AN EVALUATION OF THE PLACEMENT AND FIBER ORIENTATION FACTORS BASED ON EXISTING UHPC CODES AND STANDARDS

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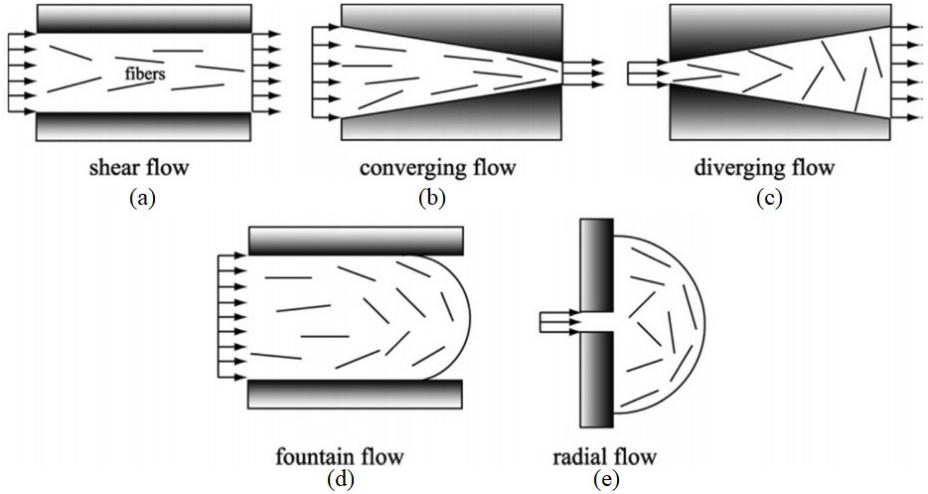
Introduction

- UHPC have been increasingly implemented for their superior structural performance
- Fiber dispersion and fiber orientation remain a concern and are shown to influence the mechanical properties
  - Yang et al. (2010) reported that casting from one end of the beam cast showed 5-15% higher bending load capacity compared to the beam cast at midspan
- Very few studies have investigated the fiber orientation in real-scale structures

Different casting methods in UHPC construction
(Source: Cor-Tuf, New York DOT)

Introduction

- Fiber orientation of UHPC members are strongly influenced by:
  - Casting flow direction of freshly mixed UHPC
  - Formwork geometry
  - Rebar arrangement
  - Casting device
  - Compaction technique
  - Rheology of the mixtures



Orientation of fibers in different flow patterns
(Kang and Kim 2012)

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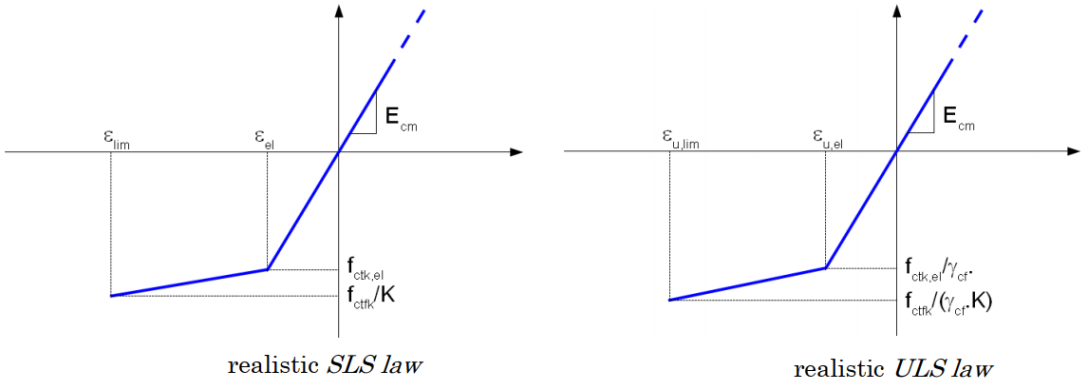
Fiber Orientation Factors in Design Codes

Codes and Guidelines with well-defined fiber orientation design factors	• AFGC Recommendation on Ultra-High Performance Fiber-Reinforced Concrete (UHPFRC) (2002 and 2013) • French National Standards: NF P18-710, NF P 18-470, NF P 18-451 • fib Model Code for Concrete Structures (2010 and 2020 under development) • Canadian Highway Bridge Design Code (2019) (CSA-S6:19)
Codes and Guidelines with other fiber orientation design factor(s)	• Swiss Institute of Engineers and Architects (SIA), Ultra-high performance fiber reinforced concrete (UHPFRC) –Materials, design and execution (2016) (SIA 2052) • Australian Standard of Concrete structures (2018) (AS 3600) • DAfStb Guideline on Steel fibre reinforced concrete (2012 and 2019)
Codes and Guidelines without fiber orientation design factors	• AASHTO LRFD guide specification for structural design with ultra-high performance concrete (2021) • Canadian Standards Association- Concrete materials and methods of concrete construction/Test methods and standard practices for concrete (2019) (CSA A23.1:19) • JSCE Recommendations for Design and Construction of High Performance Fiber Reinforced Cement Composites with Multiple Fine Cracks (HPFRCC) (2008) • JSCE Recommendations for the Design and Construction of Ultra High Strength Fiber-Reinforced Concrete (UHSFRC) of JSCE (2006) • KICT Design Guideline for K-UHPC (2014) • KCI-M-19-006, The Structural Design Guidelines of Fiber Reinforced SUPER Concrete (2019)

K factors from AFGC Recommendations

- AFGC Recommendation, 2002 first introduced two K factors to address the effect of fiber dispersion and orientation
  - Account for the differences between lab cast samples and in-situ samples
  - K_{global} for global effect
  - K_{local} for local effect
- K factors are used to modify the post-cracking strength of UHPC in design.



Tensile strength constitutive law of UHPC for thin cross-sections (AFGC recommendation 2013)

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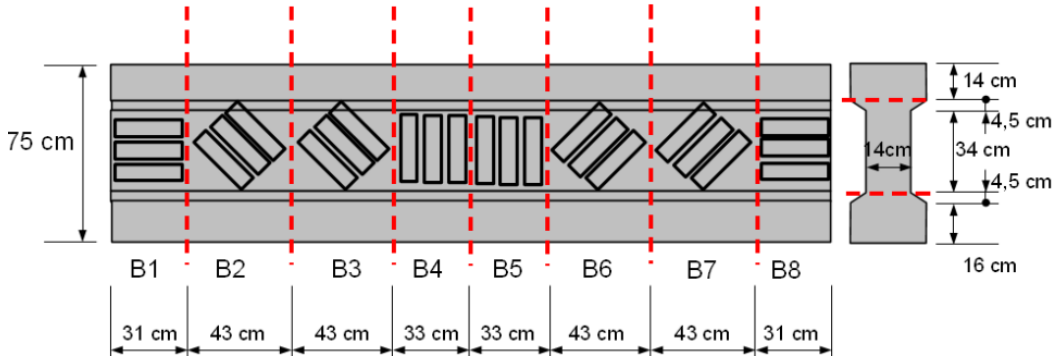
K factors from AFGC Recommendations

- K factors can be obtained by direct testing of mock-up sections
  - $K_{global} = \frac{\overline{M_{m,max,i}}}{\overline{M_{s,max,i}}}$
  - $K_{local} = \frac{\overline{M_{m,max,i}}}{(M_{s,max,i})_{min}}$
  - Default value: K_{global}=1.25, K_{local} = 1.75
- The approach have been employed productively to enhance casting practices and structural safety
- It is costly to adopt in individual projects
- fib Model Code, Canadian Highway Bridge Design Code introduced similar design factors and offers recommended values in absence of mock-up testing



Sawing of the mock-up from Saint-Pierre la Cour Project (AFGC Recommendation)

Mock-up of one half of a π-shape beam before and after sawing (Simon et al. 2013)

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North America Design Codes

- AASHTO LRFD guide specification for structural design with UHPC
  - No fiber orientation factors considered
  - Assumes random fiber orientation
  - Appropriate construction methods and the casting processes should apply
  - Construction guides are under development

North America Design Codes

- CSA: A23 Concrete materials and methods of concrete construction/Test methods and standard practices for concrete
  - Place UHPC monolithically.
  - If not possible, ensure monolithic interface.
  - Avoid wave front intersection, promote fiber distribution.
  - Apply internal mixing if unavoidable wave front intersection.
  - Prevent fiber flow conflicts with stress orientation.
  - Avoid injurious vibration/shock to prevent fiber issues.
  - Deposit UHPC continuously during section placement.
  - Cast UHPC into plastic form.
  - Pour point should not advance ahead of wave front.
  - Pour UHPC from one end or behind wave front.
  - Consolidate UHPC to prevent segregation and redistribution.
  - Avoid internal vibration, use validated external vibrators.

Perspectives from UHPC Producer

- Interviewed UHPC producers in USA and Canada for casting method of I-beams and H piles
  - A wide range of casting procedures are used:
    - Casting devices: chute, bucket, tuckerbilt
    - From one end/from multiple locations in the middle
    - Few of them apply vibration/tapping/agitation during casting
    - Casting with different molds and in different directions
    - Experience producers have established SOPs
    - New starters are generally more cautious
  - Most producers optimized the casting by optimizing the mixture
  - No evaluation of fiber orientation/distribution

Casting of H-piles in H-direction (photo courtesy: Cor-Tuf)

Casting H-piles in I-direction(photo courtesy: Smart UP)

Casting of H-piles in H-direction using closed form (photo courtesy: FACCA Inc.)

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Ongoing Effort

- Assessment and optimization of the casting procedure for UHPC structural elements
  - Conduct mock-up casting of standard UHPC sections, quantify the fiber orientation/distribution under different casting procedures
  - Develop a casting procedure with a defined confidence level for standard UHPC sections
  - Determine necessary fiber orientation factors to be used in design
  - Remove the necessity of full-scale testing of structural elements and mock-ups for individual projects
  - Maintaining the reliability of UHPC strength properties assumed in design

Summary

- In review of the available design codes, the concept K factors from the AFGC recommendation is the most well-established method to determine the effect of fiber orientation in the structural design, however, the mandatory mock-up testing maybe costly for individual projects
- In the North America, current design guides assume random fiber orientation and require that proper casting procedures to be specified
- Different UHPC producers utilize rather different casting methods even for the same type of elements
- There is lack of quantification on the actual fiber orientation in real-scale structures and the influence of casting procedures
- An ongoing project aims to assess and optimize the casting procedure for standard UHPC sections to improve the reliability and confidence in the design

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Thank you

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