FRPRCS - 10

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Experimental Investigation of HFRP Composite Beams

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Presentation Outline

Part 1

Flexural Test of HFRP Beams

Part 2

Flexural Test of HFRP-NSC Composite Beams

Part 3

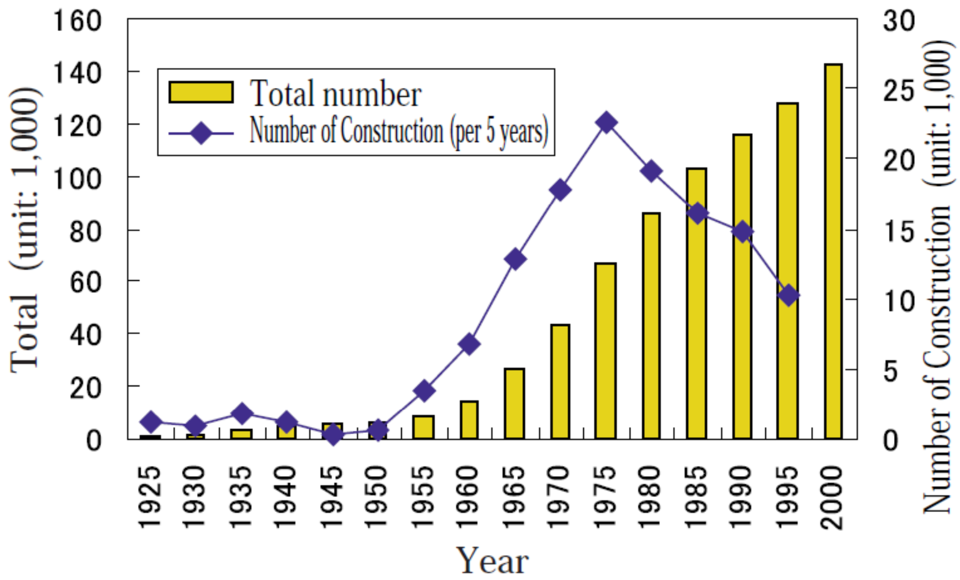
Flexural Test of HFRP-UHPFRC Composite Beams

Conclusions

Presentation Outline

- Part 1: Flexural Test of HFRP Beams
- Part 2: Flexural Test of HFRP-NSC Composite Beams
- Part 3: Flexural Test of HFRP-UHPFRC Composite Beams

Flexural Test of HFRP Beams: Introduction



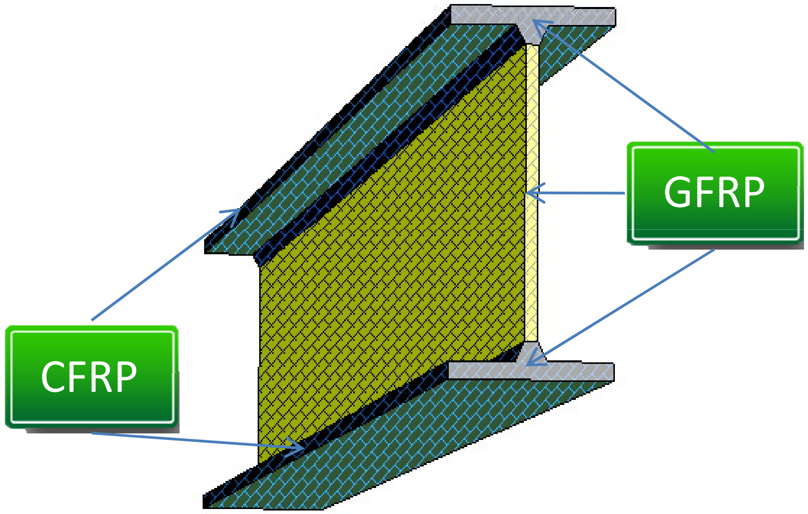
Total number of bridges in Japan

Rust and damage in girders (Kuretsubo Bridge)

Flexural Test of HFRP Beams: Introduction

Fiber Reinforced Polymers (FRP)

- ✓ High specific strength/stiffness
- ✓ High durability
- ✓ Low life-cycle costs
- ✓ Corrosion resistance
- ✓ Lightweight

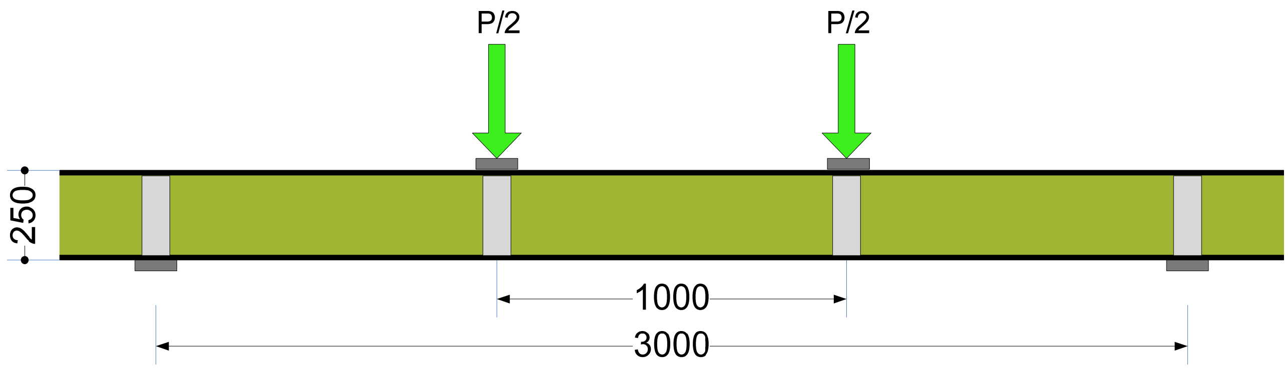


Why hybrid FRP?

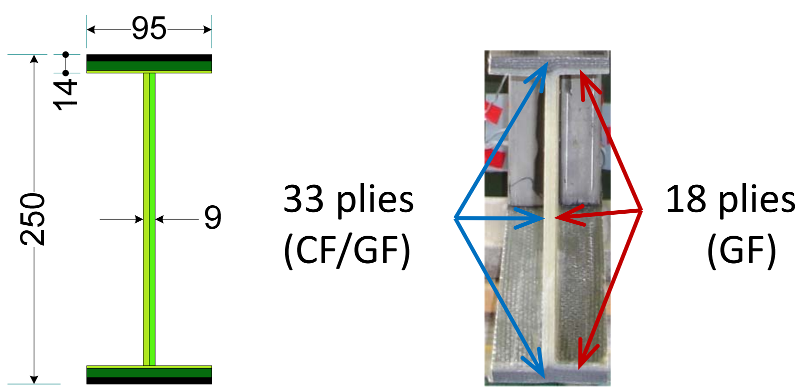
Hybridization with carbon fibers of glass fiber composites is known to enhance fatigue performance and environmental resistance compared to all-glass composites.

The failure strain of carbon fiber appears to be greater in a hybrid than in an all-carbon fiber composite structure.

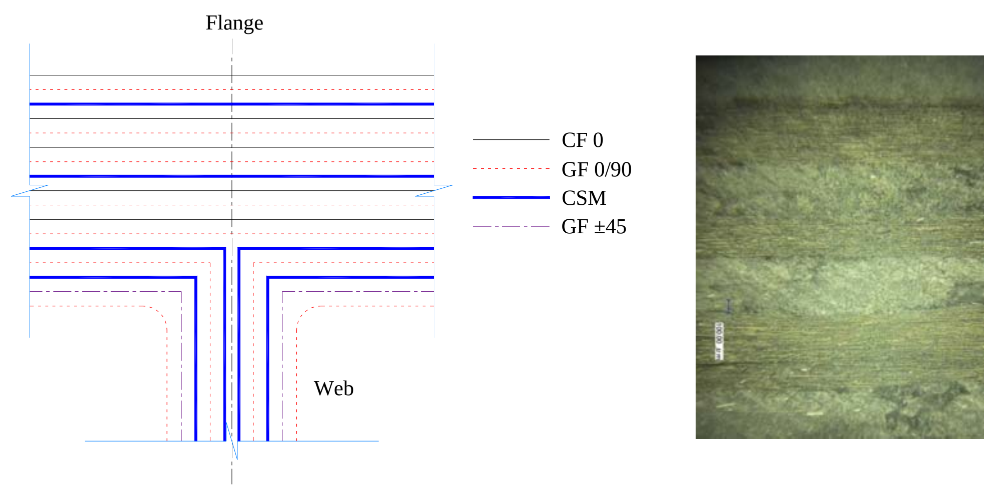
A number of specimen were tested under four point bending



Beam elevation



Cross section



Layer composition

Flexural Test of HFRP Beams: Experiments

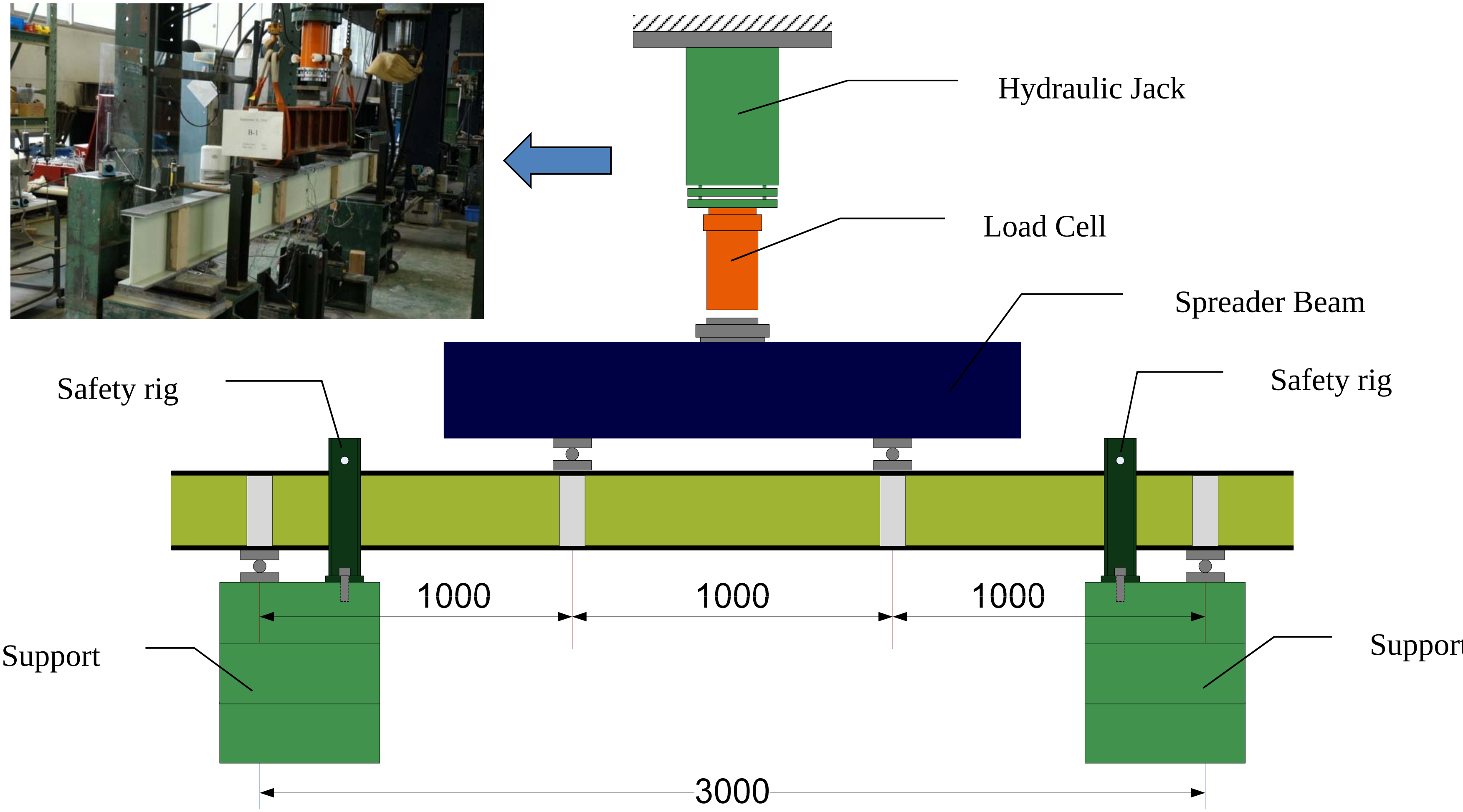
Mechanical properties of materials

Parameters	Notation	CFRP 0°	GFRP 0/90°	GFRP ±45°	GFRP CSM
Volume fraction	V_f (%)	55	53	53	25
Young's modulus	E_{11} (GPa)	128.1	25.9	11.1	11.1
	E_{22} (GPa)	14.9	25.9	11.1	11.1
Shear modulus	G_{12}	5.5	4.4	10.9	4.2
Poisson's ratio	ν_{12}	0.32	0.12	0.29	0.31
Volume content	Flange (%)	33	17	41	9
	Web (%)	0	43	43	14

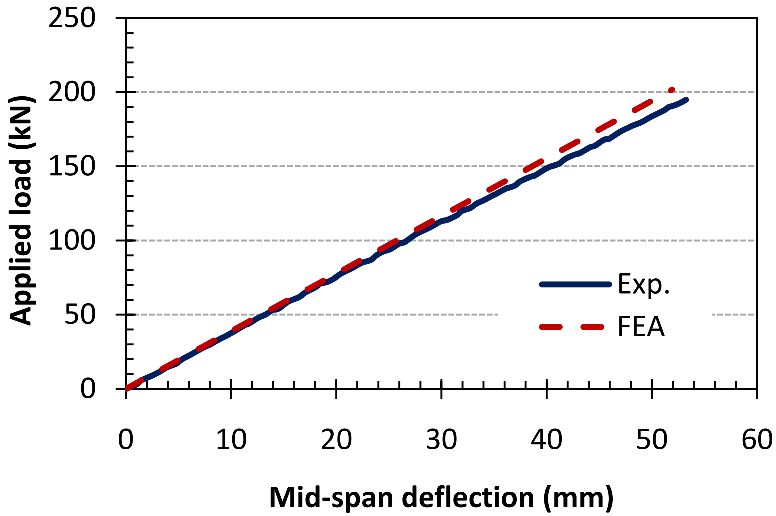
Effective mechanical properties of HFRP laminates

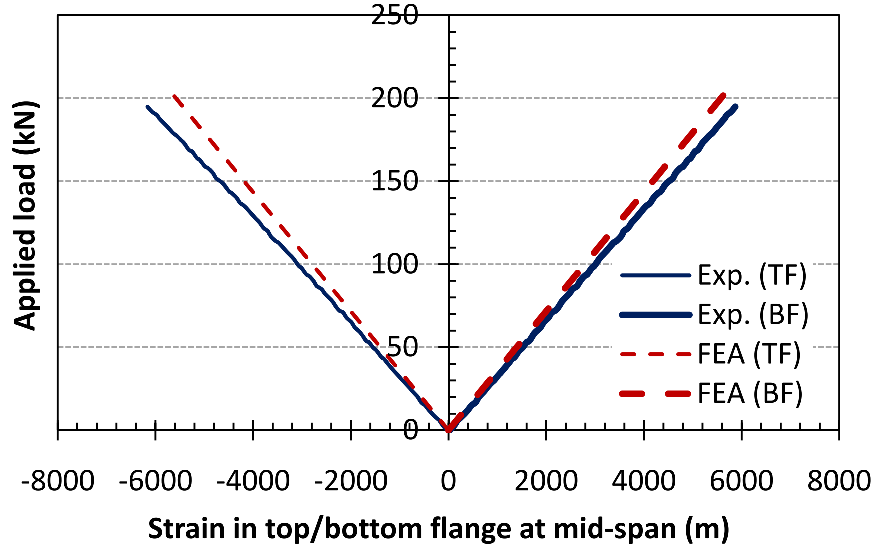
Parameters	Flange	Web
Compressive strength (MPa)	394	299
Tensile strength (MPa)	884	185
Young's modulus (GPa)	49.6	17.8

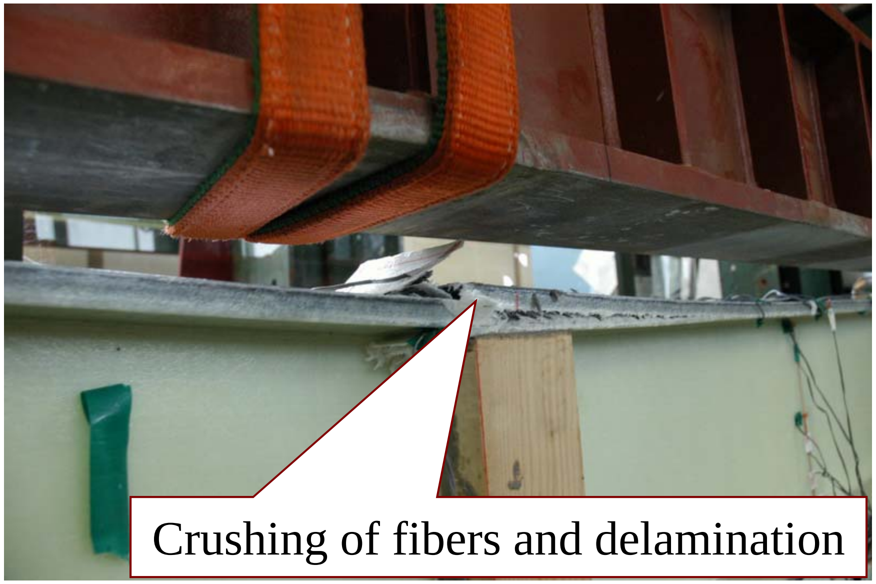
Flexural Test of HFRP Beams: Experiments

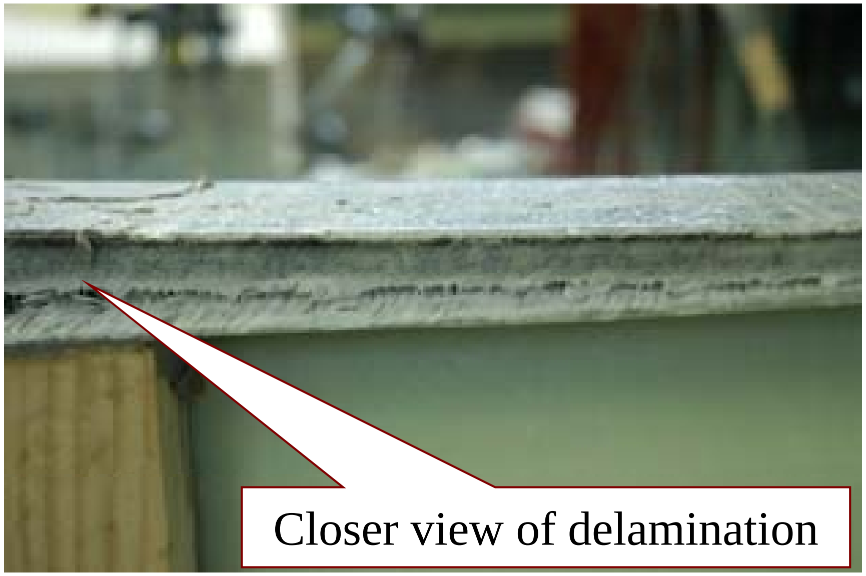


Flexural Test of HFRP Beams: Results









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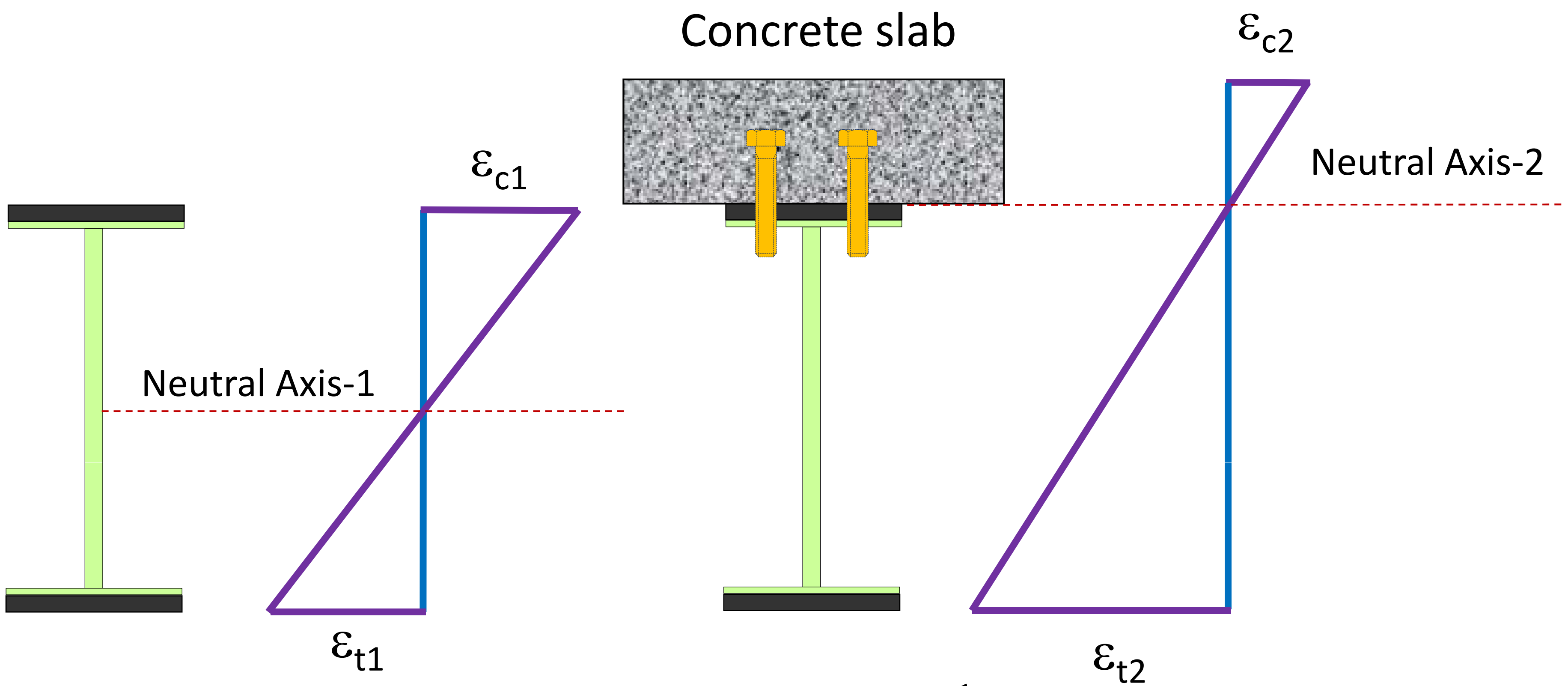
- Part 1: Flexural Test of HFRP Beams
- Part 2: Flexural Test of HFRP-NSC Composite Beams
- Part 3: Flexural Test of HFRP-UHPFRC Composite Beams

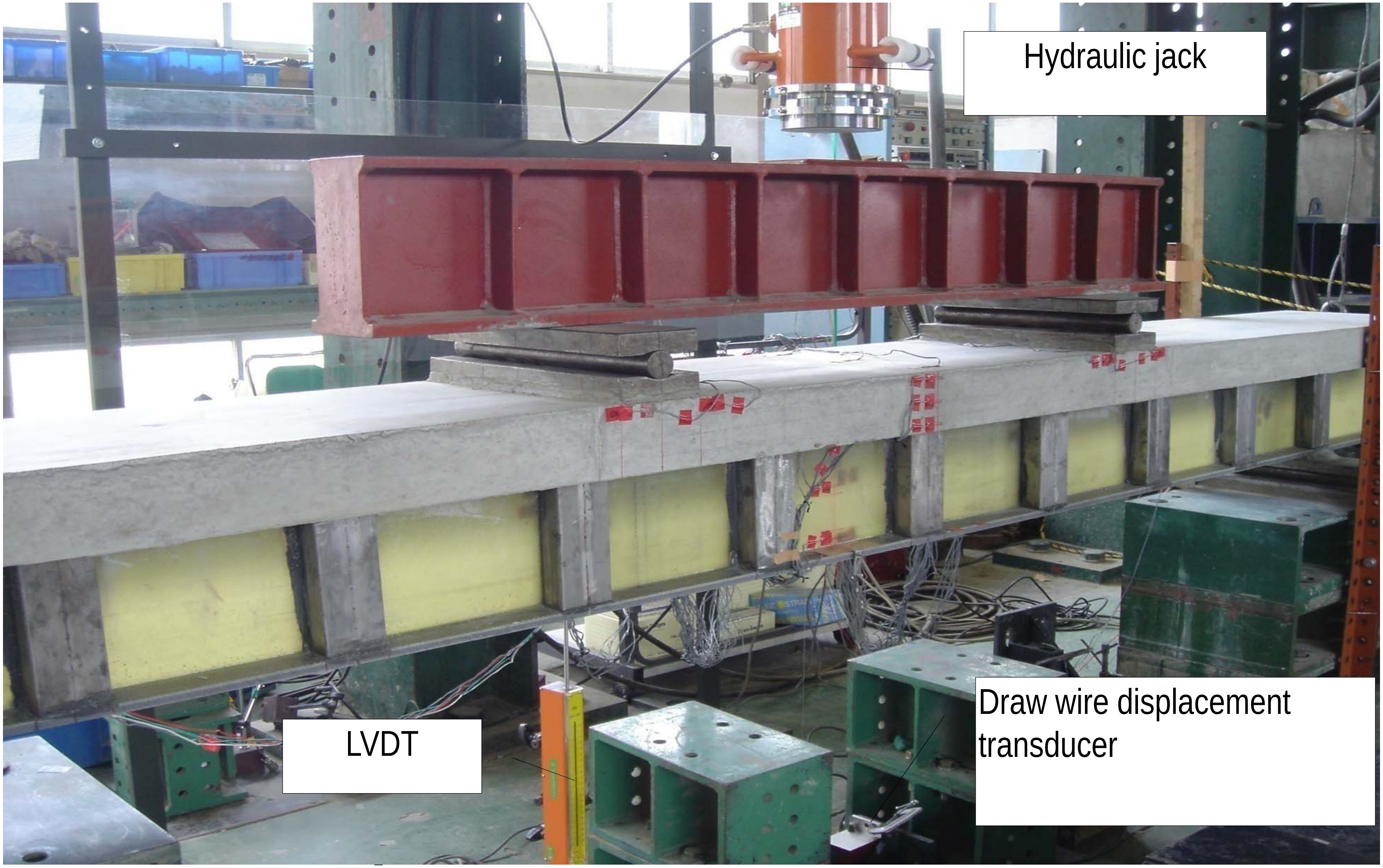
Flexural Test of HFRP-NSC Composite Beams: Introduction



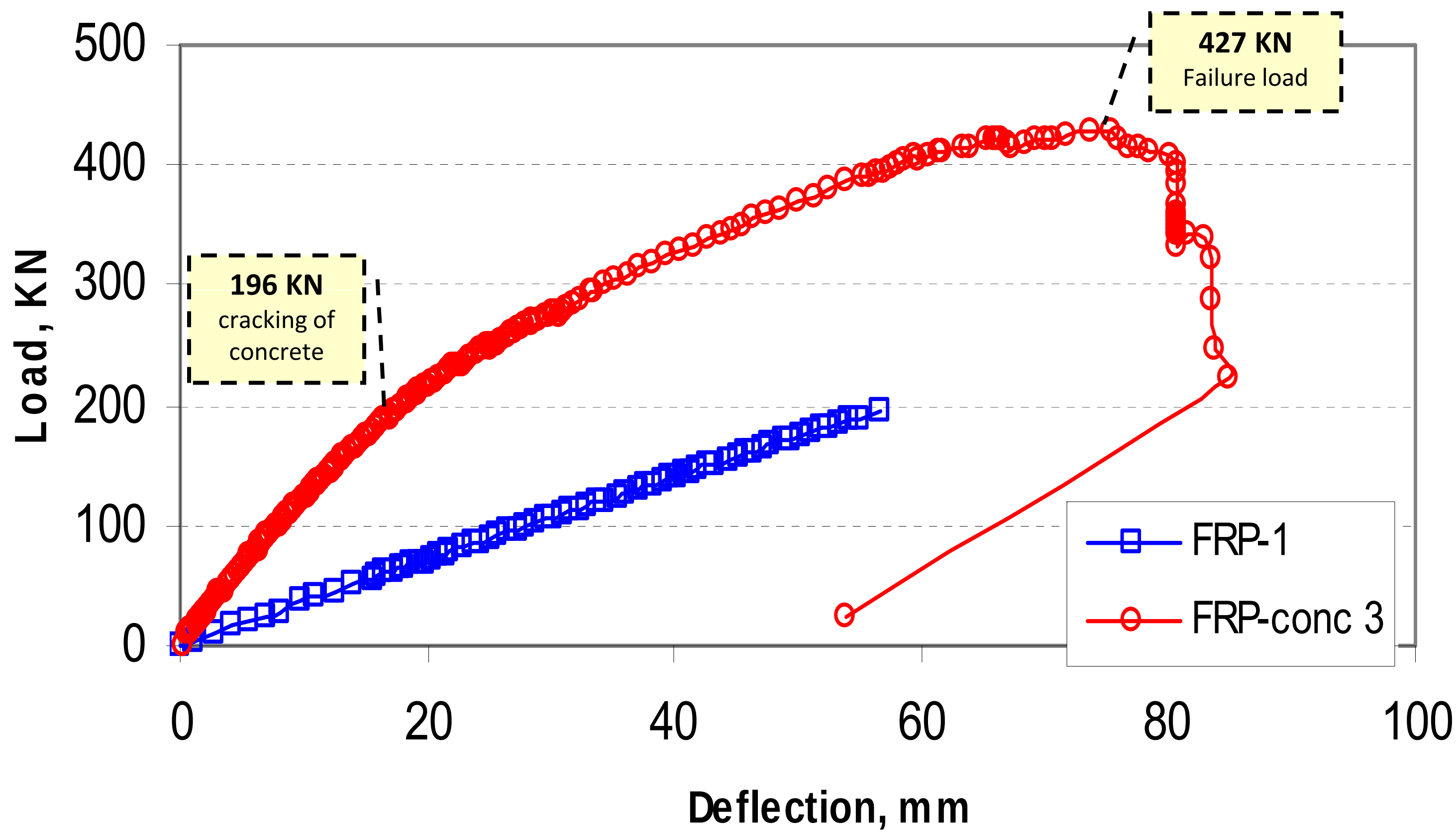
$\varepsilon_{c1} \approx \varepsilon_{t1}$

$\varepsilon_{c2} < \varepsilon_{t2}$

Flexural Test of HFRP-NSC Composite Beams: Experiments



Flexural Test of HFRP-NSC Composite Beams: Results



Load and mid-span deflection

Flexural Test of HFRP-NSC Composite Beams: Failure Mode

Compression failure of NSC slab

Shear failure of HFRP beam

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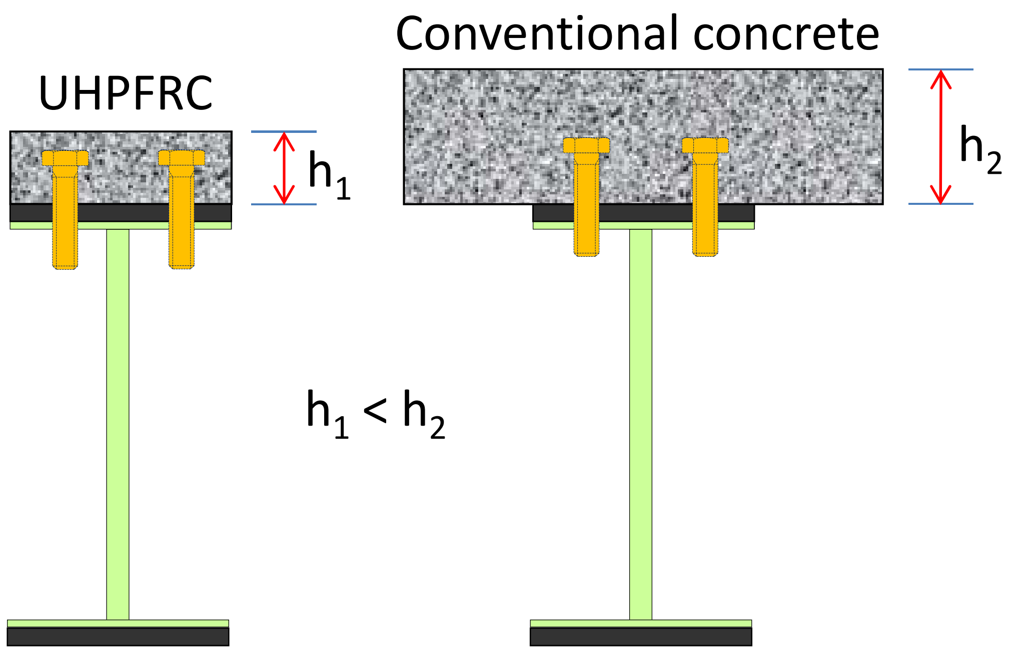
Flexural Test of HFRP-UHPFRC Composite Beams: Introduction

UHPFRC = **U**ltra-High Performance **F**iber-Reinforced **C**oncrete
"**SUQCEM** - **SU**per High **Q**uality **CE**mentitious **M**aterial"

- High strength
- High durability
- Reduce weight of structure, etc



Flexural Test of HFRP-UHPFRC Composite Beams: Materials

UHPFRC

Mix Proportions of UHPFRC (JSCE 2006)

Air content (%)	Unit quantity (kg/m^3)				Steel fiber (kg/m^3)
	Water	Premix cement	Sand	W.R. Admixture	
2.0	205	1287	898	32.2	137.4

Mechanical properties of UHPFRC

Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Young Modulus (kN/mm^2)
173	14.3	48.6

Flexural Test of HFRP-UHPFRC Composite Beams: Test Variables

Test variables

†B = Bolts; ††SA = Slab Anchors; †††BE = Bolts and Epoxy

Beam	Shear connector	Epoxy bonding	Width of UHPFRC slab (mm)	Thickness of UHPFRC slab (mm)	Embedded length of bolt (mm)
†B-135-50	Bolt M16	-	135	50	35
††SA-135-50	Slab anchor M10	-	135	50	35
†††BE-95-50	Bolt M16	○	95	50	35
†††BE-135-35	Bolt M16	○	135	35	30
†††BE-135-50	Bolt M16	○	135	50	35

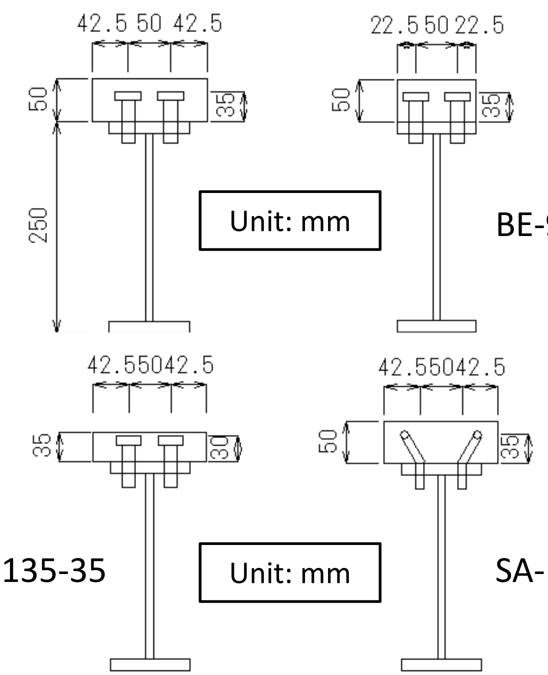
Specimen layouts

B (BE)-135-50

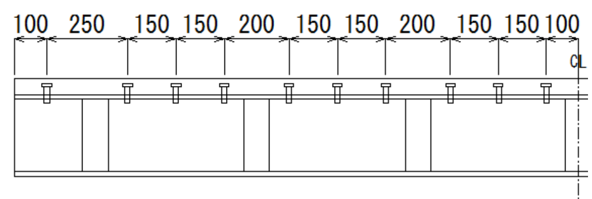
BE-95-50

BE-135-35

SA-135-50

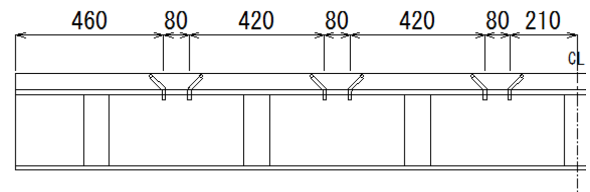


Unit: mm



Configurations with bolts

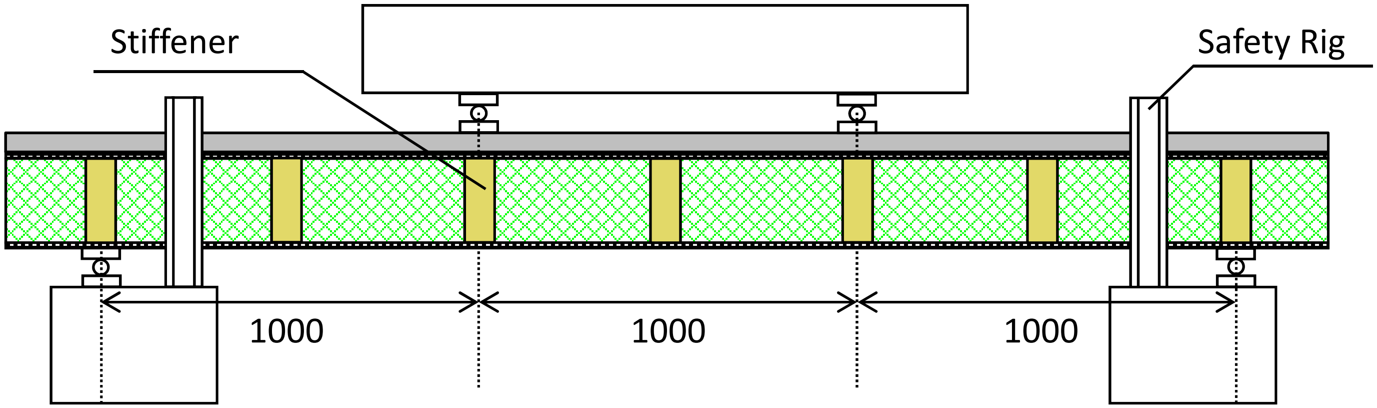
Unit: mm



Configurations with slab anchors

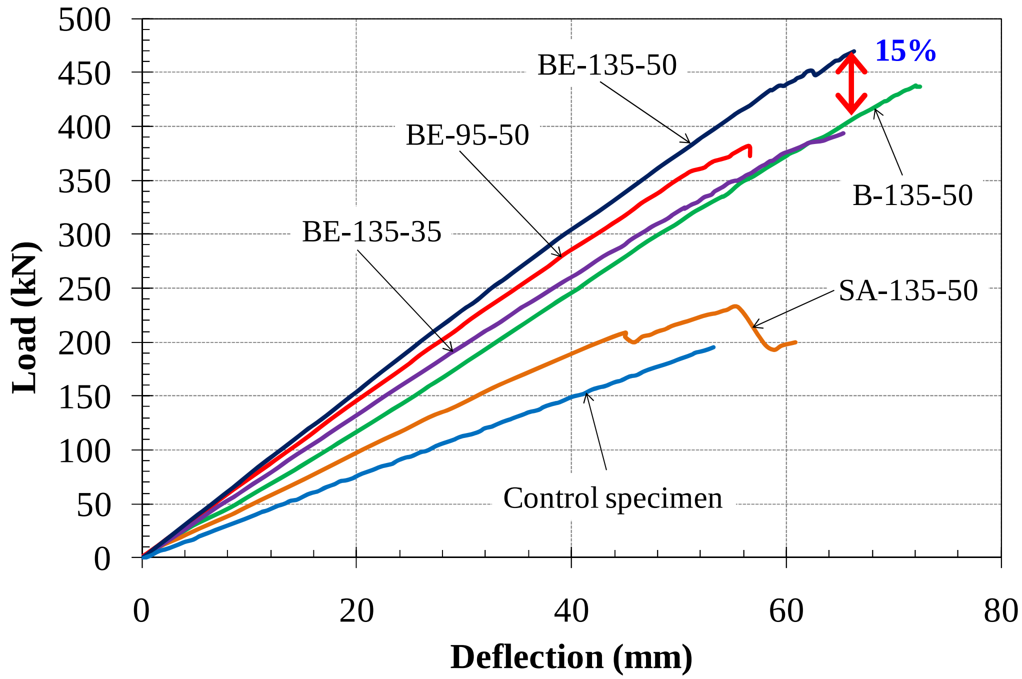
Flexural Test of HFRP-UHPFRC Composite Beams: Test Setup

Test setup



Flexural Test of HFRP-UHPFRC Composite Beams: Test Results

- Load-deflection relationship



- Failure mode

HFRP flange delamination failure (SA-135-50)

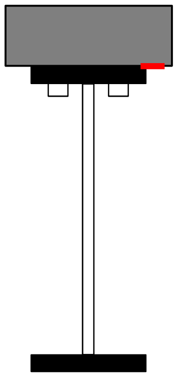
HFRP-UHPFRC Composite girder → ❖ Increase flexural strength and stiffness
❖ Prevent fracture of HFRP in the compressive flange

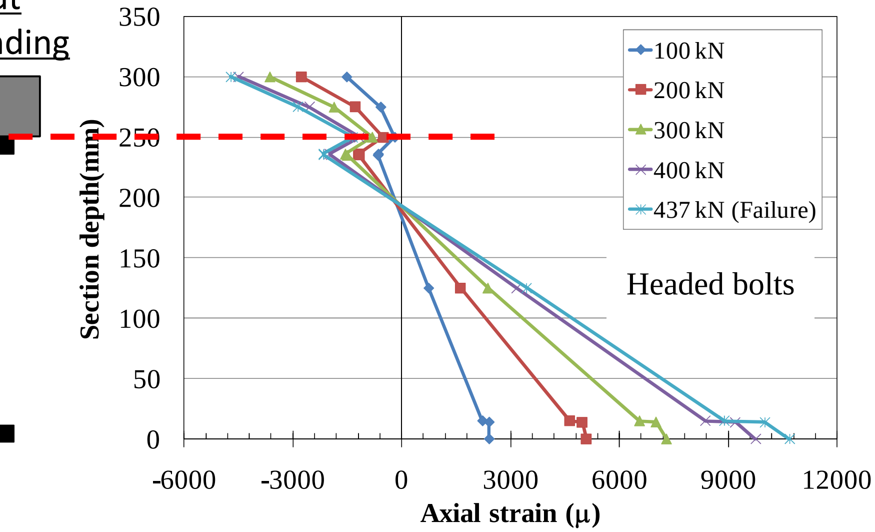
Shear connectors combined with adhesive bonding → ❖ Increase stiffness

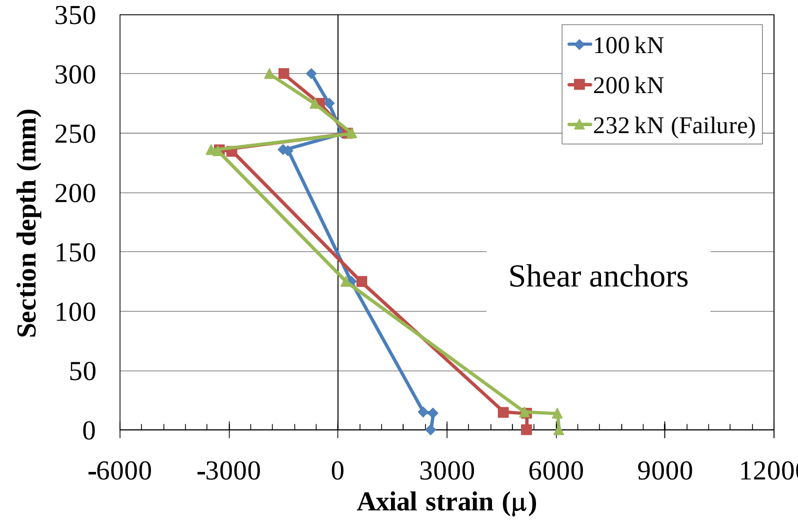
Flexural Test of HFRP-UHPFRC Composite Beams: Test Results

Strain distribution at mid-span section

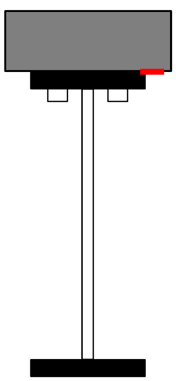
Without epoxy bonding

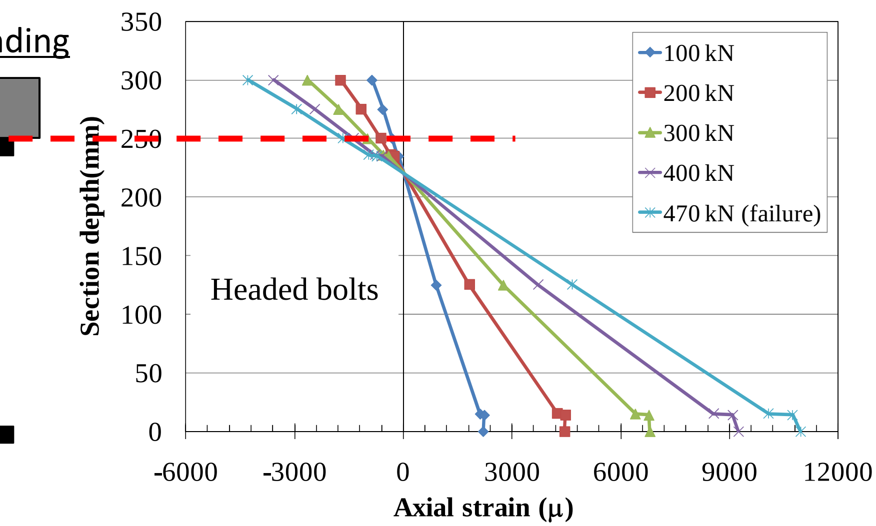






With epoxy bonding



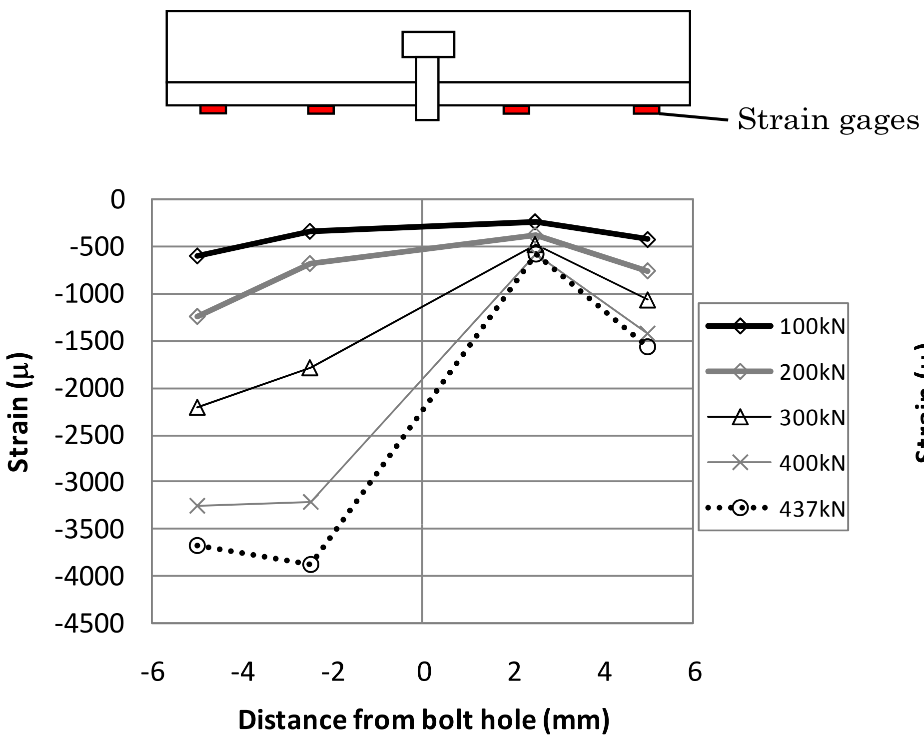


Nonlinear strain distribution initiated at the bottom of the HFRP compressive flange → Slipping at the interface between the UHPFRC slab and the HFRP beam

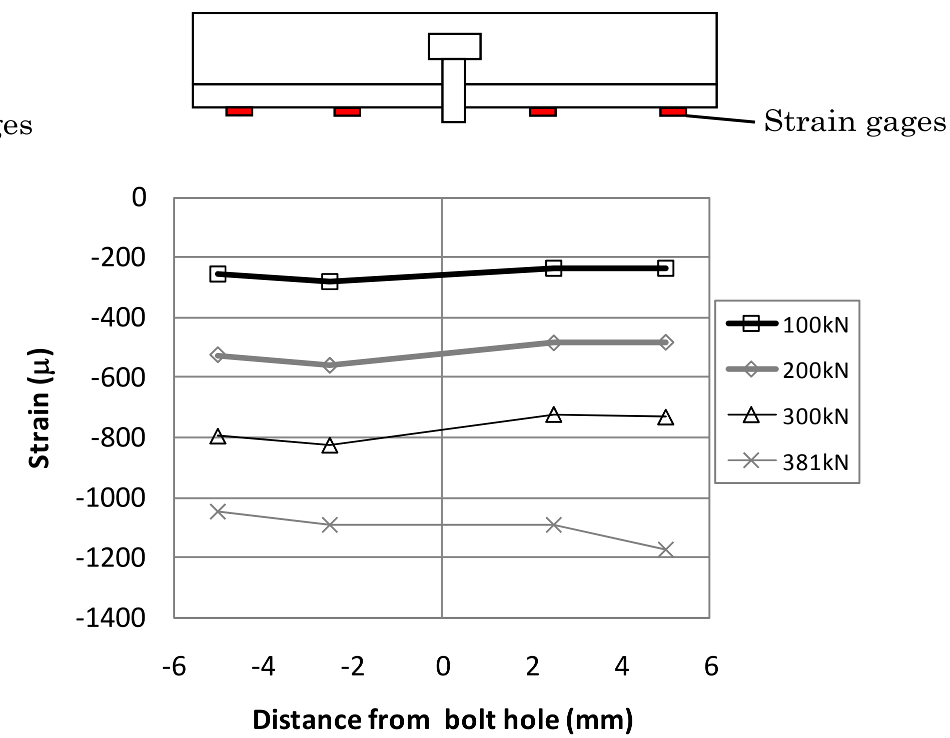
Linear strain distribution through the cross-section up to failure → Full composite action until the final failure

Flexural Test of HFRP-UHPFRC Composite Beams: Test Results

◆ Strain Distribution in HFRP Top Flange near Bolt Hole



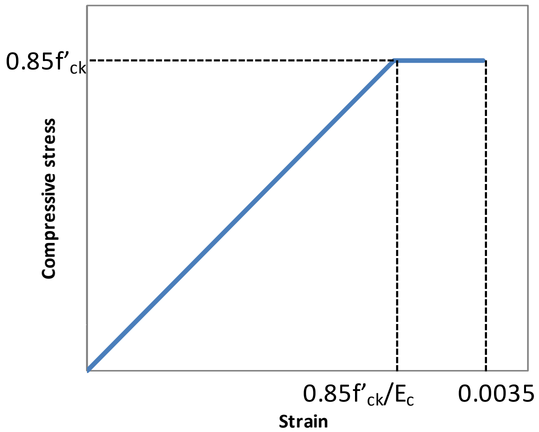
(a) Specimen without epoxy



(b) Specimen with epoxy

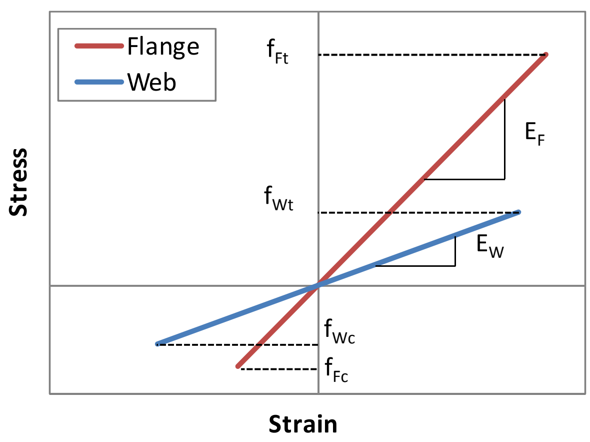
Flexural Test of HFRP-UHPFRC Composite Beams: Comparisons

UHPFRC



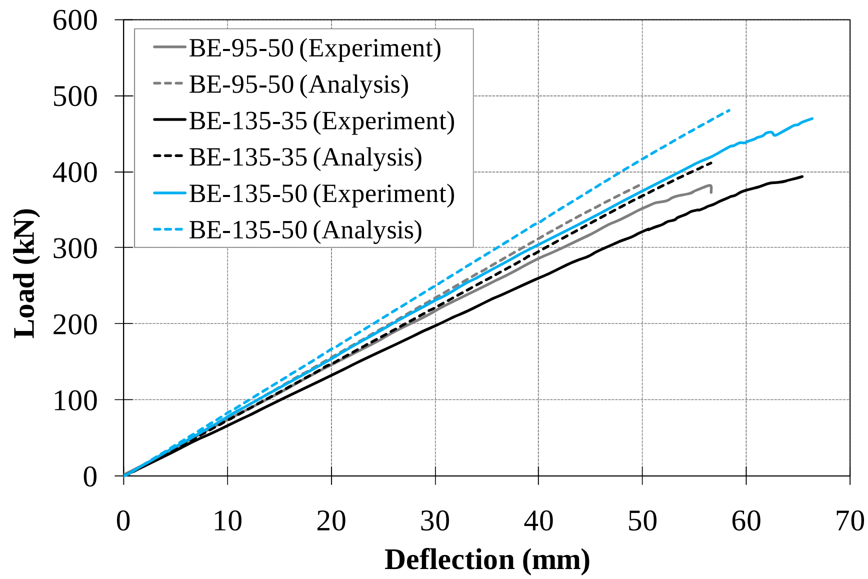
Bi-linear relationship for UHPFRC (JSCE 2006)

HFRP



Flexural Test Results at Failure of HFRP-UHPFRC Composite Beam

Beam	Predicted failure load, kN	Actual failure load, kN	Predicted/actual failure mode
B-135-50	—	438	Compression – UHPFRC
SA-135-50	—	232	Delamination – HFRP top flange
BE-95-50	384	382	Compression – UHPFRC
BE-135-35	411	394	Compression – UHPFRC
BE-135-50	481	470	Compression – UHPFRC
HFRP-NSC	—	427	Compression – NSC



Conclusions

1) The investigated HFRP beams behave linearly under flexural load and failed suddenly without forewarning. The failure was crushing of fibers near the loading point due to load concentration followed by the delamination of the compressive flange between the interface of CFRP and GFRP layers.
2) Composite beams consisting of HFRP beams and concrete topping slabs significantly improve their flexural stiffness and effectively utilize the superior properties of the HFRP materials.
3) The use of UHPFRC slab is more effective than NSC slab in terms of structural stiffness and weight.
4) HFRP-UHPFRC composite beams with headed bolt shear connectors provide considerable stiffness and strength increase compared with HFRP beams without concrete topping slab.
5) Composite beams with epoxy bonding between the UHPFRC slab and HFRP beam top flange showed an approximately 15% increase in flexural stiffness than beams connected with bolts only.

Thank you for your kind attention.