सत्यमेव जयते

MINISTRY OF ROAD TRANSPORT & HIGHWAYS

WORKSHOP ON POPULARISING USE OF UHPFRC & FACTORY MANUFACTURED PRE-CAST CONCRETE ELEMENTS

GAPS IN DESIGN & CONSTRUCTION GUIDELINES

BY

ADITYA SHARMA – DIRECTOR, RAMBOLL

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CONTENT

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UHPC DEFINITION

- **Ultra-High-Performance Concrete (UHPC) is a cementitious composite characterized by a significant amount of cement (higher than 600 kg), small aggregates size (lower than 6 mm), binder (pozzolana, fly ash, silica fume, reactive powder) and a low water/cement ratio ($w/c \leq 0.2$).**

- **This mix design creates a dense and interconnected microstructure with high homogeneity,**

- **Mechanical properties of UHPC include compressive strength greater than 150 MPa and sustained post cracking tensile strength greater than 5 MPa.**

- **UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.**

UHPFRC DEFINITION

This is the concrete having high compressive strength and high post cracking tensile strength giving it ductile behavior in tension, whose Non-brittle behavior makes it possible to design structure members without reinforcing steel

Main properties of UHPFRC detailed in AFGC Setra (French) Recommendations

- Compressive Strength 180 – 200 MPa (2002) extended to 150-250 MPa (2013)
- Direct tensile strength 7 to 12 MPa
- Post cracking stress (for 0.3mm crack opening) : 7 to 12 MPa (strain hardening/softening)
- Youngs modulus : 45 to 65 GPA
- Total shrinkage : 550 to 800 µm/m

Other Notable features

- High dependency on the tensile Behaviour on the fiber orientation (K factor)
- Water/Binder ratio lower than 0.25, and typically between 0.16 and 0.20
- High content of binder, which leads to the absence of capillary porosity
- Fibres to ensure a ductile behaviour
- Thin members is one where the thickness e is such that e ≤ 3 Lf where Lf is the length of the longest fibres. Other members are considered to be thick members.

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DIFFERENCE WITH CONVENTIONAL CONCRETE

- The difference between UHPFRC and conventional concrete mix design lies in particular in the amount of binder, the size of the aggregate and the presence of fibres.

- Compared to a conventional concrete, the matrix of the UHPFRC is much denser.

- In order to produce this type of concrete, it is important to achieve the maximum possible packing density of all granular constituents.

- Large number of super-plasticizers in order to obtain an acceptable workability is also a characteristic of the UHPFRC.

- The maximum grain size for ultra high-performance concrete is usually not larger than 2 mm

- UHPFRCs are subjected to a thermal treatment during curing. The heat treatment initiates the formation of more hydrates, which give the raise to the improved characteristics.

- Inclusion of the fibres for tensile design.

DIFFERENCE WITH CONVENTIONAL CONCRETE DESIGN- ACCOUNTING FOR FIBER DISTRIBUTION

- **The orientation of the fibres is an important parameter of the tensile design principles and is expressed by a set of orientation factors K..**

- **To cover the difference in fibre orientation due to UHPFRC placement, the various justifications are based on a design principles considering an orientation factor K which takes the value Kglobal or Klocal.**

- **Klocal is considered for local effects corresponding to resistant mechanisms which require fibre contribution in very localised areas (for example the diffusion of prestressing forces).**

- **Kglobal deals with the global effects corresponding to resistant mechanisms which require the fibres to act over wider areas and where a localised fault will not have significant consequences (for example shear, bending resistance of member).**

- **The orientation factor K is established on the basis of tests on a representative model of the actual structure in accordance with Annex F of standard NF P18-470.**

- **The orientation factor K may differ according to the directions of stress and parts of the structure considered. In the various checks involving this factor, its determination must relate to the direction perpendicular to the potential cracking plane in the resistant mechanism considered. Failing a direct**

Tensile property of UHPFRC

- In addition to the high compressive strength UHPC/UHPFRC shows a considerable increase in characteristic tensile strength (f_{ctk}), which can range from 7 to 11 Mpa

- However, unlike conventional concrete UHPC retains tensile strength after cracking.

- Due to the fibers either strain hardening or softening occurs depending on the fiber content, geometry and orientation

- For thick elements low strain-hardening behavior is assumed with a characteristic elastic tensile stress (f_{ctk},el) of 9MPa and a characteristic post-cracking strength (f_{ctfk}) of 9MPa. To be ascertained by Test

- The design stress-strain curve for low strain-hardening.

STANDARDS AVAILABLE

UHPC structural design guidance has already been developed for practice around the world. The most prominent among them are

1. **French**
2. **Swiss**
3. **Canadian**

French guidance was first published as SETRA-AFGC Interim Recommendations (2002). These recommendations were updated, refined, and expanded over the years until recently when they were recrafted as formal addendums to the Eurocode as French National Annexures.

- **NF P18-470 "UHPFRC: Specification, performance, production and compliance -**
- **NF P 18-710 - National addition to Eurocode 2 — Design of concrete structures: specific rules for Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC)**
- **NF P 18-451 "Execution of concrete structures – Specific Rules for UHPFRCs based on NF EN 13670**

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Challenges of adopting UHPFRC

- Even though UHPFRC has been used since early 2000, and after considerable research and development , there is still reluctance to use UHPFRC as a mainstream material for infrastructure development worldwide as opposed to Conventional concrete

- Southeast Asian countries like Malaysia UHPFRC has been used by specialised agencies/vendors for bridges in rural areas where sourcing materials, site access and construction method are major constraints when using the conventional technology.
- Large parts of Europe USA conventional concrete still remains the main material.
- Australia for example has built its first UHPFRC bridge (the Shepherd gully bridge) in 2005 , however in the next 10-15 years no UHPFRC bridges has been built .
- This is primarily due to high initial cost , lack of expertise in the industry , some material concerns, and reluctance to replace new technologies and materials in place of conventional concrete which have been used for decades without any issues.

Challenges and gaps in design and Construction guidelines

Although UHPC/UHPFRC has been applied in more than hundred bridges worldwide, there are some restrains that may limit its extensive applications.

1. **Inadequacies of mechanical properties** : At present, there are no uniform standards for the UHPC property test method and a quality evaluation index.
2. **Mix design :** Developing a rational and accurate method for the optimization of UHPC constituents and mix design (rather than relying on commercial mixes)
3. **Specifications :** Only guidelines from specific countries are available based on the construction requirement and expertise specific to the country. Need for uniform guidelines are required addressing the following issues

- **Material standards (constituents and composition; material properties (statistically significant for design); tolerances, batching, packaging, marking, and storage; QA/QC and safety issues)**
- **Laboratory and Field-Testing Standards & methods; specimen details and preparation; procedure, precision, reporting, etc.; and lab qualification)**
- **Structural design codes (including minimum ductility requirement; bending with or without axial force, shear, torsion, punching, creep and shrinkages; impact strength and fire resistance/parameters for fire design; dosage of fibers; and dispersion of fibers**
- **Construction procedures and practices (mixing, placement, consolidation, curing)**
- **Operation and maintenance guidelines**
- **Inspection and monitoring methods to verify properties of material, as-processed material characteristics, structural competency, and performance**
- **Durability and sustainability requirements (including cover provisions; chloride transfer characteristics; key performance indicators for sustainable infrastructure such as service design life;**
- **Service life prediction methods**

Challenges and gaps in design and Construction guidelines

4) Deficiencies of UHPC/UHPFRC : materials have a lower water-binder ratio and incorporate a large amount of active admixture, as the hydration of the cementitious material progresses, its shrinkage also increases. If handled improperly, it may cause crack

5) Application prospect of UHPC in long-span bridge : At present, some types of flaw appeared in long-span Bridge, including:

- The general deflection and crack of prestressed concrete continuous box girder;
- Concrete crack in the negative moment area of steel -concrete composite beams

6) Low w/b of UHPC: High energy mixers are required for properly mixing its constituents. Furthermore, several modifications in precast site mixers are required for the successful production of UHPC precast elements

7) Orientation of fibers : The flexural properties of UHPC are predominantly influenced by the orientation of fibers. Therefore, developing a reliable method allowing the effective distribution of fibers in its matrix with desired orientation is required, especially for casting slender elements.

8) High shrinkage strains: Shrinkage strains in UHPC mixtures are higher than that in normal concrete. Therefore, special admixtures or preventive measures are required for mitigating issues related to dimensional stability particularly in Bridges.

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Challenges and gaps in design and Construction guidelines

9) Steam curing arrangement: The high strength and durability properties of UHPC are highly dependent on thermal treatment. Therefore, special arrangements for thermal curing for on-site construction and at precast facilities need to be explored.

10)UHPC under Dynamic, Fatigue and impact loading: Very limited literature is available on the actual behavior of UHPC and testing under dynamic effects such as earthquake or impact loading

11) Cost of raw materials : If viewed solely on the cost per cubic meter of material, the cost of UHPC materials is much higher than the cost of conventional strength concrete. This may be a deterrent. However, UHPC materials may offer unique advantages and higher performance levels that justify the increased cost and possible slender elements along with larger spans may offset or decrease cost compared to conventional concrete.

Way forward

- Fundamental modeling for static and dynamic behaviors of bridge elements/components using UHPC materials. The models can be involved in popular commercially available software (e.g., SOFISTIK, MIDAS,LUSAS, SAP2000 and ANSYS, etc.). The numerical modelling of UHPFRC structures is essential. At present software's do not include this material,. As UHPFRC has a strain-hardening behavior, non-linear analysis is Essential to be performed
- 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) as per Indian standards and construction practice.
- Design and construction method of prestressed UHPC girders developed for long-span bridges specially in terms of deflection and concrete cracking in areas of negative moment in continuous beam
- Stability of slender UHPC members might be critical. There is a limit as to how thin or small a member can be and still satisfy deflection and vibration criteria which may be critical in UHPFRC sections compared to conventional concrete where concrete stress may be the governing criteria.
- Obtain better understanding of cementitious materials, compositions, phases and hydration mechanism
- Optimal performance and reliability-based design methods involving in 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.
- Enable international collaboration through exchange agreements, workshops, conferences and

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Conclusion

- **UHPC materials have excellent mechanical properties and durability, which can improve the connection integrity of bridge component joints,.**
- **However, they are currently only used in small and medium-sized bridges or pedestrian bridges.**
- **It is expected that measures to tackle issues such as general deflection, fatigue crack in steel structure, higher shrinkage strains and a series of challenging problems for large span bridges will be addressed in future.**
- **Although the relatively high cost of UHPC materials, maintenance requirements and the lack of standard specifications for design at current stage, more and more researchers, bridge owners and engineers have recognized its application potentials in bridge engineering.**
- **The extensive researches on UHPC's preparation techniques, material properties, structural design methods and specifications will promote wider applications and reducing the material cost**

Bright ideas. Sustainable change.

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