reluis

Rete dei Laboratori Universitari di Ingegneria Sismica e Strutturale

SETTIMANA NAZIONALE DELLA PROTEZIONE CIVILE

6/13 OTTOBRE 2024

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SAIE
Bologna, 9/12 ottobre 2024

SCUOLA DI INGEGNERIA STRUTTURALE – RELUIS

Bologna, 9-11 ottobre 2024

I calcestruzzi fibrorinforzati (FRC) per il miglioramento sismico delle strutture esistenti

Giovanni Plizzari e Luca Facconi
Università di Brescia

RINFORZO DELLA MURATURA MEDIANTE INTONACI: RIFERIMENTI NORMATIVI

I COMPOSITI A BASE CEMENTIZIA RINFORZATI CON FIBRE D'ACCIAIO (FIBER REINFORCED MORTAR): RIFERIMENTI NORMATIVI

- I calcestruzzi fibrorinforzati sono impiegati da tempo nella realizzazione di elementi strutturali prefabbricati (travi, conci di rivestimento per gallerie, pannelli di rivestimento, ecc.), solai e pavimentazioni. L'Italia è stato uno dei primi paesi al mondo a dotarsi di linee guida e normative (CNR-DT204:2006, UNI11039:2003) per la qualifica e la progettazione di elementi strutturali in FRC.

- La normativa italiana (NTC18) ha introdotto solo recentemente la possibilità d'impiego di tali materiali nelle applicazioni strutturali:

11.2.12. CALCESTRUZZO FIBRORINFORZATO (FRC)

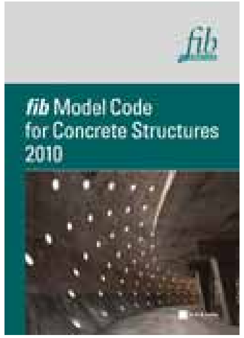
Il calcestruzzo fibrorinforzato (FRC) è caratterizzato dalla presenza di fibre discontinue nella matrice cementizia; tali fibre possono essere realizzate in acciaio o materiale polimerico, e devono essere marcate CE in accordo alle norme europee armonizzate, quali la UNI EN 14889-1 ed UNI EN 14889-2 per le fibre realizzate in acciaio o materiale polimerico.

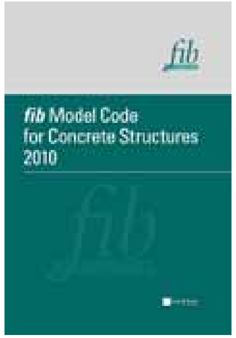
La miscela del calcestruzzo fibrorinforzato deve essere sottoposta a valutazione preliminare secondo le indicazioni riportate nel precedente § 11.2.3 con determinazione dei valori di resistenza a trazione residua f_{R1k} per lo Stato limite di esercizio e f_{R3k} per lo Stato limite Ultimo determinati secondo UNI EN 14651:2007.

Per la qualificazione del calcestruzzo fibrorinforzato e la progettazione delle strutture in FRC si dovrà fare esclusivo riferimento a specifiche disposizioni emanate dal Consiglio Superiore dei Lavori Pubblici.

- Nel 2022 il CSLLPP ha introdotto le Linee Guida per la progettazione, la messa in opera, il controllo e il collaudo delle strutture in FRC. Indicazioni per la qualifica di tali materiali sono contenute nelle apposite Linee Guida emanate dal CSLLPP nel 2019.

- Le Linee Guida applicative hanno di fatto in buona parte recepito le indicazioni riportate nel fib Model Code 2010.





RINFORZO DELLA MURATURA MEDIANTE INTONACI: PROGETTI IN CORSO

I COMPOSITI A BASE CEMENTIZIA RINFORZATI CON FIBRE D'ACCIAIO (FIBER REINFORCED MORTAR): INDICAZIONI SPECIFICHE PER LE MURATURE?

Le NTC18 (par. 8.6) consentono l'utilizzo di materiali non tradizionali per interventi su strutture esistenti purché essi siano **identificabili**, in **possesso di specifica qualificazione** all'uso previsto e siano **oggetto di controllo** in fase di accettazione in cantiere. Per quanto concerne la qualifica, è possibile far riferimento alle apposite Linee Guida del CSLLPP (2019) per l'identificazione, la qualificazione, la certificazione di valutazione tecnica ed il controllo di accettazione dei calcestruzzi fibrorinforzati FRC (Fiber Reinforced Concrete).

Allo stato attuale non sono disponibili specifiche indicazioni normative o linee guida dedicate alla progettazione di interventi di rinforzo delle strutture in muratura mediante intonaci fibrorinforzati (FRM)

Attività di ricerca, volte allo sviluppo proposte normative, sono tutt'ora in fase di svolgimento. Fra gli altri si ricordano:

reluis

Progetto DPC-ReLUIS 2024-2026 – WP14: Materiali Strutturali innovativi per la Sostenibilità delle Costruzioni

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Return

Progetto PNRR «RETURN» - Multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate - Spoke VS3

Calcestruzzo Fibrorinforzato (CNR DT 204)

“Il calcestruzzo fibrorinforzato è un materiale composito caratterizzato da una matrice cementizia e da fibre discrete (discontinue). La matrice è costituita da calcestruzzi o da malte, normali o ad alte prestazioni. Le fibre possono essere di acciaio, di materiale polimerico, di carbonio, di vetro o di materiale naturale.”

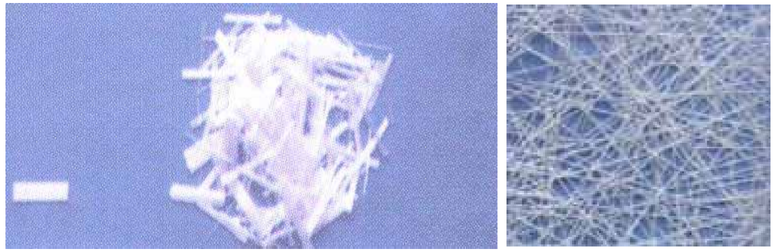
Fibre per calcestruzzo

Si differenziano in base al tipo di forma e di materiale di cui sono costituite

- **Fibre di Acciaio**

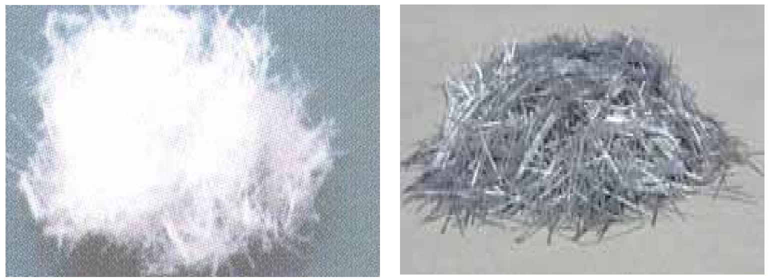
- **Fibre di Alluminio**

- **Fibre di Vetro**



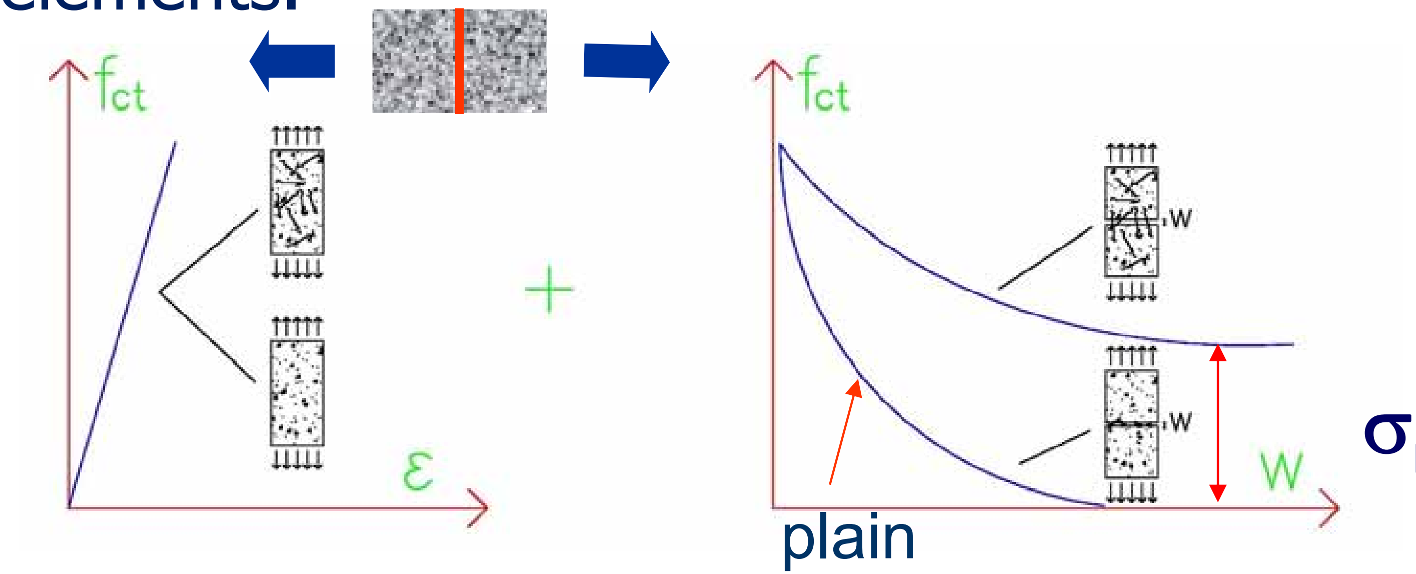
- **Fibre di Carbonio**

- **Fibre di Polipropilene**



An additional performance provided by FRC

FRC allows to overcome the critical property concerning the tensile behavior of concrete since it provides a post-cracking resistance that can be particular useful in several structural elements.



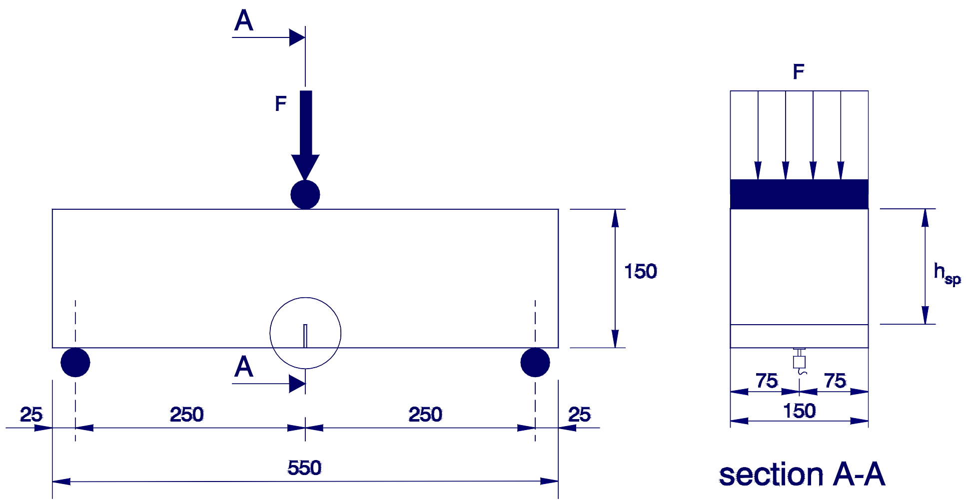
Fibre content

$V_f \leq 1\%$

$\sigma_{res}(w)$

- durability (cracking control)
- anchorage lengths
- deformability (tension stiffening)
- minimum reinforcement (N, M, V)
- fatigue
- D regions (spalling, bursting, splitting)

FRC classification (3PBT)



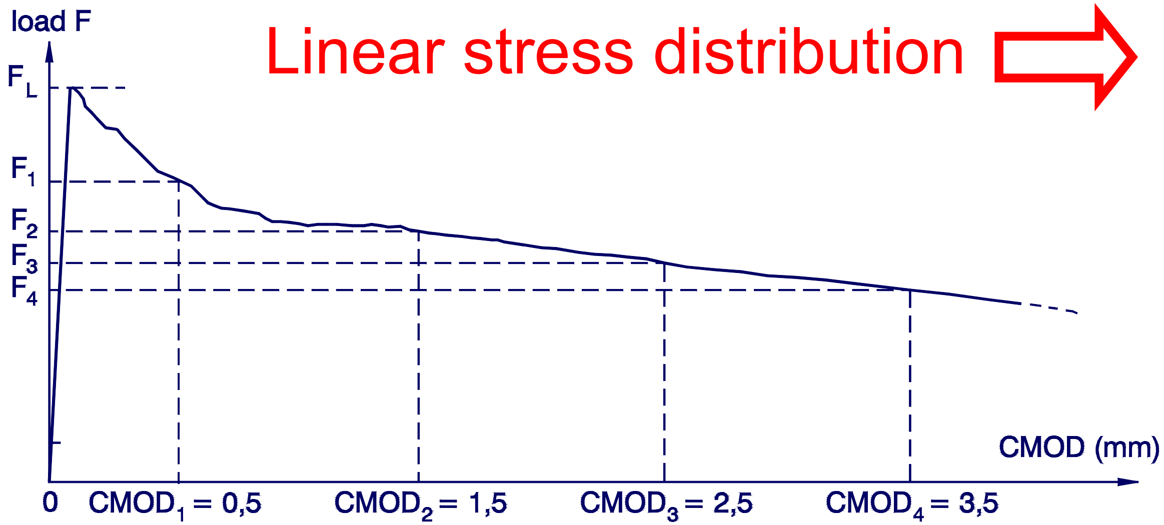
EN 14651

h_{sp} = 125 mm

b = 150 mm

Linear stress distribution ⇒

$$f_{R,j} = \frac{3 F_j l}{2 b h_{sp}^2}$$



FRC performance classes (New fib Model Code)

Post-cracking residual strength can be classified by using two parameters, namely fR1k (representing the strength interval) and a letter a, b, c, d or e (representing the ratio fR3k/fR1k).

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 and e* correspond to the ratios:

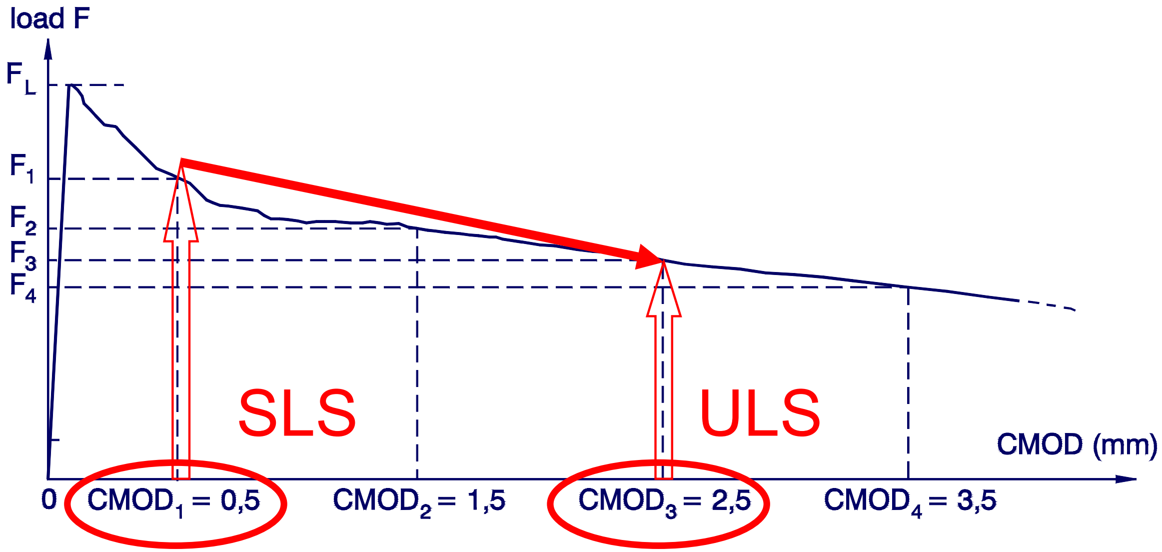
a if $0.5 \leq f_{R3k}/f_{R1k} \leq 0.7$

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

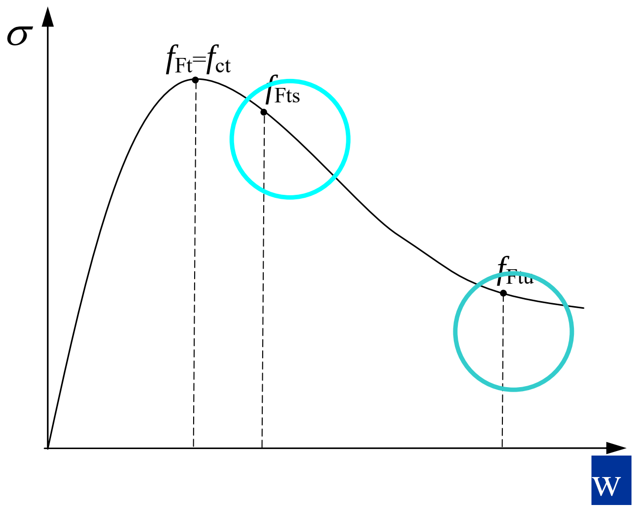
e if $1.3 \leq f_{R3k}/f_{R1k}$



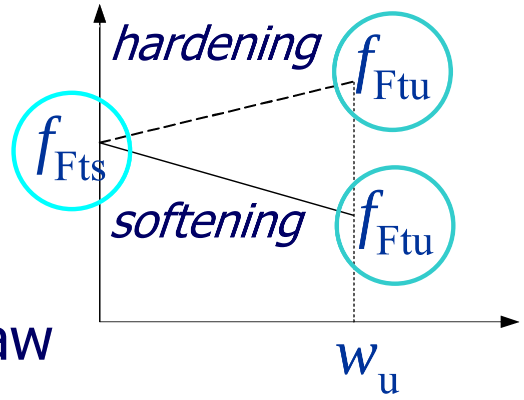
The designer has to specify the class, the residual strength ratio and the material of the fibre

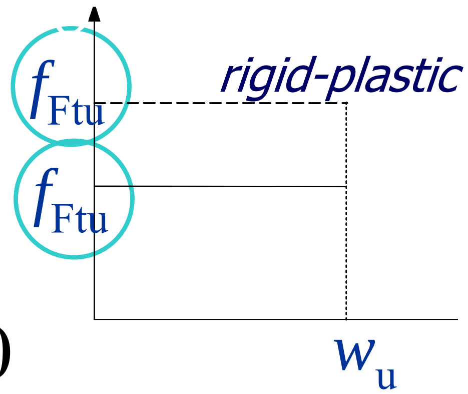
Constitutive law in uniaxial tension: s-w

- Experimental result: **σ_N – CMOD** → **σ – w**



Simplified constitutive law σ - w

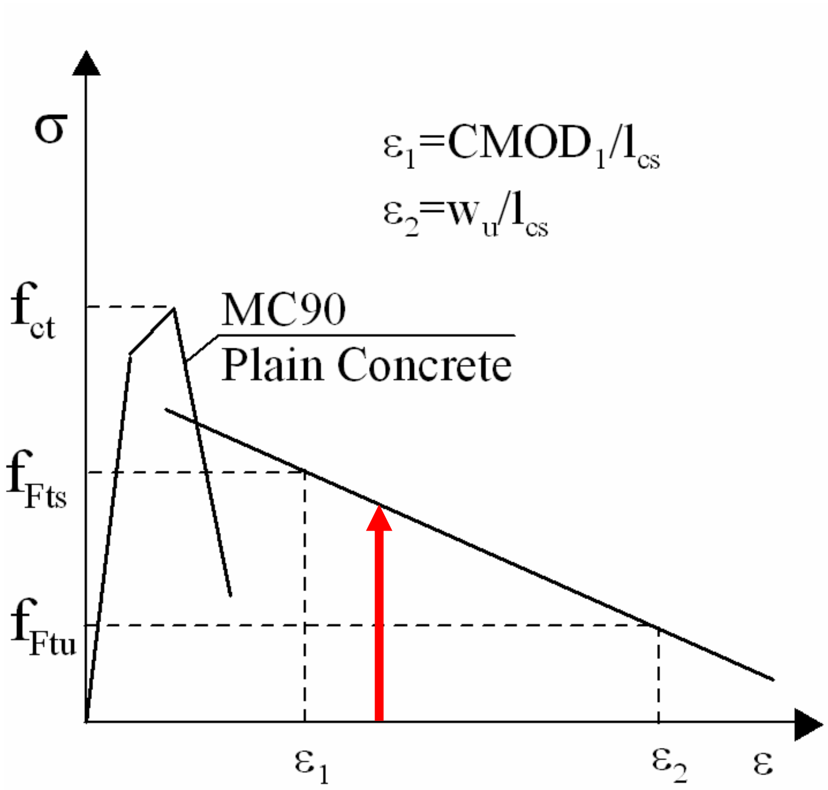


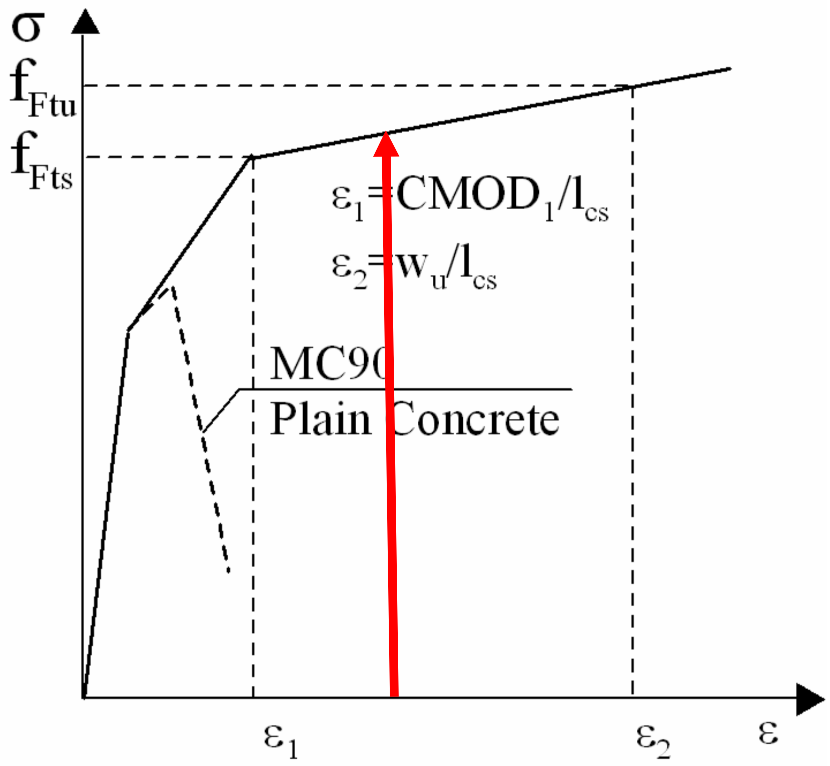


$$f_{Fts} = 0.45 f_{R1}$$

$$f_{Ftu} = f_{Fts} - \frac{w_u}{CMOD_3}(f_{Fts} - 0.5 f_{R3} + 0.2 f_{R1}) \geq 0$$

The post-cracking strength in MC 2010

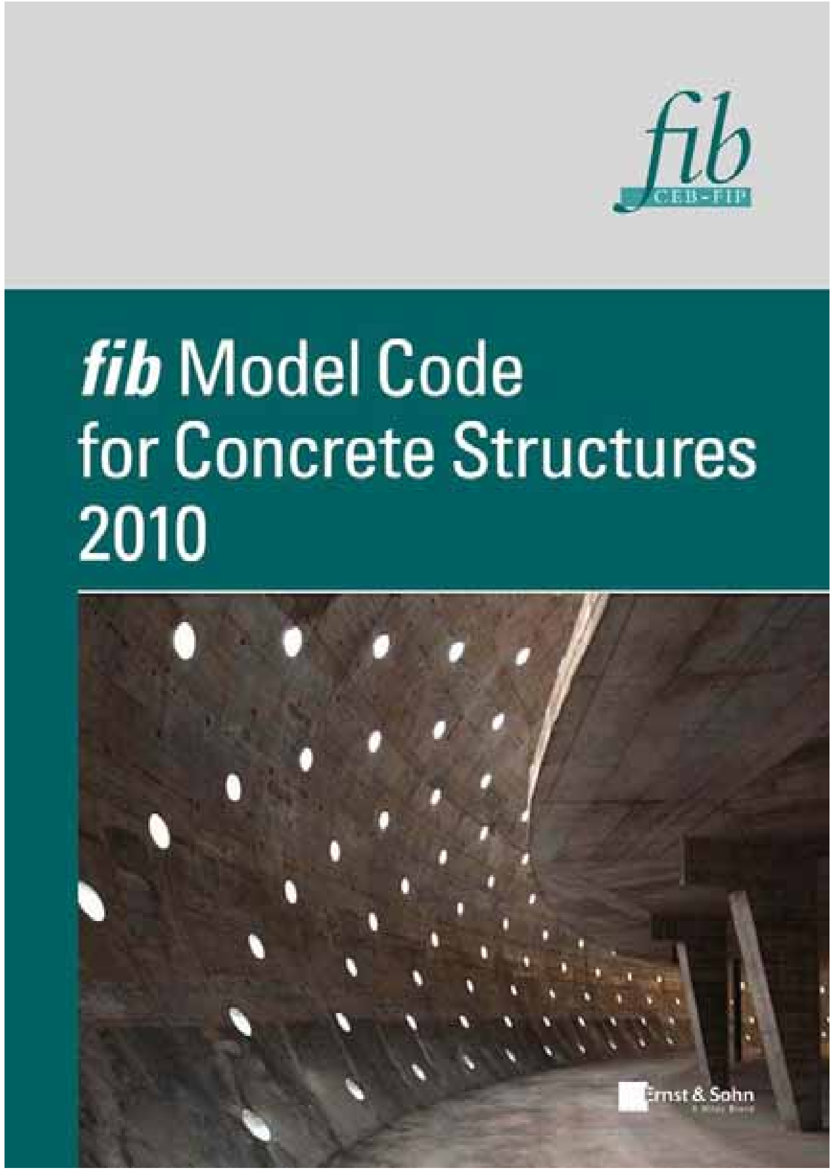


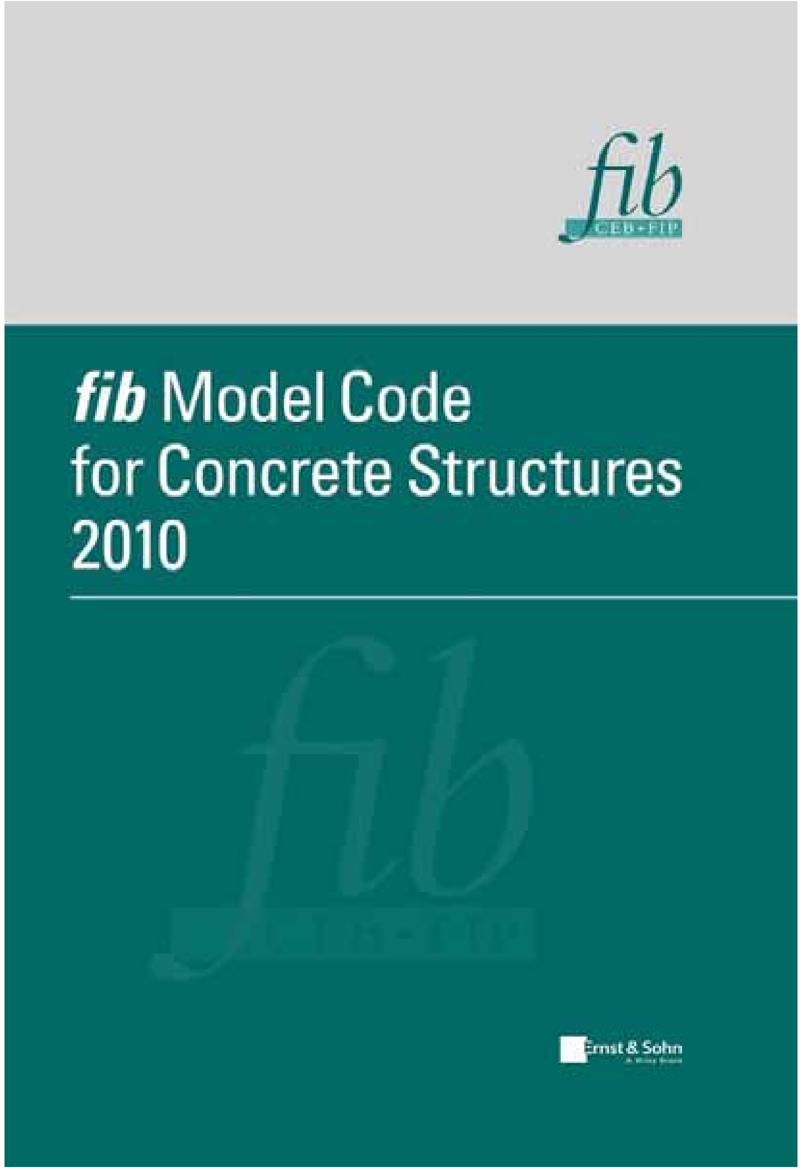


$\varepsilon_1 = \varepsilon_{SLS} = CMOD_1/l_{cs}$

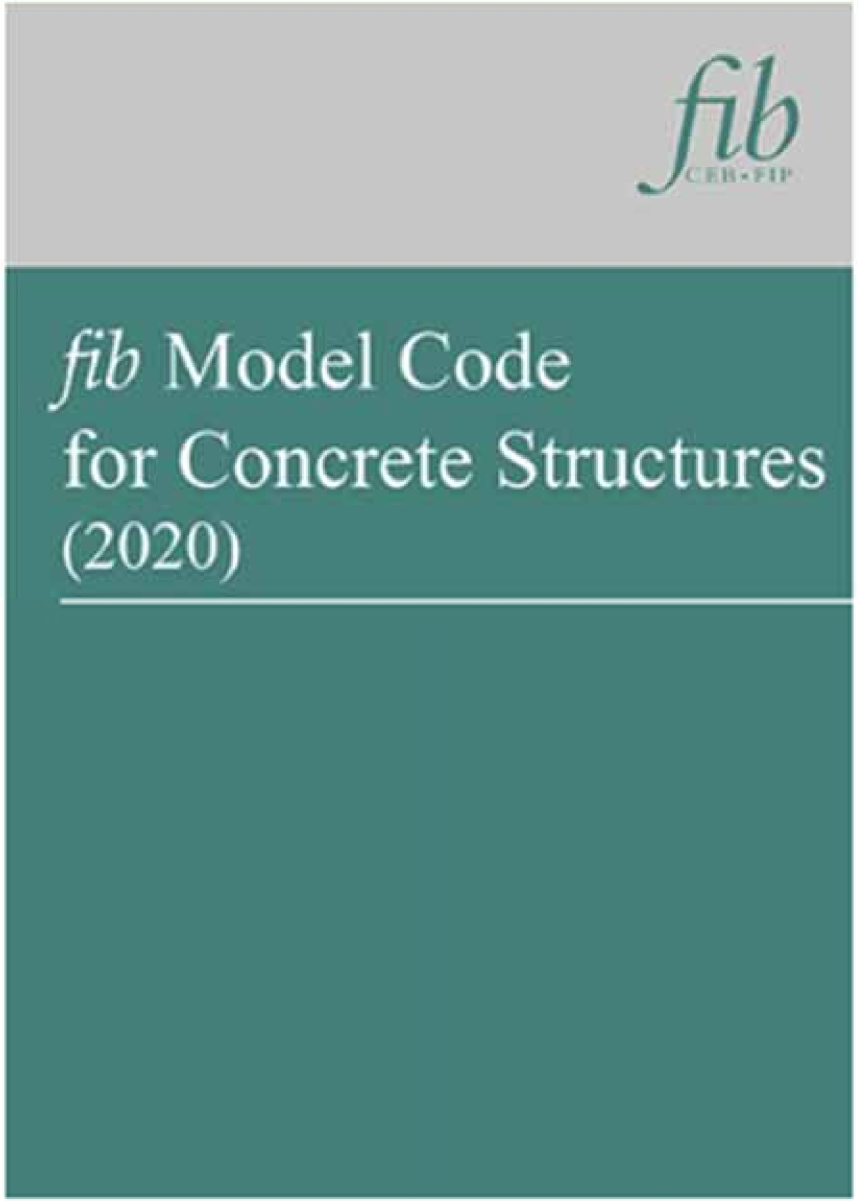
$\varepsilon_2 = \varepsilon_{ULS} = w_u/l_{cs}$ (=2% or 1%)

fib Model Code 2010





fib Model Code 2020



Special focus on rehabilitation of existing structures

Le nuove NTC

GAZZETTA UFFICIALE

DELLA REPUBBLICA ITALIANA

PARTE PRIMA Roma - Martedì, 20 febbraio 2018 SI PUBBLICA TUTTI I GIORNI NON FESTIVI

DIREZIONE E REDAZIONE PRESSO IL MINISTERO DELLA GIUSTIZIA - UFFICIO PUBBLICAZIONE LEGGI E DECRETI - VIA ARENULA, 70 - 00186 ROMA
AMMINISTRAZIONE PRESSO L'ISTITUTO POLIGRAFICO E ZECCA DELLO STATO - VIA SALARIA, 691 - 00138 ROMA - CENTRALINO 06-85081 - LIBRERIA DELLO STATO
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N. 8

MINISTERO DELLE INFRASTRUTTURE
E DEI TRASPORTI

DECRETO 17 gennaio 2018.

Aggiornamento delle «Norme tecniche per le costruzioni».

Il FRC nelle nuove NTC

11.2.12. CALCESTRUZZO FIBRORINFORZATO (FRC)

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Consiglio Superiore dei Lavori Pubblici
Servizio Tecnico Centrale

Linea guida per l'identificazione, la qualificazione, la certificazione di valutazione tecnica ed il controllo di accettazione dei calcestruzzi fibrorinforzati FRC (Fiber Reinforced Concrete)

Aggiornamento Novembre 2021

Le nuove linee guida per la progettazione di elementi in FRC

Consiglio Superiore dei Lavori Pubblici

Servizio Tecnico Centrale

Linee guida per la progettazione, messa in opera, controllo e collaudo di elementi strutturali in calcestruzzo fibrorinforzato con fibre di acciaio o polimeriche.

Edizione maggio 2022

Eurocode 2

CEN/TC 250/SC 2/WG 1 **N 1296**

CEN/TC 250/SC 2/WG 1 "Coordination and Editorial Panel"
WG Secretariat: **DIN**
Convenor: **Hallgren Mikael Mr**

FprEN_1992-1-1_e_stf_2022-07-24 FIN clean

Document type	Related content	Document date	Expected action
Project / Other		2022-08-01	INFO

Description

Please find attached the working document draft FprEN 1992-1-1 which gives the status of the work in progress of last week. This working document contains all technical changes decided at the Oslo meeting. Clause, Figure and Table numbering have been updated and finalised. Work on updating / correcting figures is still ongoing (Note: for Fig. L.2a) the wrong figure has been inserted) - attached is a copy of all figures as they shall appear in the final standard (Figures-rev13). Also ongoing is the verification of the list of NDPs, of all references in the document, of numbering of definitions and updating the table of contents of the standard.

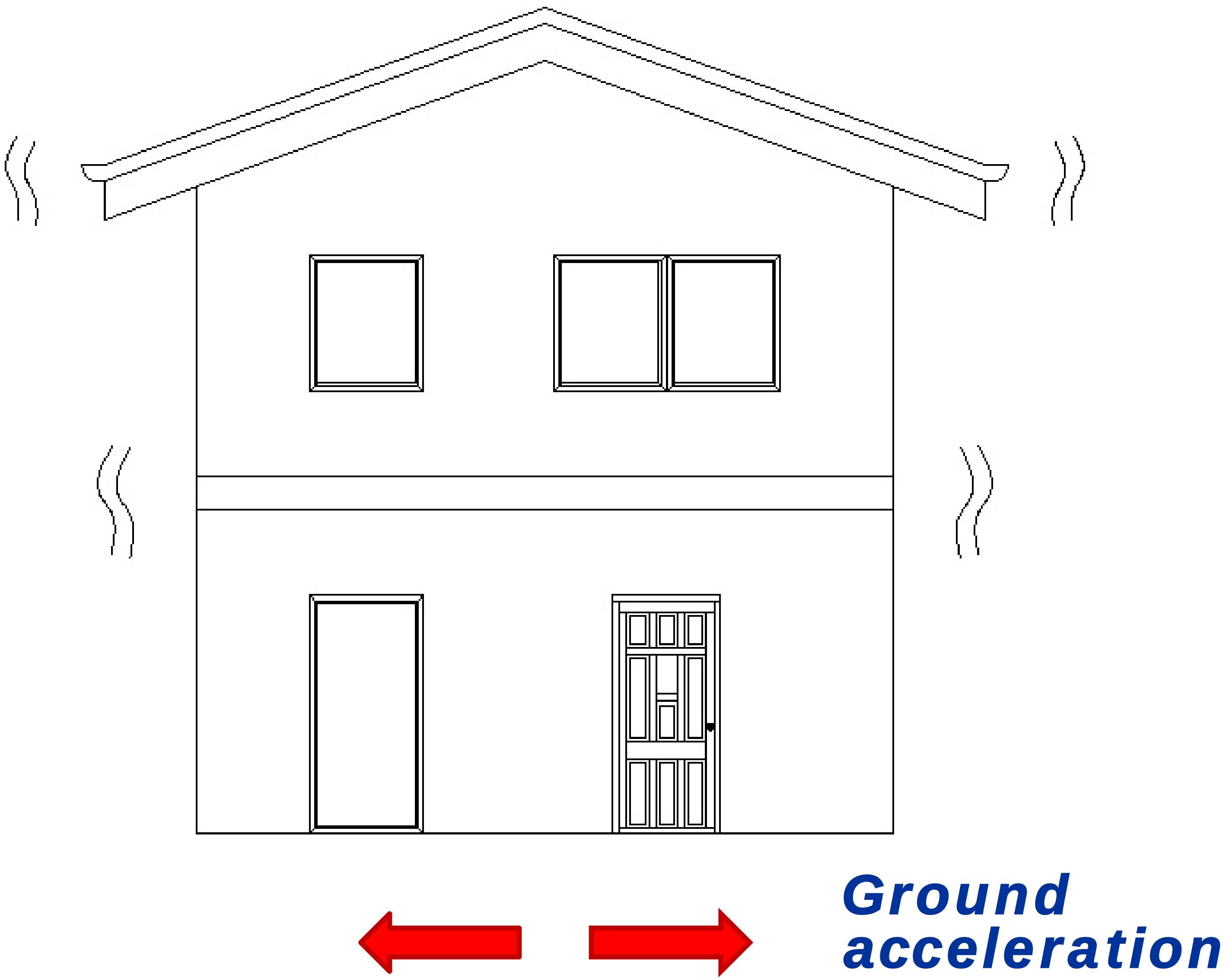
Please check that all the decided technical changes of the Oslo meeting have been integrated and report back to us prior to or at the August 16 meeting. We will inform you during our August 16, 2022, meeting about the further editorial corrections.

HPFRM for retrofitting a masonry house

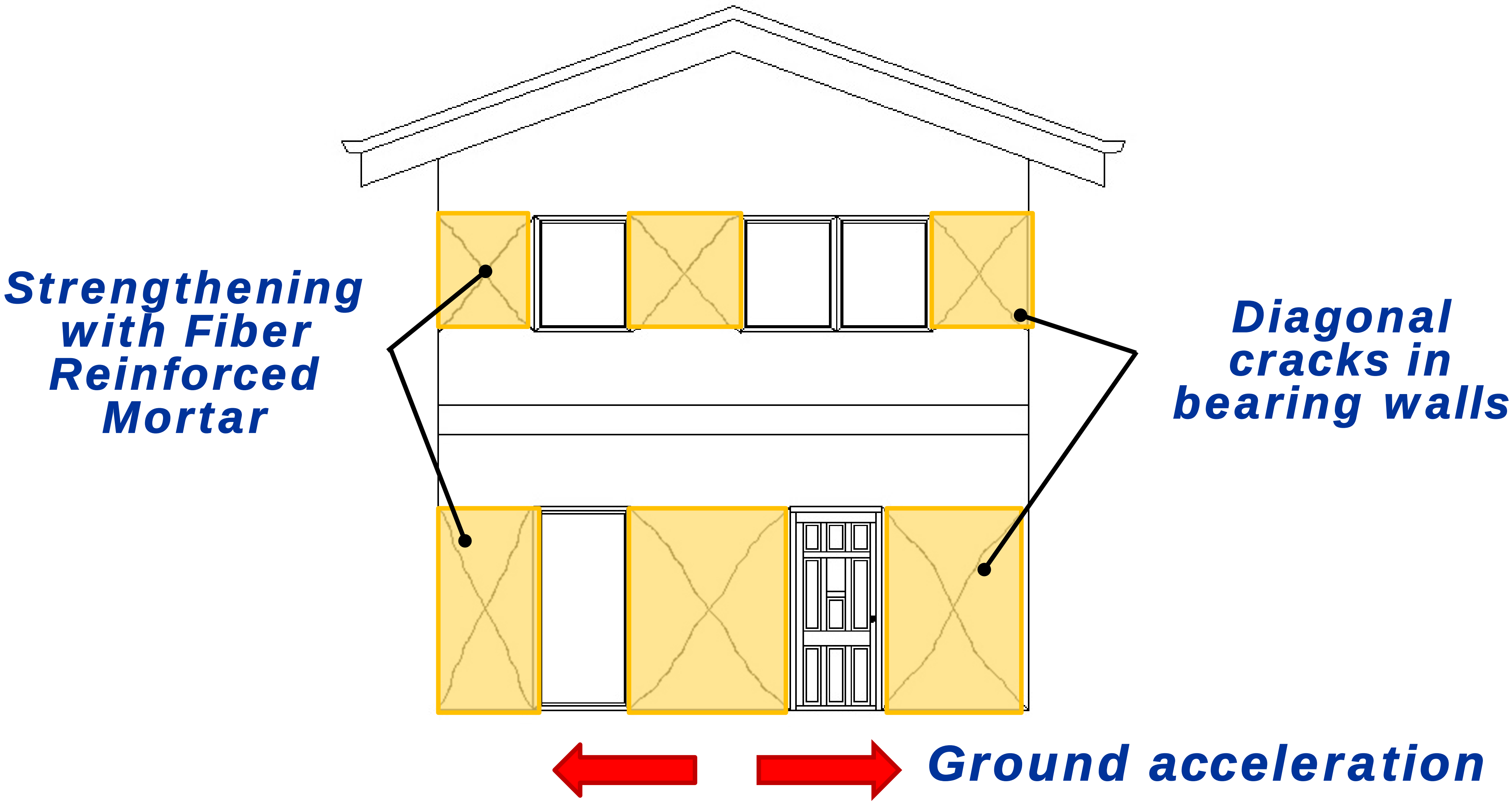
Masonry house after central Italy earthquake

Masonry house after central Italy earthquake

Masonry buildings reinforced with FRC mortar



Strengthening with Fiber Reinforced Mortar



Research project

TEST ON FULL-SCALE MASONRY **BUILDING** BEFORE AND AFTER STRENGTHENING

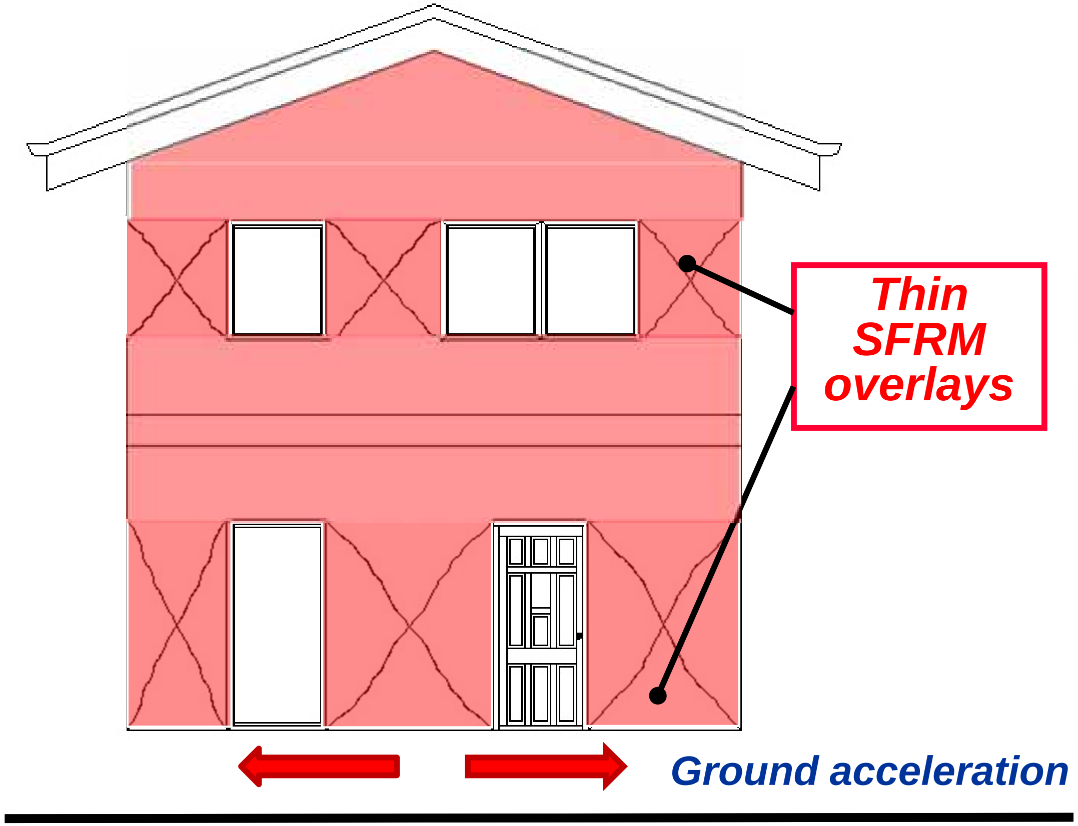
MECHANICAL CHARACTERIZATION TESTS ON **MASONRY**

ANALYTICAL PROPOSAL TO ESTIMATE LATERAL RESISTANCE OF URM PANELS STRENGTHENED WITH SFRM COATING

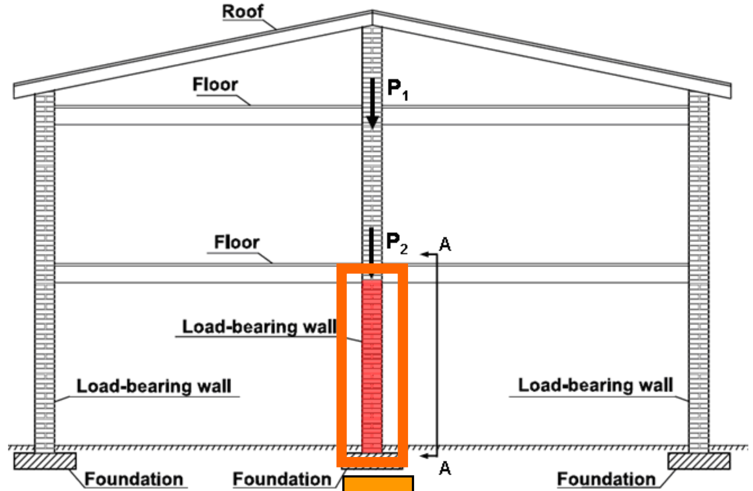
Experimental tests on walls: aim of the research

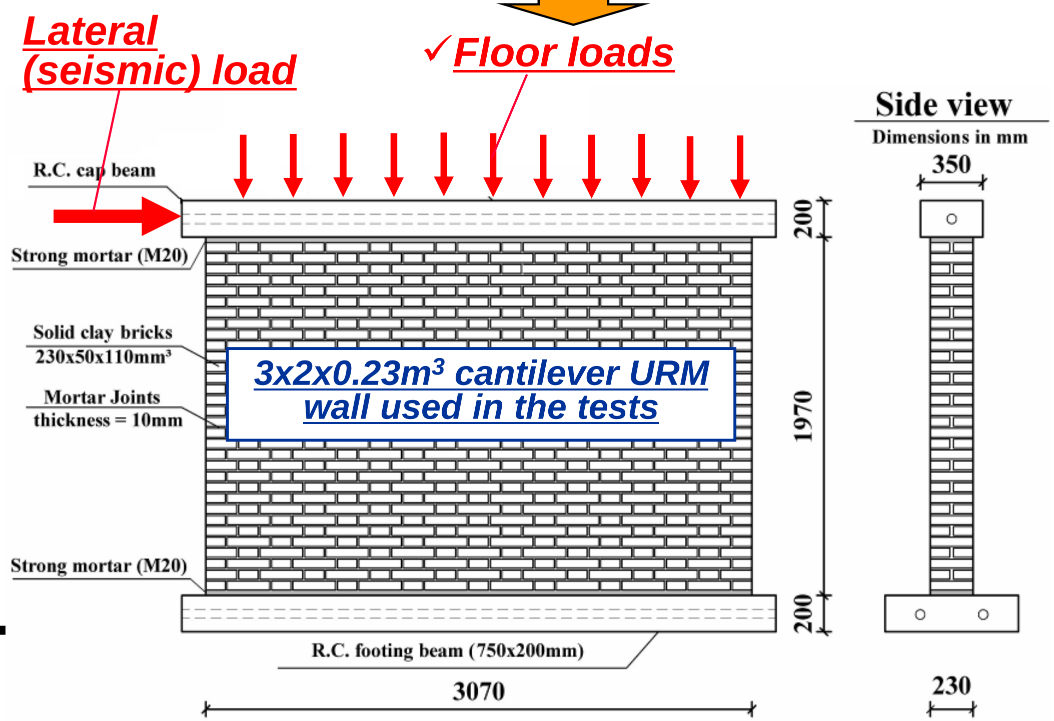
To use thin overlays made of an innovative steel fiber reinforced mortar for:

- *improving the out-of-plane resistance of masonry walls (future step of the research);*
- *enhancing the in-plane shear capacity of the masonry walls*



Section view of a typical 2-storey URM building





FRC properties

Volume fraction V_f = 0,82%

L_f , Φ_f

LUNGHEZZA L_f [mm]	DIAMETRO Φ_f [mm]	RAPPORTO D'ASPETTO L_f / Φ_f [-]	RESISTENZA A TRAZIONE [MPa]	FORMA
15	**0,40**	**38**	**> 2400**	**Uncinate**

Flexural tensile strength (a) (EN 1015-11,2007) → 6 MPa

Compression strength (b) (EN 1015-11,2007) → 48,3MPa

Average elastic modulus (EN 12390-1) → 33600MPa

Tensile strength (EC2) → 3,85MPa

Wall tests

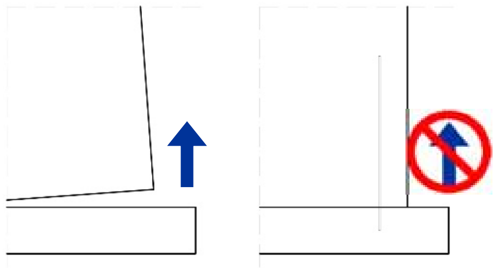
FULL-SCALE TESTS ON HOLLOW CLAY BLOCK MASONRY WALLS

UN-STRENGTHENED

- Masonry thickness: 240 mm

2 layers of SFRM WITHOUT and WITH CONNECTIONS to foundation

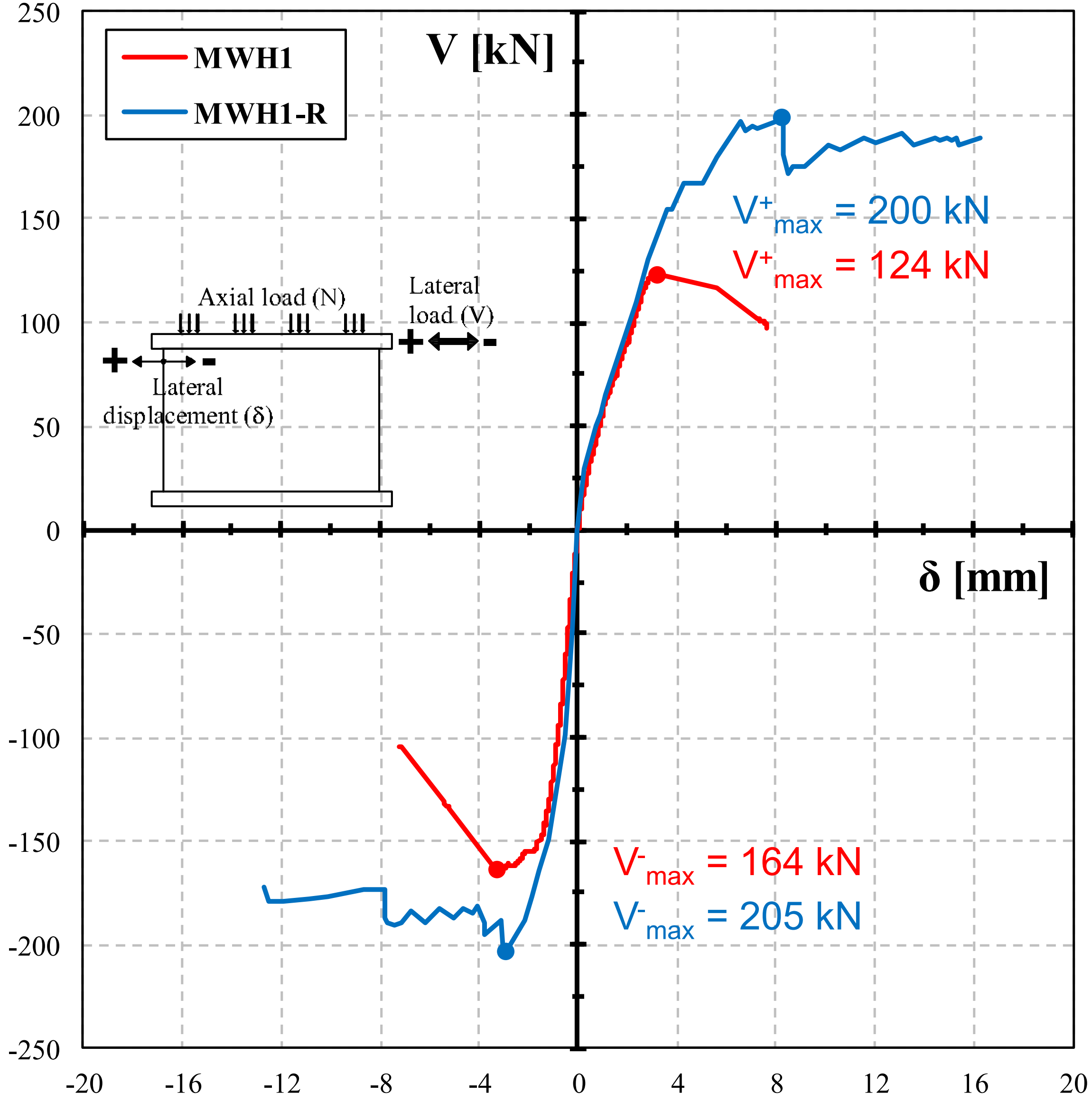
- Masonry thickness: 240 mm
- Coating thickness: 25 mm on both sides



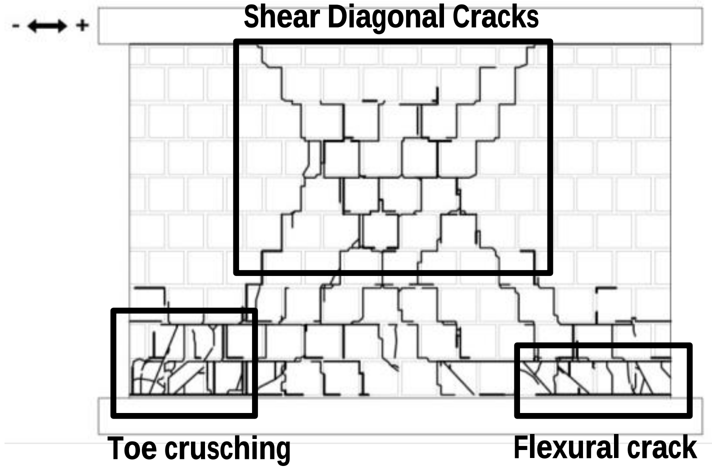
CONNECTIONS TO FOUNDATION

steel rebars Φ8@550mm

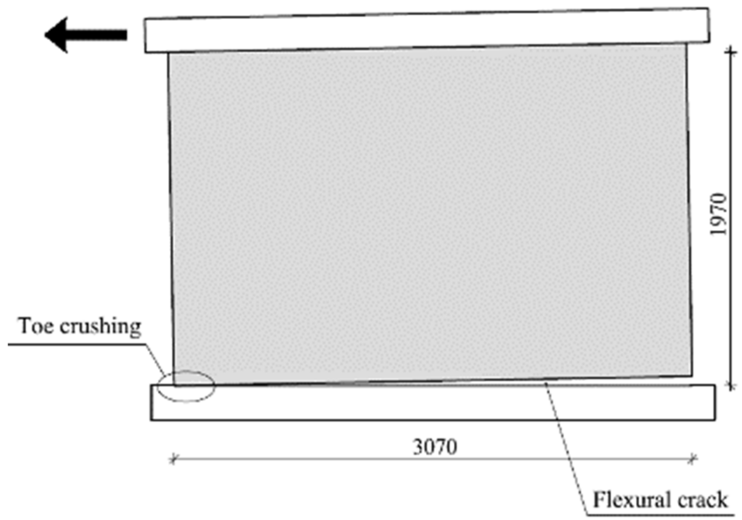
Wall test results



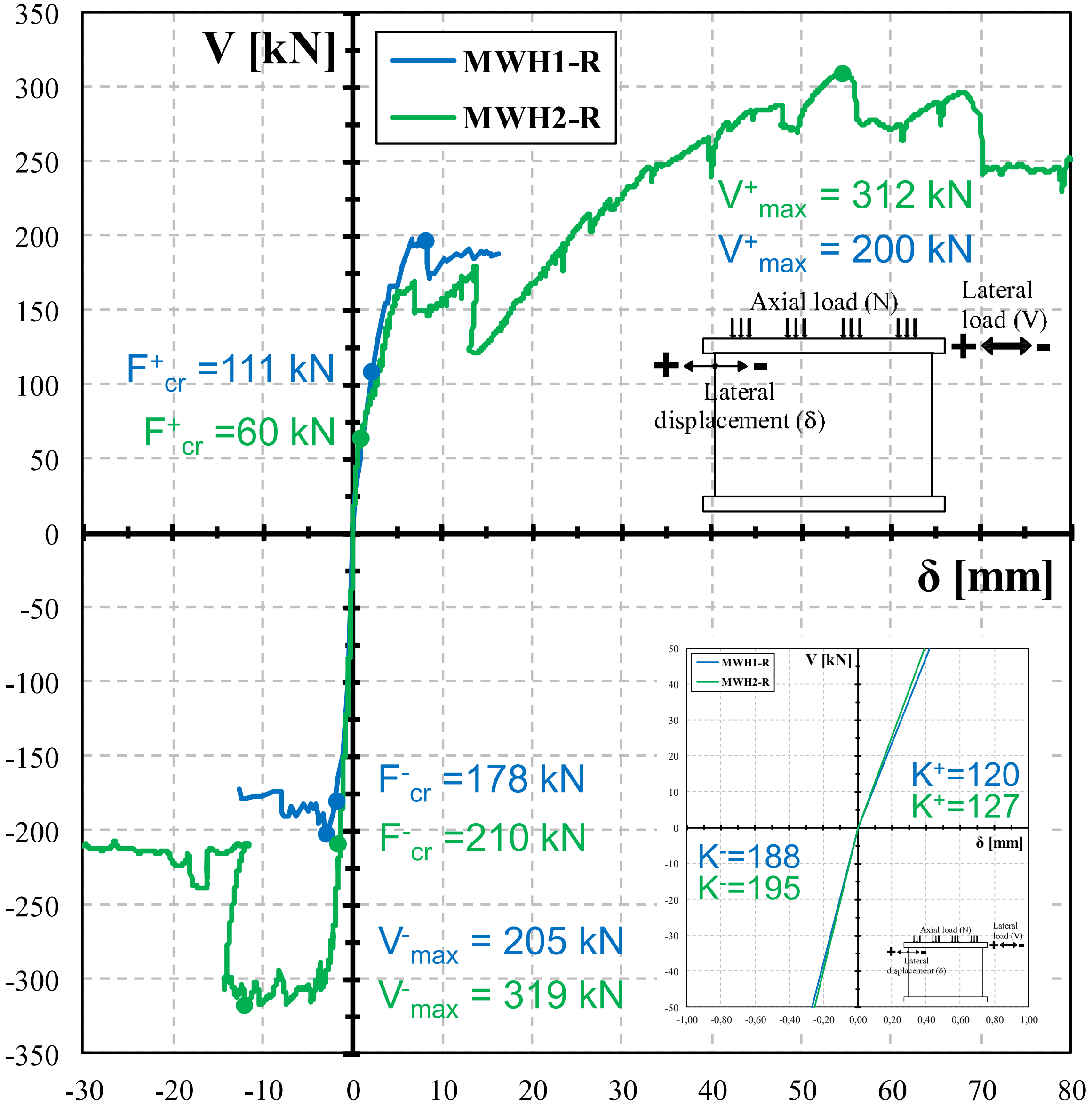
UN-STRENGTHENED



STRENGTHENED



Anchoring the plaster to the foundation



UN-ANCHORED

ANCHORED

Full scale test on a two-stories house

STRUCTURE

- Hollow-clay brick masonry
- Wooden floors and roof
- Seismic floor diaphragms

LOADS

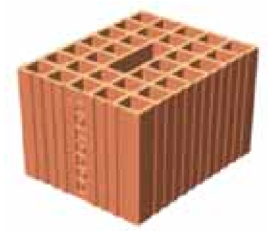
- Quasi-static reverse cyclic test

RETROFITTING: SFRM coating

- on the external surface
- 25 mm thick
- Anchored in foundation

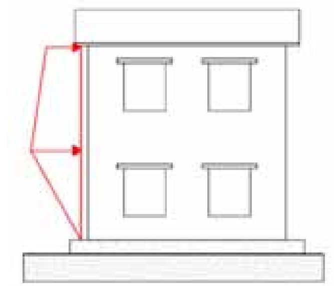
Masonry units

TYPE OF UNITS



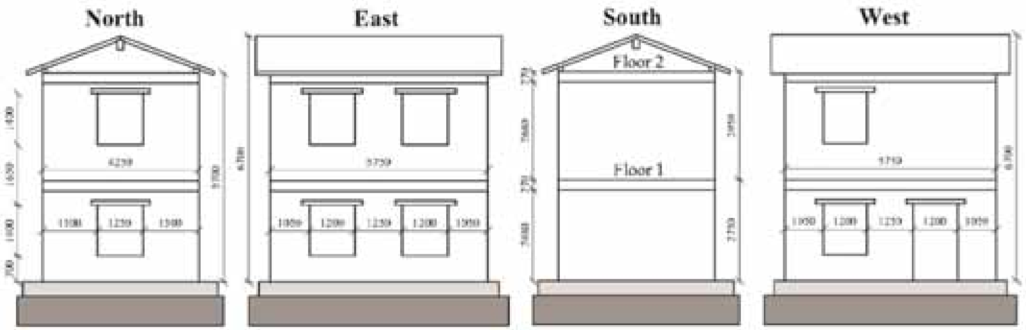
Thickness=200mm;
vertical holes 60%

LOADING DISTRIBUTION



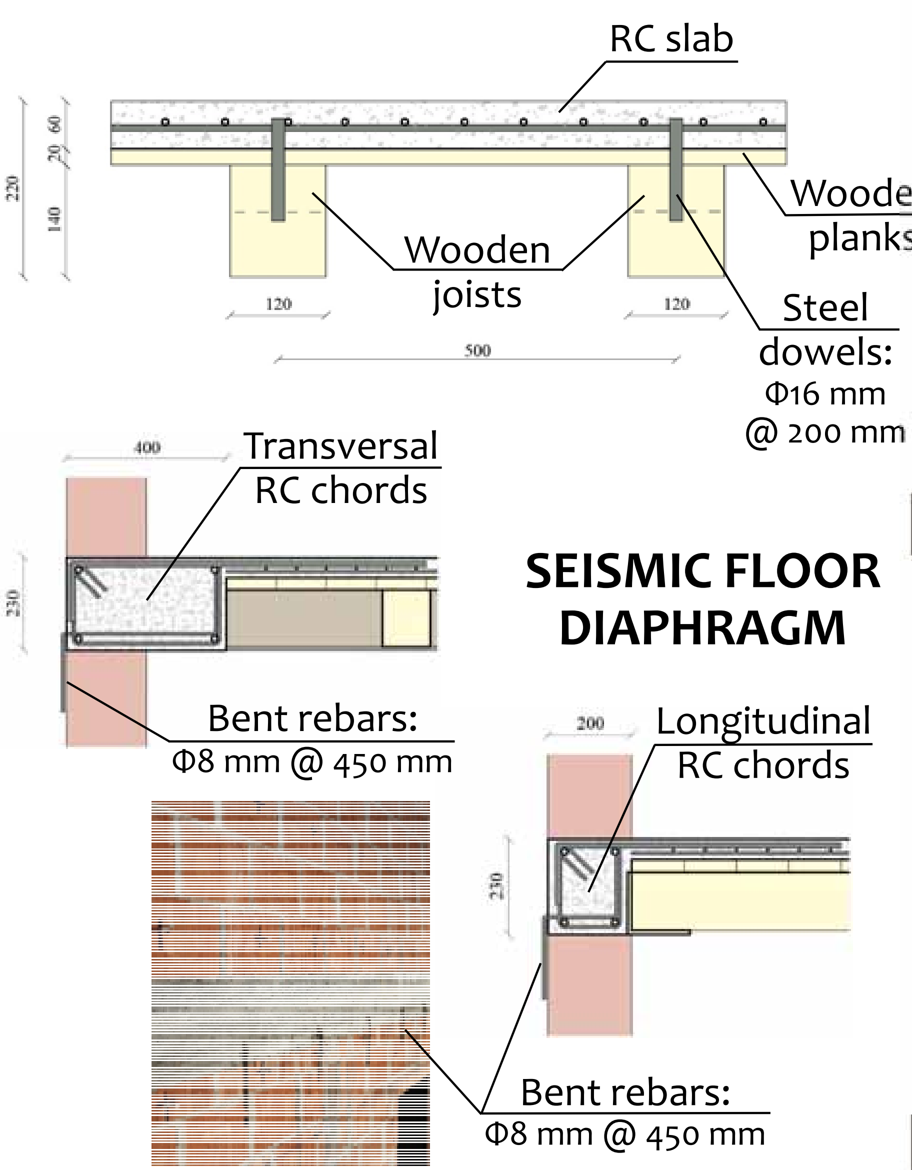
Proportional to
floor mass

OPENINGS CONFIGURATION

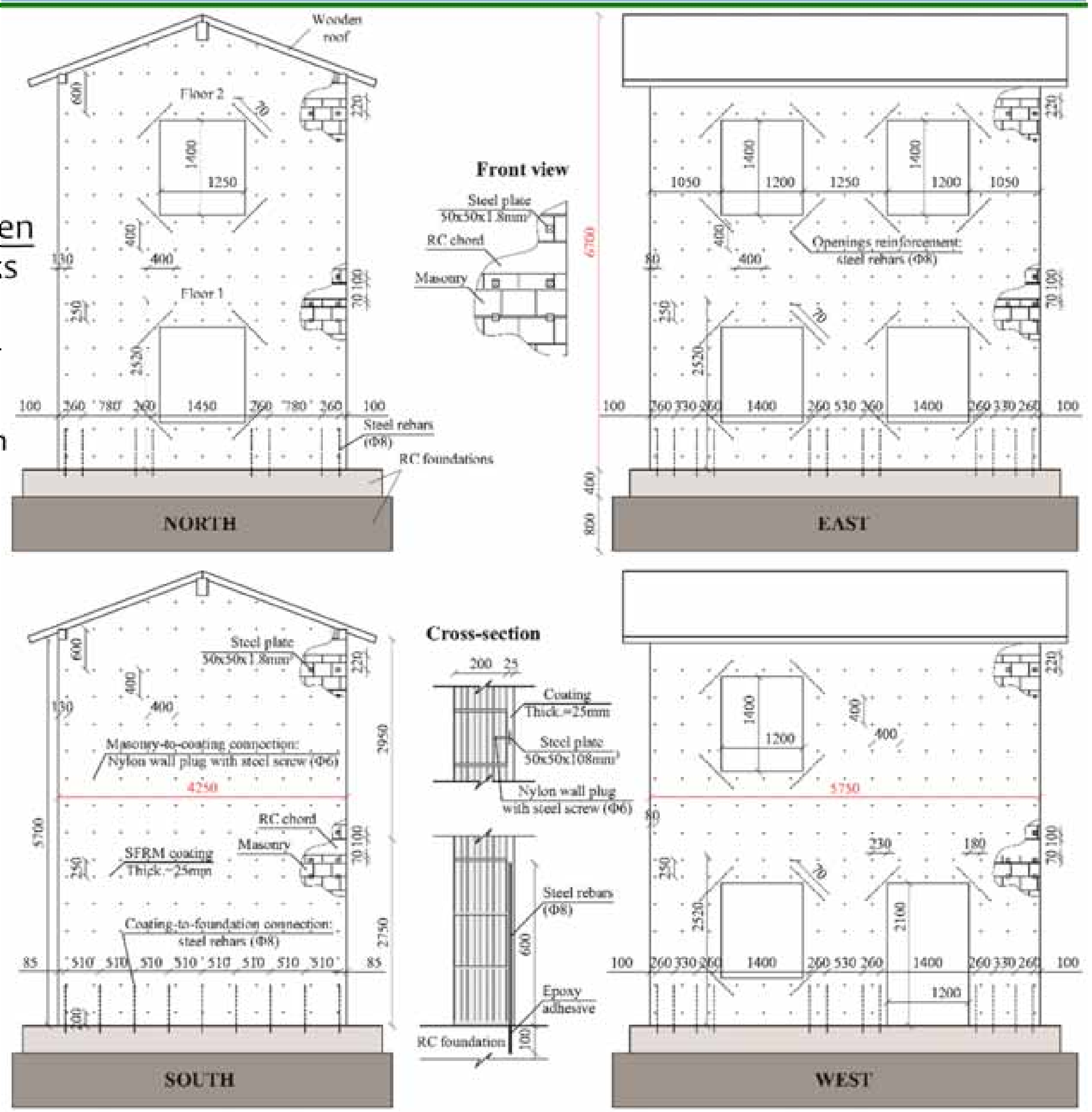


1 door + 8 windows

Specimen geometry



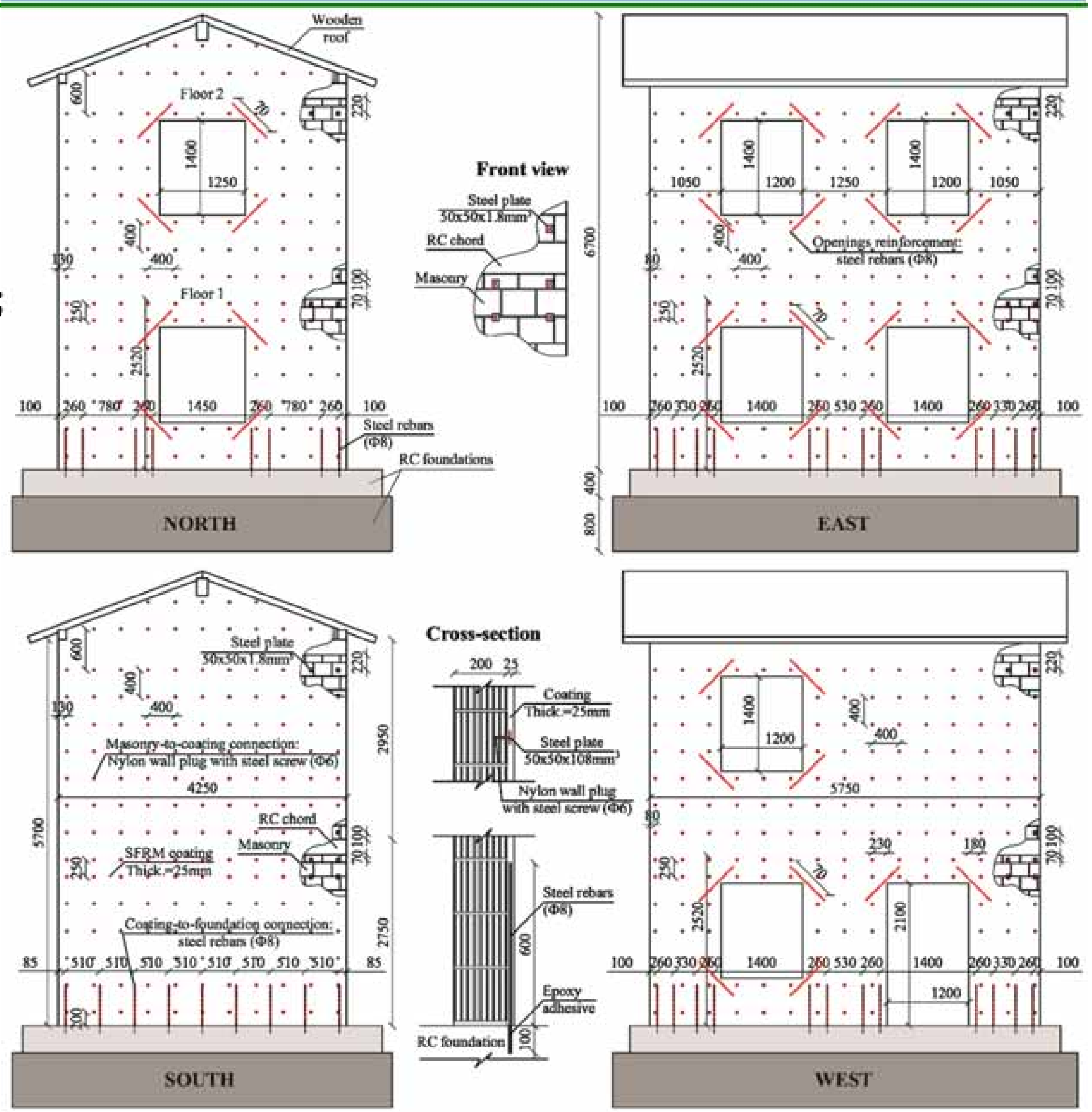
SEISMIC FLOOR DIAGRAPHM



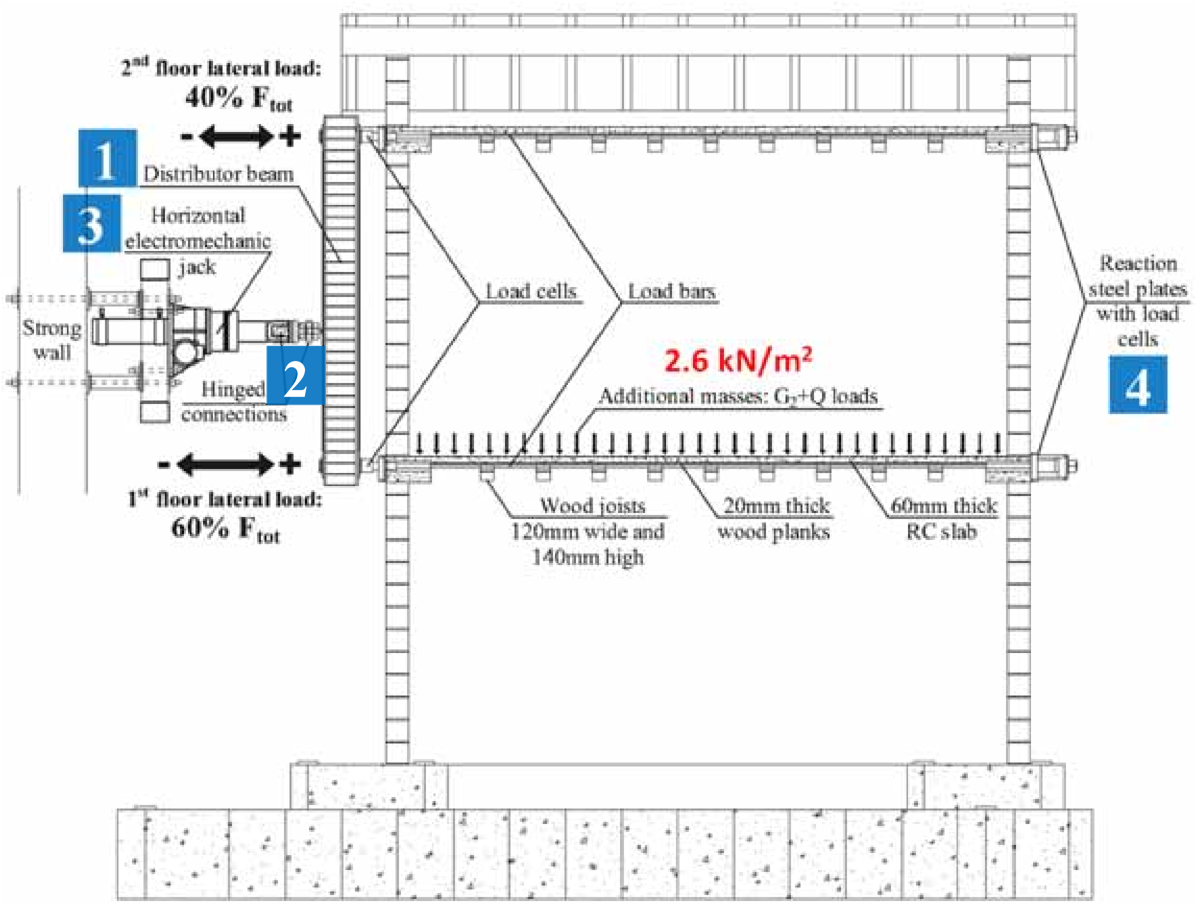
Additional reinforcement and connectors

CONNECTIONS

- Steel rebars embedded in SFRM;
- Series of layers of SFRM up to 25 mm;
- Finishing and curing.

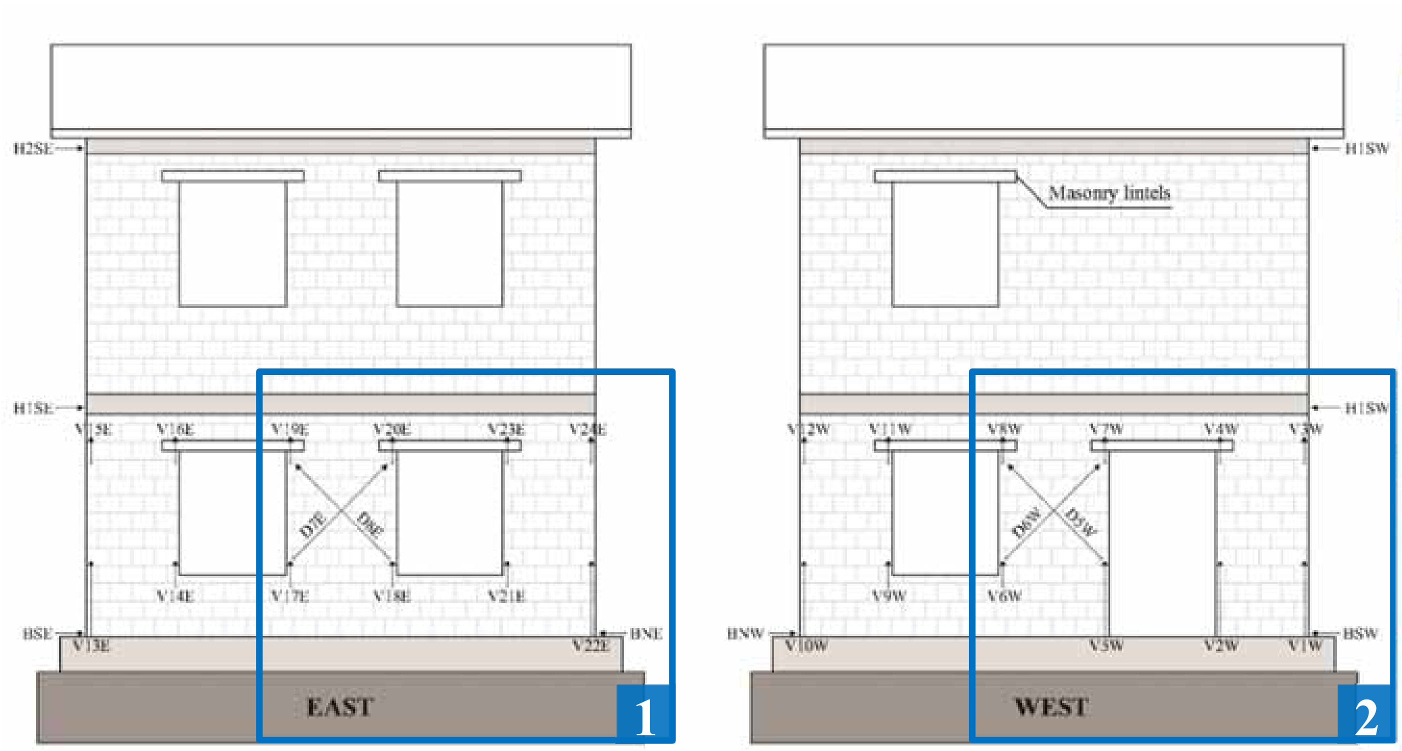


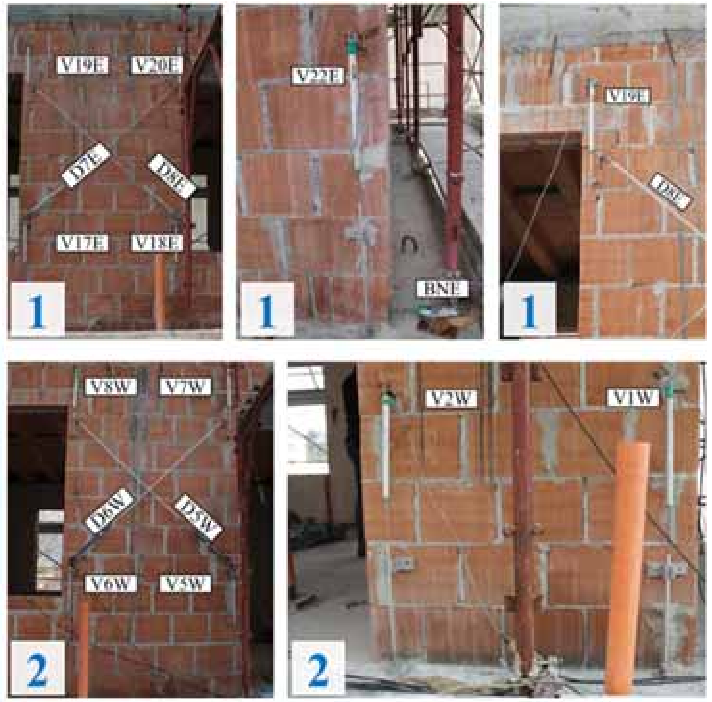
Test set-up



$$Drift\ (\%) = \frac{\delta_2}{h_2} = \frac{\frac{[(H2SW-BSW)+(H2SE-BSE)]}{2}}{h_2} = \frac{average\ top\ floor\ displacement}{height\ of\ 2nd\ floor\ horizontal\ load}$$

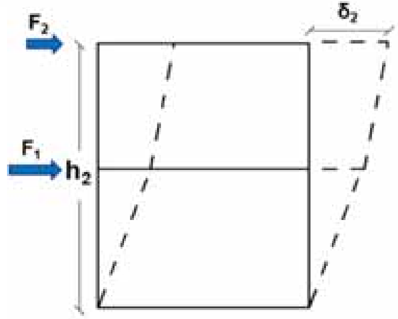
Instrumentation





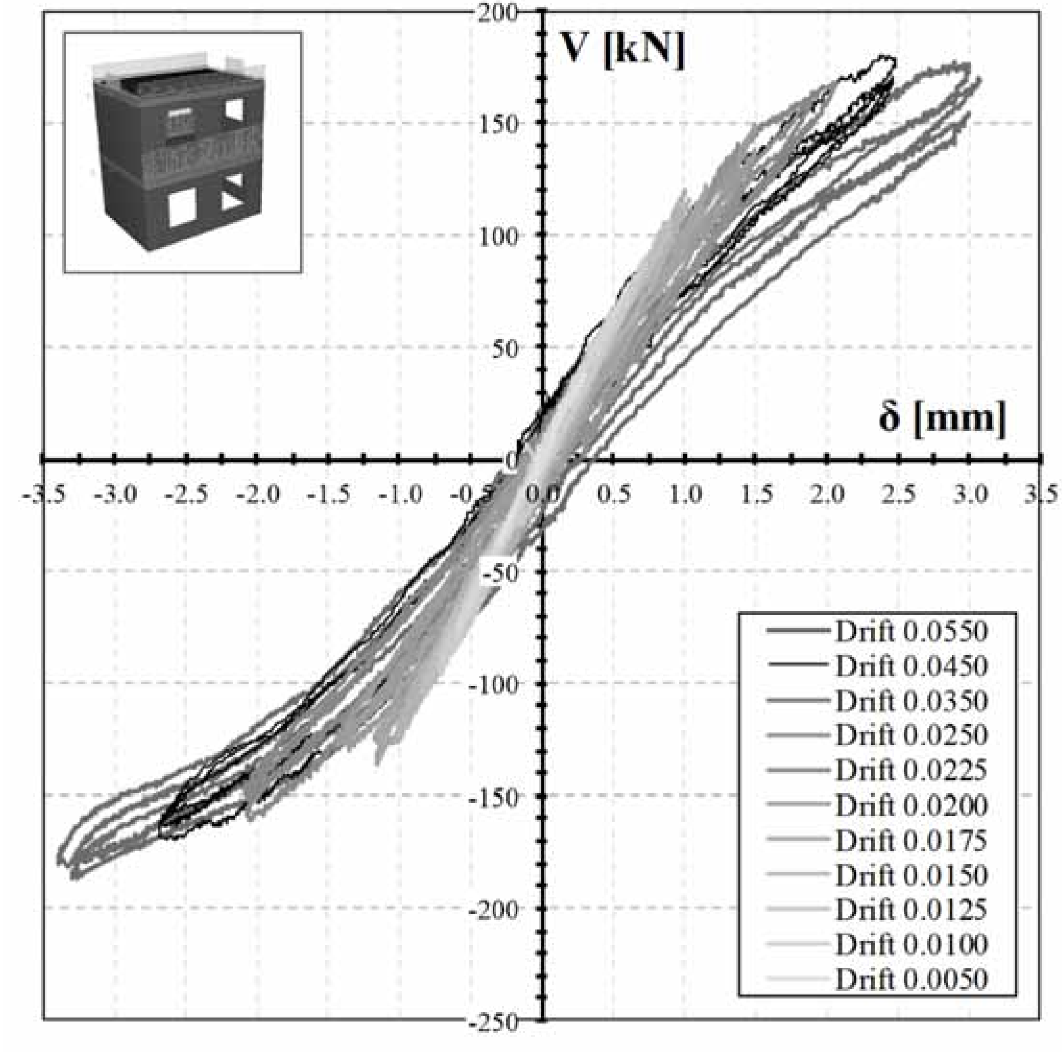
DISPLACEMENT CONTROL:

$$Drift\ (\%) = \frac{\delta_2}{h_2} = \frac{\frac{[(H2SW-BSW)+(H2SE-BSE)]}{2}}{h_2} = \frac{\text{average top floor displacement}}{\text{height of 2nd floor horizontal load}}$$



Experimental results from the un-strengthened building

CYCLIC RESPONSE

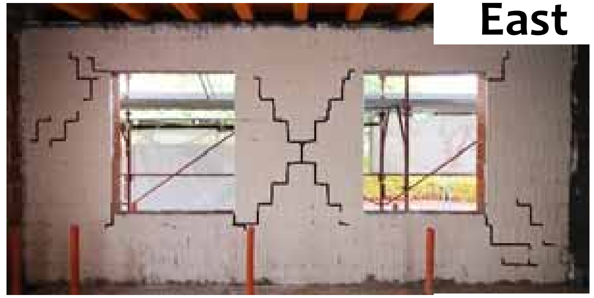


FAILURE MODE:

In-plane longitudinal wall response

Diagonal shear failure of masonry piers at ground floor

East

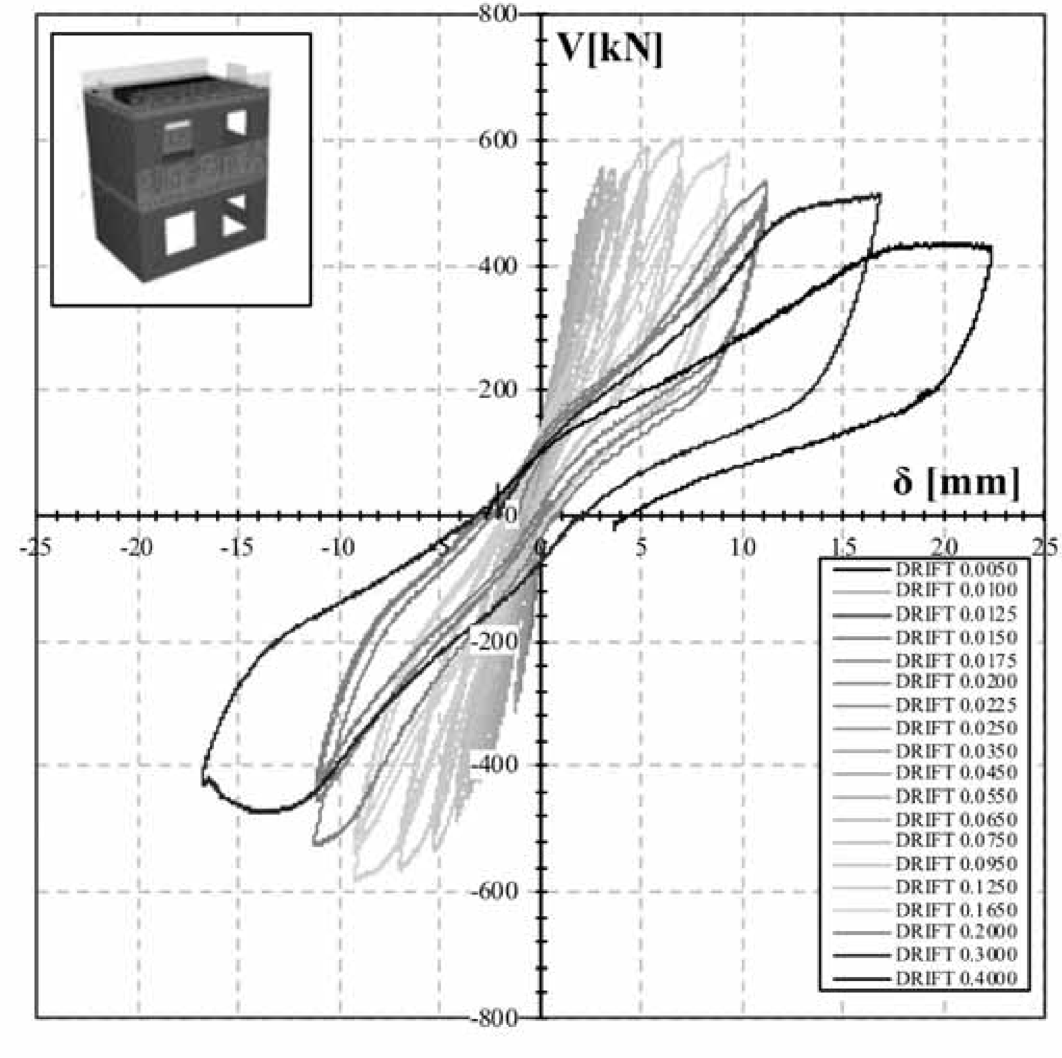


West

	Positive loading direction	Negative loading direction
K_S [kN/mm]	134	128
$V_{cracking}$ [kN]	120	128
V_{peak} [kN]	180	179
δ_{peak} [mm]	2.4	3.4

Experimental results from the strengthened building

CYCLIC RESPONSE

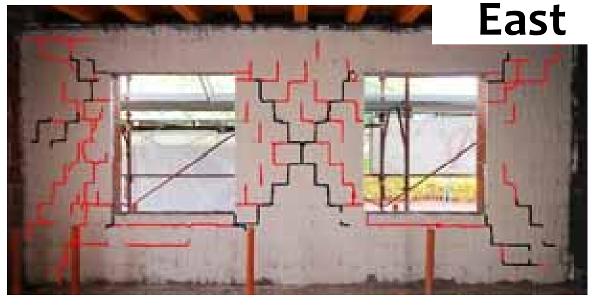


FAILURE MODE:

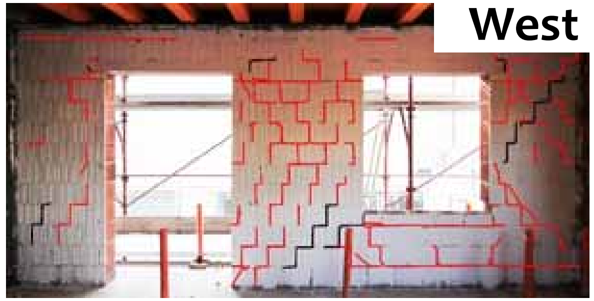
In-plane longitudinal wall response

Very spread crack pattern of inner masonry piers at ground floor

East



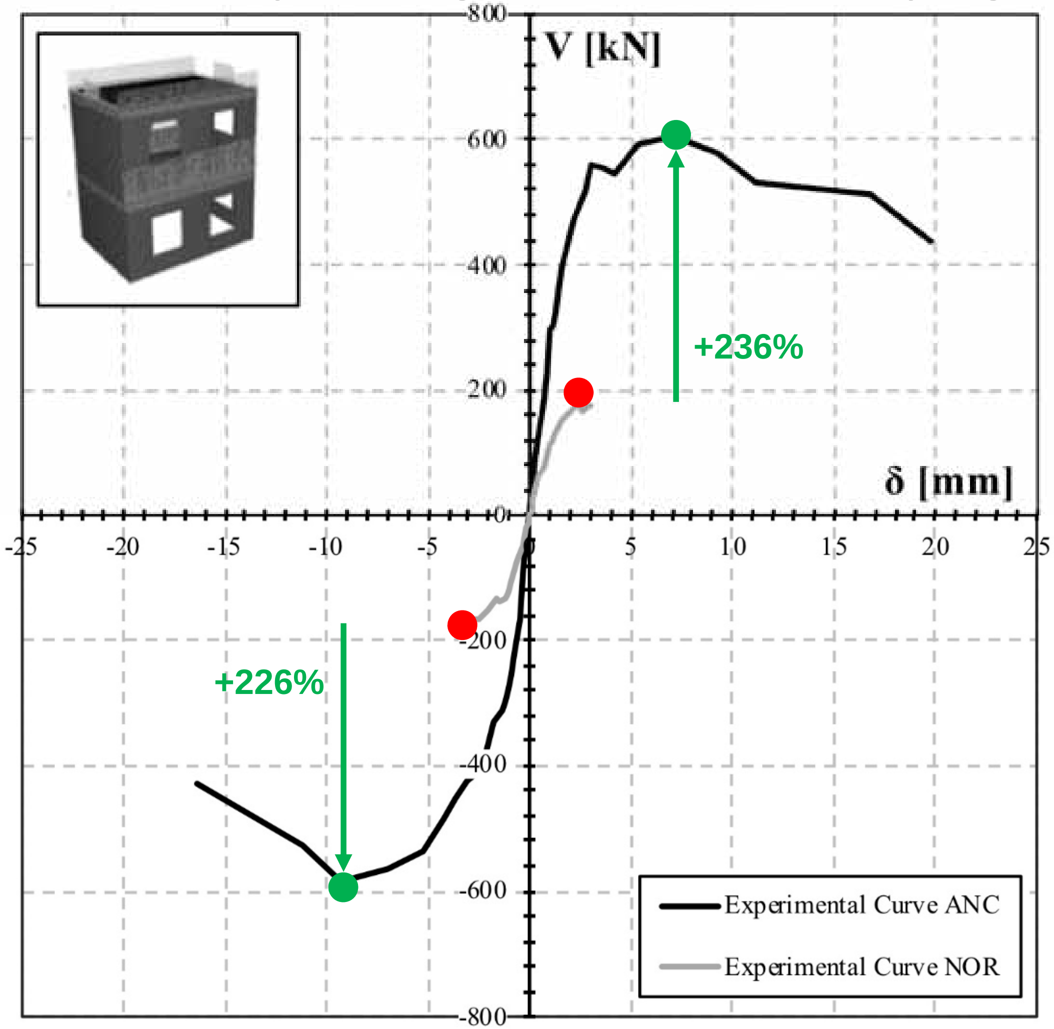
West



	Positive loading direction	Negative loading direction
K_S [kN/mm]	348	318
$V_{cracking}$ [kN]	515	405
V_{peak} [kN]	605	584
δ_{peak} [mm]	6.99	9.22

Strengthened vs. unstrengthened response

LATERAL LOAD – DISPLACEMENT ENVELOPES

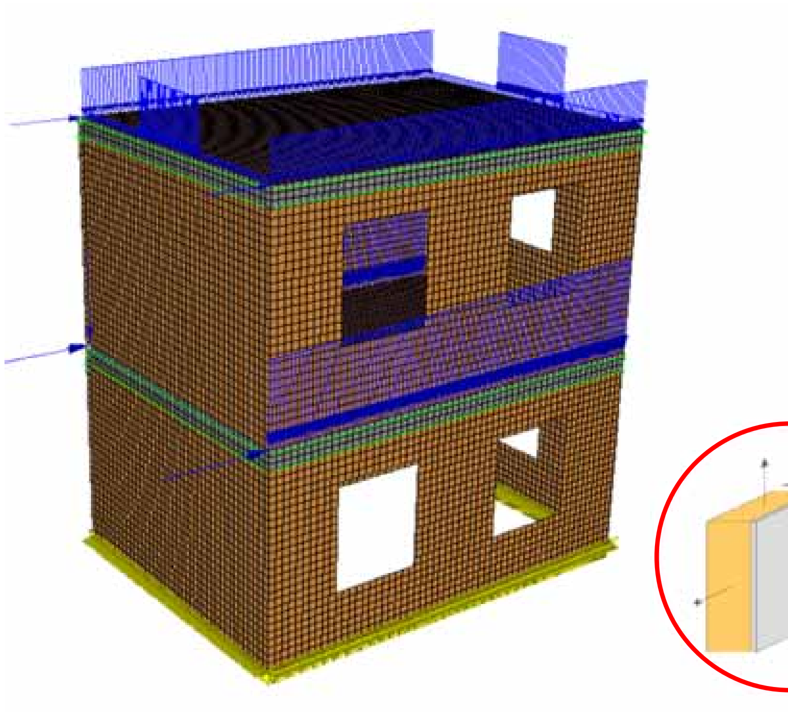


	MB	MB-R+SR
K^{+}_{S} [kN/mm]	134	348 (+160%)
K^{-}_{S} [kN/mm]	128	318 (+148%)
$V^{+}_{cracking}$ [kN]	120	515 (+329%)
$V^{-}_{cracking}$ [kN]	128	405 (+216%)
V^{+}_{peak} [kN]	180	605 (+236%)
V^{-}_{peak} [kN]	179	584 (+226%)

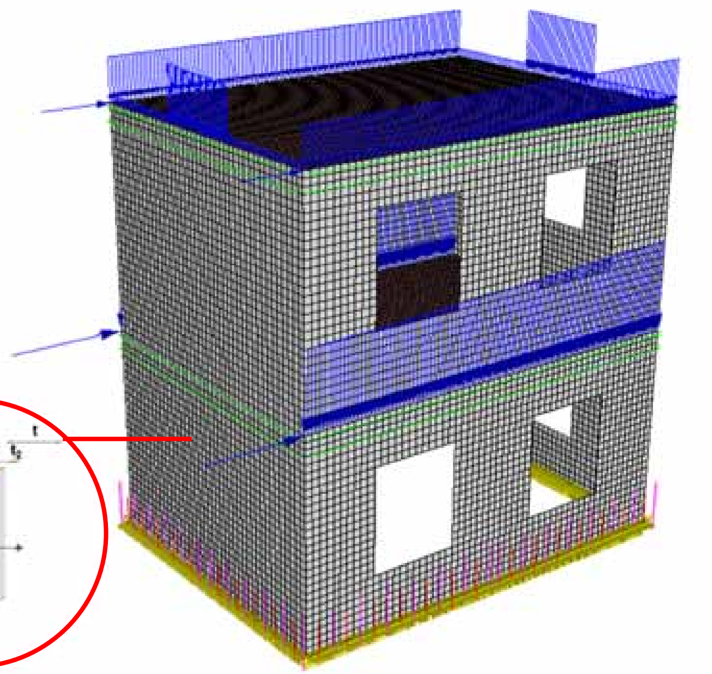
Strength and stiffness improvement provided by 25 mm of SFRM on the external surface of the building

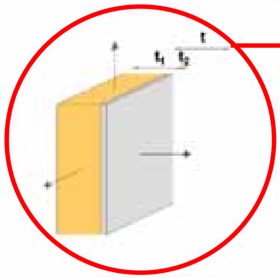
Numerical modelling

UN-STRENGTHENED:



STRENGTHENED with SFRM:



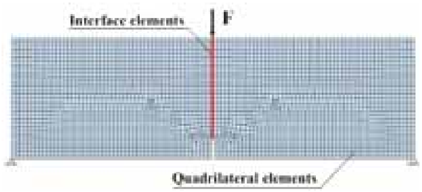


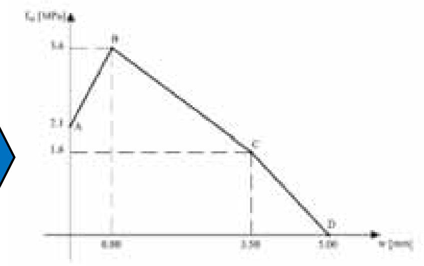
ELEMENTS:

- Curved Shell Elements (CQ40S);
- Curved Shell Layered Elements (CQ40L);
- Reinforcement.

INDIRECT DISPLACEMENT CONTROL, by means of Arc-length technique.

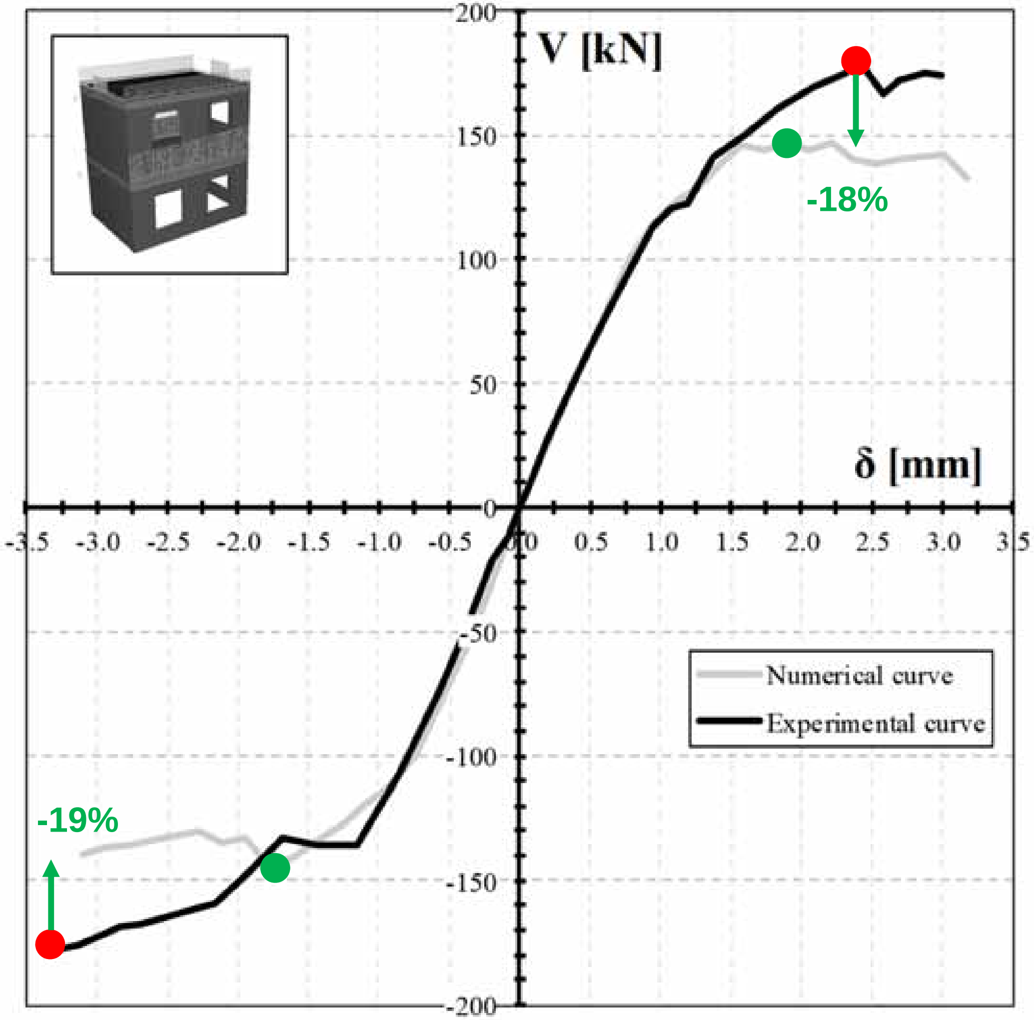
BACK ANALYSIS





Un-strengthened model: experimental vs. numerical results

LATERAL LOAD – DISPLACEMENT ENVELOPES

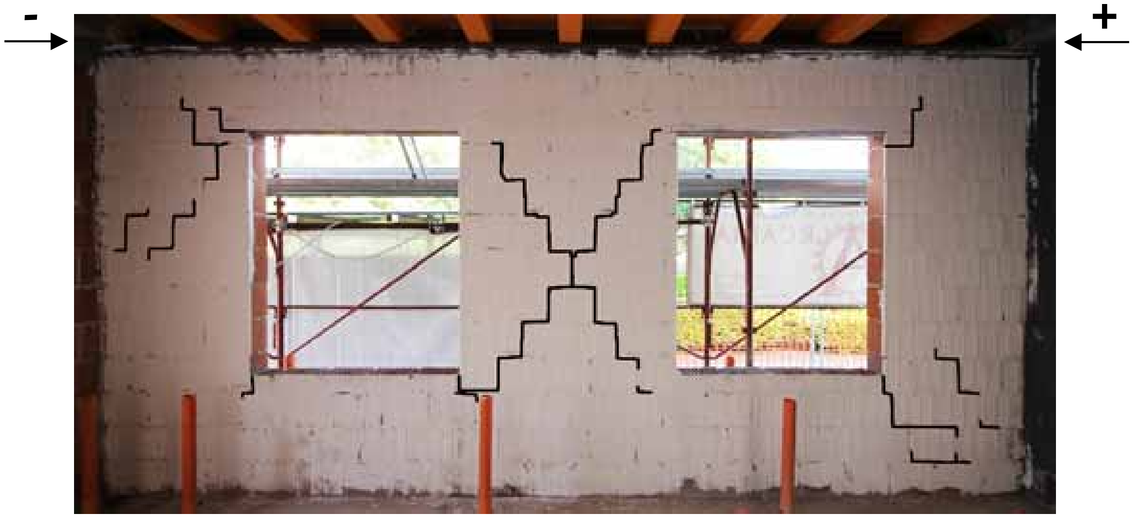


	Experimental	Numerical
K^{+}_{S} [kN/mm]	134	129 (-4%)
K^{-}_{S} [kN/mm]	128	153 (+20%)
$V^{+}_{cracking}$ [kN]	120	114 (-5%)
$V^{-}_{cracking}$ [kN]	128	112 (-12%)
V^{+}_{peak} [kN]	● 180	● 148 (-18%)
V^{-}_{peak} [kN]	● 179	● 146 (-18%)

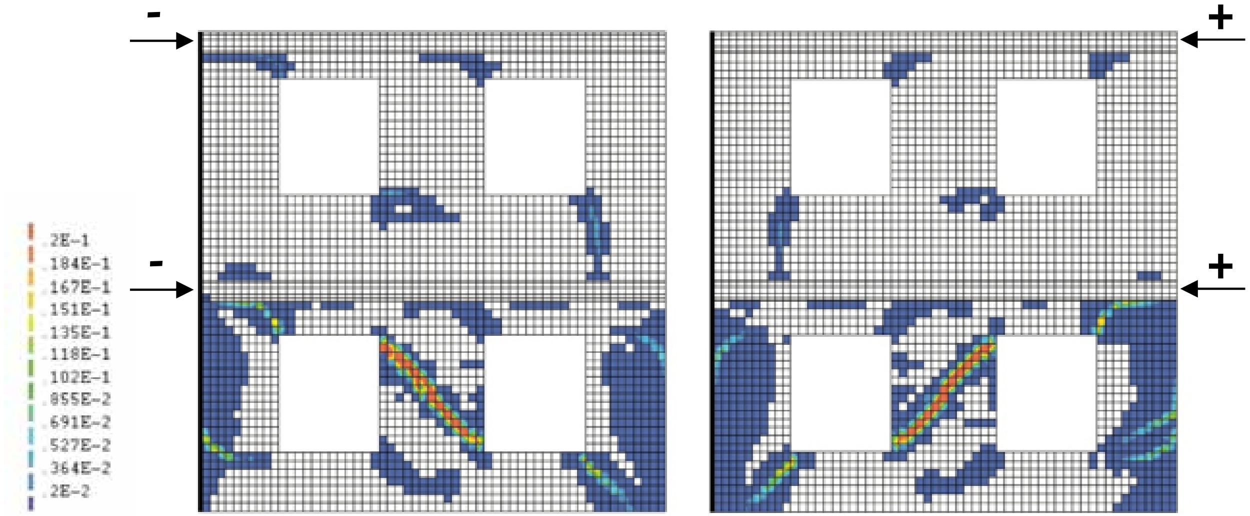
Numerical initial stiffness closed to the experimental one

First cracking and maximum numerical loads slightly underestimated

Un-strengthened model: experimental vs. numerical results



Pier 1 Pier 2 Pier 3



Pier 1 Pier 2 Pier 3 Pier 1 Pier 2 Pier 3

CRACK PATTERNS AT THE END OF EXPERIMENTAL TEST (inside view of East façade at ground floor)

⬇

MAIN MECHANISMS:

Diagonal shear failure of central pier (**Pier 2**)

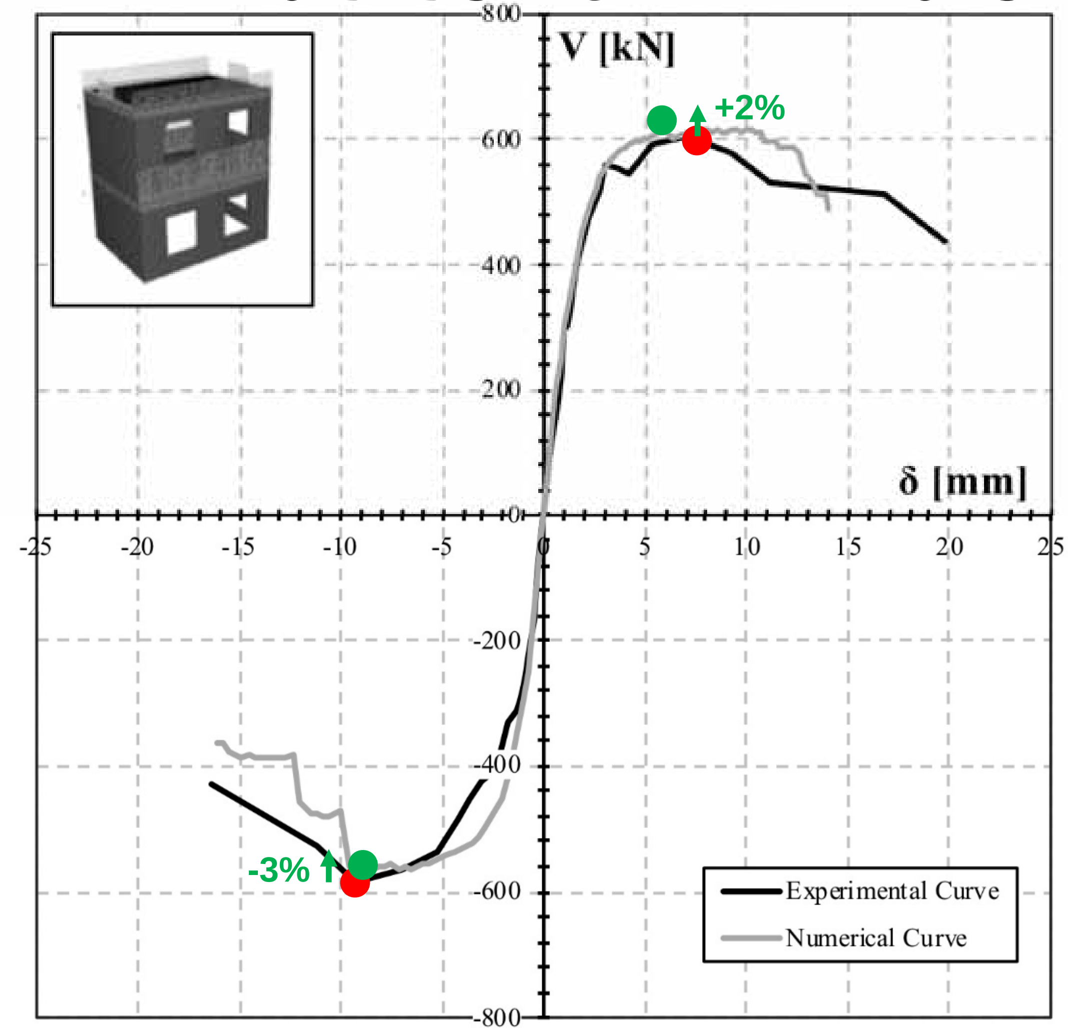
Rocking mechanism of the external piers (**Pier 1** and **Pier 3**)

⬆

TENSILE CRACKING STRAIN AT THE COLLAPSE OF NUMERICAL ANALYSIS

Strengthened model: experimental vs. numerical results

LATERAL LOAD – DISPLACEMENT ENVELOPES



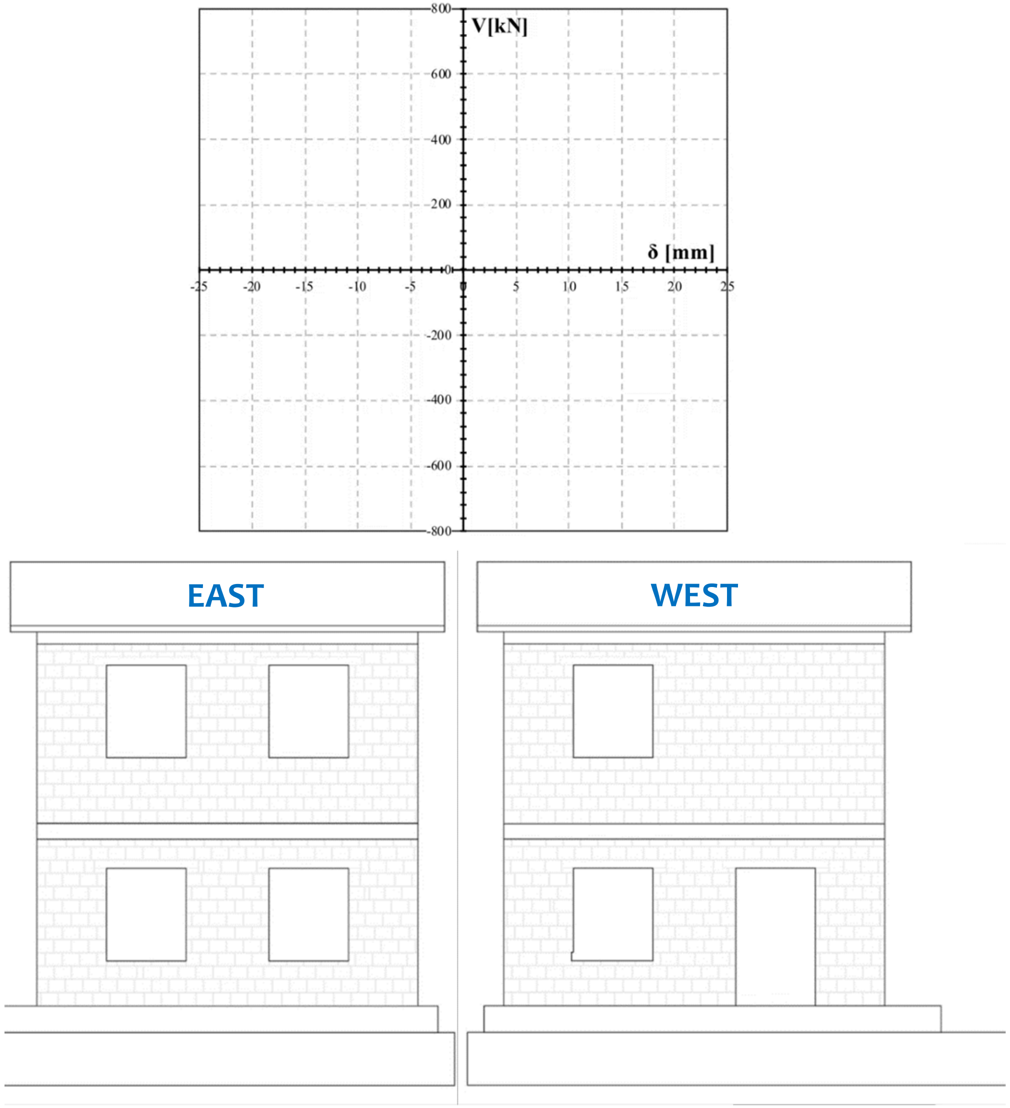
	Experimental	Numerical
K^{+}_{S} [kN/mm]	348	338 (-3%)
K^{-}_{S} [kN/mm]	318	371 (+17%)
$V^{+}_{cracking}$ [kN]	515	500 (-3%)
$V^{-}_{cracking}$ [kN]	405	450 (+11%)
V^{+}_{peak} [kN]	● 605	● 616 (+2%)
V^{-}_{peak} [kN]	● 584	● 566 (-3%)

Very good prediction of the experimental response:

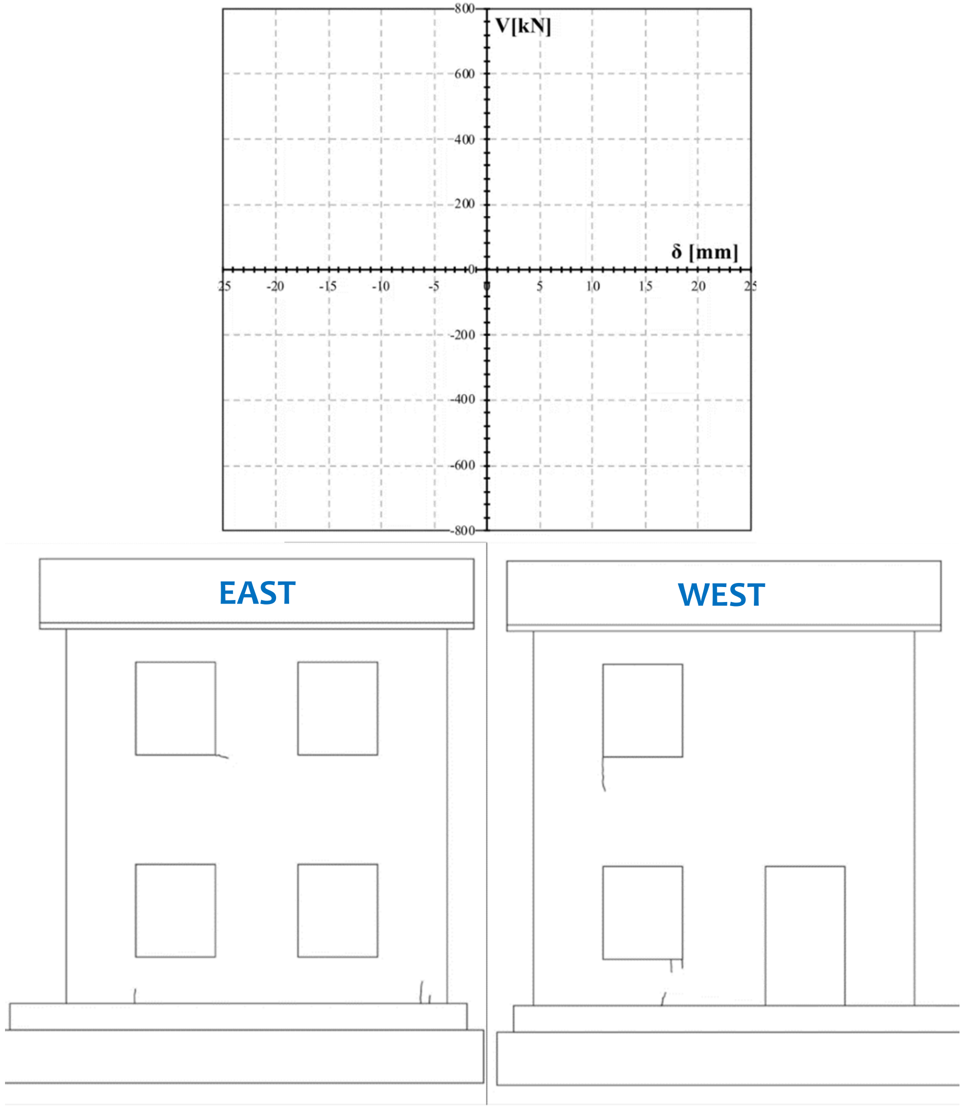
numerical initial stiffness, first cracking and maximum numerical loads closed to the experimental ones

Experimental crack development

UN-STRENGTHENED BUILDING

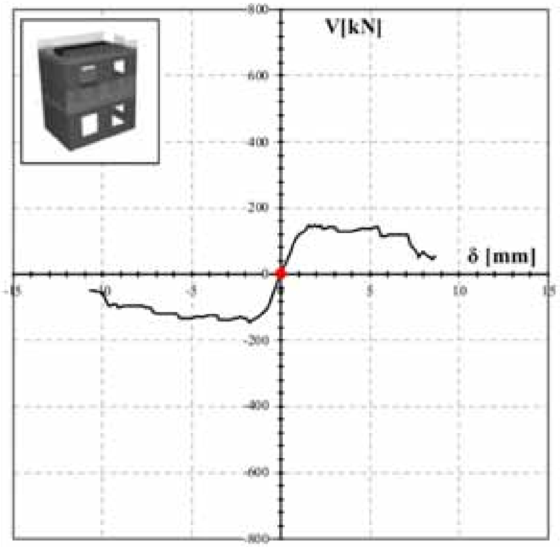


STRENGTHENED BUILDING

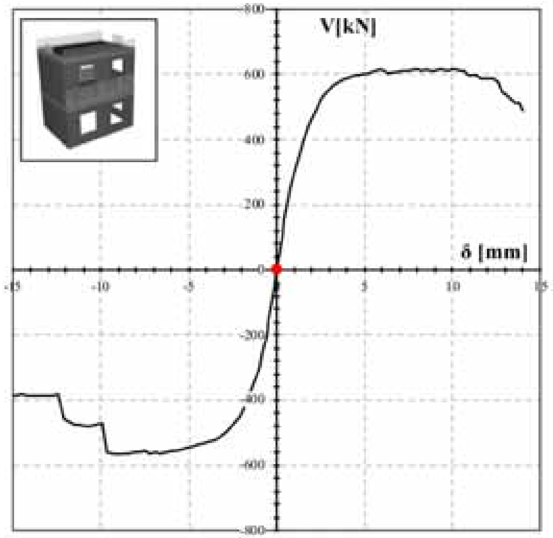


Numerical crack development

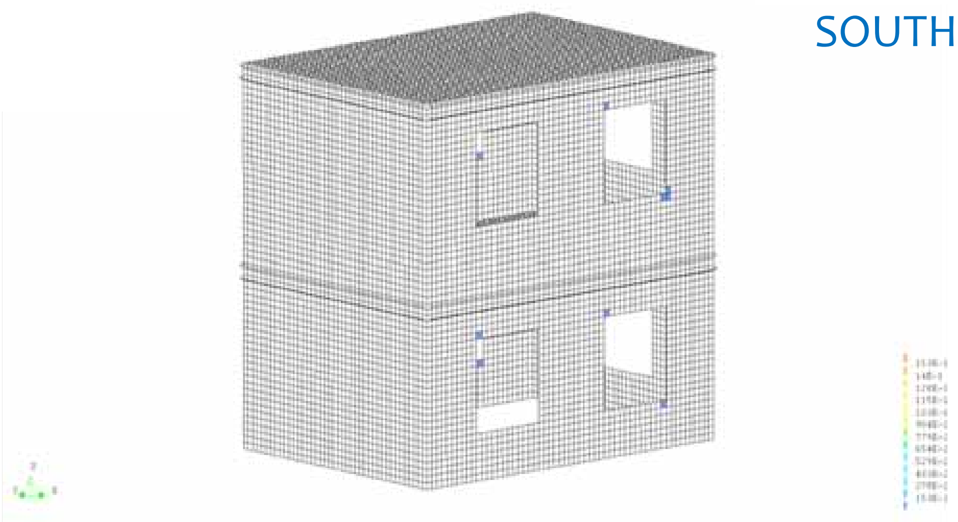
UN-STRENGTHENED BUILDING

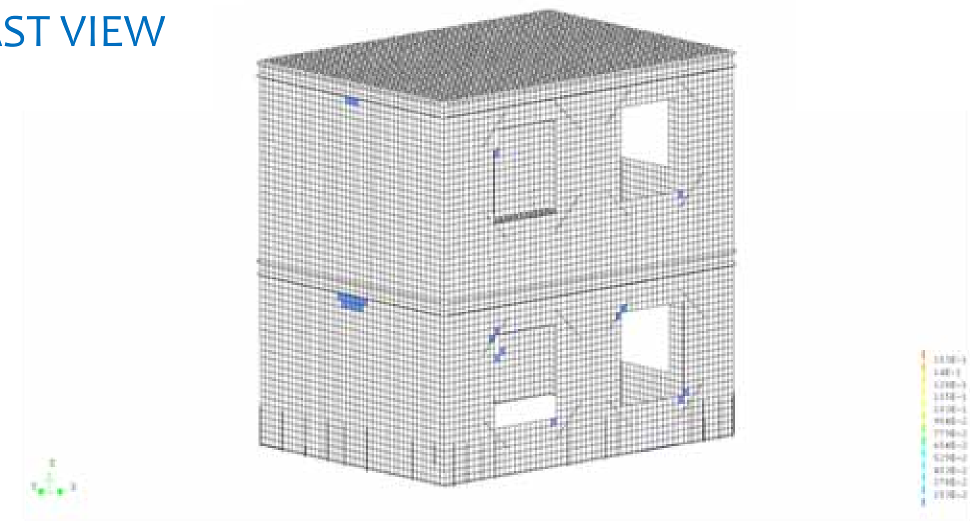


STRENGTHENED BUILDING



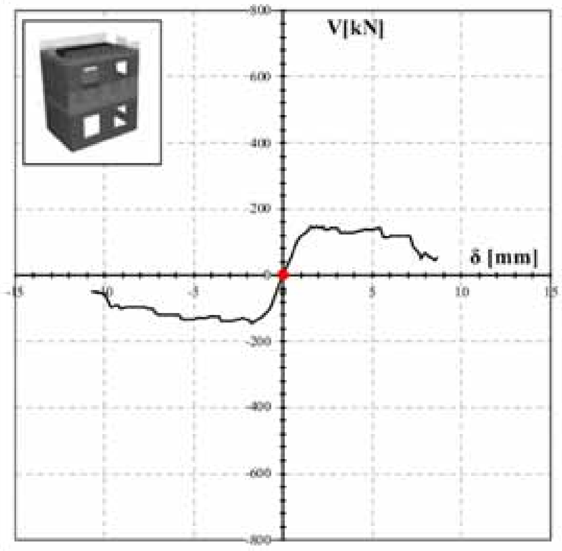
SOUTH-EAST VIEW



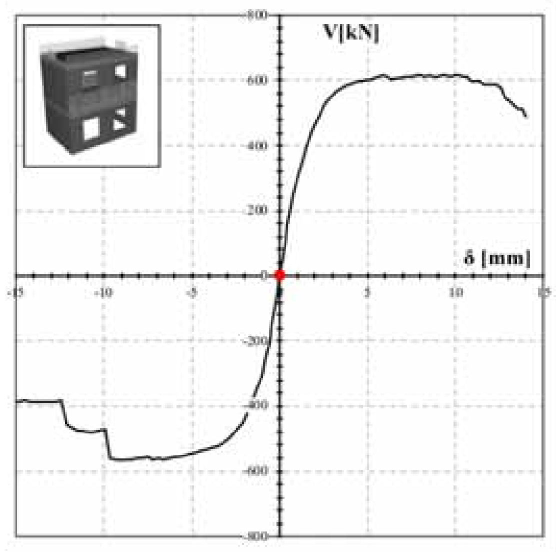


Numerical development

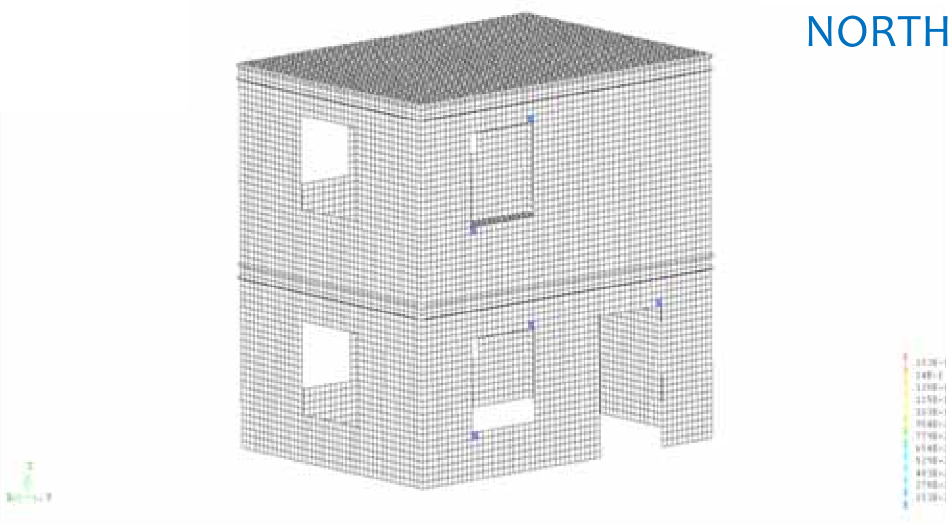
UN-STRENGTHENED BUILDING

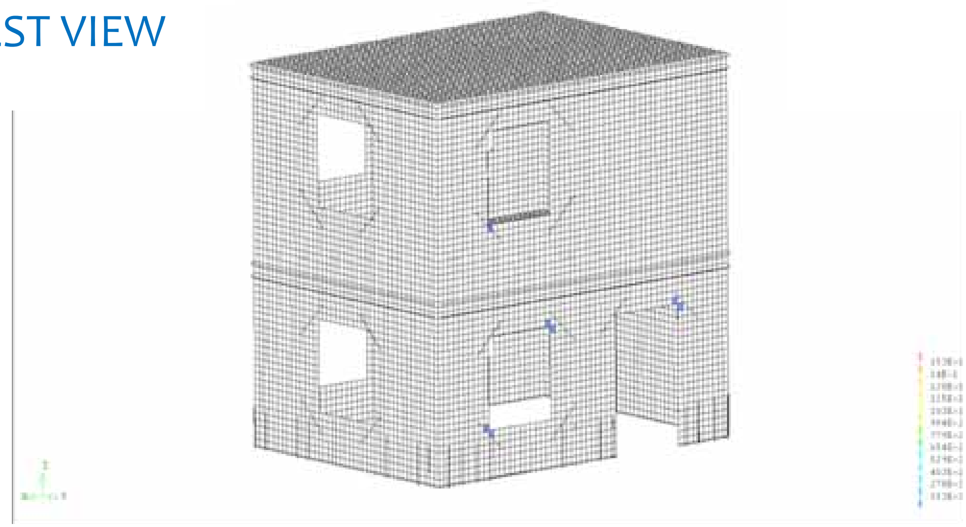


STRENGTHENED BUILDING

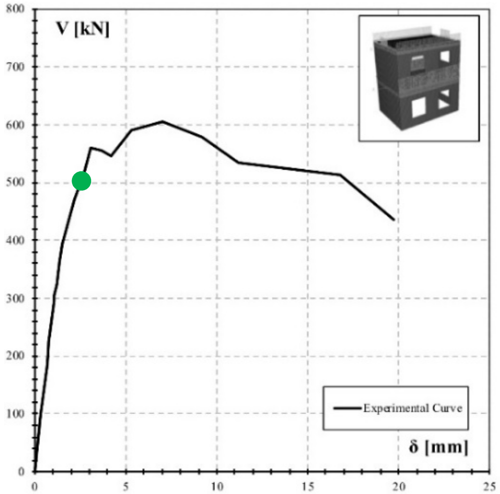


NORTH-WEST VIEW





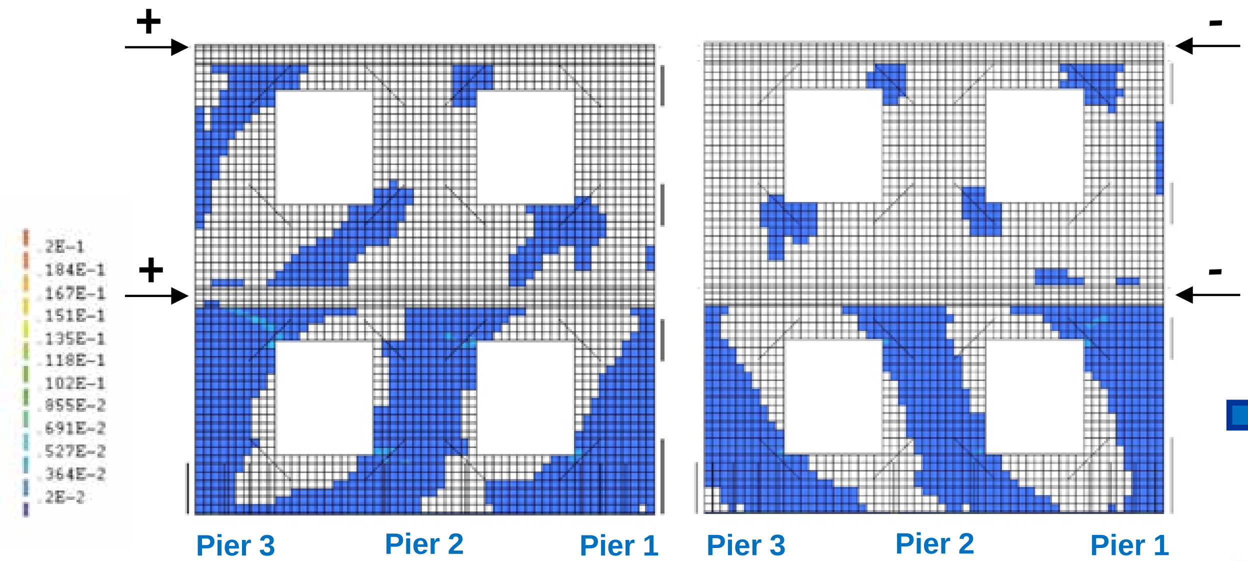
Strenghthened model: experimental vs. numerical results



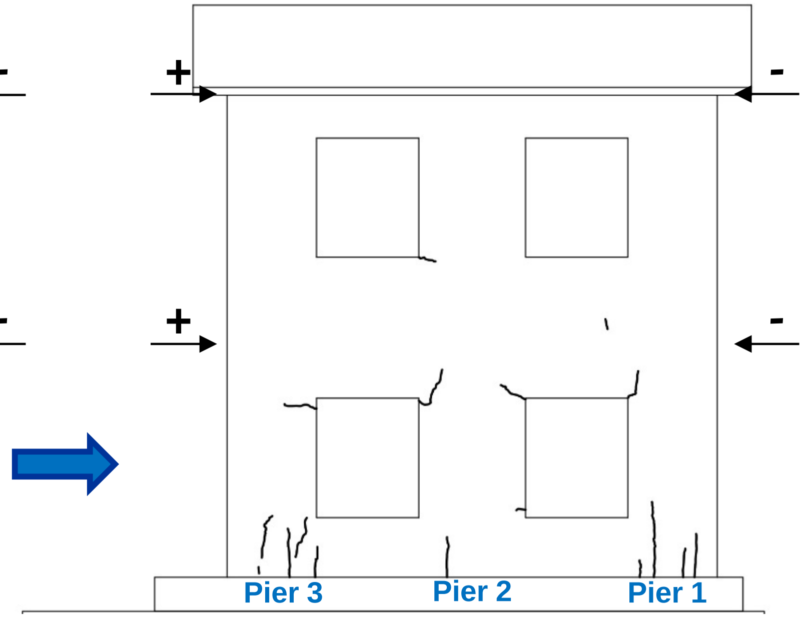
First cracks starting from the corner of the openings

	Experimental result	Numerical result
V[kN]	516.6	540
δ[mm]	2.72	2.78

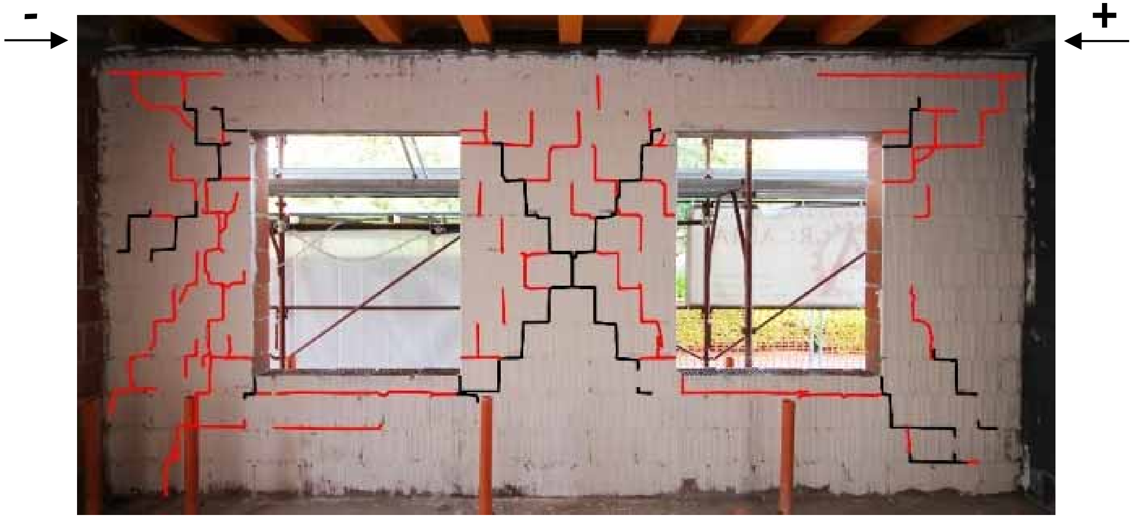
DRIFT 0.045%
(Load Step 15)



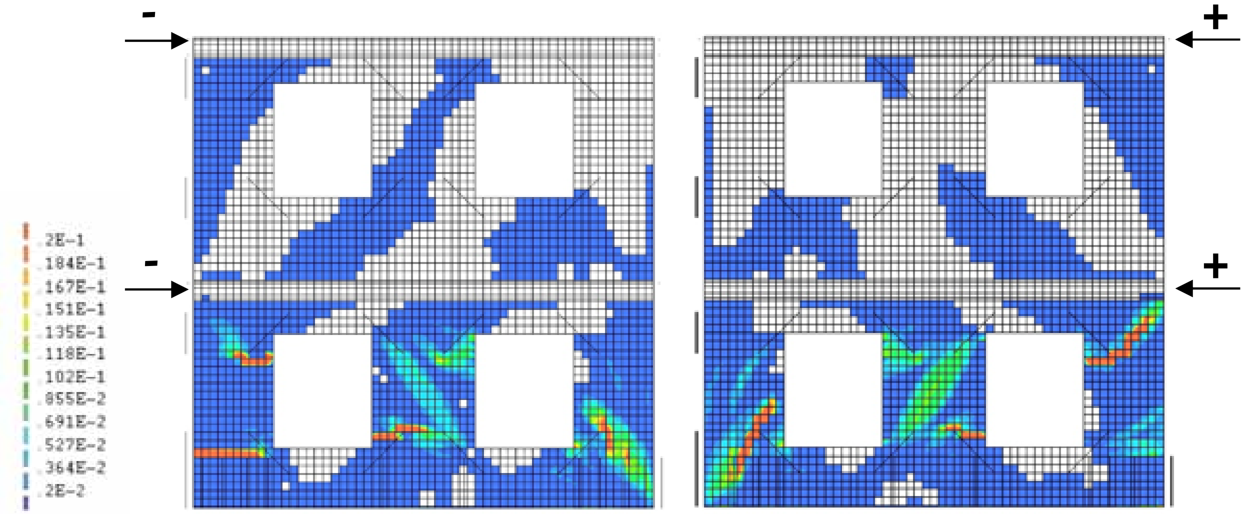
East façade



Strenghthened model: experimental vs. numerical results



Pier 1 Pier 2 Pier 3



Pier 1 Pier 2 Pier 3 Pier 1 Pier 2 Pier 3

CRACK PATTERNS AT THE END OF EXPERIMENTAL TEST (inside view of East façade at ground floor)

⬇

MAIN MECHANISMS:

Diagonal shear failure of central pier (**Pier 2**) and of **Pier 1**

Rocking mechanism of the external piers (**Pier 1** and **Pier 3**)

⬆

TENSILE CRACKING STRAIN AT THE PEAK OF NUMERICAL ANALYSIS

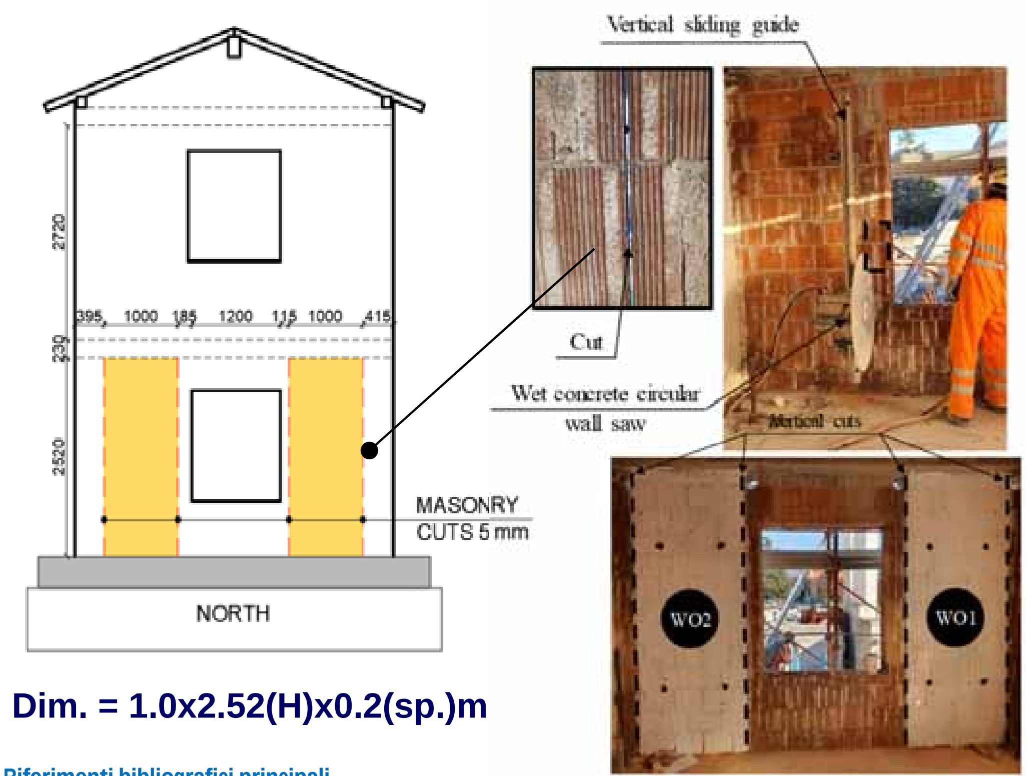
RINFORZO DELLA MURATURA MEDIANTE INTONACI: TEST SPERIMENTALI

PROVE DI FLESSIONE FUORI DAL PIANO DI PARETI RINFORZATE CON INTONACI FRM

L'edificio rinforzato con tecnica FRM descritto in precedenza e' stato impiegato per lo svolgimento di prove cicliche di flessione fuori piano. Le prove hanno coinvolto due tipologie di pareti: 1) one-way spanning wall (elementi trave). 2) Two-way spanning wall (elementi piastra).

ONE-WAY SPANNING WALL

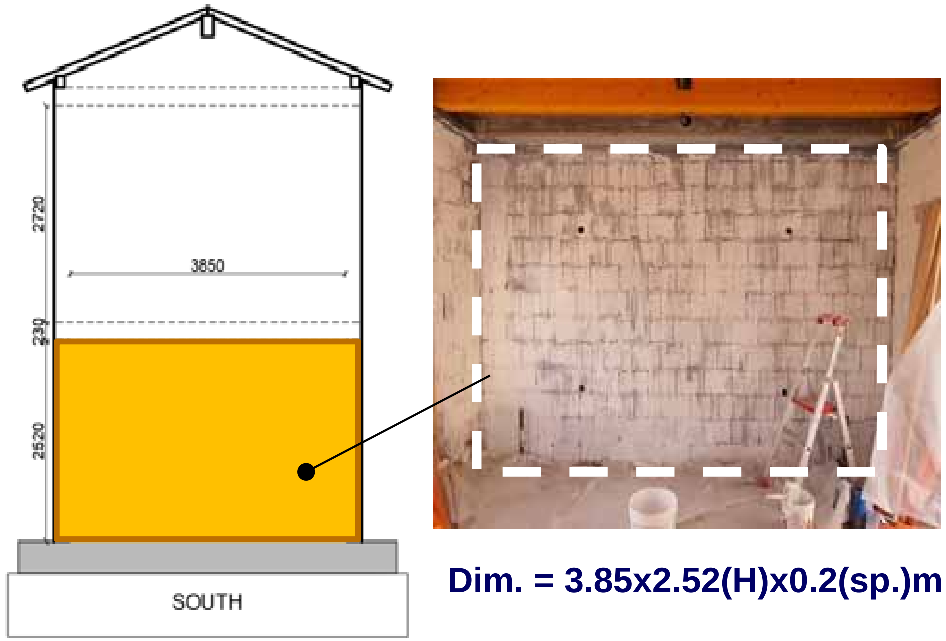
(comportamento a trave)



Dim. = 1.0x2.52(H)x0.2(sp.)m

TWO-WAY SPANNING WALL

(comportamento a piastra)



Dim. = 3.85x2.52(H)x0.2(sp.)m

NB: la muratura è continua lungo i 4 lati della parete

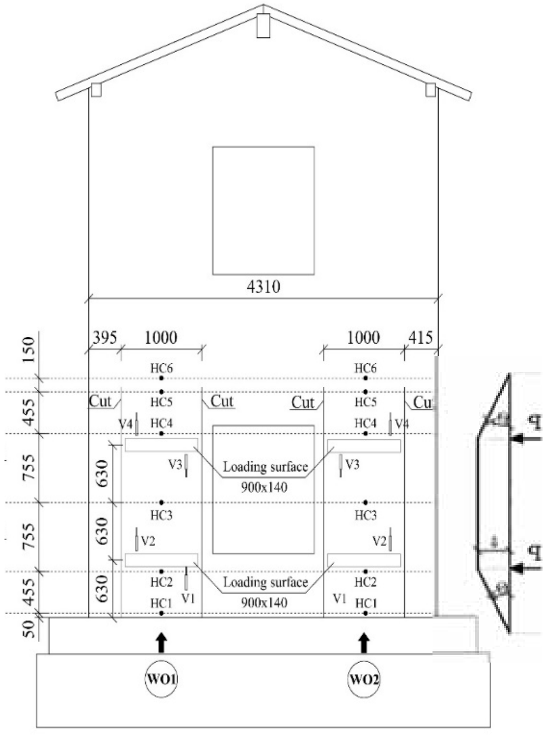
Riferimenti bibliografici principali

Lucchini, S. S., Facconi, L., Minelli, F., & Plizzari, G. A. (2023). Experimental and numerical evaluation of the out-of-plane bending behavior of masonry walls retrofitted by Steel Fiber Reinforced Mortar coating. Procedia Structural Integrity, 44, 2206-2213.

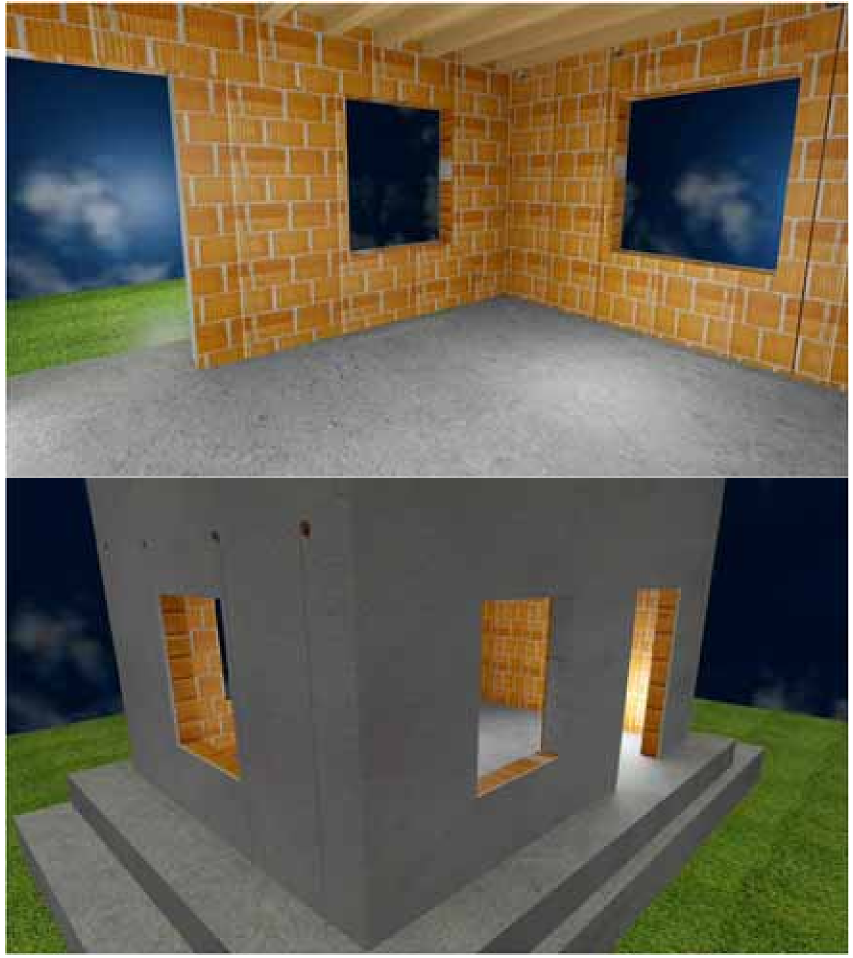
RINFORZO DELLA MURATURA MEDIANTE INTONACI: TEST SPERIMENTALI

PROVE DI FLESSIONE FUORI DAL PIANO DI PARETI RINFORZATE CON INTONACI FRM

ONE-WAY SPANNING WALL



Front view (North wall - outer surface)



Punti di carico

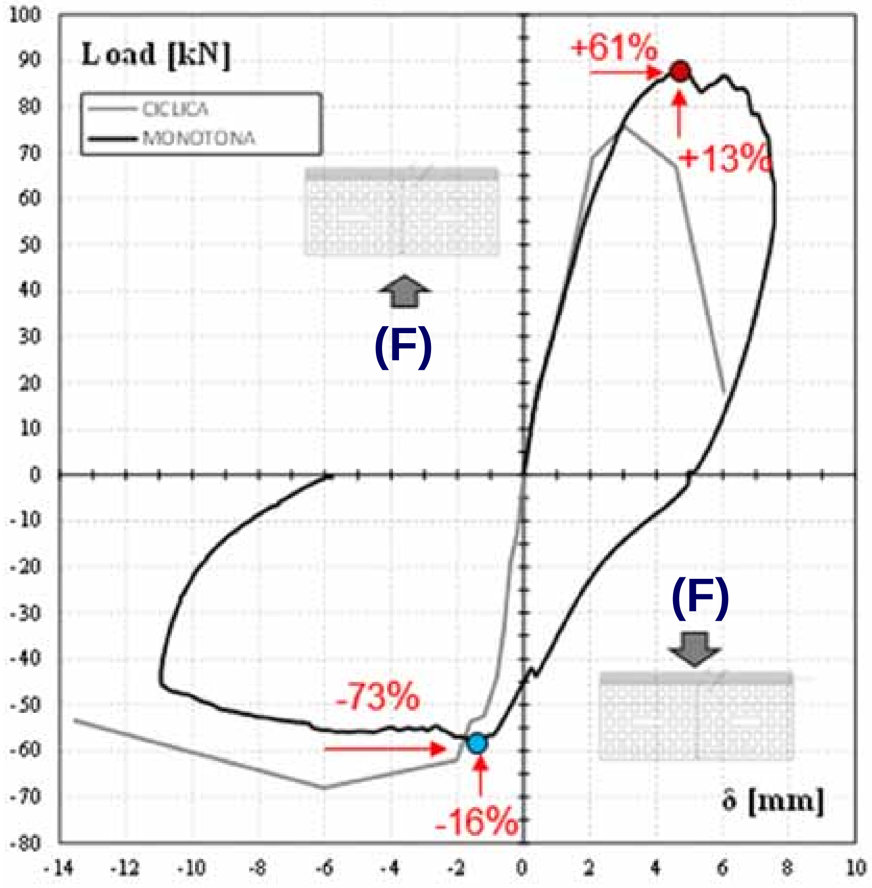
RINFORZO DELLA MURATURA MEDIANTE INTONACI: TEST SPERIMENTALI

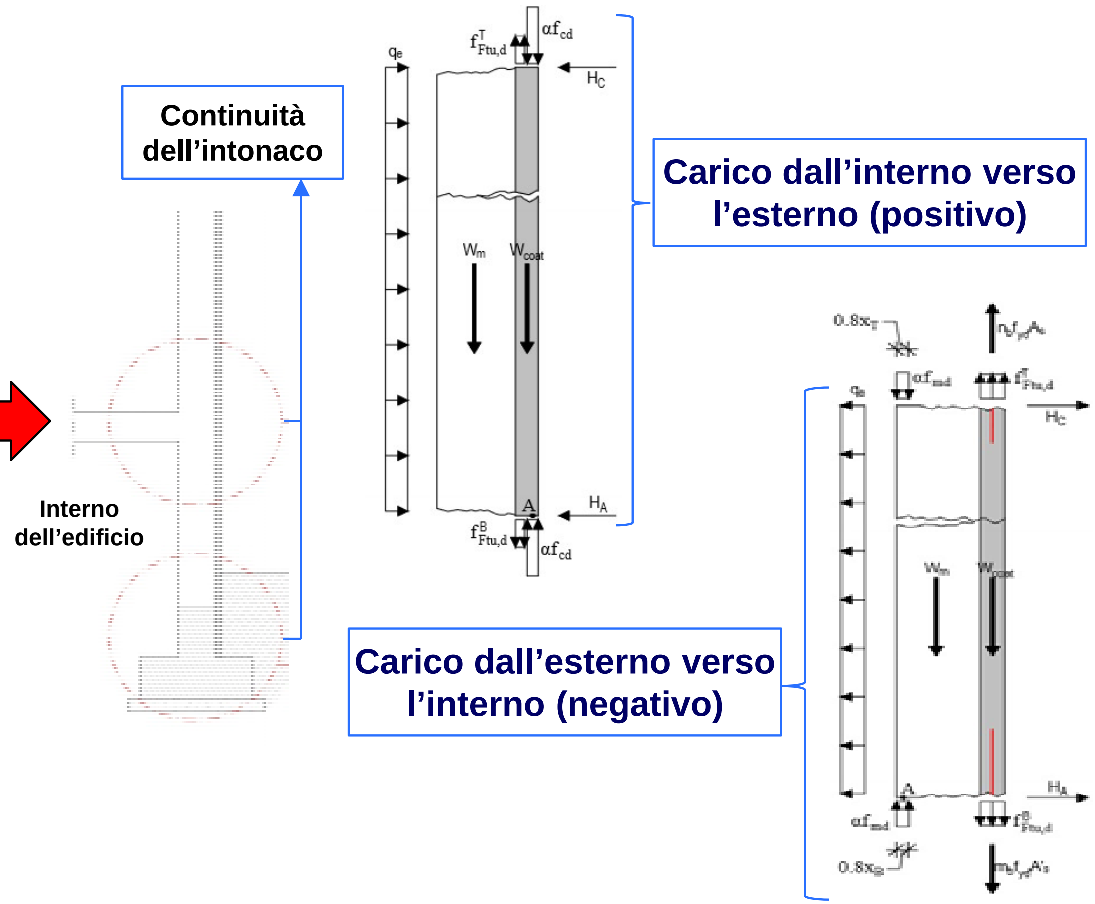
PROVE DI FLESSIONE FUORI DAL PIANO DI PARETI RINFORZATE CON INTONACI FRM

RISULTATI DELLE PROVE CICLICHE SU ONE-WAY SPANNING WALLS

Il comportamento della parete nelle due direzioni è molto simile, nonostante la non simmetria del rinforzo!

Carico vs. spostamento max. orizzontale

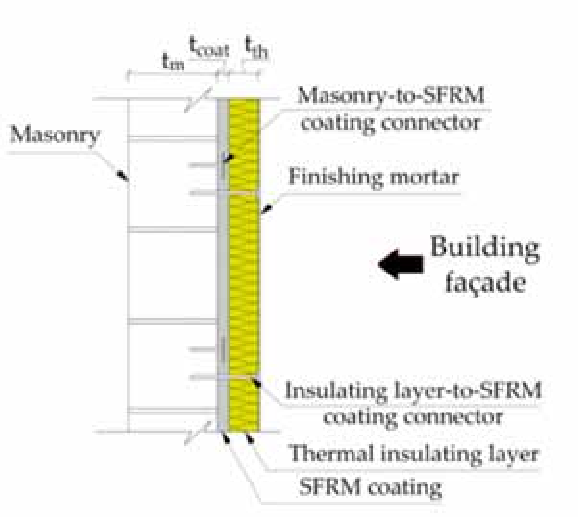


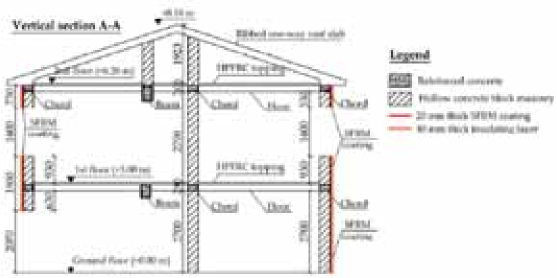


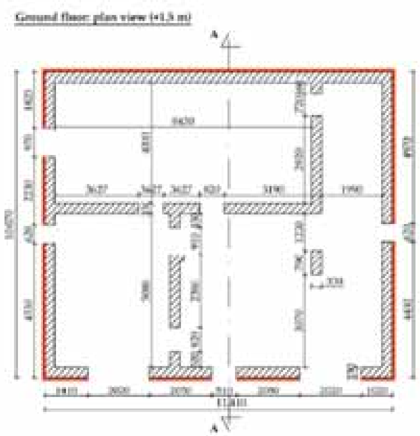
MIGLIORAMENTO ENERGETICO DI EDIFICI ESISTENTI

IMPIEGO DEGLI INTONACI FRM PER IL RINFORZO SISMICO ED EFFICIENTAMENTO ENERGETICO DEGLI EDIFICI ESISTENTI (progetto SISMACOMF)

Combinazione di intonaco FRM con pannelli isolanti applicati in facciata

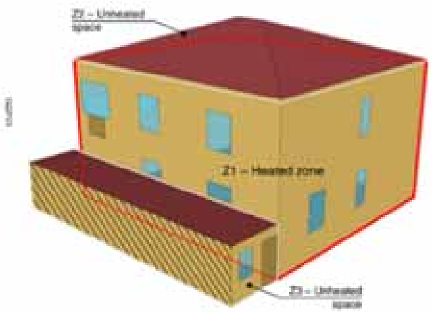


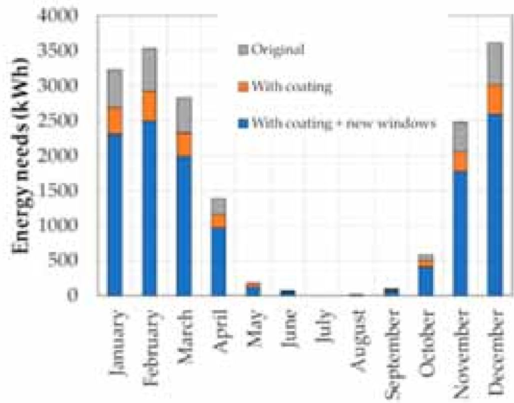




Test in camera climatica dell'efficacia della tecnica proposta

Analisi del fabbisogno energetico di un edificio in muratura esistente



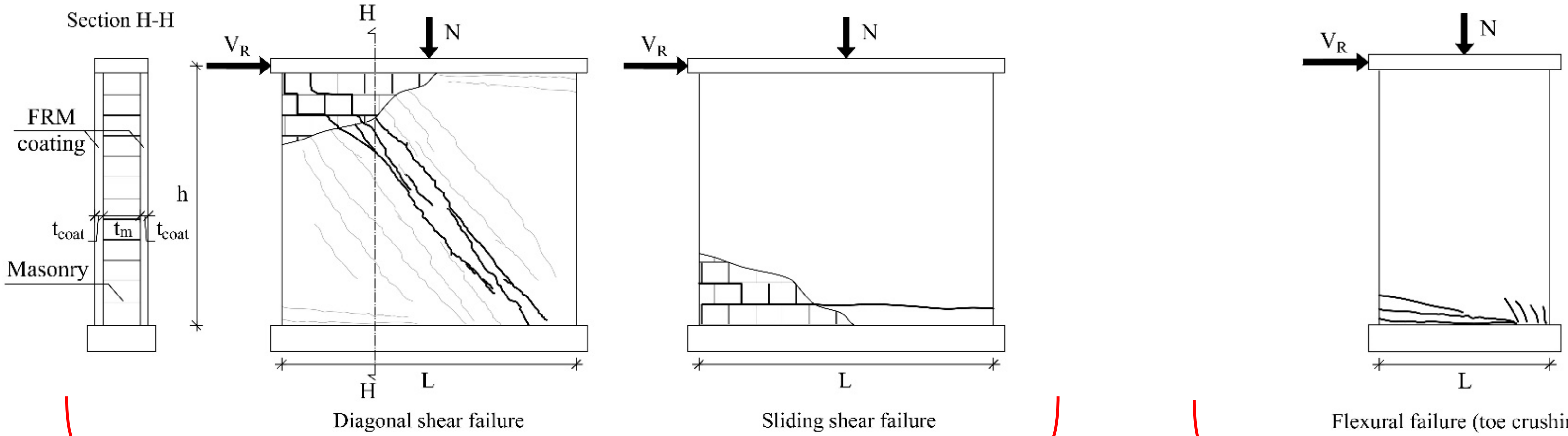


Facconi, L., Lucchini, S. S., Minelli, F., Grassi, B., Pilotelli, M., & Plizzari, G. A. (2021). Innovative method for seismic and energy retrofitting of masonry buildings. Sustainability, 13(11), 6350.

APPROCCIO ANALITICO PER IL CALCOLO DELLA RESISTENZA DI PARETI CON INTONACI FRM

MODELLO PROPOSTO

Il modello proposto consente di calcolare la resistenza nel piano di pareti rinforzate su uno o entrambi i lati, partendo dall'ipotesi di perfetta aderenza fra intonaco e muratura



Rottura per taglio

Rottura per presso-flessione

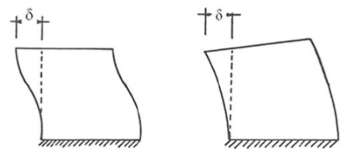
$$V_R = \min(V_{R,t}; V_{R,s})$$

$V_{R,s}$ → Resistenza taglio-scorrimento

$V_{R,t}$ → Resistenza taglio-trazione

$$V_{Rd} = \frac{M_{Rd}}{\alpha h}$$

M_{Rd} → Momento resistente



$\alpha = 0,5$ $\quad$ $\alpha = 1$

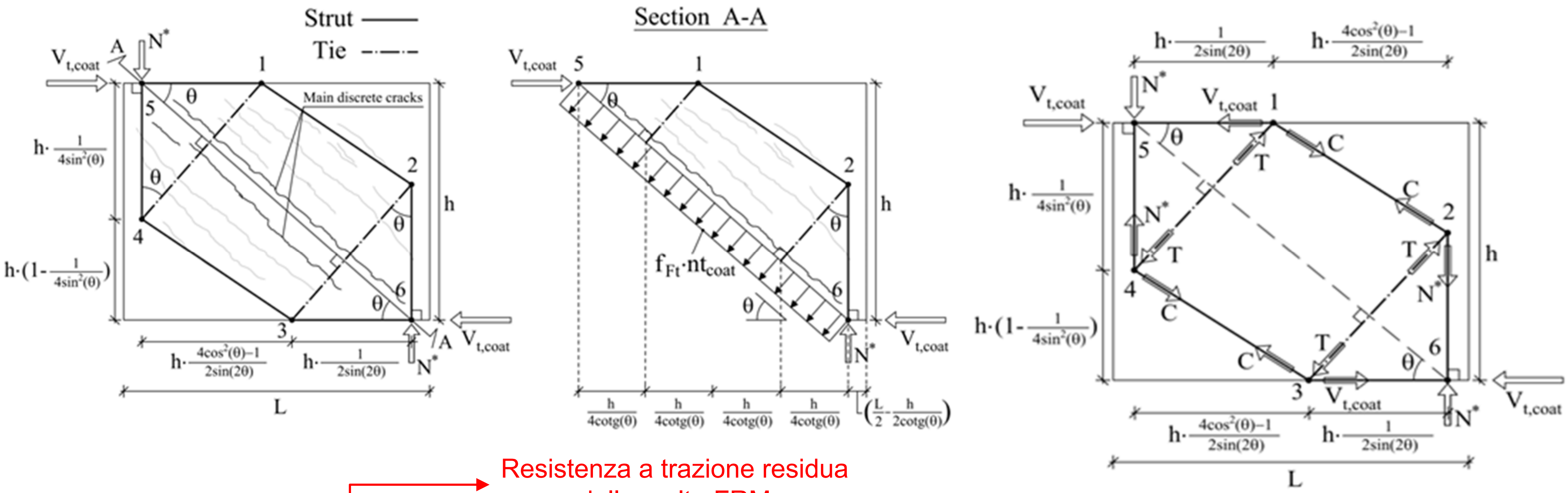
Riferimenti bibliografici principali

- Facconi, L., Lucchini, S. S., Minelli, F., & Plizzari, G. A. (2023). Analytical model for the in-plane resistance of masonry walls retrofitted with steel fiber reinforced mortar coating. Engineering Structures, 275, 115232.

APPROCCIO ANALITICO PER IL CALCOLO DELLA RESISTENZA DI PARETI CON INTONACI FRM

MODELLO PER IL CALCOLO DELLA RESISTENZA A TAGLIO TRAZIONE

Contributo dell'intonaco alla resistenza a taglio ($V_{t,coat}$)



Resistenza a trazione residua della malta FRM

n¶strati d'intonaco (1, 2)

Spessore del singolo strato d'intonaco

$$V_{t,coat}=m\cdot f_{Ftd}\cdot nt_{coat}\cdot\frac{h}{2\cdot\sin^2(\theta)}$$

$V_{t,coat}=N^*\cdot cotg(\theta)$

$C=\sqrt{(N^*-nt_{coat}\cdot f_{Ft}\cdot\frac{h}{2}\cdot cotg(\theta))^2+(nt_{coat}\cdot f_{Ft}\cdot\frac{h}{2})^2}$

$T=\frac{f_{Ft}\cdot h\cdot nt_{coat}}{2\sin(\theta)}$

C = Compression force

T = Tension force

Concluding remarks

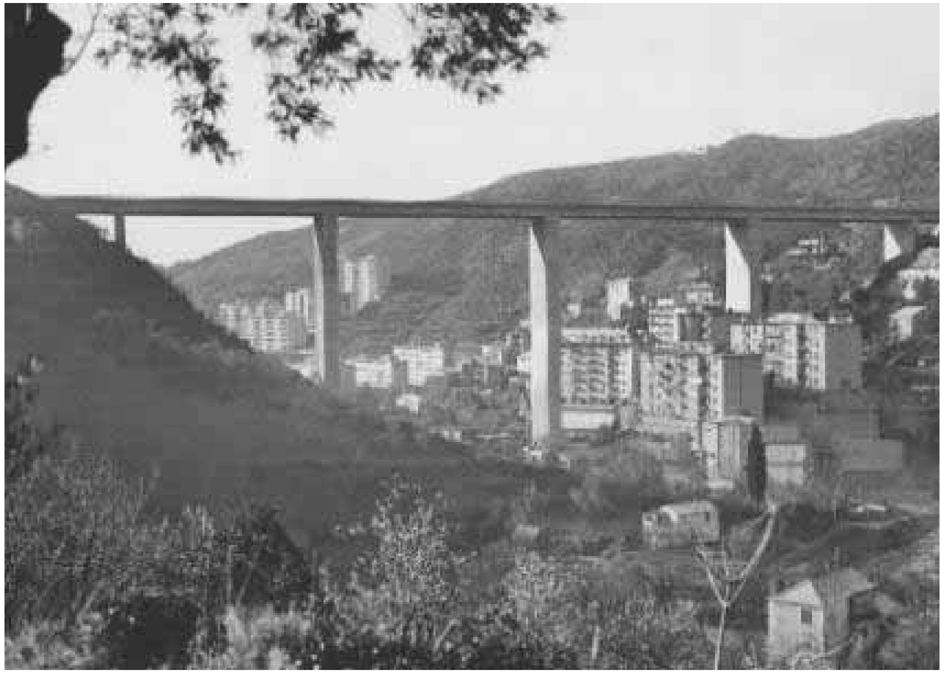
- Among the new materials, HPFRC represents a promising solution for retrofitting bridge piers for seismic actions.
- The proposed technique remarkably increases both the bearing capacity and the durability (due to a lower porosity of FRC) that may provide a new service life to the structure.
- Referring to existing masonry building, HPFRM may represent an efficient strengthening technique that elminates possible out-of-plane collapses of the walls and remarkably increases the in-plane-resistance of the wall.
- By considering the box behavior of the building, the FRM may be used as external plaster; this allows people to stay in the house during construction works.
- The proposed technique may be used for increasing the seismic resistance as well as for repairing a building after an earthquake.

HPFRC for existing bridges

Structural vulnerability

Why structural rehabilitation?

After more than fifty years from the opening of the largely discussed "Autostrada del Sole" Highway in 1964, the infrastructure system in Italy appears marked by the passing of time, similarly to what observed in several other countries worldwide.



SALCI S.p.A./ GENOVA-SESTRI LEVANTE motorway / Rivarolo-Rapallo section 6th lot (1963-1967). / Bridge on t. Sturla, with 5 spans of 48.00 m and 1 of 38.40 m, beams in c.a.p., drilled with a special trellis of varus; Max height on the valley 83.00 m.

Why structural rehabilitation?

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.

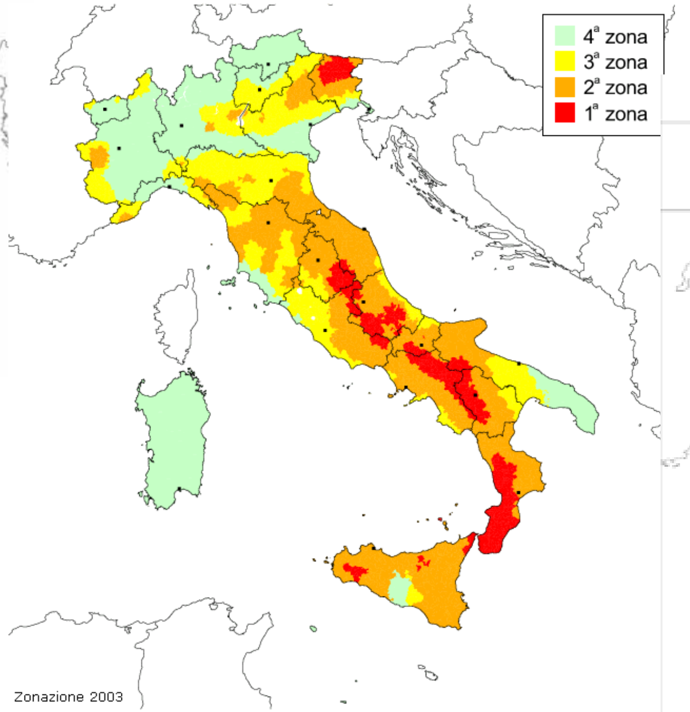
Sismic map development

1984

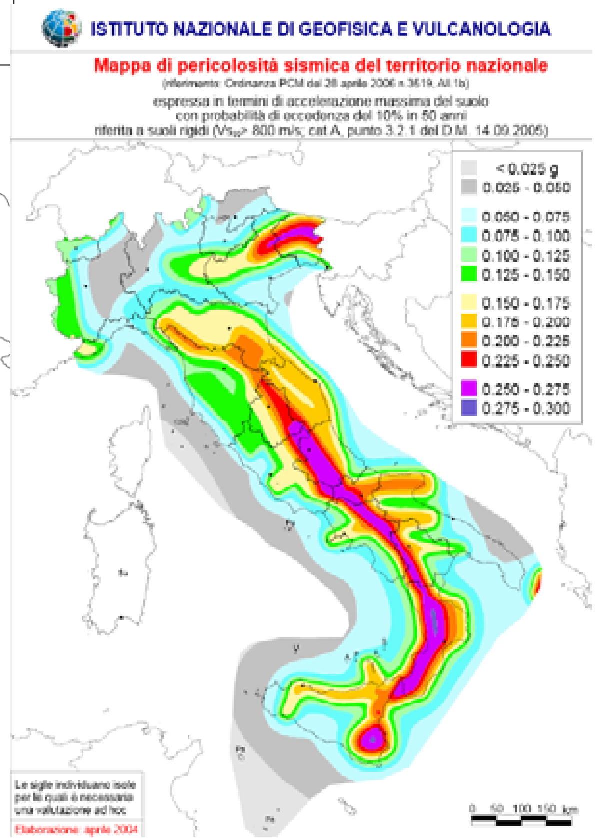
1998

Istituto Nazionale di Geofisica e Vulcanologia

2003



Today



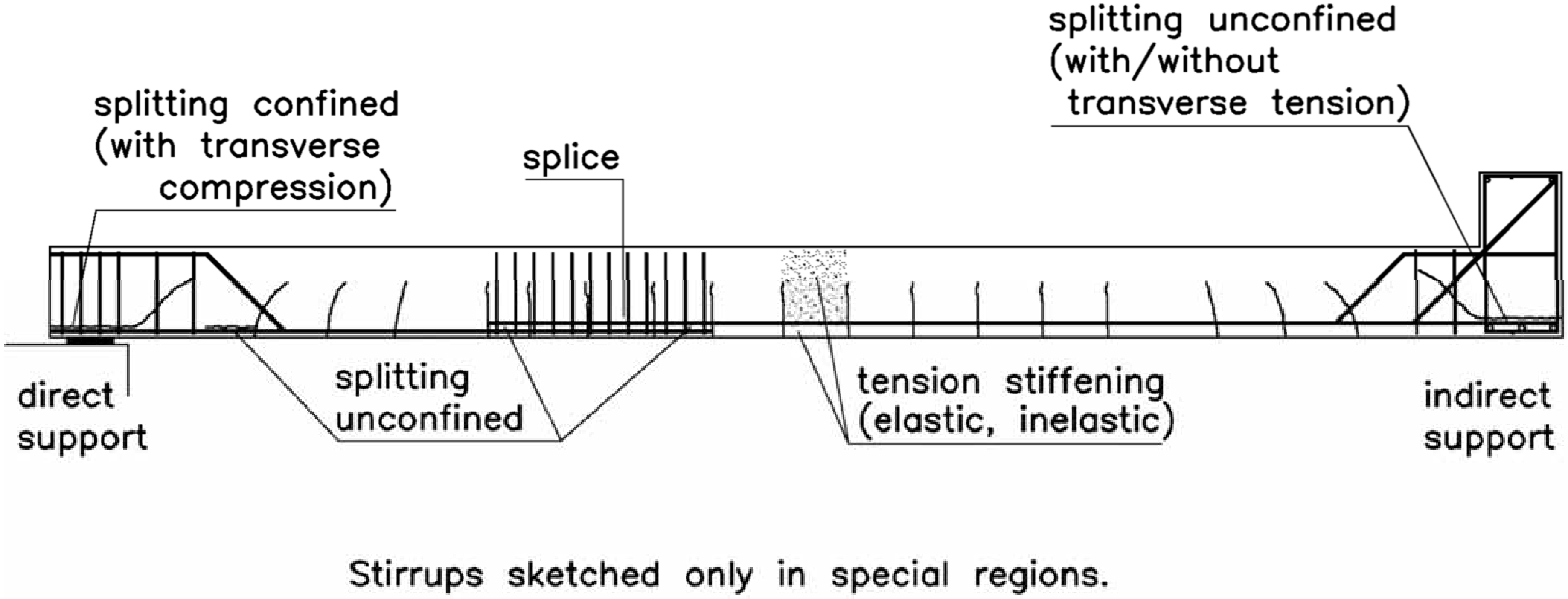
Increment of vehicle number and traffic loads (also heavy loading) and new seismic regulations are setting new requirements to adapt the existing infrastructure, which should be otherwise replaced.

Why structural rehabilitation?

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

Viaduct A14 highway, 2017

Cracks in beams



Durability of structures

Durability

Between two cracks

Lower porosity

W/C ratio

At crack location

Decrease crack width

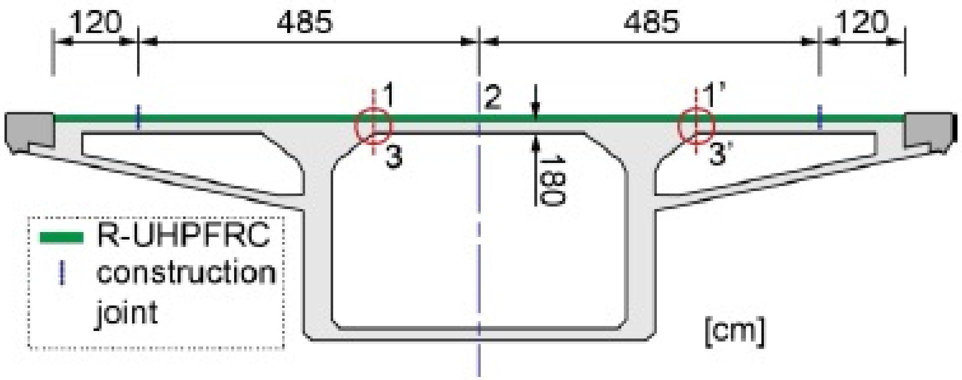
Crack control

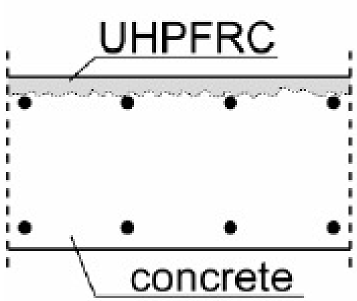
UNIVERSITY OF BRESCIA

High performance Fiber Reinforced Concrete (HPFRC)

Bridge deck strengthening with UHPFRC

Chillon viaducts along Lake Geneva





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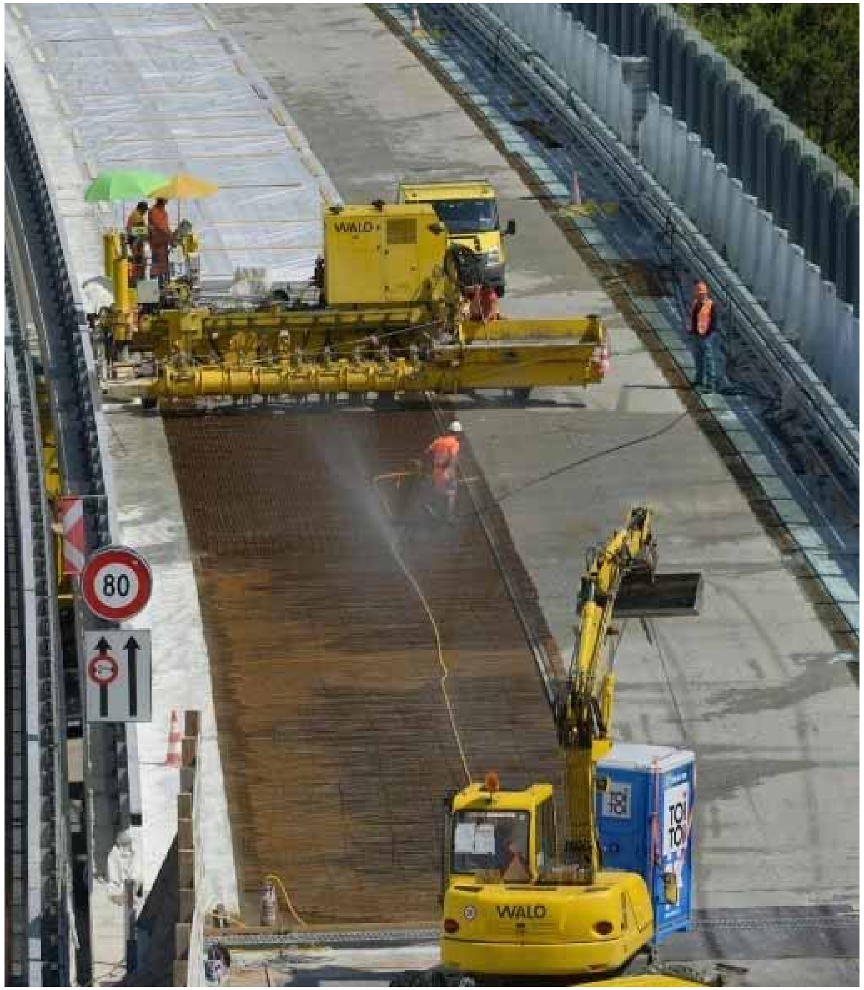
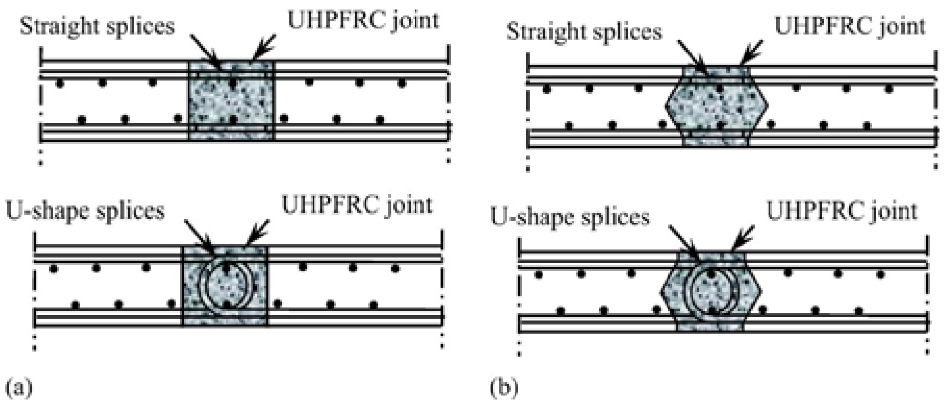
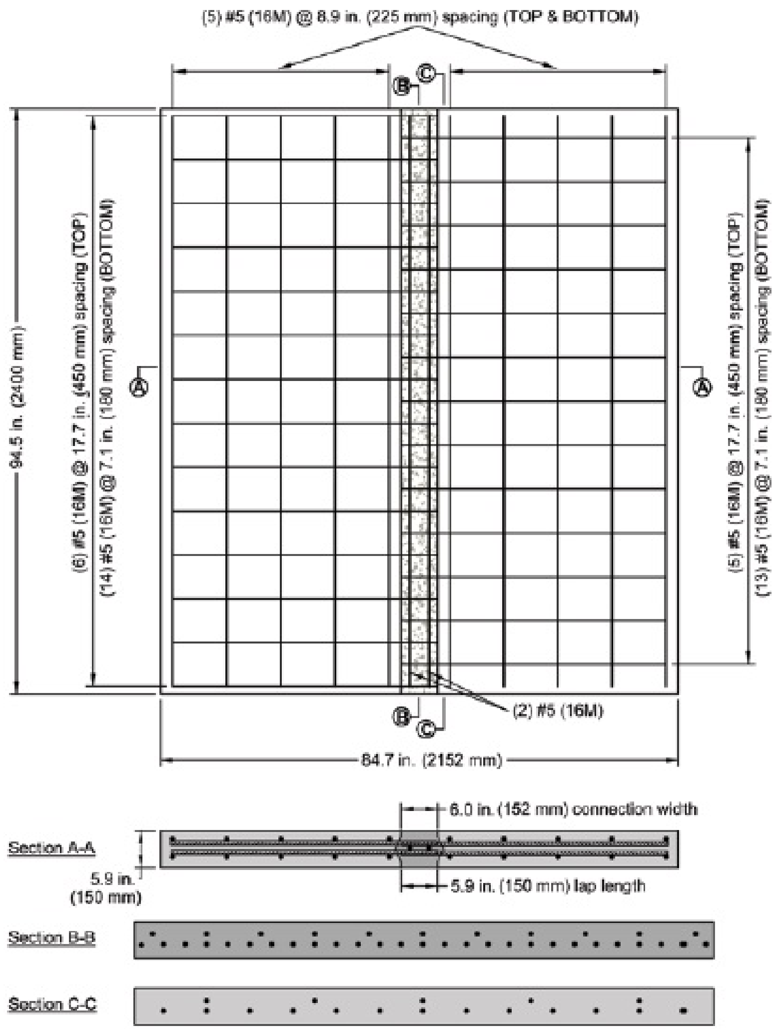
Chillon viaducts along Lake Geneva

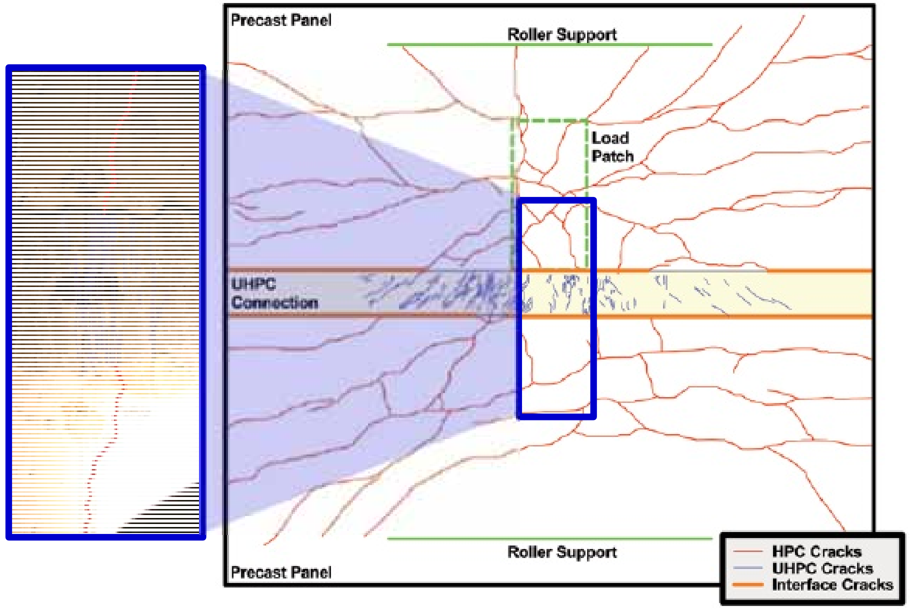


Cast-in-place joints with UHPFRC



Cast-in-place joints with UHPFRC



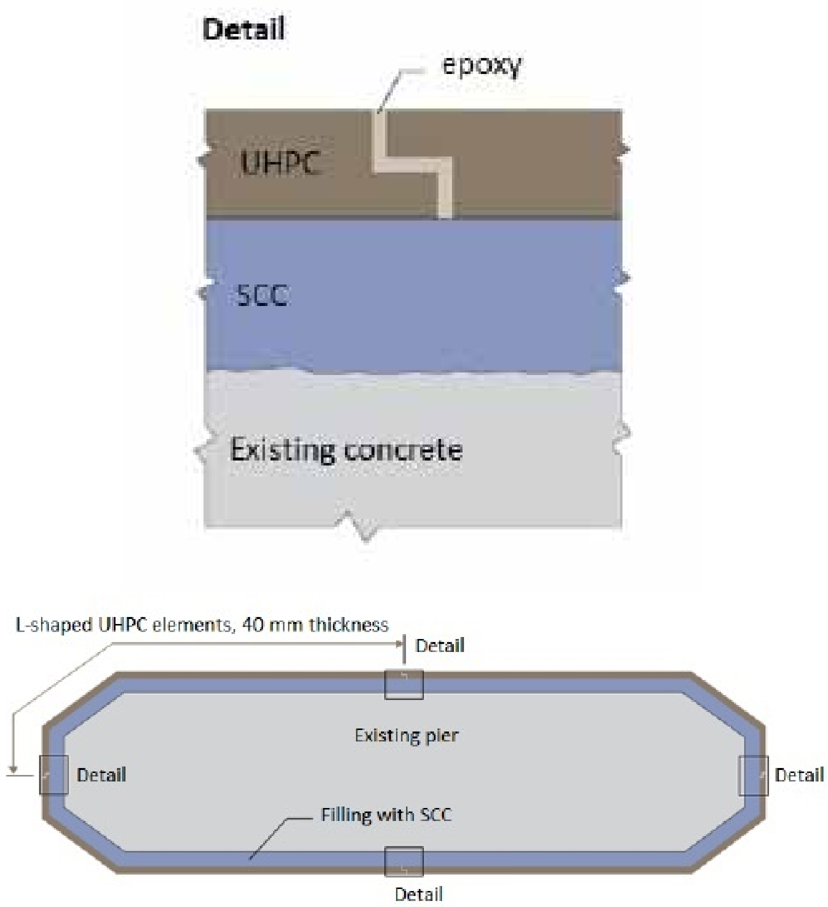


New York State Department of Transportation (NYSDOT)

Bridge pier jacketing with UHPFRC

The Mission Bridge, Abbotsford, British Columbia (CA)

Bridge pier jacketing with UHPFRC



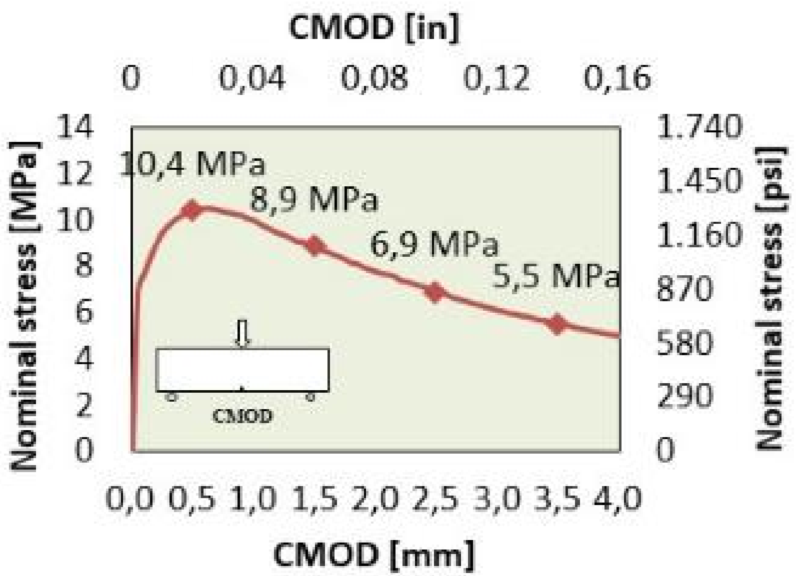
Bridge pier repair with UHPFRC at the A1, Killwangen (CH)

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)



High Mechanical Performances

R_{cm} = 136 Mpa

E_{cm} = 45 Gpa

f_{ctm} = 14 MPa

Durability

- REPAIR
- STRENGTHENING
- SEISMIC RETROFITTING

Toughness

f_{R1m} = 10 MPa

f_{R3m} = 7 MPa

Fire/high Temperature Behavior

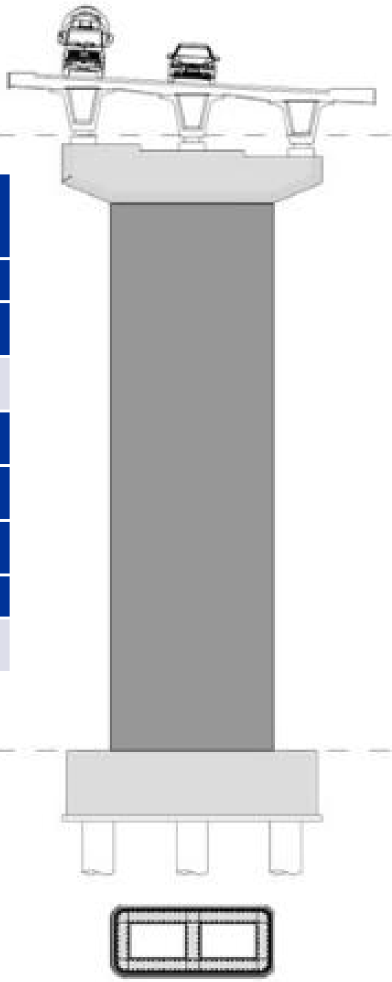
Fibres were made of stainless steel, crimped, 19 mm long, with 0.13 mm diameter. The maximum aggregate size was 4 mm to fit the critical thickness of 30 mm of the jacketing

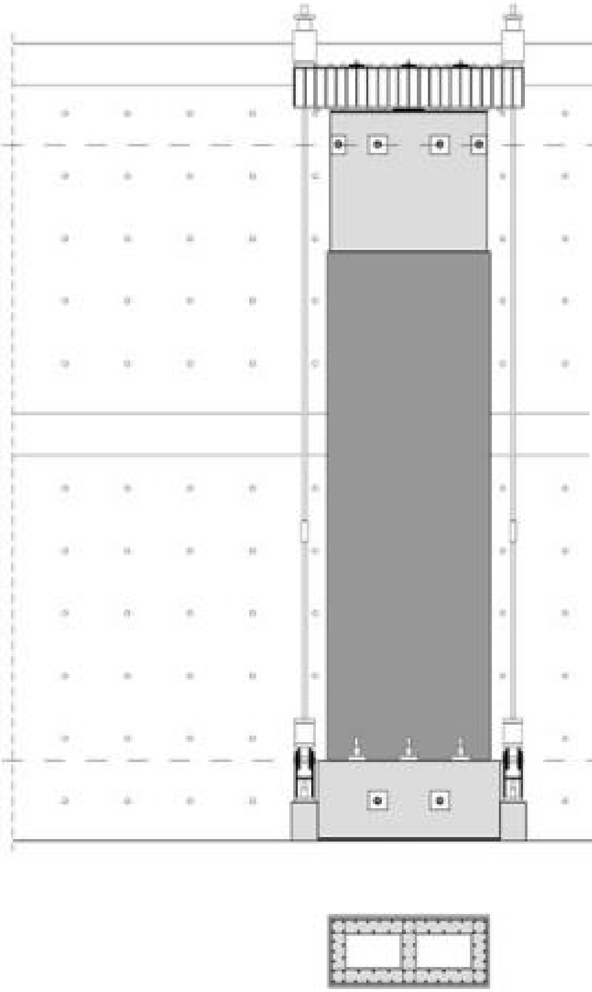
Previous tests on UHPFRC jacketing

- 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%

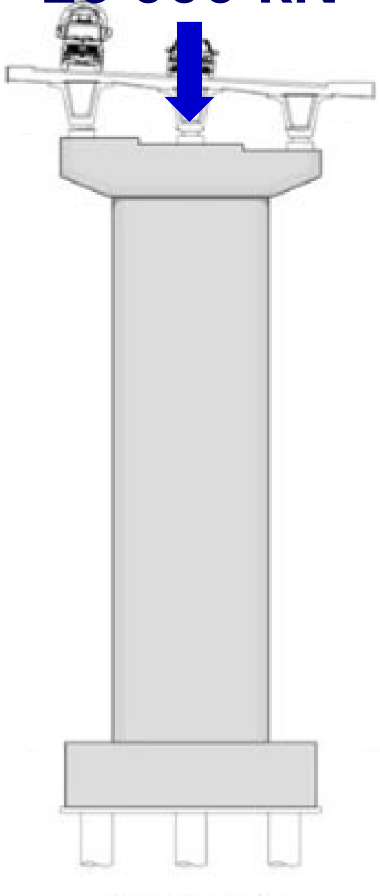


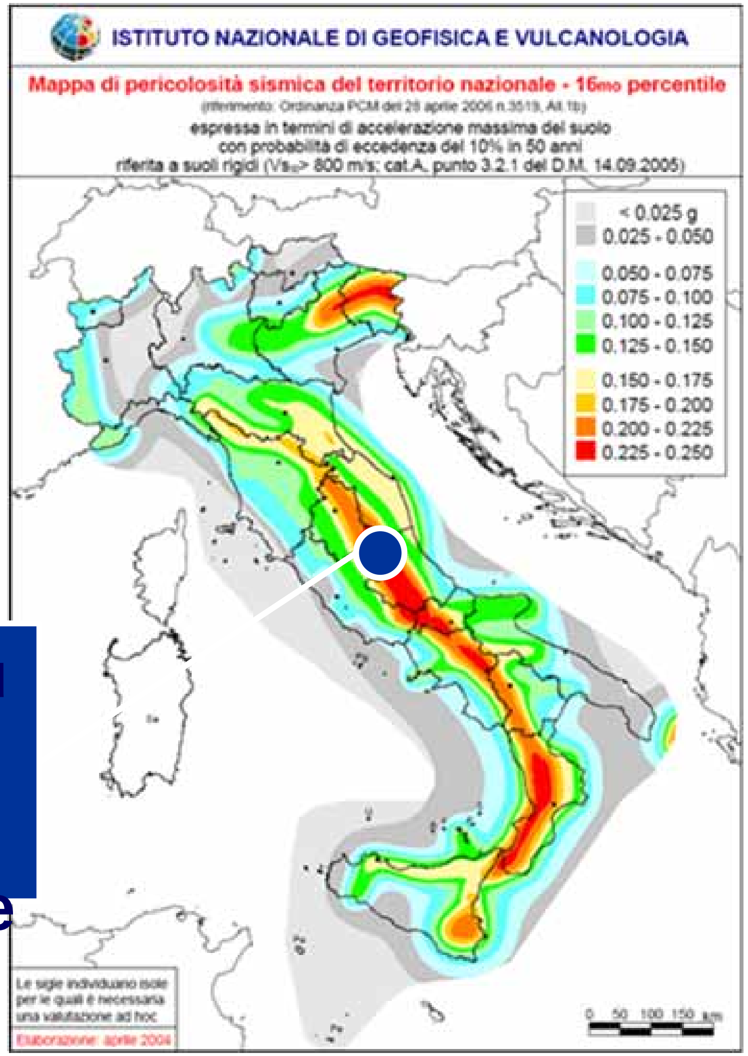


	Reduced scale (1:4)
A_C	0,596 m^2
A_S	10 160 mm^2
t_{UHPFRC}	30 mm
A_{UHPFRC}	0,131 m^2
H_{UHPFRC}	**4,9 m**
V_{UHPFRC}	0,642 m^3
ρ_S	1,70%
$\rho_{S,\ added}$	0,65%

Extension of working life is possible?

16 000 kN





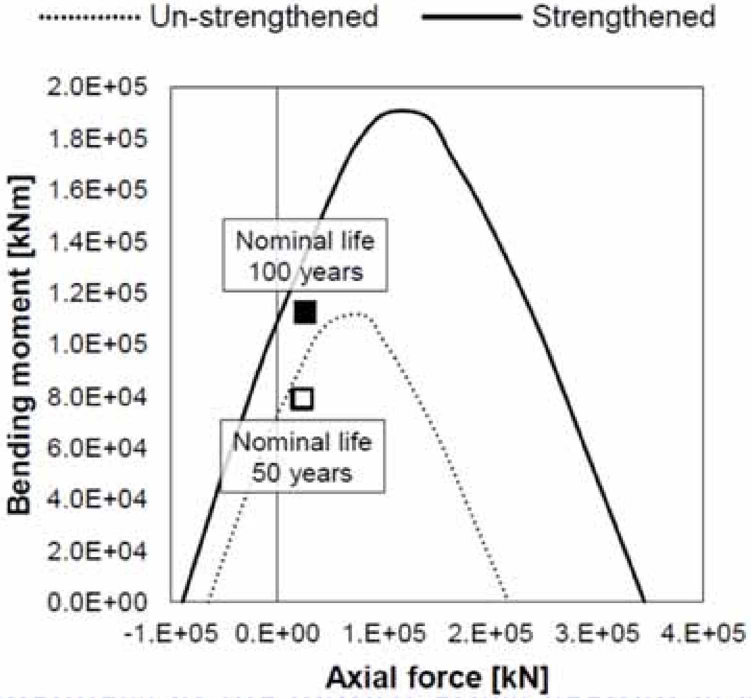
Longitude 12.943

Latitude 42.834

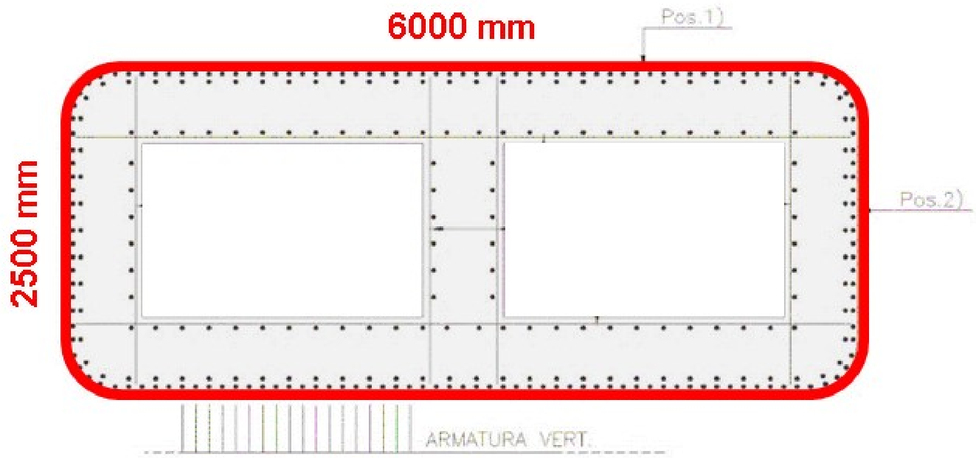
Strengthening design

HPFRC Jacketing

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).

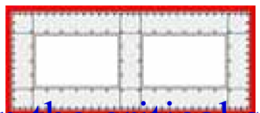


Jacketing thickness: 120 mm



Specimen scaled 1:4

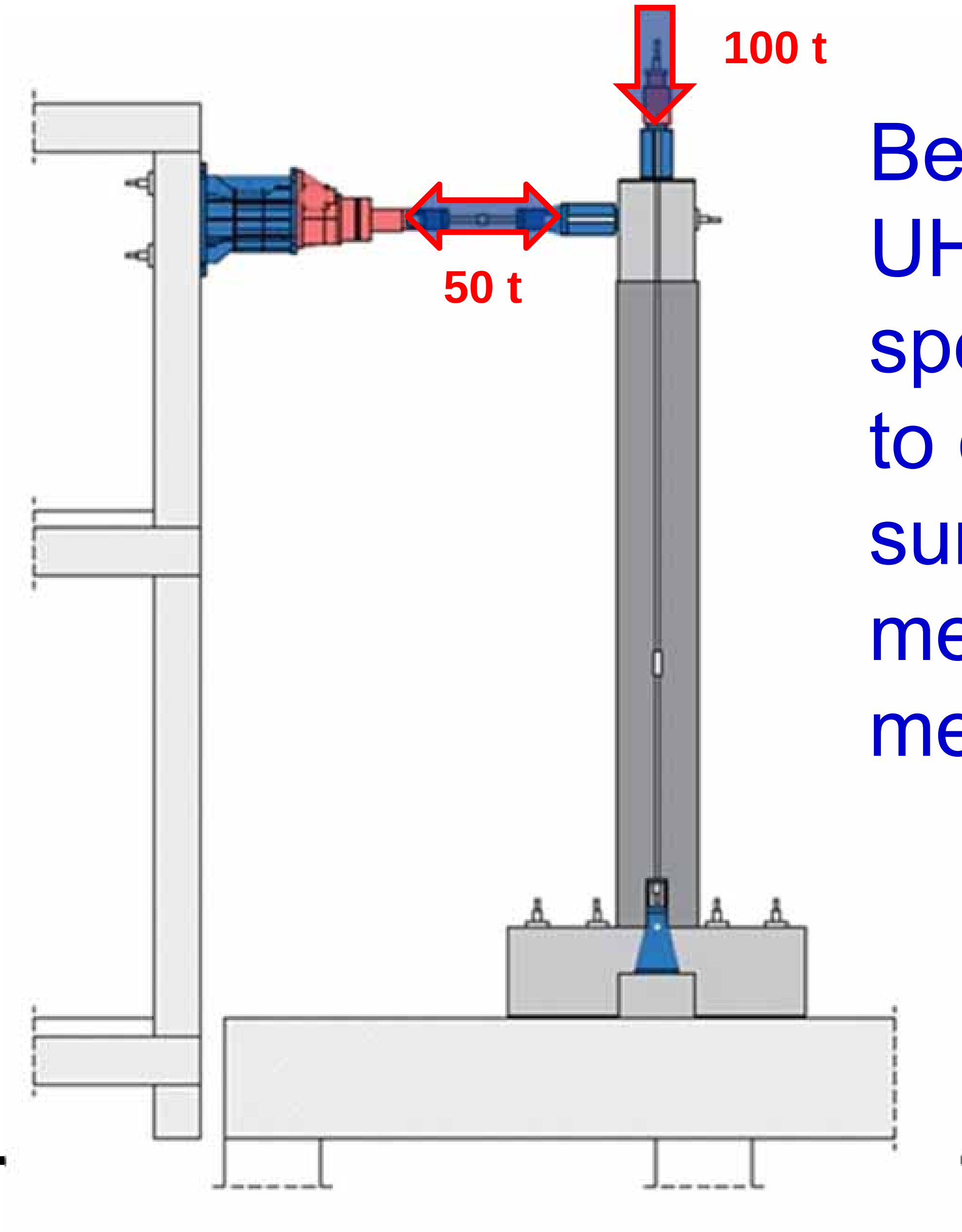
Jacketing thickness: 30 mm



The [illegible] 0 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.

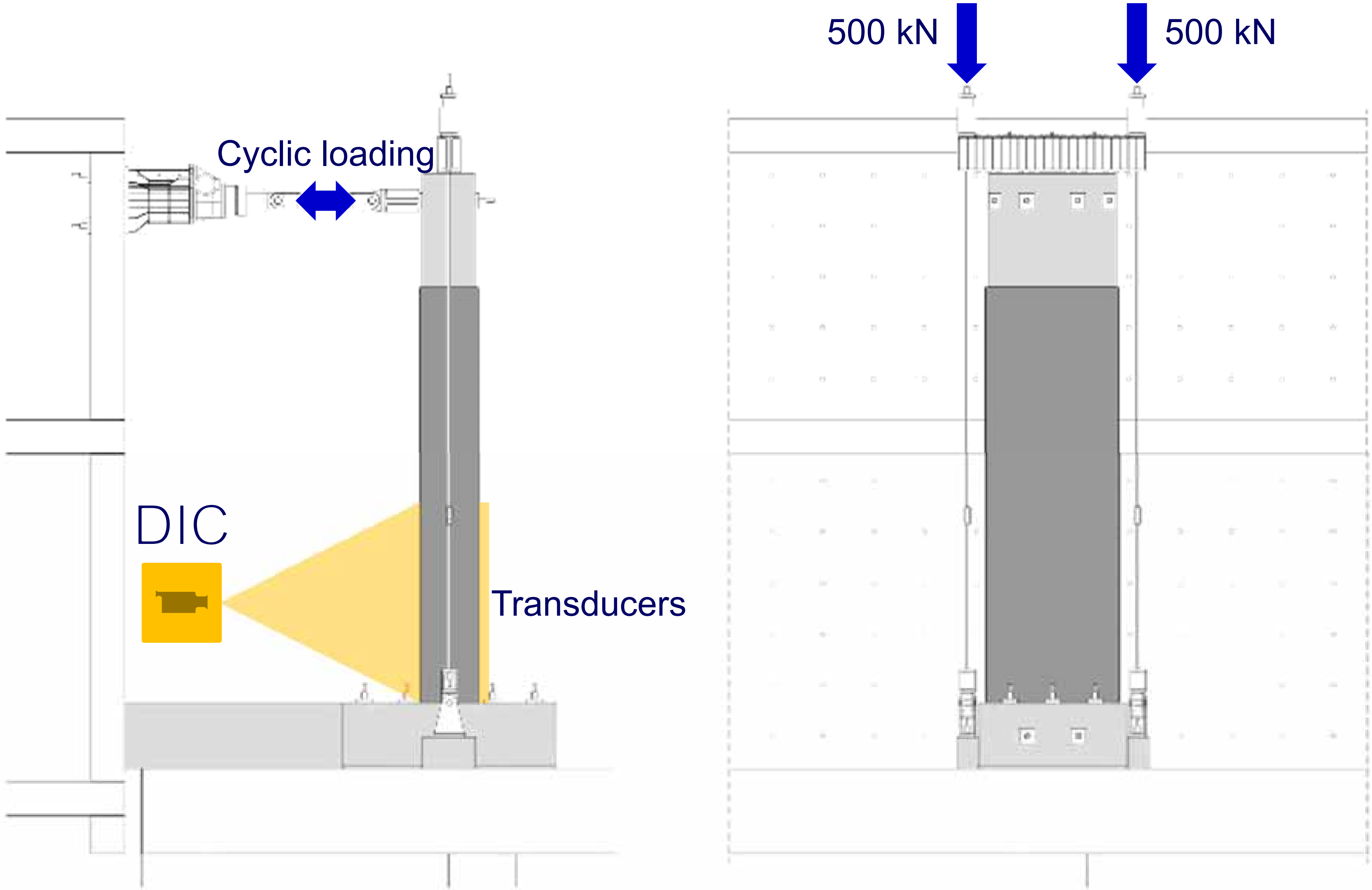
Experimental investigation.

Experimental set-up



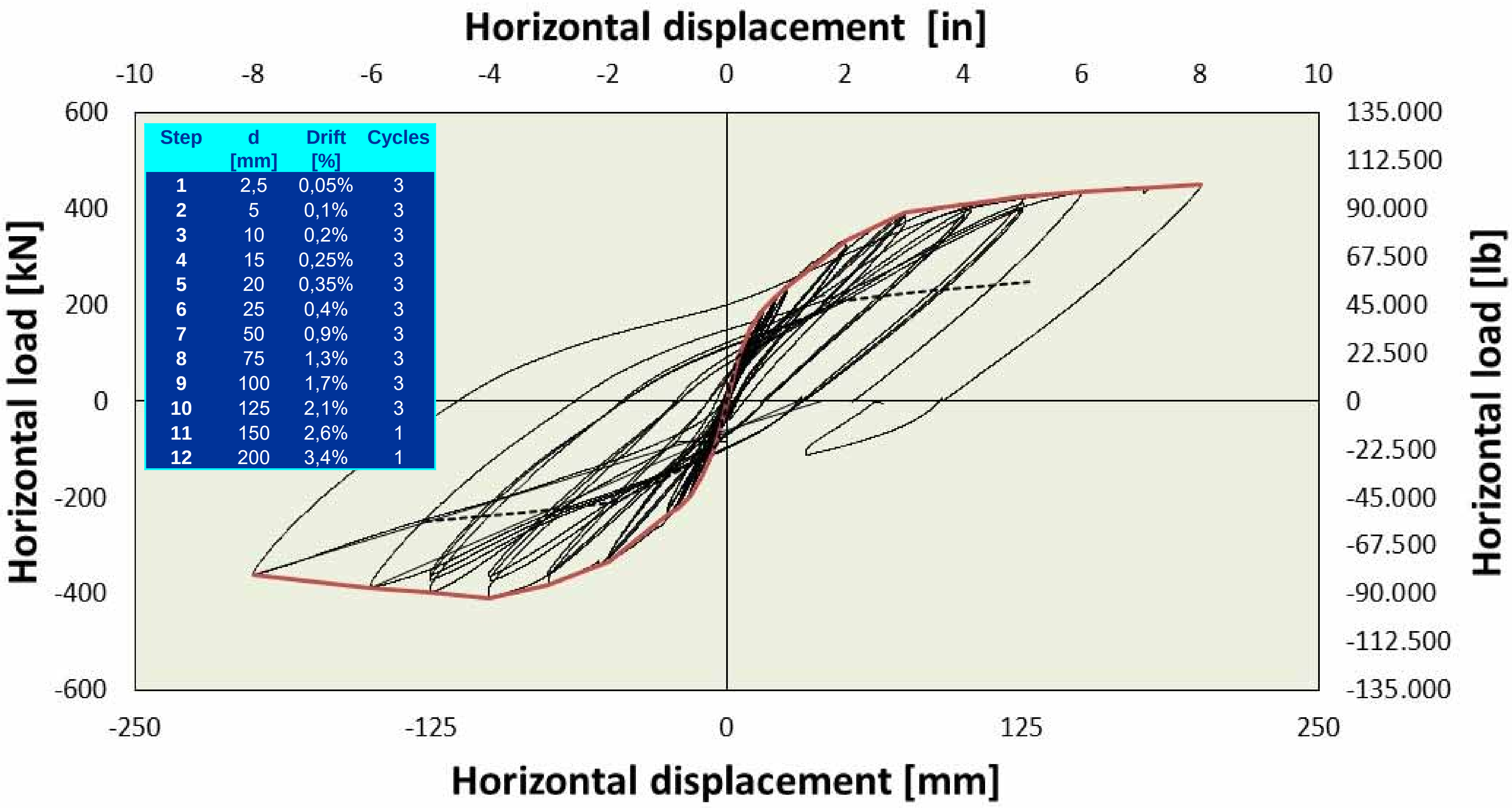
Before placing the UHPFRC layer, the RC specimen was sandblasted to obtain a very rough surface (R_t= 3.0 mm) measured with sand patch method

Crack detection



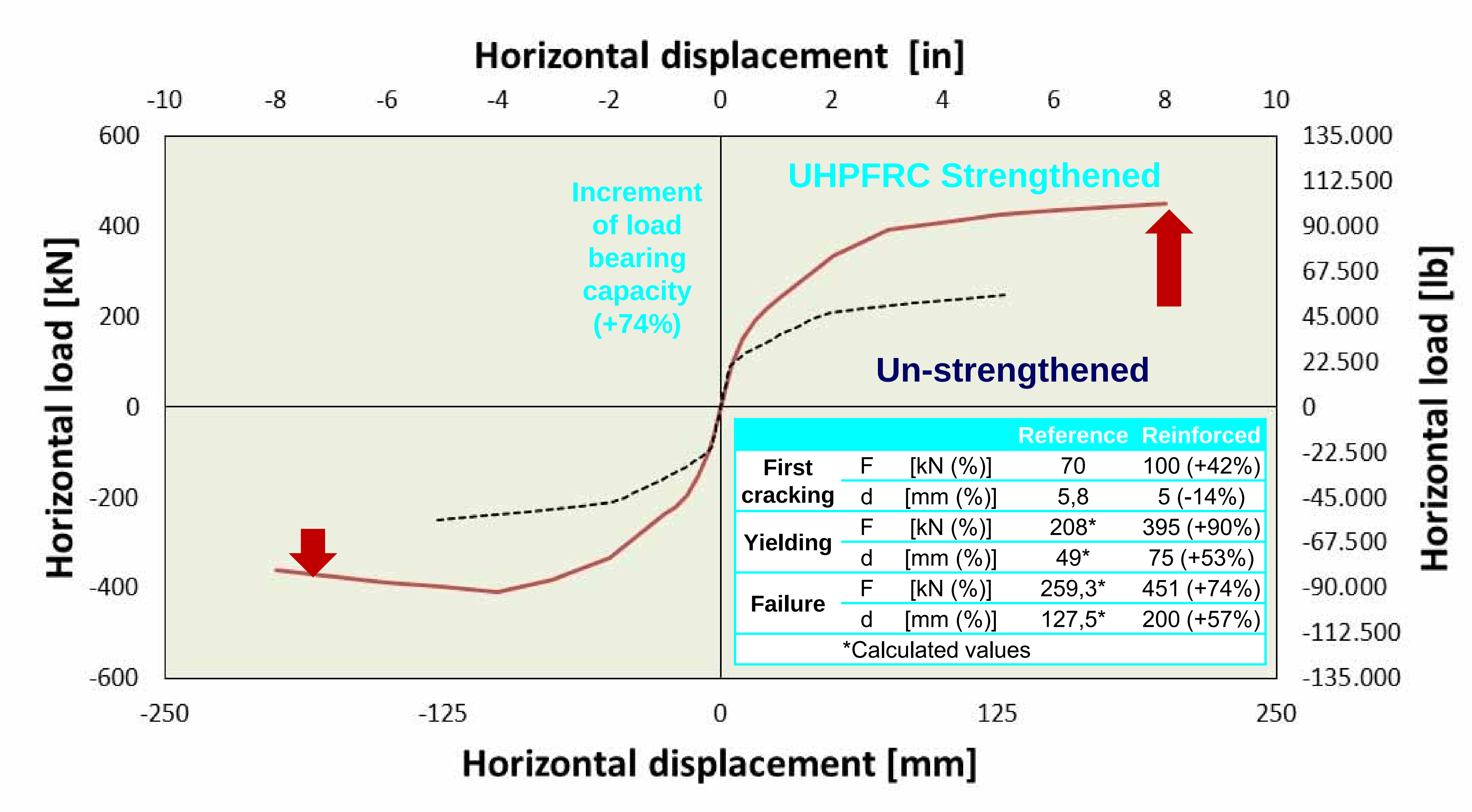
Pier deformation

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

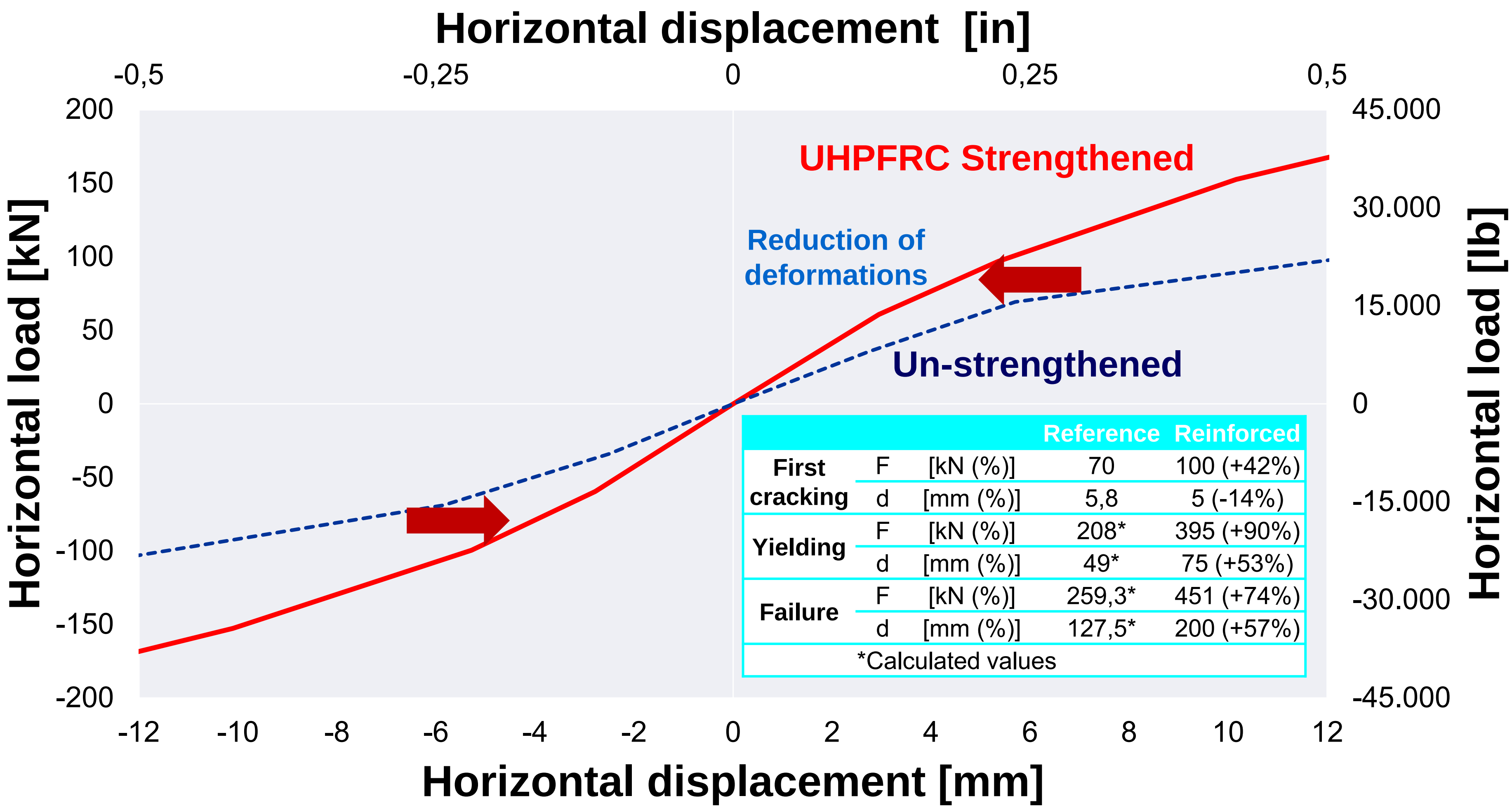


			Reference	Reinforced
First cracking	F	[kN (%)]	70	100 (+42%)
	d	[mm (%)]	5,8	5 (-14%)
Yielding	F	[kN (%)]	208*	395 (+90%)
	d	[mm (%)]	49*	75 (+53%)
Failure	F	[kN (%)]	259,3*	451 (+74%)
	d	[mm (%)]	127,5*	200 (+57%)

*Calculated values

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

Reduction of deformations



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	d	[mm (%)]	49*	75 (+53%)
Failure	F	[kN (%)]	259,3*	451 (+74%)
	d	[mm (%)]	127,5*	200 (+57%)

*Calculated values

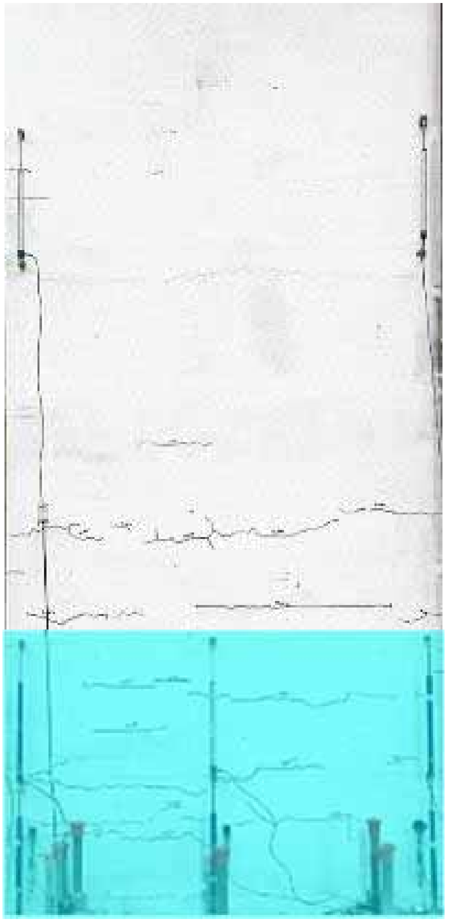
Main experimental results

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.

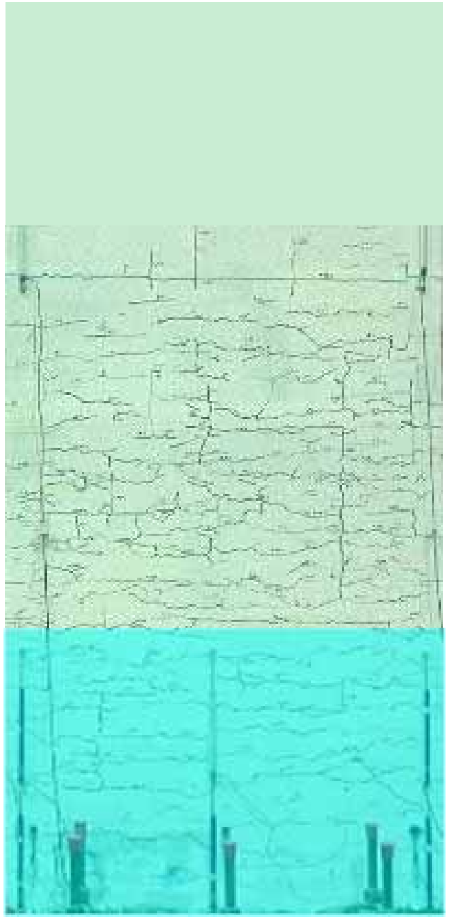
Cracking development.

H = 153 kN
d = 10 mm
D = 0,17%

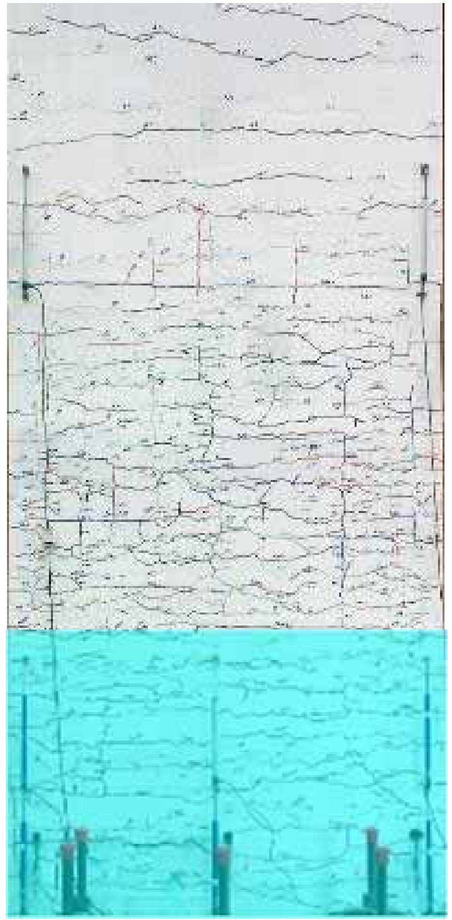


H = 217 kN
d = 20 mm
D = 0,34%

H = 395 kN
d = 75 mm
D =1,29%

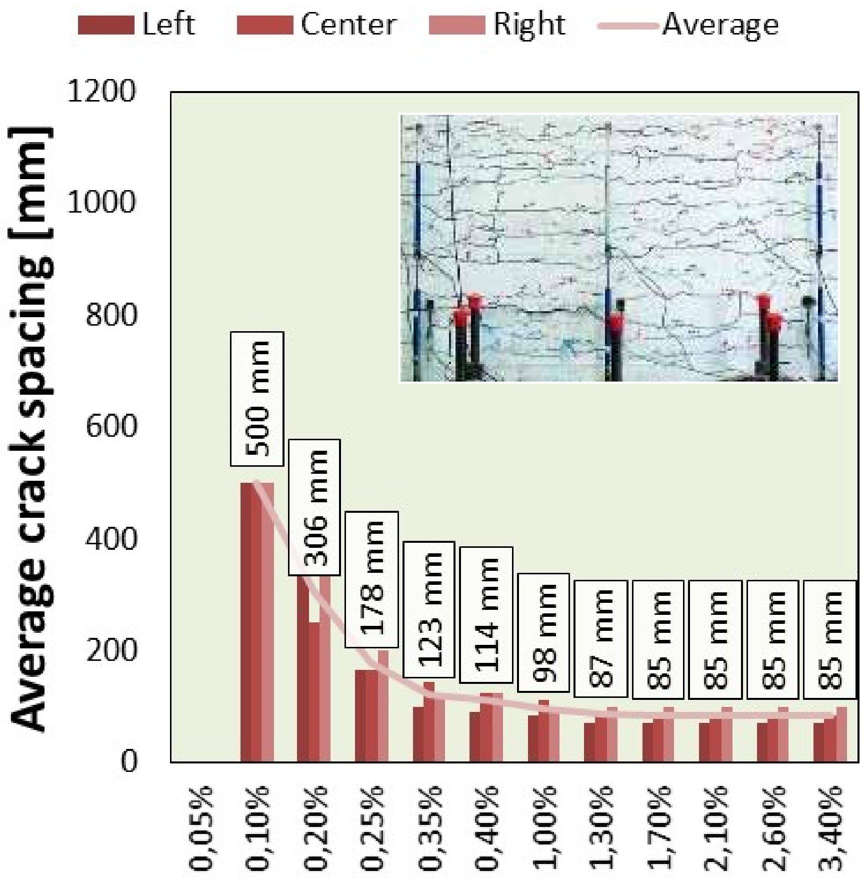


H = 412 kN
d = 100 mm
D = 1,72%

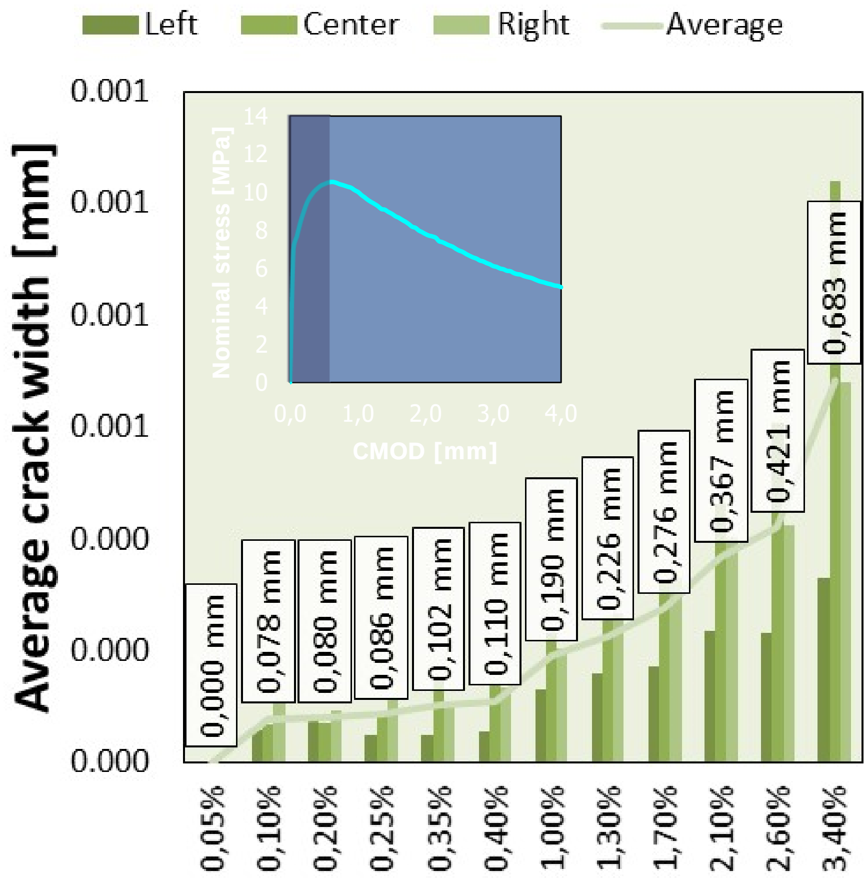


Average crack spacing and width.

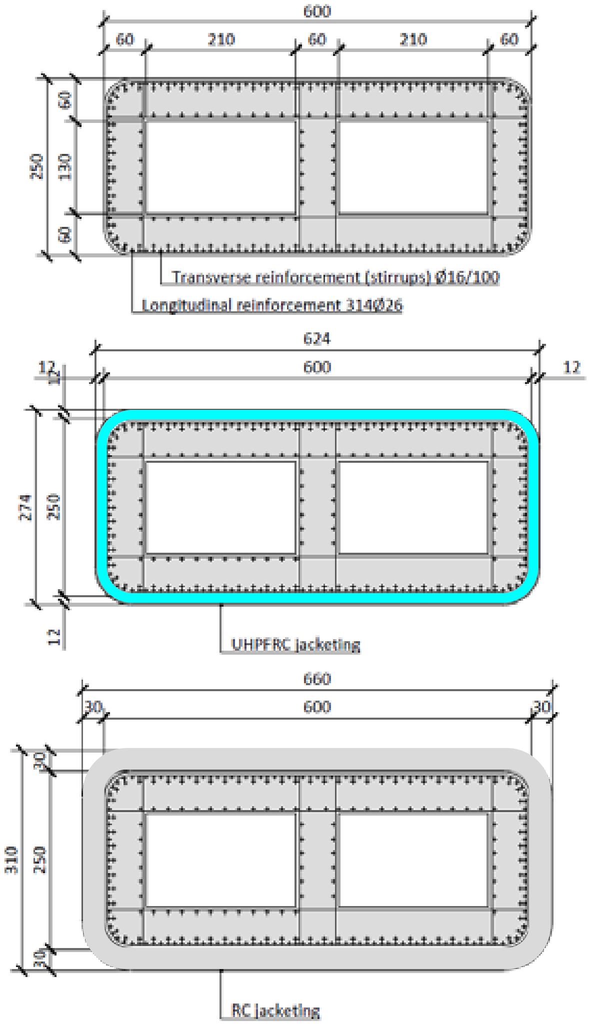
Crack spacing

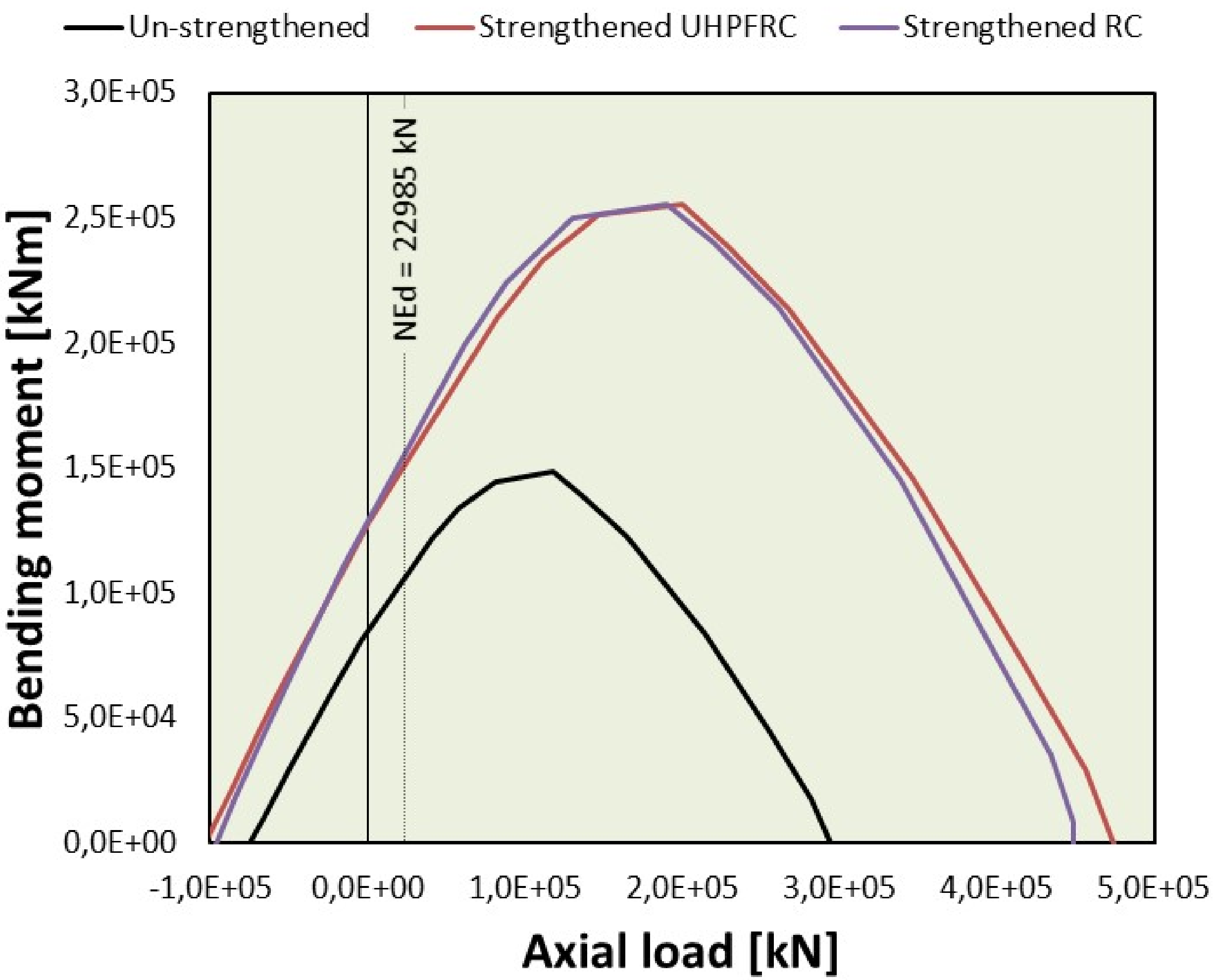


Crack width

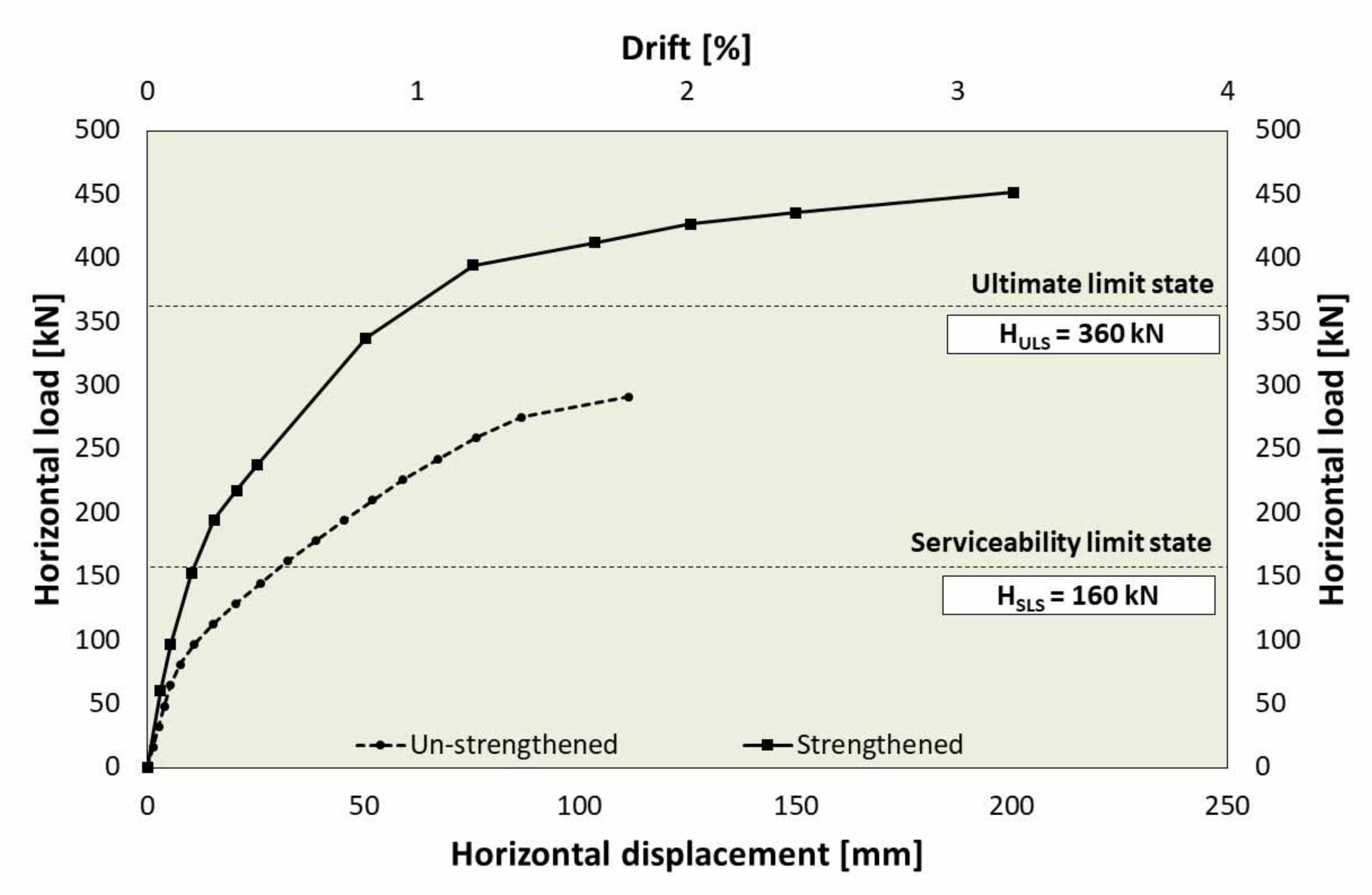


Extension of working life is possible?





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 thanks to controlled cracking process and intrinsic material's properties.

Findings of the analytical study

- The seismic performance of 120 mm of UHPFRC (C130) can be reached with 300 mm of traditional RC (C28/35).

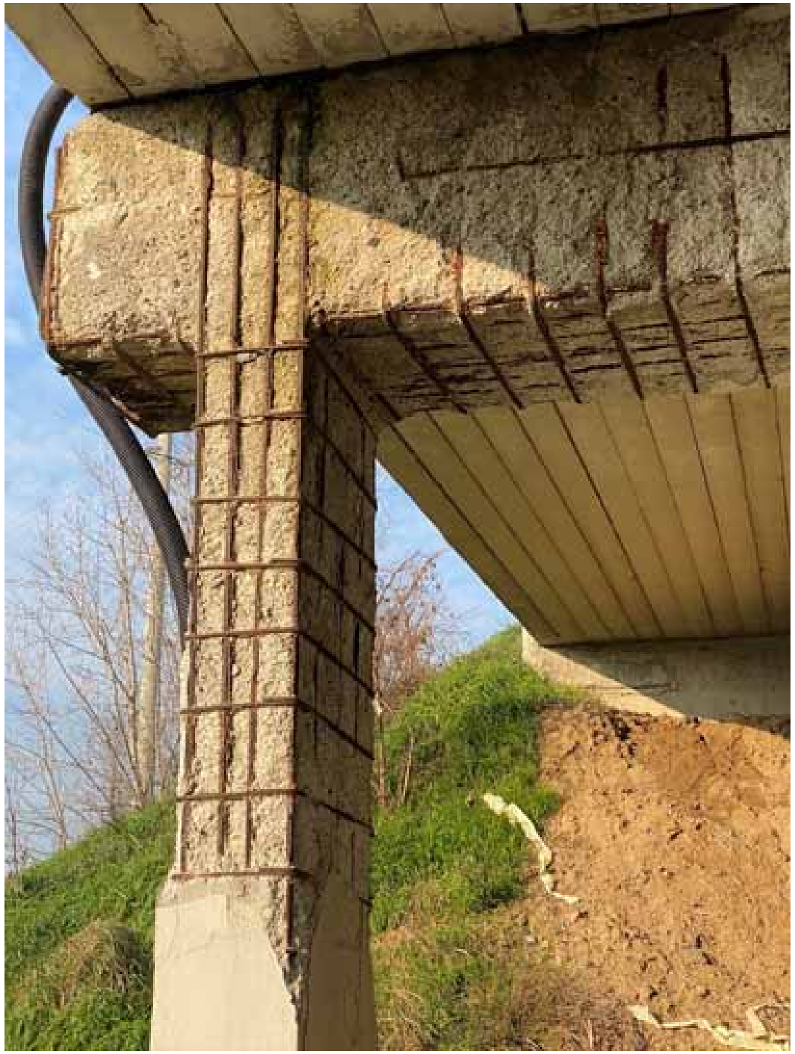
- Working life can be extended from 67 years to 107 years using UHPFRC and to 81 years using traditional RC.

- The probability of cracking can be strongly reduced with UHPFRC in respect to traditional RC.

EU funded project: MoSoRe@UniBS

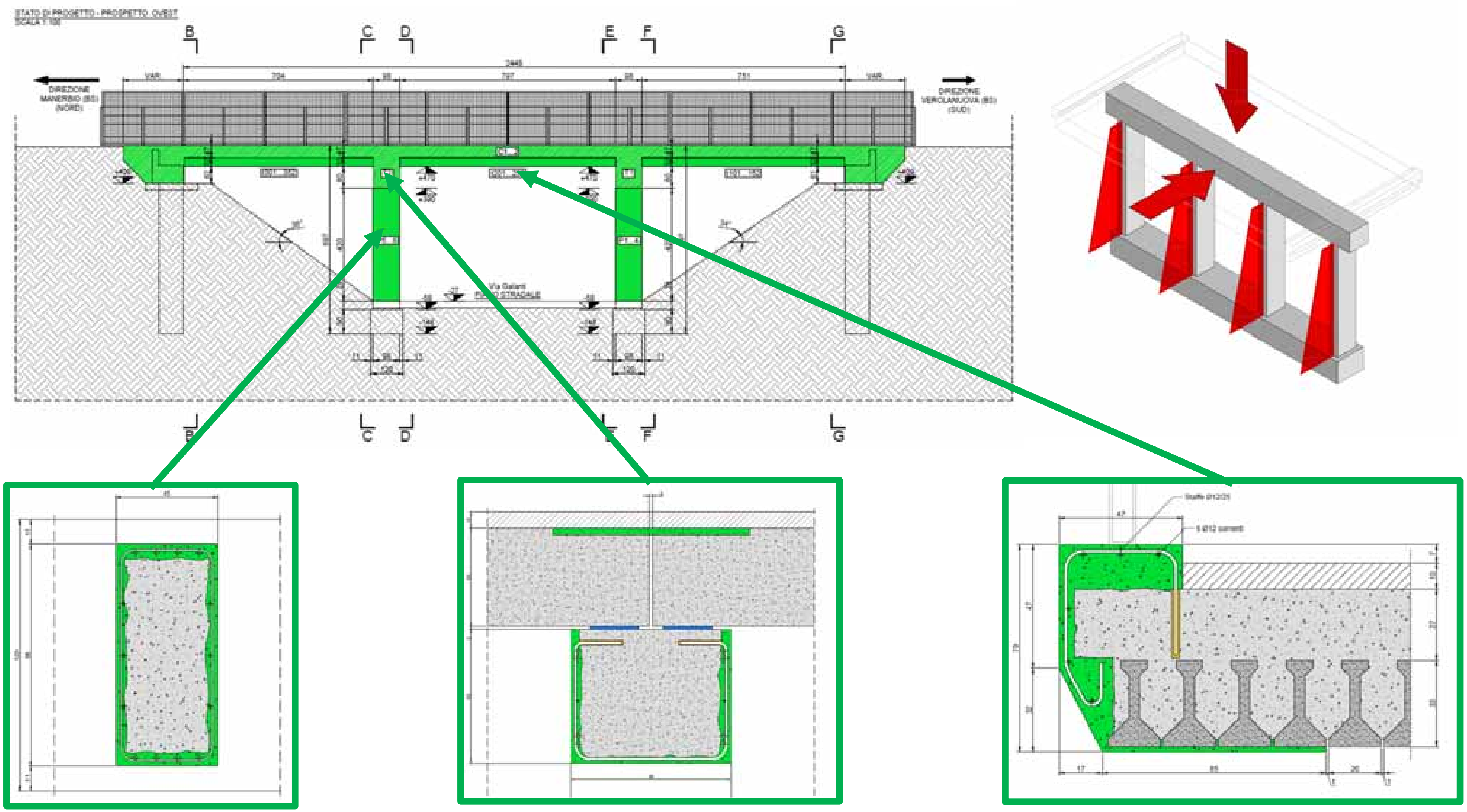
MoSoRe@UNIBS

SMALL ROAD BRIDGE SOUTH BRESCIA (IT)



SEVERE REINFORCEMENT CORROSION

EU funded project: MoSoRe@UniBS

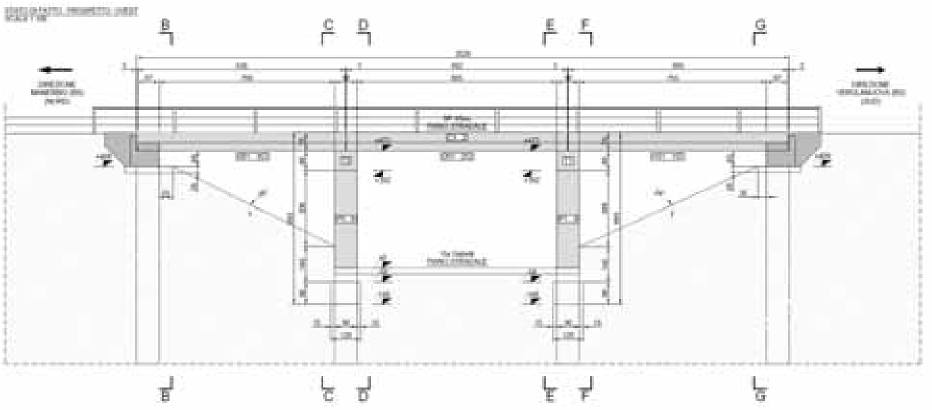


COLUMN

CAP BEAM

KERB

Case study: two bridges on the SP45bis «Gardesana occidentale»



Degradation of the sub-structures

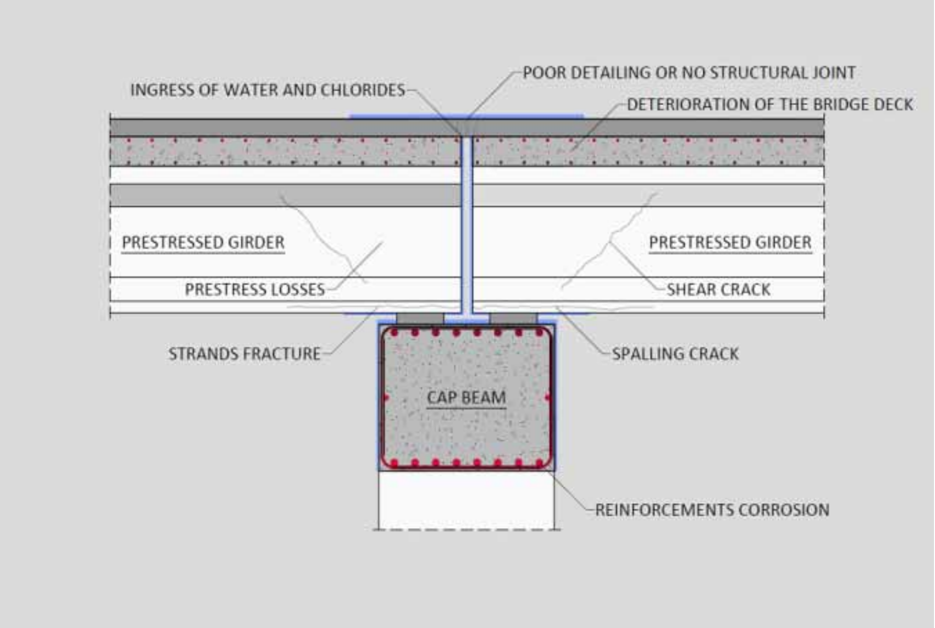
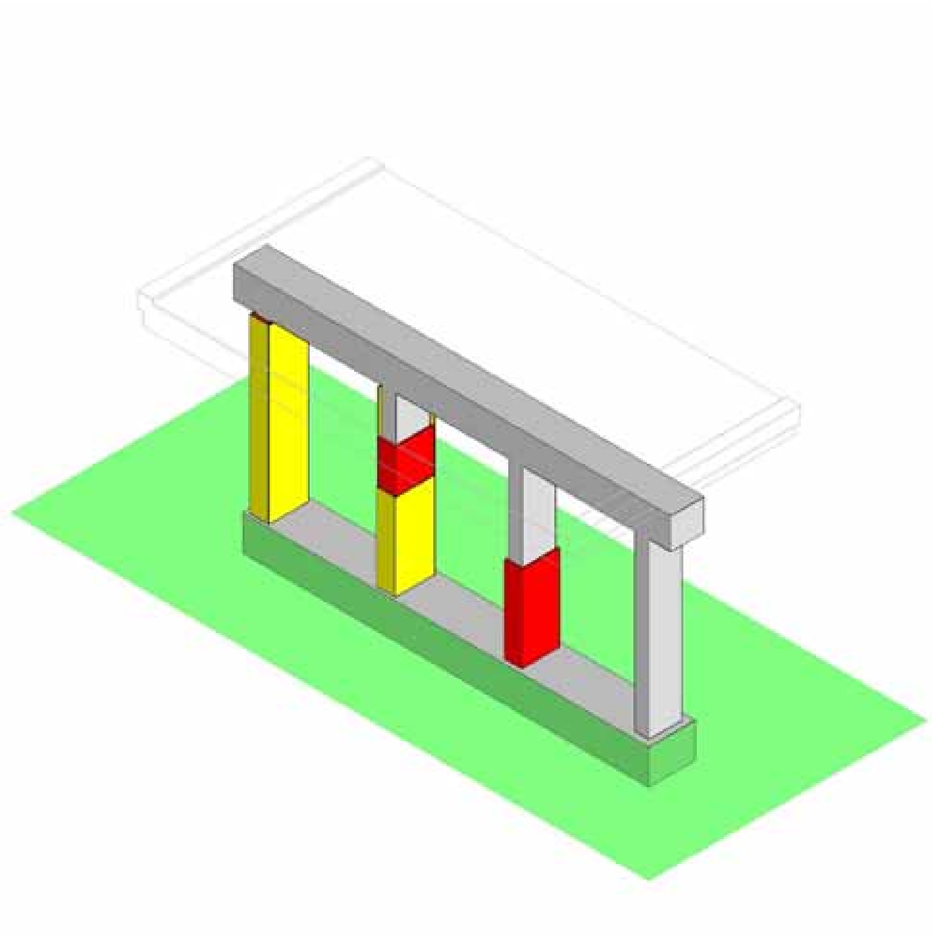
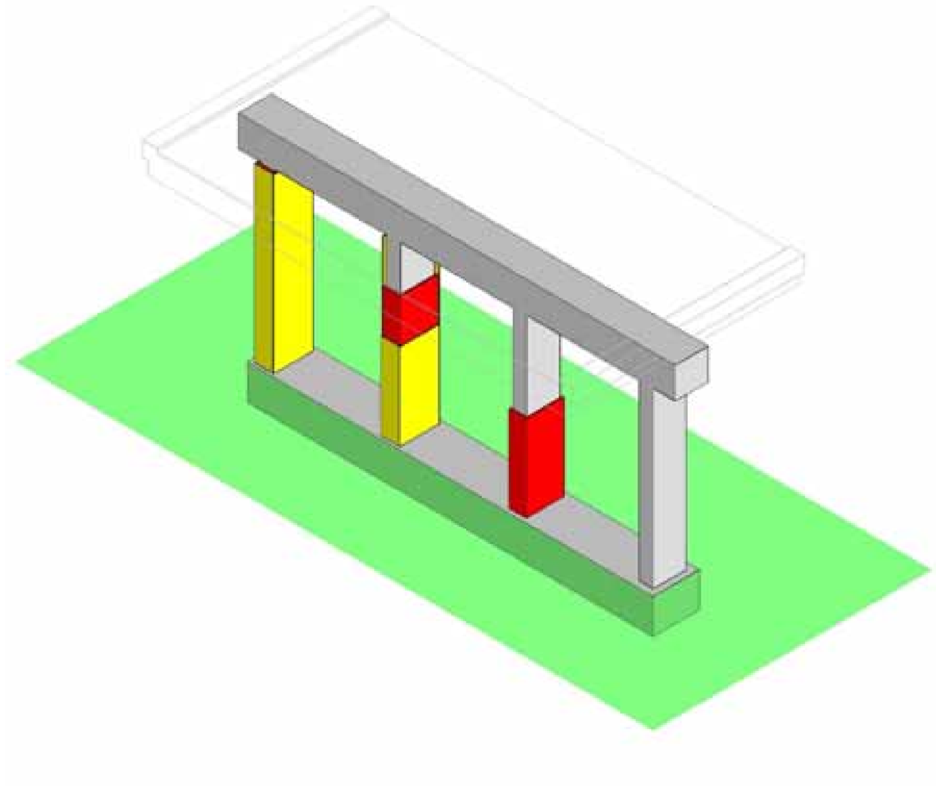


Figure 3: Cap beam and prestressed girders experiencing significant corrosion level.

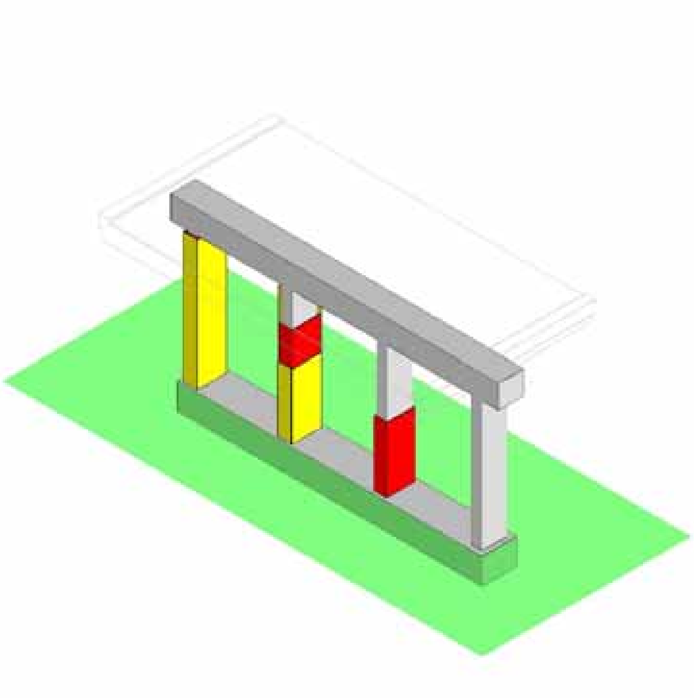
Jacketing with UHPFRC



Jacketing with UHPFRC

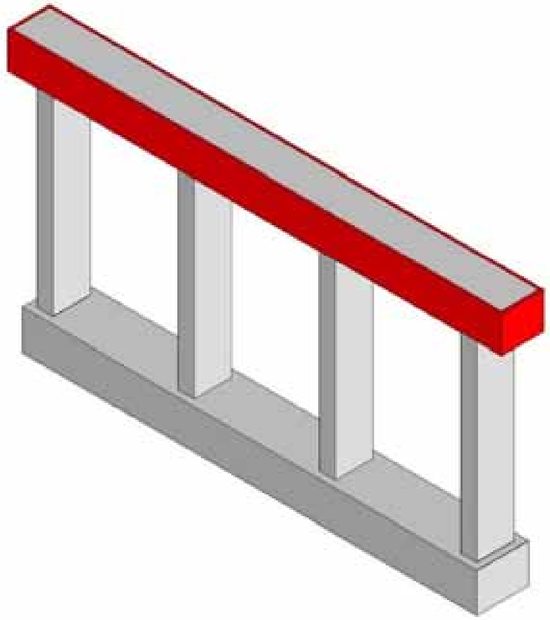


Jacketing with UHPFRC

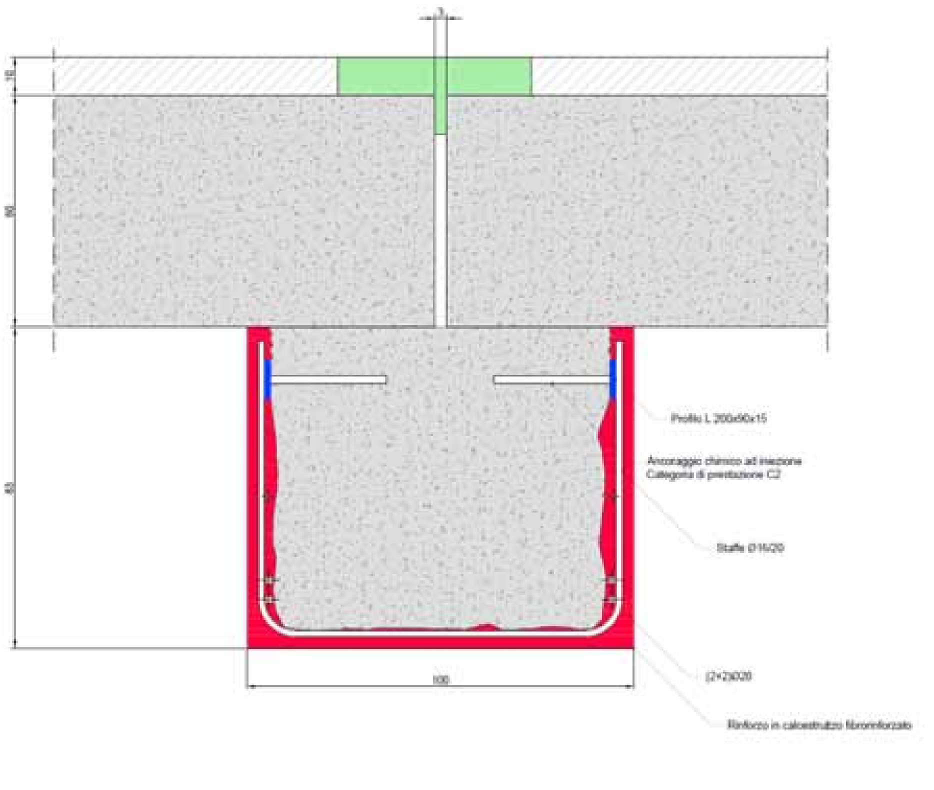


Jacketing with UHPFRC

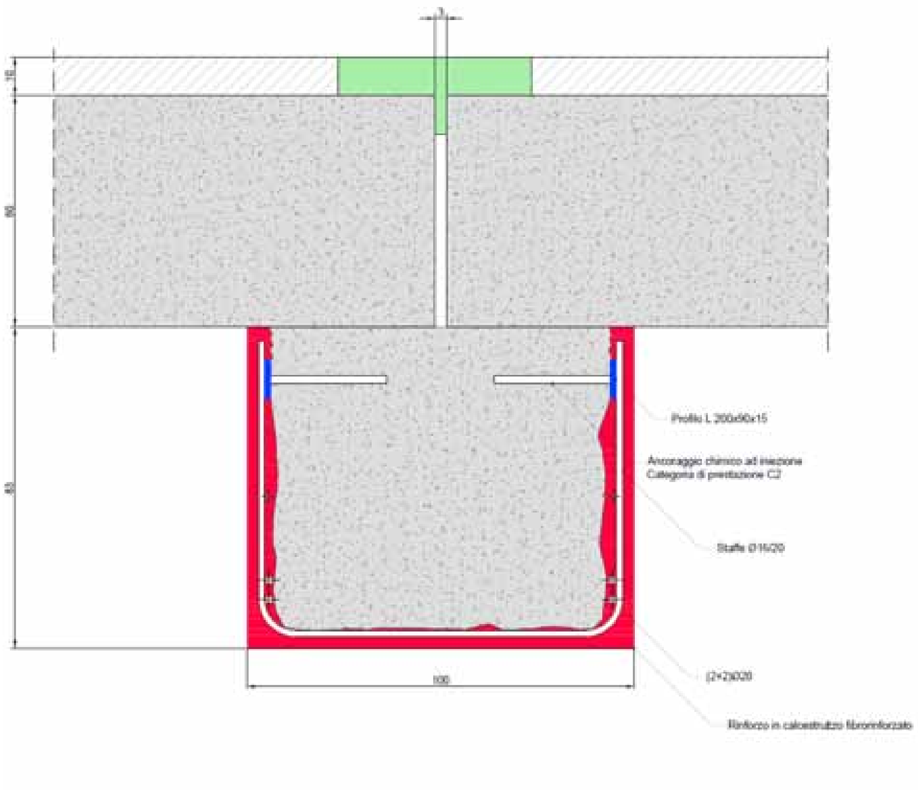
Jacketing with UHPFRC

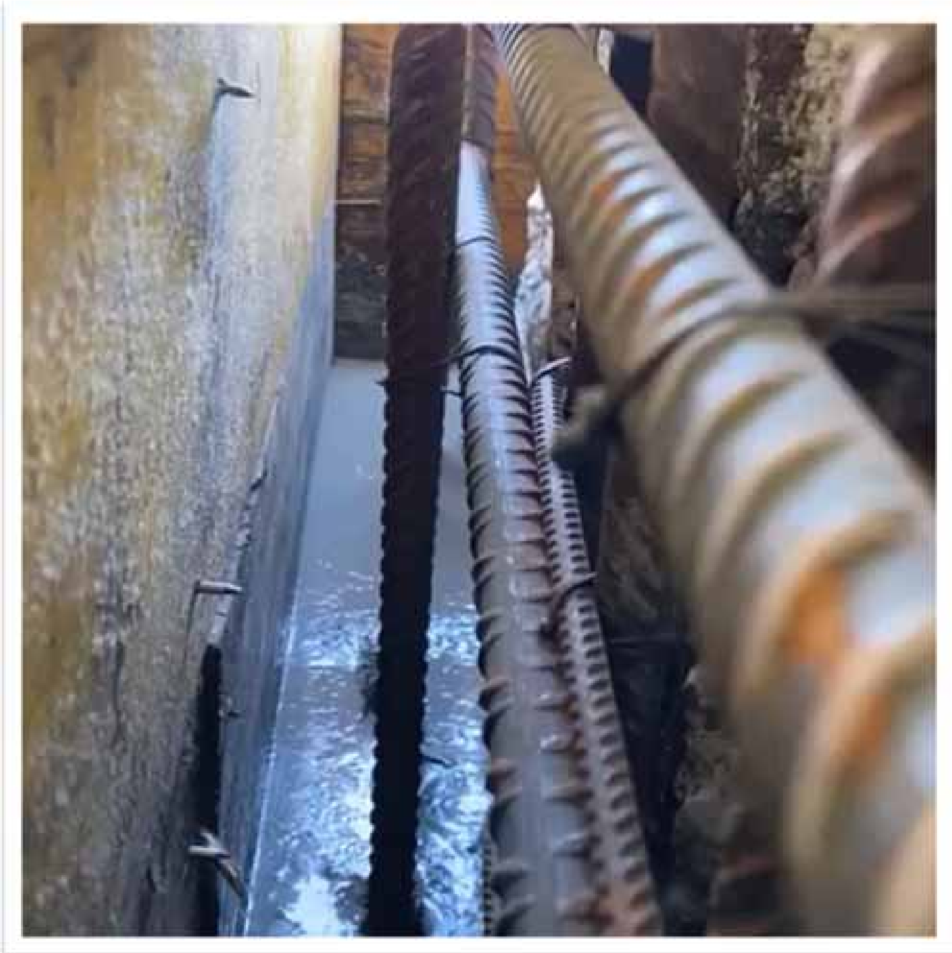


Jacketing with UHPFRC

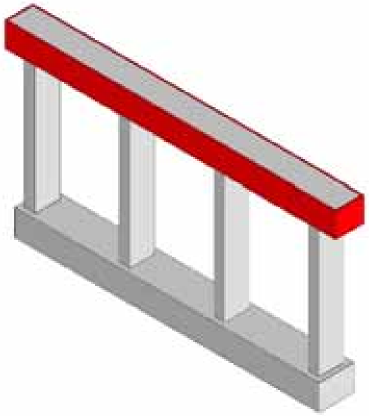


Self-consolidating UHPFRC



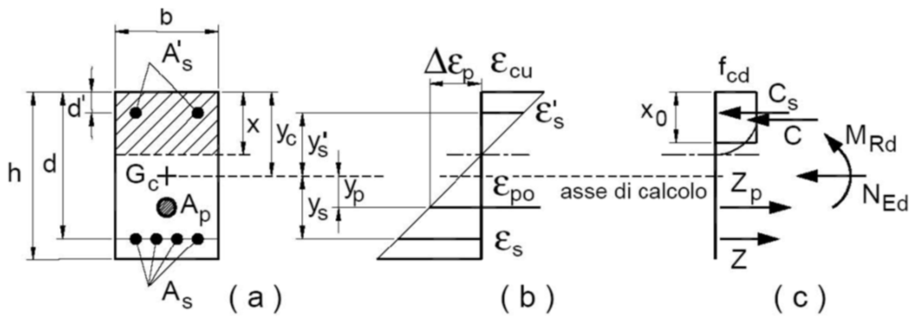


Jacketing with UHPFRC

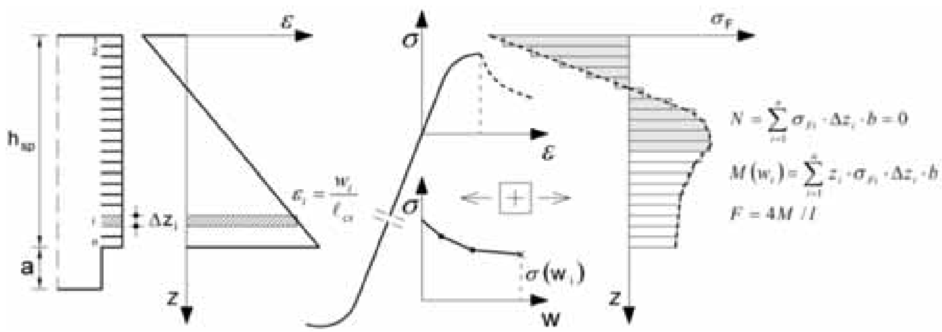


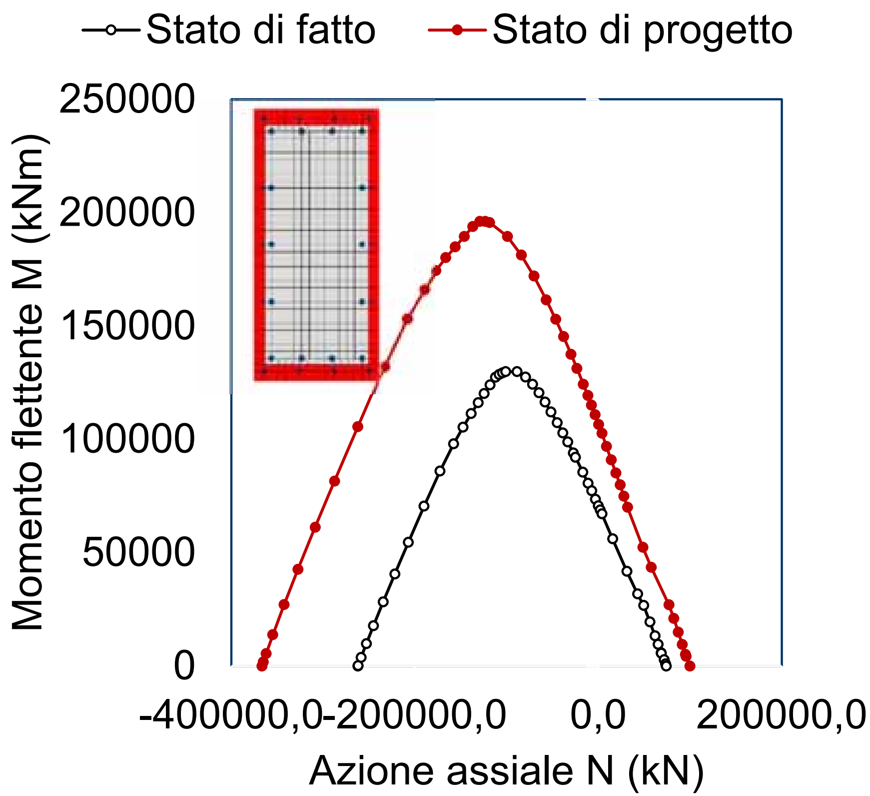
UHPFRC strengthening

Verifiche di resistenza e duttilità

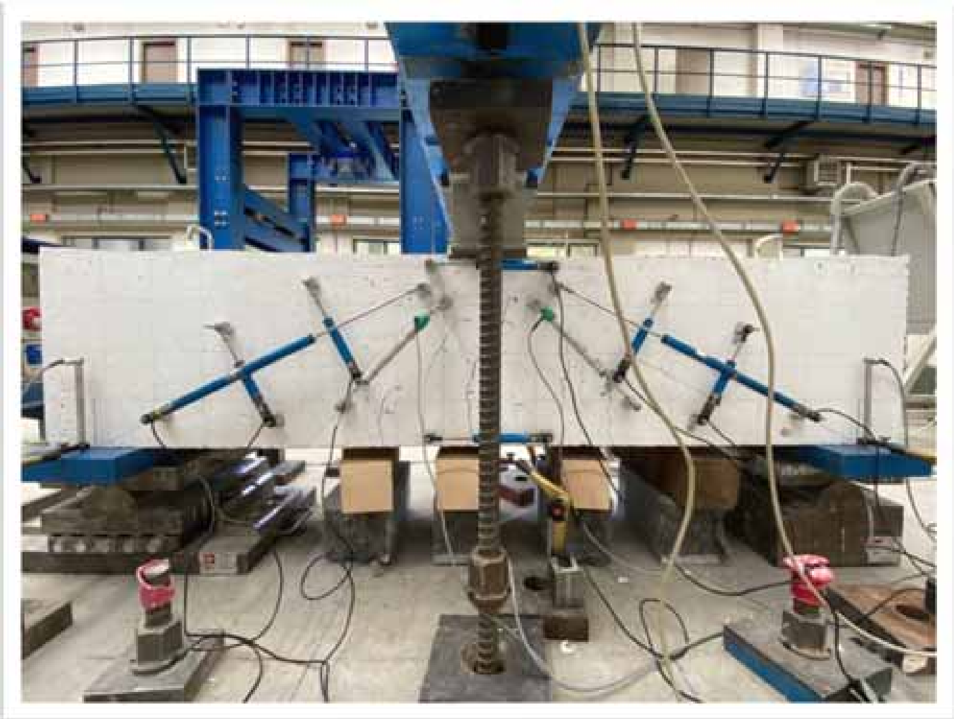


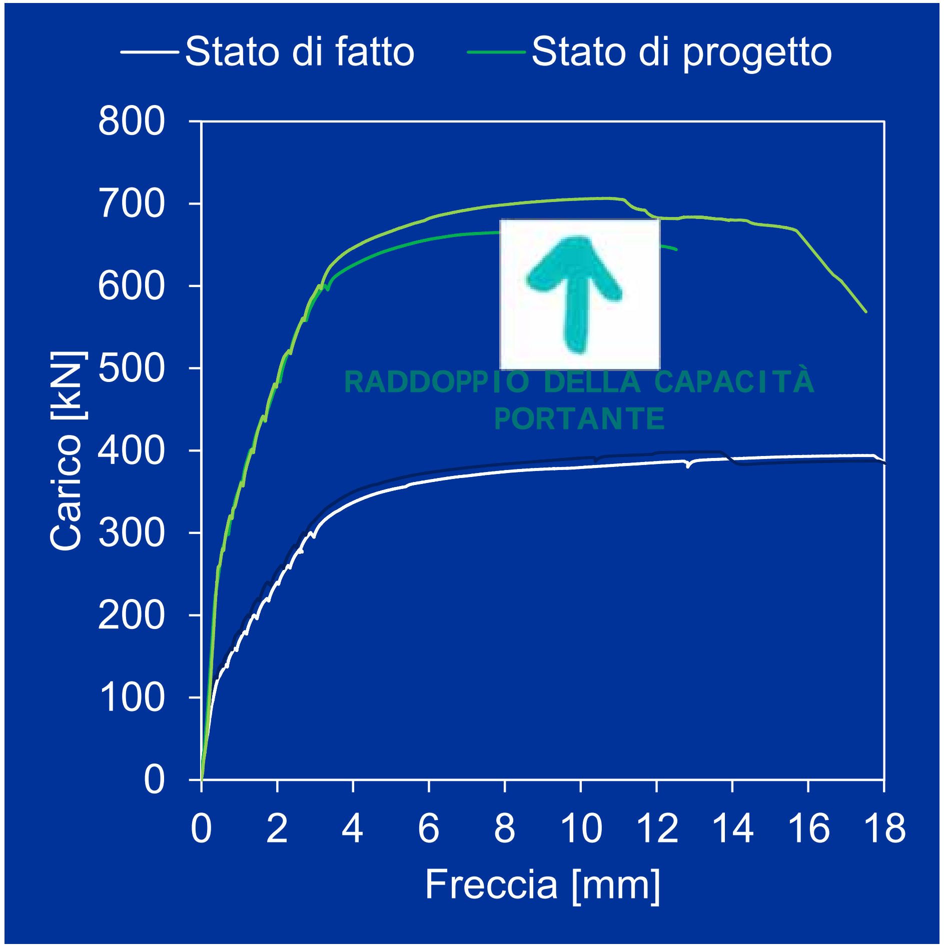
Contributo delle fibre





Experimental activities



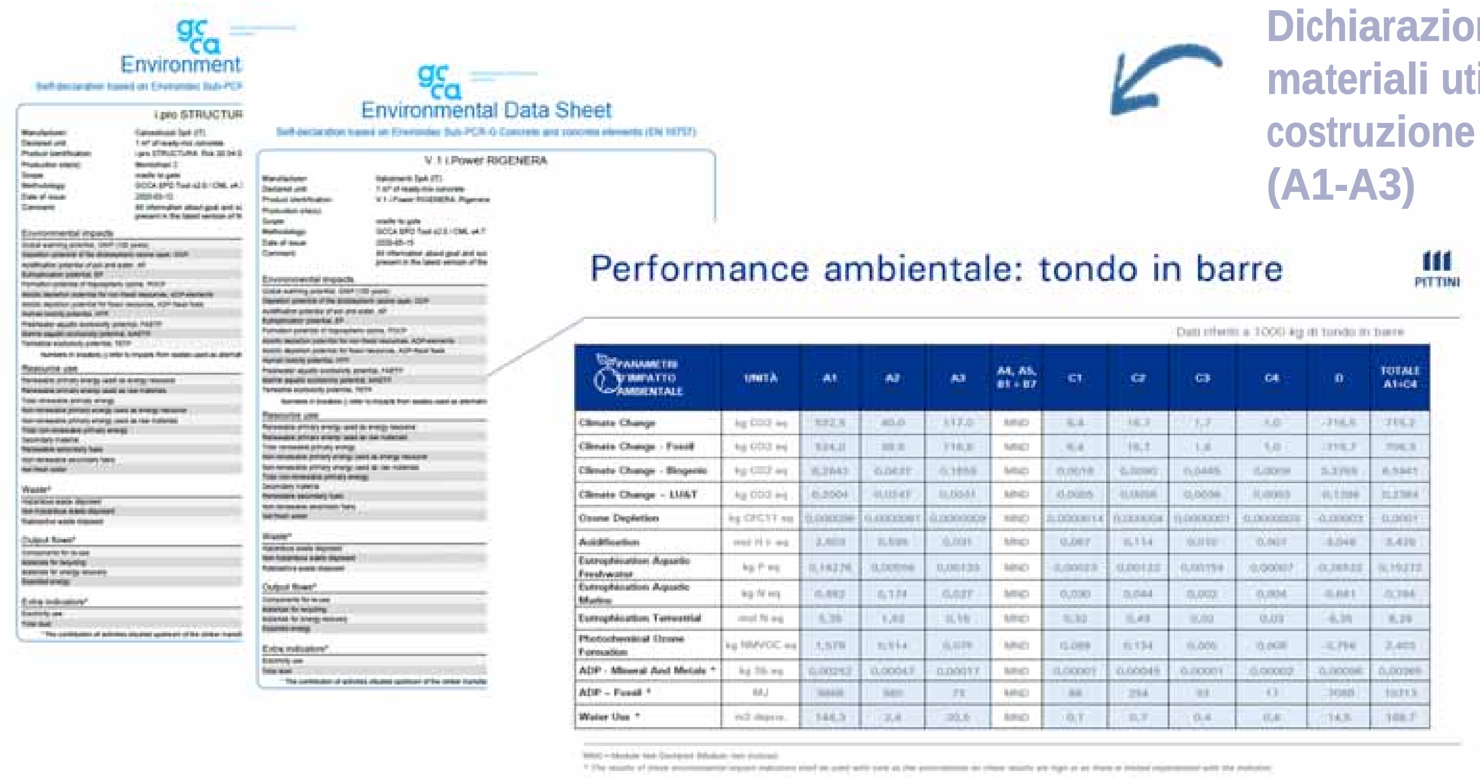


Sustainability issues

Demolizione e ricostruzione

Riparazione con HPFRC

GWP comparison based on EPDs



Prodotto Ambientale Dichiarazioni (EPD) dei materiali utilizzati per la costruzione o la riparazione (A1-A3)

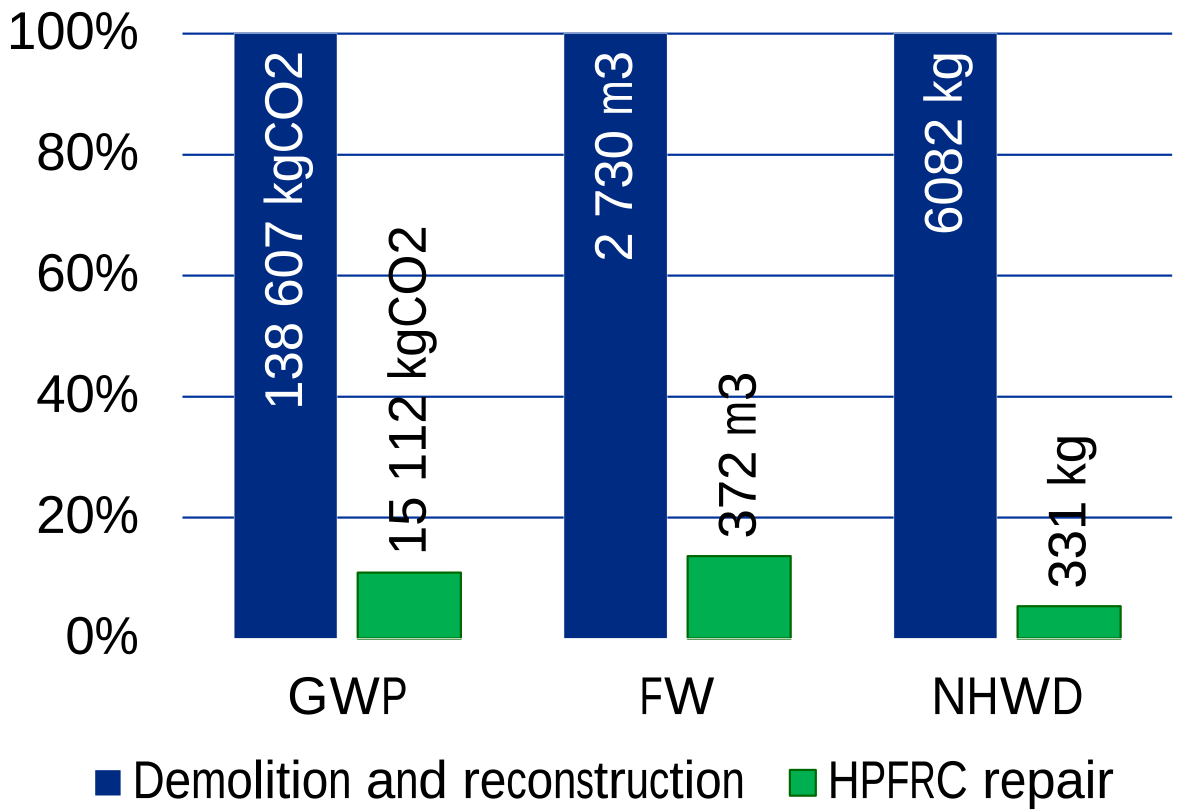
GWP comparison based on EPDs

Fasi:

- A1-A3 (Dalla culla al cancello)

Categorie di impatto LCA:

- GWP – Global Warming Potential
- FW – Fresh Water
- NHWD – Non-Hazardous Waste Disposal



reluis

Rete dei Laboratori Universitari di Ingegneria Sismica e Strutturale

SETTIMANA NAZIONALE DELLA PROTEZIONE CIVILE

PROTEZIONE CIVILE

6 / 13 OTTOBRE 2024

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SAIE

Bologna, 9/12 ottobre 2024

SCUOLA DI INGEGNERIA STRUTTURALE – RELUIS

Bologna, 9-11 ottobre 2024

I calcestruzzi fibrorinforzati (FRC) per il miglioramento sismico delle strutture esistenti

Giovanni Plizzari e Luca Facconi

Università di Brescia