ACI / JCI – 6th Joint Seminar
Advancing the Design of Concrete Structures

Assessment of Fiber Reinforced Cement Composites for Structural Uses

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Outline

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1. Background

2. Effect of fiber orientation on fresh and hardened properties
- Ordinary FRC is assumed as homogeneous material
- Assessment by means of meso-scale analysis

3. Overlay application using UHPFRC
- Repair applications using UHPFRC is increasing
- Estimate induced stress due to shrinkage is important
  (e.g. pseudo perfect constrained testing is adapted)

4. Concluding Remarks

Background

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✓Fiber Reinforced Concrete(FRC)

- ◆Addition of fibers can dramatically improve strength, toughness and so on.
- ◆Narrow crack width in FRC enhances the extension of life cycle.
- ◆Various kinds of fibers(steel or synthetic) are used.

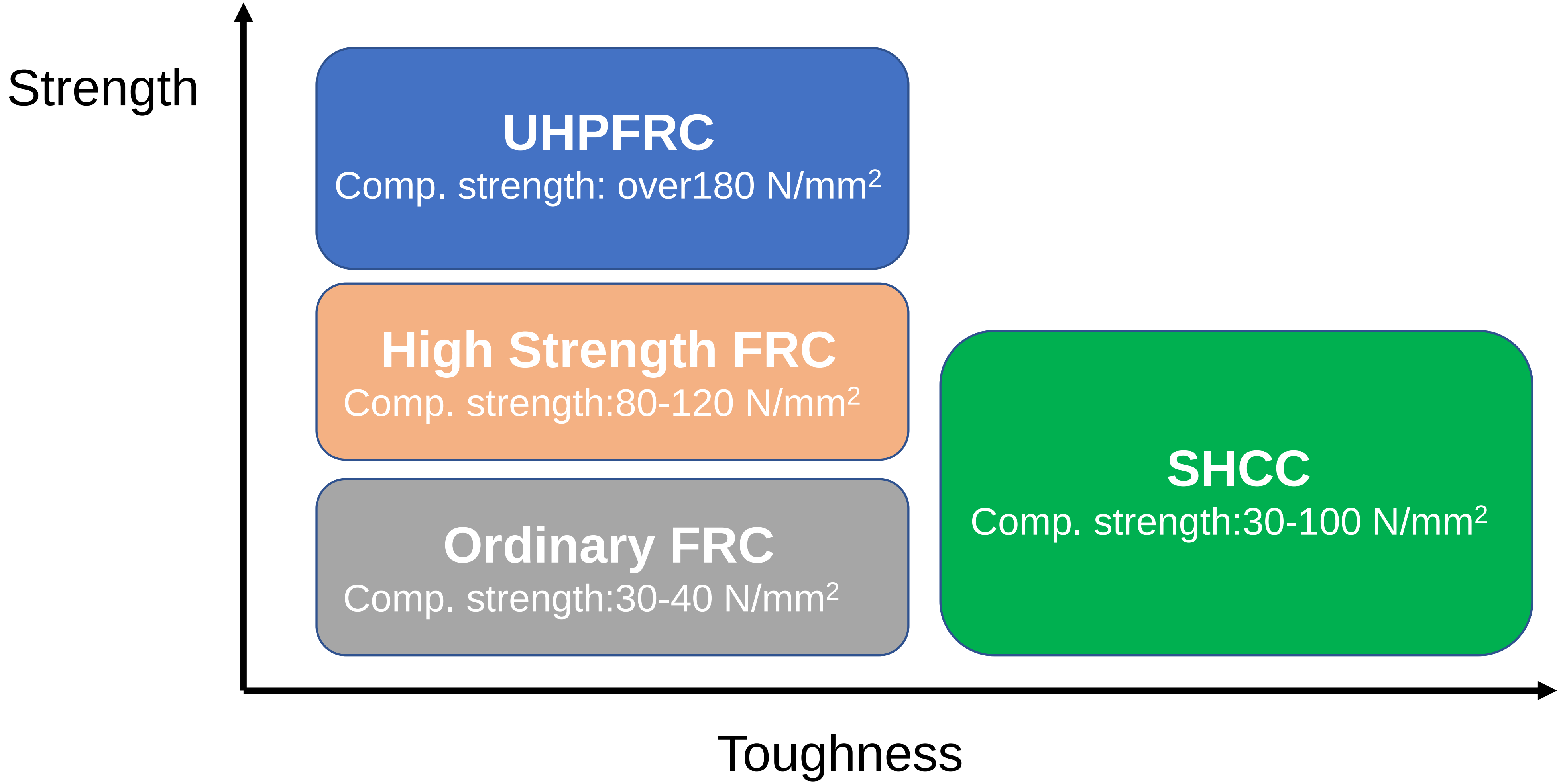
PVA fiber

PP fiber

Steel fiber

Strength vs Toughness

- ◆Wide variety of mechanical properties, such as strength, toughness…
- ◆Precast(heat curing), on site casting for repair applications



UHPFRC

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- Ultra High Performance Fiber Reinforced Composites (UHPFRC) exhibits novel mechanical properties in addition to high durability.

→Compressive strength: over 180 MPa, Tensile strength: over 8 MPa.

→Significant fiber orientation is observed because of self compacting.

- Conventional UHPFRC requires heat curing (e.g. 90 degrees for 48 hours) to enhance the properties.

→UHPFRC without heat curing has been also developed in recent year

→Repair application is one of the target

Applications

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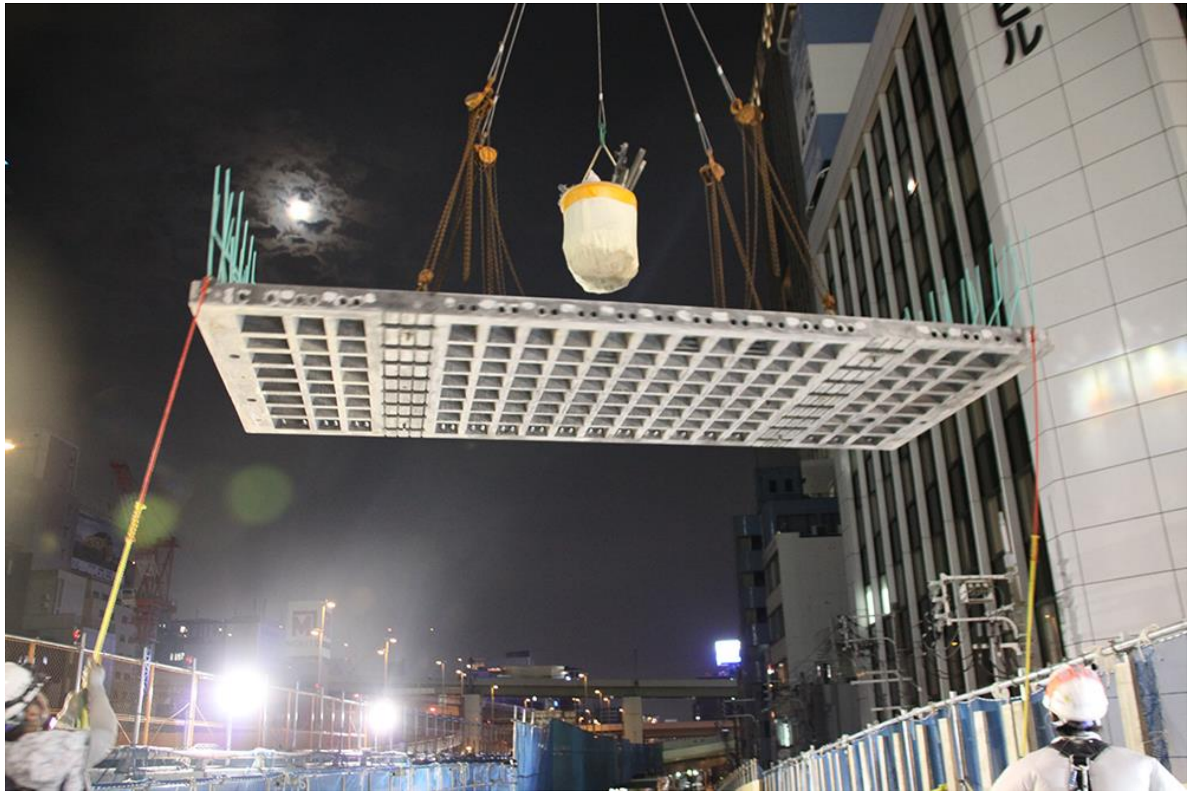
Replacement of RC slab in bridge



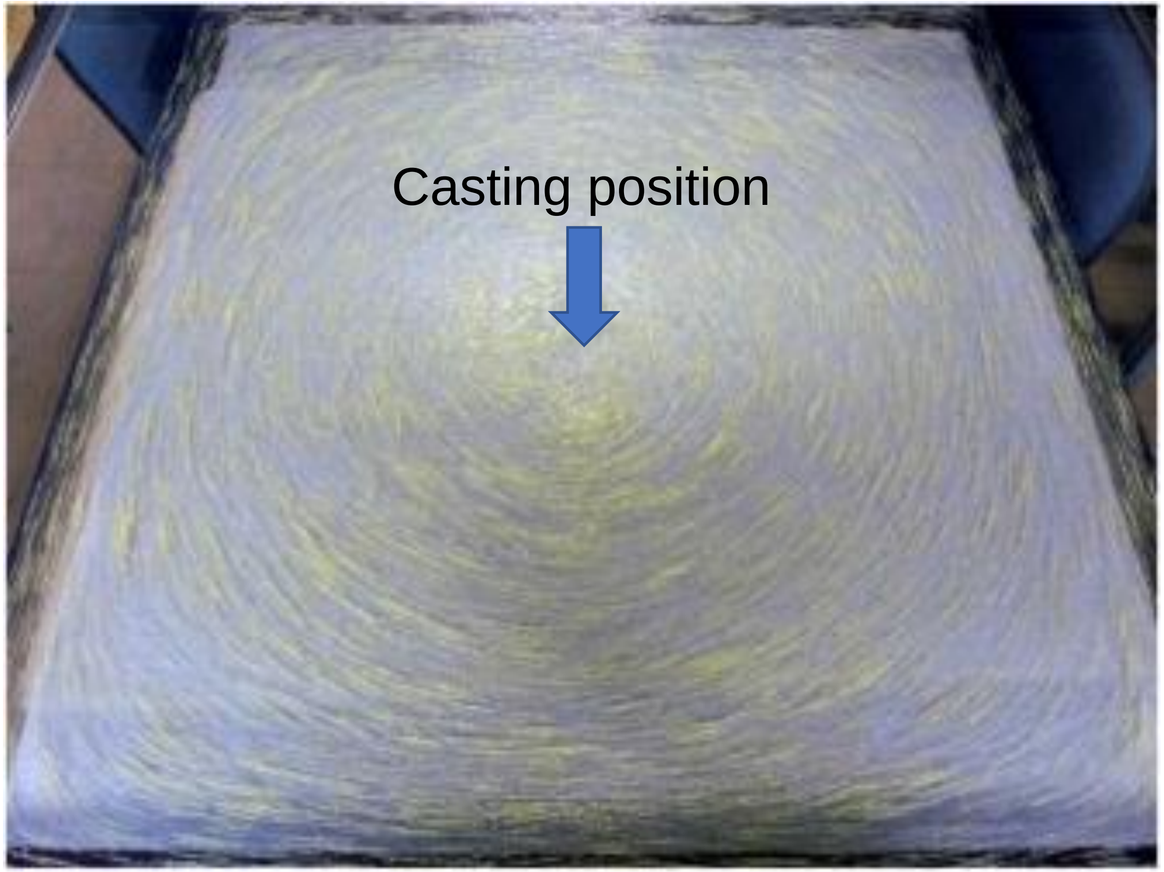
(Hanshin Expressway)

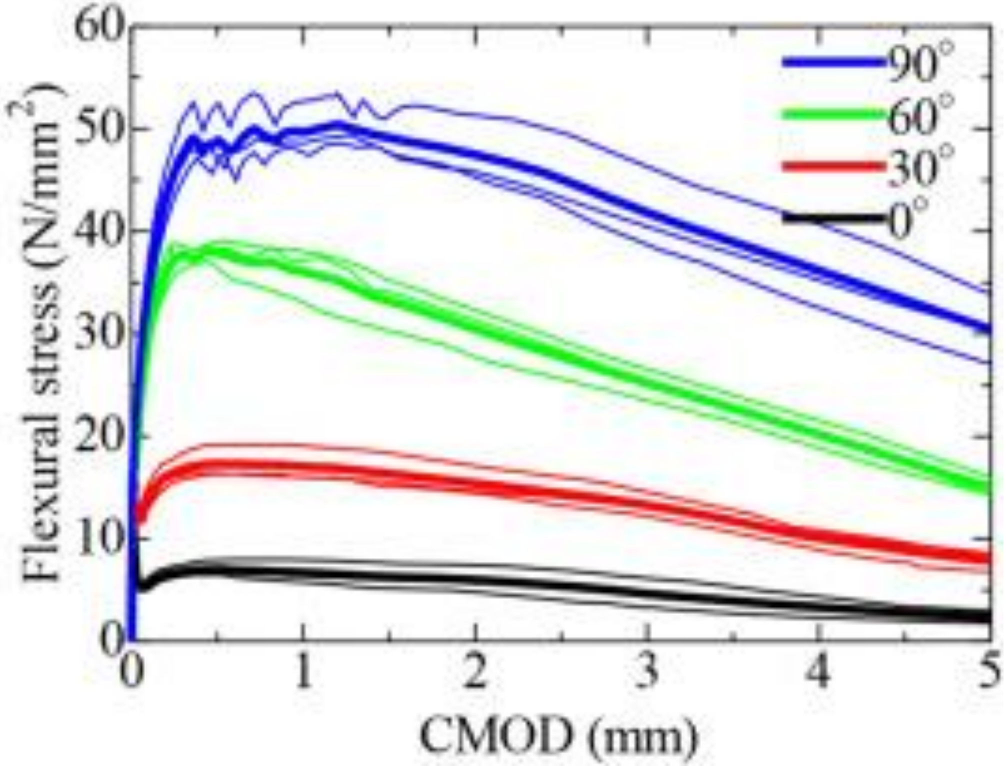
Overlay of RC slab in bridge

(Kajima Corporation)

Behavior of Discretized Fibers

◆Fiber orientation depending on casting of FRC





Y. Uchida et al.

Estimation of Fiber Orientation by 3D-DEM

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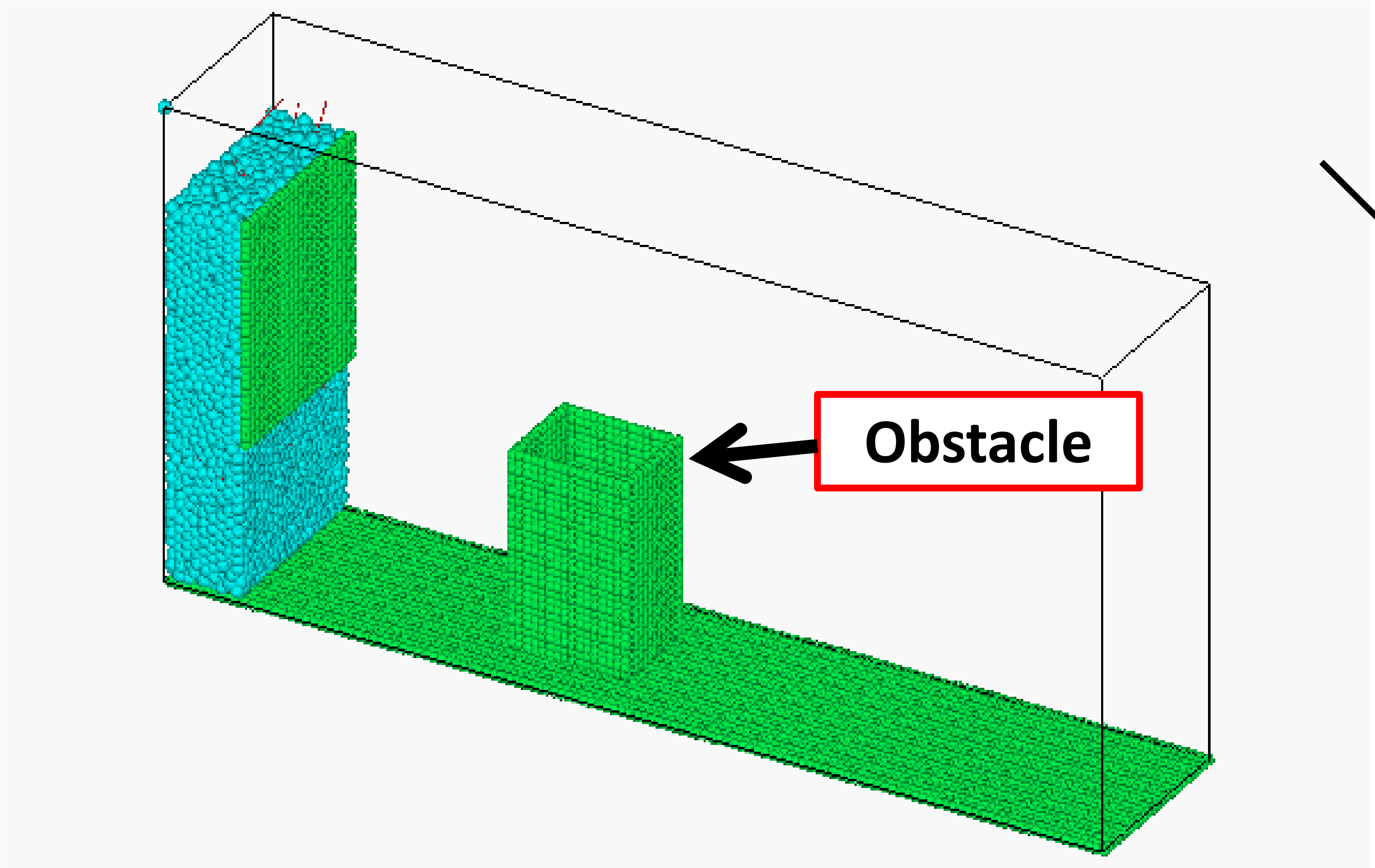

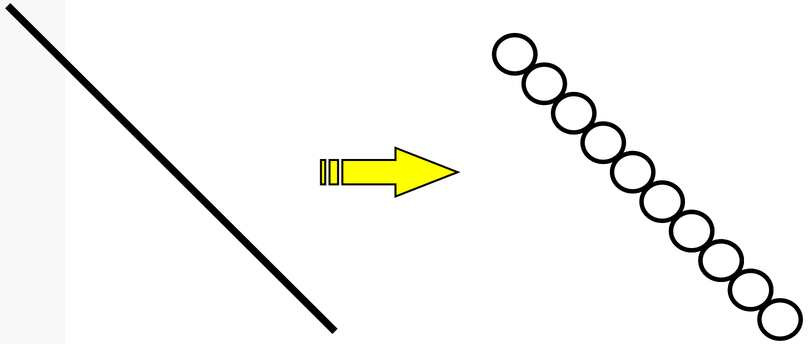

- Short fiber is modeled by connected sphere elements
- Parameters reflect viscosity of matrix is adapted

Blue：Mortar, Red：Fiber, Green：Formwork

Estimation of Fiber Orientation by 3D-DEM

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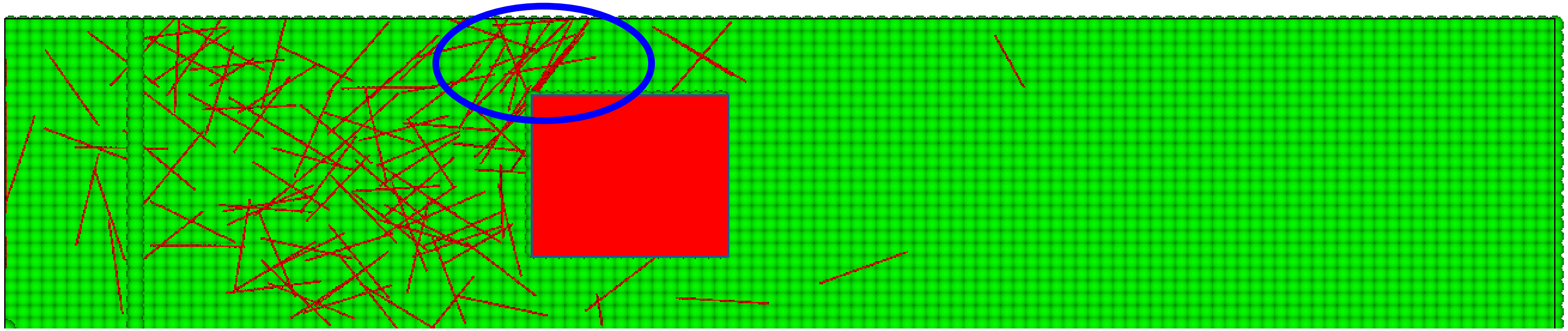
Obstruction



◆ To understand fiber distribution and orientation in an element is important

Structural Analysis Based on Discretized Fibers

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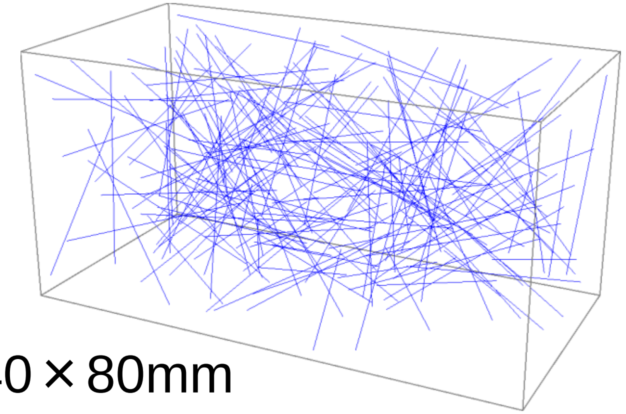
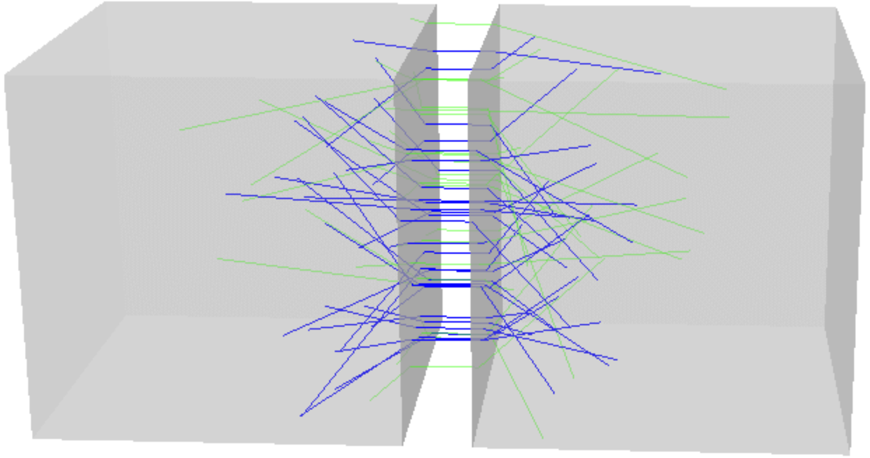
Discrete fibers（PP, V_f = 2%）



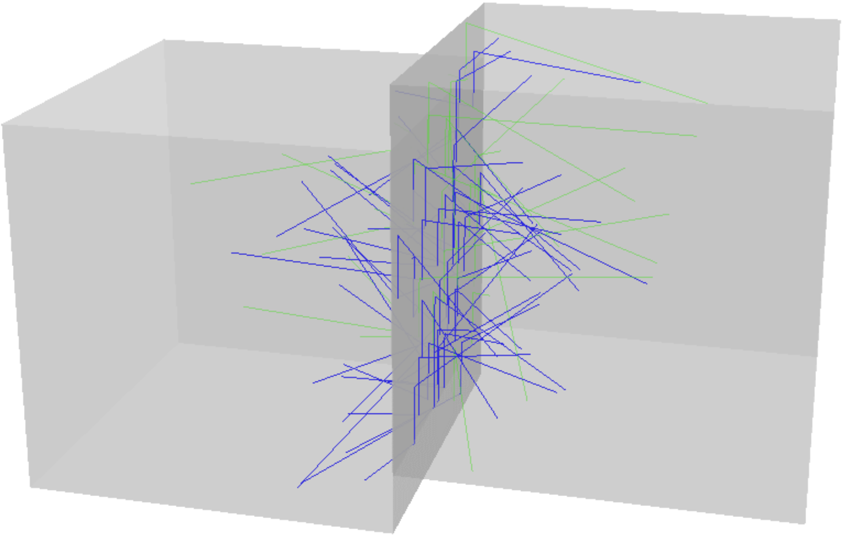
40×40×80mm

Bridging fibers

Pull-out fibers



Tensile analysis（Mode I）



Shear analysis（ModeII）

Structural Analysis Based on Discretized Fibers

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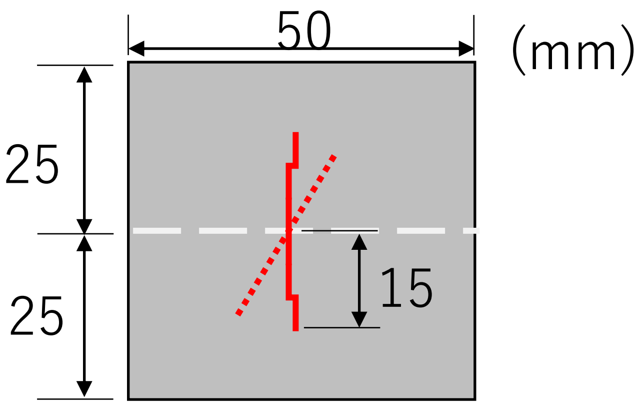
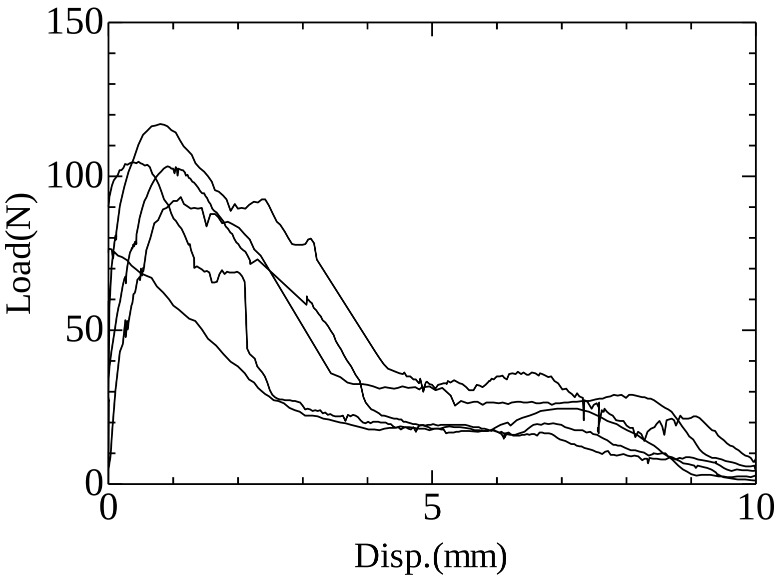
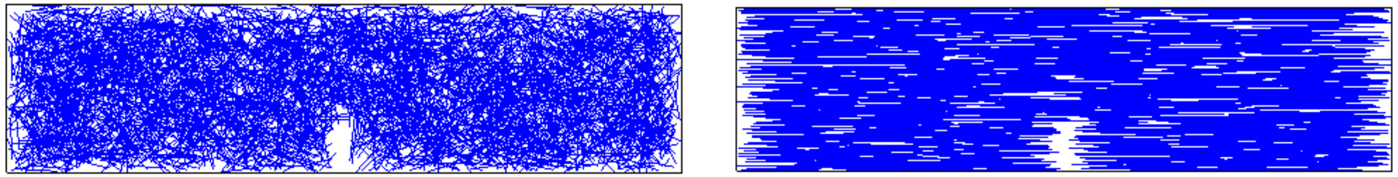
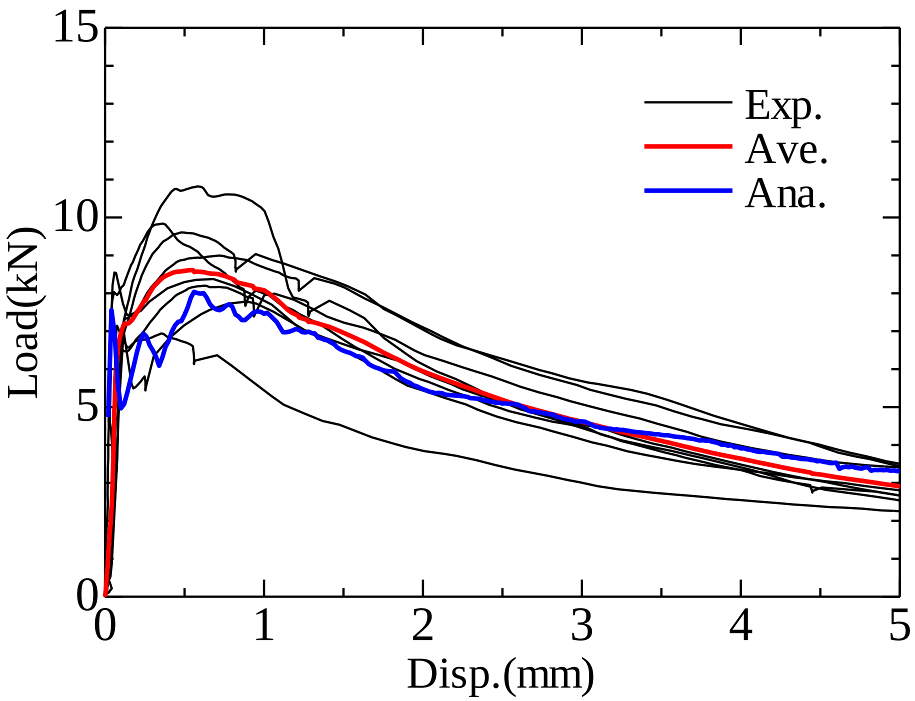




Pull-out behavior of single fiber includes inclined fiber



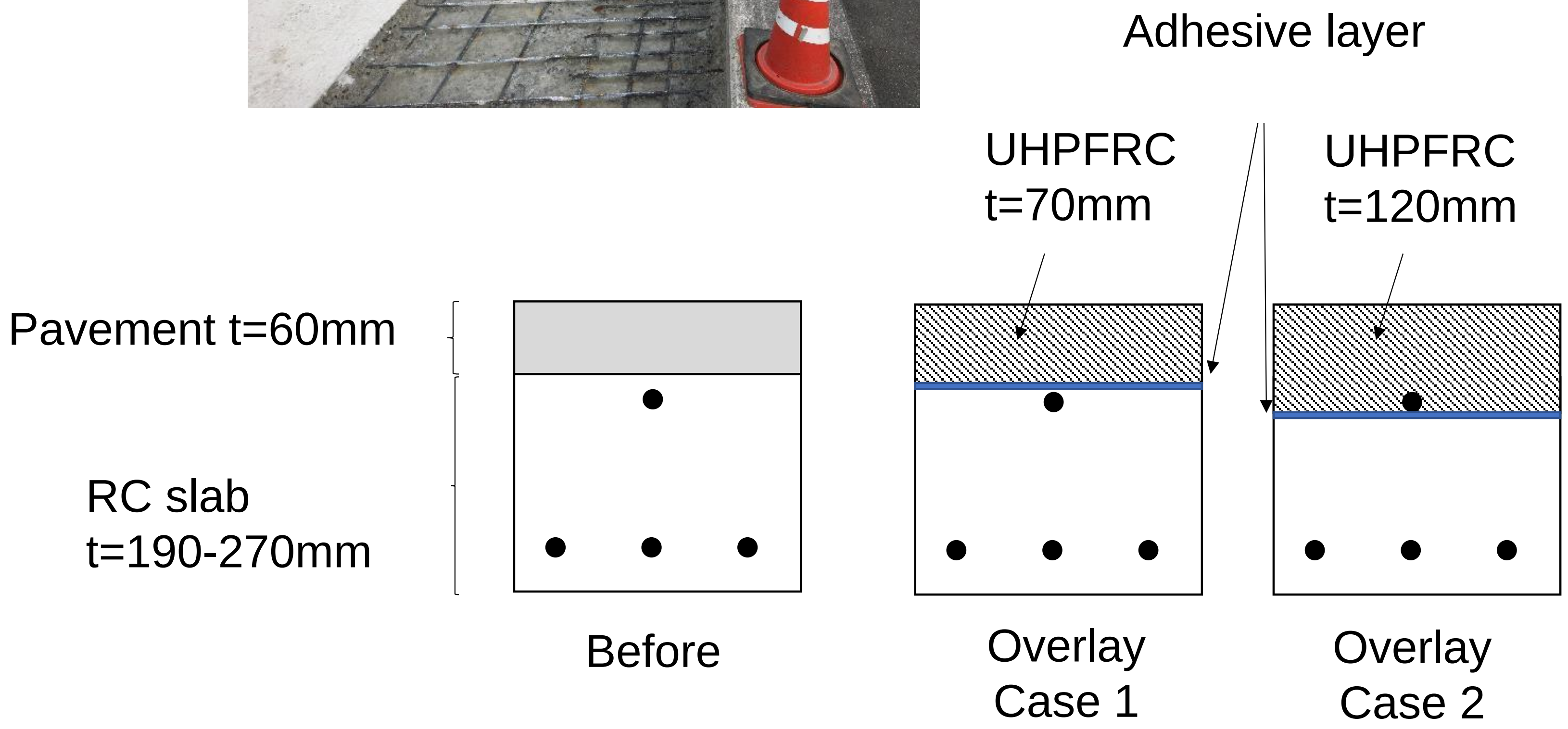
Fiber orientation and distribution



Failure behavior

These approach helps to interpret structural response of FRC depending on fiber orientation

Target(Overlay of RC slab)



Objectives

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- A resistance against shrinkage cracking should be evaluated quantitatively.

→It depends on development of strength, Young's modulus, creep behavior in early age.

- "IF NO CRACK" Evaluation of risk or margin to crack initiation might be useful in design of repair application.

Induced stress due to shrinkage of the UHPFRC was evaluated by means of pseudo perfect constrained testing, and resistance against shrinkage crack was also assessed.

Experimental Procedures

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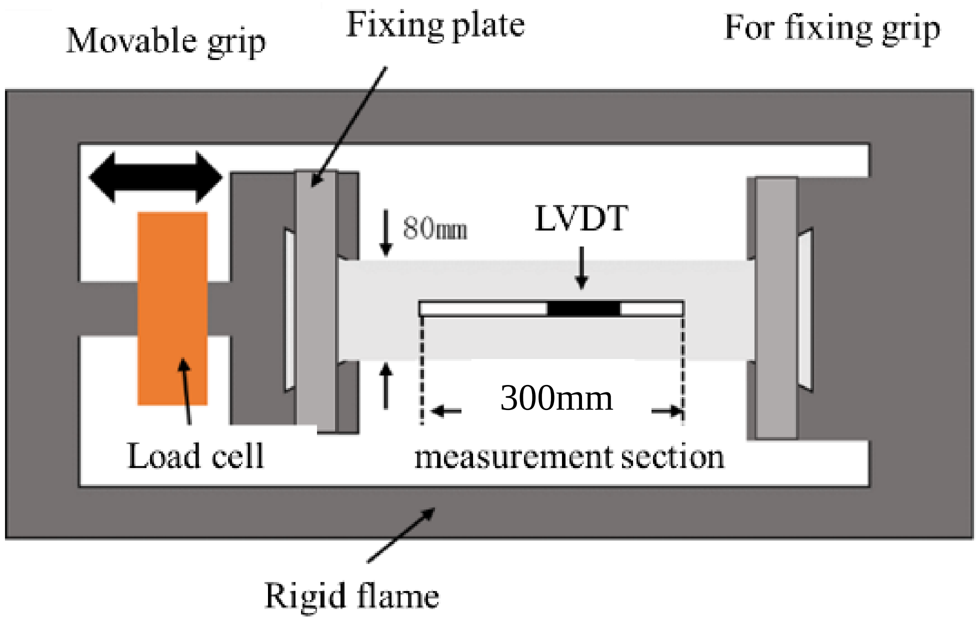
What is pseudo perfect constrained testing?

- The pseudo perfect constrained testing is based on Temperature Stress Testing Machine (TSTM) (Kovler 1994) developed for the purpose of measuring internal stress of early age concrete.
- The deformation due to shrinkage of UHPFRC was virtually constrained in the axial direction.



Operations

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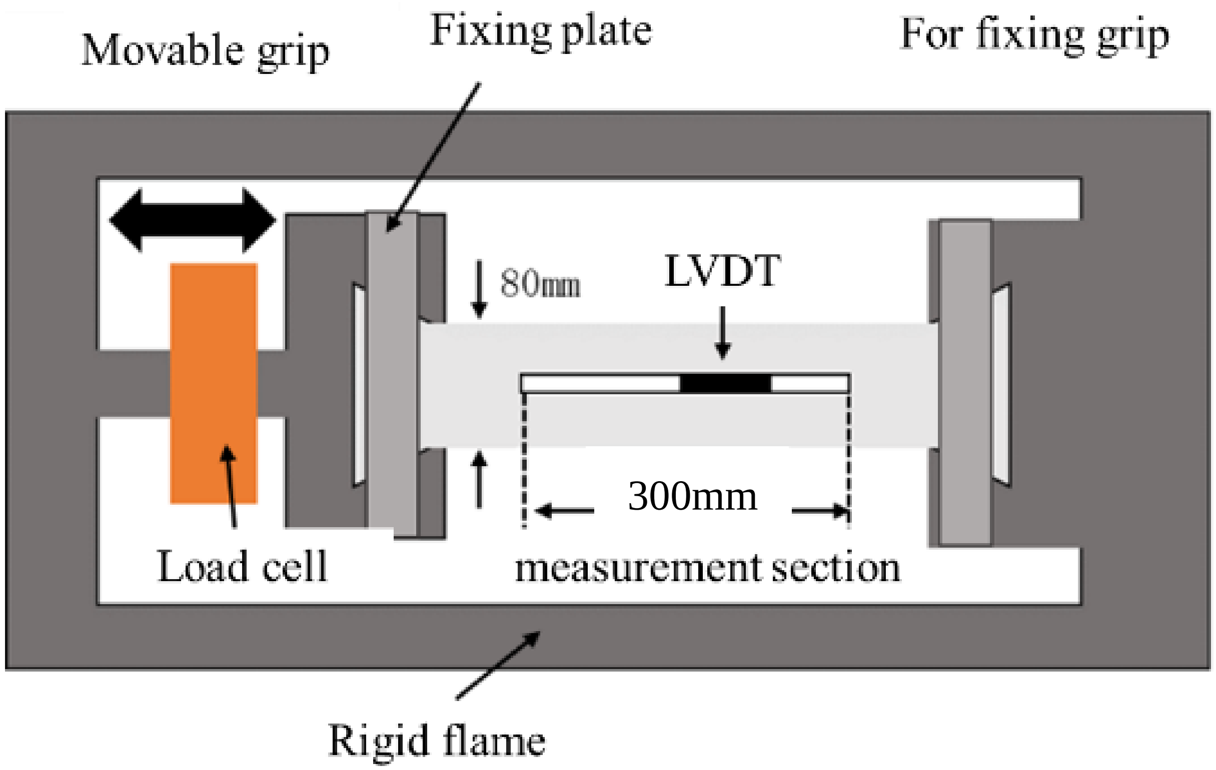
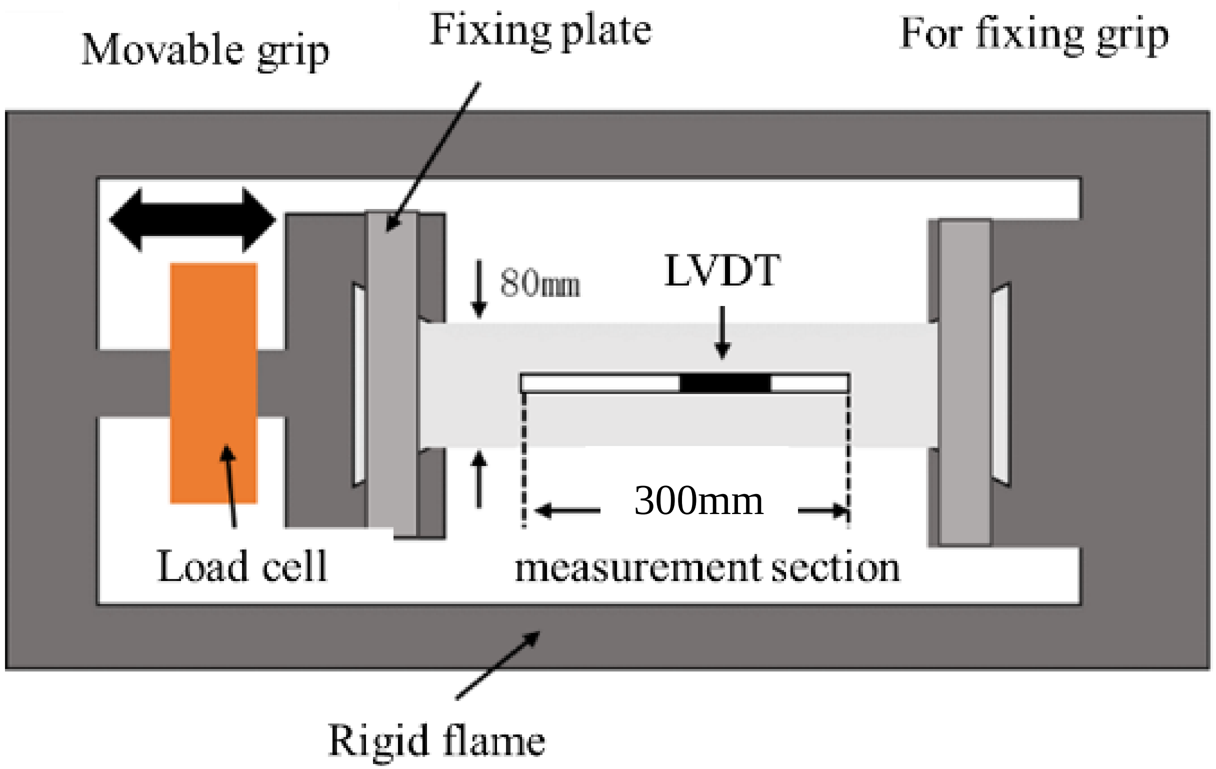
- At the age of 12hours after casting, the mould was removed, and LVDT was set to measure a shrinkage strain (300mm).



Operations

- When the shrinkage strain of 10 microns was detected, the movable grip was adjusted to be strain of 0 micron.
- A load cell was connected to the movable grip and load was measured through the test.
- The induced stress was calculated from the measured load divided by cross sectional area of the specimen.



Specimens

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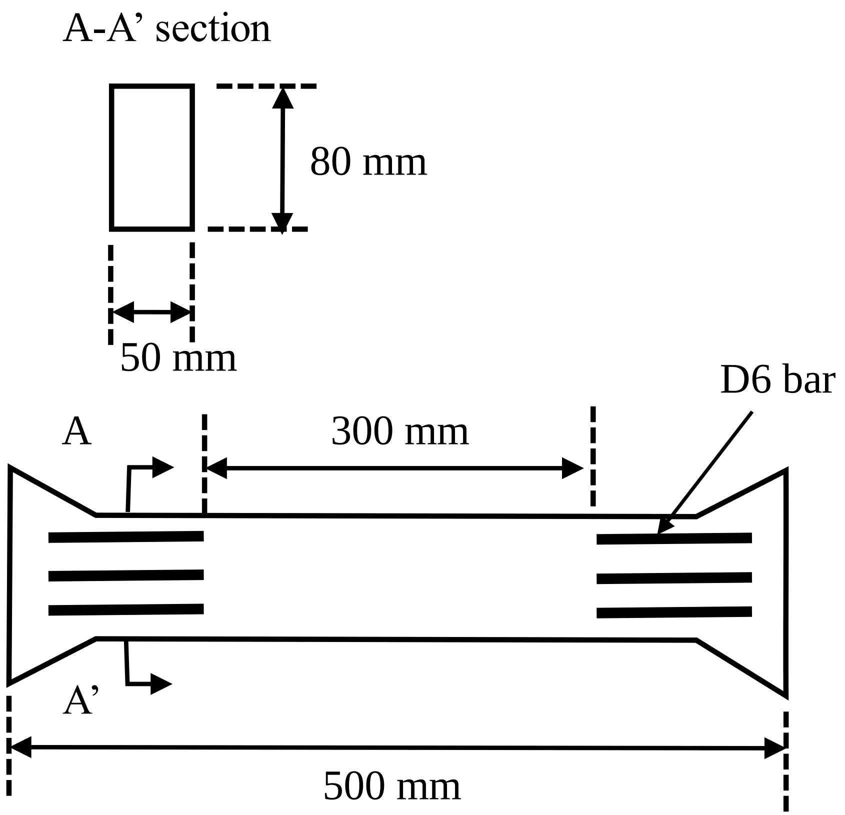
- The shape of the specimen is dog-bone type.
- The dimensions of the specimen were 500mm in length, 80mm in width, and 50mm in height.
- Three reinforcements with length of 70mm and diameter of 6mm long were placed at both ends to prevent cracks due to stress concentration.



Material(UHPFRC)

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- W/B=13%
- Steel fibers
  (length of 13mm and diameter of 0.16mm, Vf= 2.0%)

W/B (%)	Unit content (kg/m^3)					
	W	Powder	Sand	S.P.	Fiber	Exp. agent
13	230	1830	330	32	15.7	20

Investigated Series

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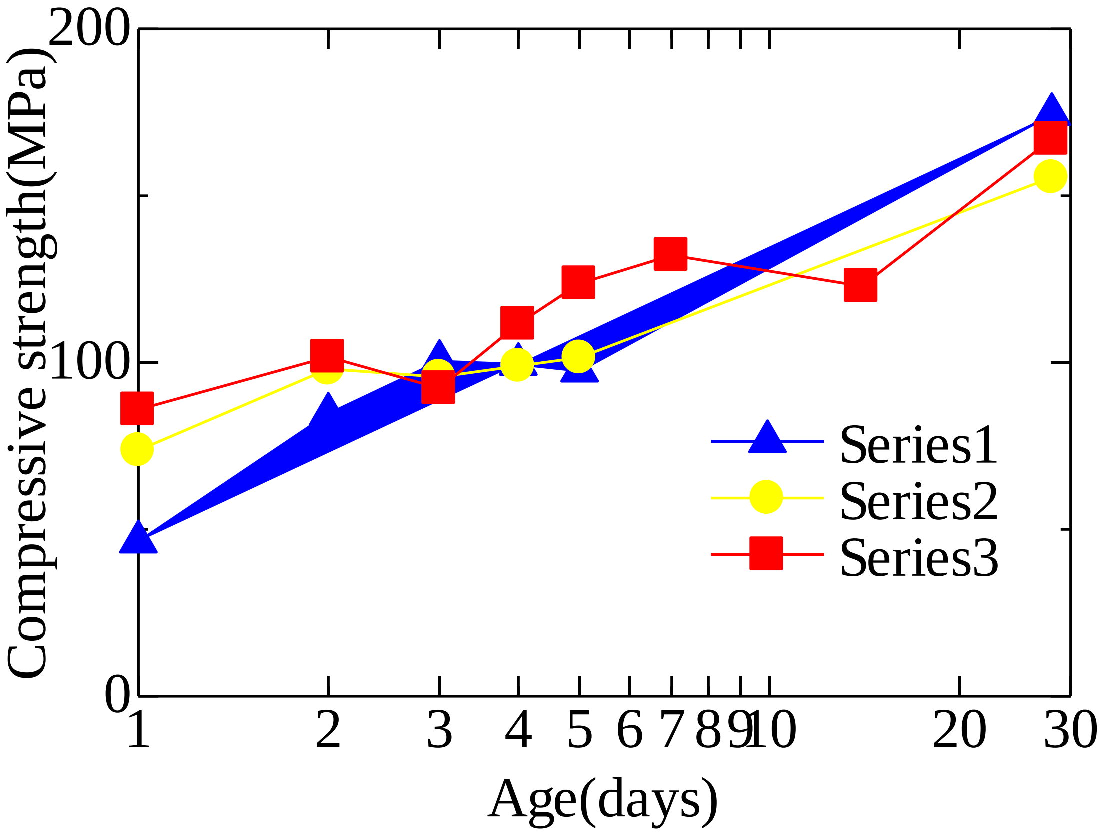
- Series 1: normal UHPFRC measured for 7 days.
- Series 2: UHPFRC with expansive agent, and measured for 7 days.
- Series 3: normal UHPFRC measured for 4 months.
- Series 4: UHPFRC with expansive agent, and measured for 4 months.

Series	Expansive agent	Measurement period
1	without	7 days
2	with	7 days
3	without	4 months
4	with	4 months

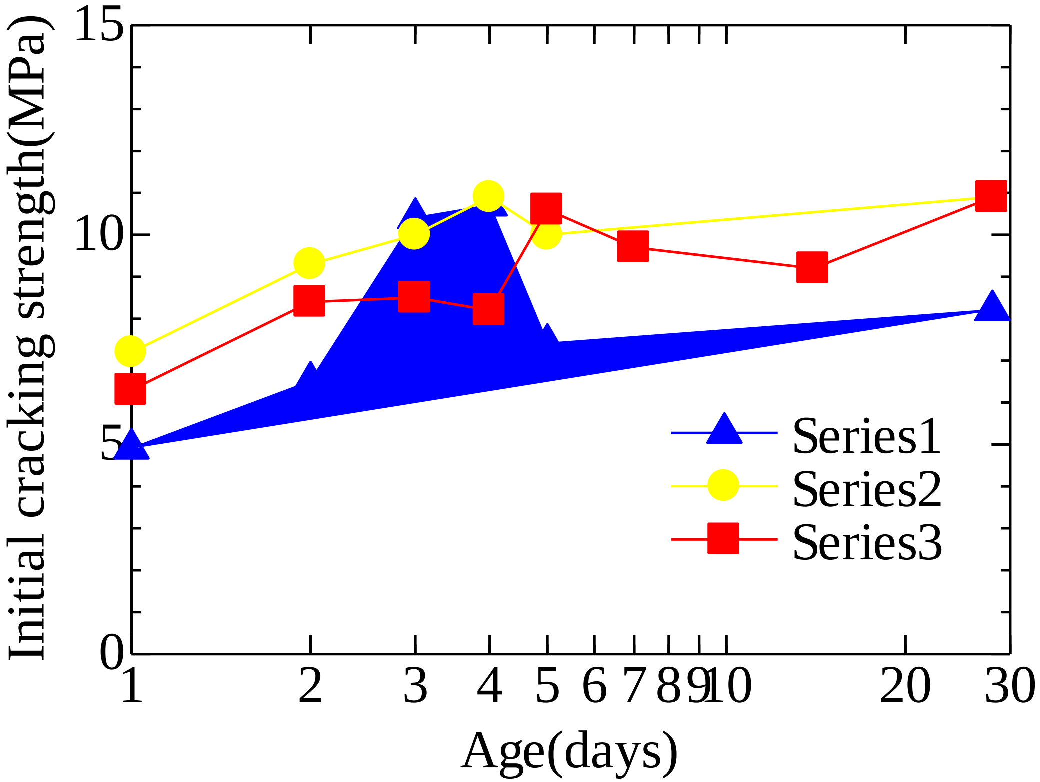
Comp. Strength

- The compressive strength of each series was over 150MPa at the age of 28days. No significant difference at 28days was found in the mix with and without expansive agent.



Initial Cracking Strength

- Initial cracking strength at the age of 28days were 10MPa.
- There was no significant difference in the mix with and without expansive agent.



Free Shrinkage

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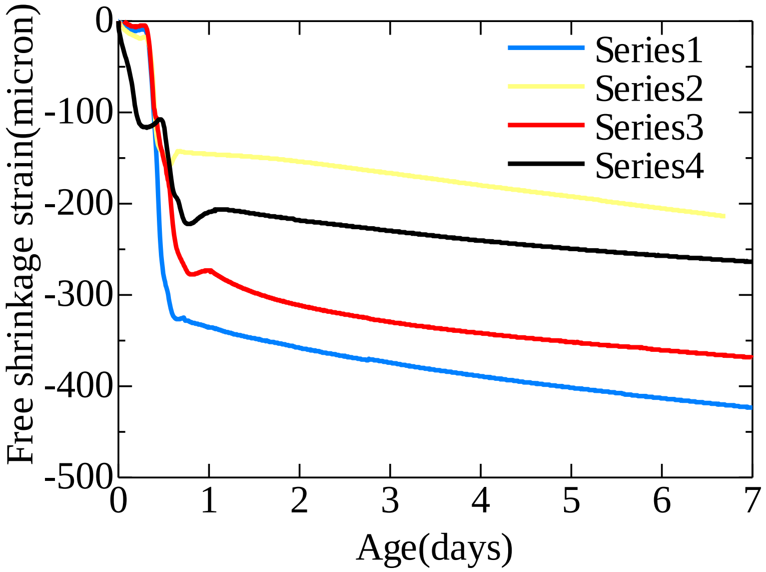
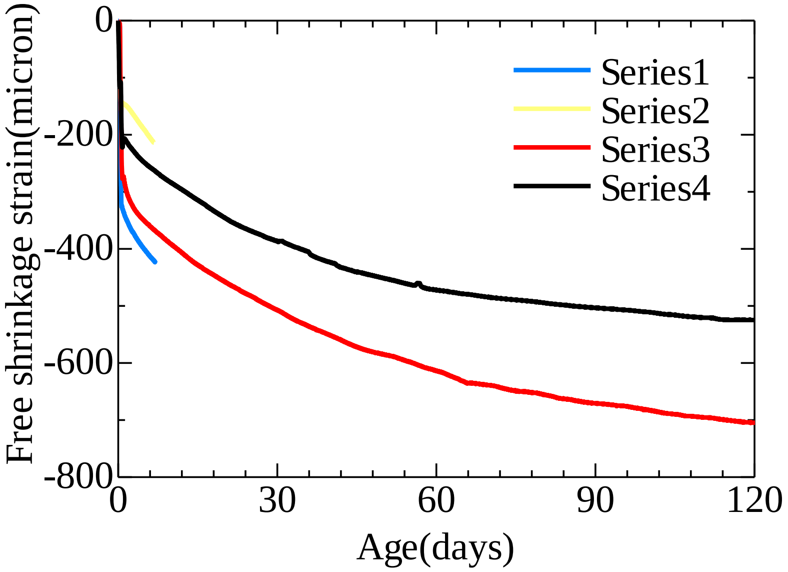
- Shrinkage strain of Series 2, which was the UHPFRC with expansive agent, was about -200micron at the age of 7 days, and it was the smallest in all series.
- Shrinkage strain of the normal UHPFRC without expansive agent was over -700micron at the age of 4 months. It was, however, about -500micron in the case of the mix with expansive agent.



Early Age



4 months

Induced Stress by Pseudo Perfect Constrained Testing

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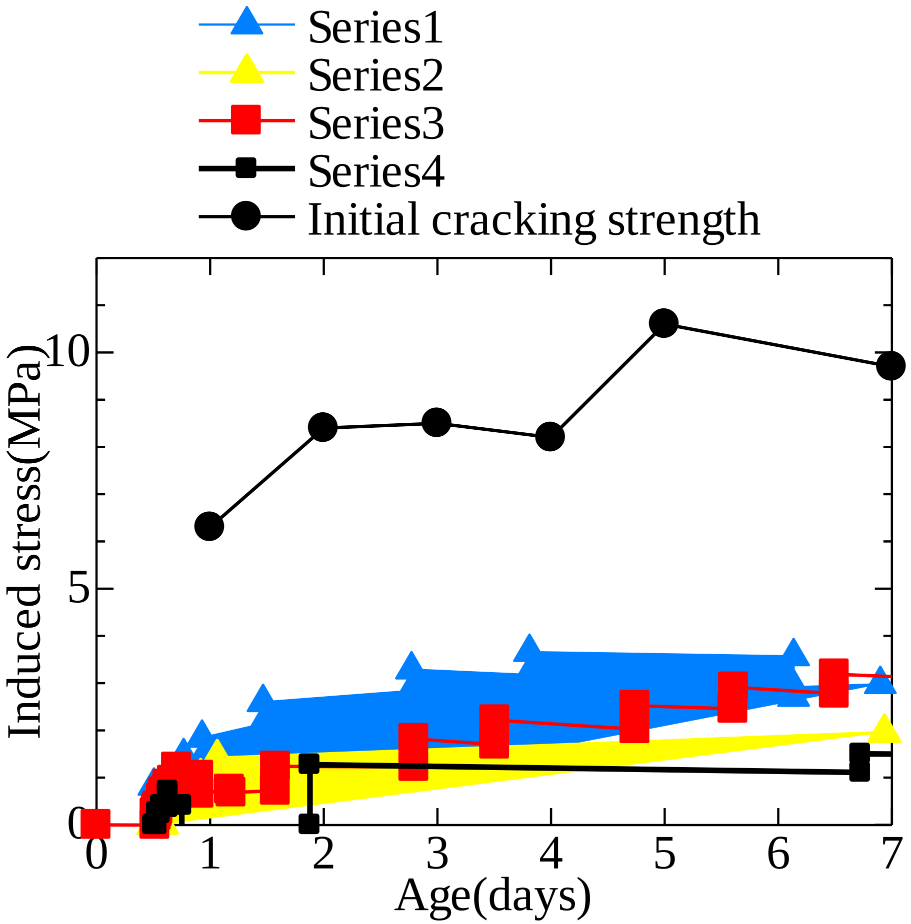
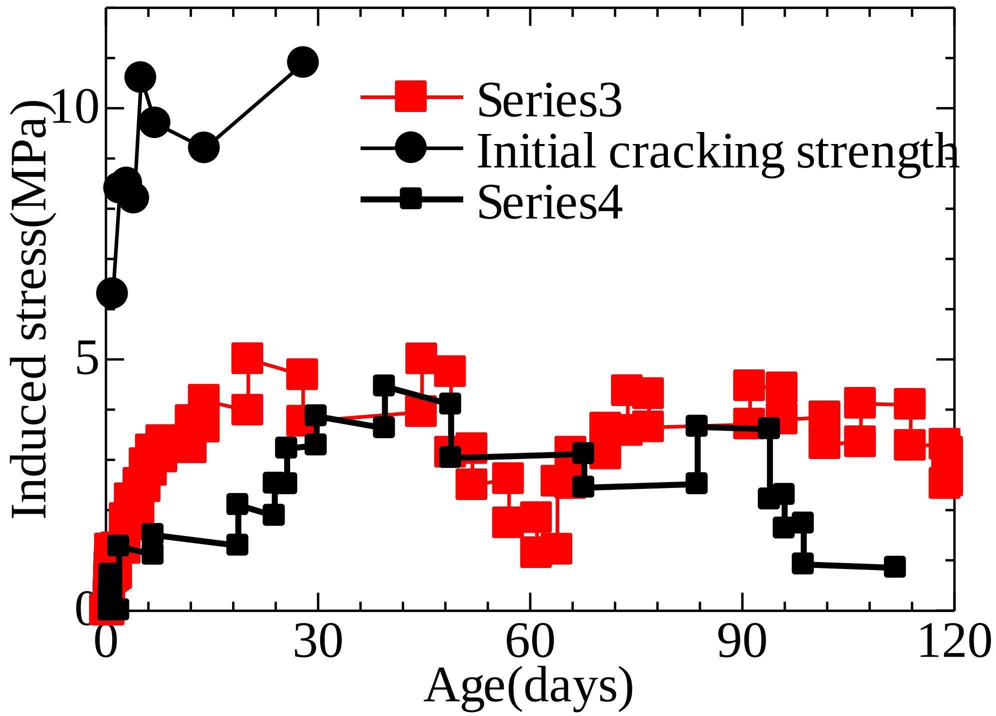
- Induced stresses in the Series 1 and 3 at the age of 7days were 3MPa, the induced stress in the Series 2 with expansive agent was only 2MPa.



Induced Stress

- Regarding the Series 3 and Series 4 at the age of 4 months, the induced stress was less than 4 MPa, and there was no significant increase from 1month. At the age of 4 months, there is effect of expansive agent on induced stress of UHPFRC.



Cracking Stress Ratio(5 days)

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- The ratio of UHPFRC without expansive agent was about 47% at the age of 5 days. On the other hand, the ratio of UHPFRC with expansive agent was less than 20% at the age of 5days.

w.o. Expansive Agent

Age	Initial cracking strength (MPa)	Induced stress(MPa)	Cracking stress ratio(%)
1	4.9	1.8	36.7
3	10.4	3.3	31.7
5	7.4	3.5	47.2

w. Expansive Agent

Age	Initial cracking strength (MPa)	Induced stress(MPa)	Cracking stress ratio(%)
1	7.2	1.4	19.4
3	10	1.6	16
5	10	1.8	18

Cracking Stress Ratio(4 months)

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- The ratios of UHPFRC without and with expansive agent were 28.4% and 8.3%, respectively. Both ratios were decreased comparing to those at 5 days.
- Creep of material itself may impart higher crack resistance to UHPFRC with increasing of age.

w.o. Expansive Agent

Age	Initial cracking strength (MPa)	Induced stress(MPa)	Cracking stress ratio(%)
1	6.3	0.7	11.1
28	10.9	3.8	34.9
120	10.9*	3.1	28.4

w. Expansive Agent

Age	Initial cracking strength (MPa)	Induced stress(MPa)	Cracking stress ratio(%)
1	7.2	0.4	5.6
28	10.9	3.9	35.8
120	10.9*	0.9	8.3

Concluding Remarks

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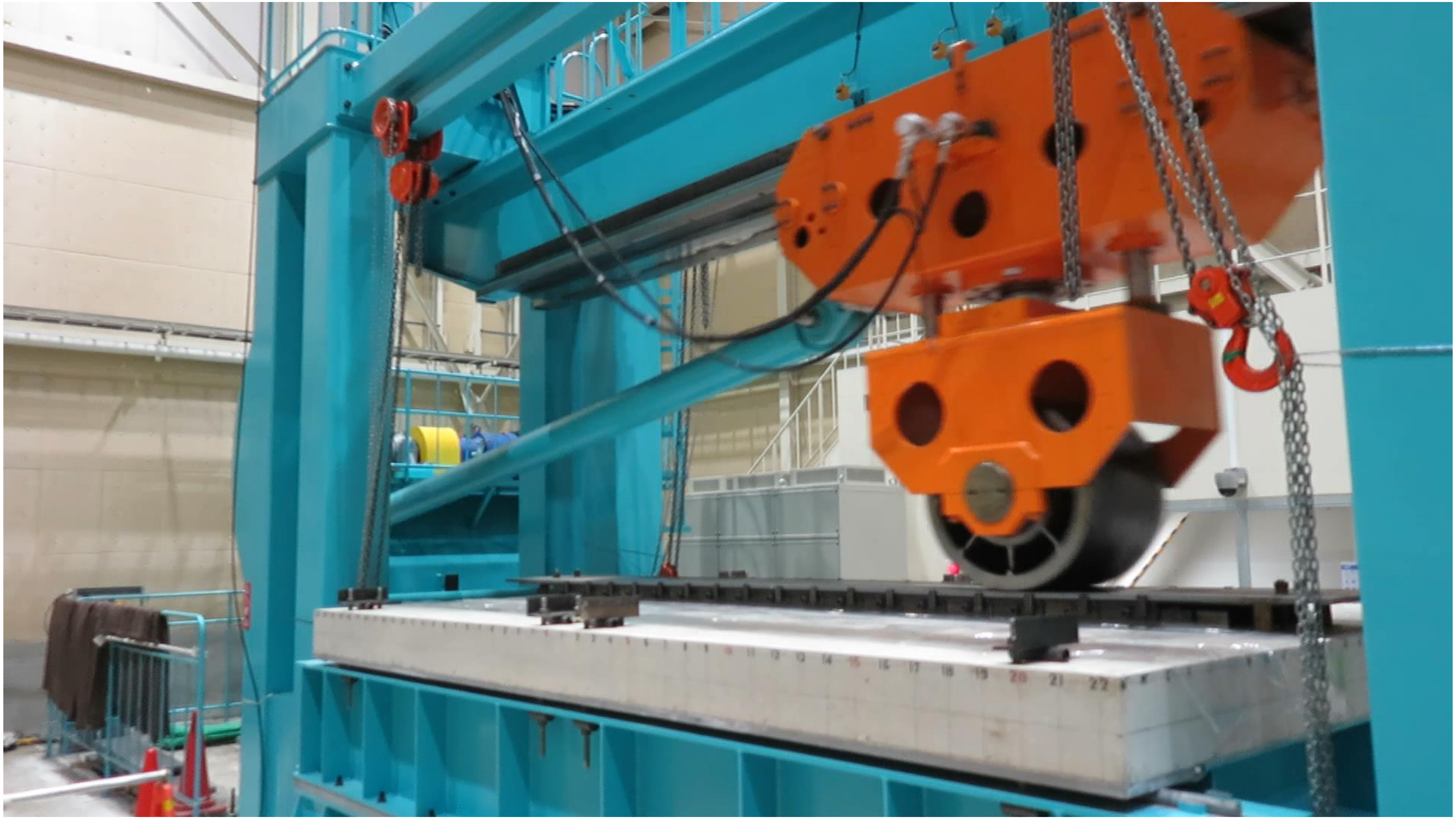
1) It is well known the mechanical properties of FRC is strongly affected by fiber orientation depending on casting manner. Numerical approach to assess fiber orientation and its affects on mechanical properties is introduced.

2) It is important to evaluate induced stress of UHPFRC in the case of repair applications, and the evaluation using pseudo perfect constrained testing was adapted. The test results showed there was enough margin to crack initiation in the UHPFRC.

Above two issues are very important and should be considered in the design of UHPFRC applications.

Assessment of Fatigue Resistance though Wheel Running Fatigue Test



Thank you for your kind attention

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