Application of Ultra-High Performance Concrete in Bridge Engineering

Discover how Ultra-High Performance Concrete (UHPC) is transforming the field of bridge engineering. With its exceptional strength, durability, and innovative properties, UHPC offers unique advantages for building high-performance bridges that can withstand extreme conditions.

By Sayan Roy

Roll - 002110601054

Introduction to Ultra-High Performance Concrete (UHPC)

Ultra-High Performance Concrete (UHPC) is a class of advanced cementitious materials characterized by its exceptional strength, durability, and flexibility. UHPC is typically composed of fine-grained cement, silica fume, quartz flour, fine sand, high-range water reducer, water, and steel or synthetic fibers.

Properties of UHPC

1. **Exceptional Strength**

   UHPC can reach compressive strengths exceeding 150 MPa, making it up to 4 times stronger than conventional concrete.

2. **Superior Durability**

   UHPC's dense microstructure and low permeability provide outstanding resistance to weathering, chemical attack, and cracking.

3. **High Ductility**

   The incorporation of steel or synthetic fibers in UHPC enhances its ductility and impact resistance, preventing sudden brittle failure.

Advantages of UHPC in Bridge Engineering

Improved Durability

UHPC's superior resistance to wear, weathering, and chemical attack extends the lifespan of bridges, reducing the need for costly and disruptive maintenance.

Enhanced Structural Integrity

The high compressive and tensile strengths of UHPC allow for slender, lightweight designs that are exceptionally strong and stable.

Design Flexibility

UHPC's versatility enables innovative bridge designs, including longer spans, unique shapes, and integrated aesthetic elements.

Improved Durability and Longevity

1 Resistance to Weathering

UHPC's dense microstructure and low permeability protect bridges from the damaging effects of water, frost, and deicing salts.

2 Corrosion Protection

UHPC's high compactness and lack of microcracks prevent the intrusion of corrosive agents, safeguarding reinforcing steel.

3 Exceptional Lifespan

Bridges constructed with UHPC can achieve service lives of 100 years or more, significantly reducing maintenance costs and disruptions.

Enhanced Structural Integrity

High Strength

UHPC's remarkable compressive and tensile strengths allow for the construction of slender, lightweight bridge designs without sacrificing structural performance.

Ductility and Resilience

UHPC's enhanced ductility and ability to absorb energy make bridges more resistant to impact, seismic events, and other extreme loads.

Reduced Maintenance

The inherent durability of UHPC minimizes the need for costly and disruptive bridge repairs, ensuring reliable long-term performance.

Innovative Design Possibilities

1

Slender Profiles

UHPC's exceptional strength-to-weight ratio allows for the construction of bridges with sleek, lightweight designs.

2

Longer Spans

The superior tensile and flexural strengths of UHPC enable the creation of bridges with longer, more efficient spans.

3

Integrated Aesthetics

UHPC's versatility enables the seamless integration of architectural features and unique design elements.

Case Studies: UHPC Bridge Projects

1. **Jakway Park Bridge Iowa, USA**

   One of the first UHPC bridges in the United States, demonstrating the material's potential for slender, efficient designs.

2. **Mars Hill Bridge Iowa, USA**

   The bridge incorporates UHPC in the deck and girders. Showcased the material's potential to reduce weight and improve durability.

3. **Sherbrooke Pedestrian Bridge Quebec, Canada**

   The bridge uses UHPC for its structural elements, allowing for an elegant and slender design. Maintains high structural performance and durability.

UHPC Bridge Projects Worldwide

Sakata-Mirar foot BE

Located in Sakata, Japan . First application of UHP concrete in Japan. It is Box girder Bridge .

Bourg-les Valence, France

The pedestrian bridge is an asymmetrical cable-stayed bridge with an articulated central pylon.

Chillon

The Viaduc de Chillon is a viaduct in Switzerland located in Veytaux to the southeast of Montreux.

Applications of UHPC in Bridges

Bridge Piers /Column

Transfers dead and live loads from the superstructure to the foundations. UHPC was utilized as a pier jacket to improve the concrete BE pier's seismic performance, corrosion resistance.

Bridge Girders

UHPC's versatility allows for the creation of advanced connection details that improve structural integrity, streamline assembly, and enhance the overall aesthetic of bridges.

Bridge Decks

UHPC's high compressive and tensile strength allows for thinner, lighter bridge decks that can span longer distances with less support

Applications of UHPC in Bridge Elements

Name of Bridge	BE Application	Structure Type	Achievements with UHPC
Zhaoqing Mafang BE , China	BE deck	Steel composite beam BE Simply supported steel composite beam BE	The First time a UHPC Deck was paired with a steel box girder to create a lighter composite girder BE.
Shijiazhuang to Cixian highway BE , China	Girder	3 Continuous Box girders with multi-span structure .	To raise the ultimate strength of the box girder while decreasing its self-weight.
Batu 6 BE , Malyasia	Whole superstructure	Single-span box girder BE	To address the need for international transportation.
Chillon viaducts	Deck Slab	Dual-box girder Structure	To advance the BE's durability and girder stiffness and the fatigue performance of the slabs.

Name of Bridge	BE Application	Structure Type	Achievements with UHPC
Sherbrooke pedestrian BE , Canada	BE deck	Space truss girder BE	To minimize the BE's self-weight and improve its corrosion resistance.
UHP, fiber-reinforced concrete arch BE	Arch Ring	Arch BE	To fulfill the strength requirements of the arch ring, which would be exposed to an anticipated CS of more than 100 MPa.
Martinet foot BE , Switzerland	Girder	A U-formed girder with a simply supported structure	To avoid damage from hazardous fluids and to maintain a crack-free condition under service stress.
Mars Hill BE , USA	I Girder	Pre-stressed beam BE	For improved lifecycle and durability
Sakata-Mirar foot BE , Japan	Box girder	Pre-stressed simply supported beam BE	To provide design guidance for the UHPC structure in Japan.

Applications of UHPC in BE Bearing Components :

Name of Bridge	Application Location	Purpose of Utilizing UHPC
Glenmore Pedestrian BE, Canada	Pre-stressed T-beam	Weather resistance and ease of maintenance-work
Jakway Park BE, USA	Pi-formed beam	To provide direction for future designs that utilize UHPC Pi-girders.
Mars Hill BE , USA	I-formed beam	To investigate UHPC characteristics and enhance their materials.
Pinel BE , France	Pre-stressed T-beam	To use UHPC for durability and rapid building.
Friedberg BE , Germany	Pi-formed beam	To use superior durability characteristics to replace an old, deteriorated timber structure.
Cat Point Creek BE , USA	I-formed beam	To use material tensile characteristics to make building simpler.

Distinction between conventional concrete and UHPC

Properties	Normal Traditional Concrete	UHPC
Compressive strength (MPa)	22-40	100 - 200
Tensile strength (MPa)	< 5	Upto 22
Flexural strength (MPa)	< 6	45
Ductility	Nil	Highly Ductile
Impact Loading	< UHPC	Tough
Abrasion Resistance	< UHPC	Tough like a Rock
Impermeabilty	Steady carbonation chloride penetration	Nil

UHPC in India :

1. Experience on Ultra-high-performance concrete in Indian condition is very limited. Moreover, codes and specifications are not available in IRC codes. Therefore, it may not be feasible at this stage to adopt this for small span structure with 30-50 m long considering viability economically. It can however be used for long span bridges like Extra Dose/Cable stayed bridge.

2. Defect liability period of such bridges/structures should not be increased in the ‘technology establishing stage’ as the construction cost with UHPC is high, which includes stringent quality control during operation, and thus increasing the defect liability period may discourage the contractor to use UHPC .

UHPC Bridge Projects in India :

1

Latur , Maharashtra

- Recently UHPC girders have been used in Sole River Bridge at Km 42+050 of NH-752K near Latur (2X56 m span)
- Indiá s 1st bridge constructed using UHPC
- The life of the bridge is 150 years
- Results in less obstruction in river flow.

2

JP Setu , Patna

A bridge over Ganga River parallel to JP Setu in Patna is under planning that envisages use of UHPFRC girders for 100 m span

Way Forward - UHPC in India

1. Development of guidelines and standards for design, construction, testing and long-term performance monitoring and evaluation (including seismic, wind-resistant, vessel collision, vehicle collision performances).

2. Fundamental modelling for static and dynamic behaviours of bridge elements/components and connections, fabricated using UHPC materials.

3. Optimal performance and reliability based design methods involving bridge's entire life-time cost considering design, construction, maintenance, and retrofit for the damaged components that may be caused by some extreme events, such as earthquake, hurricane, vessel collision etc.

Limitations of UHPC in Bridge Engineering

Cost of Raw materials :

The costs of raw UHPC materials are more costly than those of standard concrete which can be a barrier to widespread adoption .

Ecological sustainability :

The production of one tonne of PC releases about the same volume of CO_2 into the atmosphere as the burning of one tonne of coal.

Limited Production Capacity :

The current production capacity for UHPC materials may not be sufficient to meet the demands of large-scale bridge projects, limiting its scalability.

Maintenance-work requirements :

UHPC requires high-temperature maintenance work throughout construction work.

Challenges and Considerations

1

Cost

UHPC can be more expensive than conventional concrete, requiring careful cost-benefit analysis in bridge projects.

2

Specialized Expertise

The successful implementation of UHPC in bridge construction requires specialized knowledge and experience.

3

Material Availability

The widespread adoption of UHPC may be hindered by the limited availability of the material in certain regions.

Conclusion and Future Prospects

1

Wider Adoption in New Construction :

Standardization and cost reductions will increase UHPC usage in new bridge projects, leading to efficient, durable structures.

2

Unparalleled Strength & Durability :

Its unparalleled strength and durability are paving the way for innovative, long-lasting, and sustainable bridge infrastructure.

3

Design Flexibility :

The design flexibility of UHPC opens up new possibilities for the future of bridge applications. The enhanced lightweight UHPC can be employed to make portable BE deck panels.

Thank You for your time and attention !