A Reinforced Concrete Bridge Pier Strengthened with HPFRC Jacketing

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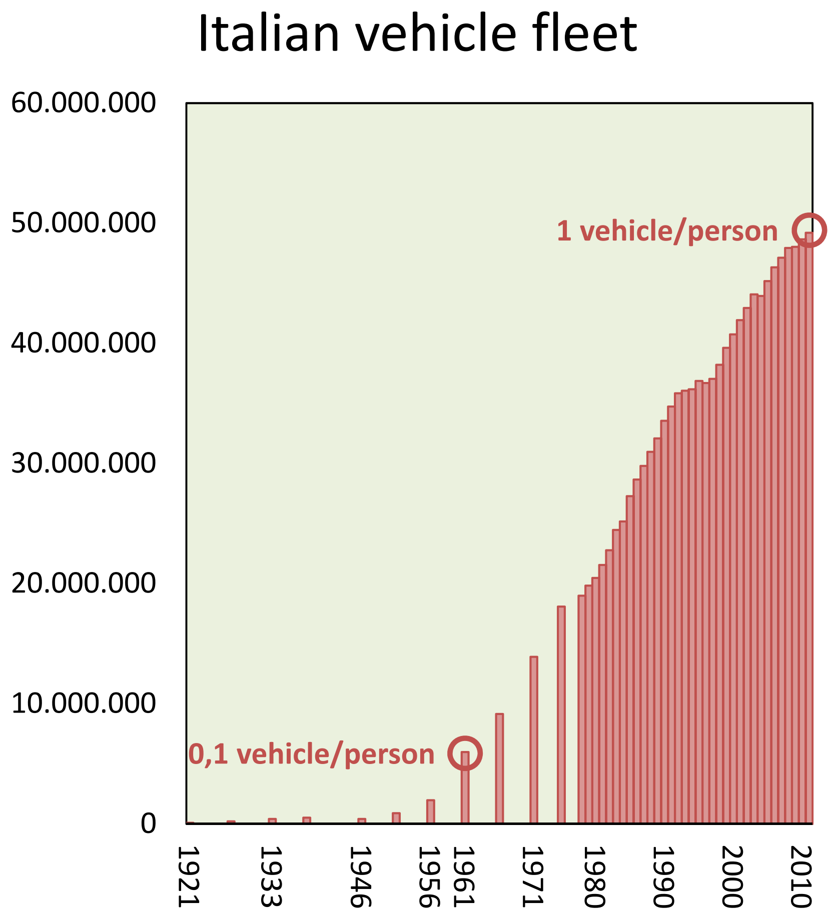
Why repair infrastructures?

Increment of vehicle number and traffic loads (also heavy loading) and new seismic regulations are setting new requirements to adapt the existing infrastructure, which should be otherwise replaced.



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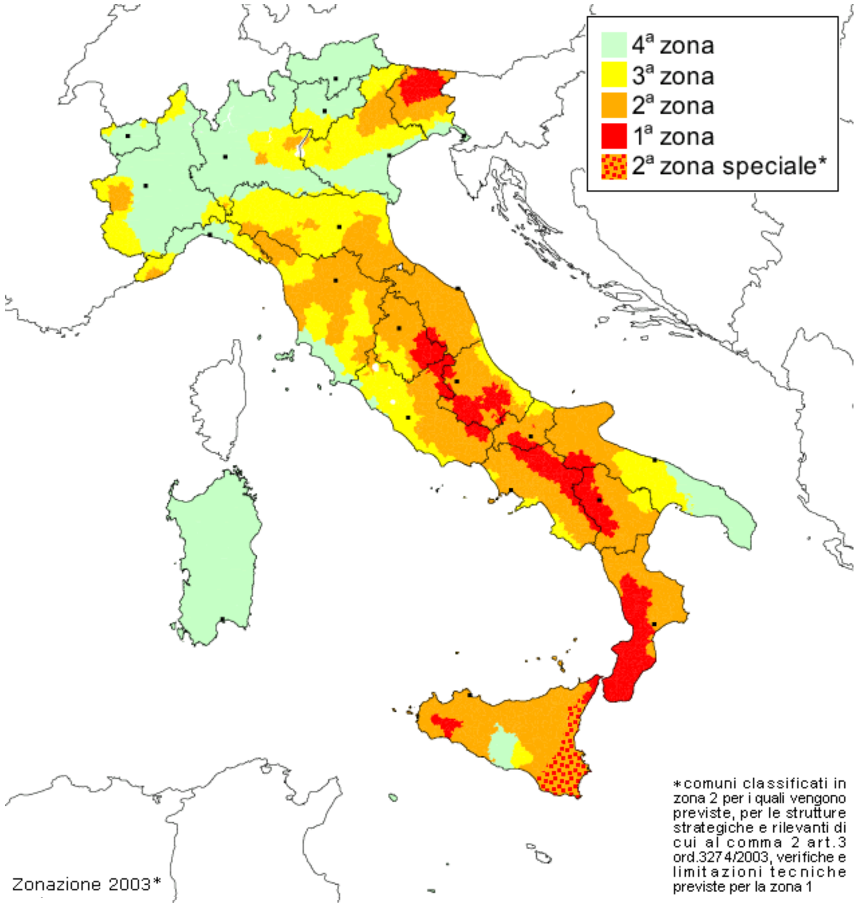


Seismic hazard map, 2003

Why repair infrastructures?

Moreover, reinforced concrete (RC) aging and deterioration have led to structural and material degradation, including severe cracking and corrosion.

Viaduct A14 highway, 2017

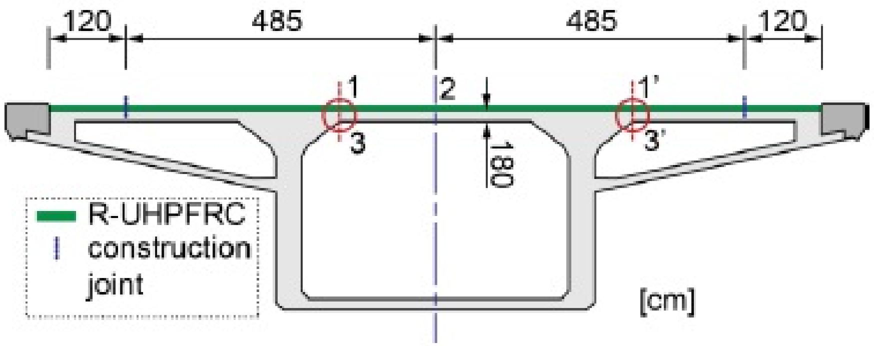
Why repair infrastructures?

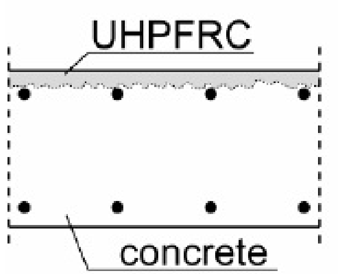
The *American Society of Civil Engineers* it has estimated that a significant percentage of the 600,000 American bridges requires strengthening or seismic retrofitting due to structural deficiencies.

Viaduct A14 highway, 2017

Bridge deck strengthening with UHPFRC.

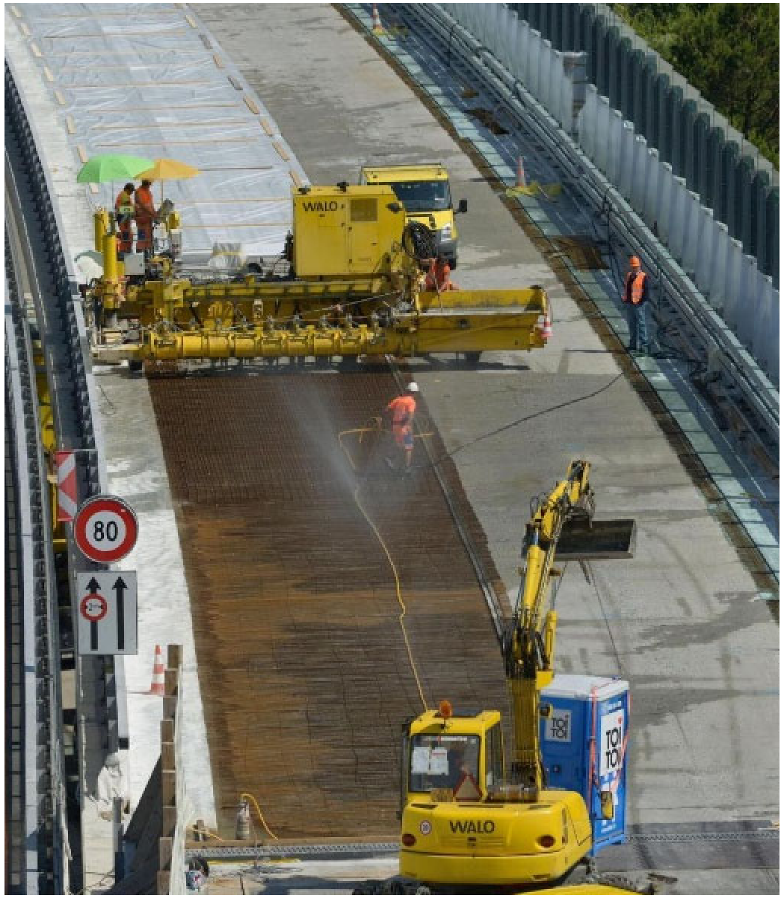
Chillon viaducts along Lake Geneva



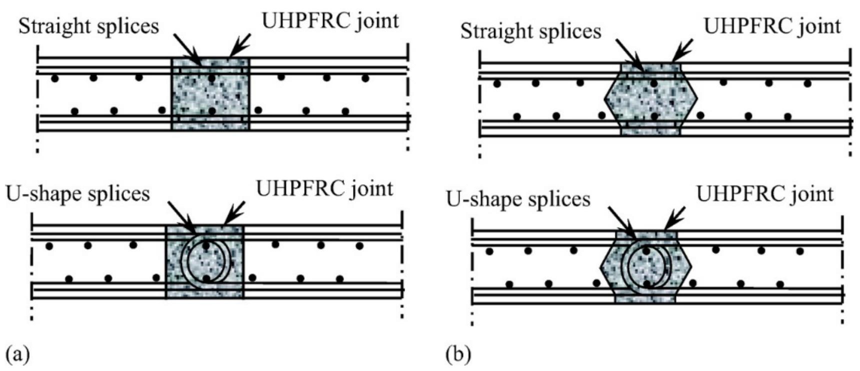


Bridge deck strengthening with UHPFRC.

Chillon viaducts along Lake Geneva



Cast-in-place joints with UHPFRC.



New York State Department of Transportation (NYSDOT)

Bridge pier jacketing with UHPFRC.

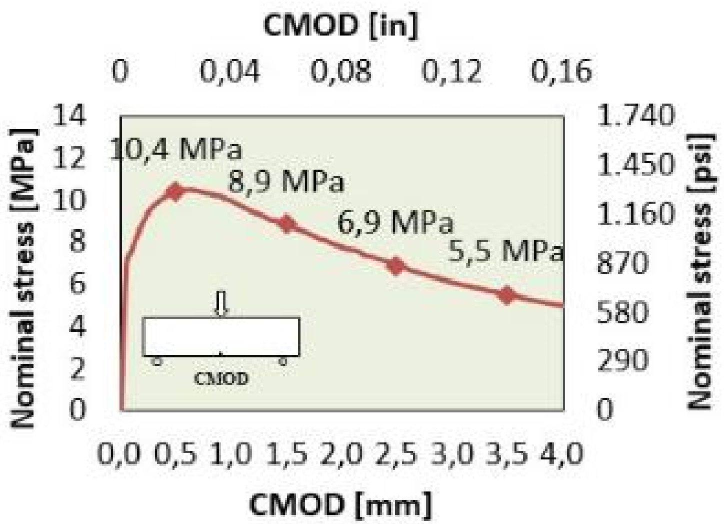
The Mission Bridge, Abbotsford, British Columbia (CA)

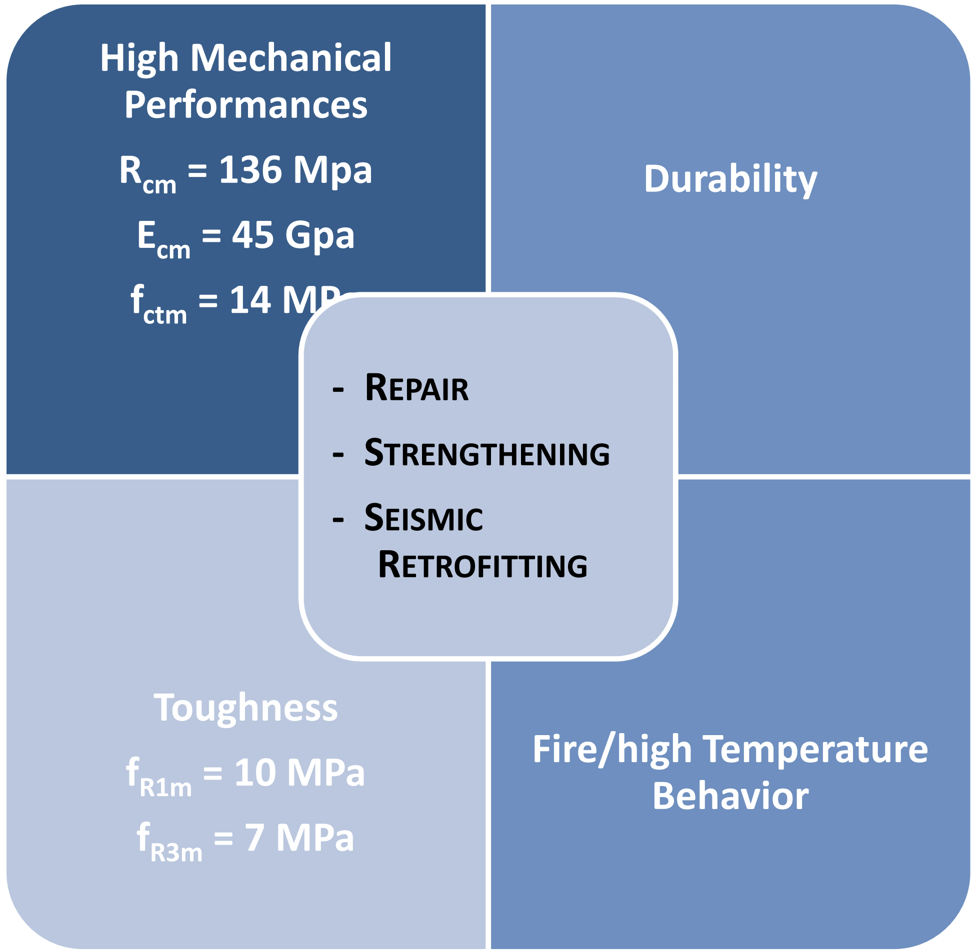
Main advantages from UHPFRC.

- Jacketing with UHPFRC offers the possibility to renew the capacity of the element to resist to the environmental actions by means of the high durability of the new cement-based repair material.
- The high performance of FRC allows to have thinner layers of jacketing materials that do not require additional rebars so there are not minimum concrete cover requirements.
- The reduced thickness slightly increases the pier thickeness which is helpful for seismic beahvior

Repair infrastructures with UHPFRC

MIX DESIGN (Volume fraction on total binder)		
	NSC	**UHPFRC**
Water/binder ratio	0.45	0.22
Aggregates	6.17	1.85
Pozzolanic addition	-	0.034
SP admixture	0.035	0.030
SRA admixture	-	0.031
Steel fibers (1%)	-	0.04
Maximum aggregate size, mm (in)	10 (⅜)	4 (⅕)





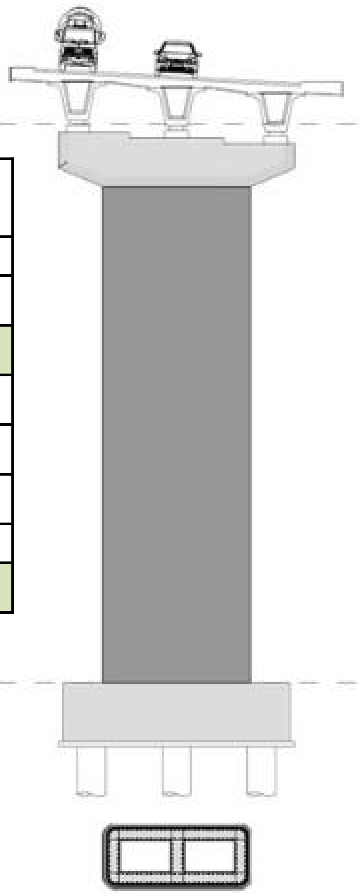
Fibres were made of stainless steel, crimped, 19 mm long, with 0.13 mm diameter. The maximum aggregate size was 4 mm to fit the critical thickness of 30 mm of the jacketing

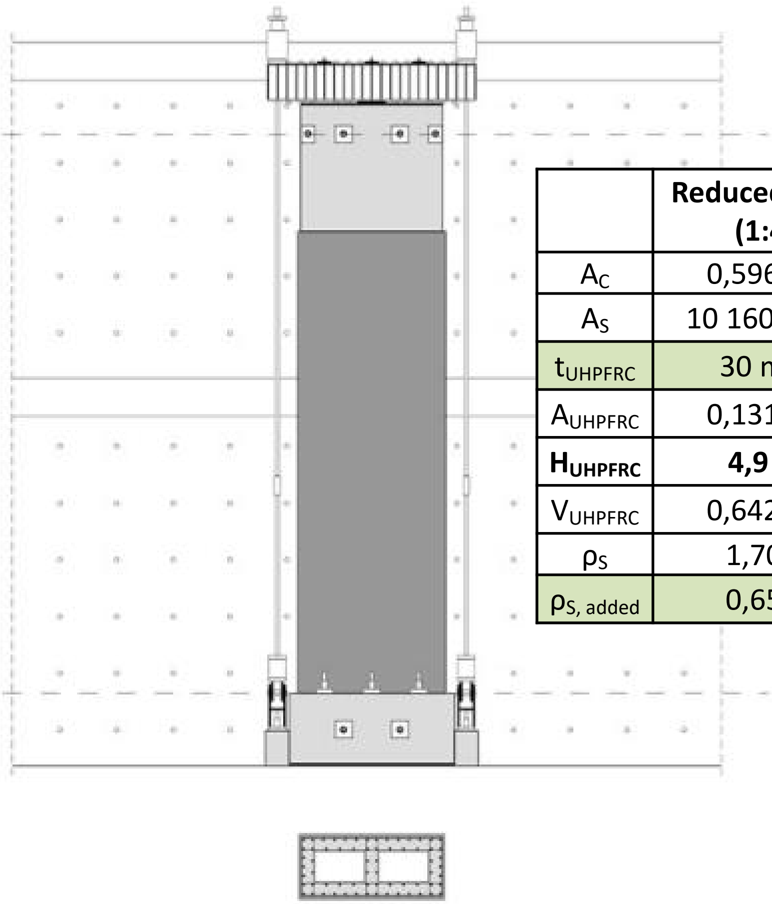
Previous tests on UHPFRC jacketing

- UHPFRC mix design for determining the most efficient material for the specific application.
- Numerical modelling for optimizing the material for the structural performance requirements
- UHPFRC-to-RC bond tests for determing the best treatment of the existing RC surface → sand blasting
- Restrained shrinkage tests for verifying possible crack development due to restrained shrinkage.

Experimental investigation.

	Real scale (1:1)
A_C	9,386 m^2
A_S	164 588 mm^2
t_{UHPFRC}	120 mm
A_{UHPFRC}	1,963 m^2
H_{UHPFRC}	**21 m**
V_{UHPFRC}	41,227 m^3
ρ_S	1,75%
$\rho_{S,\ added}$	0,65%

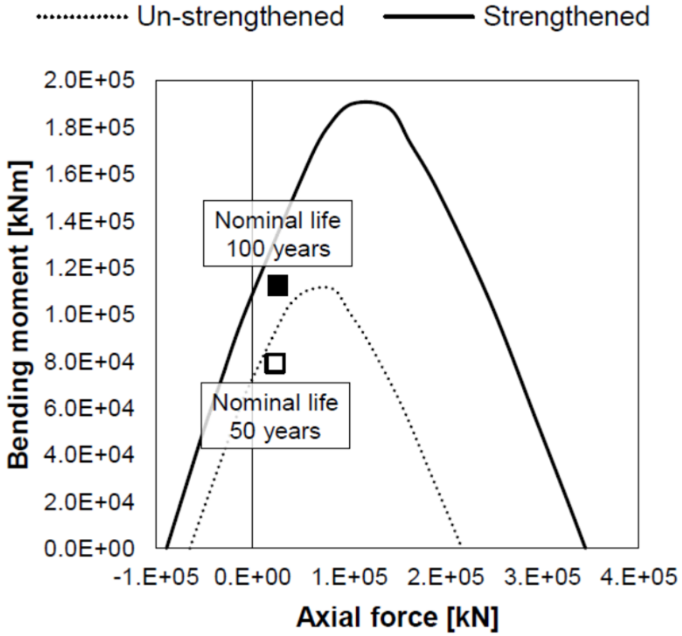




	Reduced scale (1:4)
A_C	0,596 m^2
A_S	10 160 mm^2
t_{UHPFRC}	30 mm
A_{UHPFRC}	0,131 m^2
H_{UHPFRC}	**4,9 m**
V_{UHPFRC}	0,642 m^3
ρ_S	1,70%
$\rho_{S,\ added}$	0,65%

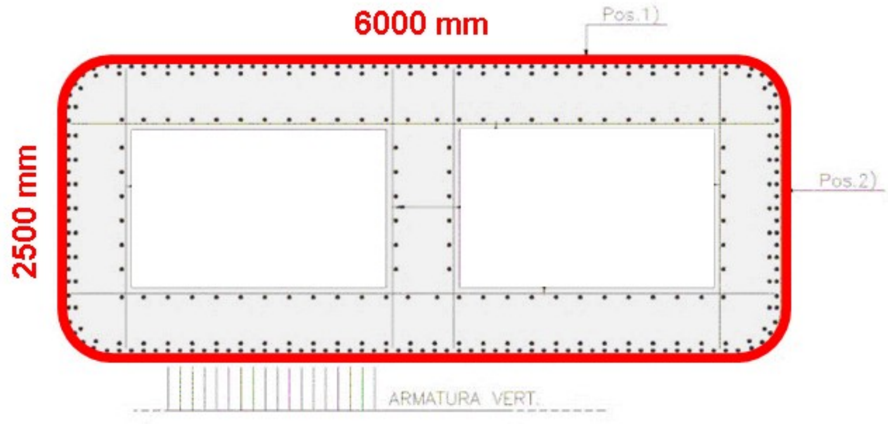
Strengthening design

Seismic actions are calculated increasing the peak ground acceleration from 0.250·g (V_N = 50 years) to 0.309·g (V_N = 100 years).



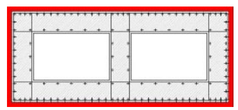
HPFRC Jacketing

Jacketing thickness: 120 mm



Specimen scaled 1:4

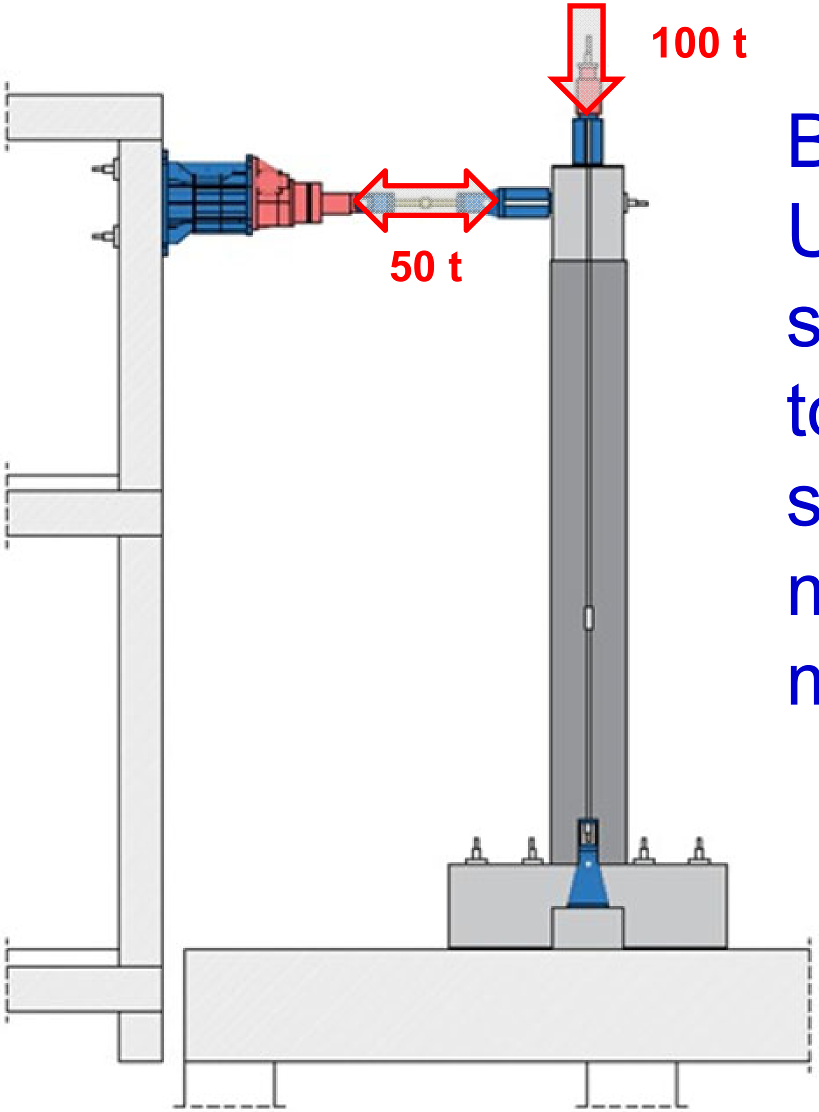
Jacketing thickness: 30 mm



The thickness of the hollow cross-section is 60 cm. The reinforcement in the critical section consists of 314 Ø26 longitudinal bars and Ø16 transverse reinforcements spaced 100 mm with a concrete cover of 40 mm.

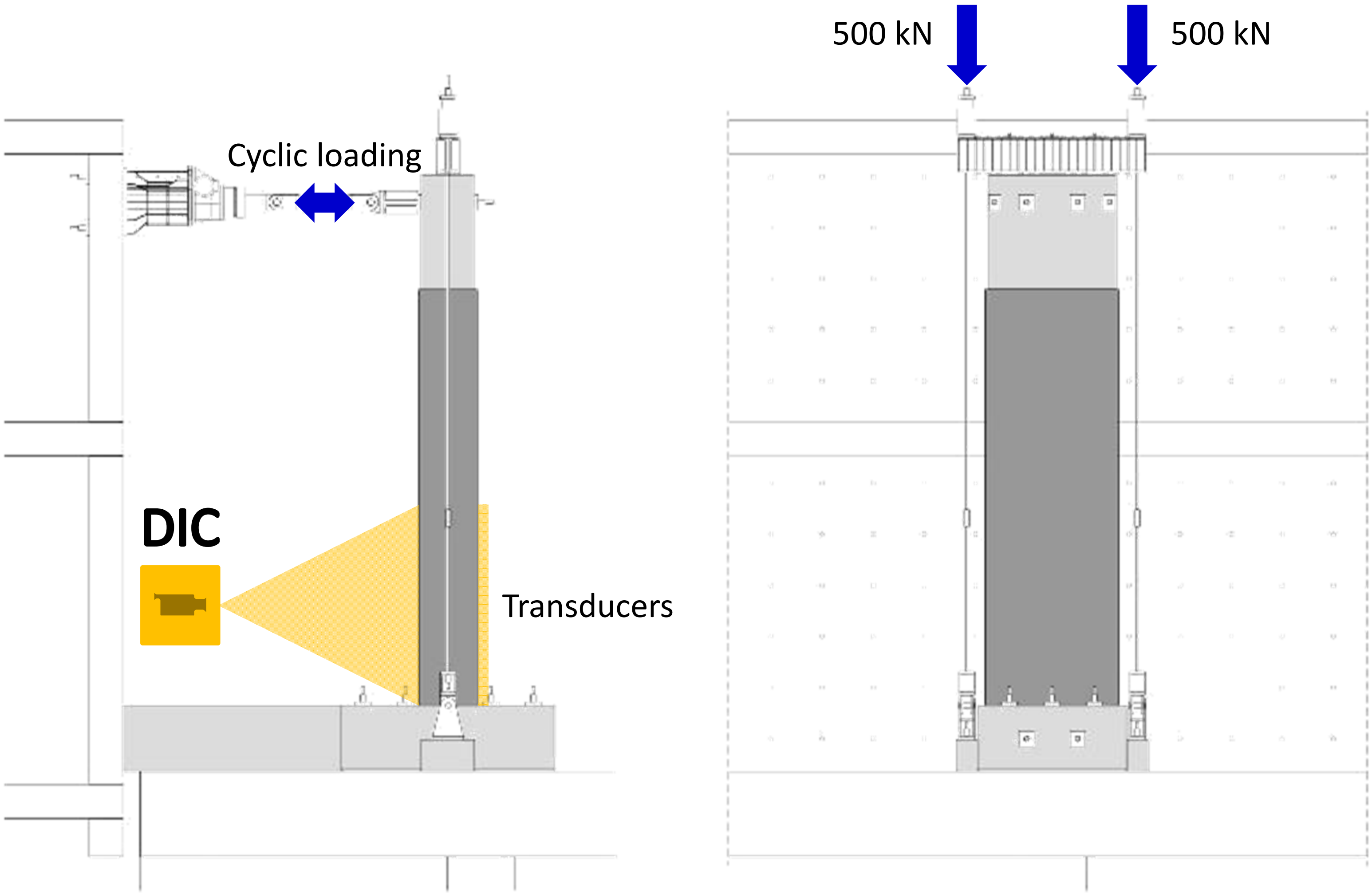
Experimental investigation.

Experimental set-up



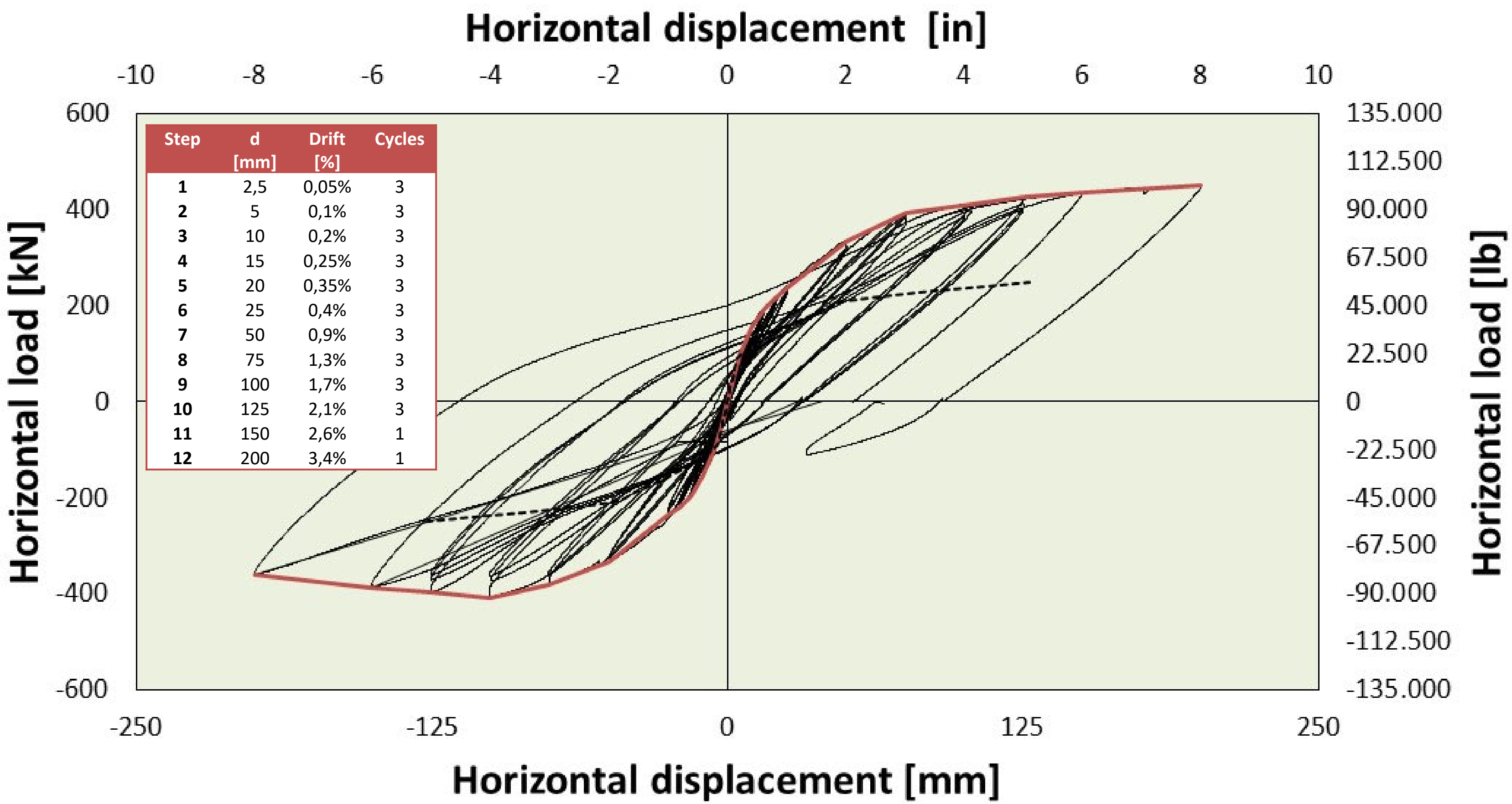
Before placing the UHPFRC layer, the RC specimen was sandblasted to obtain a very rough surface (R_t= 3.0 mm) measured with sand patch method

Experimental investigation.



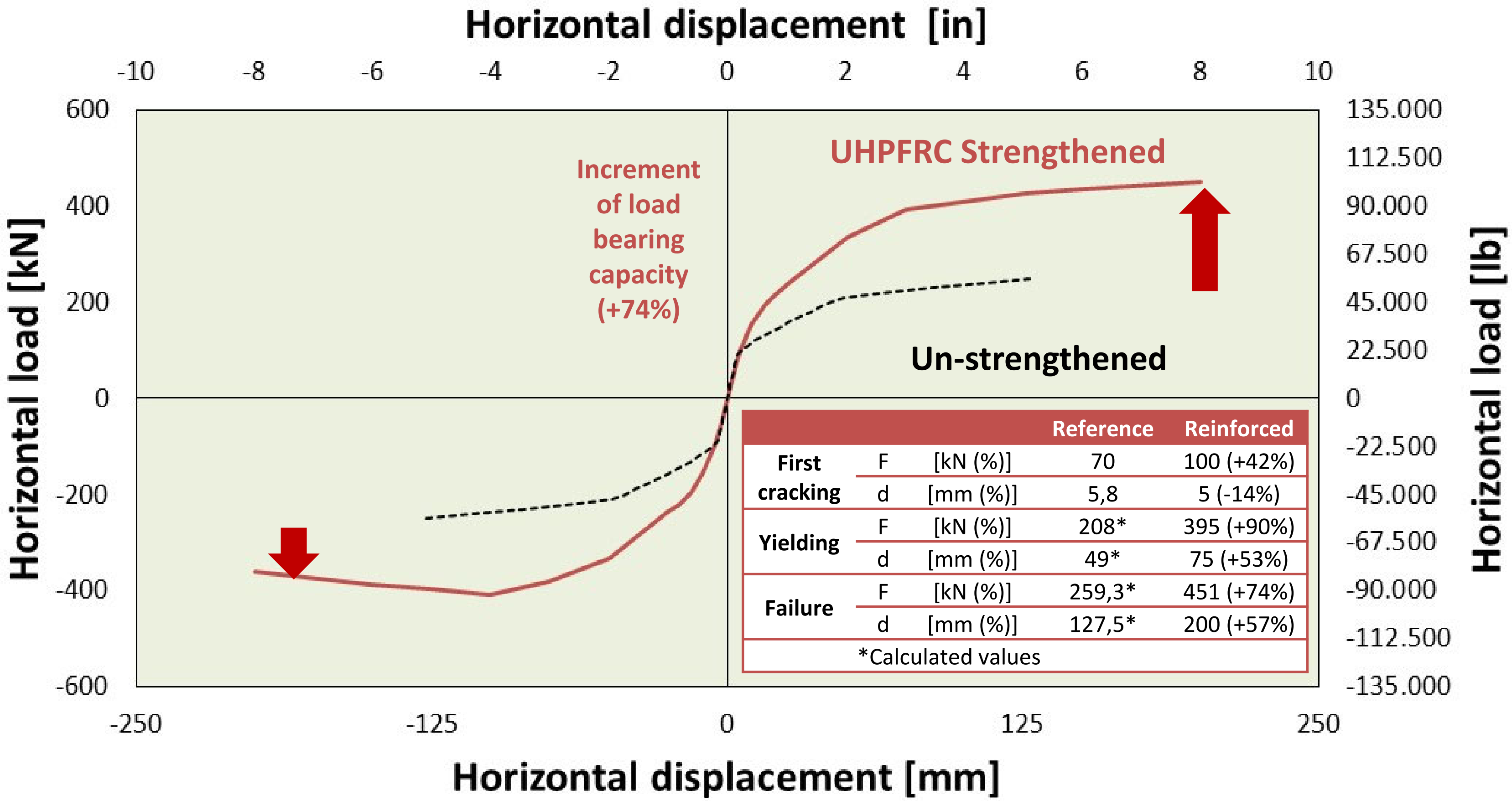
Experimental investigation.

Quasi-static cyclic loading test.



Step	d [mm]	Drift [%]	Cycles
1	2,5	0,05%	3
2	5	0,1%	3
3	10	0,2%	3
4	15	0,25%	3
5	20	0,35%	3
6	25	0,4%	3
7	50	0,9%	3
8	75	1,3%	3
9	100	1,7%	3
10	125	2,1%	3
11	150	2,6%	1
12	200	3,4%	1

Increment of load bearing capacity.

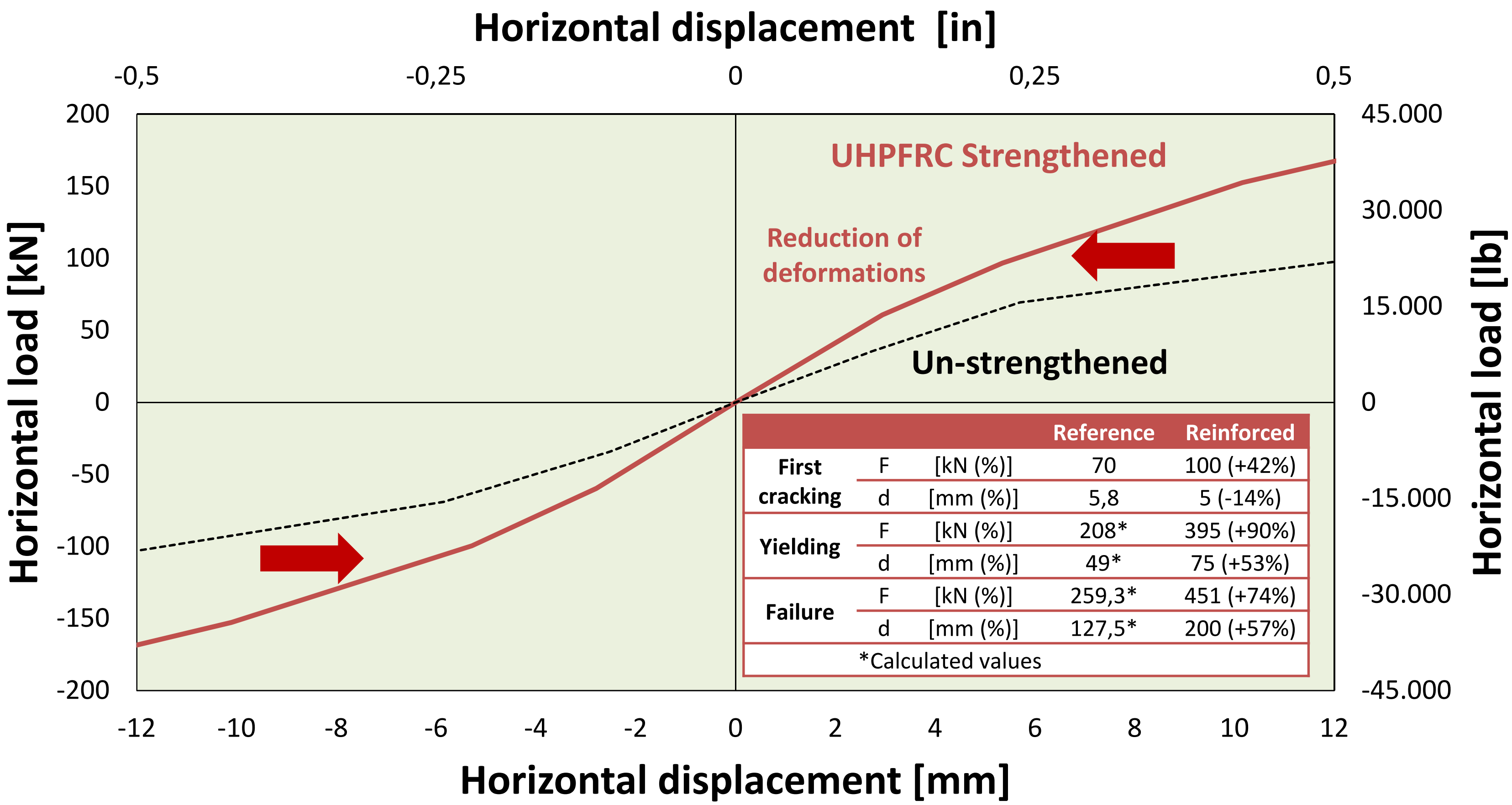


			Reference	Reinforced
First cracking	F	[kN (%)]	70	100 (+42%)
	d	[mm (%)]	5,8	5 (-14%)
Yielding	F	[kN (%)]	208*	395 (+90%)
	d	[mm (%)]	49*	75 (+53%)
Failure	F	[kN (%)]	259,3*	451 (+74%)
	d	[mm (%)]	127,5*	200 (+57%)

*Calculated values

Buckling of the jacketing was observed at the base of the south face (front).

Reduction of deformations.



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*Calculated values

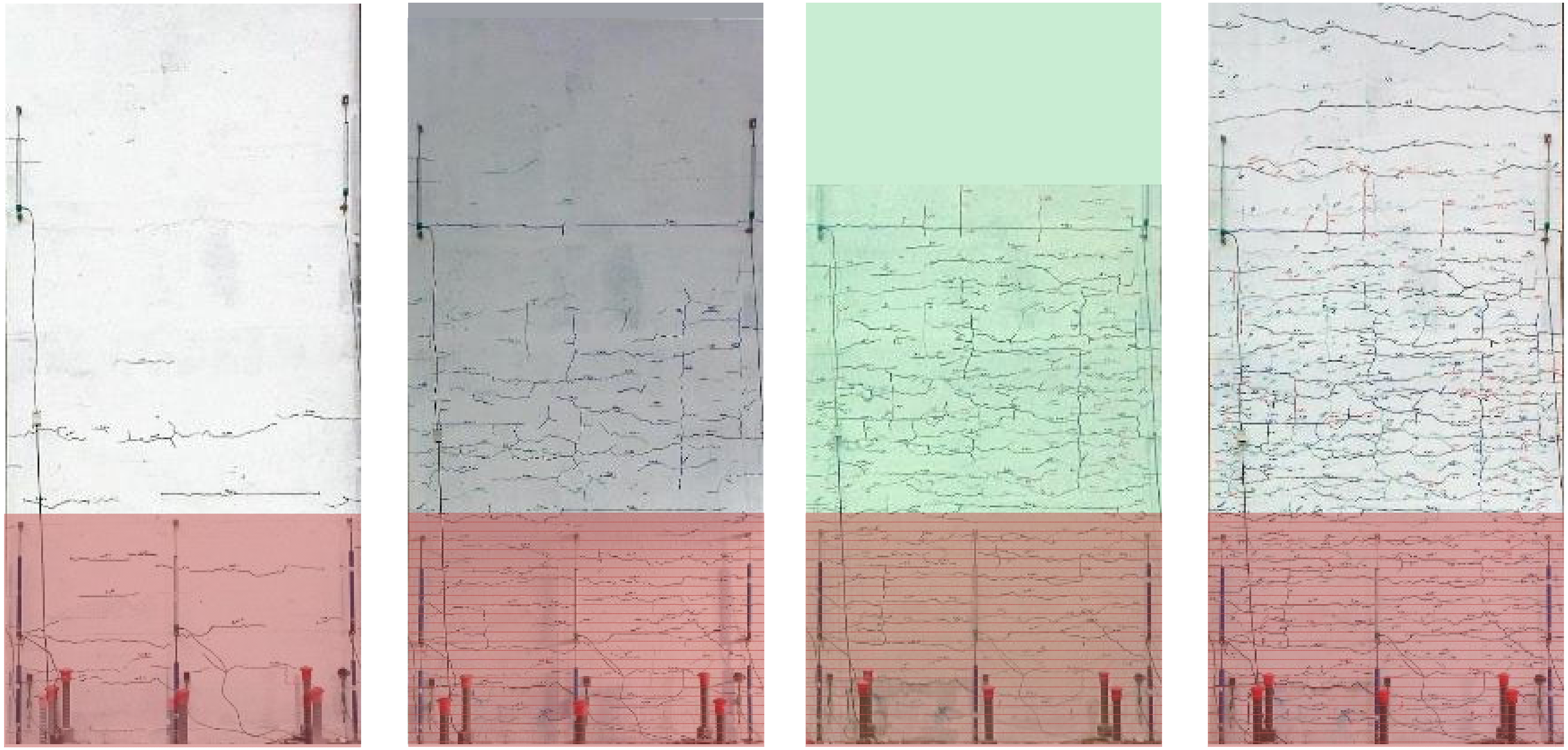
Main experimental results

First cracking	H [kN]	d [mm]	θ [%]
Un-strengthened	70	5.8	0.1
Strengthened	100 (+42%)	5 (-14%)	0.1 (-14%)
First yielding	**H [kN]**	**d [mm]**	**θ [%]**
Un-strengthened	208*	49*	0.8*
Strengthened	395 (+90%)	75 (+53%)	1.3 (+53%)
Failure	**H [kN]**	**d [mm]**	**θ [%]**
Un-strengthened	259*	127*	2.2*
Strengthened	451 (+74%)	200 (+57%)	3.4 (+57%)

*Calculated values with f_y = 450 MPa.

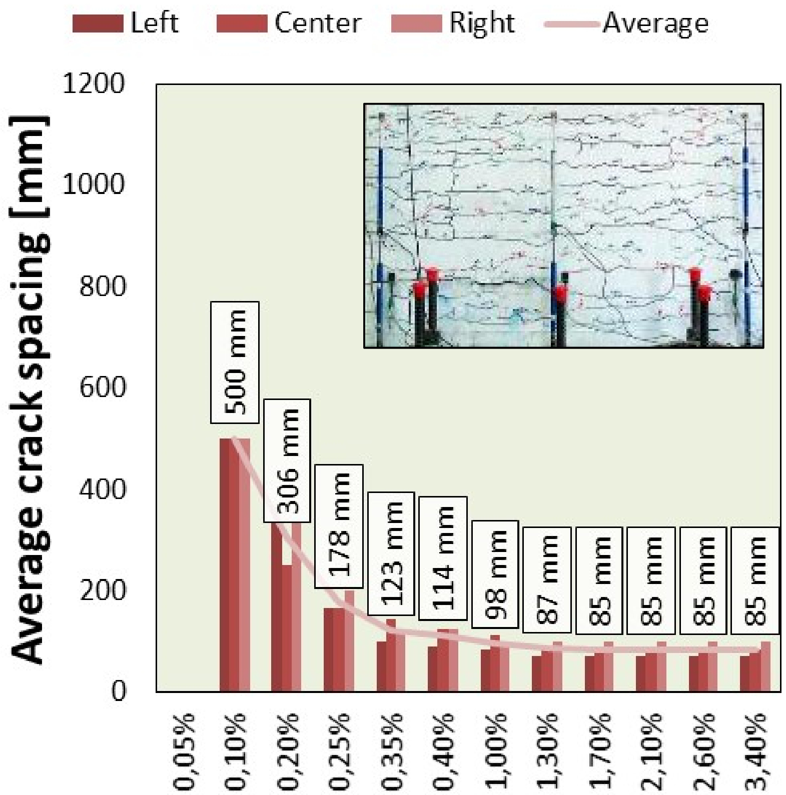
Cracking development.

H = 153 kN	H = 217 kN	H = 395 kN	H = 412 kN
d = 10 mm	d = 20 mm	d = 75 mm	d = 100 mm
D = 0,17%	D = 0,34%	D =1,29%	D = 1,72%

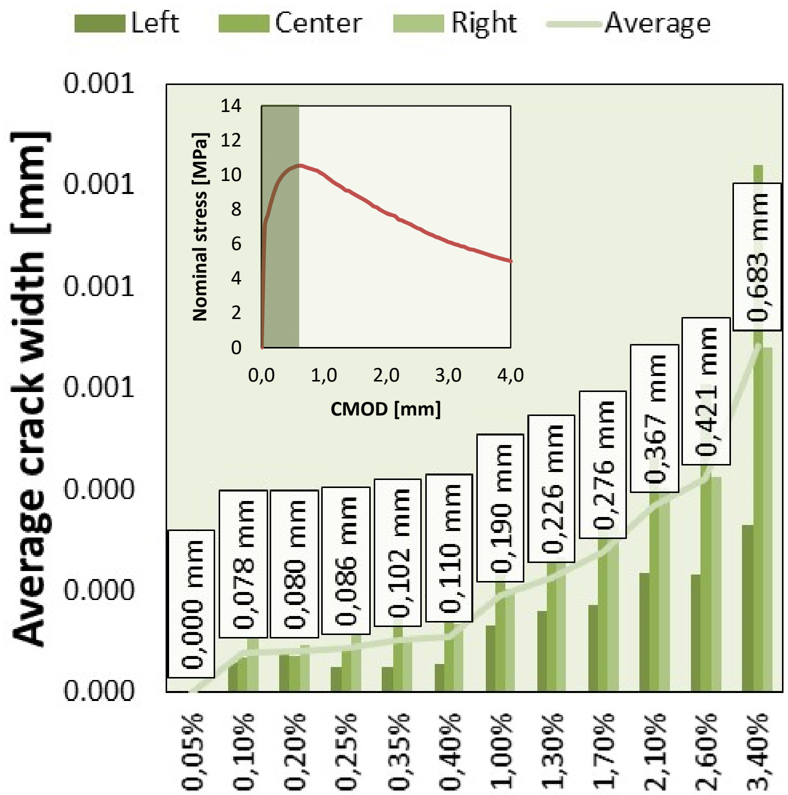


Average crack spacing and width.

Crack spacing



Crack width



FRC performance classes (New fib Model Code)

Post-cracking residual strength can be classified by using two parameters, namely f_{R1k} (representing the strength interval) and a letter a, b, c, d or e (representing the ratio f_{R3k}/f_{R1k}).

The strength interval is defined by two subsequent numbers in the series:

1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 [MPa]

while the letters *a, b, c, d*

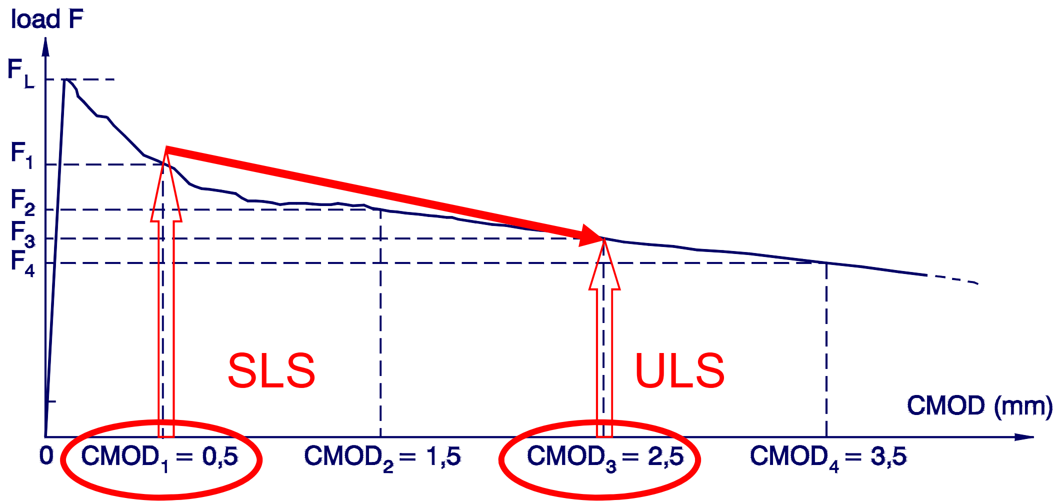
a if $0.5 \leq f_{R3k}/f_{R1k} \leq 0.7$

b if $0.7 \leq f_{R3k}/f_{R1k} \leq 0.9$

c if $0.9 \leq f_{R3k}/f_{R1k} \leq 1.1$

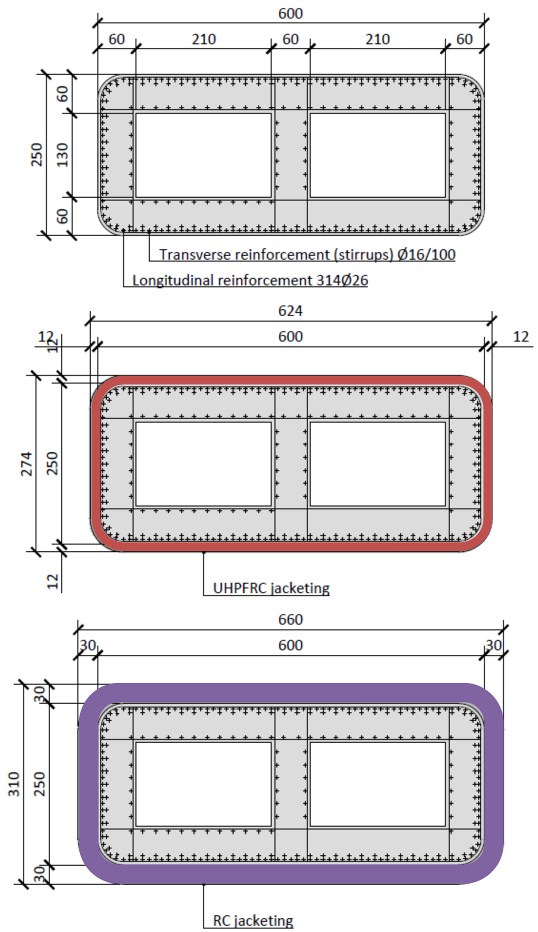
d if $1.1 \leq f_{R3k}/f_{R1k} \leq 1.3$

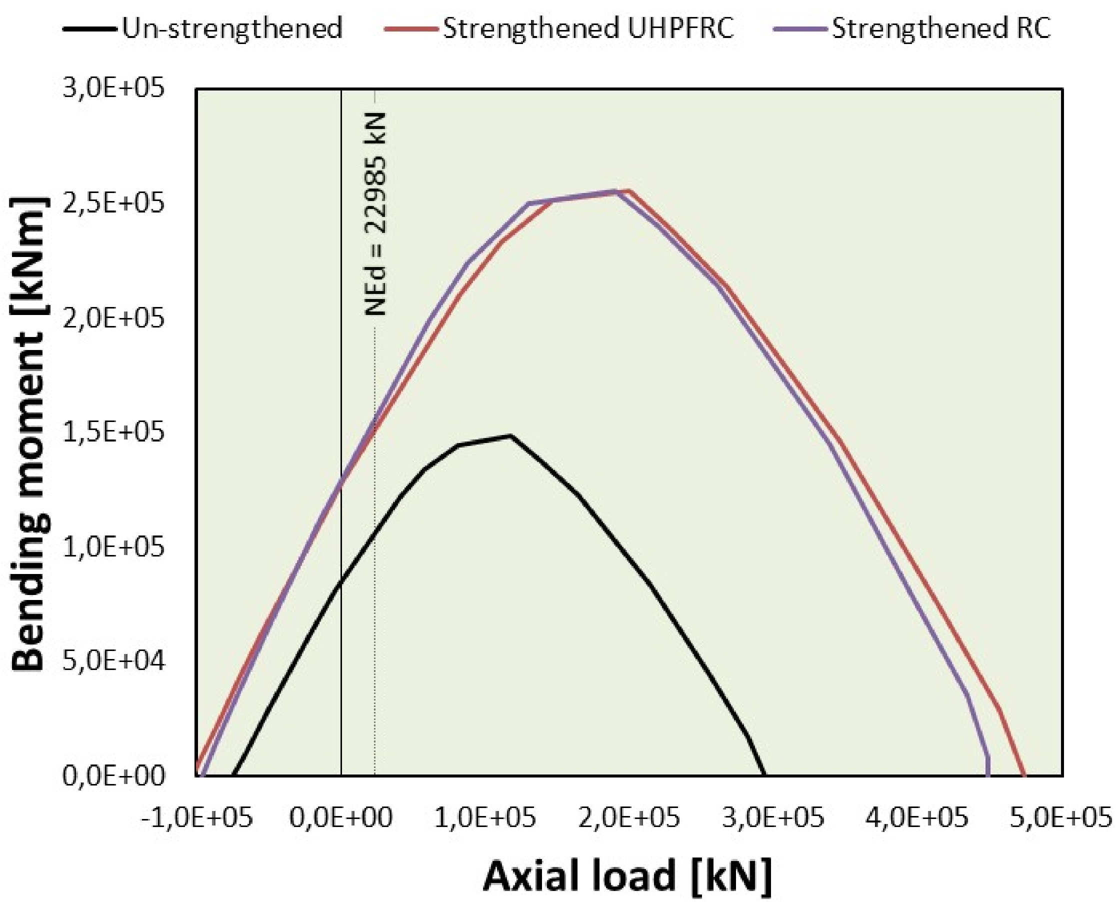
e if $1.3 \leq f_{R3k}/f_{R1k}$



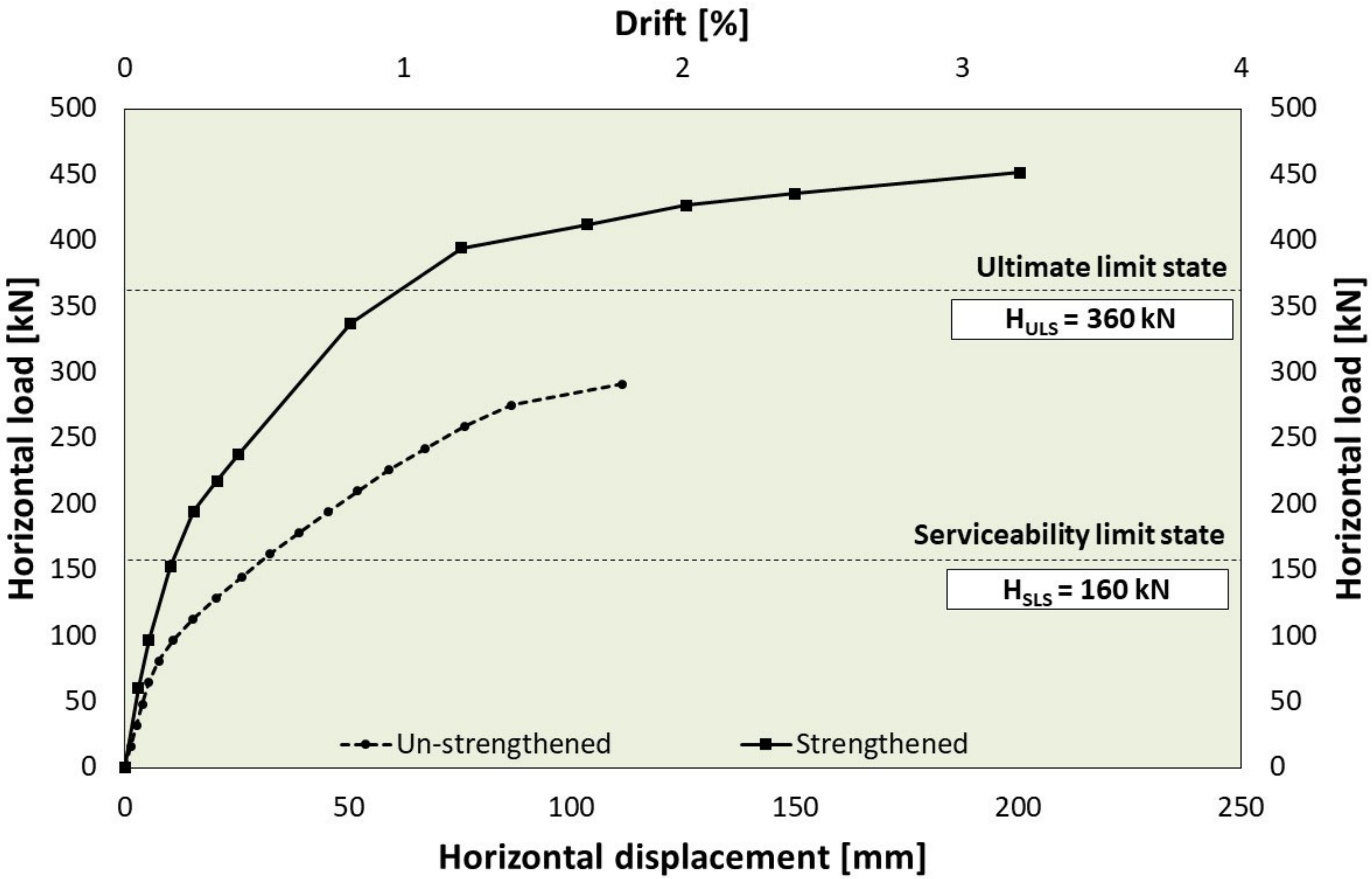
The designer has to specify the class, the residual strength ratio and the material of the fibre

Extension of working life is possible?





Increment of load bearing capacity.



Findings of the experimental campaign.

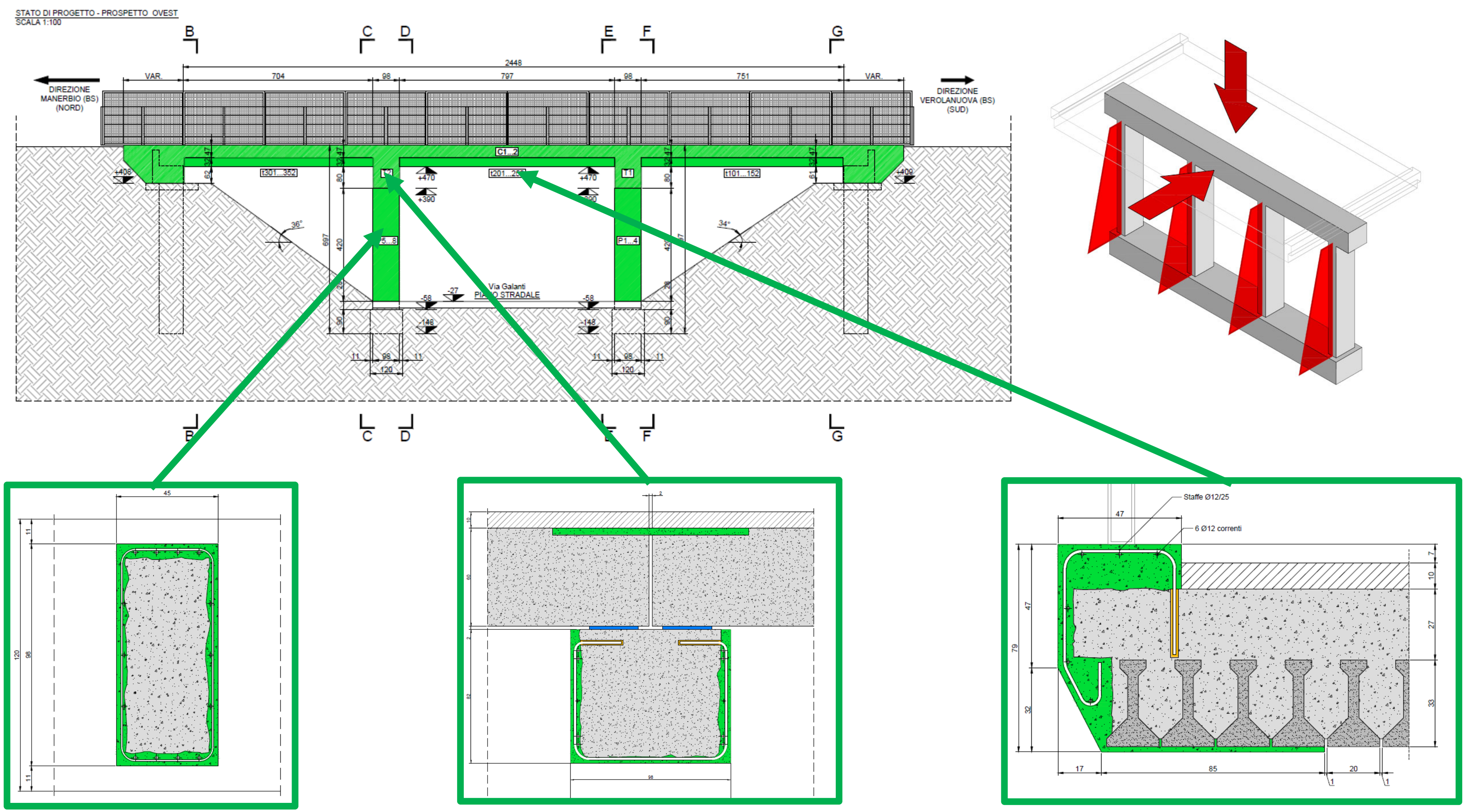
- Reduction of seismic vulnerability at ULS by increasing load bearing capacity and ductility.
- Performance improvement at SLS by reducing cracking and deformability.
- Durability enhancement due to a better controlled cracking process and intrinsic material's properties.

EU funded project: MoSoRe@UniBS

SMALL ROAD BRIDGE SOUTH BRESCIA (IT)

SEVERE REINFORCEMENT CORROSION

EU funded project: MoSoRe@UniBS



COLUMN **CAP BEAM** **KERB**

EU funded project: MoSoRe@UniBS

CONCRETE REMOVAL

CASTING PHASE

JACKETING

PUMPING PHASE

Thank you!

Contacts.

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