MŰEGYETEM 1782

fib CEB-FIP

fib-course
on
„UHPC materials and structures"

Challenging concrete structures for the low carbon society

27 August 2024, Budapest

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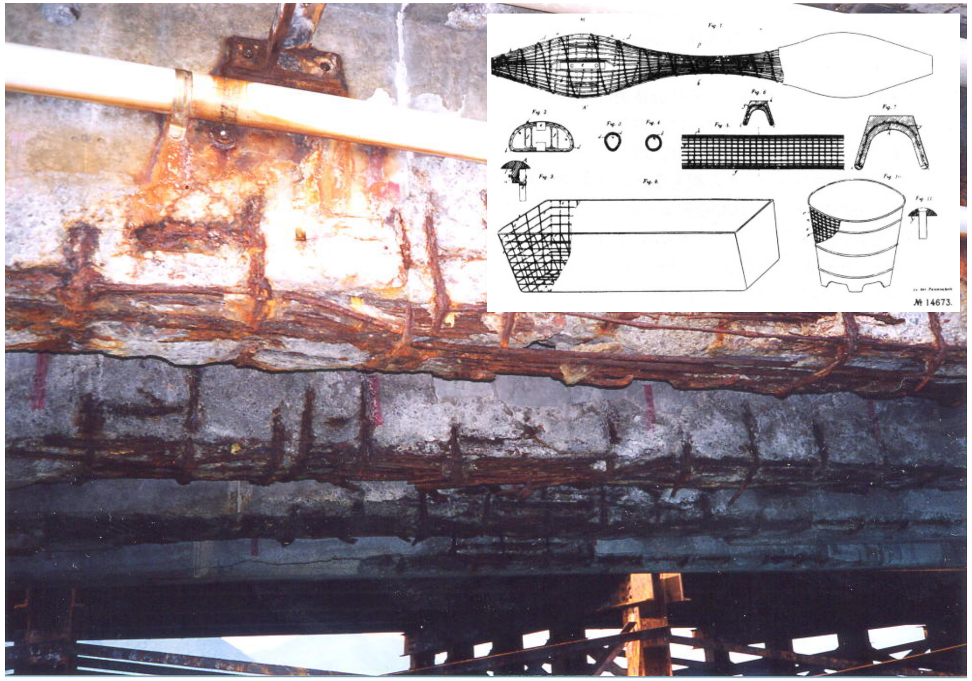
Sumitomo Mitsui Construction

Should we go back to the Roman concrete?

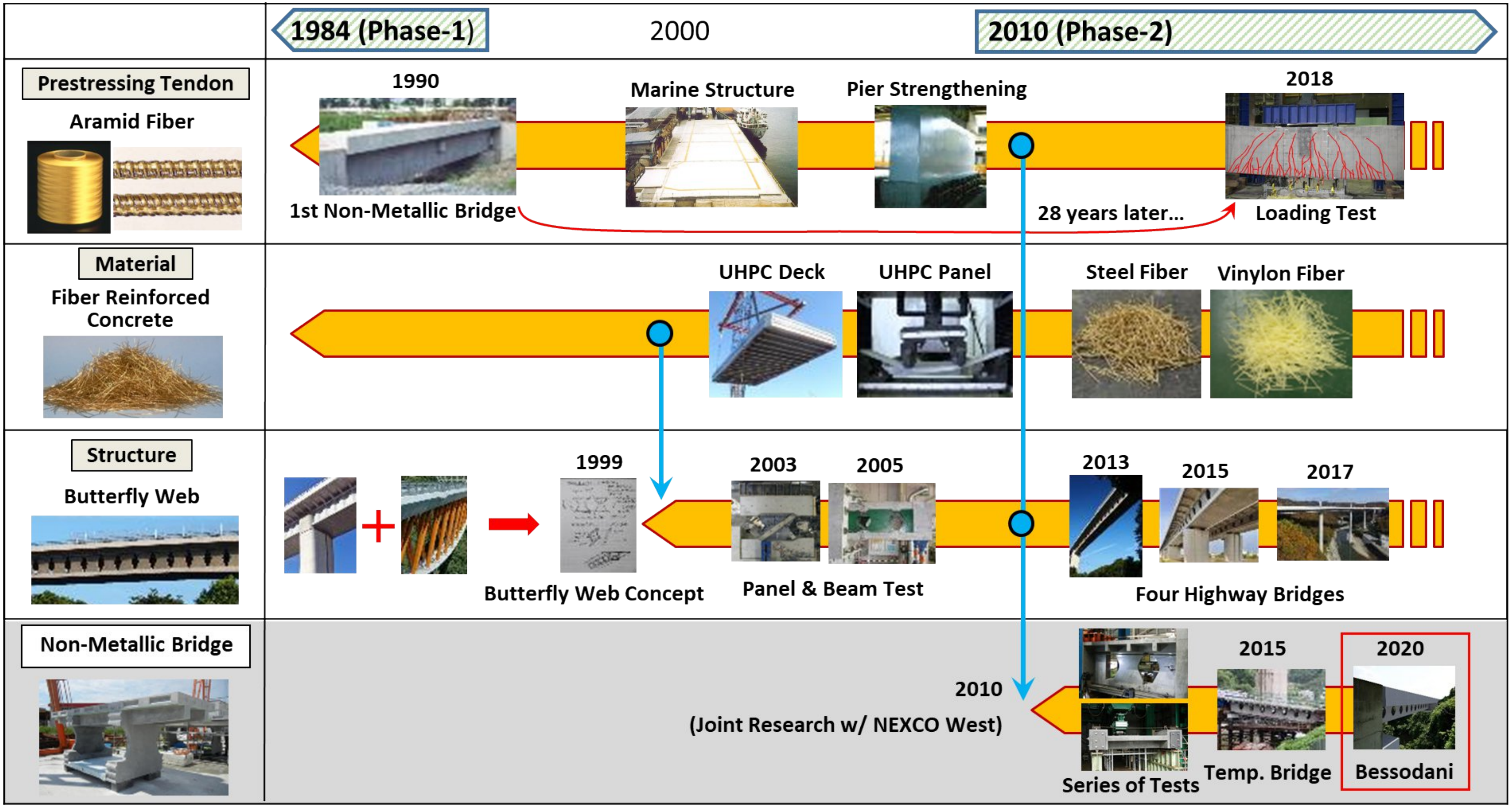
- ✓ Invention 1, Portland Cement : 1824 (UK)
- ✓ Invention 2, Reinforced Concrete : 1867 (F)
- ✓ Invention 3, Prestressed Concrete : 1936 (F, D)

≠



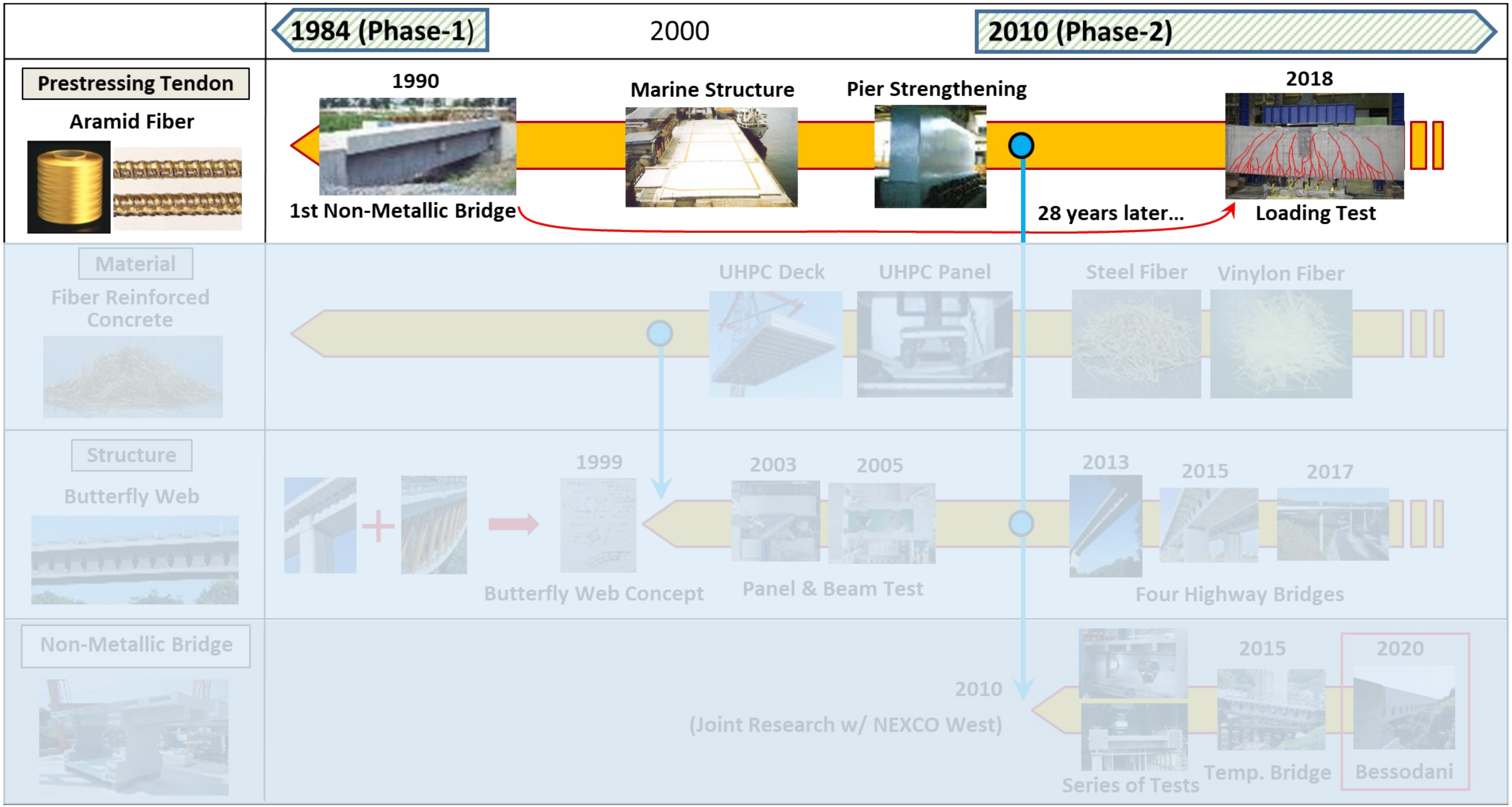
Pantheon (Rome, BC25)

History of non-metallic bridges



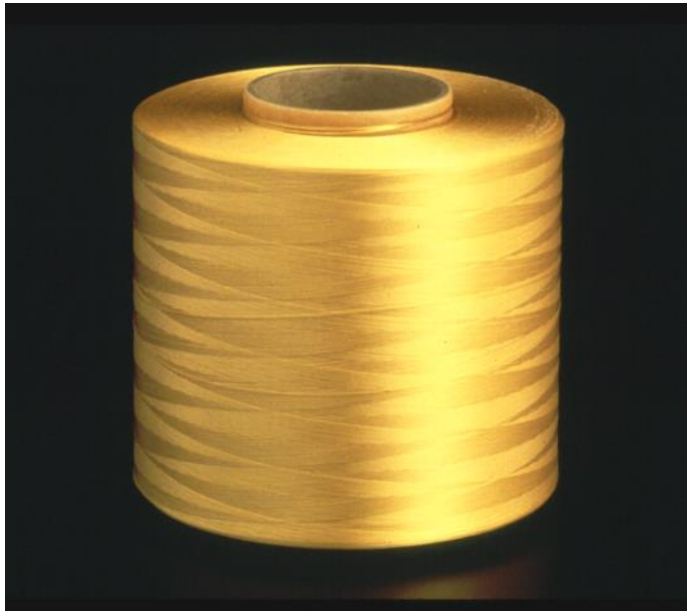
1. 1st generation non-metallic bridges (1984 -)

History of non-metallic bridges

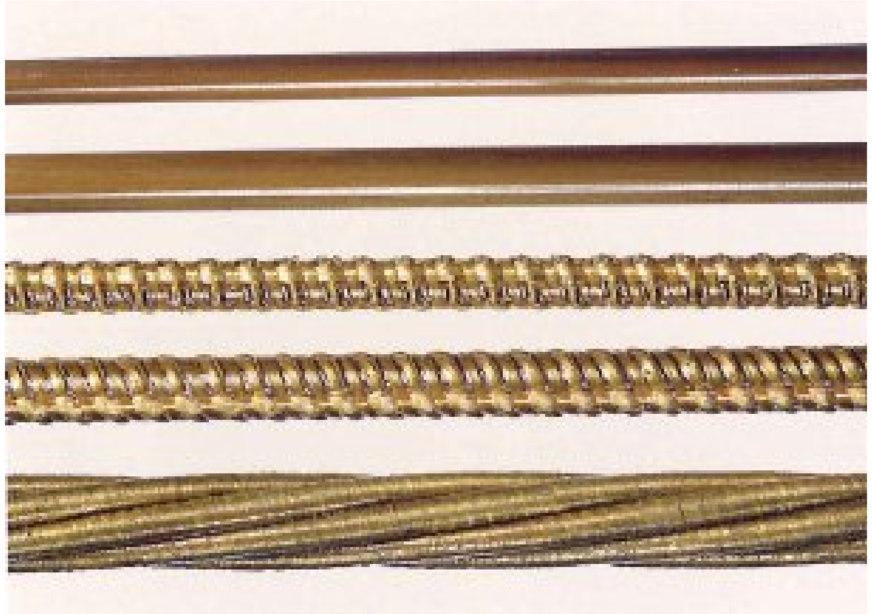


Aramid FRP for prestressing tendons

✓Technora© by Teijin has alkali resistance.



Aramid fiber



Aramid FRP rods & strand

1st generation non-metallic bridges

Pre-tension beams
(Non-metallic bridge)

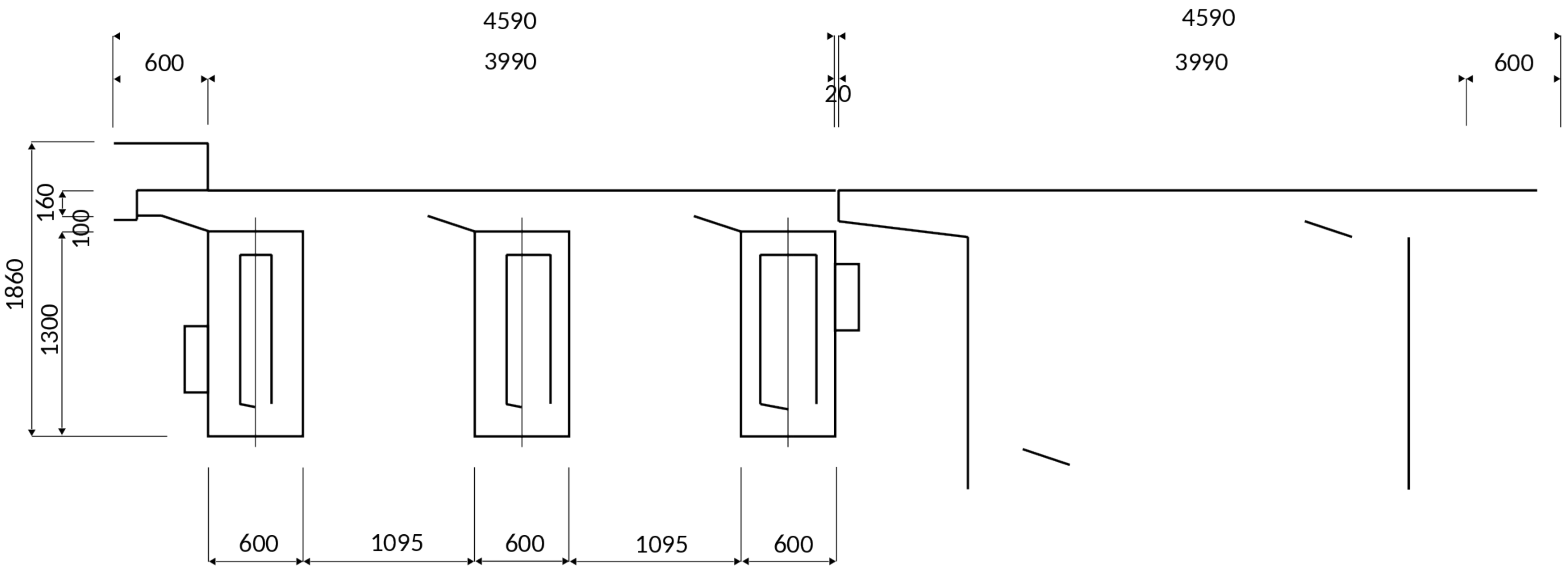
Post-tension beam
(Nom-metallic tendon)

1st generation non-metallic bridges

✓Development of non-metallic structure targeted for maglev train.

L=12.5m

L=25.0m

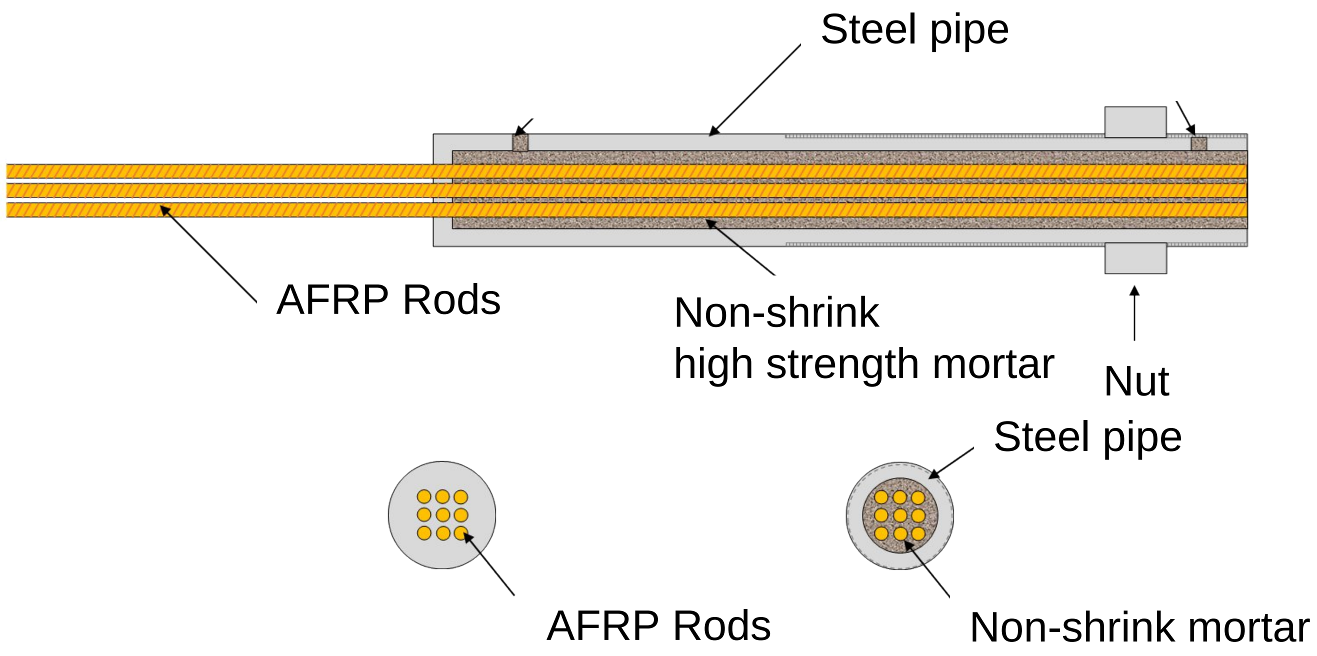


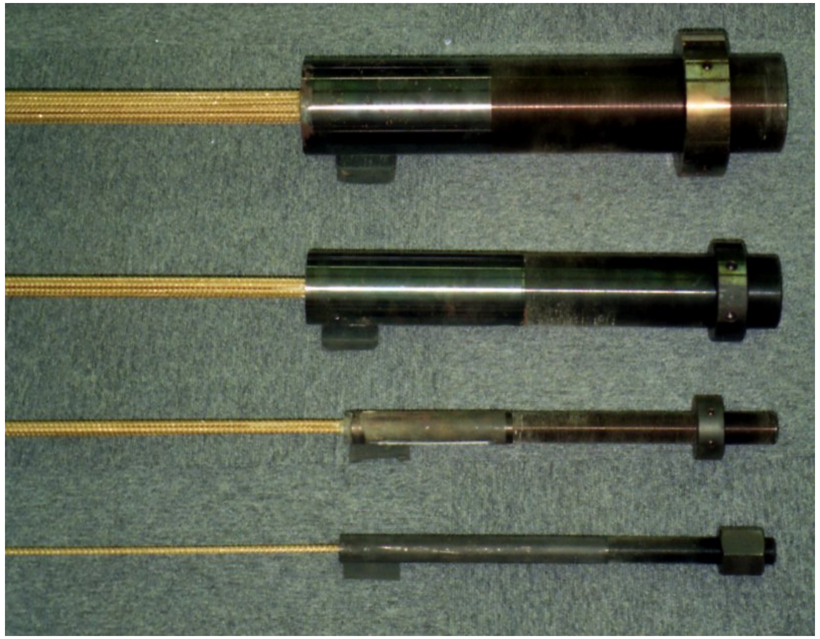
Pre-tension beams
(Non-metallic bridge)

Post-tension beam
(Nom-metallic tendon)

Temporary steel anchorage for AFRP tendons

✓AFRP is anchored by bond stress with high strength non-shrink mortal.

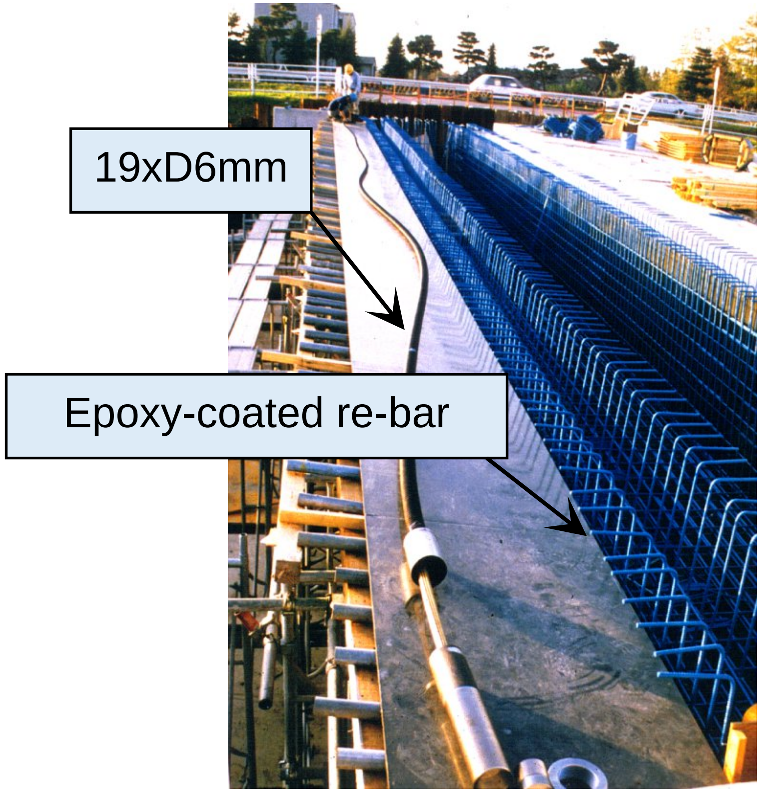




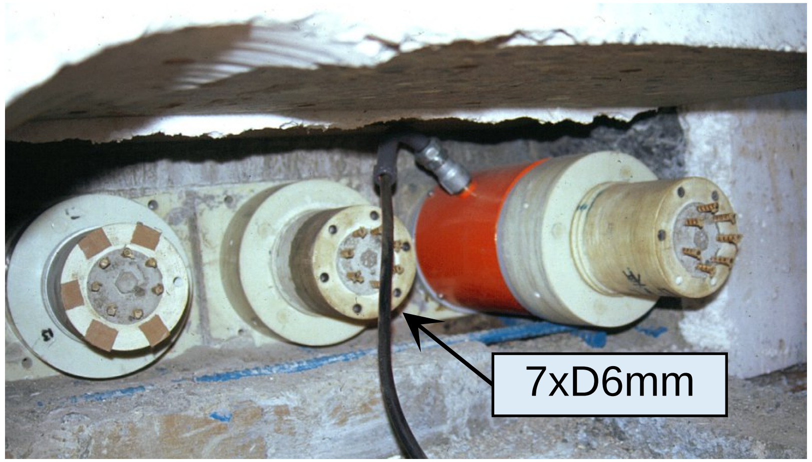
Temporary steel anchorages

Non-metallic bridge (post-tension beam)

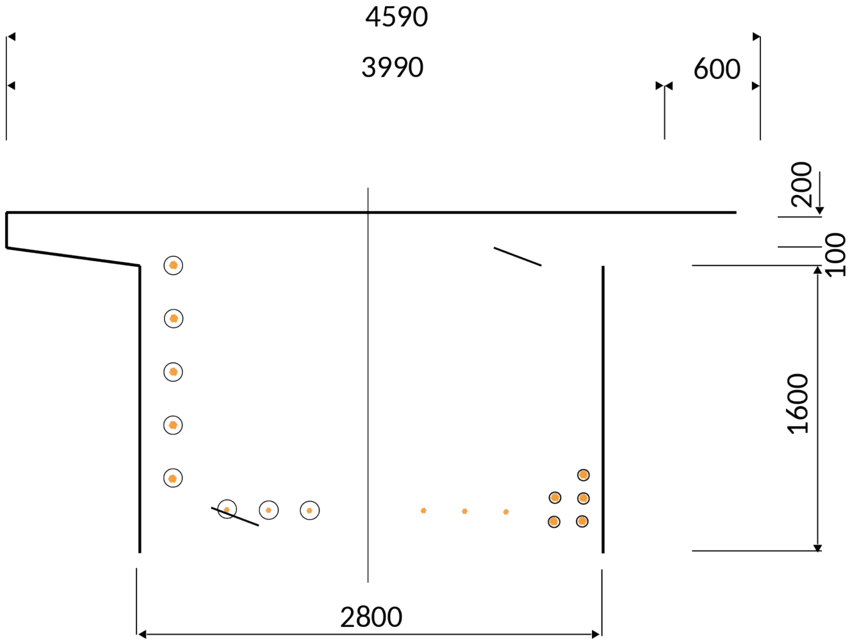
✓Epoxy-coated steel re-bars and AFRP internal and external tendons



L=25.0m

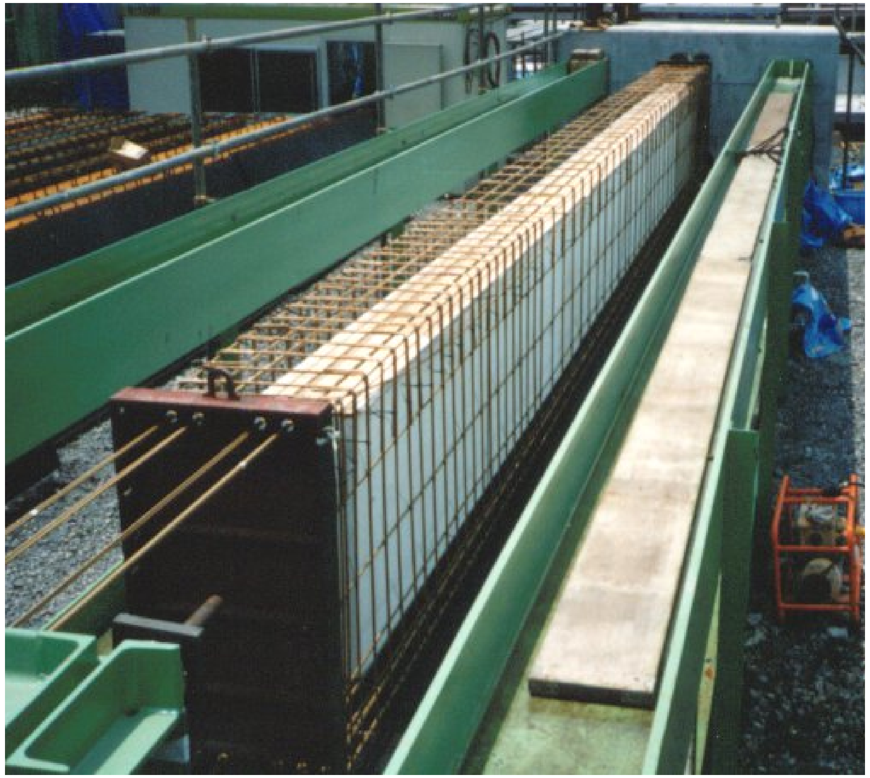


GFRP anchorage for
AFRP external tendons

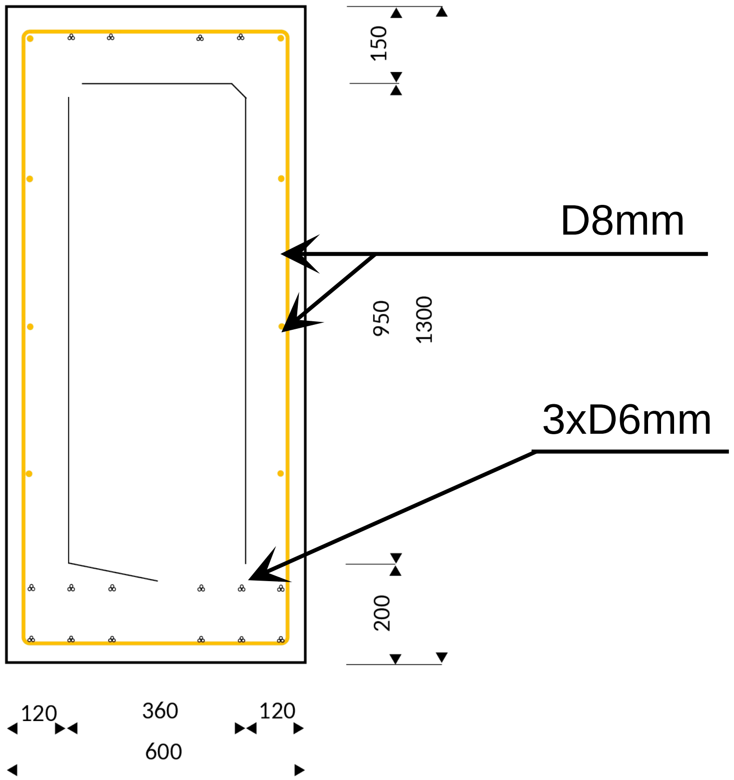


Non-metallic bridge (pre-tension beam)

✓All reinforcing materials are AFRP.



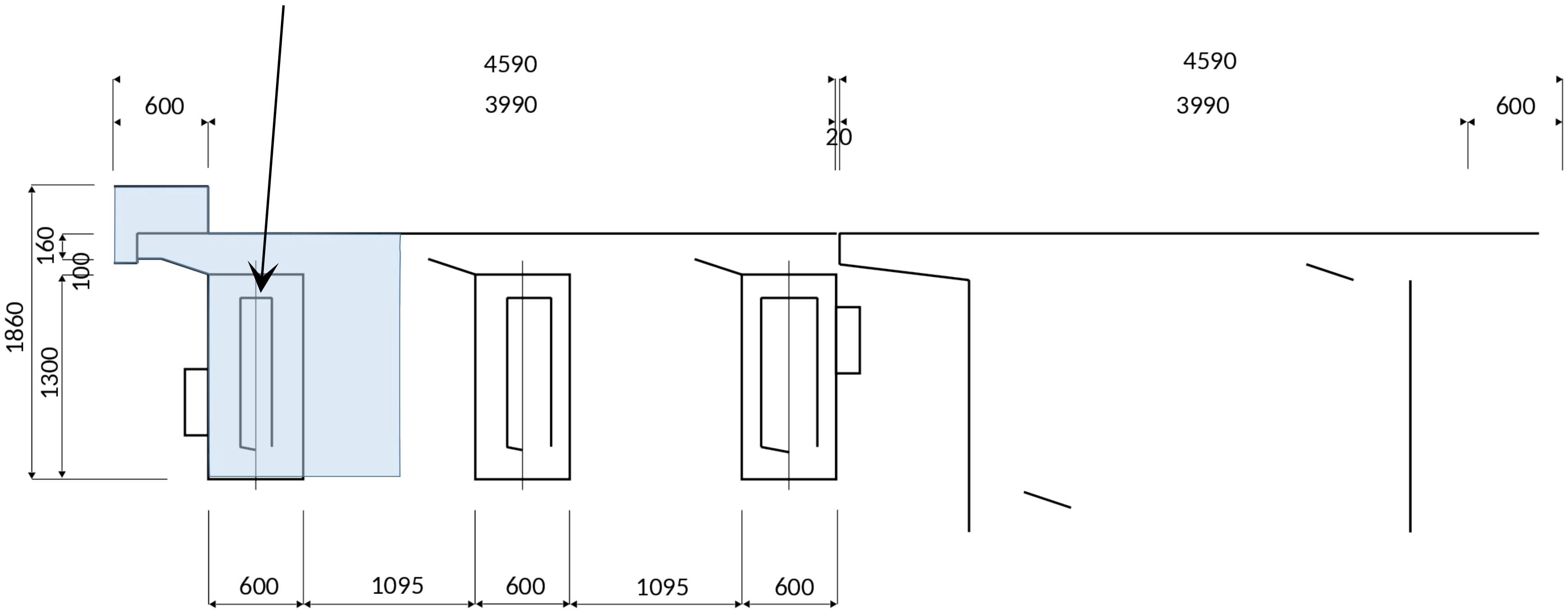
L=12.5m



✓But cost was **2.5 times**! Then 1st generation non-metallic bridge was suspended.

28 years old beam (2018)

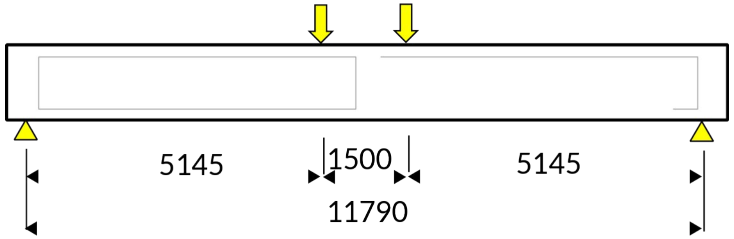
28 years old beam was removed and tested in 2018.

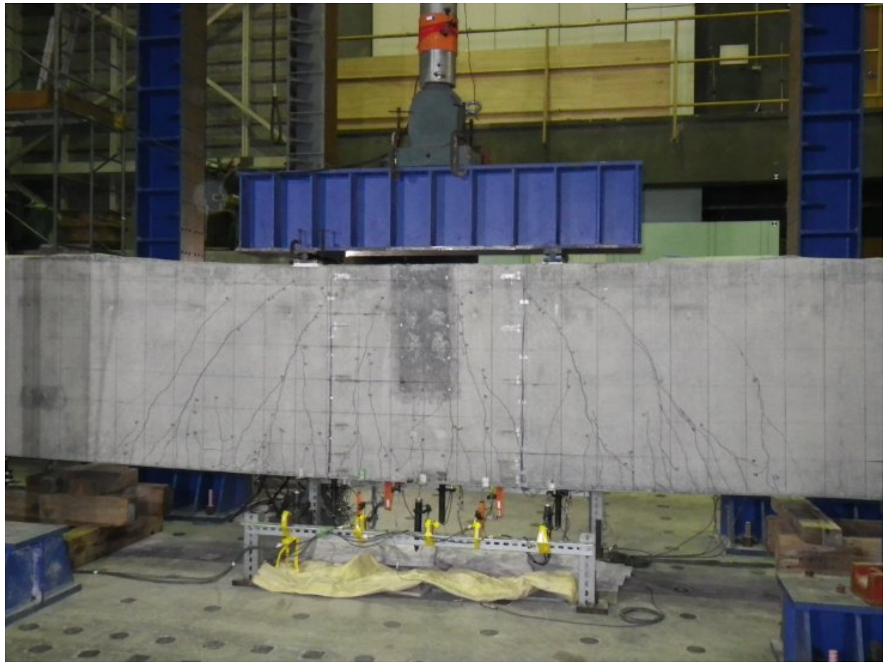


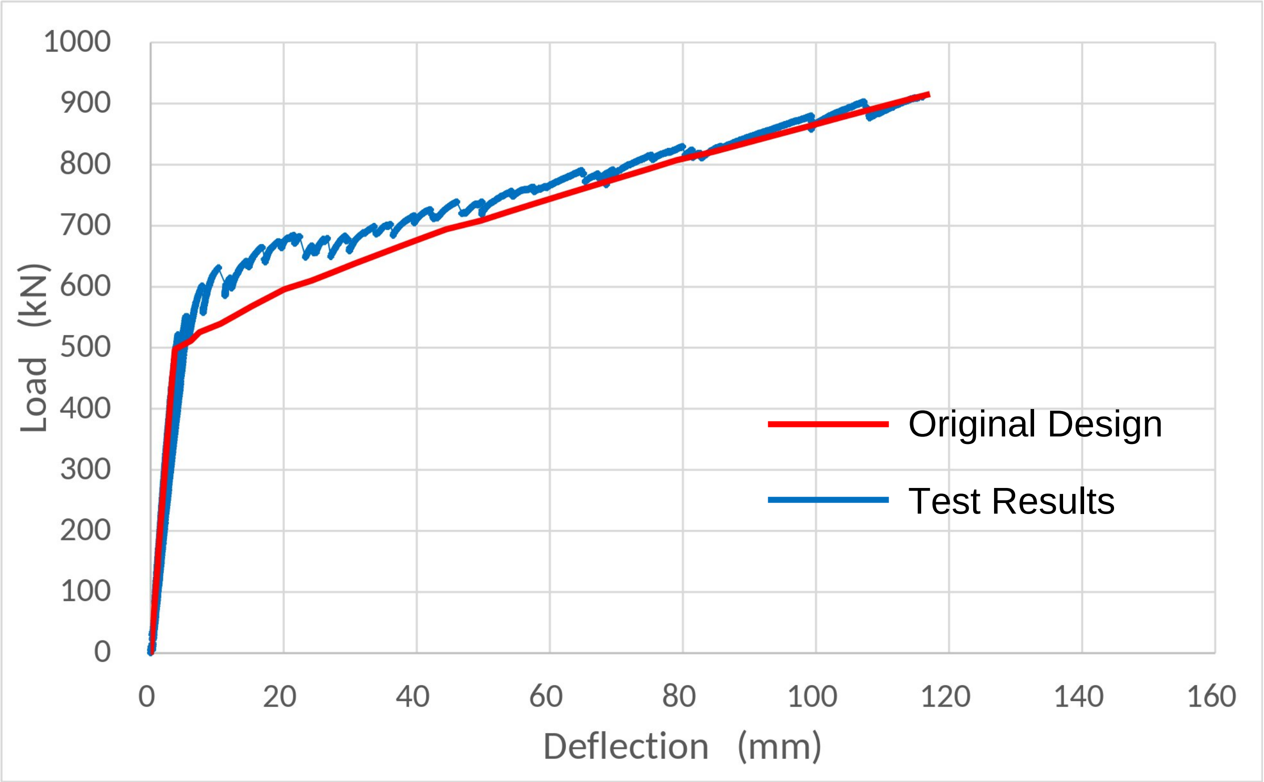
Pre-tension beams
(Non-metallic bridge)

Load bearing capacity test (2018)

✓28 years old beam performed very well.



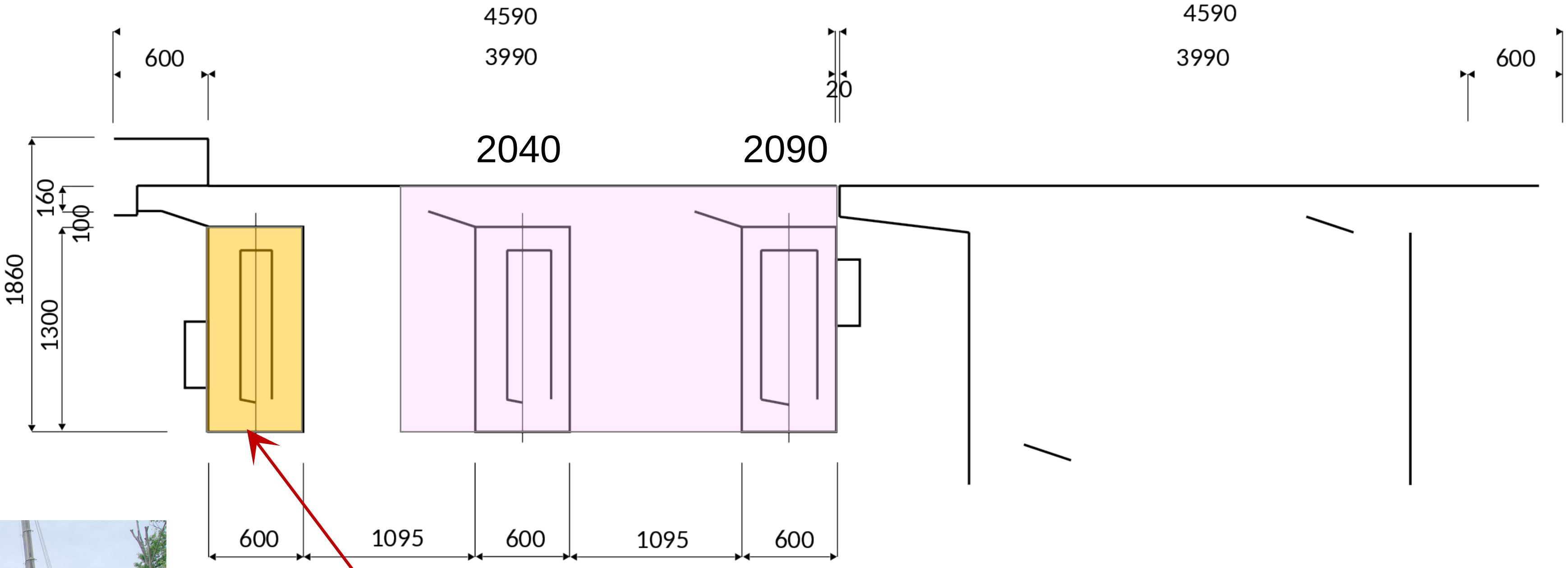




Load VS Deflection

In the future

✓We still have two specimens for 2040 and 2090.

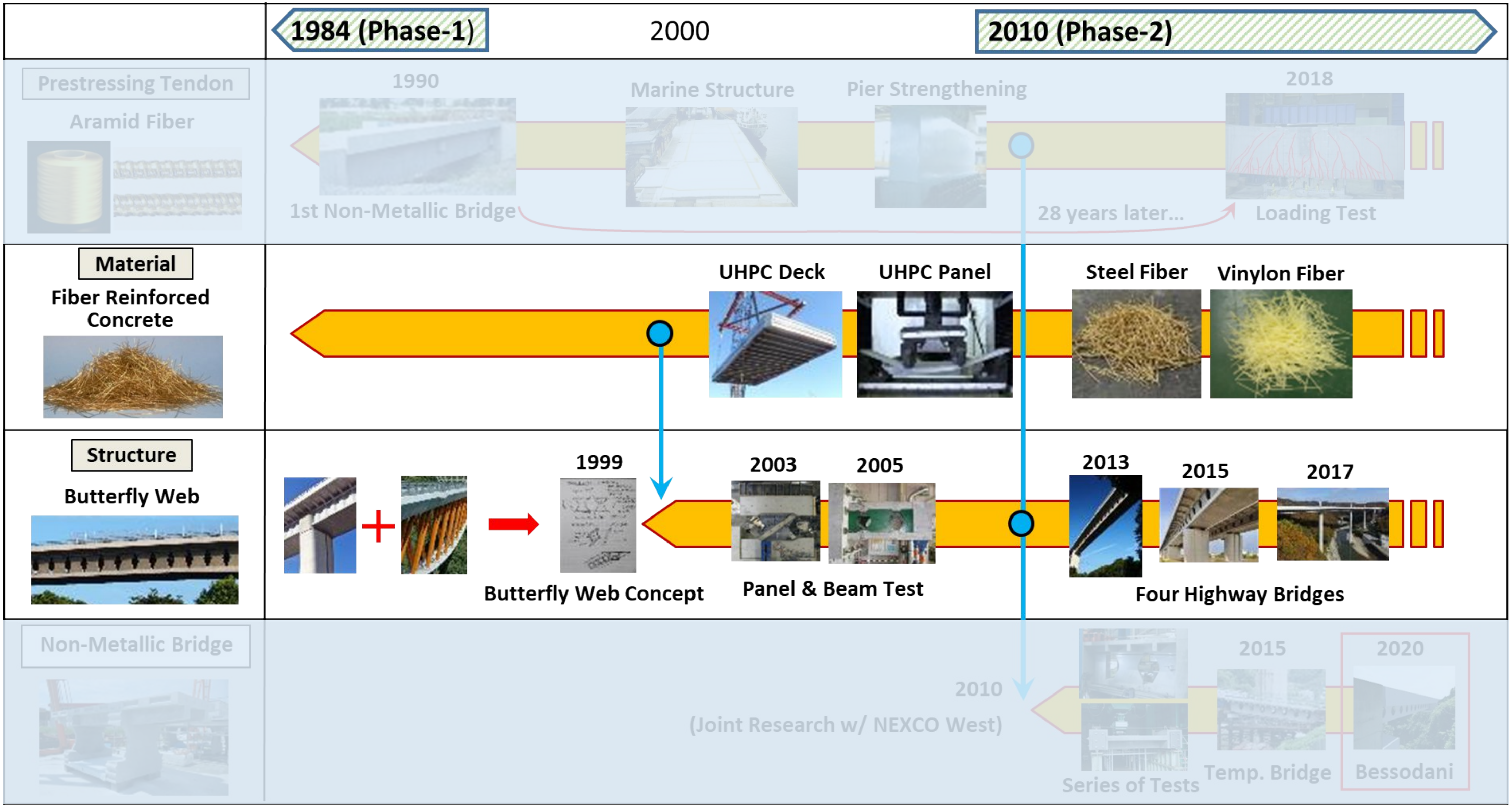


Zero cement concrete + AFRP

2. Evolution of materials and structures (2001-)

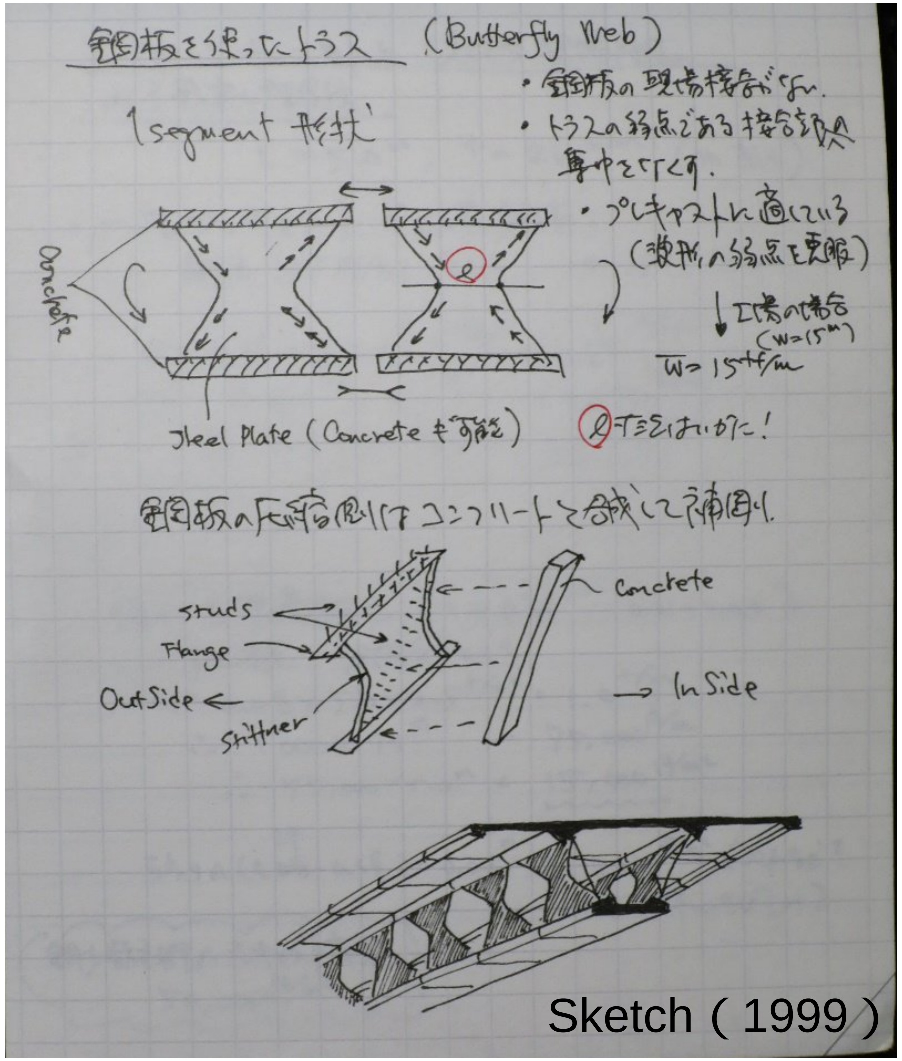
Butterfly web and fibre reinforced concrete

History of non-metallic bridges



Conceptual design of butterfly web bridge

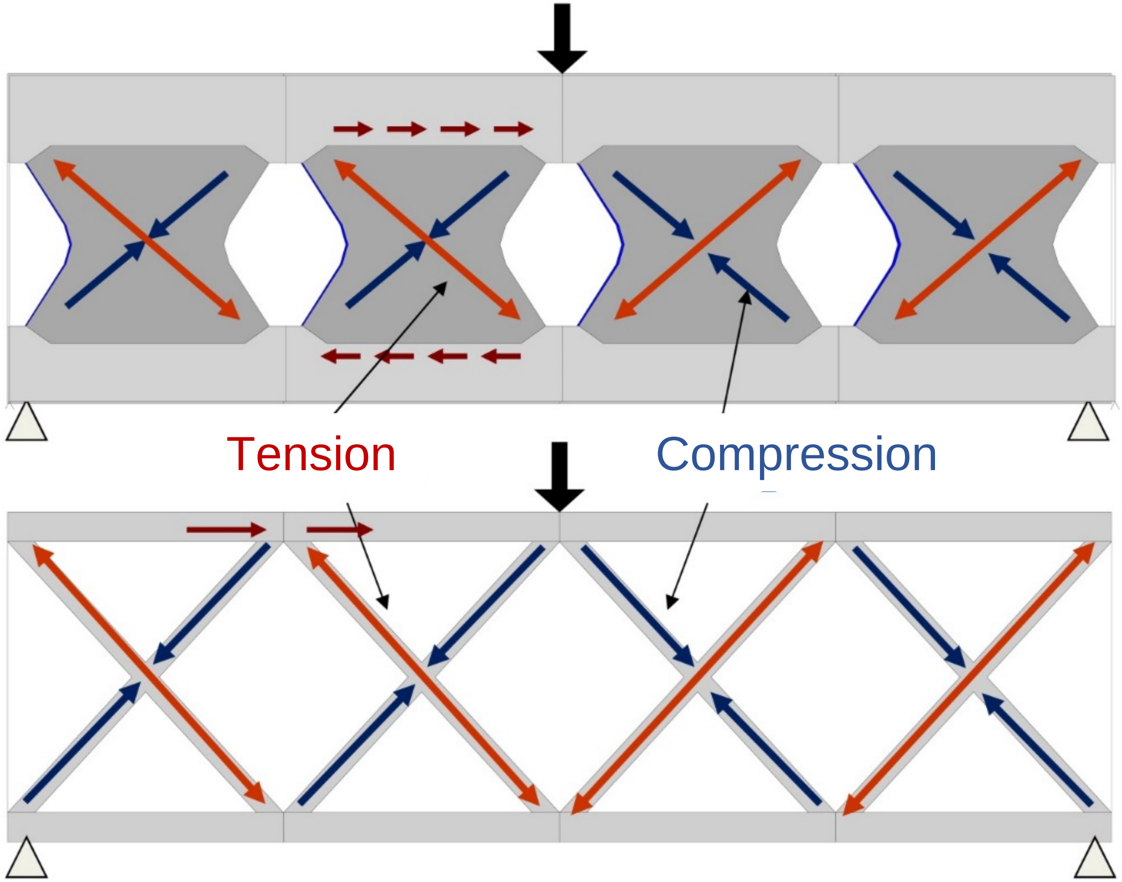
✓ Butterfly webs can make structures lighter.



Sketch (1999)

Structural behavior of butterfly web bridge

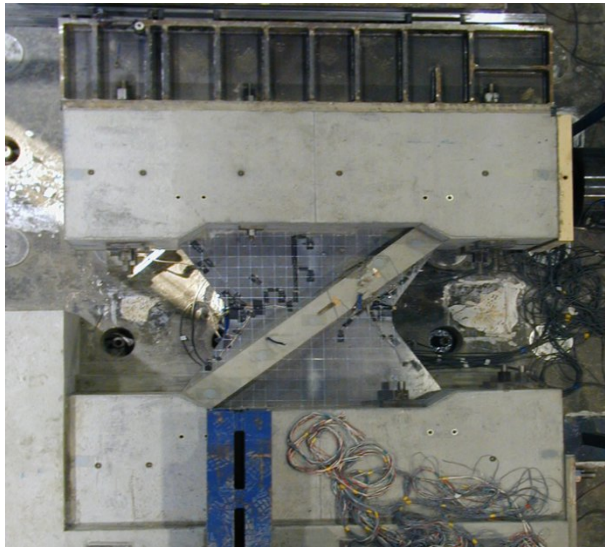
- ✓ Structural behavior of butterfly web = Double Warren Truss



A series of tests for butterfly web (steel panel)

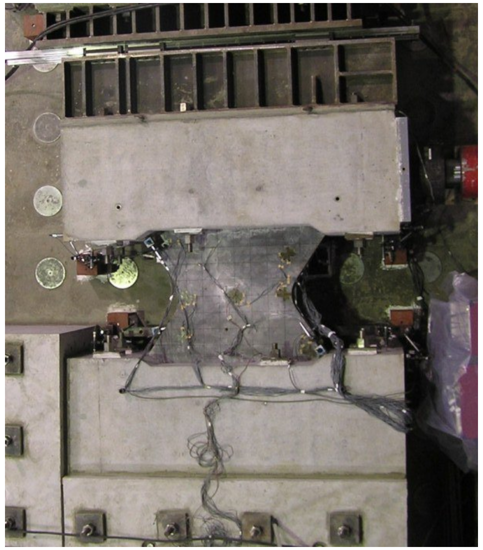
- ✓ Confirmation of fractural mode
- ✓ Establishment of design method

Steel panel (2003)



Beam (2005)

UHPC panel (2006)



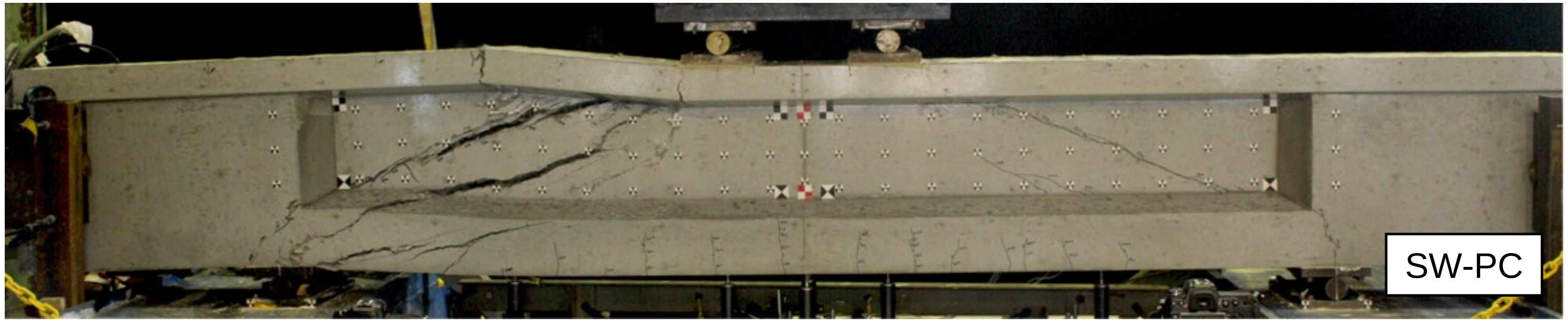
Material properties of HPC (concrete panel)

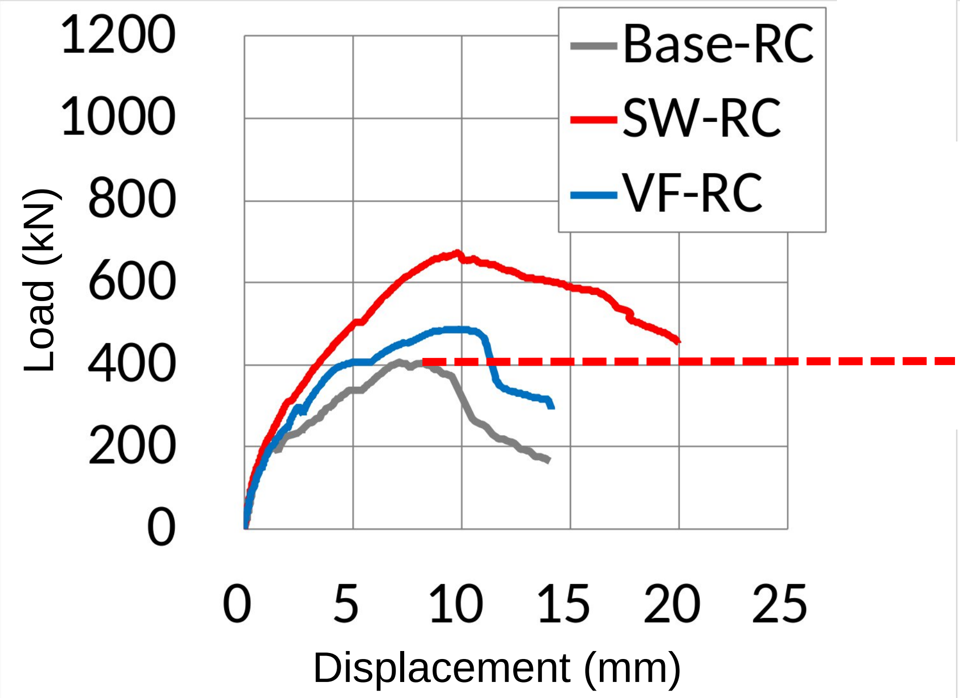
✓ No special materials are used.

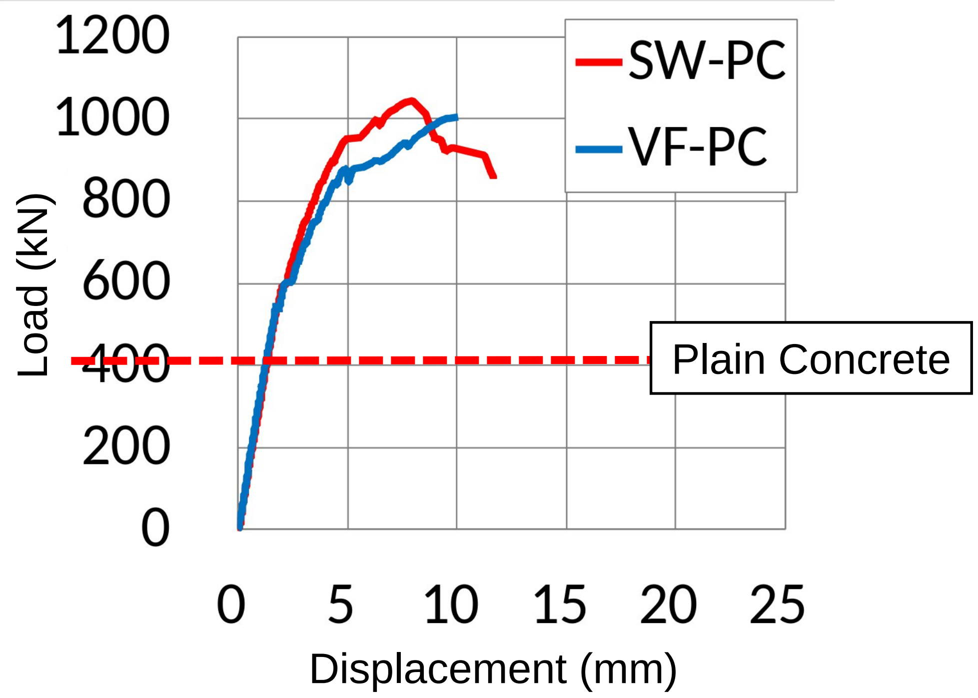
- f_{ck} = <u>80MPa</u> concrete base
- More than 2000N/mm^2 tensile strength steel
  0.5% content in volume
  D = 0.2mm, L = 22mm steel fiber

Name	Steel Fiber		Slump	W/B	Content (kg/m^3)				
	sort	volume	(cm)	(%)	W	C	SF	S	G
SW	SW	0.50%	20±2.0cm	25	175	630	70	408	596

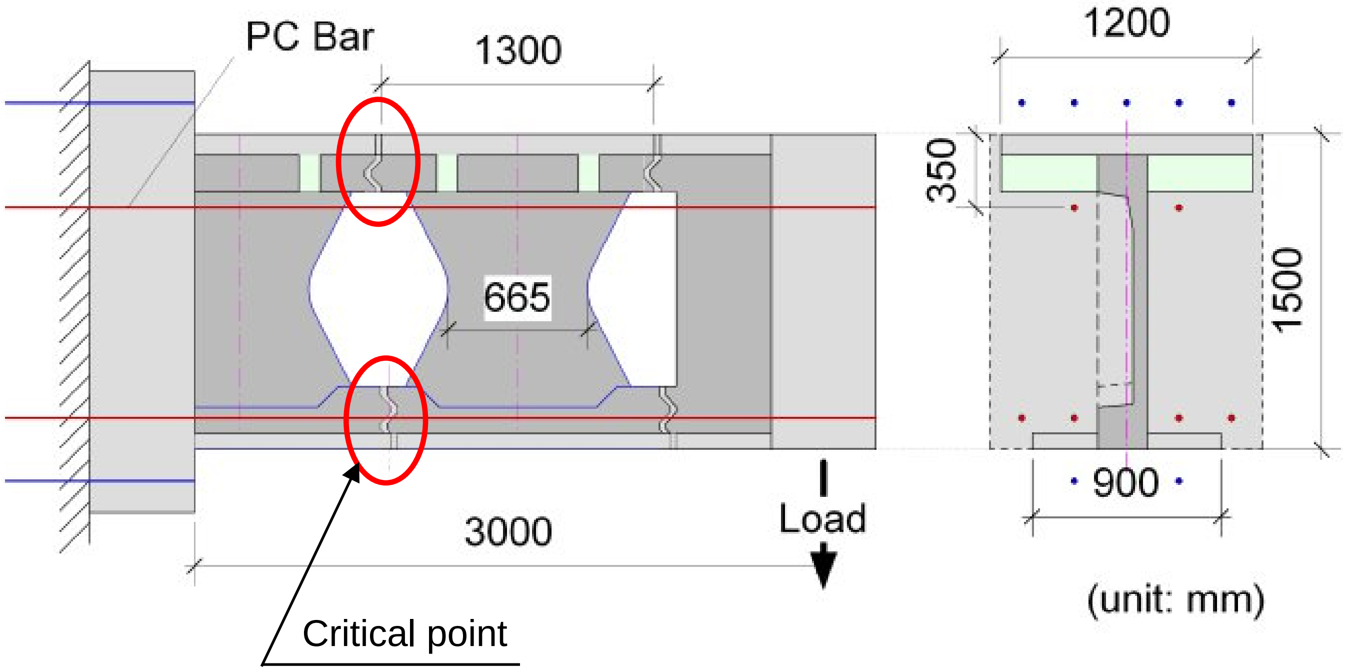
Flexural strength test of prestressed concrete beam

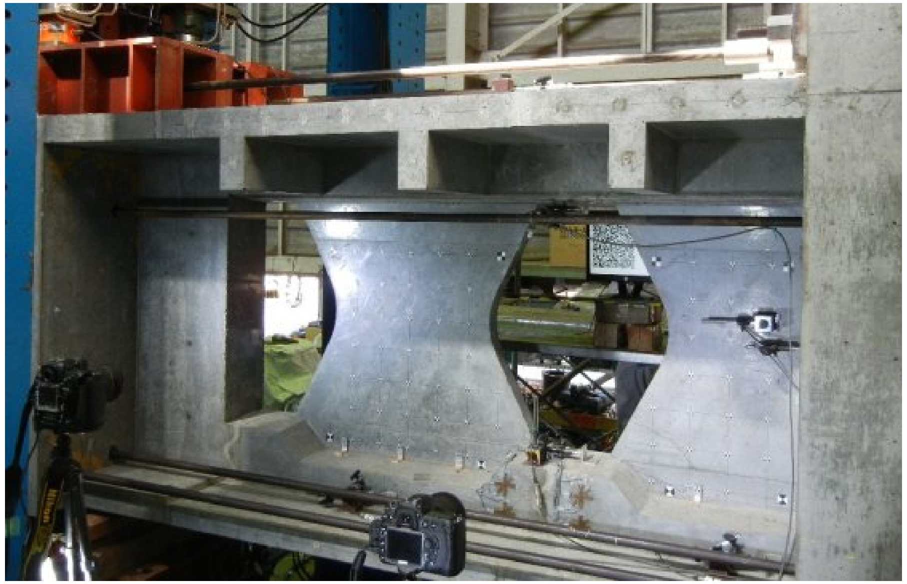






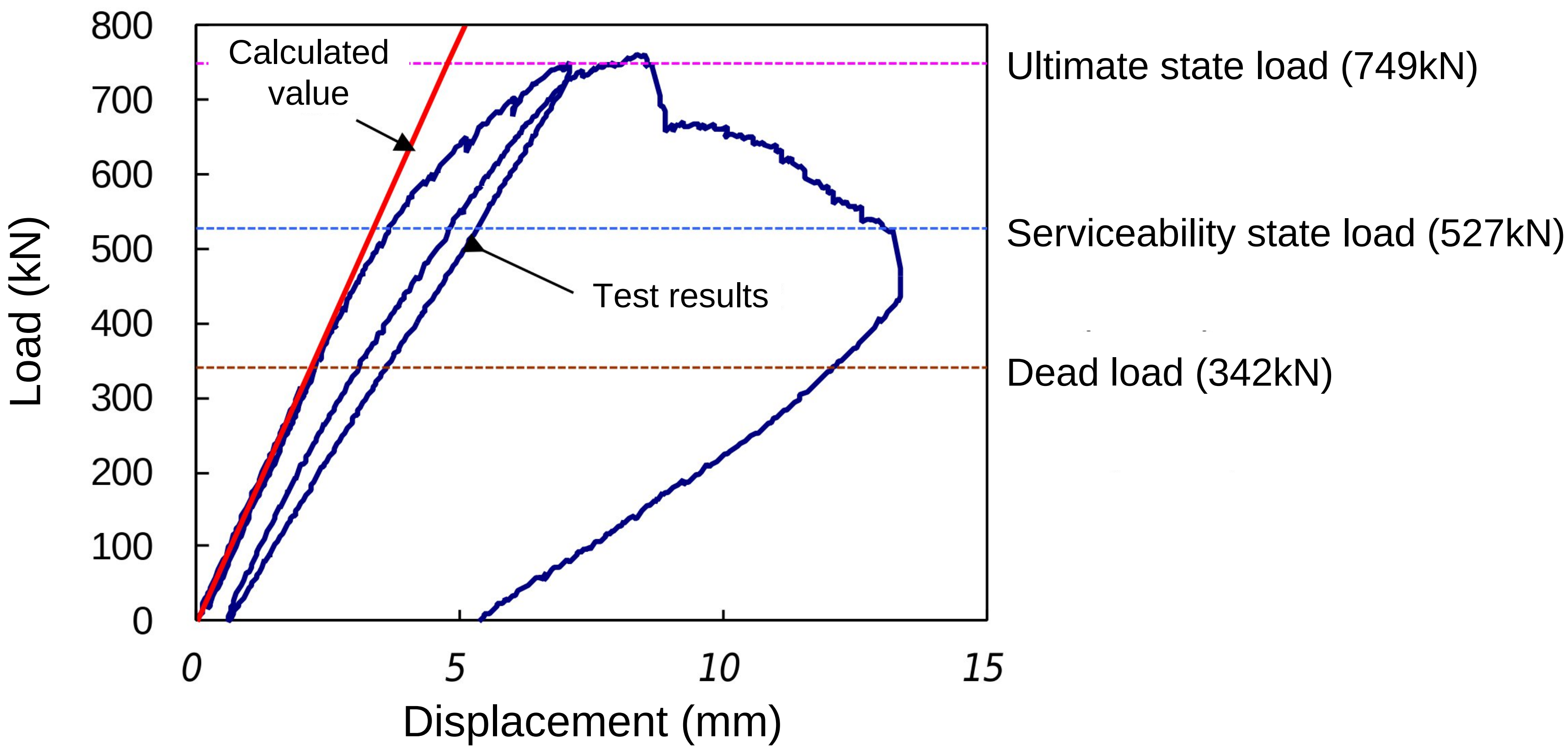
Beam test of HPC butterfly panels



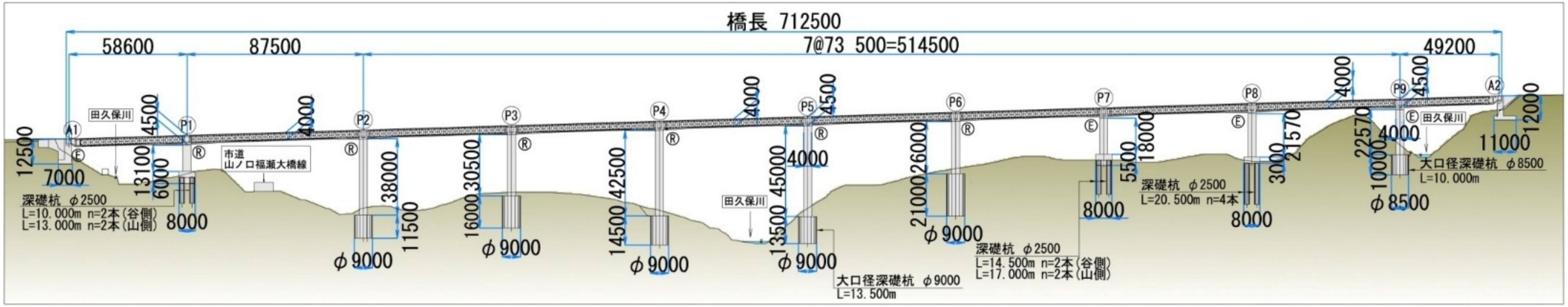


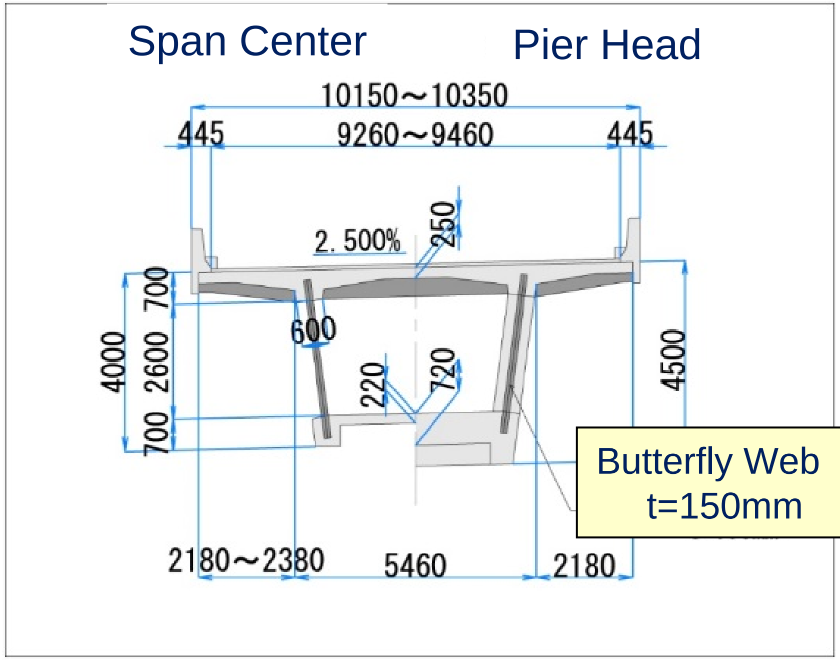
Results of beam test

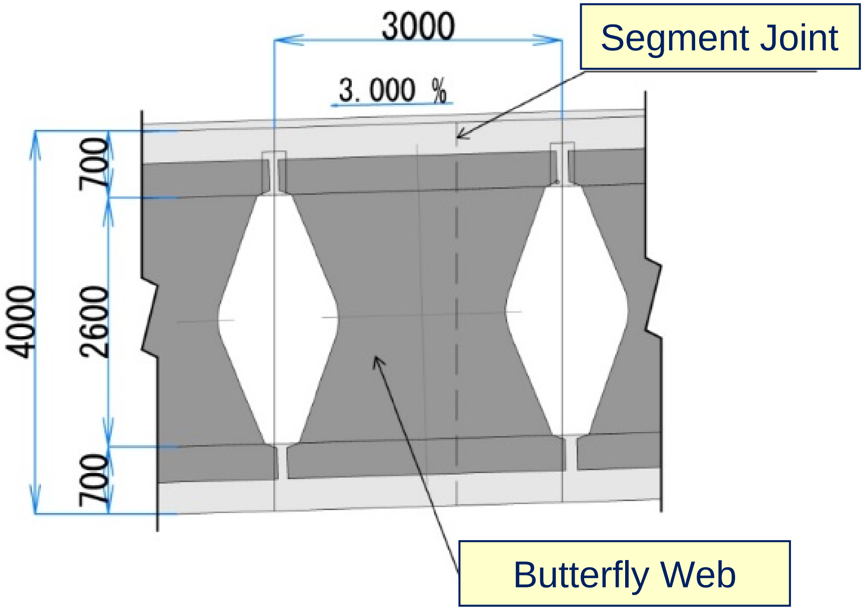
- ✓ Shear capacity can be designed by the ordinal design method.
- ✓ Developed detail provided required strength.



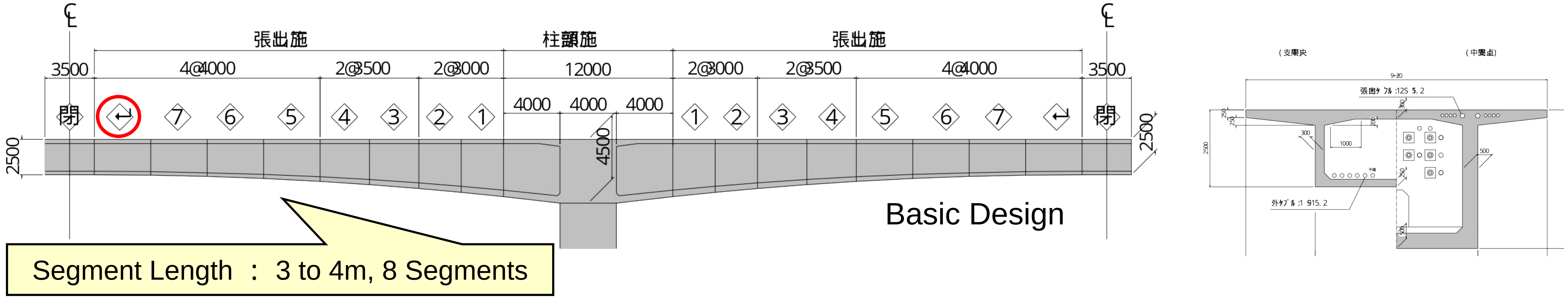
Takubogawa Bridge (2013)

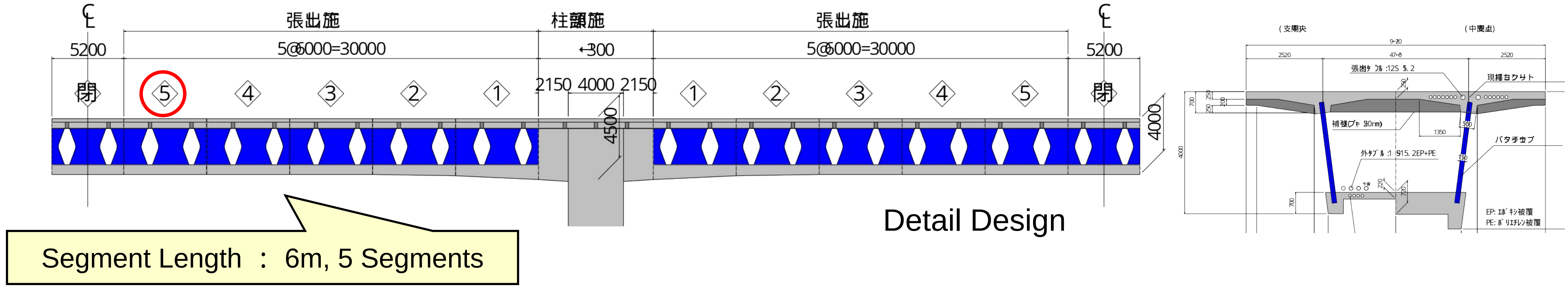






Conventional box girder VS new structure





Prefabrication of butterfly web panels

Pretension steel strands

Butterfly panels

Cantilevering construction

Inside view

Easy maintenance!

Takubogawa Bridge (2013)

Achievements of butterfly web bridges

Takubogawa Bridge
(2013)

Okegawa Viaduct
(2015)

Akutagawa Bridge
(2015)

Mukogawa Bridge
(2017)

Bessodani Bridge
(2020)

Nakatsugawa Bridge
(Under construction)

Okegawa Viaduct (2015)

✓Bridge deck area : 35,000 m^2 = 18 months construction time

Mukogawa Bridge (2017)

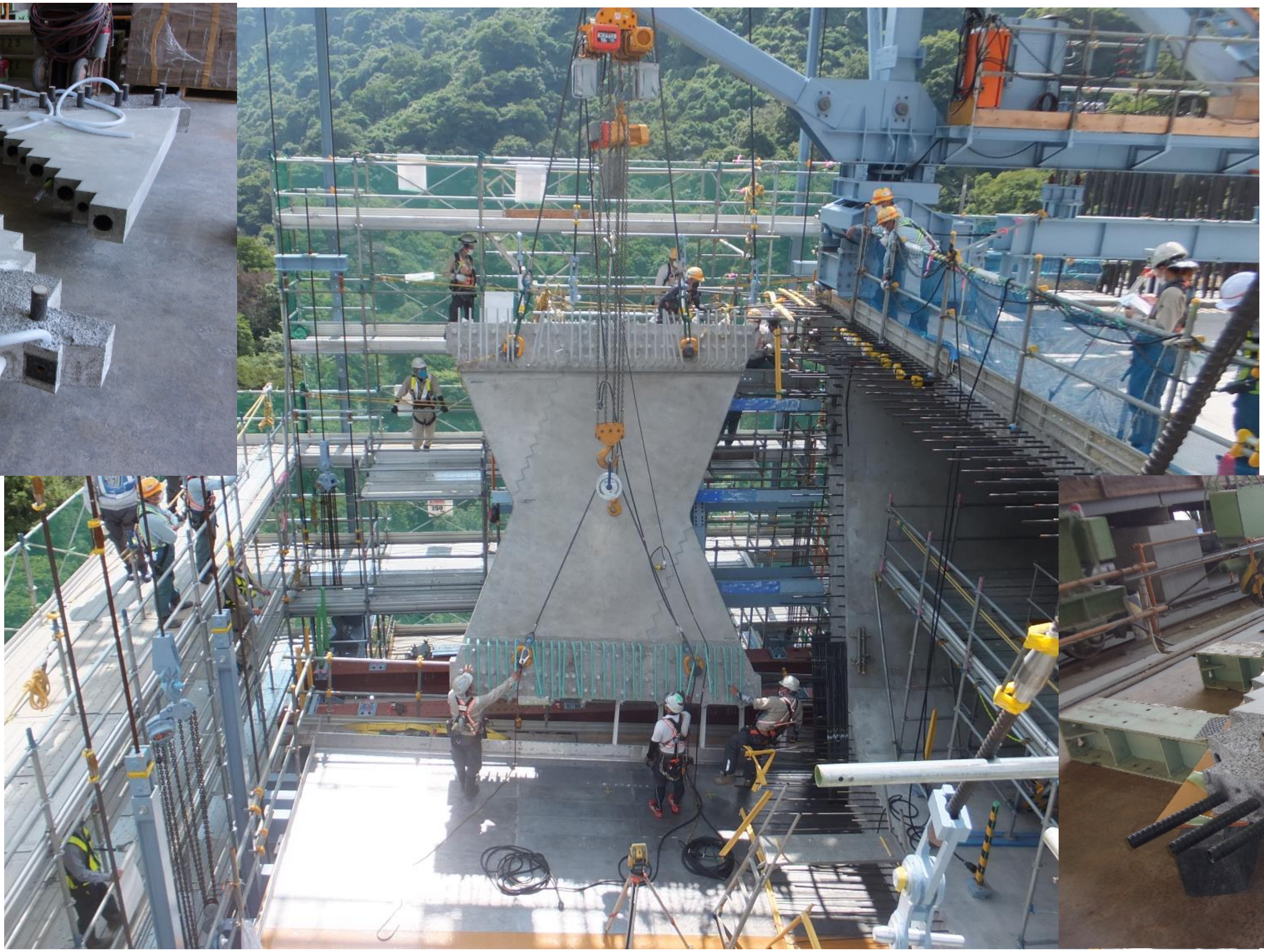
✓ Extradosed bridge with butterfly web

Nakatsugawa Bridge (under construction)

Nakatsugawa Bridge (under construction)

- ✓ Large size butterfly web

Side triangular parts



Central square part

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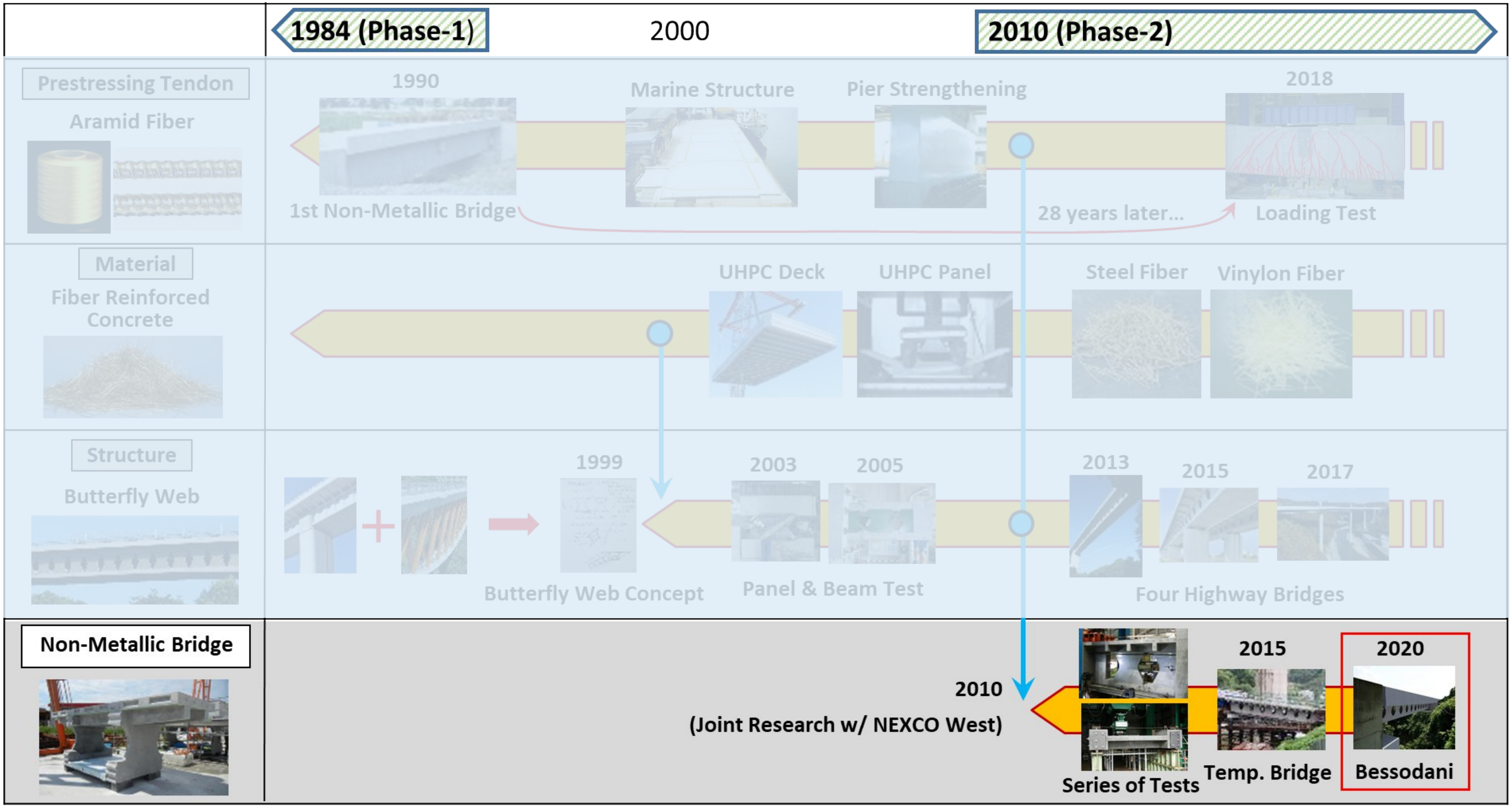
Nakatsugawa Bridge (under construction)

3. 2nd generation non-metallic bridges (2010 -)

History of non-metallic bridges



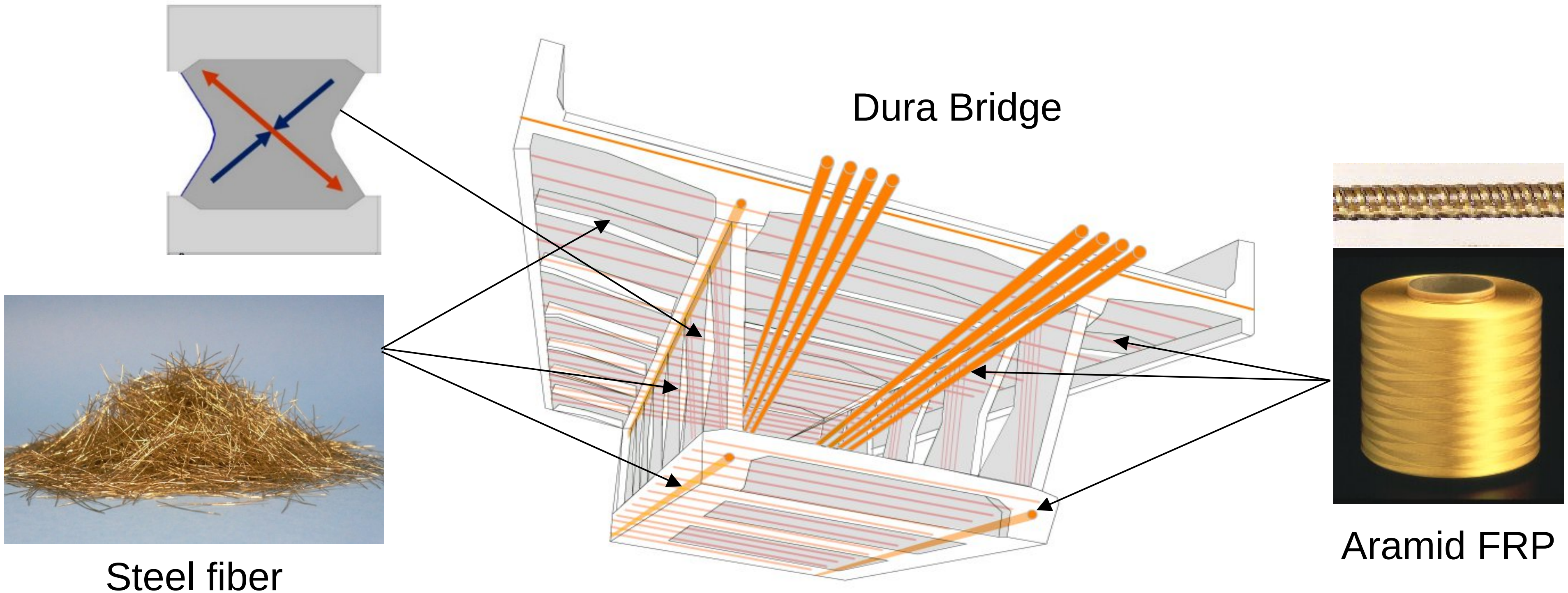
Joint research with NEXCO West (2010 -)

- **Requirements**
  - 1.5 times of initial cost. (< Maintenance cost is 2 to 2.5 times of initial cost)
  - Minimum life cycle cost. (= Almost no maintenance)
- **Different situation from 1G**
  - Fiber reinforced concrete has been available. (= No re-bar in concrete)
  - Development of light weight structure. (= Butterfly web)

Concept of the highly durability of concrete bridge

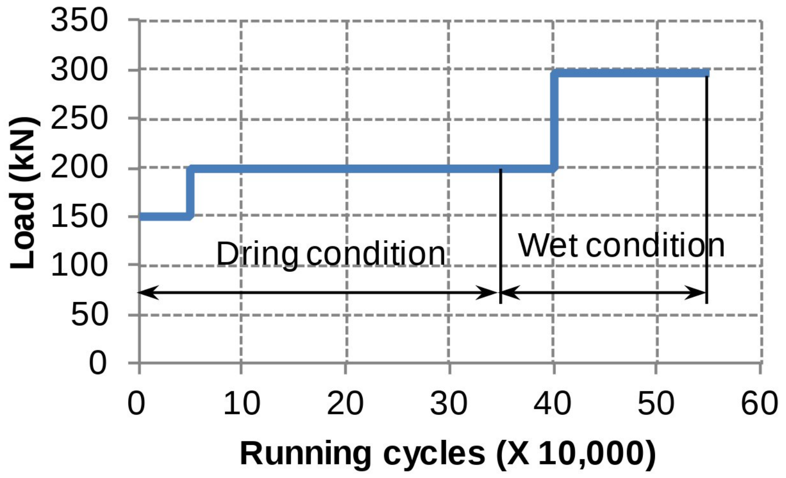
✓Construction cost is within 1.5 times of that by conventional technology.

Butterfly web



Steel fiber

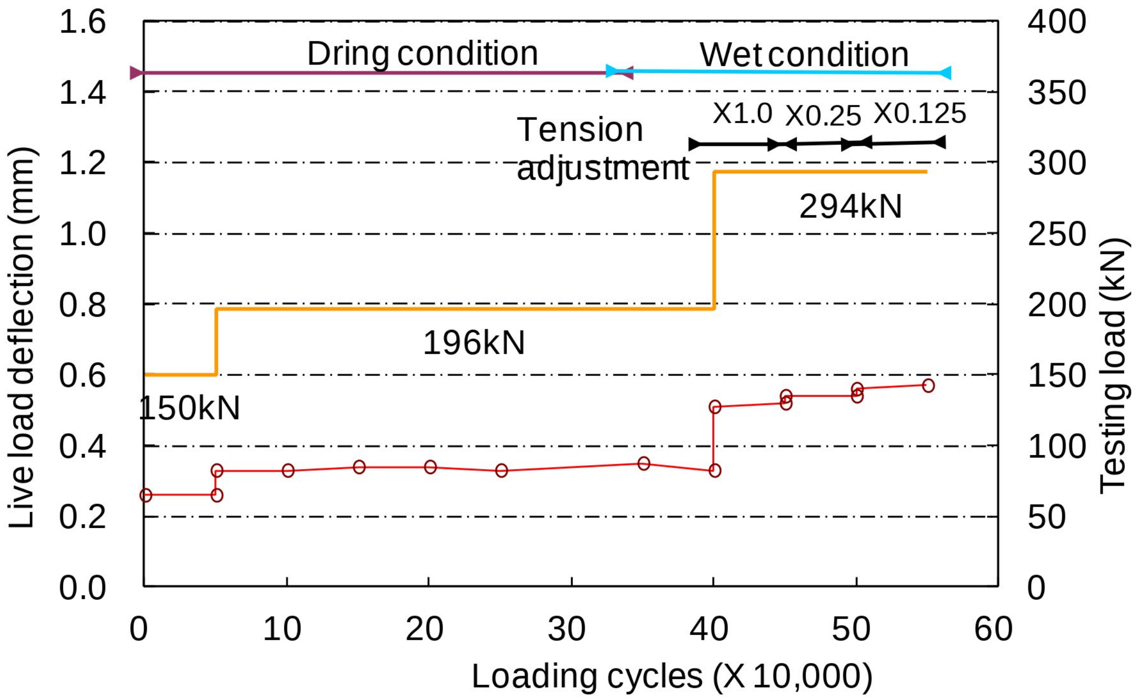
Fatigue test of upper deck (wheel running test)



Fatigue test of upper deck (wheel running test)

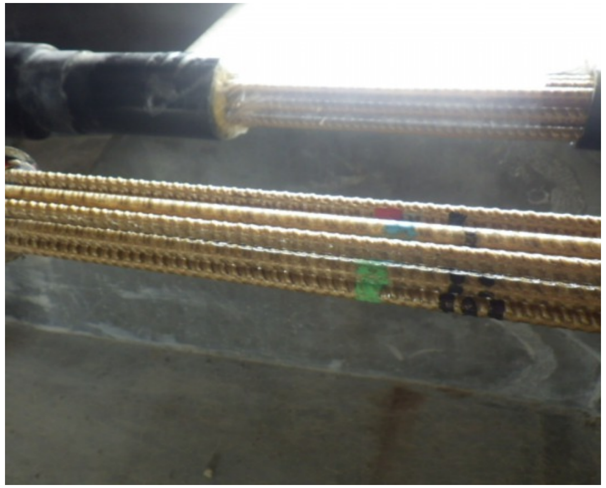
Results of wheel running test

- ✓ No crack, no opening of the Joint
- ✓ No damage after equivalent 100-year loading
- ✓ Same performance as ordinary prestressed concrete deck slabs



2nd generation non-metallic bridge (2015)

Two years temporally bridge (L=14m)



Prefabrication

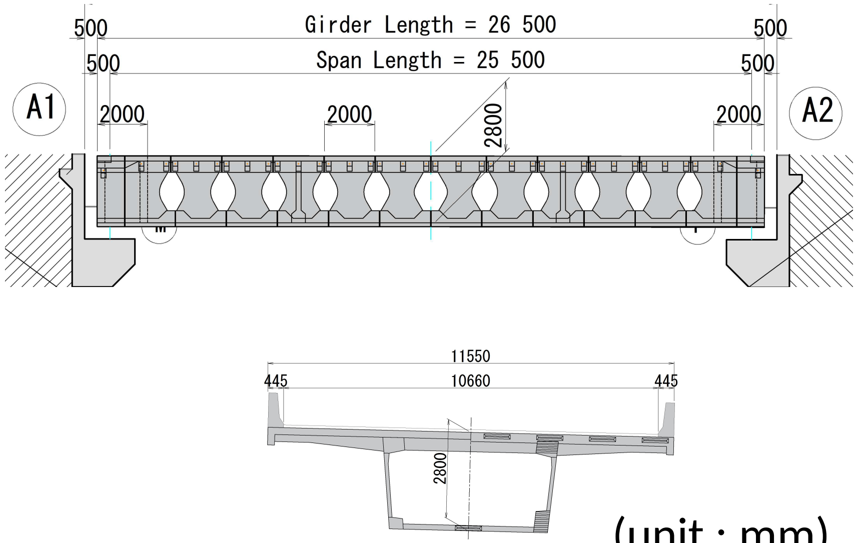
Fabrication of web

Fabrication of upper deck

Bessodani Bridge (2020)

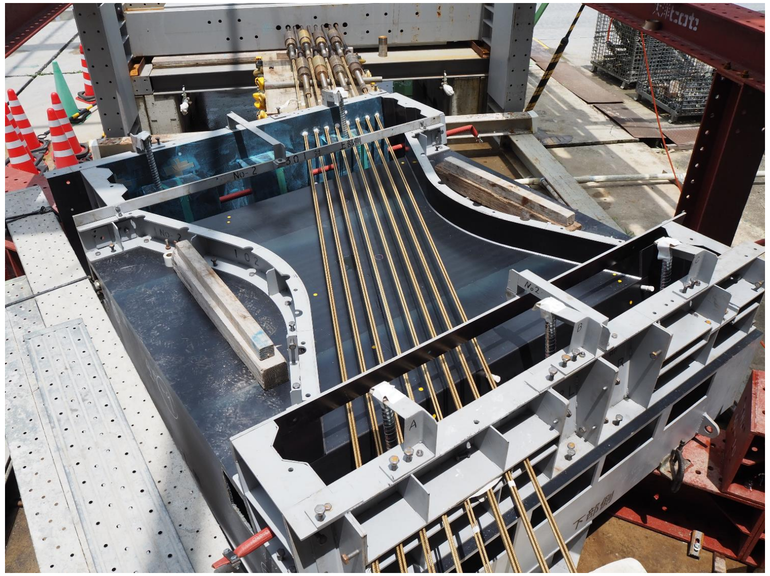
- ✓ 1st in the world as a highway non-metallic bridge

L=25.5m

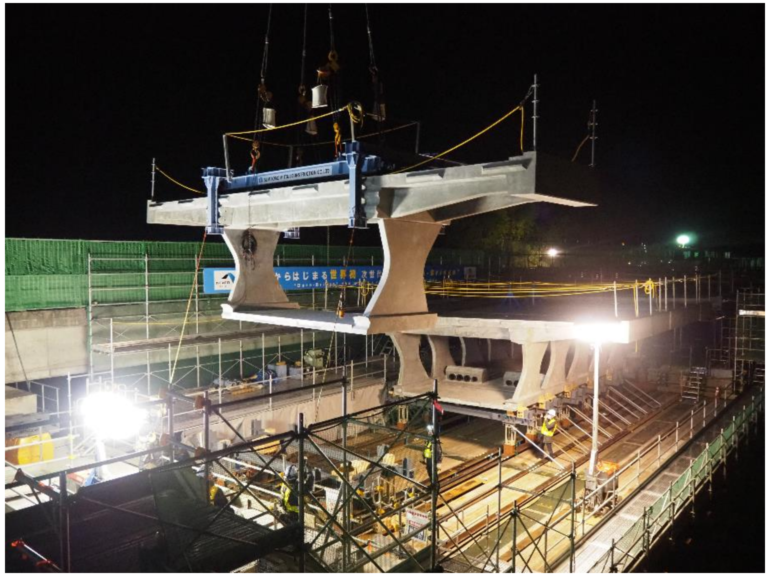


(unit : mm)

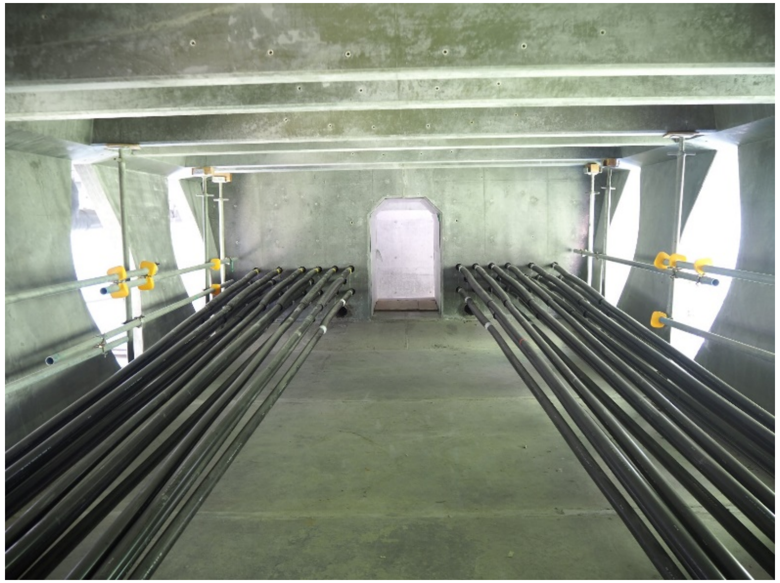
Bessodani Bridge (2020)



Prefabrication of butterfly web pretensioned by aramid FRP



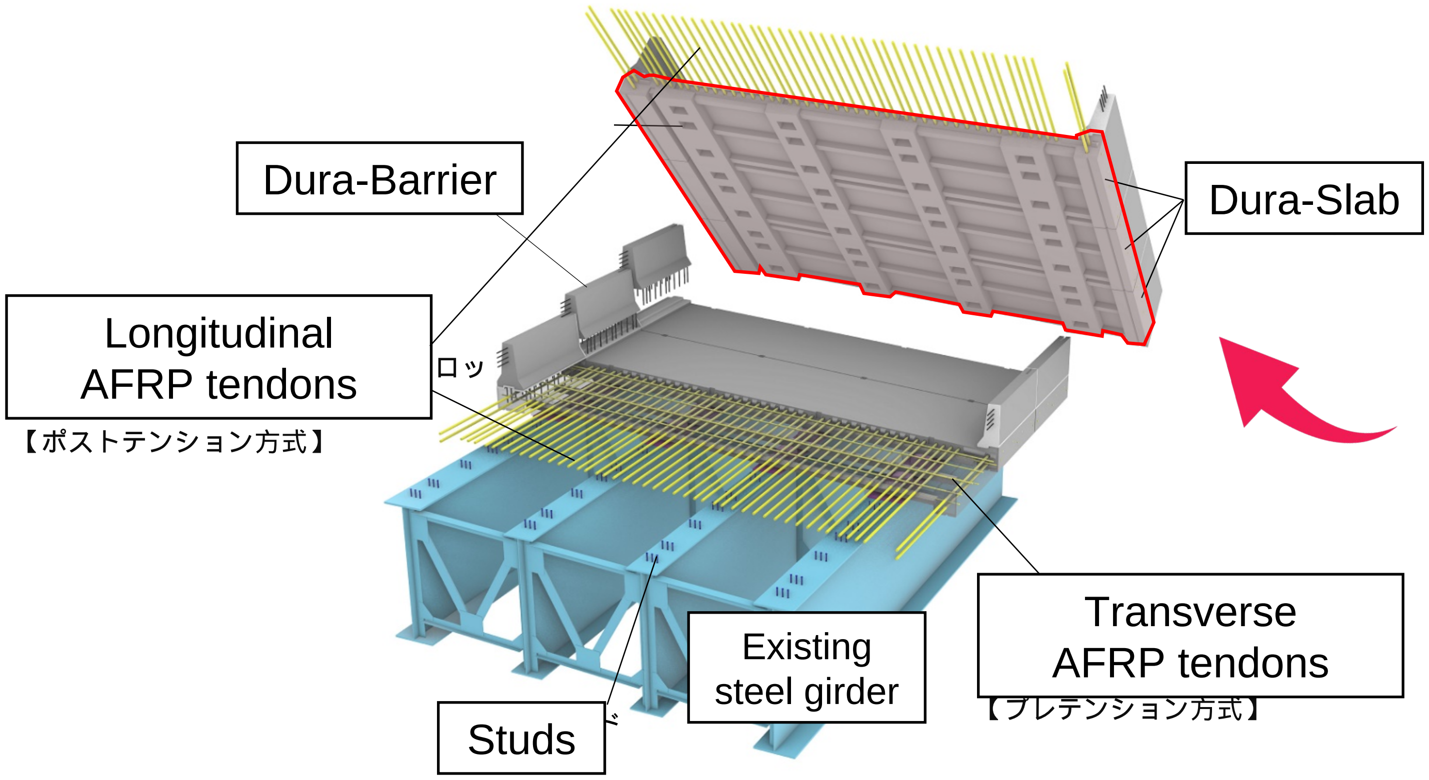
Installation of segment



Inside view

Rehabilitation by non-metallic concrete deck

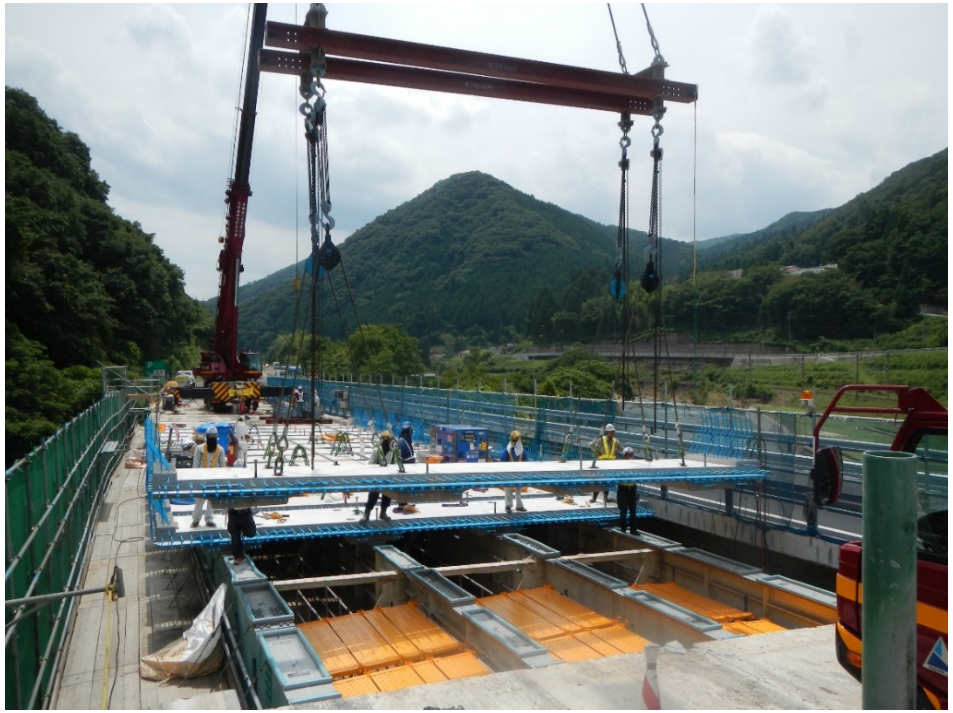
- ✓ Refurbishment by non-metallic concrete deck
- ✓ Non-metallic concrete deck with Polyvinyl alcohol fiber 1% content in volume



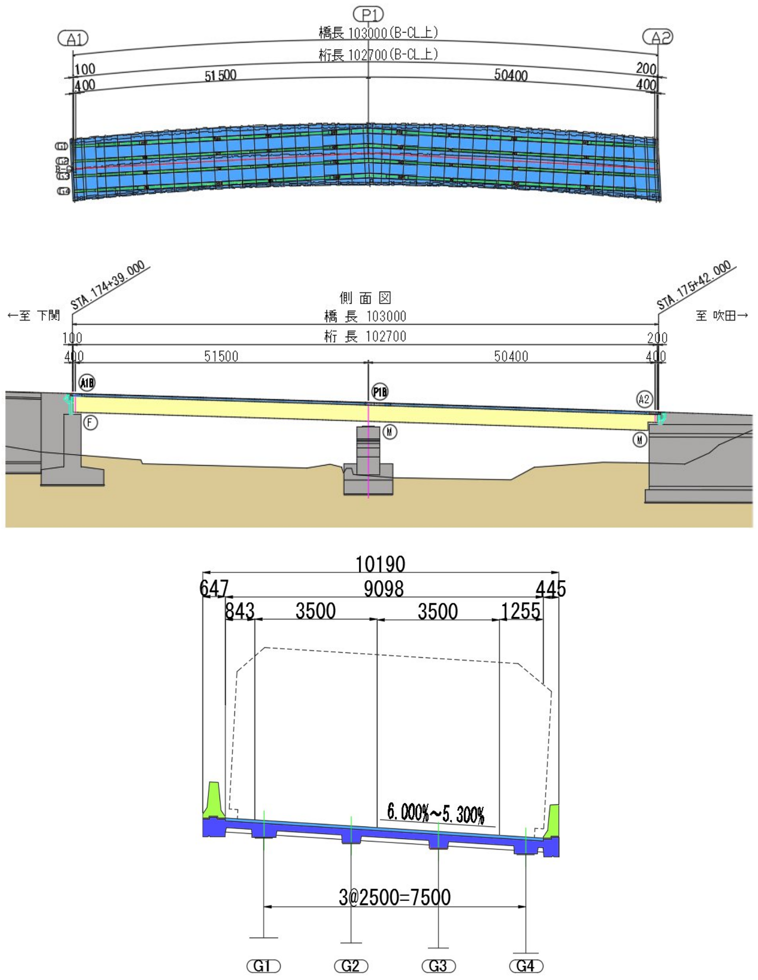
Polyvinyl alcohol fiber

Highway bridge deck rehabilitation

- ✓ RC slab is heavily deteriorated by deicing salt.
- ✓ 60-year reinforced concrete slab is replaced to precast prestressed concrete slab.



Tadeno-daini Bridge (2021)

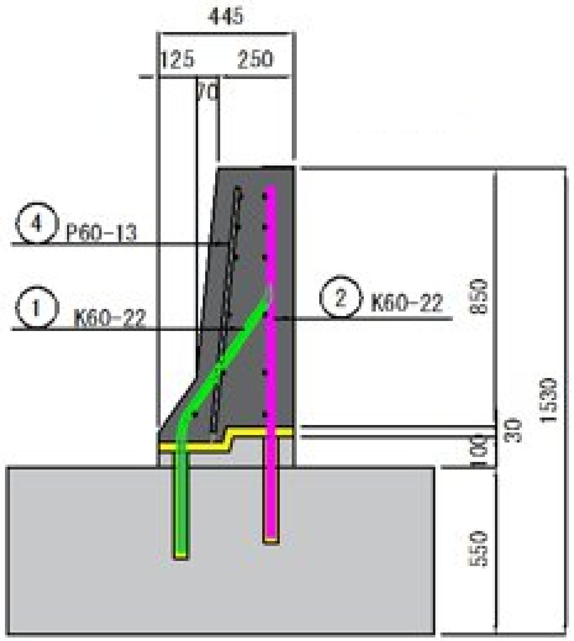


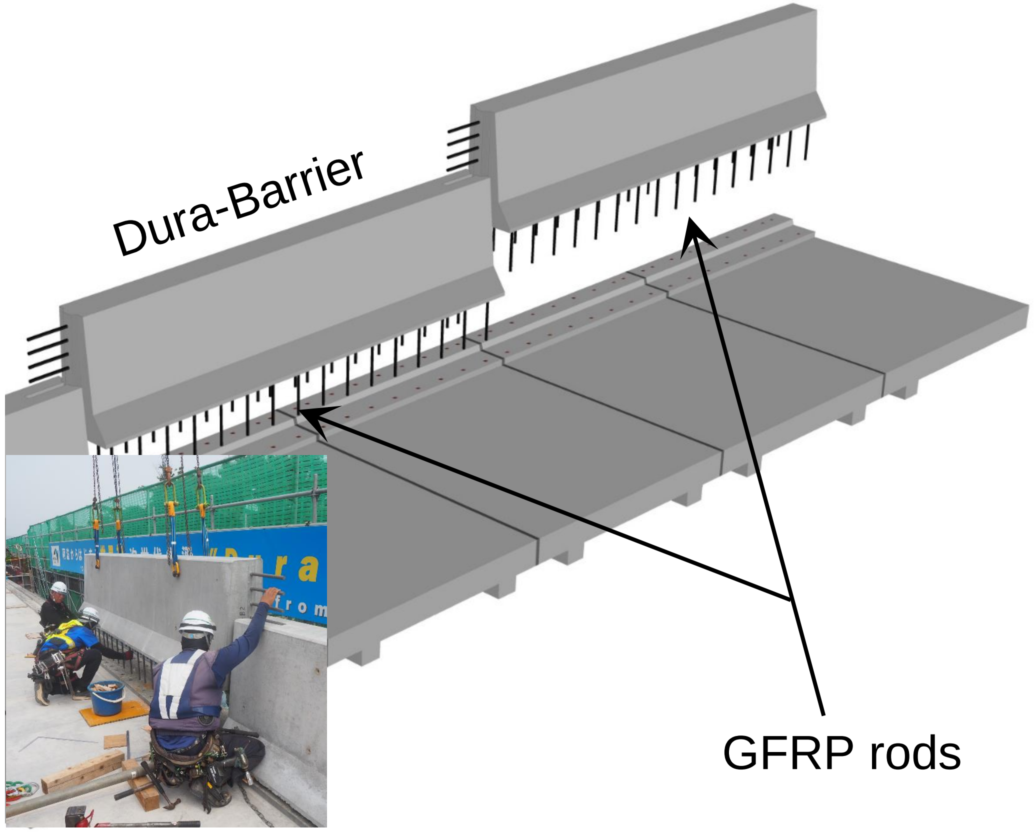
Installation of panel

Prefabrication of Dura-slab pretensioned aramid FRP

Non-metallic concrete barrier

✓ Non-metallic Concrete Barrier with Polyvinyl alcohol fiber

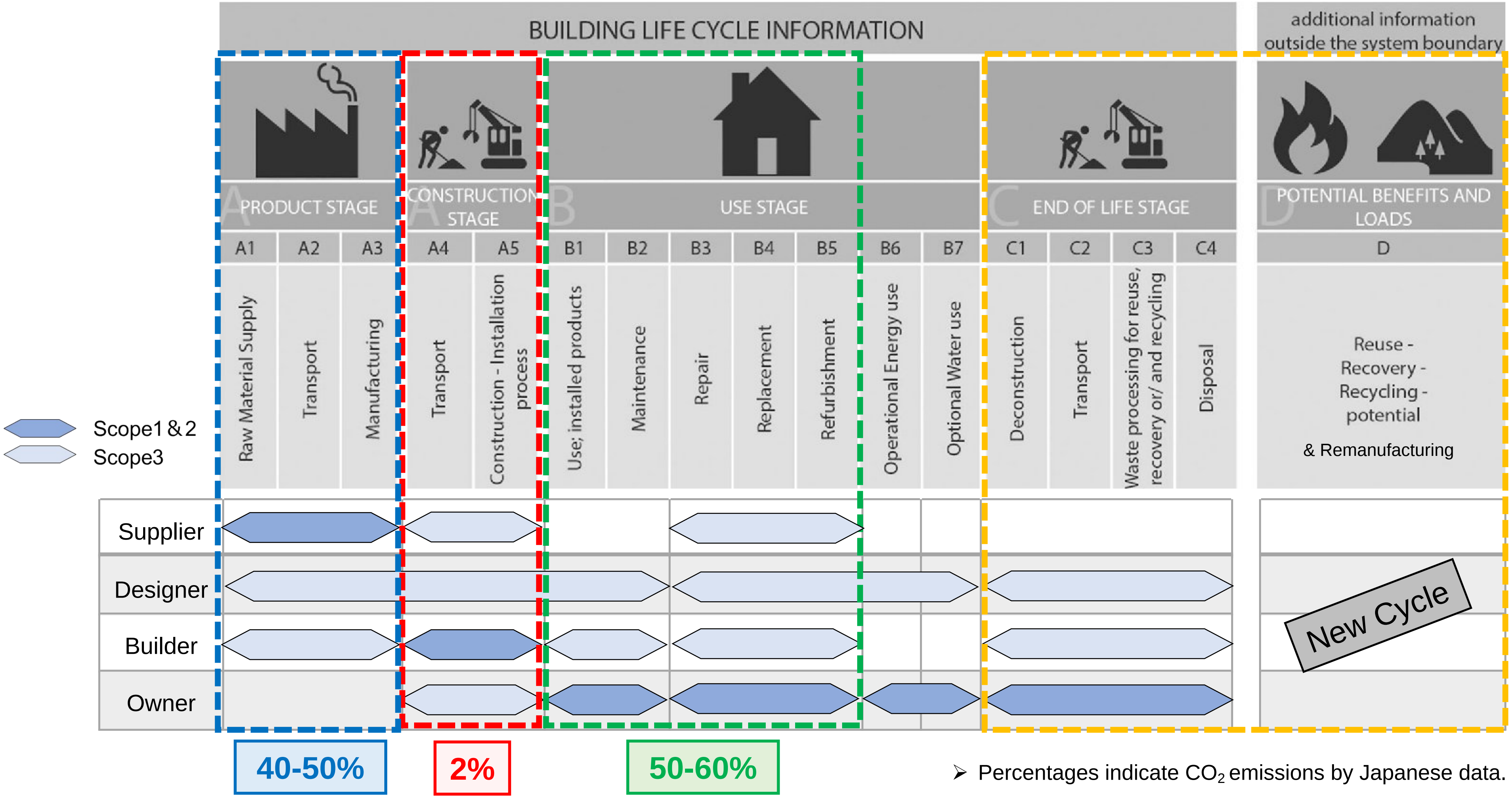




Impact Test

4. CO_2 emissions in the use stage

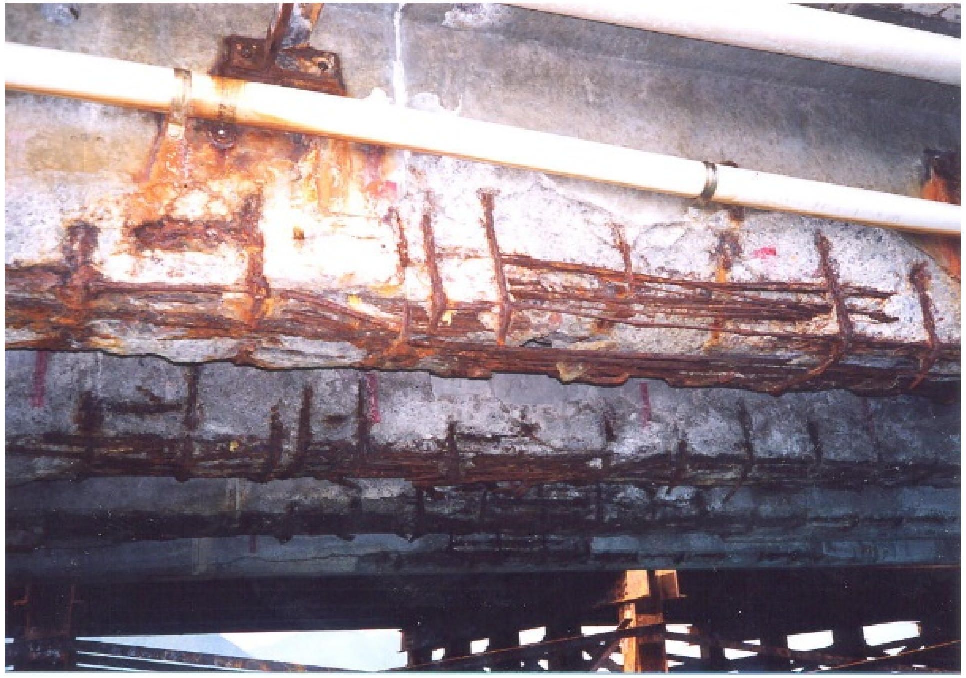
CO_2 emission in construction supply chain

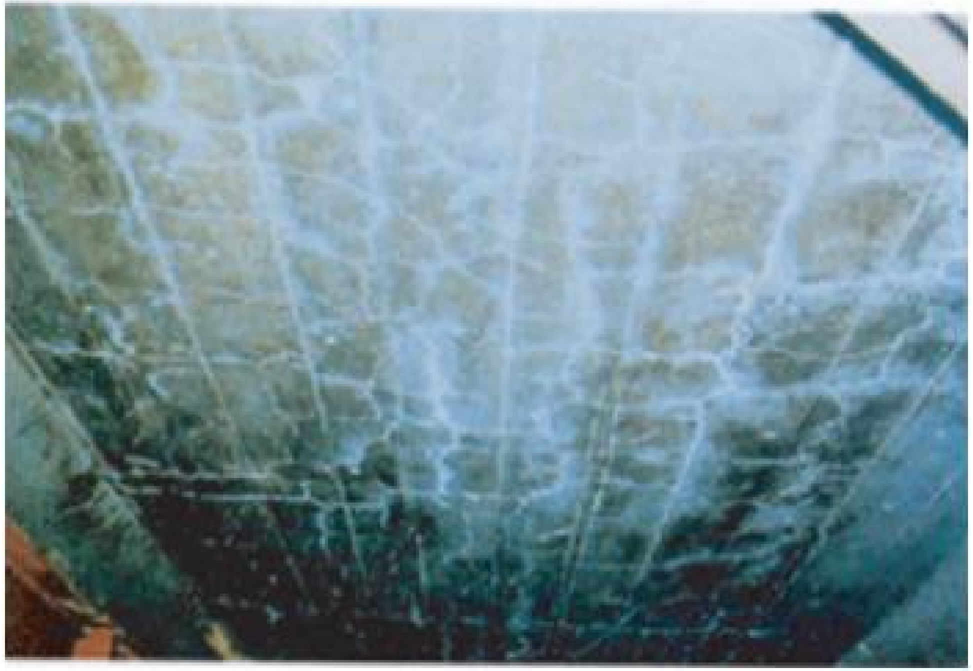


➤ Percentages indicate CO_2 emissions by Japanese data.

Deterioration of concrete structures in the use stage

- ✓ 60-year-old concrete RC slabs are being renewed at a cost two to four times of the original construction cost.
- ✓ Deterioration of the rebar generates maintenance costs and emits CO_2 emissions during intervention.





Highway bridge deck rehabilitation

✓ Intervention is a construction operation and affects social activities in the surrounding area.

https://www.kozobutsu-hozen-journal.net/news/13171/

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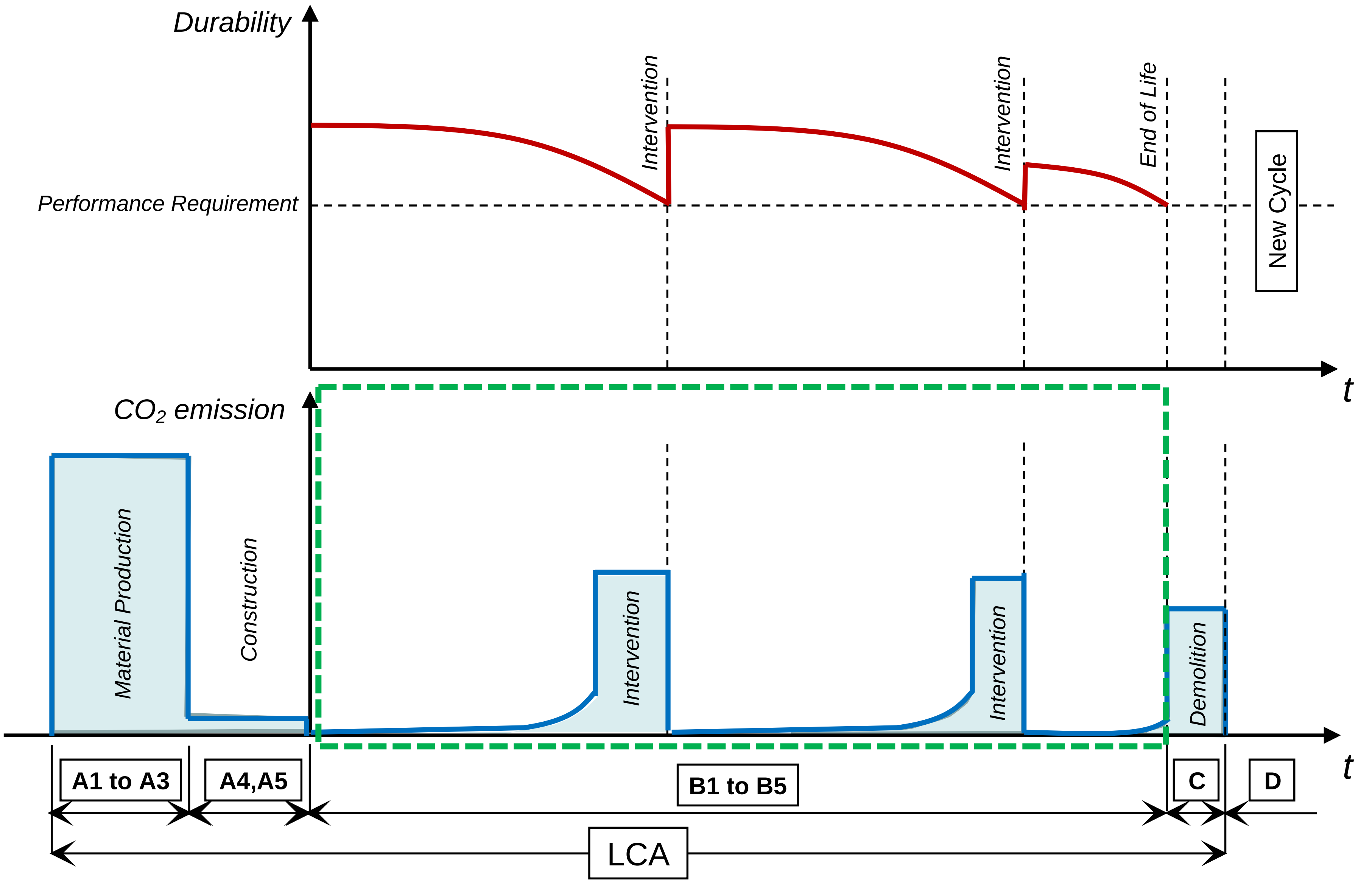
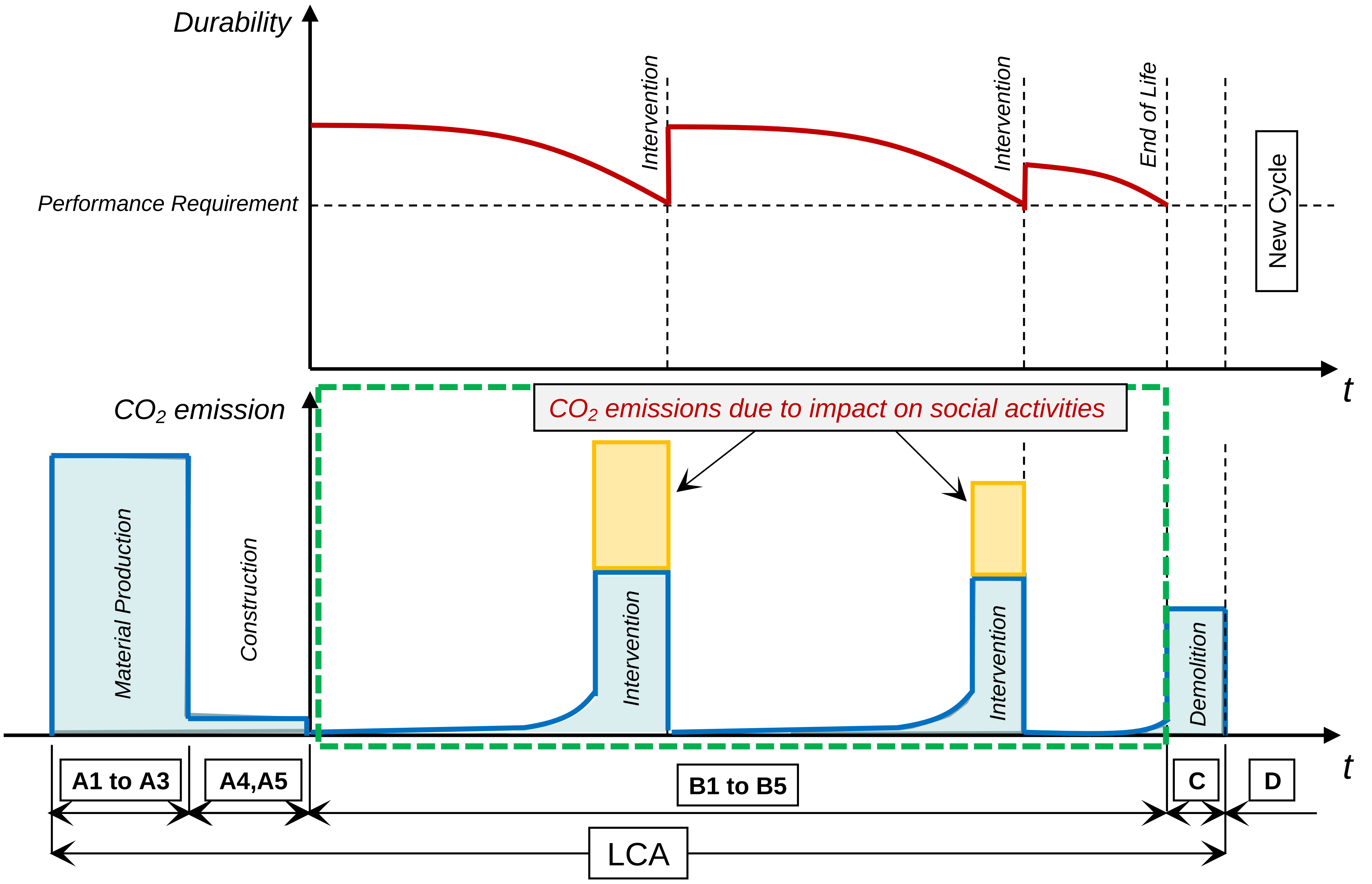
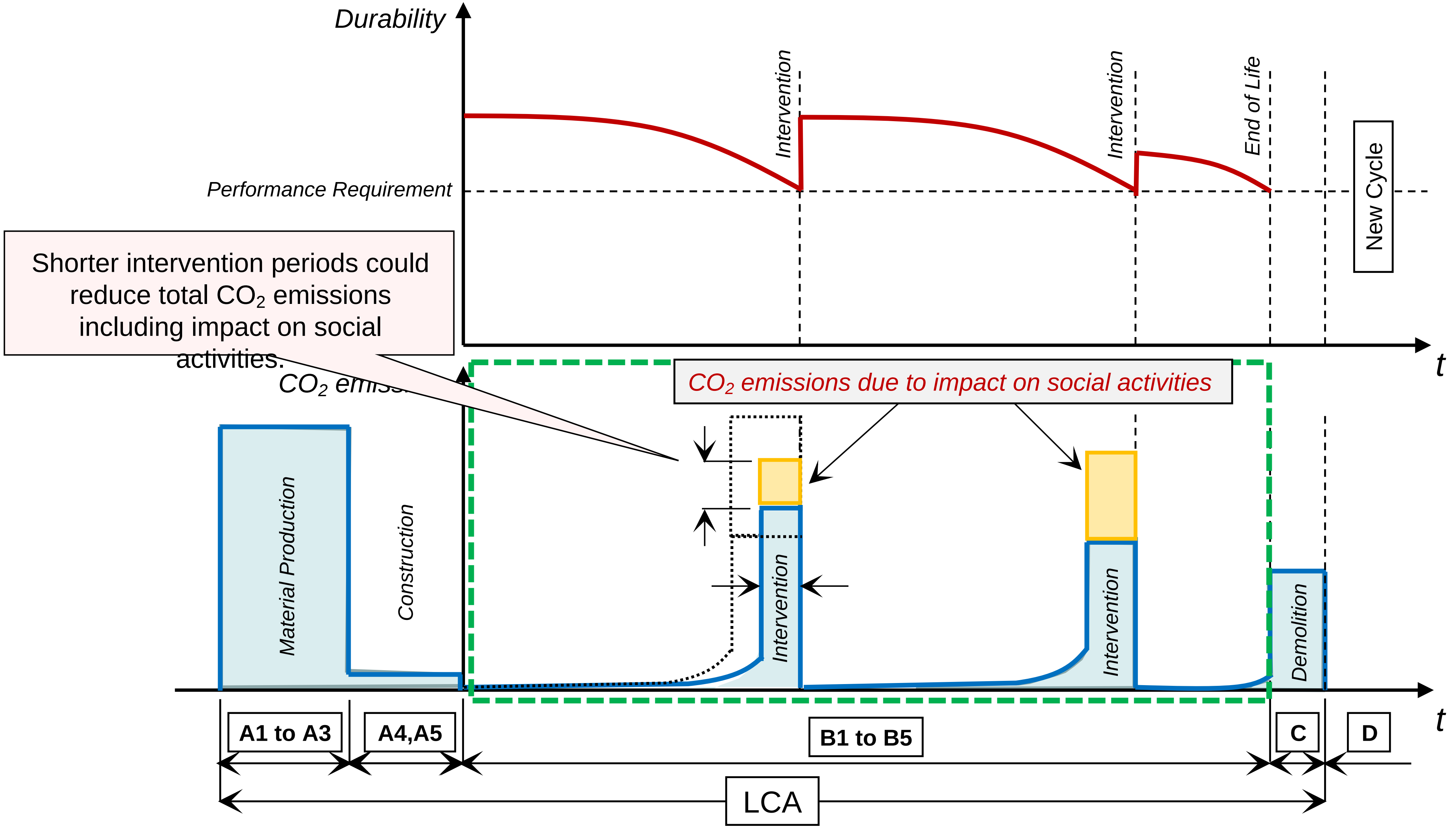
CO_2 emissions in intervention



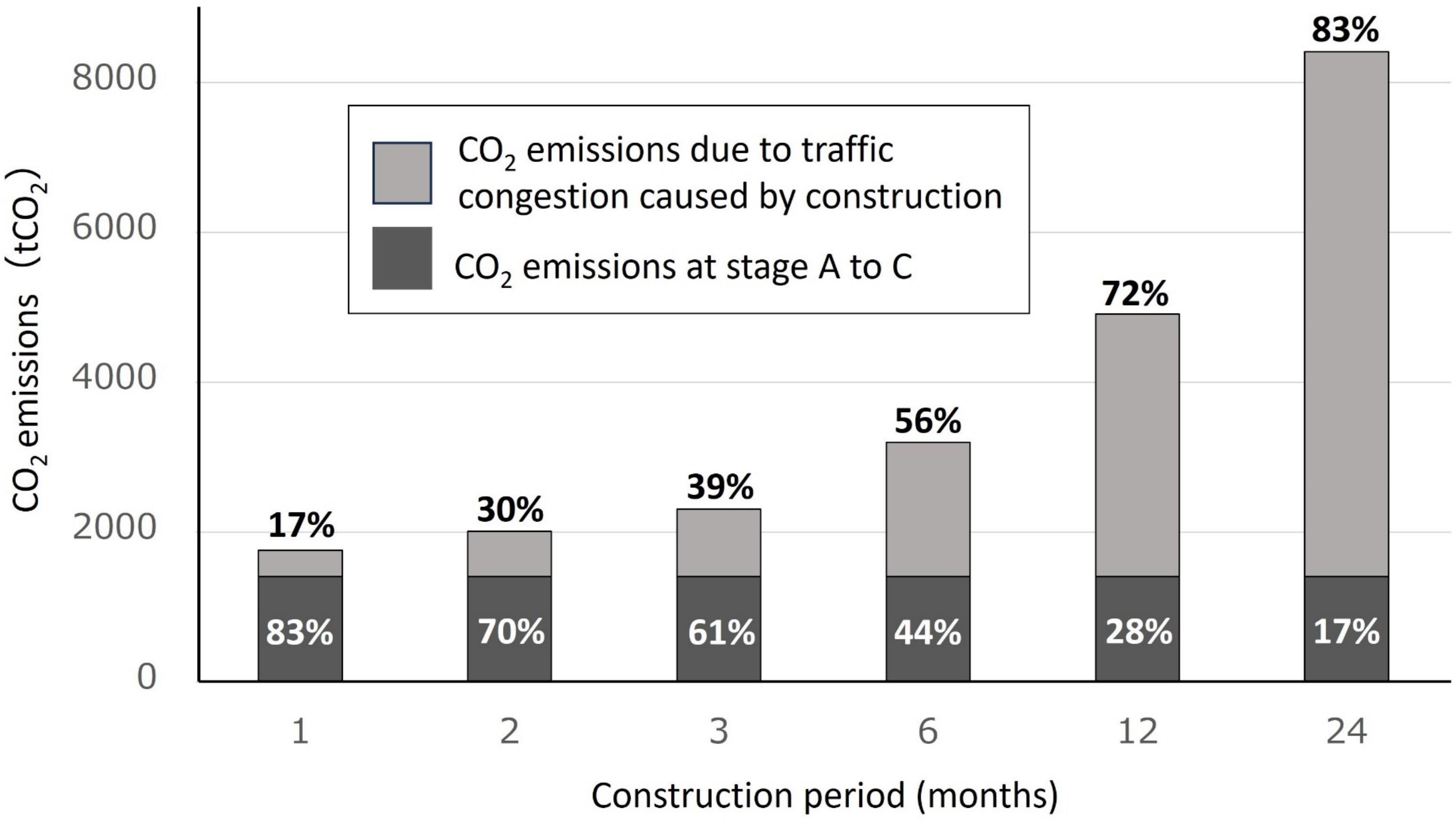
CO_2 emissions due to impact on social activities



CO_2 emissions due to impact on social activities

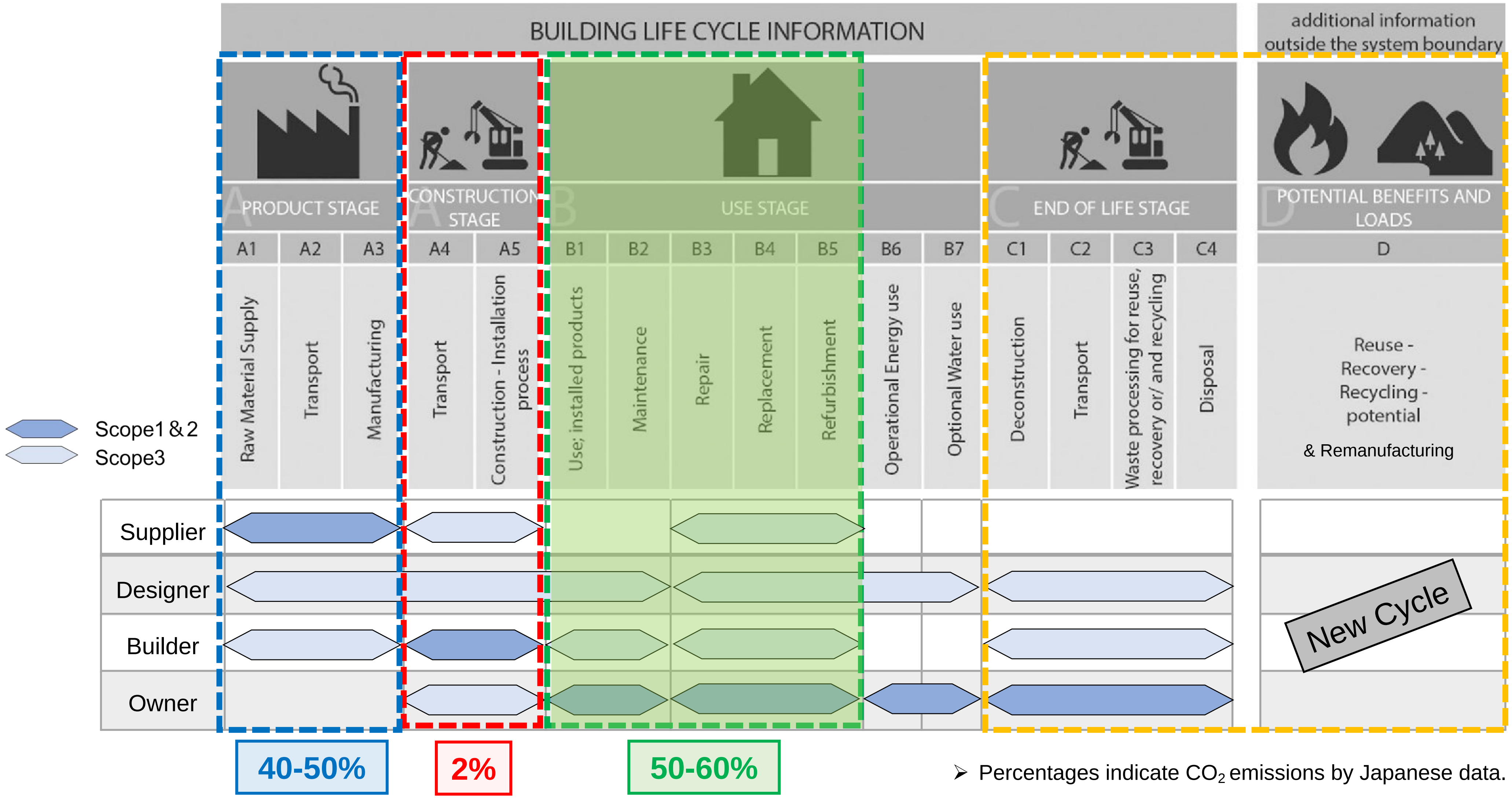


Construction period vs. CO_2 emissions



1) Haist, M.; Bergmeister, K.; Fouad, N.A.; Curbach, M.; Deiters, M.V.; Forman, P.; Gerlach, J.; Hatzfeld, T.; Hoppe, J.; Kromoser, B.; Mark, P.; Müller, C.; Müller, H.S.; Scope, C.; Schack, T.; Tietze, M.; Voit, K.: Nachhaltiger Betonbau - Vom CO2 - und ressourceneffizienten Beton und Tragwerk zur nachhaltigen Konstruktion; In: Bauphysik-Kalender, Schwerpunkt: Nachhaltigkeit, Fouad, Nabil A. (Eds.), Ernst & Sohn, Berlin, 2023, pp. 259-363
4) Deutscher Beton- und Bautechnik-Verein e. V. (2015) Beispiele zur Bemessung nach Eurocode 2, Band 2: Ingenieurbau, 1. Auflage. Berlin: Ernst & Sohn.
5) Lange, M.; Hendzlik, M.; Schmied, M. (2020) Klimaschutz durch Tempolimit – Wirkung eines generellen Tempolimits auf Bundesautobahnen auf die Treibhausgas-emissionen in: Texte/Umweltbundesamt 38/2020, Dessau- Roßlau: Umweltbundesamt

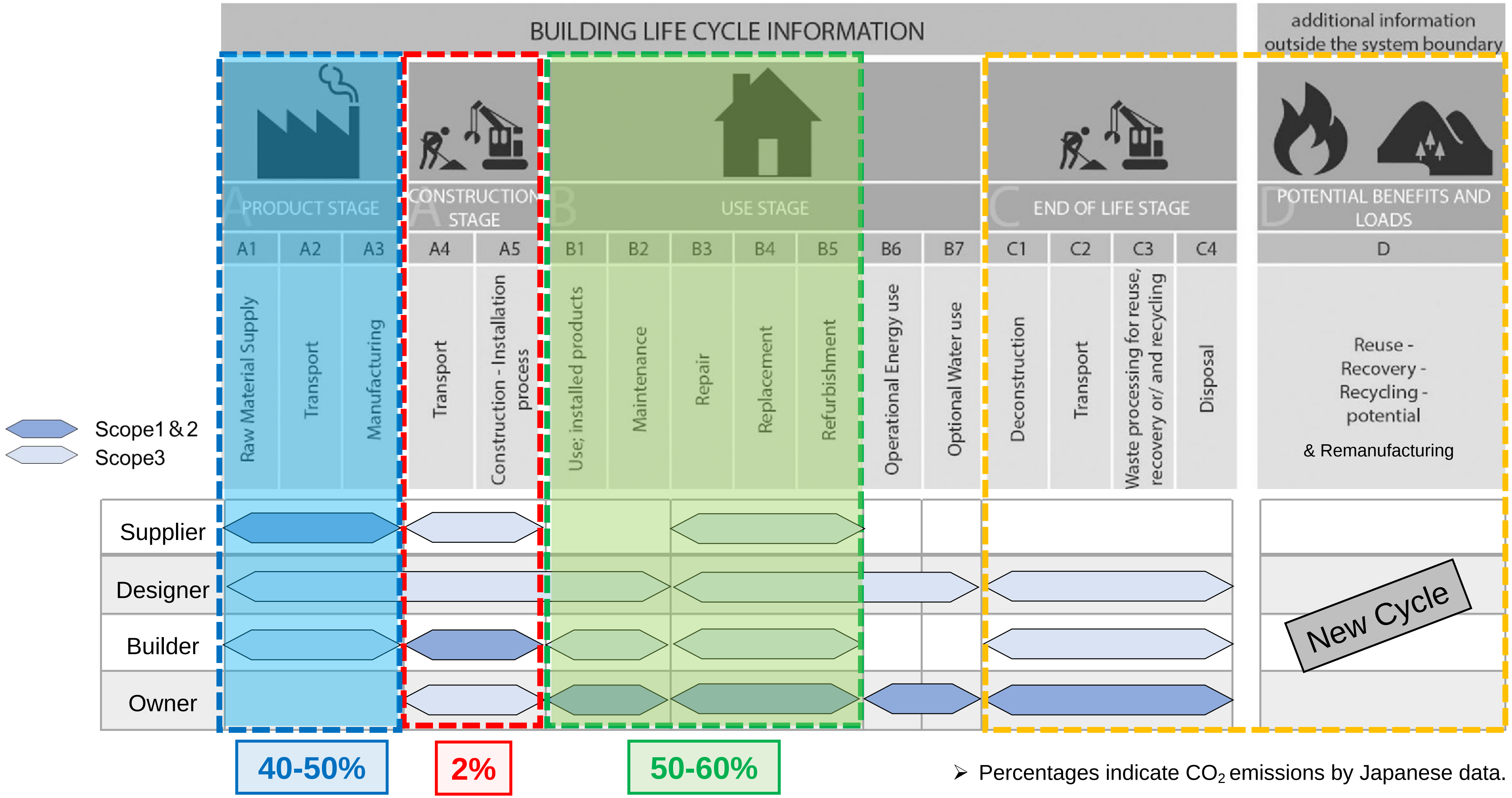
CO_2 emission in construction supply chain



➢ Percentages indicate CO_2 emissions by Japanese data.

5. Towards low carbon concrete structures

CO_2 emission in construction supply chain



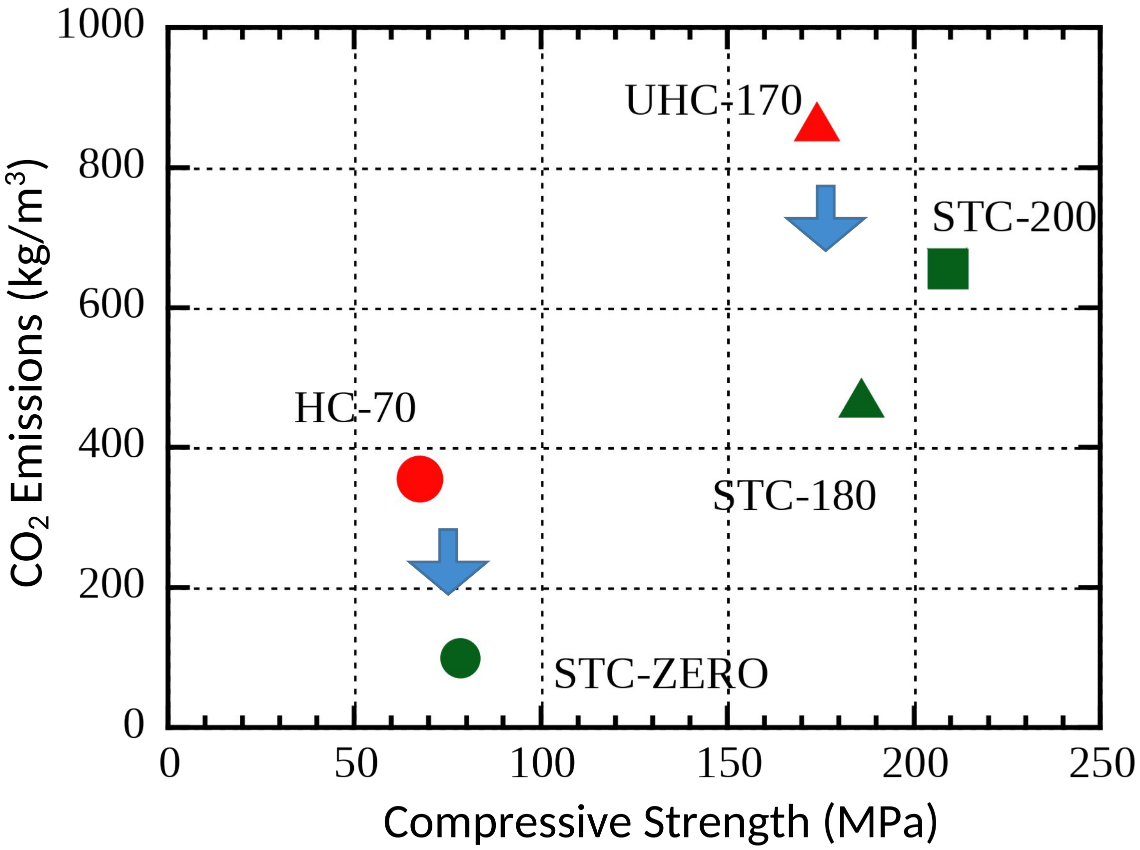
➢ Percentages indicate CO_2 emissions by Japanese data.

Zero cement concrete

1. Carbon emissions can be reduced up to 70% .
2. Maximum strength of 150 MPa can be achieved without steam curing.
3. Drying shrinkage is extremely small at around 100μ.
4. Creep is small at one-third that of conventional concrete.
5. Heat generated during hardening is 30 - 40℃ lower than conventional concrete.
6. Mixing water can be cut by about half.

Zero cement concrete

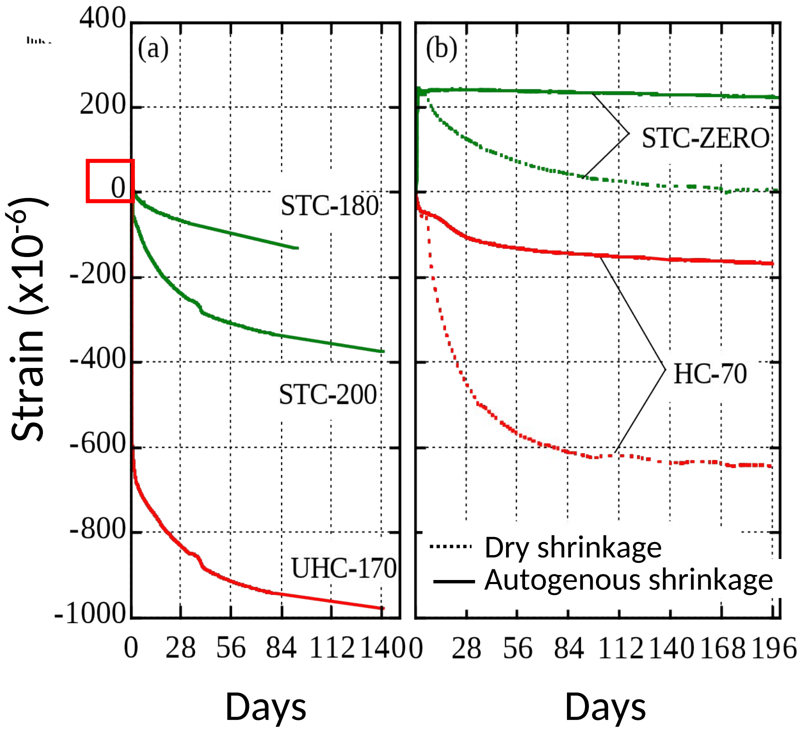
✓ Low carbon concrete up to 70% CO_2 emissions



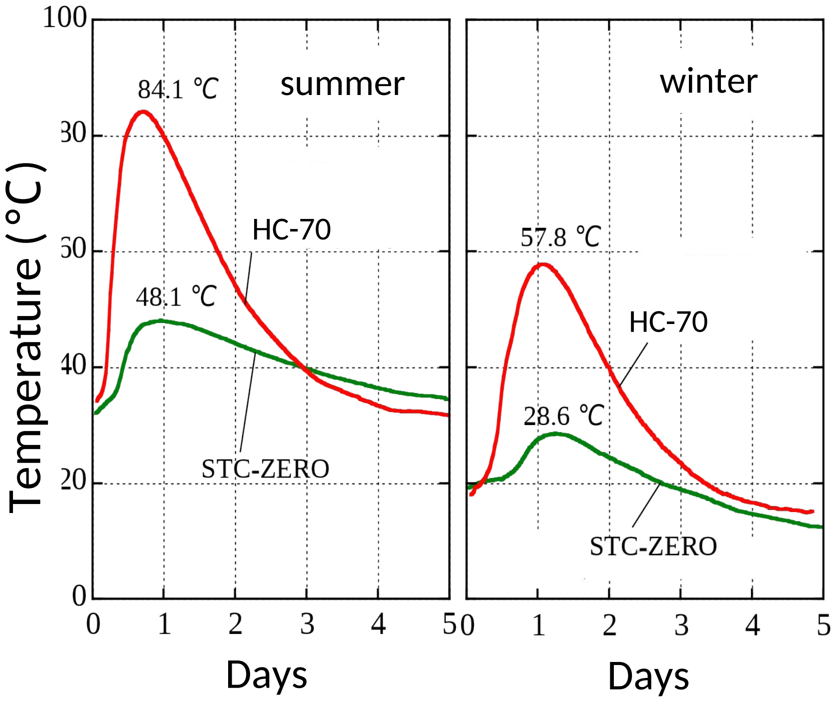
Zero cement concrete

✓ Material-derived cracking factors can be reduced.

Ultra low shrinkage

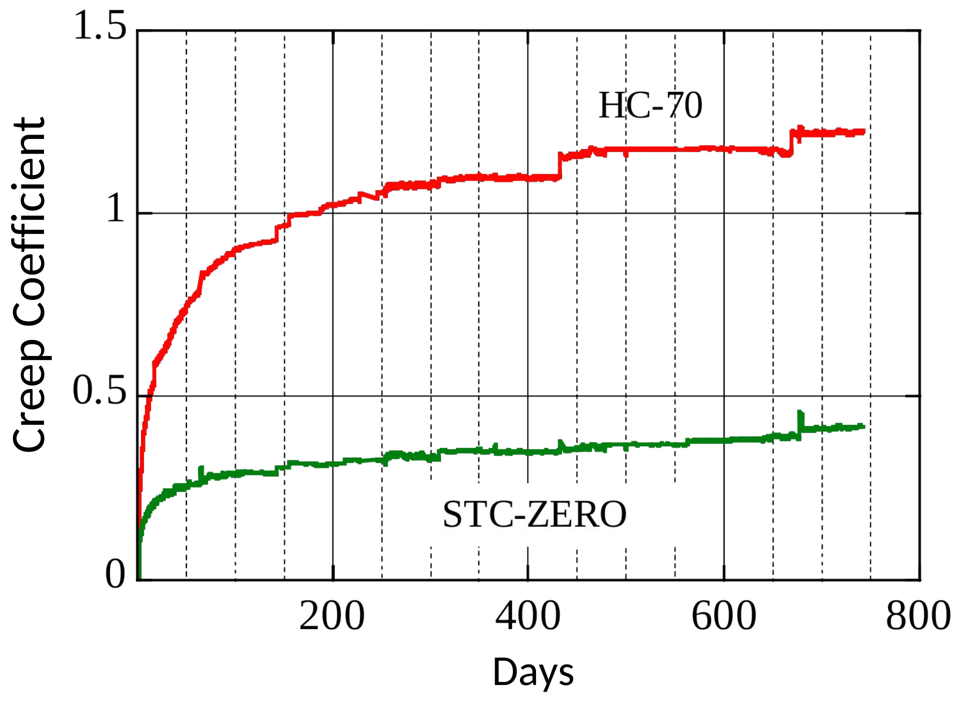


Ultra low heat generation



Zero cement concrete

- ✓ Ultra low creep → Possibility of reduction of prestressing tendons



Zero cement concrete + non-metallic reinforcements

✓ Zero cement concrete + aramid pretension tendons

+

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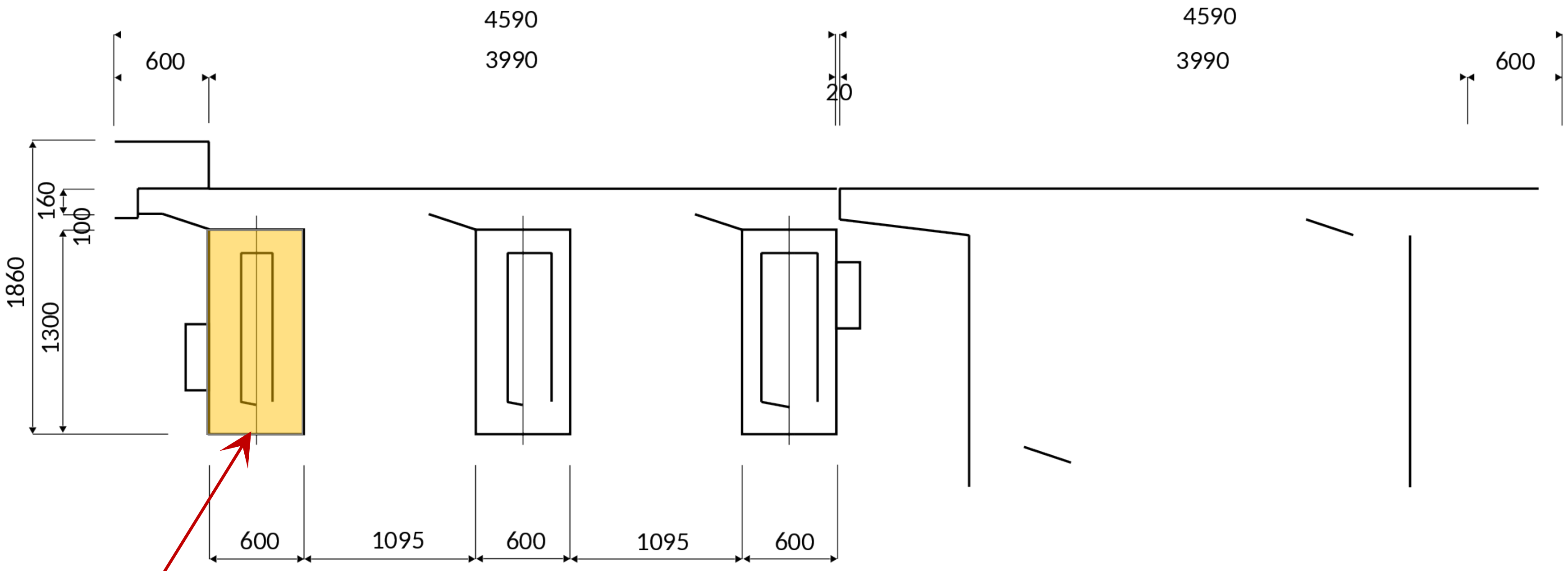
- ✓ Low carbon concrete with low pH value is advantageous for FRP.
- ✓ Suitable for precast due to slow strength development. (CO_2 emission during steam curing)
- ✓ Possibility of mixing with seawater.

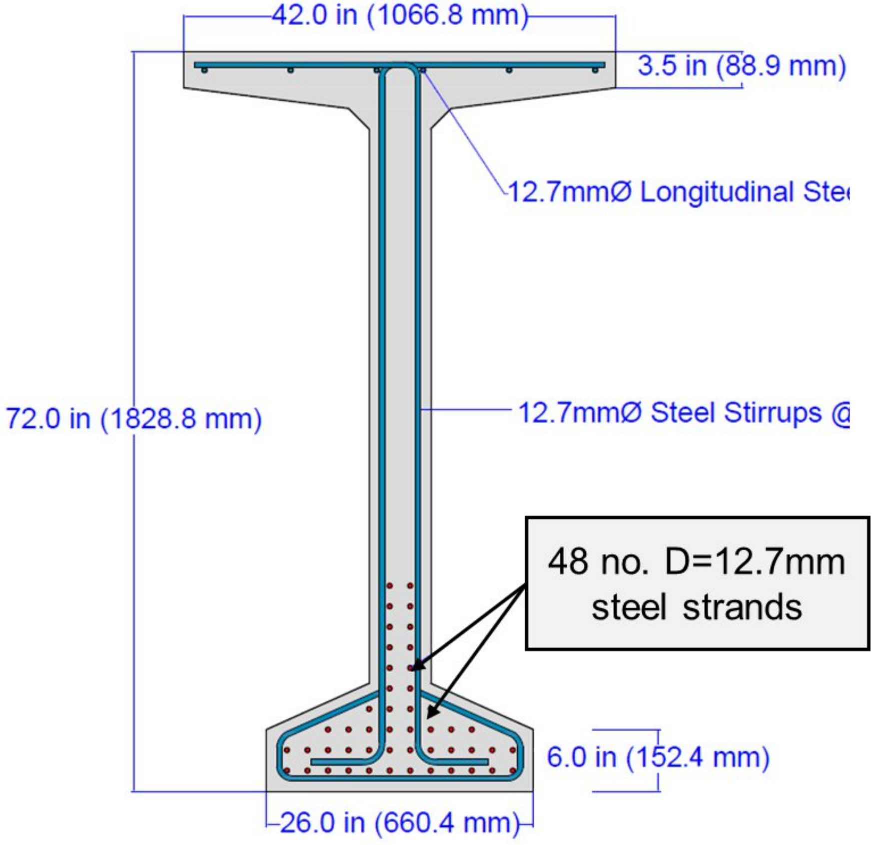
Evolution of 2nd generation non-metallic bridge



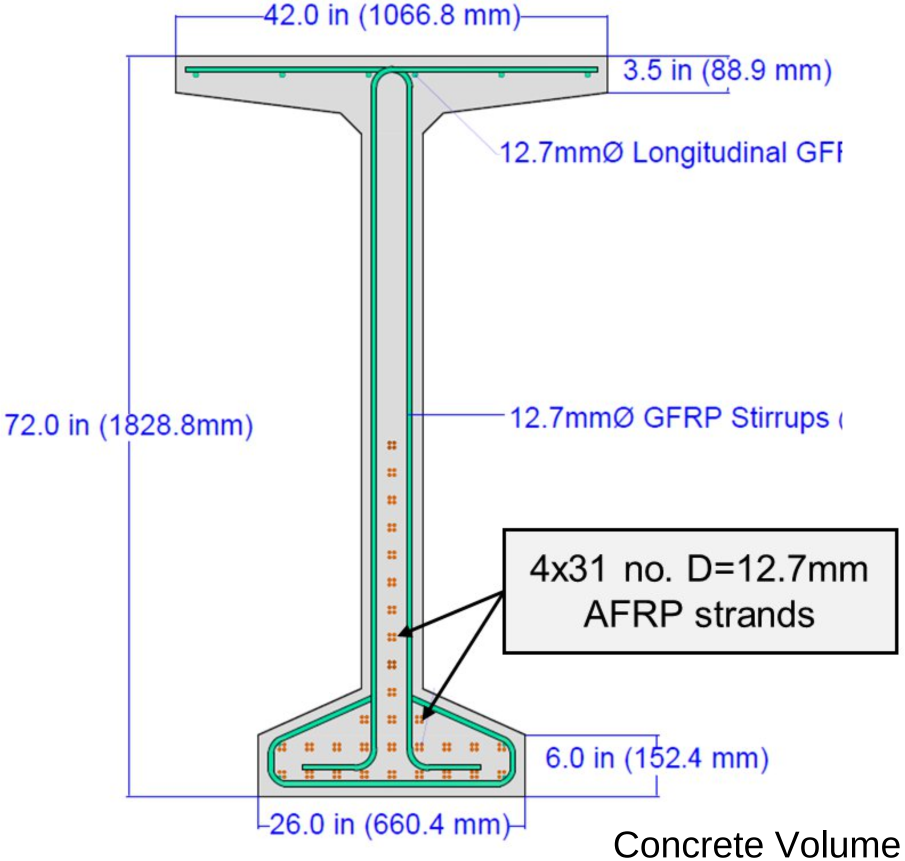
Zero cement concrete + AFRP

Non-metallic & zero cement bulb tee girder (L=37m)

Conventional girder

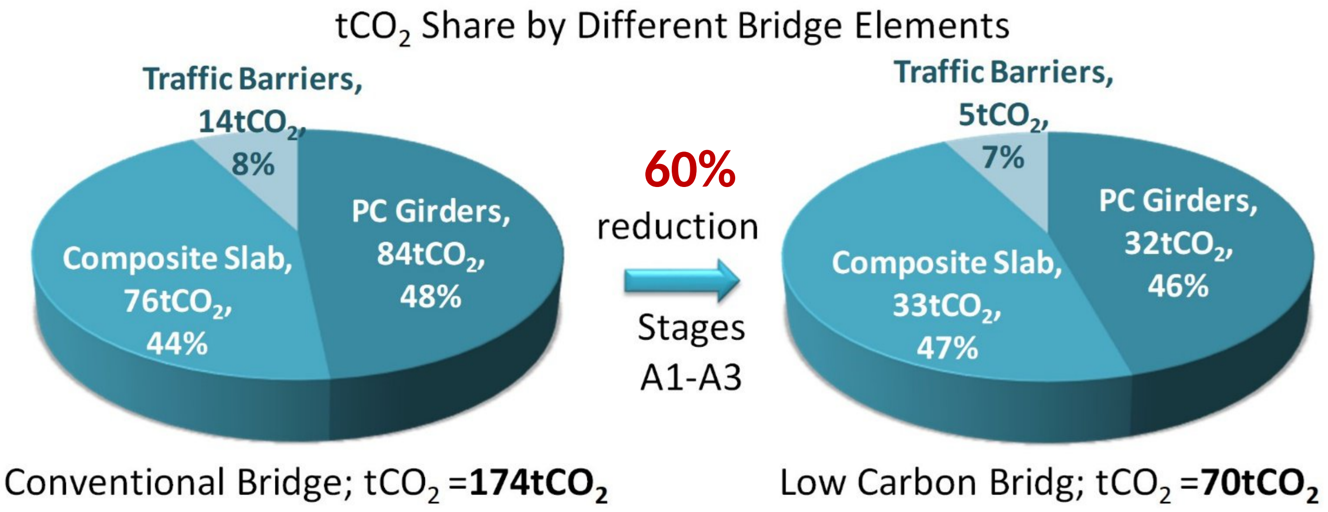


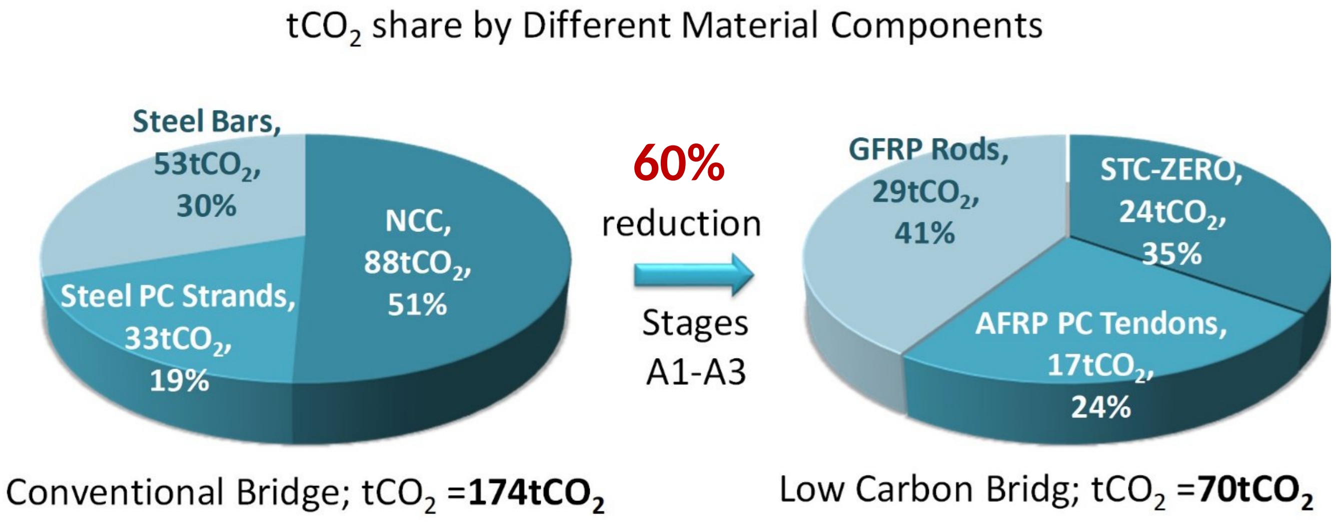
ZCC+AFRP girder



Concrete Volume : 18.25m^3
(No reduction of thickness)

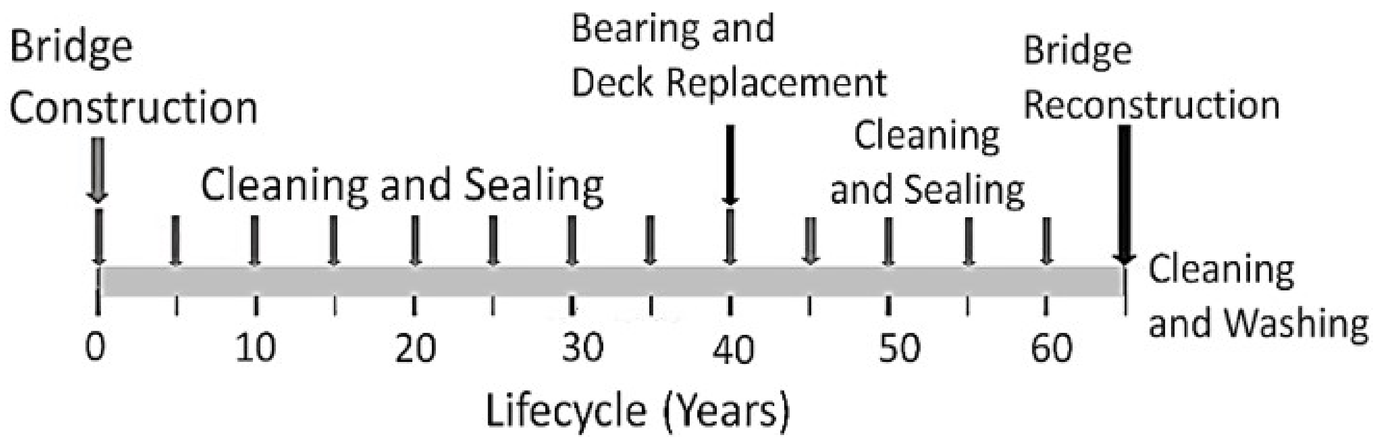
CO_2 emissions of bridge elements and components

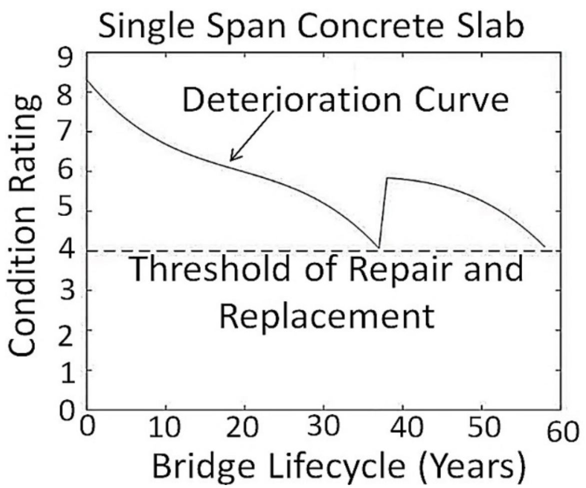




Lifecycle profile and deterioration curve of concrete deck

Conservation scenario of Indiana, US





Condition Rating

9 Excellent Condition
8 Very Good Condition—No problems noted
7 Good Condition—Some minor problems
6 Satisfactory Condition
5 Fair Condition
4 Poor Condition
3 Serious Condition
2 Critical Condition
1 "Imminent" Failure Condition
0 Failed Condition

Estimation of LCA

	Lifecycle factor	tCO_2				Whole life emission rate (tCO_2/m^3)	tCO_2 reduction (%)
		Stage A		Stage B and Stage C	(A+B+C)		
		A1-A3 (80% of A)	A4-A5 (20% of A)				
Conventional Bridge	Repair & Replacement	174	43	326 (1.5 times of A)	543	2.2	NA
Low Carbon Bridge	No Repair & Replacement	70	18	4.5 (12% of whole life emission)	100	0.4	82

82% reduction

- ✓ Stage A; Material production & construction stage
- ✓ A1-A3; Material production stage
- ✓ A1-A5; Construction stage
- ✓ Stage B; Use stage
- ✓ Stage C; End of life stage

➢ Arifa Z. Kasuga A. LCA of a challenging low carbon ultra-high durability non-metallic bridge. Proceedings of the *fib* Congress, Oslo. pp 2100-2109, 2022

Back to the Roman concrete with modern technology

Pantheon (Rome, BC25)

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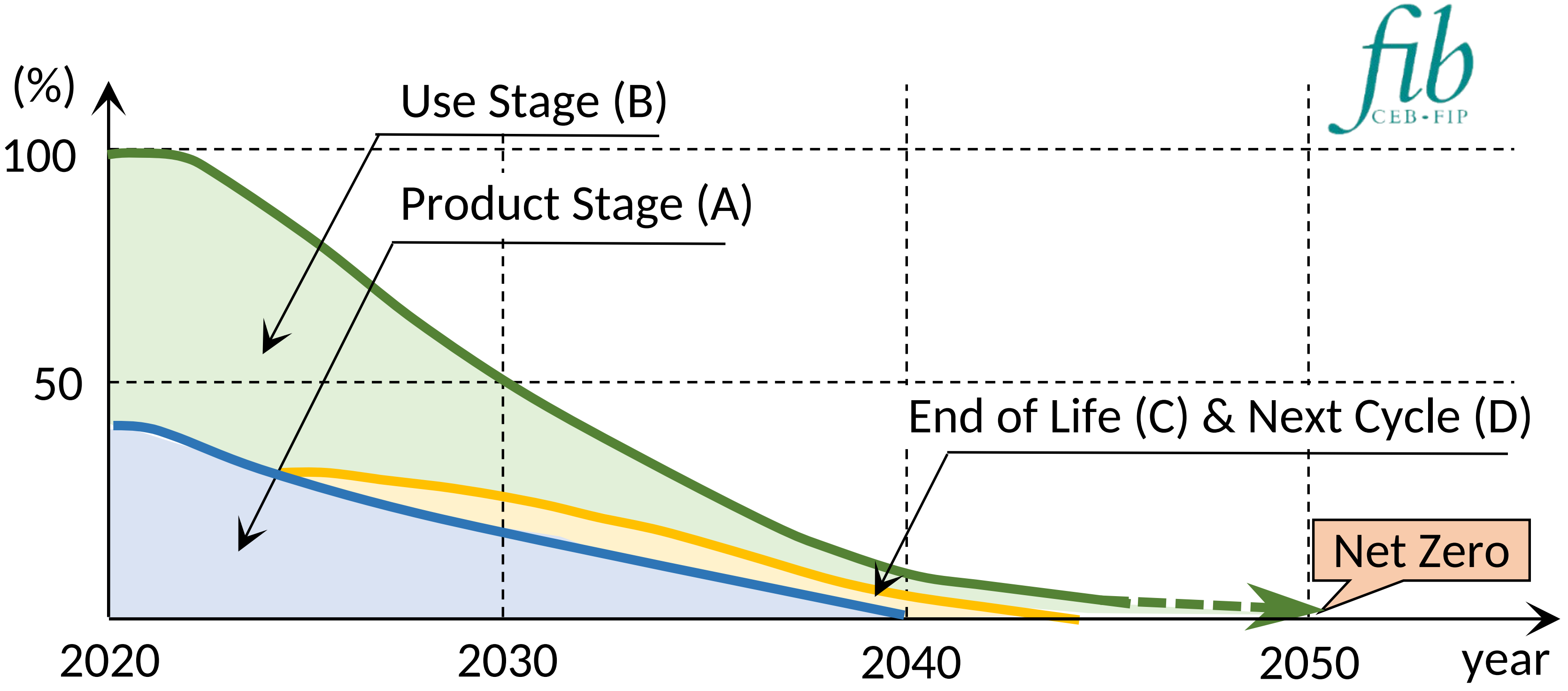
130 MPa concrete without Portland cement & aramid FRP tendons

Roadmap to Carbon Neutrality for *fib* Members

✓ CO_2 emissions due to new construction and intervention of existing structures



Conclusions

1. To reduce future maintenance, non-metallic bridge was developed by new technologies of butterfly web and fiber reinforced concrete.
2. Fatigue performance of non-metallic deck is sufficient for more than 100-year service.
3. The proposed structure has performance which can meet required design criteria.
4. Non-metallic technology makes the structure durable and leads to minimum life cycle cost. This is a sustainable solution.
5. Action is required to reduce CO_2 emissions as quickly as possible using the technology available today.

Thank you for your attention.