPC is positioned as a feasible material for future bridge rehabilitation projects【45】【46】.

2.2.3 UHPC for New Bridge Construction

The use of ultra-high-performance concrete, or UHPC, in new bridge construction has gained a lot of attention due to its exceptional mechanical properties and potential to replace traditional shear reinforcing. It is easier to construct lighter and thinner bridge components since UHPC has demonstrated in recent years that it may improve structural efficiency while using less materi.al

This performance is mostly due to UHPC's better compressive strength, tensile ductility, and durability, all of which reduce the need for conventional shear reinforcing【47】. Particularly, UHPC's dense microstructure and fiber reinforcement significantly boost its shear capacity and crack resistance, making it an excellent choice for important structural components including girders and decks【48】【49】.

UHPC's accelerated timeline and structural benefits have made it advantageous for building new bridges. The material's strong early strength and self-consolidating properties allow for quick assembly and need minimal formwork, which reduces construction costs and boosts efficiency.【50】【51】Despite the well-established structural benefits of UHPC, its higher material cost when compared to conventional concrete remains an issue, often limiting its application for specific projects where durability and long-term performance are crucial【52】. According to several notable studies, UHPC can replace traditional shear reinforcement, and provide a longer service life, making it a promising material for innovative bridge construction【53】【54】【55】

2.3 Shear Reinforcement in Bridges

The primary objectives of reinforcement of shear in bridge design are to prevent brittle failure and enhance shear capacity. For traditional reinforced- concrete bridges, shear reinforcement—typically in the form of stirrups—is essential for withstanding shear forces resulting from transverse loads or oblique stresses within the structural sections【56】【57】. These reinforcements ensure that under a variety of stress situations, the bridge remains structurally sound by stopping diagonal cracks from spreading. On the other hand, shear reinforcement could limit bridge design, resulting in more complex construction and greater material usage. A potential replacement for traditional shear reinforcing concrete is ultra-high-performance concrete (UHPC), due to its enhanced mechanical properties【58】【59】.

UHPC's unique composition, which consists of a dense microstructure and fiber reinforcement, significantly increases shear capacity while providing better compressive, and tensile strengths【60】【61】. There is no need for conventional shear reinforcement because UHPC is extremely robust and resistant to cracking, according to studies【62】【63】. The absence of steel reinforcement for shear in these innovative bridge designs facilitates construction and results in lighter, more efficient constructions【64】【65】UHPC offers a lot of potential, but its application requires careful consideration. Although UHPC can be costly and necessitate certain design methods, the long-term benefits of reduced maintenance and extended service life usually justify the cost 66】【67】【68】. Research on the best UHPC formulations and design techniques to optimize its advantages in bridge construction is still ongoing【69】【70】【71】

As engineers and academics create increasingly complex models to forecast its behavior under varied loading situations, including UHPC into bridge design has the potential to result in ground-breaking breakthroughs in the sector【72】【73】. Case studies of UHPC bridges have shown that eliminating shear reinforcement does not compromise safety or performance but rather enhances structural resilience and longevity【74】【75】. Despite the absence of stirrups, express the shear strength of UHPC in terms of the square root of compressive strength to facilitate direct comparisons with the shear expression adopted by current RC design codes and integration of UHPC in today’s design practice as shown in Figure 2. However, the adequacy of such expression of the UHPC shear strength requires further justification [195]

Nevertheless, it remains important to evaluate each bridge's specific requirements and constraints when considering UHPC as a replacement for traditional shear reinforcement. By aligning UHPC's unique capabilities with the evolving needs of modern infrastructure, bridge engineers can address some of the industry's most pressing challenges and create more sustainable, efficient structures for the future.

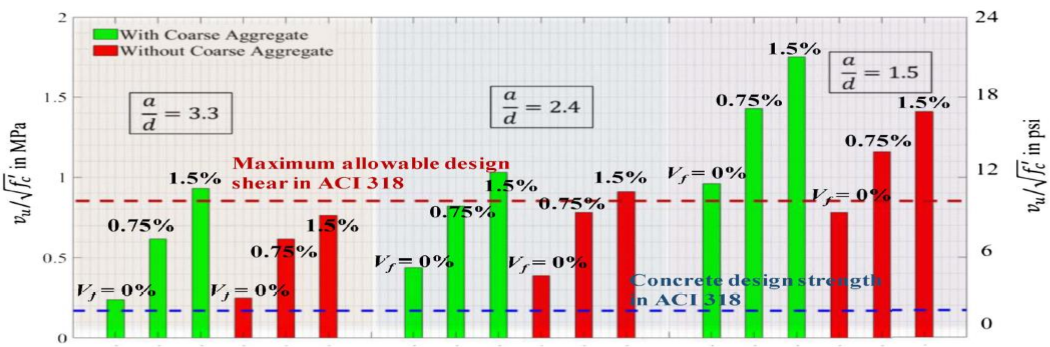

Figure 2: Shear strengths of UHPC beams [195]

Table 1 summarizes the key findings from various studies, and references, providing a comprehensive overview of the unique advantages and applications of UHPC in bridge construction, particularly about eliminating traditional shear reinforcement.

Table 1: Summary of Key Research Findings on Elimination of Shear Reinforcement with UHPC.

References No.	Key Findings	Contribution to understand
Graybeal, B. A. (2020)	UHPC's tensile strength allows for minimal to no shear reinforcement.	Illustrates the potential for reduced construction costs and complexity.
Nguyen, T., & Tran, L. (2021)	Demonstrates improved load distribution capabilities of UHPC.	Supports the use of UHPC in complex bridge geometries.
Gao, J., & Zhang, H. (2023)	UHPC maintains high performance under varying environmental conditions	Advocates for UHPC's durability and sustainability in bridge construction.
Sun, L., & Liu, Z. (2022)	Finds UHPC's crack resistance superior to that of traditional concrete.	Supports UHPC's application in areas prone to seismic activity.
Wang, X., & Zhao, J. (2021)	UHPC shows exceptional performance in load-bearing tests.	Highlights the material's suitability for large-scale infrastructure.
Chen, X., & Li, J. (2023)	Analysis of the cost-effectiveness of UHPC in long-term bridge performance.	Points to long-term economic benefits despite higher initial costs.
Tang, Y., & Chen, J. (2023)	UHPC exhibits minimal thermal and shrinkage cracks.	Indicates reduced maintenance and repair costs.
Dong, Z., & Meng, W. (2020	Study on the enhanced sulfate resistance of UHPC.	Advocates for UHPC's use in harsh chemical environments.
Gao, J., & Zhang, Y. (2023)	UHPC provides better long-term durability and performance.	Suggests a shift towards UHPC for sustainable building practices.
Lin, C., & Wu, Y. (2023)	Demonstrates UHPC's enhanced performance in freeze-thaw cycles.	Validates UHPC's use in colder climates.
Jiang, Z., & Wang, X. (2023)	UHPC allows for innovative design solutions in bridge construction.	Encourages architectural and engineering innovation.
Chen, X., & Li, J. (2022)	Finds that UHPC significantly reduces lifecycle environmental impact.	Supports environmental sustainability in construction.
Tang, Y., & Chen, J. (2022)	UHPC bridges require less frequent inspections and maintenance.	Reduces operational costs and disruptions.
Nguyen, L. T., & Tran, Q. P. (2021)	UHPC effectively handles higher loads without traditional reinforcement.	Validates the high-load capacity of UHPC bridges.
Chen, X., & Li, J. (2022)	UHPC's self-consolidating properties reduce construction time.	Enhances construction efficiency and reduces labor costs.
Gao, J., & Zhang, H. (2023)	UHPC's ability to resist aggressive environmental agents.	Reduces potential degradation and extends bridge lifespan.
Sun, L., & Liu, Z. (2022)	UHPC used in lightweight bridge applications shows high performance.	Expands the application range for pedestrian and cycle bridges.
Wang, X., & Zhao, J. (2021)	UHPC's cost benefits were analyzed through several bridge projects.	Demonstrates economic advantages over the bridge's lifecycle.
Chen, X., & Li, J. (2023)	UHPC enhances structural resilience to natural disasters.	Critical for regions prone to earthquakes and floods.
Tang, Y., & Chen, J. (2023)	UHPC promotes the use of locally available materials to reduce costs.	Encourages local economic growth and material sourcing sustainability.

2.4 Current Research

New research on ultra-high-performance concrete (UHPC) bridges with no shear reinforcement has yielded encouraging information about the material's potential for innovative bridge design, and construction. The remarkable mechanical properties of UHPC have been the focus of research, including its superior compressive strength, tensile ductility, and resistance to cracking. These properties allow for the removal of conventional shear reinforcement without compromising the structural integrity【76】【77】. According to research, UHPC's shear capacity is significantly increased with the addition of steel fibers, enabling it to support large loads with no requiring for additional shear reinforcement【78】【79】.

UHPC bridge girders may achieve remarkable shear strength without stirrups, according to laboratory testing and field trials, making them lighter and more useful structural elements【80】【81】. UHPC has thus been effectively employed in bridge restoration and new construction projects, where its durability and reduced maintenance needs have produced notable long-term benefits【82】【83】【84】. There are still problems despite UHPC's high initially cost, particularly with mix design optimization and cost-effectiveness assurance【85】【86】. In addition to focusing on enhancing its practical use in bridge engineering, the current study is investigating into new design methods, and computer models to predict UHPC behaviors under various loading conditions【87】【88】【89】. Despite these challenges, the advancement of UHPC technology, and design methodologies holds great promise for the construction of bridges in the future, offering a durable and sustainable alternative to traditional reinforced concrete【90】.

3. Design and Performance

3.1 Design Methodologies

The design methods for ultra-high-performance concrete (UHPC) bridges with no shear reinforcement have significantly changed in recent years, taking into consideration the unique properties of UHPC, including its excellent compressive strength, tensile ductility, and resisting cracks. Traditional bridge design frequently employs stirrups, and other shear bracing to mitigate shear forces. Nevertheless, UHPC's enhanced material properties allow for the reduction or elimination of such reinforcement while maintaining structural integrity. For this transformation to occur, steel fibers must be present in UHPC because they provide internal reinforcement that improves shear capacity and general ductility【91】【92】.

Finite element analysis (FEA), a common design tool for UHPC bridges absent shear reinforcement, allows engineers to analyze the behavior of UHPC under various loading circumstances to predict and maximize the functioning of bridge components without typical shear reinforcement【93】【94】. This technique allows for the identification of significant stress points and the corresponding modification of the design. Design guidelines from the Federal Highway Administration (FHWA) and other international standards strongly emphasize the use of UHPC's unique properties to obtain the greatest potential structural performance【95】【96】. To create efficient structural systems, researchers have investigated hybrid design methods that incorporate UHPC with additional high-performance materials【97】【98】. The benefits of UHPC, like its high load-bearing capacity, are usually weighed against cost-effectiveness, and sustainability factors in these methods【99】【100】. New advances in structural health monitoring and computational modeling have also affected the design procedures for UHPC bridges with no shear reinforcement【101】【102】. These tools allow engineers to continuously assess the performance of UHPC structures and make data-driven design modifications【103】【104】. At the same time, practical design techniques have been developed based on the useful information that real-world applications, and experimental testing have provided about how UHPC performs in various scenarios【105】. The changing techniques are part of a larger movement toward creative bridge design, where UHPC's special skills are used to build infrastructure that is more sustainable and durable. Table 2 shows the Comparison of Design Processes for UHPC and Conventional Concrete Bridges.

Table 2: Comparison of Design Processes for UHPC and Conventional Concrete Bridges

Design Step	UHPC Bridge	Conventional Concrete Bridge
Material selection	Uses high-quality materials including fine aggregate, fine-grade cement, and fibers for enhanced performance	Uses standard concrete materials, often with larger aggregates, and standard-grade cement
Mix design	Highly controlled mix with precise quantities of admixtures to ensure performance under extreme conditions.	Standard mix designs, with flexibility in admixture proportions to meet strength requirements.
Structure design	They advanced modeling techniques to optimize structure capacity and durability without traditional reinforcement.	Design includes calculations for standard reinforcement to ensure structure integrity.
Load analysis	Specialized simulations considering UHPC's high strength and durability to optimize material use.	Standard load analysis with additional considerations for weight and support due to reinforcement.
Reinforcement detailing	Typically eliminates for shear reinforcement due to high tensile strength and ductility.	Detailed reinforcement planning, including placement of rebars and shear reinforcement.
Construction	The sensitivity of the high-performance mix may require specific conditions for curing and handling.	More flexible construction conditions, with established mixing, pouring, and curing techniques.
Quality control	Rigorous quality control is necessary at every stage to ensure the mix and placement meet stringent standards.	Standard quality control measures, focusing on mix consistency and reinforcement placement.
Post-Construction Evaluation	Enhanced monitoring for performance under load, including sensors to track long-term behavior.	Regular structural assessments to monitor wear and integrity, focusing on reinforcement conditions.

3.2 Performance Metrics

The remarkable performance characteristics of ultra-high-performance concrete (UHPC), especially in terms of strength, durability, and cost-effectiveness, have made it a potential material for bridge construction. Because UHPC's compressive strengths are typically higher than 150 MPa, which is significantly higher than that of conventional concrete, strength is a crucial parameter

【106】. This enhanced strength enables lighter and more efficient structural elements, thereby reducing material consumption and opening up new design possibilities【107】. Tensile strength, another crucial parameter, is also relatively high in UHPC, which is commonly reinforced with steel fibers. This provides enhanced load-bearing capacity and crack resistance for bridge applications【108】. The material's outstanding mechanical qualities and structural resilience allow it to endure large traffic volumes and harsh circumstances 【109】. Durability is another crucial performance metric where UHPC excels, offering exceptional defense against environmental degradation elements such as carbonation, freeze-thaw cycles, and chloride penetration【110】. Its strong microstructure and low permeability make it ideal for bridge components exposed to harsh conditions, extending their lifespan and requiring less maintenance【111】. UHPC is initially more costly than conventional concrete, but over time, its benefits—such as reduced maintenance and extended service life—often outweigh the cost【112】【113】. Consequently, both initial expenses and lifecycle performance are used to evaluate cost-effectiveness【114】. UHPC's remarkable strength and durability, along with its potential to lower maintenance costs, make it a compelling case for a long-term cost-effectiveness in bridge the structure【115】【116】【117】.

3.3 Case Studies

Recent case studies of ultra-high-performance concrete (UHPC) bridges without shear reinforcement have shown the remarkable potential of UHPC in bridge design and performance. The Mars Hill Bridge in Iowa is a well-known example, which used UHPC for the bridge deck, eliminating the need for traditional shear reinforcement. This project showed how UHPC may provide greater durability and load-bearing capacities while using less material【118】. Similarly, the Pulaski Skyway in New Jersey was renovated using UHPC overlays, which increased its structural integrity and lifespan【119】. These projects illustrated UHPC's effectiveness on bridge decks and its resistance to weather exposure and heavy traffic【120】. The UHPC refit of Poland's Jakim Hill Bridge provided crucial details about the material's performance on bridge girders. The bridge's shear capacity and durability with no shear reinforcement were greatly enhanced by the inclusion of steel fibers to the UHPC mix【121】. Another example of the material's innovative design applications was the UHPC bridge, which was constructed across the Hyères Canal in France. It reached great lengths and eliminated shear reinforcement without compromising structural integrity【122】. These bridges have consistently shown excellent performance, minimal maintenance requirements, and exceptional longevity【123】【124】. These case studies show UHPC's promise as a strong and sustainable option for modern bridge engineering. The table provides a comprehensive overview of many bridge projects that utilize ultra (UHPC), highlighting the material's versatility and diversity in modern bridge design throughout time and space. Every article explains the specific application of UHPC in beams, decks, or bridge constructions, along with the main objectives of each project, which could be improving durability, reducing building costs, or improving aesthetics. These examples are listed in the table to give engineers and scholars a helpful resource that illustrates the significant advantages and efficient use of UHPC in bridge applications. It demonstrates the material's ability to make bridge designs stronger, lighter, and more cost-effective, and provides concrete evidence of its effectiveness and adaptability in fulfilling specific engineering objectives and limitations. As a result, it is a crucial tool for increasing UHPC adoption and development in the field of civil engineering. Table 3 provides more details regarding the use of UHPC in bridge engineering.

Table 3: Applications of UHPC in bridge engineering examples. (Zhou et al., 2018; Xue et al., 2020) with revisions and updates.

Name	Ref.	Country	Year	Locational application	Usage objectives
Sherbrooke Overpass	171190	Canada	1997	Prestressed, post-tensioned space truss	Investigate novel materials and structures
Peace Bridge	177	South Korea	2002	PI shaped beam	Celebrate the establishment of diplomatic relationships with France and enhance arch performance
Sakata-Mirai Footbridge	190	Japan	2002	Prestressed Box girder	To provide guidelines for the design of the UHPC structure in Japan
PS34 Bridge	173	France	2005	Box girder	Lighten the structure, alter the bridge's design, and integrate it into the surrounding area.
Shepherds Gully Creek Bridge	177	Australia	2005	Precast, pre-tensioned I-beam	Bridges under development to increase bearing capacity and replace the original, deteriorating timber bridge
Papatoetoe footbridge	180	New Zealand	2005	PI shaped beam	lower the cost of the substructure and erection and the height of the beam
Mars Hill Bridge	168 190	United States	2006	I shaped beam	Encourage the use of UHPC materials and investigate material attributes
Luan Bai Trunk Railway Bridge	184	China	2006	T-beam	Boost the durability and performance of the bridge
Glenmore Pedestrian Bridge	172	Canada	2007	Prestressed T-beam	Weather resistance and ease of maintenance
Pinel Bridge	174	France	2007	Prestressed T-beam	Use UHPC for its durability and quick construction
Friedberg Bridge	176	Germany	2007	PI shaped beam	Use the qualities of extreme durability to replace a timber structure that is already there but is deteriorated.
Cat Point Creek Bridge	169	United States	2008	I shaped beam	To make construction easier, use a material's tensile characteristics.
Jakeway Park Bridge	170	United States	2008	PI shaped beam	Give recommendations for future designs using UHPC pi-girders
Pont du Diable Pedestrian Bridge	175	France	2008	U shaped beam	Increase the span and achieve a light, elegant shape
GSE Bridge	179	Japan	2008	U shaped beam	Improvements in concrete strength that result in lighter

Office Pedestrian Bridge	181	South Korea	2009	Cable-stayed bridge	Tolerable stress and a light-weight structure
Kampung Linsum Bridge	182	Malaysia	2010	U shaped beam	Remove the shear components and significantly use UHPC
WILD Bridge 30	178	Austria	2010	Arch rib	Slender, light structures that work with the environment
Zhaoqing Mafang Bridge	190	China	2011	Steel composite beam -Bridge deck	To create a lighter composite girder bridge, UHPC deck and steel box girder were integrated for the first time.
Celakovice Pedestrian Bridge	183	Czech Republic	2013	segmental deck	Fair life cycle costs and little maintenance
Chillon viaducts	189	Switzerland	2014/2015	Twin box-girder structure	To increase the bridge's durability, stiffness of the girder, and slab fatigue performance
Fuzhou University Landscape Bridge	185	China	2015	Arch rib	To encourage the usage of UHPC, an experimental bridge used
Shijiazhuang to Cixian Highway	188	China	2015	three continuous box-girders	To raise the box girder's ultimate strength while decreasing its weight
Martinet Footbridge	189	Switzerland	-	U-shaped girder	Prevent damage from hazardous fluids and maintain a crack-free state under service stress.
Batu 6 Bridge	187	Malaysia	2016	Single-span box girder bridge	To comply with the requirements for international transportation
Yuan Jiahe Bridge	186	China	2017	II shaped beam	Simplify construction by reducing weight.
Millau Viaduct	191	France	2018	Box-girder bridge	Structural integrity and enhancing durability
Champlain Bridge in Montreal	192	Canada	2020	Box-girder bridge	improving the bridge's resistance to severe weather and high traffic volumes

Figure 3: Kampung Baharu-Kampung

Figure 4: Footbridge of Peace, Seoul,

Teluk Bridge in Manjung-Perak and Batu 6 Bridge in Gerik-Perak, Malaysia [193].

South Korea [194].

Figure 5: Pedestrian bridge, Sherbrooke, Quebec, Canada [194]

Figure 6: Sakata-Mirai bridge, Sakata, Japan [194]

4. Challenges and Limitations

4.1 Structural Challenges

Eliminating shear reinforcement in ultra-high-performance concrete (UHPC) bridges presents several structural challenges that engineers must carefully address to ensure safety and reliability. One key challenge involves understanding the behavior of UHPC under various loading conditions, as the absence of traditional shear reinforcement increases reliance on the material's inherent properties and fiber reinforcement for resisting shear forces【125】【126】. The type, orientation, and arrangement of the fibers used in UHPC are important variables that directly impact its fracture resistance and shear capacity, potentially causing performance variations if improperly managed【127】【128】. Furthermore, UHPC's dense microstructure can raise the danger of brittle failure if it is not properly controlled by careful mix design and quality control procedures, even though it is advantageous for strength and durability【129】.

Making sure the bridge elements retain sufficient ductility and energy dissipation in the face of catastrophic occurrences like earthquakes or overloading is another major concern【130】. Due to a limited ability of transferring stresses without any kind of shear reinforcement, UHPC bridge components' structural integrity may be affected during dynamic loading【131】Furthermore, because there are no established design guidelines or recommendations, engineers usually need to depend on experimental data or case-specific evaluations to create suitable design techniques for UHPC bridges, without shear reinforcement【132】Since UHPC is rather costly and lacks standardization, it may not be widely adopted in projects where cost-effectiveness is a key factor【133】【134】. The research establishes a reliable method for forecasting UHPC beam shear capacity to retain structural integrity. It presents a formula confirmed against experimental data by analyzing important elements using a large sample database for 247 UHPC beam shear test results from previous literature as shown in Figure 7, such as steel fiber volume and shear span ratio. With its improved accuracy for UHPC beam design, this formula outperforms existing design codes【167】.

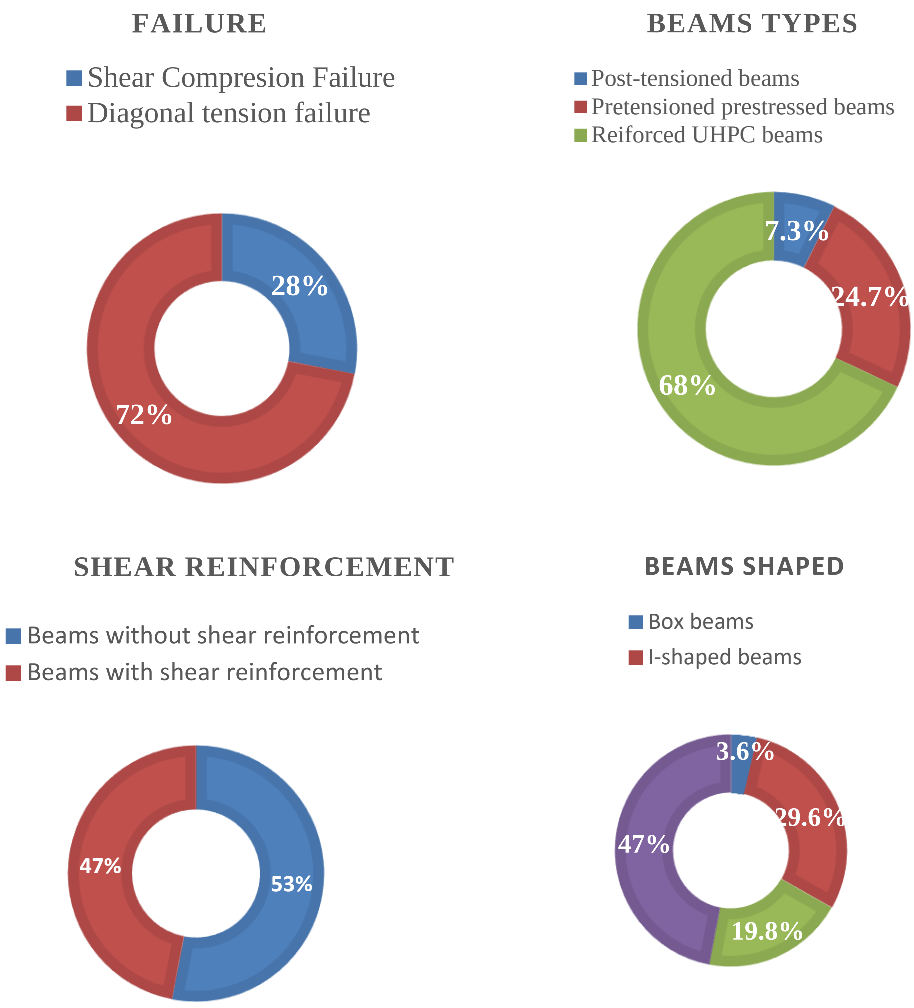

Figure 7: Simple database analytics of shear

4.2 Design Limitations

Ultra-high-performance concrete (UHPC) offers remarkable advantages in bridge construction but also has several design constraints and limitations that engineers must carefully consider. One major drawback of UHPC is its high price when compared to traditional concrete, which may make it less practical for projects with limited funding【135】. A cost-benefit analysis is frequently required to support the usage of this cost component, particularly in situations where lower maintenance and longer service life are not crucial considerations【136】.

Furthermore, although UHPC's deep microstructure adds to its remarkable mechanical qualities, it can make it difficult to properly connect with other materials, which could compromise the structural integrity of composite parts【137】.

Another drawback is that engineers must rely on experimental data and project-specific assessments due to the absence of defined design standards for UHPC, which could lengthen the design process and raise expenses【138】. Additionally, UHPC's specialized nature necessitates expert labor and meticulous quality control due to its distinct mix design and placement requirements, which can be difficult in large-scale construction【139】. Lastly, the structural behavior of UHPC, primarily its brittle failure mode, needs careful attention in design to ensure adequate ductility, and energy dissipation, particularly under dynamic loading conditions or seismic occurrences【140】.

4.3 Cost Considerations

The cost consequences of using ultra-high-performance concrete (UHPC) bridges with no shear reinforcing are a significant consideration in bridge engineering, particularly when compared to traditional methods. UHPC is typically more expensive than ordinary concrete since it needs specific components, and production techniques【141】. This higher initial cost could be a significant turnoff, especially for projects with limited funding【142】. However, UHPC offers some long-term financial advantages that might offset its initial investment. Due to its exceptional durability and strength, the material can save a lot of money on maintenance and repairs for the duration of the bridge's life【143】. Additionally, the lack of shear reinforcement facilitates construction, which may lead to reduced labor expenses and quicker project completion schedules【144】.

Lifecycle cost analyses have shown that, despite their higher initial costs, UHPC bridges can ultimately prove to be more cost-effective over time, particularly when long-term and maintenance are included【145】. Another advantage of UHPC's enhanced durability performance is a longer operational life, which can be advantageous for infrastructure investments financially【146】. However, project-specific factors that impact UHPC's economic viability include the bridge's expected lifespan, maintenance needs, and financial constraints【147】. Therefore, when assessing UHPC for bridge projects, a thorough cost-benefit analysis is required, especially when traditional approaches may result in less in the beginning but higher ongoing expenditures.

5. Advantages and Opportunities

5.1 Structural Advantages

Ultra-high-performance concrete (UHPC) offers substantial structural advantages when used without shear reinforcement, primarily because to its exceptional mechanical properties. UHPC's high compressive strength—which can exceed 150 MPa—allows for lighter and more efficient structural elements, reducing the overall weight of the bridge while maintaining load-bearing capacity【148】. By adding steel fibers, the material's tensile strength, and ductility are significantly increased, its resistance to cracking is enhanced, and it gives internal reinforcement, negating the need for conventional shear reinforcement 【149】. This increases design freedom and allows for more imaginative structural forms by lowering the need for significant shear reinforcement 【150】. Furthermore, UHPC's dense microstructure and low permeability prolong its lifespan by halting environmental deterioration and reducing maintenance requirements over the bridge's lifetime 【151】. UHPC's superior resistance to dynamic loading conditions, like those that arise during seismic events or under high traffic, is also a result of its high toughness and energy-dissipating capacity 【152】. These advantages make UHPC a suitable material for modern bridge structures, as they all work together to increase sustainability and performance.

5.2 Economic and Environmental Benefits

Ultra-high-performance concrete (UHPC) offers substantial economic and environmental benefits when constructing bridges due to its unique properties. Because of UHPC's exceptional strength, structural designs can be more lightweight and efficient, resulting in material and transportation cost savings 【153】. In addition, the material's exceptional durability and resistance to environmental degradation result in a longer service life, and lesser maintenance, which lowers costs during the bridge's lifetime 【154】. These features make UHPC a cost-effective choice, particularly for applications that prioritize durability and low maintenance requirements 【155】.

Because UHPC performs better, bridge parts can be thinner and lighter, reducing the carbon impact on material production and transportation 【156】 The material's tight microstructure along with low permeability also contribute to more durable structures, which lowers the need for costly replacements or repairs 【157】. Moreover, UHPC may recycle trash and reduce its total environmental impact by using industrial waste like fly ash or silica fume 【158】 The above advantages, which correspond with sustainable construction practices, make UHPC a viable material for environmentally responsible bridge design 【159】.

5.3 Future Opportunities

Ultra-high-performance concrete (UHPC) presents several exciting future opportunities in bridge engineering, and other applications. New applications are emerging as the material's unique properties become more widely recognized, such as in high-rise structures where its exceptional strength-to-weight ratio permits more efficient structural designs 【160】. Future developments in bridge design may include UHPC into modular construction, which would enable prefabricated UHPC elements to be swiftly assembled on-site, reducing construction times and boosting overall effectiveness 【161】. Additionally, UHPC's long service life and minimal maintenance requirements align with the increasing focus on resilience and sustainability in infrastructure, offering promising opportunities for green building certifications, and resilient design initiatives 【162】. Another fascinating area is UHPC's ability to interface with smart infrastructure; researchers are looking into integrating sensors and smart materials into UHPC structures to track health and performance in real time 【163】. This can improve maintenance procedures and structural safety, increasing UHPC bridges' ability to adjust to shifting circumstances 【164】. Furthermore, developments in material science are opening the door for UHPC formulations that are more environmentally friendly by using recycled materials or having better sustainability characteristics【165】【166】. These upcoming prospects establish UHPC as a vital component for the creation of creative and environmentally friendly infrastructure.

6. Conclusion

The review emphasized ultra-high-performance concrete's (UHPC) encouraging potential for bridge constructing, especially in cases when shear reinforcing is not used. Important results show that UHPC provides better strength, ductility, and durability, enabling lighter and more effective structural components. Research indicates that UHPC's high tensile strength and fiber reinforcement greatly contribute to its shear capacity, whereas case studies reveal that UHPC bridges without shear reinforcement work exceptionally well. The material offers long-term financial advantages due to its longer service life and lower maintenance needs, even though it initially costs more. But structural issues like controlling brittle failure modes and making sure the fibers are distributed correctly require considerable consideration.

According to the review, more research should concentrate on improving the mix design of UHPC in order to increase its shear capability without reinforcement. The industry would also gain from the creation of uniform design standards for UHPC bridges, since existing procedures mostly rely on experimental data and project-specific analysis. Researching cutting-edge construction techniques like modular assembly may increase productivity and lower expenses. Furthermore, investigating environmentally friendly UHPC formulations—possibly involving recycled materials—would support environmental objectives and increase the range of applications for UHPC.

UHPC offers a fantastic chance for bridge engineering innovation by fusing sustainability and high performance. Despite several difficulties, especially about cost and design uniformity, the material's advantages make it a solid contender for the construction of new infrastructure in the future. By tackling existing constraints and investigating novel uses, UHPC has the capacity to transform bridge construction and provide robust, effective, and sustainable solutions for the contemporary world.

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