

Introduzione al FRC e principali aspetti normativi



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**UTILIZZO DEL CALCESTRUZZO FIBRORINFORZATO NELLE CABINE DI
TRASFORMAZIONE MT/BT IN C.A.V.**

Milano – 1 Giugno 2018

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 il calcestruzzo

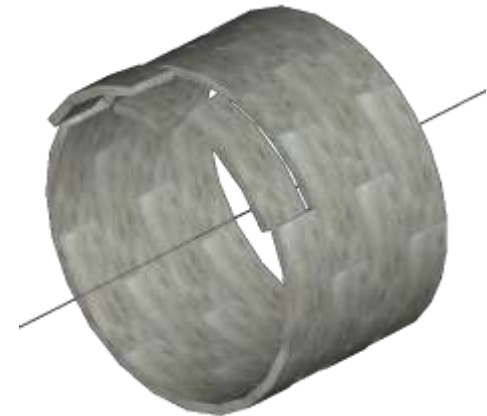


Elemento di rinforzo caratterizzato geometricamente da una dimensione prevalente rispetto alle altre, avente superficie liscia o ruvida, di forma rettilinea o sagomata, in grado di essere disperso omogeneamente nell'impasto.

Main FRC uses

Many structural and non structural elements are designed and reinforced with FRC, as **PARTIAL** or **TOTAL** substitution of conventional reinforcement:

- Factory pavements, highways, parking areas
- Heavy prefabrication structural elements
- Light prefabrication elements
- Tunnel linings



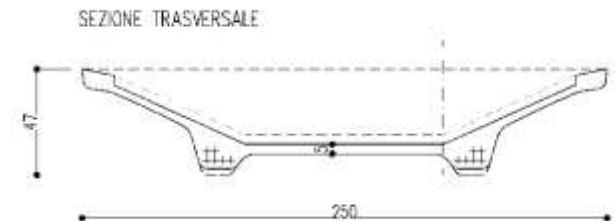
Principali vantaggi del FRC

CONSTRUCTIVES:

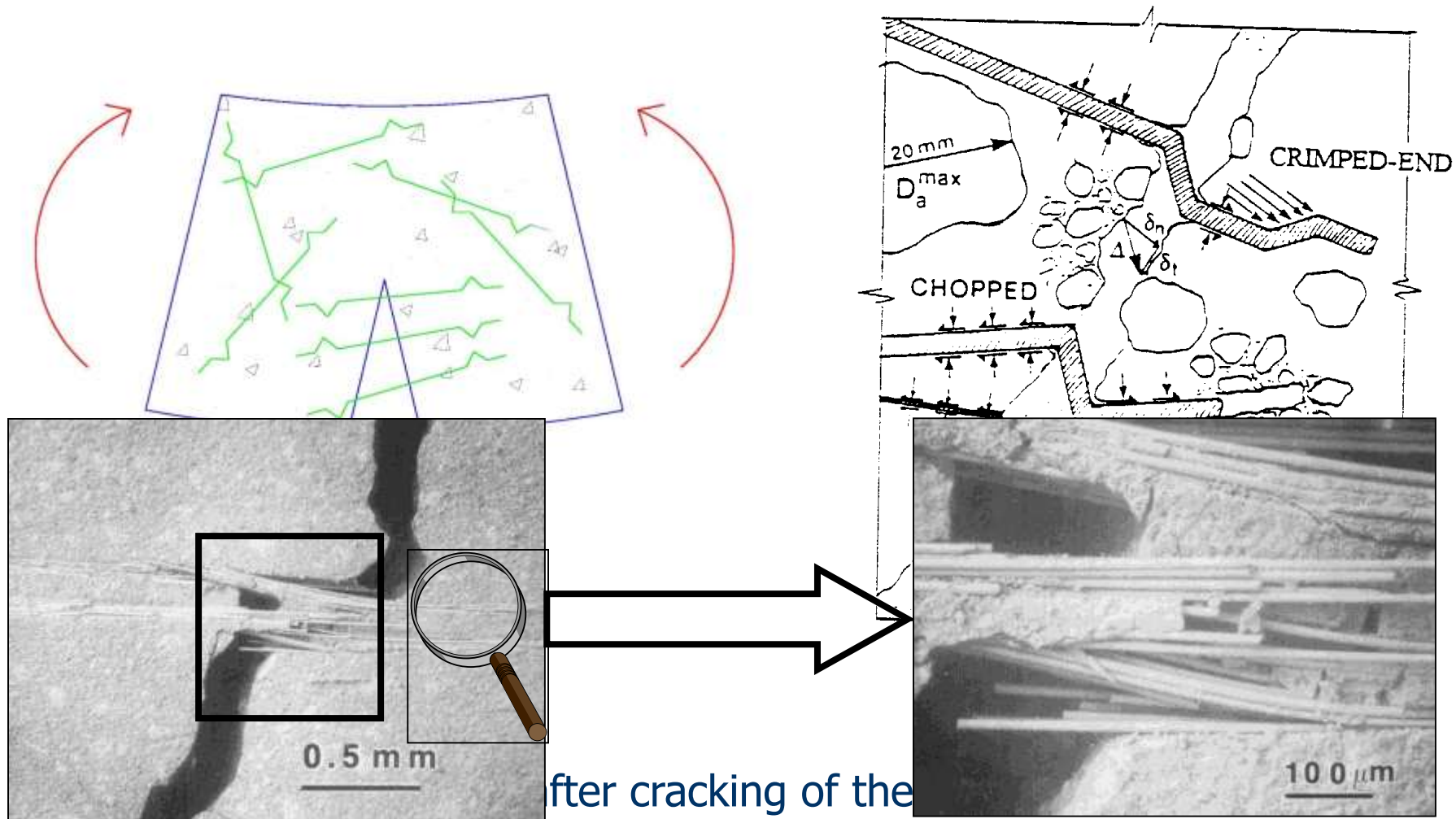
- AVOID CONVENTIONAL REINFORCEMENT (WELDED MESH)
- LABOR REDUCTION
- REDUCTION OF CHECKING TIME
- REINFORCEMENT CORRECTLY PLACED

STRUCTURALS:

- SMALLER CRACK WIDTH OPENINGS
- LONGER DURABILITY
- BETTER IMPACT AND ABRASION STRENGTH
- BETTER FATIGUE STRENGTH

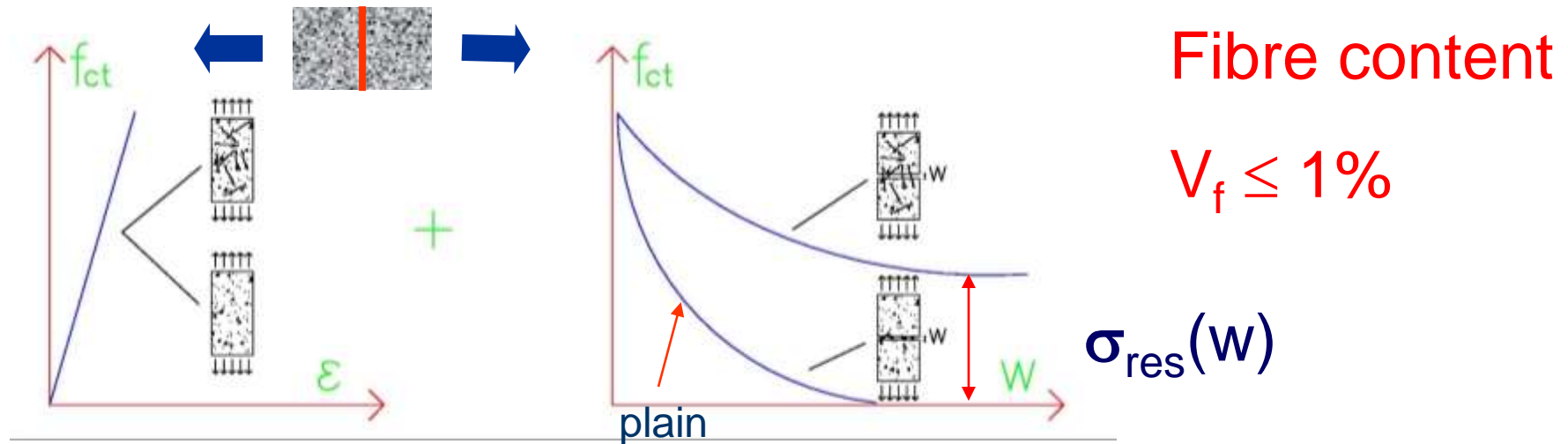


Effetti delle fibre nel calcestruzzo



after cracking of the

Effetti delle fibre nel calcestruzzo



Fibre effects

- durability (cracking control)
- anchorage lengths
- deformability (tension stiffening)
- stress limits in P/C elements
- minimum reinforcements (N, M, V)
- fatigue
- shrinkage
- D regions (spalling, bursting, splitting)

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



Normative per la progettazione

Normativa per la progettazione

UNI 11188, 2006: Progettazione, esecuzione e controllo degli elementi strutturali in calcestruzzo rinforzato con fibre d'acciaio.

CNR DT 204, Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Strutture di Calcestruzzo Fibrorinforzato

M LL. PP. Normativa tecnica per le costruzioni

CNR – DT 204

CONSIGLIO NAZIONALE DELLE RICERCHE

COMMISSIONE INCARICATA DI FORMULARE PARERI IN MATERIA
DI NORMATIVA TECNICA RELATIVA ALLE COSTRUZIONI

**Istruzioni
per la Progettazione, l'Esecuzione ed il Controllo
di Strutture
di Calcestruzzo Fibrorinforzato**



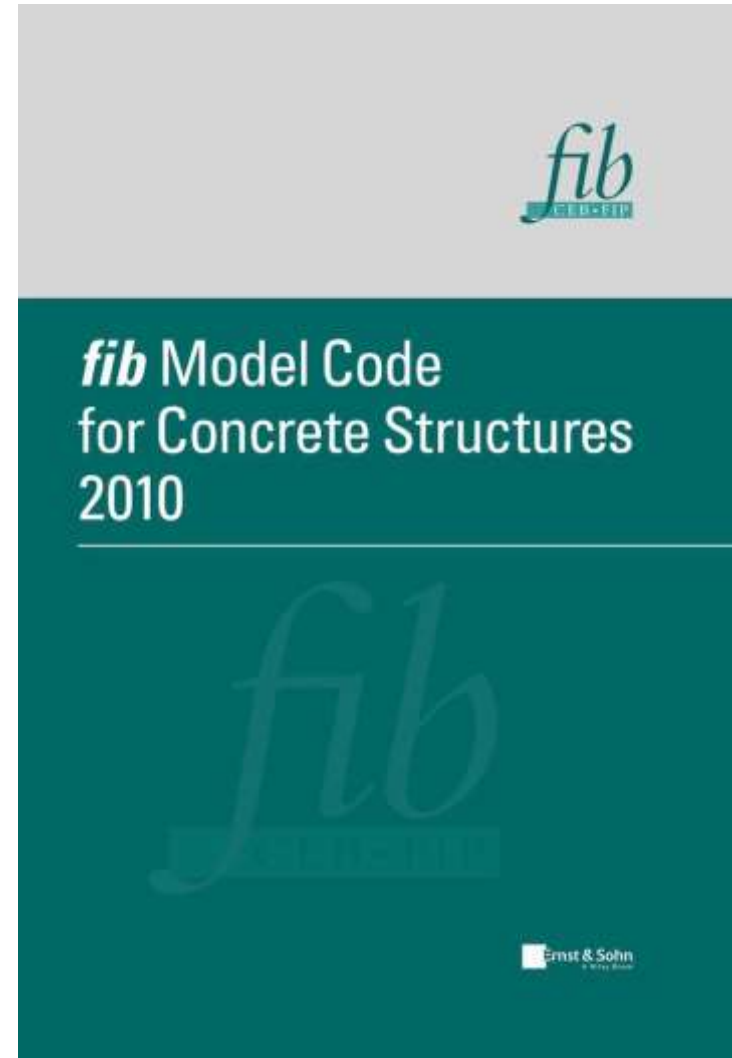
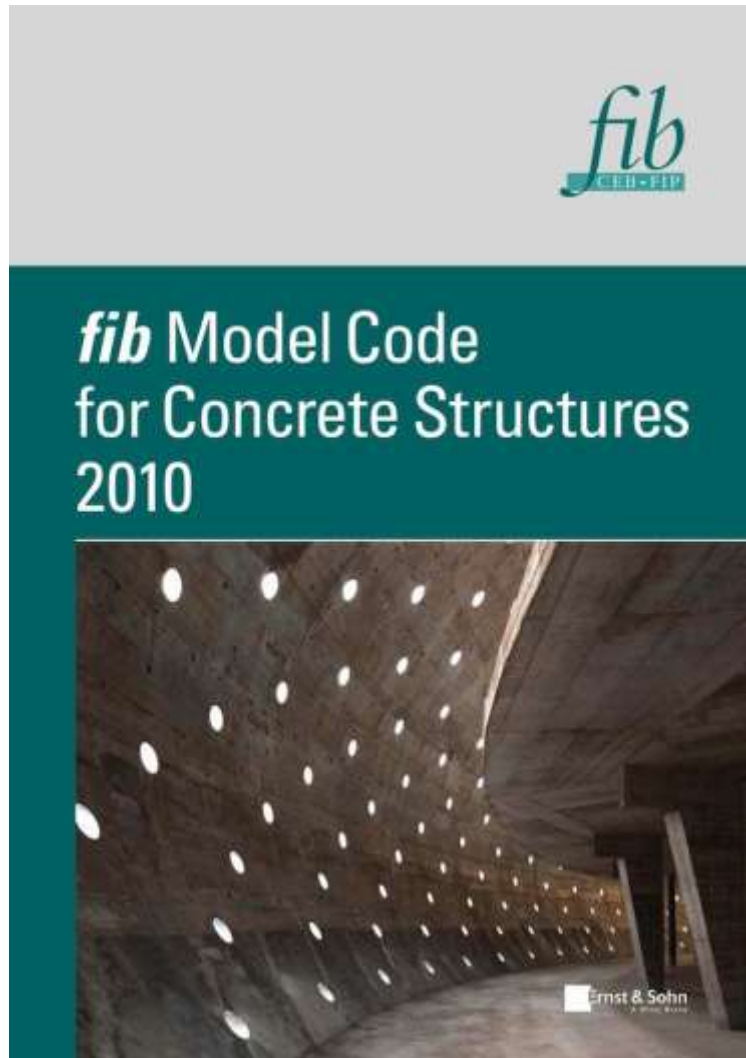
Istruzioni CNR

Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Strutture in Calcestruzzo Fibrorinforzato

INDICE

- 1 PREMESSA
- 2 MATERIALI
- 3 CONCETTI BASILARI
- 4 VERIFICA DI RESISTENZA ALLO SLU
- 5 STATO LIMITE DI ESERCIZIO
- 6 DURABILITA'
- 7 RESISTENZA AL FUOCO
- 8 MONITORAGGIO E CONTROLLO DI PRODUZIONE

fib Model Code 2010


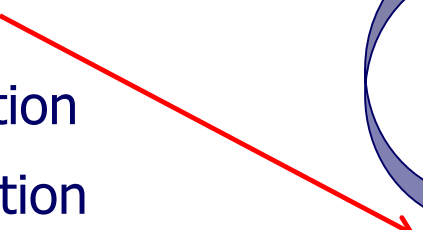


fib Model Code: new contents

- New types of concrete (FRC)
- New types of reinforcement (fibres)
- New design criteria
- Design for service life
- Upgrading of structures
- Defined performance design
- Quality of execution



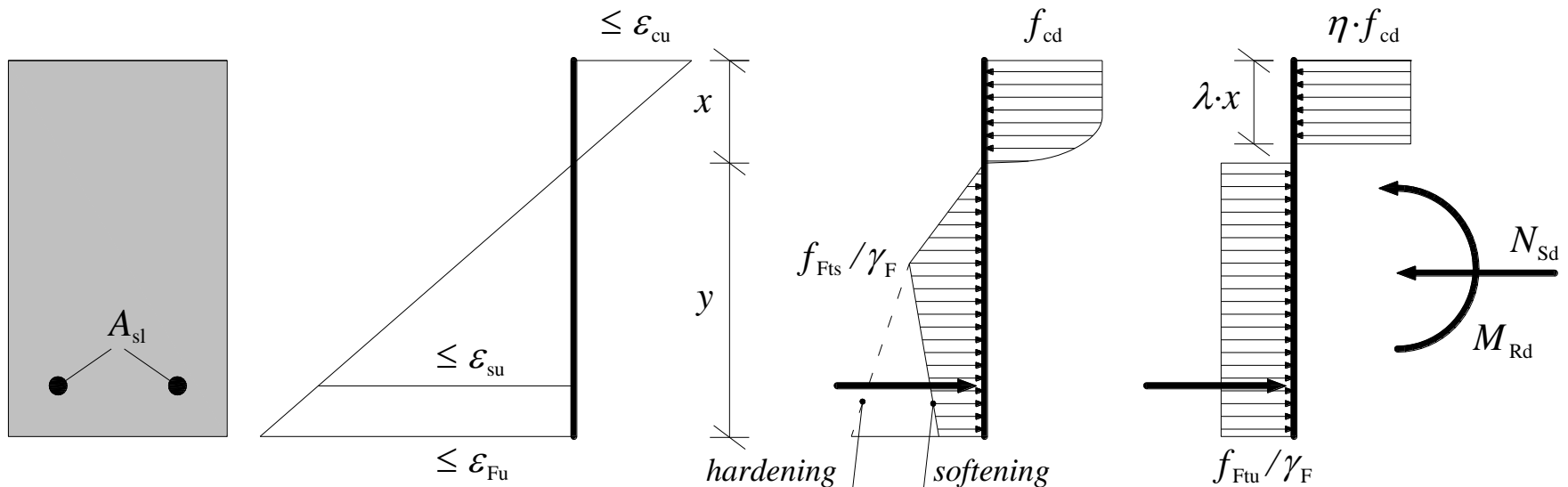
fib Model Code 2010: Index

1. Scope
 2. Terminology
 3. Basic Principles
 4. Design Principles
 5. **Materials** 
 6. Interface characteristics
 7. **Design** 
 8. Construction
 9. Conservation
 10. Dismantlement
- 5.1. Concrete
 - 5.2. Reinforcing steel
 - 5.3. Prestressing steel
 - 5.4. Prestressing systems
 - 5.5. Non-metallic reinforcement
 - 5.6. **Fibres / fibre reinforced concrete**
- Joint chapters prepared by *fib* TG 8.3 "Fiber reinforced concrete" and *fib* TG 8.6 "Ultra high performance fiber reinforced concrete"

Ultimate Limit States (ULS) Verification

The bending failure is considered to occur when one of the following conditions arises:

- attainment of the maximum compressive strength, ε_{cu} , in the FRC;
- attainment of the maximum tensile strength ε_{su} , in the steel (if present);
- attainment of the maximum tensile strength, ε_{Fu} , in the FRC.

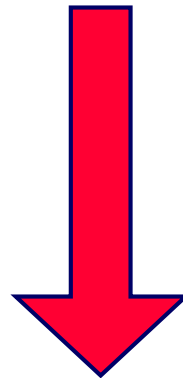


fib Model Code 2020

Special focus on rehabilitation of
existing structures
(work in progress)

Main goal of the fib Model Code

To provide guidance to engineers to properly (and safely) design FRC structural elements both at serviceability and ultimate limit states, based on the state-of-the-art knowledge



CLASSIFICATION

Base requirement for structural design

Engineers can design structures with new materials only if they are performance based!

Structural design of concrete in tension

$$f_{cd} = \frac{f_{ck}}{\text{Safety factor}}$$

Concrete class

C40/50

FRC classification

- A performance approach is chosen: the material has to be tested as composite, because the mechanical response cannot be properly identified by knowing the mix design and the mechanical characteristics of each component

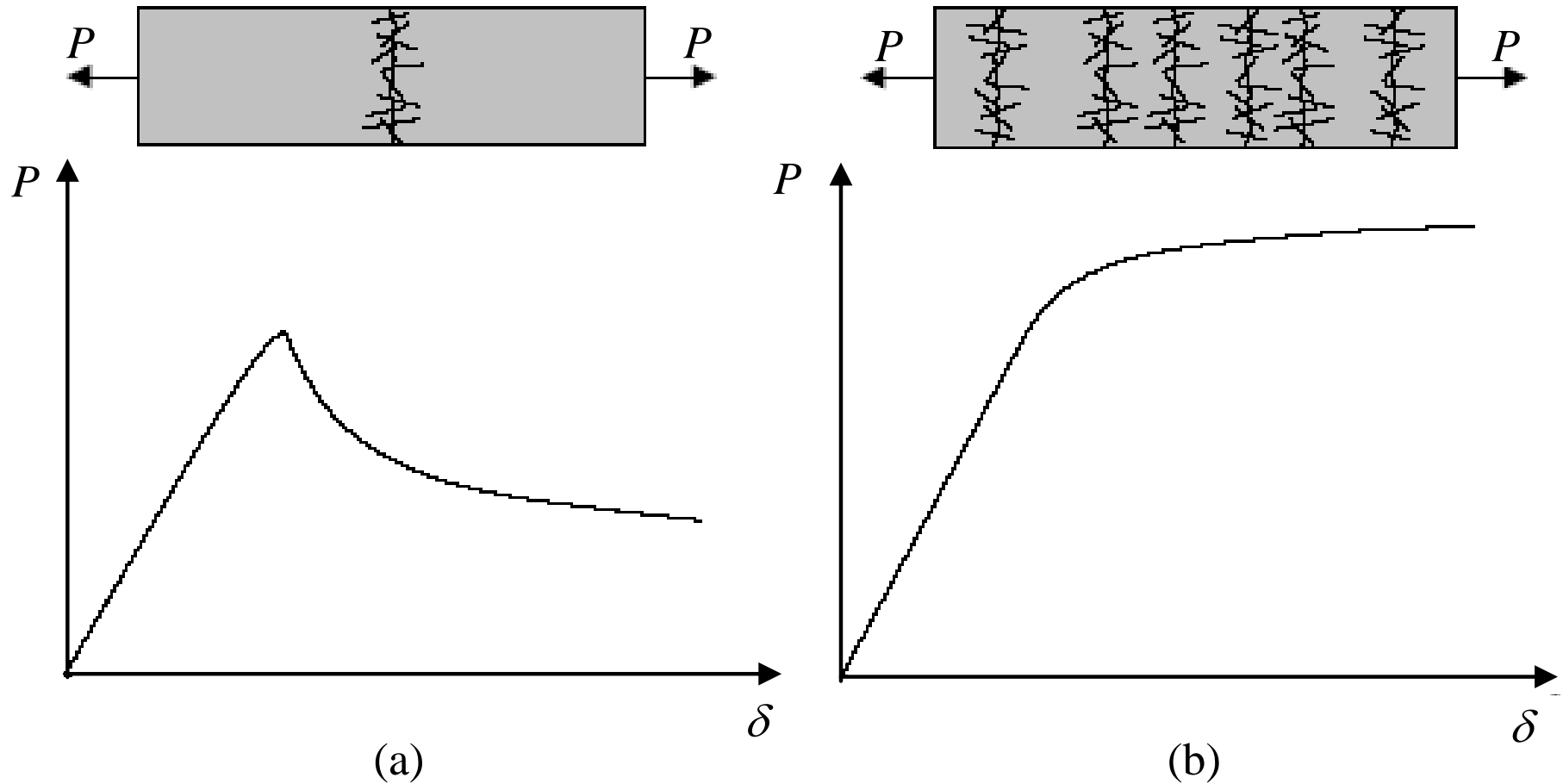
UNIAXIAL TENSION TEST



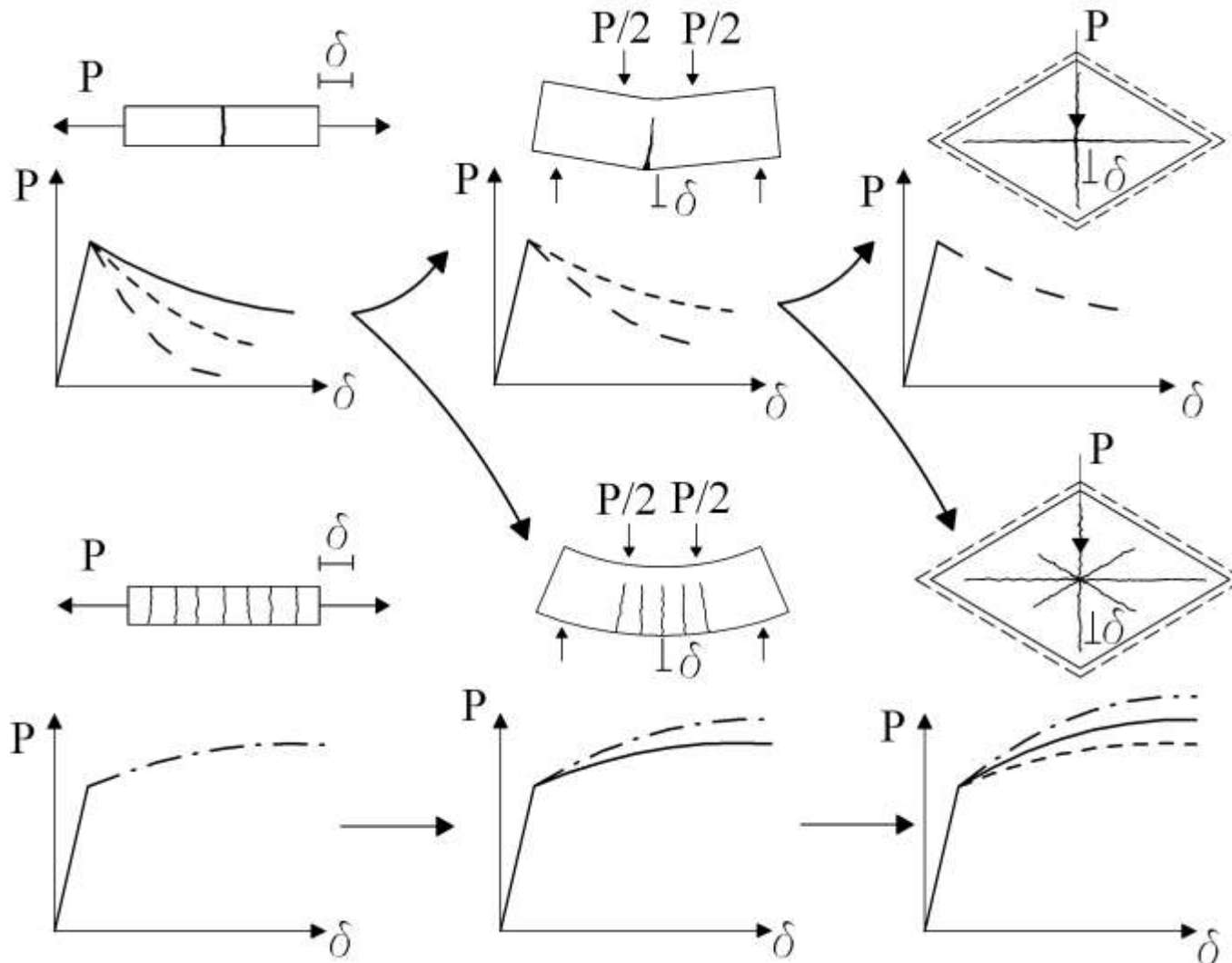
BENDING TEST



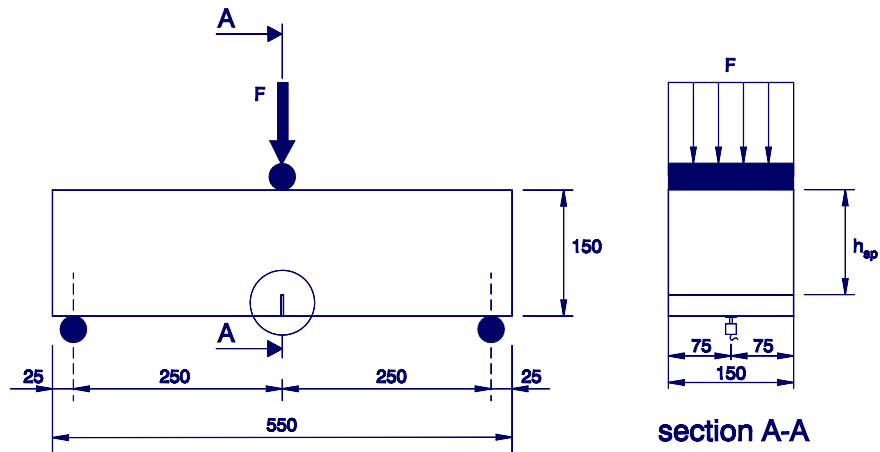
Hardening and softening materials in tension



From material to structural behavior



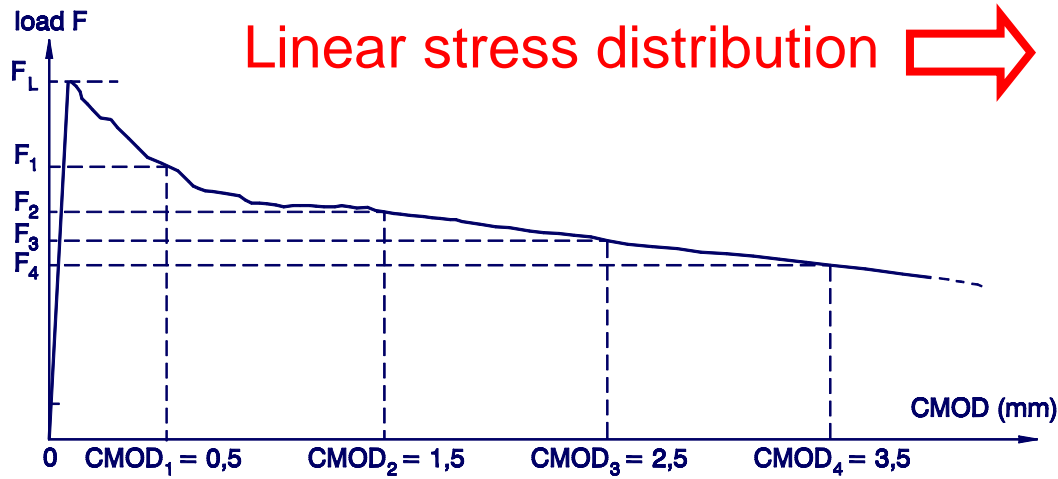
FRC classification (3PBT)



EN 14651

$$h_{sp} = 125 \text{ mm}$$

$$b = 150 \text{ mm}$$



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

FRC performance classes (New fib Model Code)

Post-cracking residual strength can be classified by using two parameters, namely 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* and *e* correspond to the ratios:

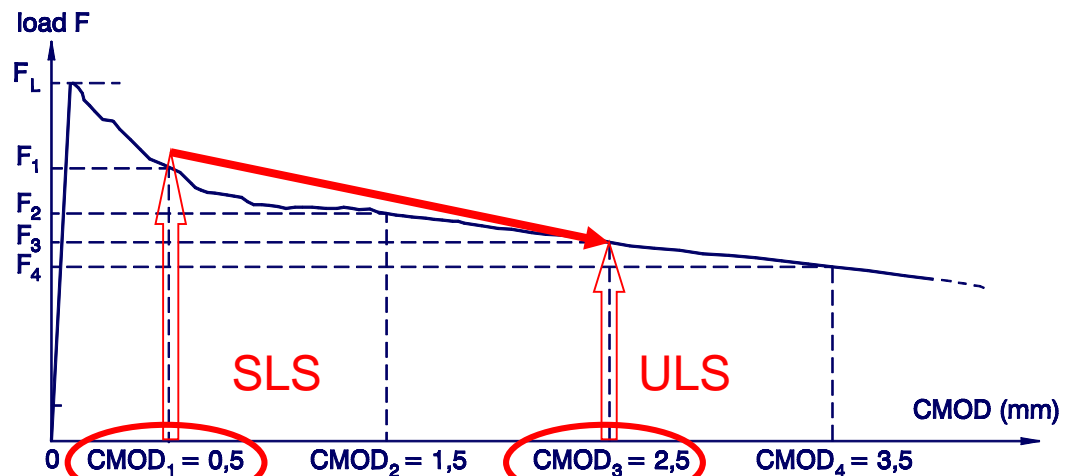
a if $0.5 \leq f_{R3k}/f_{R1k} \leq 0.7$

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

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

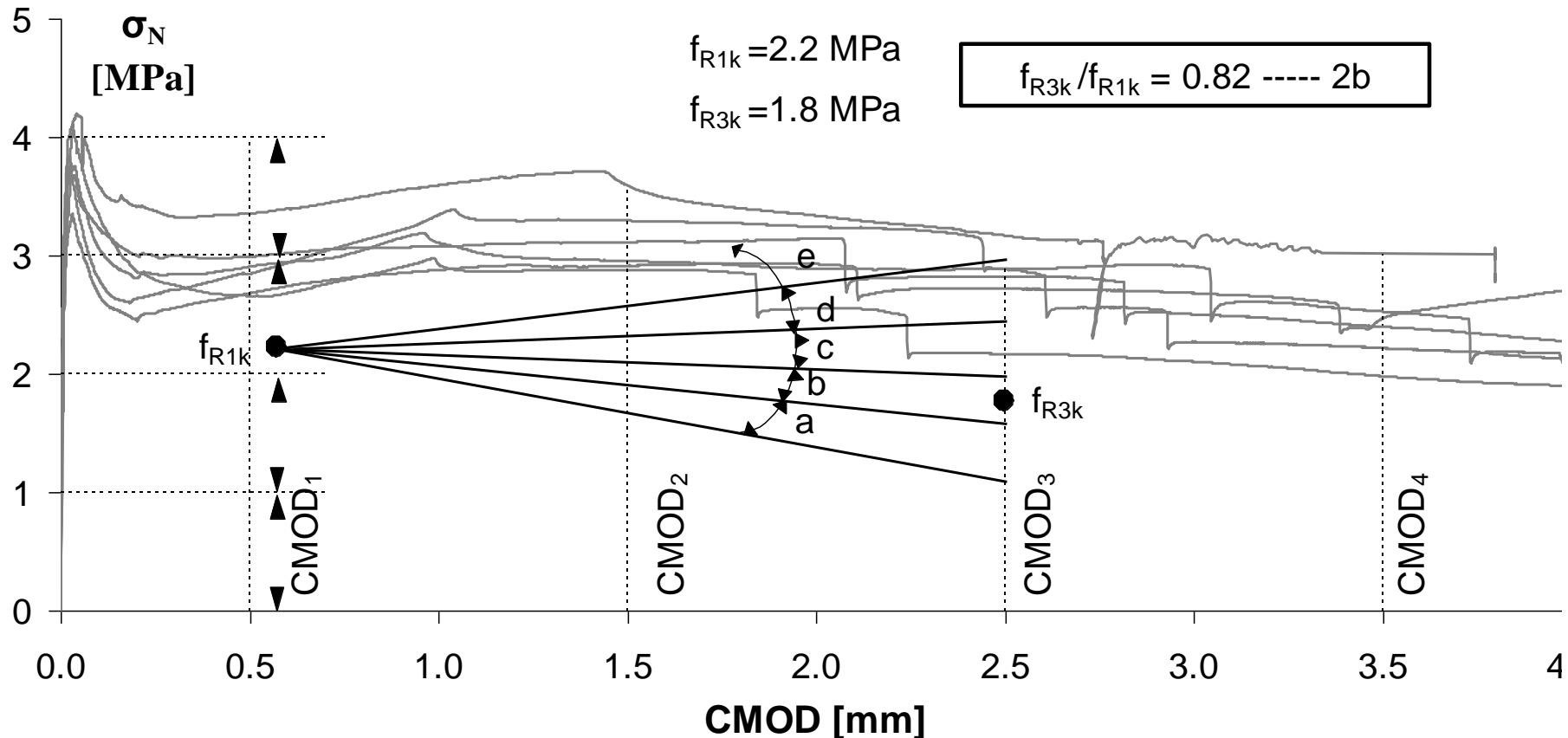
d if $1.1 \leq f_{R3k}/f_{R1k} \leq 1.3$

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

Performance classes



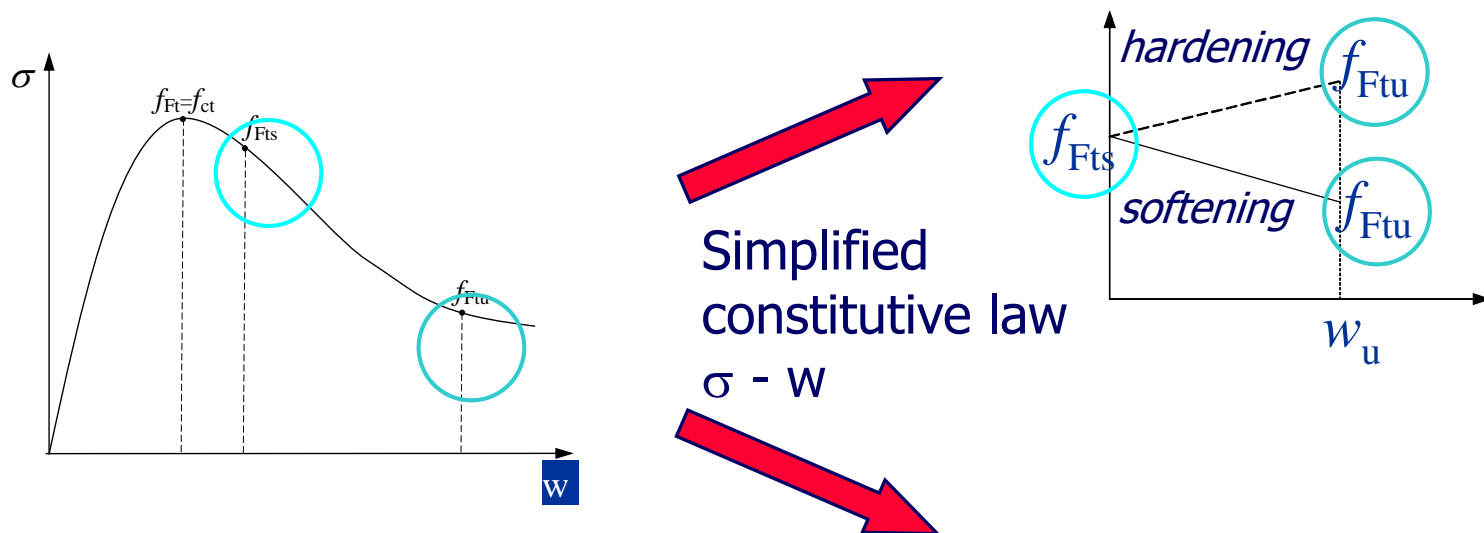
Minimum requirements for structural applications:
 Fibres can substitute conventional reinforcement
 (rebars) only if the following relationship is
 fulfilled:

$$f_{R1k}/f_{Lk} > 0.4$$

$$f_{R3k}/f_{R1k} > 0.5$$

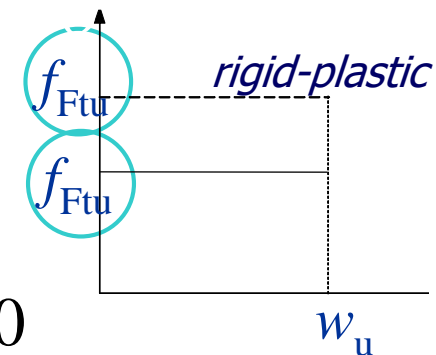
Constitutive law in uniaxial tension: σ - w

- Experimental result: σ_N – **CMOD** \longrightarrow σ – **w**

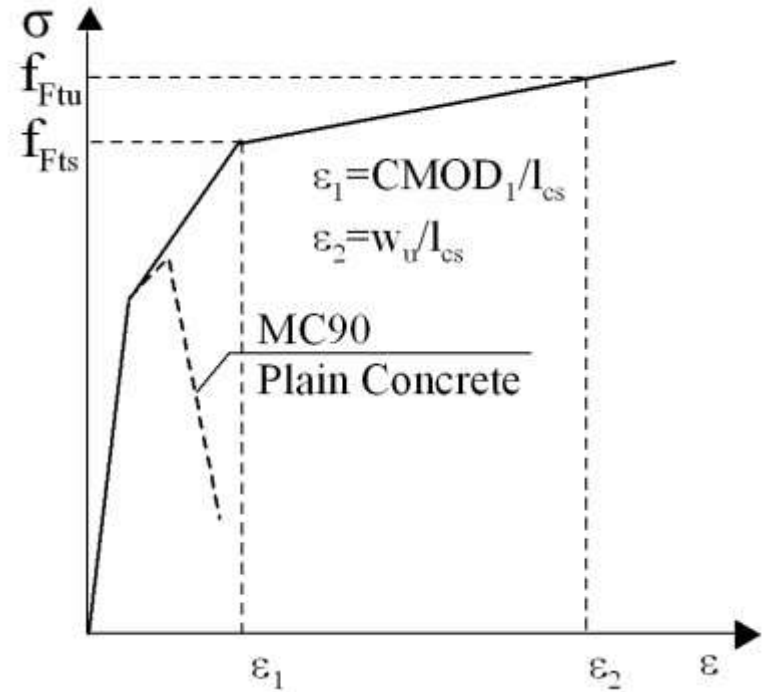
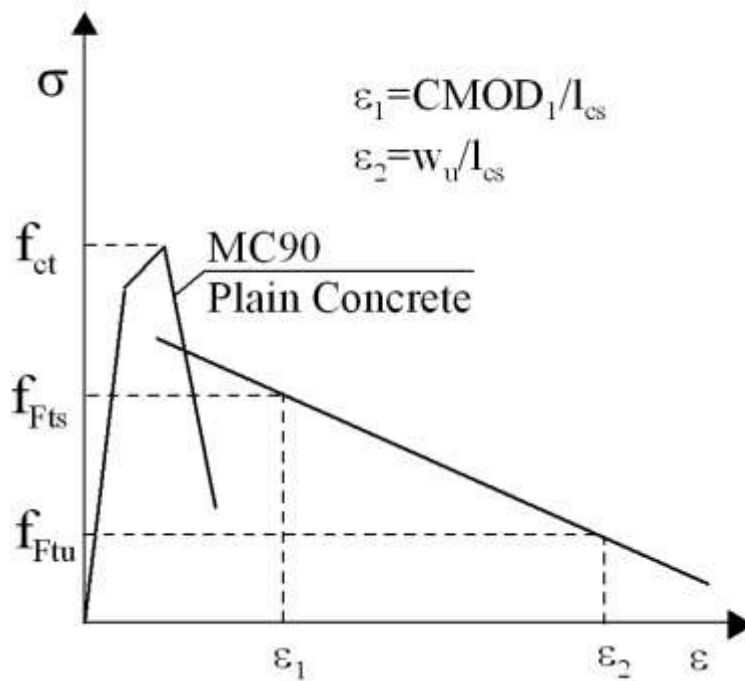


$$f_{Fts} = 0.45 f_{R1}$$

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



Stress-strain relationship



$$\varepsilon_1 = \varepsilon_{\text{SLS}} = \text{CMOD}_1 / l_{cs}$$

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

Partial safety factors

ULS:

	Ordinary quality control
FRC in compression	As plain concrete
FRC in tension	
FRC in tension (residual strength)	$\gamma_F = 1.5$

SLS: $\gamma_F = 1$

Eurocode 2

Annex to EN 1992-1-1

CEN TC 250/SC2/WG1/TG2

SFRC - Steel Fibre Reinforced Concrete

This draft annex to EN 1992-1-1 is currently being prepared by CEN TC 250/SC2/WG1/TG2.

It describes all additions and changes to EN 1992-1-1, required for the application of SFRC within the scope of EN 1992-1-1. Unchanged parts of EN 1992-1-1 remain valid.

Le nuove NTC



Ministero delle Infrastrutture e dei Trasporti
Consiglio Superiore dei Lavori Pubblici
Servizio Tecnico Centrale

BOZZA DI REVISIONE DELLE NORME TECNICHE PER LE COSTRUZIONI

Il FRC nelle nuove NTC

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.

Le nuove linee guida per la progettazione di elementi in FRC

Consiglio Superiore dei Lavori Pubblici

Servizio Tecnico Centrale

Linee guida per l'identificazione, la qualificazione, la certificazione d'idoneità tecnica all'impiego ed il controllo di accettazione dei fibrorinforzati FRC (Fiber Reinforced Concrete)

Le nuove linee guida per la progettazione di elementi in FRC

1. *SCOPO e CAMPO DI APPLICAZIONE*
2. *CARATTERISTICHE DEL COMPOSITO E DEI RELATIVI COMPONENTI*
3. *QUALIFICAZIONE INIZIALE DELLA PRODUZIONE IN STABILIMENTO E CONTROLLO PERMANENTE DELLA PRODUZIONE*
4. *PROCEDURA DI QUALIFICAZIONE*
5. *PROCEDURE DI ACCETTAZIONE IN CANTIERE*

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 FRC (Fiber Reinforced Concrete)

Le nuove linee guida per la progettazione di elementi in FRC

*SCOPO E CAMPO DI APPLICAZIONE
PROPRIETA' MECCANICHE DEL FRC
COEFFICIENTI DI SICUREZZA PARZIALI
ORIENTAMENTO DELLE FIBRE
VERIFICHE AGLI STATI LIMITE ULTIMI
VERIFICHE AGLI STATI LIMITE DI ESERCIZIO
REQUISITI MINIMI PER LA DUTTILITA' STRUTTURALE
PROCEDURE DI ACCETTAZIONE IN CANTIERE
Prove preliminari sui prodotti premiscelati*

Normative sul materiale

Standards sul materiale

EN 14889-1, Fibres for concrete — Part 1: Steel fibres —
Definition, specifications and conformity

EN 14889-2, Fibres for concrete — Part 2: Polymer fibres —
Definition, specifications and conformity

UNI 11039: Calcestruzzo rinforzato con fibre d'acciaio; (1a)
Parte I: Definizioni, classificazione e designazione; (1b)
Parte II: Metodi di prova.

CEN EN 14651 Test method for metallic fibre concrete –
Measuring the flexural tensile strength (limit of
proportionality (LOP), residual).

EN 14721, Precast concrete products - Test method for metallic
fibre concrete - Measuring the fibre content in fresh and
hardened concrete.

Standards sul materiale

EN 14845-1, Test methods for fibres in concrete - Part 1:
Reference concretes

EN 14845-2, Test methods for fibres for concrete — Part 2 —
Effect on concrete.

Verifica della distribuzione delle fibre

Le fibre devono presentare una distribuzione omogenea all'interno dell'impasto. Il raggiungimento di tale condizione può essere ostacolato dalla formazione di accumuli di fibre, comunemente indicati con i termini di “grumi”, “ciuffi” o “grovigli”. In particolare, la loro presenza, seppur limitata, può provocare occlusioni tali da rendere difficoltose le operazioni di pompaggio.

La distribuzione uniforme delle fibre nell'impasto può essere verificata con la EN 14721

Design concepts

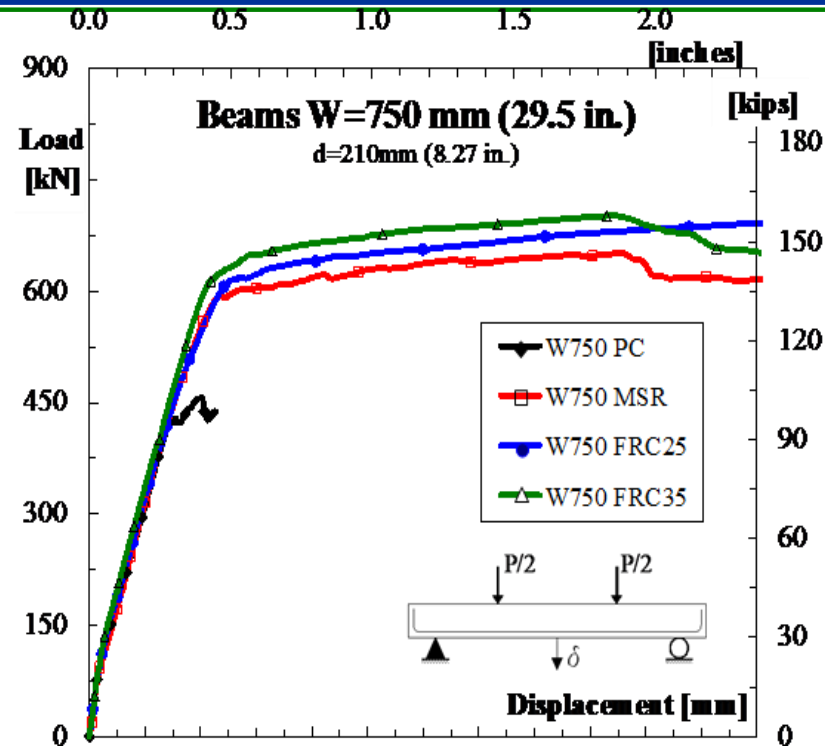
Optimized reinforcement: definition

Place the best performing reinforcement (fibers and/or rebars) where required by tensile stresses in the structural elements

Reinforcement use in structural elements

- In structural elements both distributed and localized stresses are generally present
- Conventional rebars represent the best reinforcement for localized stresses
- Fibers represent the best reinforcement for diffused stresses
- Structural optimization generally requires the use of a combination of rebars and fibers
- Structural ductility is generally enhanced

Wide Shallow Beams with $b=750$ mm

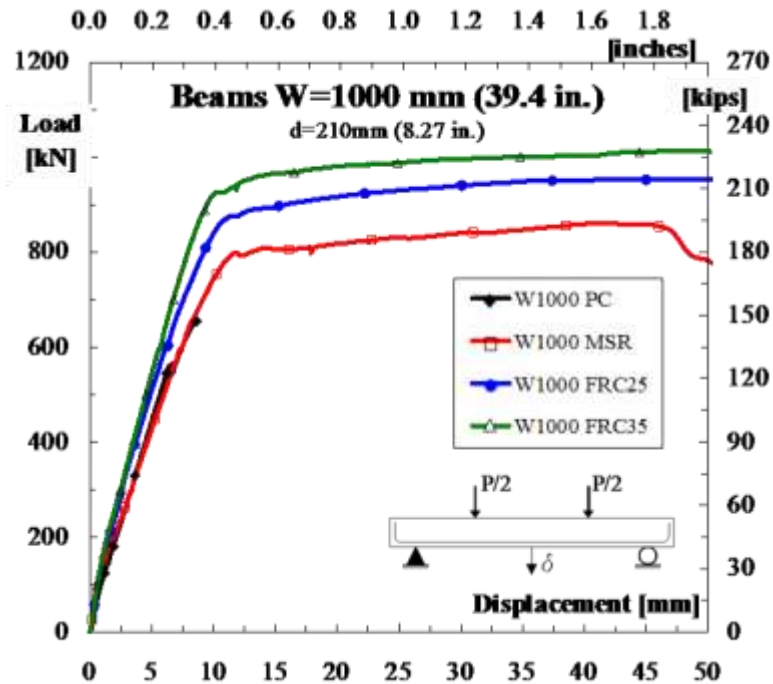


W750 PC



W750 FRC25

Wide Shallow Beams with $b=1000$ mm



W1000 MSR

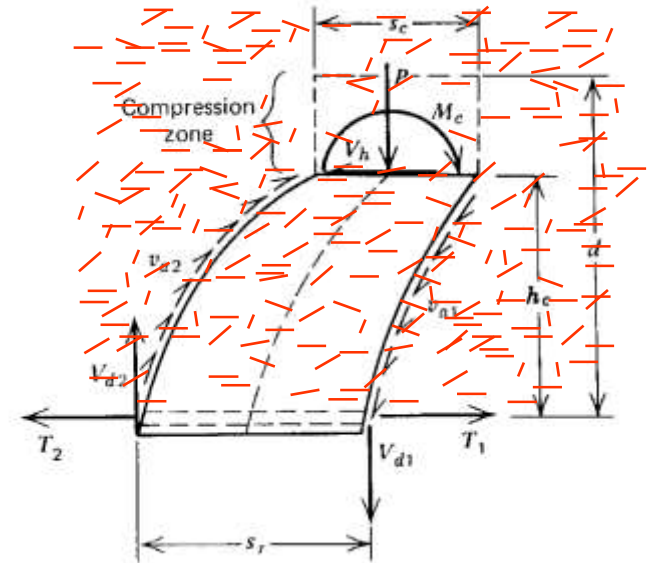
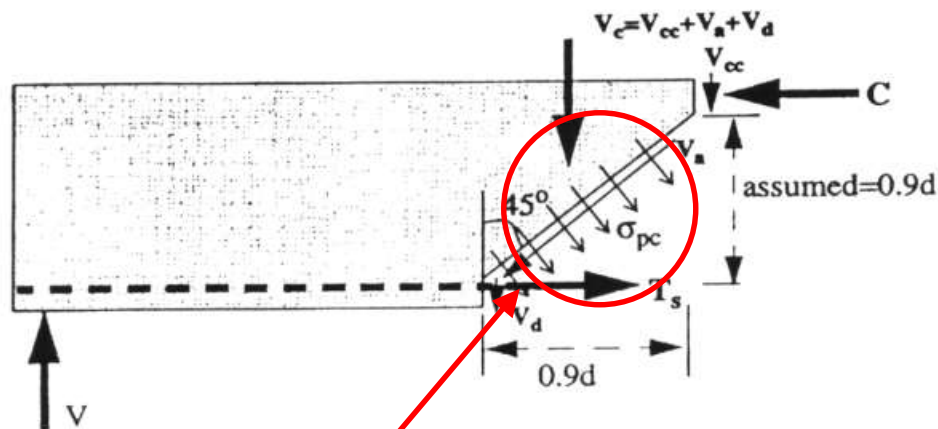


W1000 FRC35

Shear in beams without stirrups

In FRC elements there is an additional contribution to shear resistance provided by fiber reinforcement:

$$V = V_c + V_f$$



V_c represents the concrete contribution.

V_f represents the fiber contribution (**post cracking strength**).

Fibers for durability of RC beams

Cracking and durability



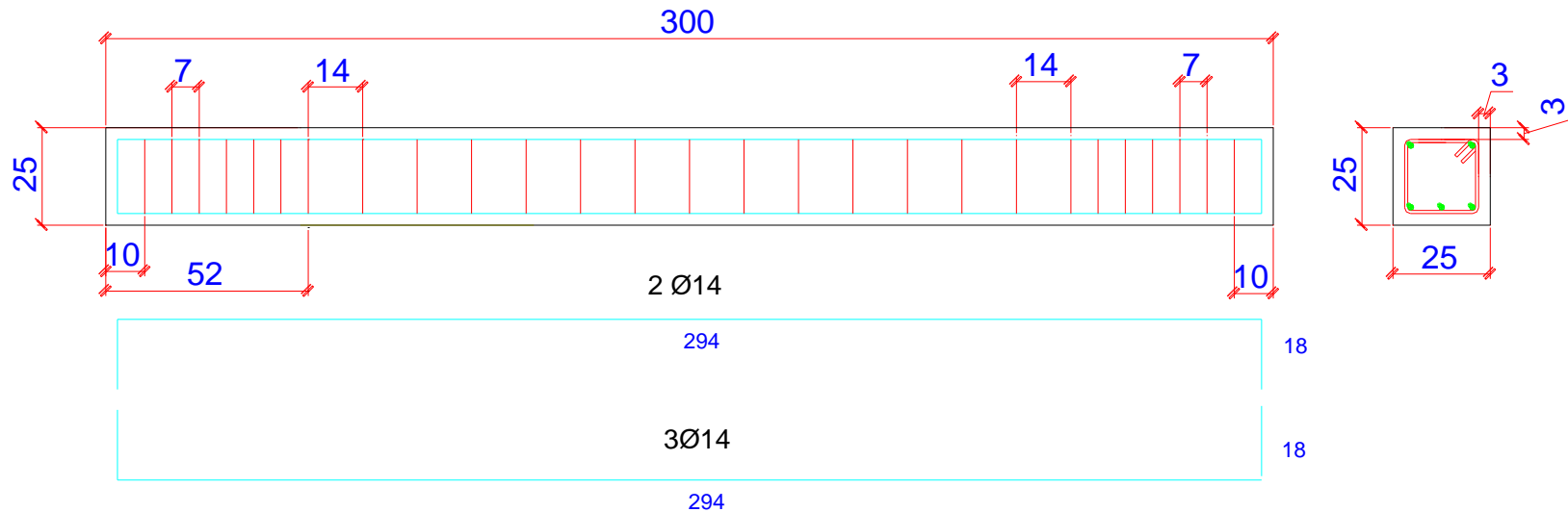
Exposure in aggressive (marine) environment

10 beams has been exposed for more than 2 years in a coastal zone, under a load equal to 50% of the ultimate load

Aim of the research: evaluate the influence of fibers on mechanical behaviour of FRC in short and long term bending test

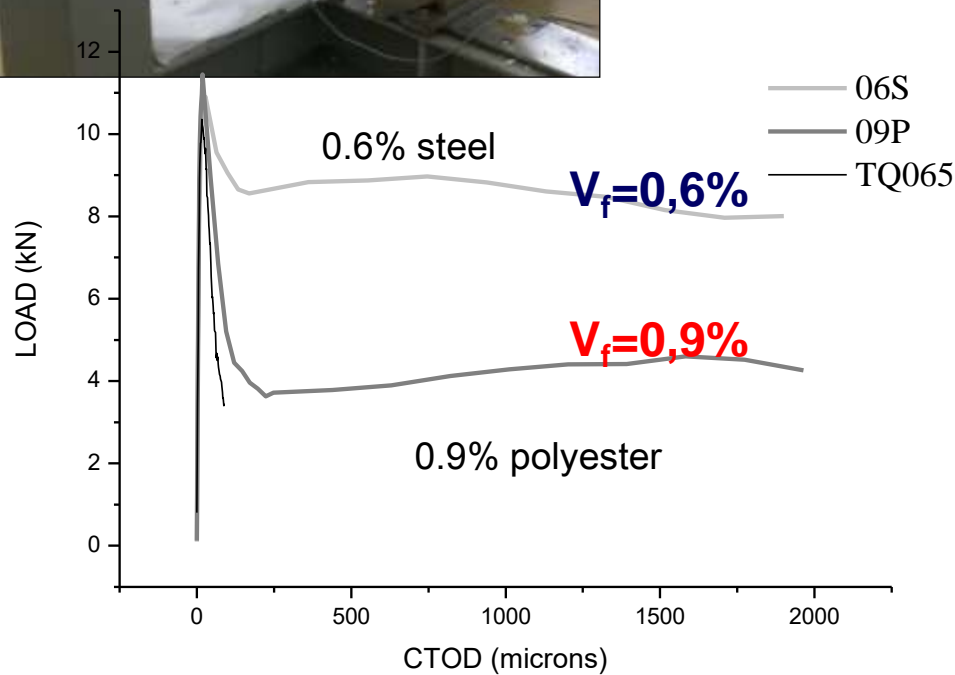
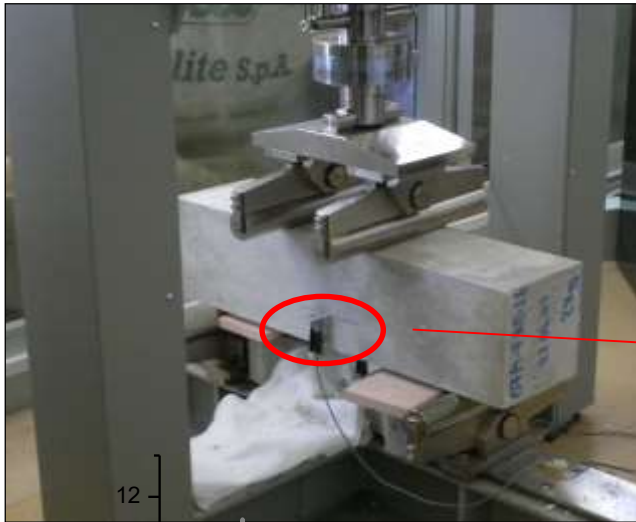


Materials

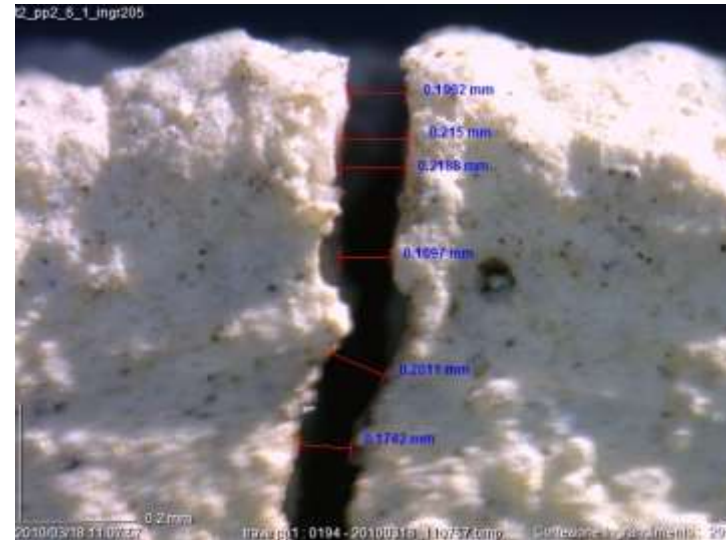


	Diameter	Yield strength (MPa)	Ultimate strength (MPa)
Longitudinal bars	14mm	520	614
Stirrups	8mm	567	600

Tests for determining material properties

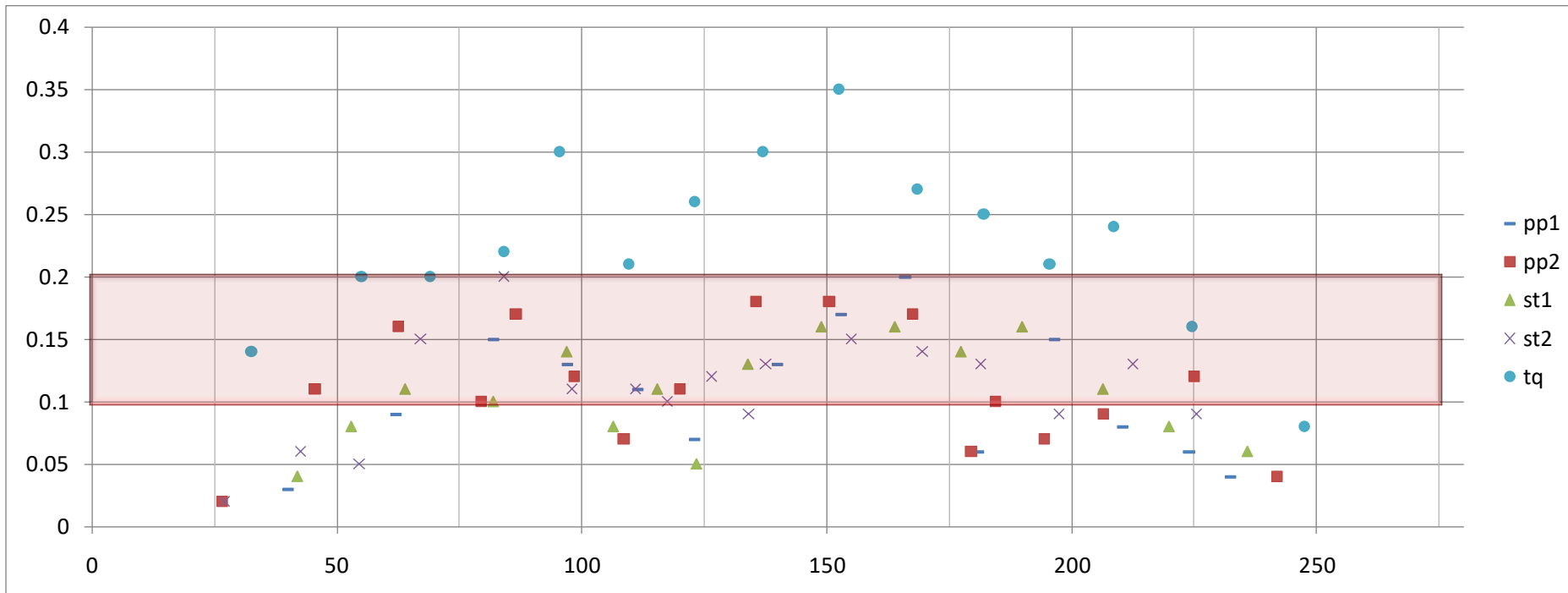


Crack monitoring



Crack width, crack length and crack position have been measured during the exposure period. The crack width has been measured with a digital microscope (200x magnification)

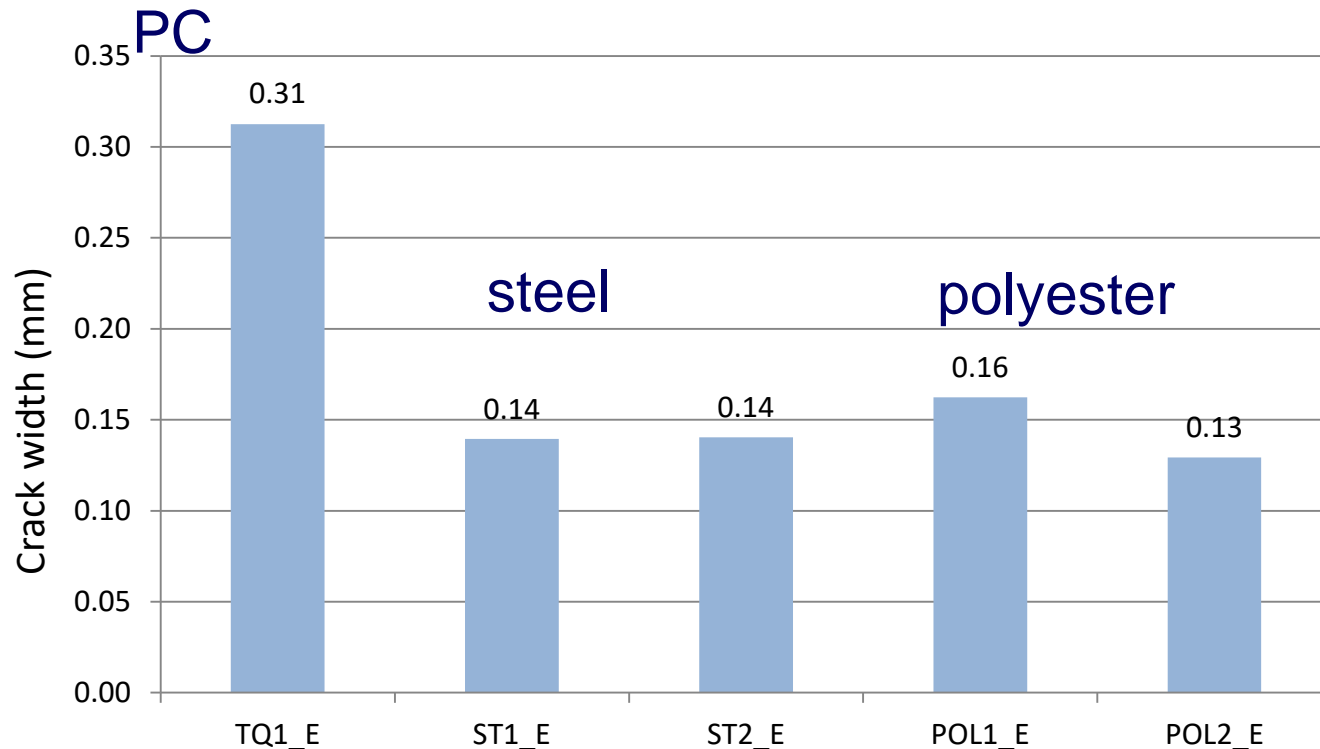
Cracking monitoring



In FRC beams the crack widths were in the range of 0.1 to 0.2 mm, without overcome the threshold of 0.2 mm. In plain beam the 93.3% of cracks had a crack width over 0.1 mm, while the 60% over 0.2 mm.

Cracking monitoring

Average of crack widths between the loading points

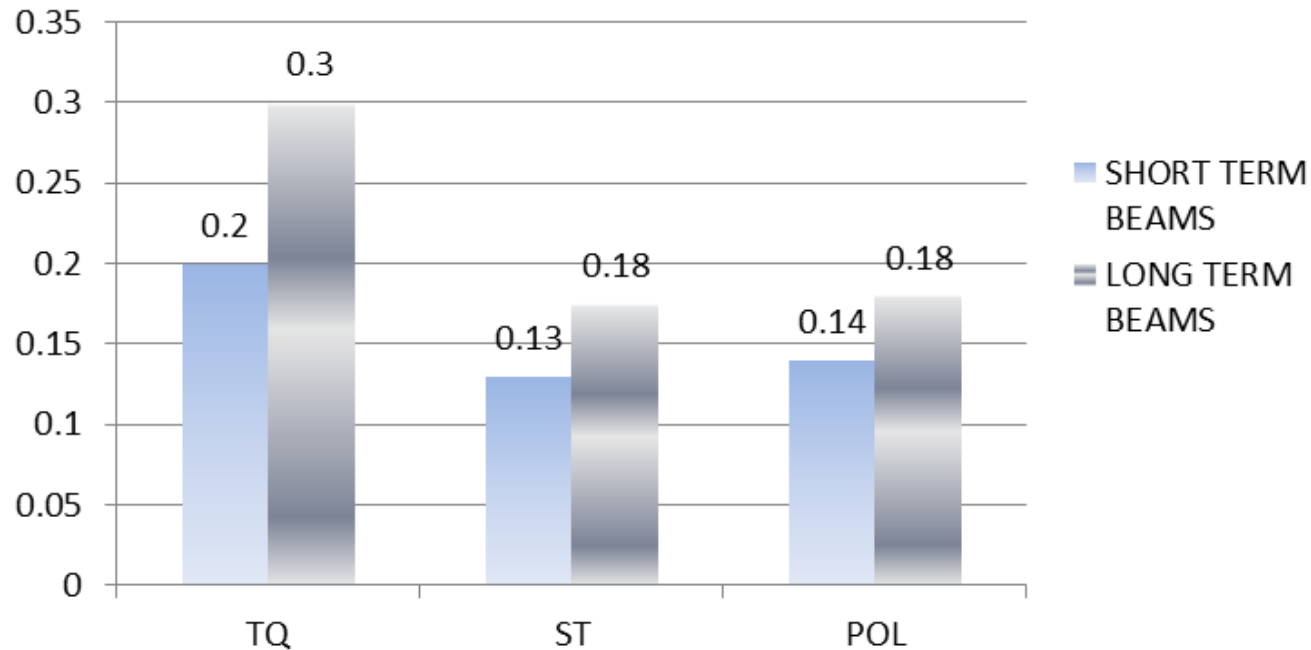


Crack width reduction of the FRC beams respect to the plain beam (Dw /%).

Beams	Dw /%
ST1-2_E	54%
POL1-2_E	53%

Cracking behavior at SLS

SLE (50 kN)



Crack width reduction of the FRC beams respect to the plain beam.

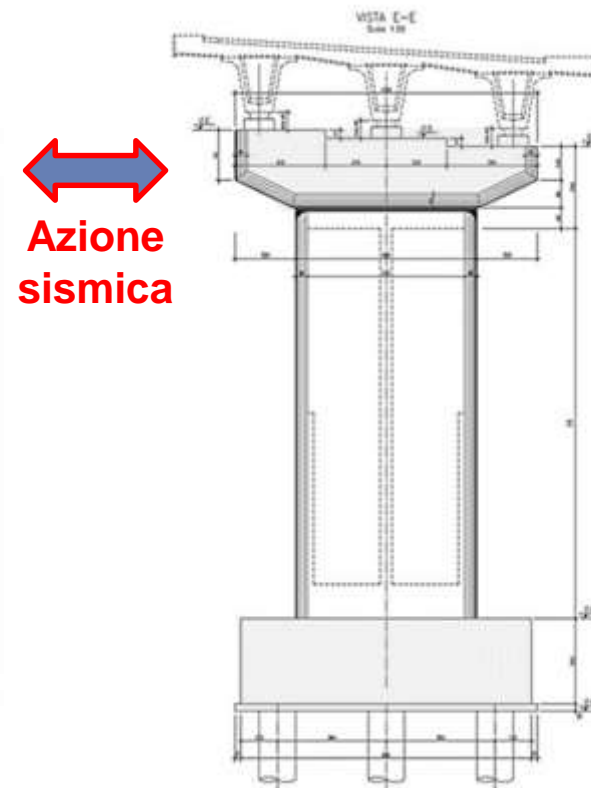
SLE (50kN)

		LONG TERM BEAMS		SHORT TERM BEAMS
ST1-2_E	43%		ST1-2	35%
POL1_E	37%		POL1-2	28%
POL2_E	43%			

FRC for structural rehabilitation

Rinforzo Pila da Ponte

CASO STUDIO: viadotto esistente

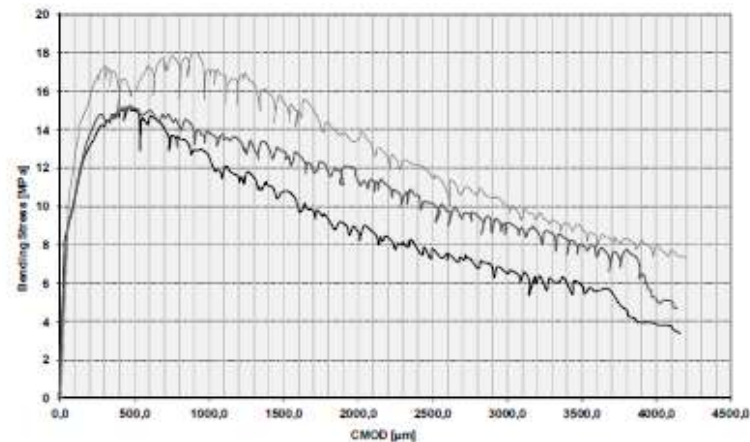


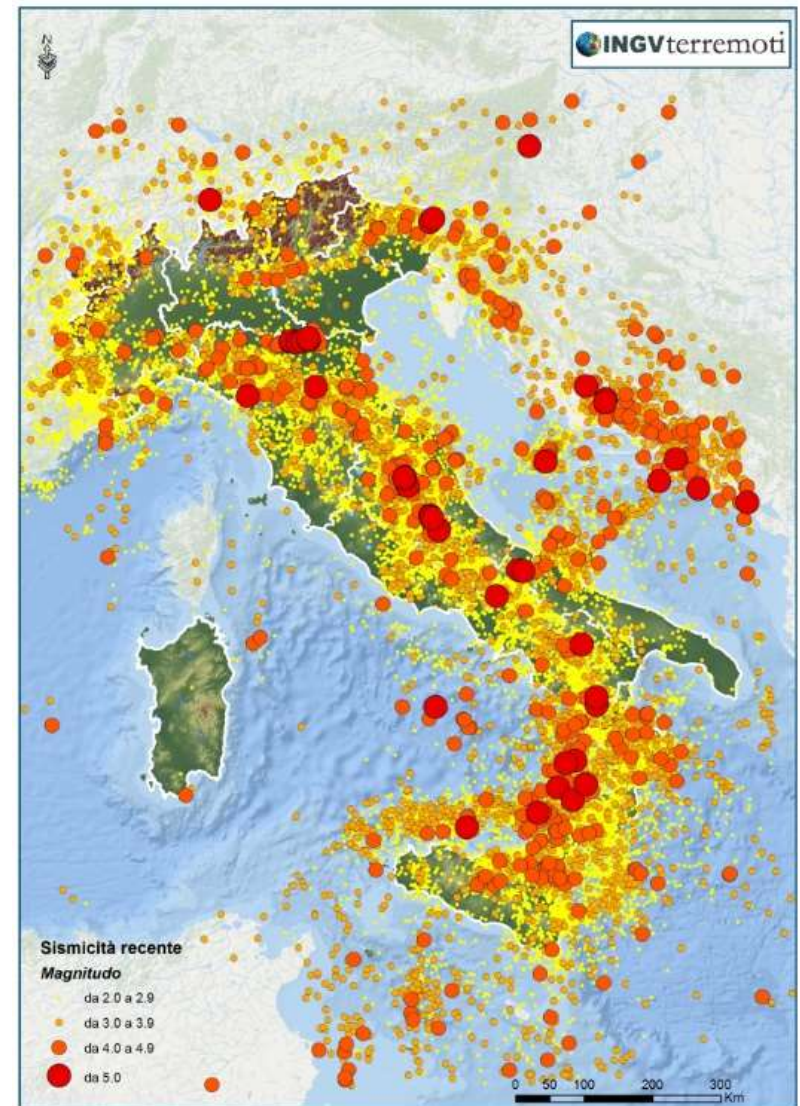
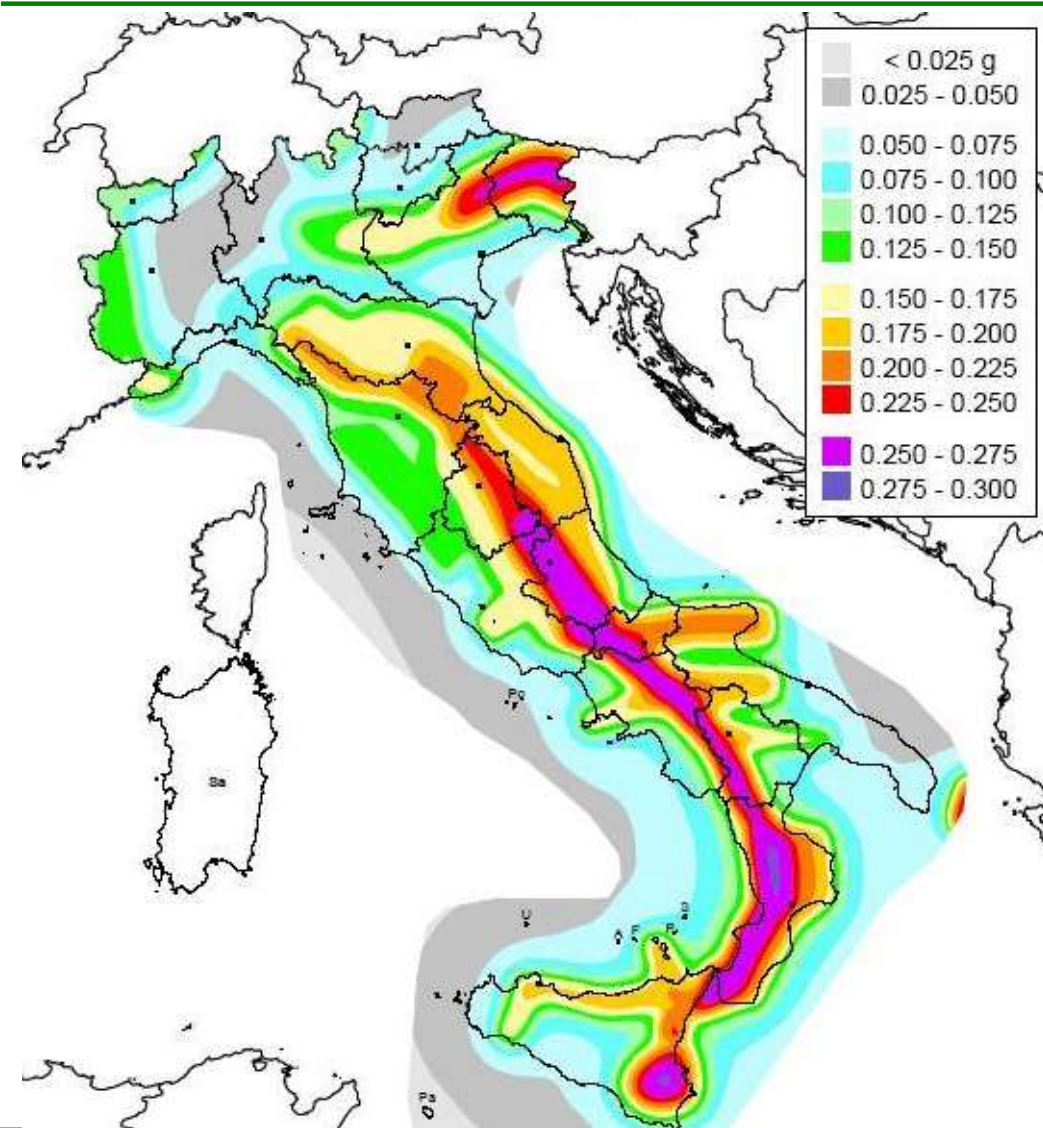
$$H = 22,40 \text{ m} \quad V_c = 210 \text{ m}^3 \quad V_r = 44 \text{ m}^3$$

Property (specimen dimension)	Standard	Value
Mass density	UNI EN 12350	2510÷2580 kg/m ³
Compressive strength at 1 day (100X100mm)	UNI EN 12390 - 3	67 MPa §
Compressive strength at 7 days (100X100mm)		111 MPa §
Compressive strength at 28 days (100X100mm)		131 MPa §
Compressive strength at 56 days (100X100mm)		>130 MPa
Cylindrical/Cubical Compressive strength ratio	-	≈ 1
Flexural strength at 28 days (10X10x400mm)	UNI EN 12390 - 5	18,4 MPa



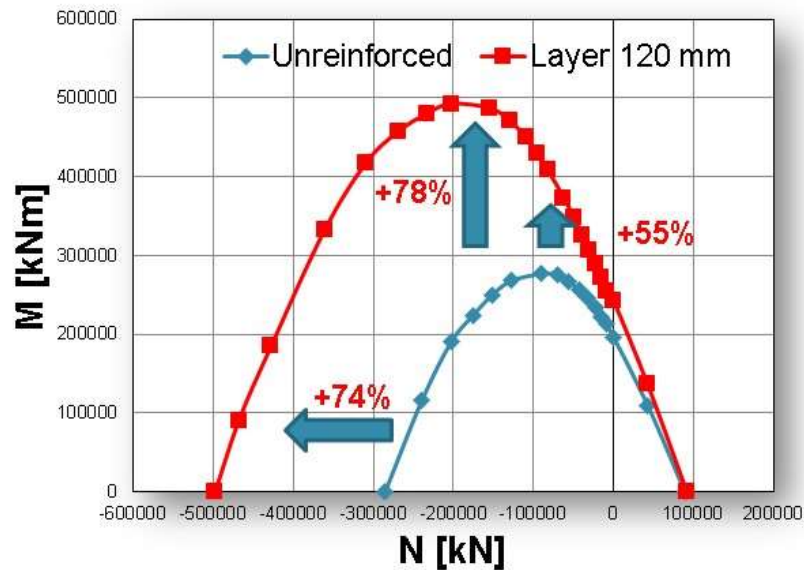
Fibre in
acciaio
INOX



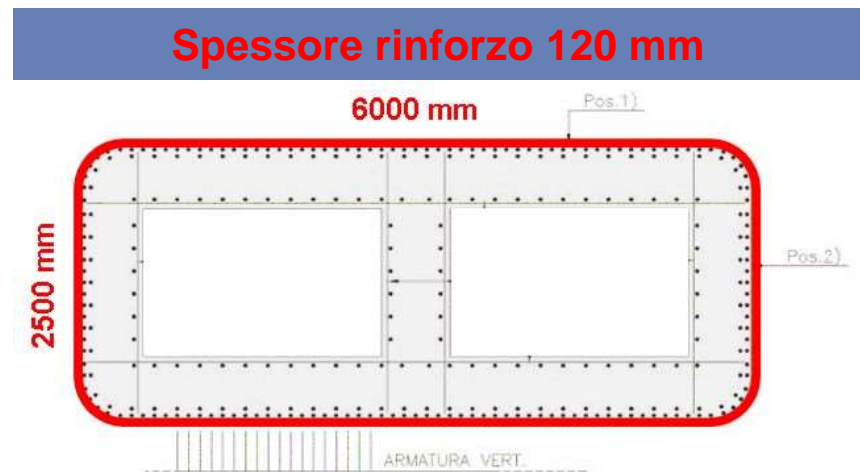


Rinforzo Pila da Ponte

Incremento della capacità portante

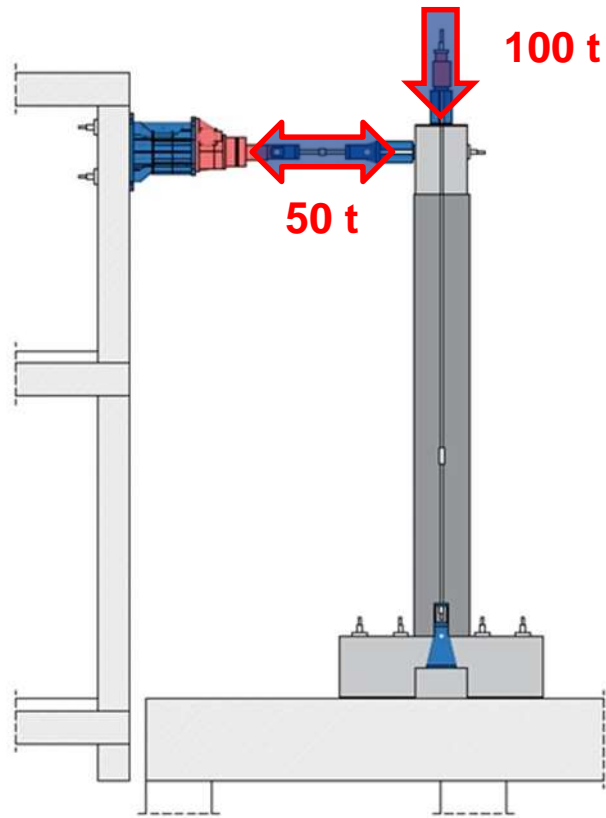


Incamicatura con calcestruzzi ad alte prestazioni (HPC)



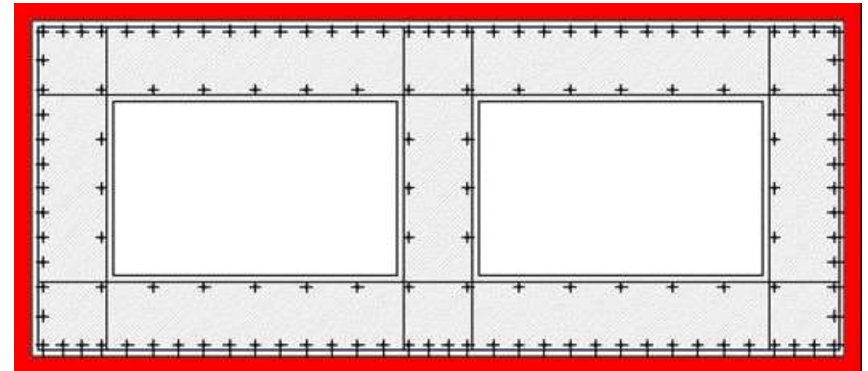
Prova Sperimentale

Setup prova sperimentale

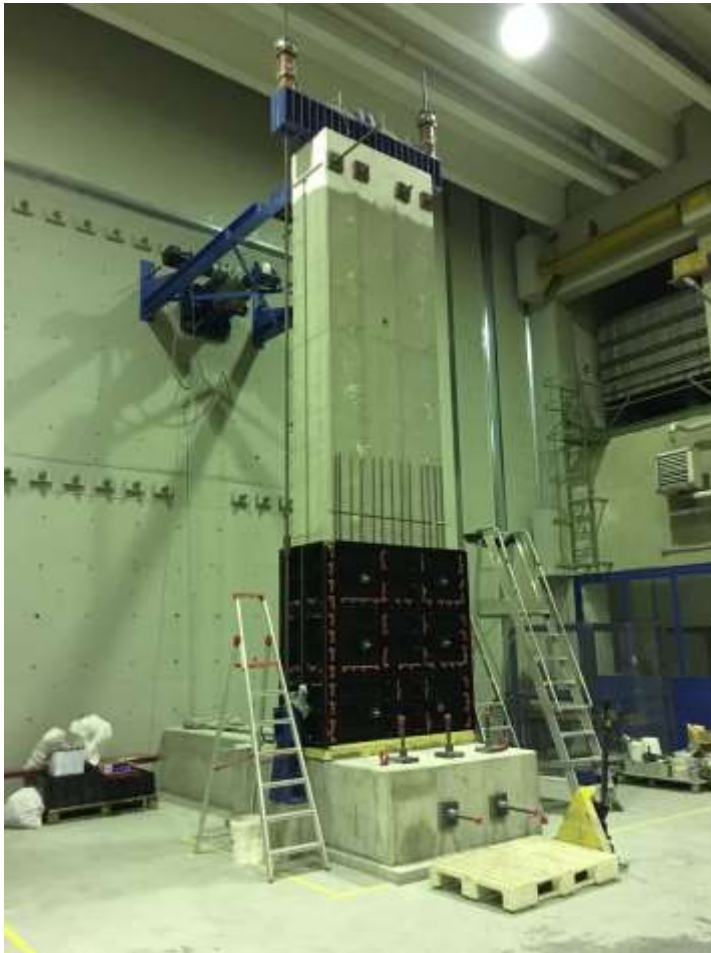


Provino in scala 1:4

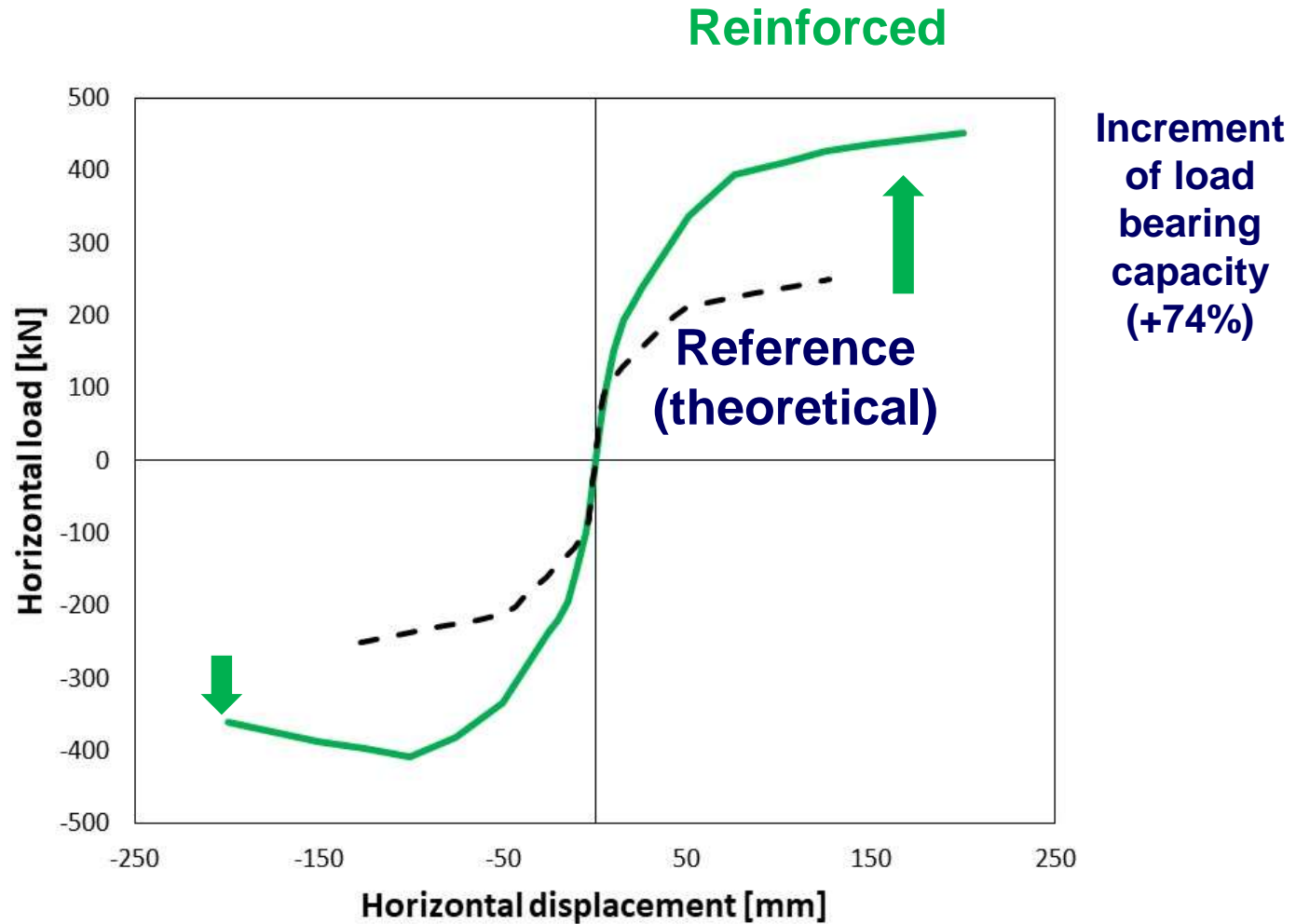
Spessore rinforzo 30 mm



Pila rinforzata



Comportamento della pila prima e dopo il rinforzo



Terremoto nell'Italia Centrale

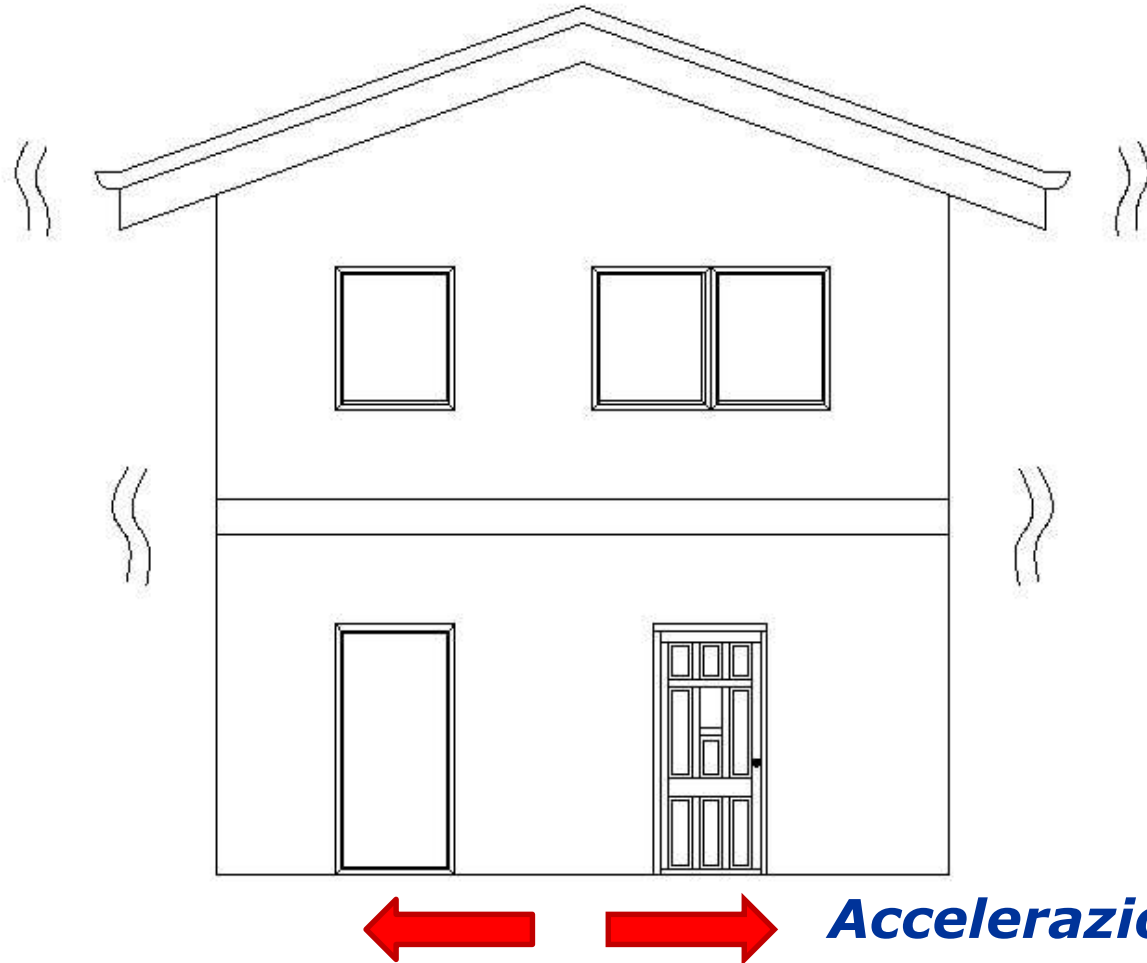


Terremoto nell'Italia Centrale



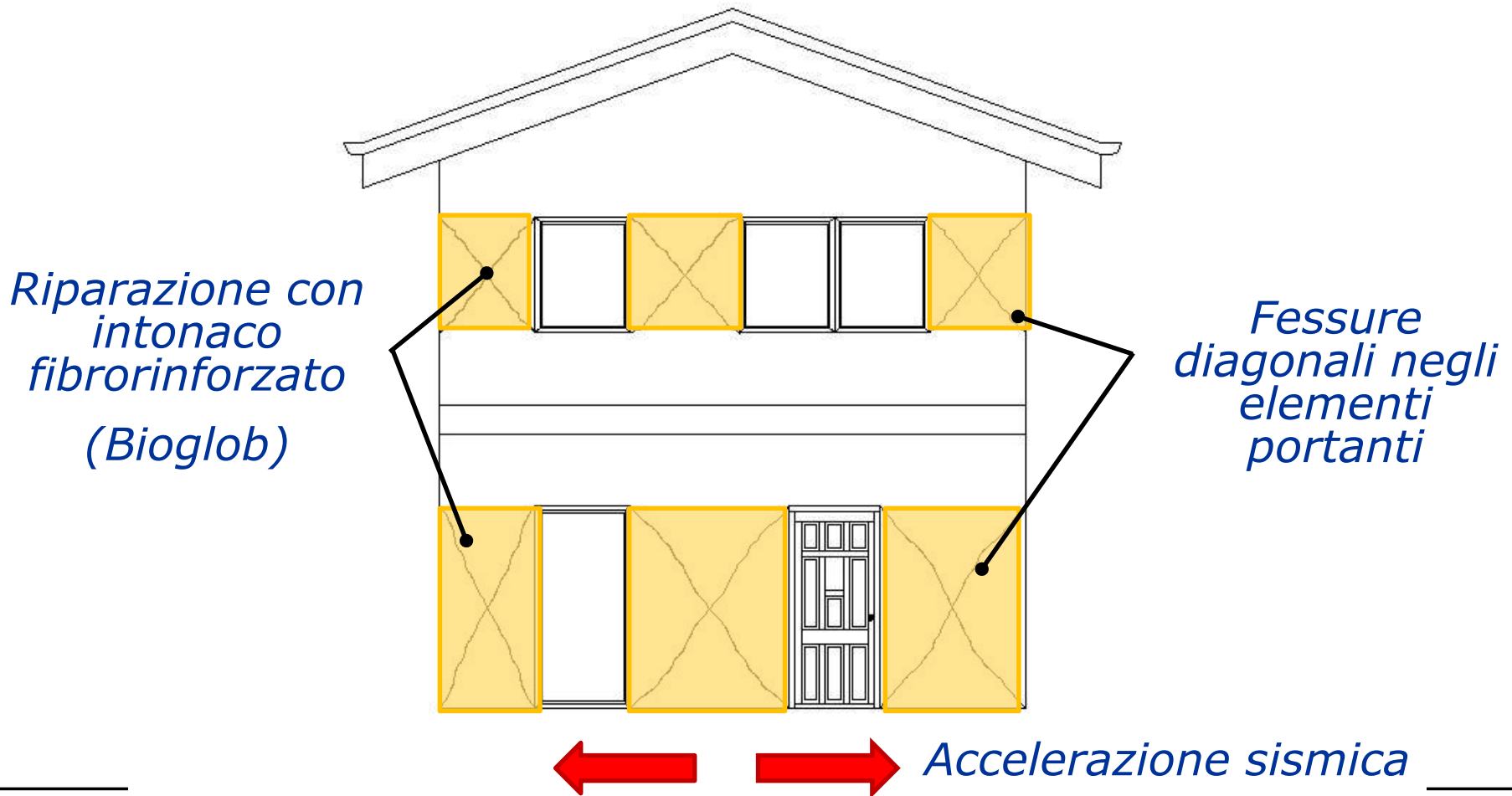
Edifici in muratura: rinforzo delle pareti portanti mediante intonaci fibrorinforzati

Edificio in muratura soggetto ad azione sismica



Edifici in muratura: rinforzo delle pareti portanti mediante intonaci fibrorinforzati

Edificio in muratura soggetto ad azione sismica



Caratteristiche della malta fibrorinforzata

MALTA AD ALTE PRESTAZIONI
FIBRORINFORZATA A BASE DI ALLUMINA
+
FIBRE METALLICHE ($V_f = 0,82\%$)

BASSISSIMO VALORE DI ASSORBIMENTO
D'ACQUA A PRESSIONE ATMOSFERICA
ELEVATO VALORE DI PERMEABILITÀ AL VAPOR
D'ACQUA

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

L_f, Φ_f

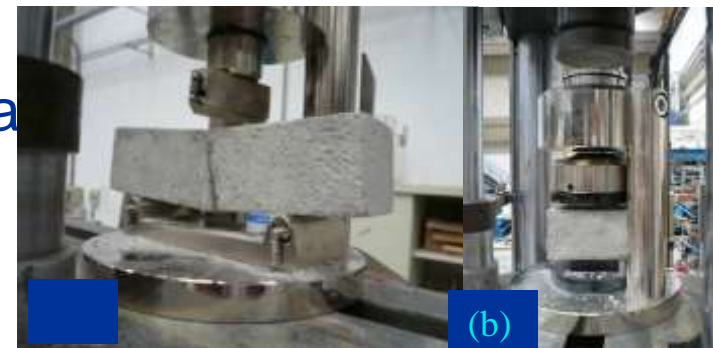


Resistenza a trazione per flessione
media (a) (EN 1015-11,2007) → 6MPa

Resistenza a compressione → 48,3MPa
media (b) (EN 1015-11,2007)

Valore medio modulo elastico → 33600MPa
(EN 12390-1)

Resistenza a trazione → 3,85MPa
(EC2)

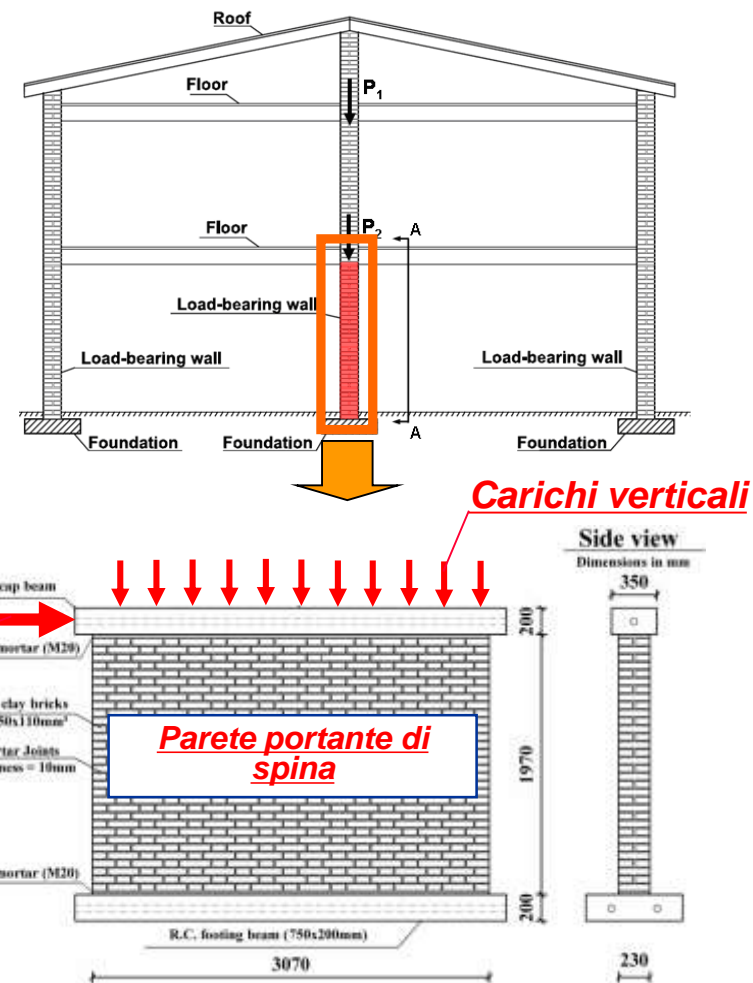
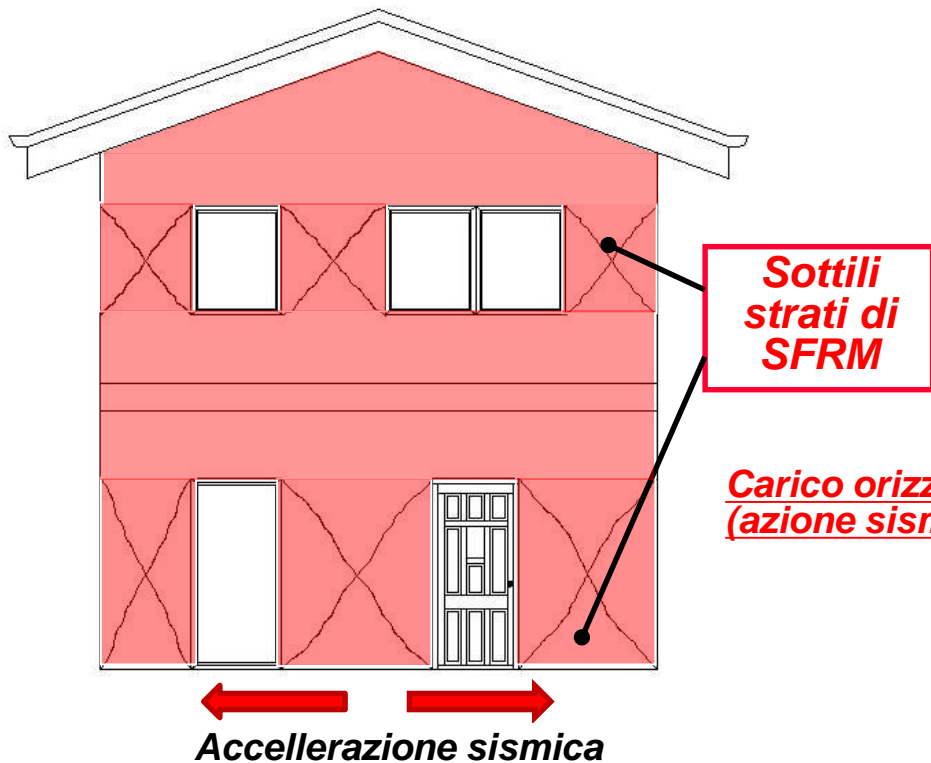


$$f_{ctm,fl} = \max \left\{ \left(1,6 - \frac{h[\text{mm}]}{1000} \right) f_{ctm}; f_{ctm} \right\}$$

Obiettivo dell'attività di ricerca

Utilizzo di sottili strati di intonaco fibrorinforzato per migliorare la resistenza nel piano di elementi strutturali in muratura

Sezione di un edificio tipo a due piani in muratura non rinforzata



Tipologia di pareti in muratura testate

**Muratura
in Mattoni
Pieni**



**Muratura in
Mattoni Forati
(Poroton P600)**

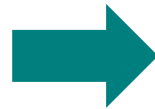
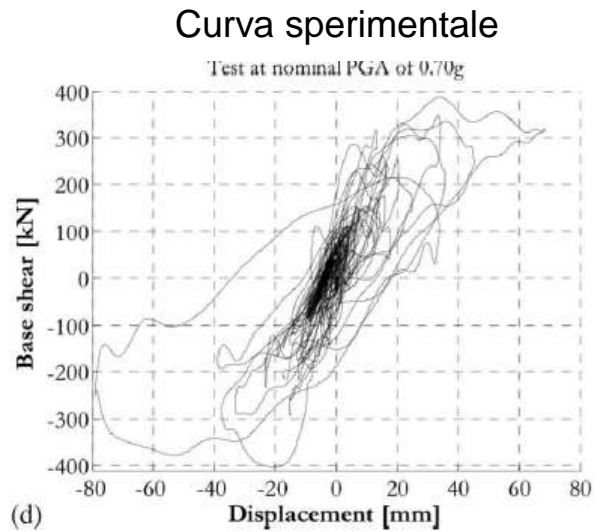


**Muratura in Mattoni
Forati con fori
orizzontali**

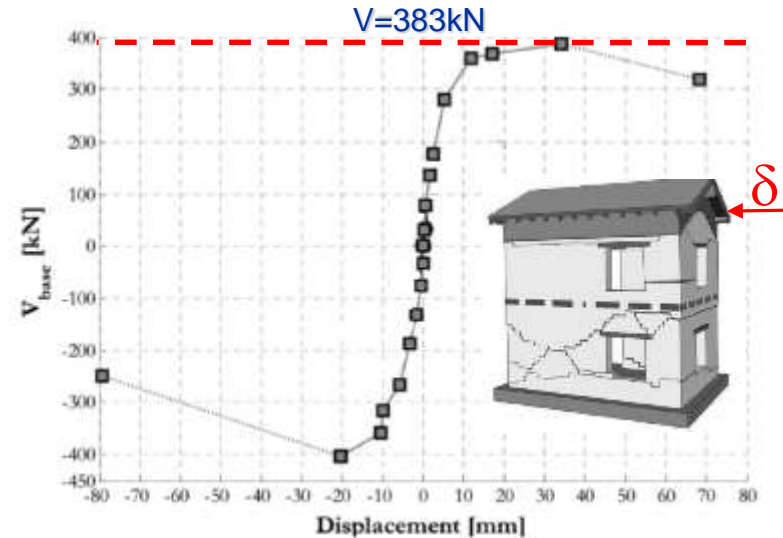


Risultati del test sull'edificio senza intonaco

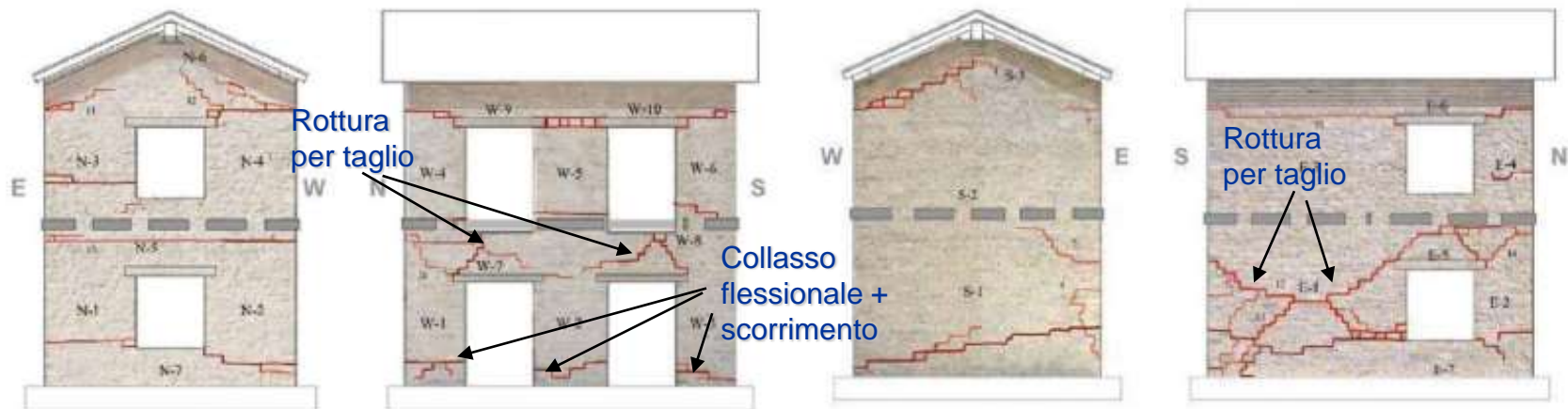
Taglio alla base vs. spostamento in sommità



Inviluppo della curva sperimentale



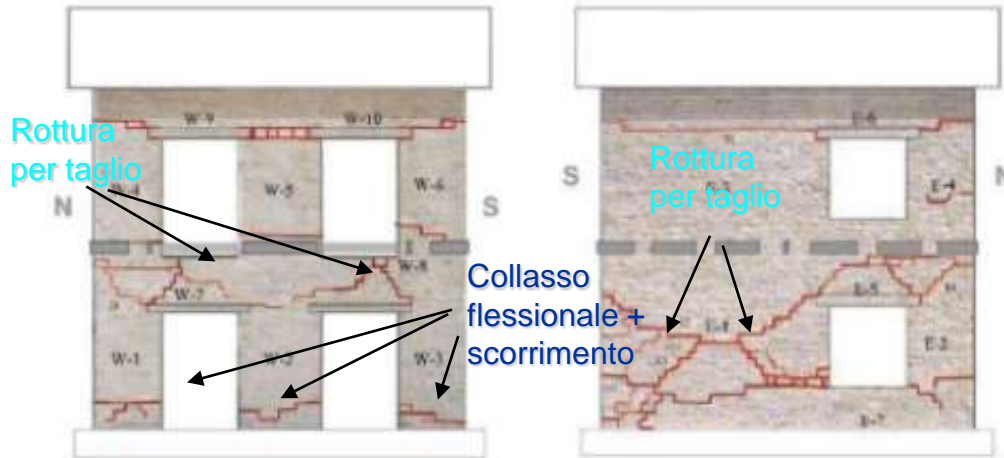
Quadro fessurativo sperimentale rilevato al termine della prova



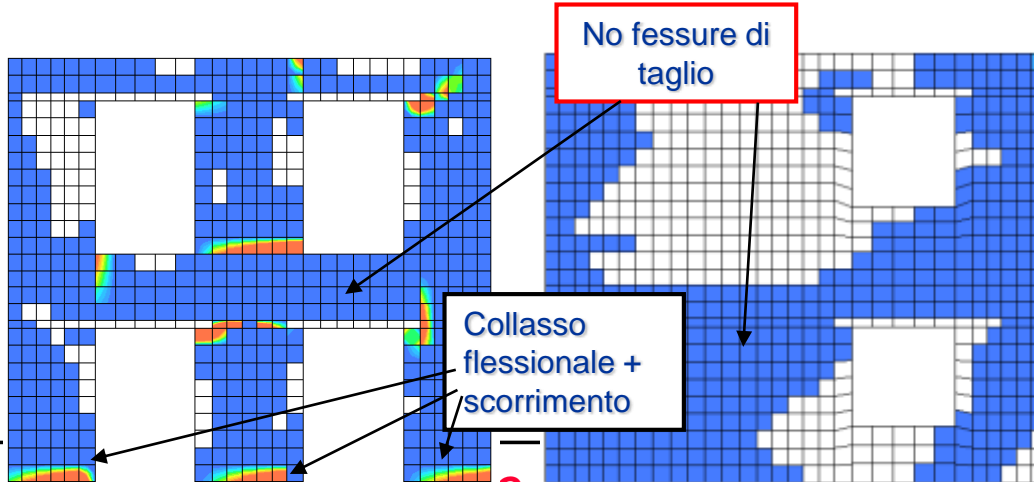
Risultati della simulazione numerica

Confronto del quadro fessurativo sperimentale e numerico

Quadro fessurativo sperimentale



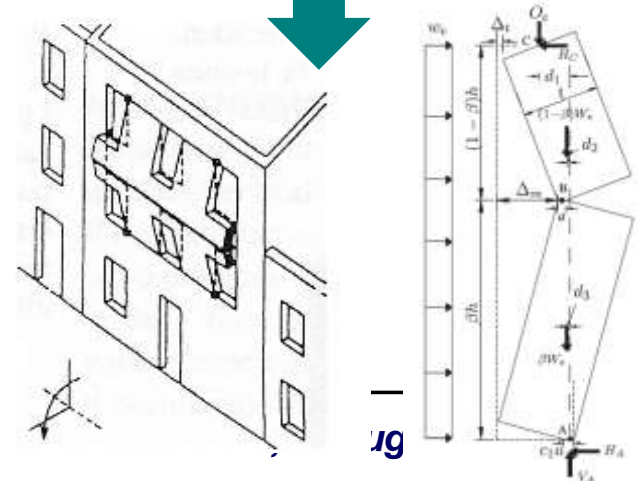
Quadro fessurativo numerico



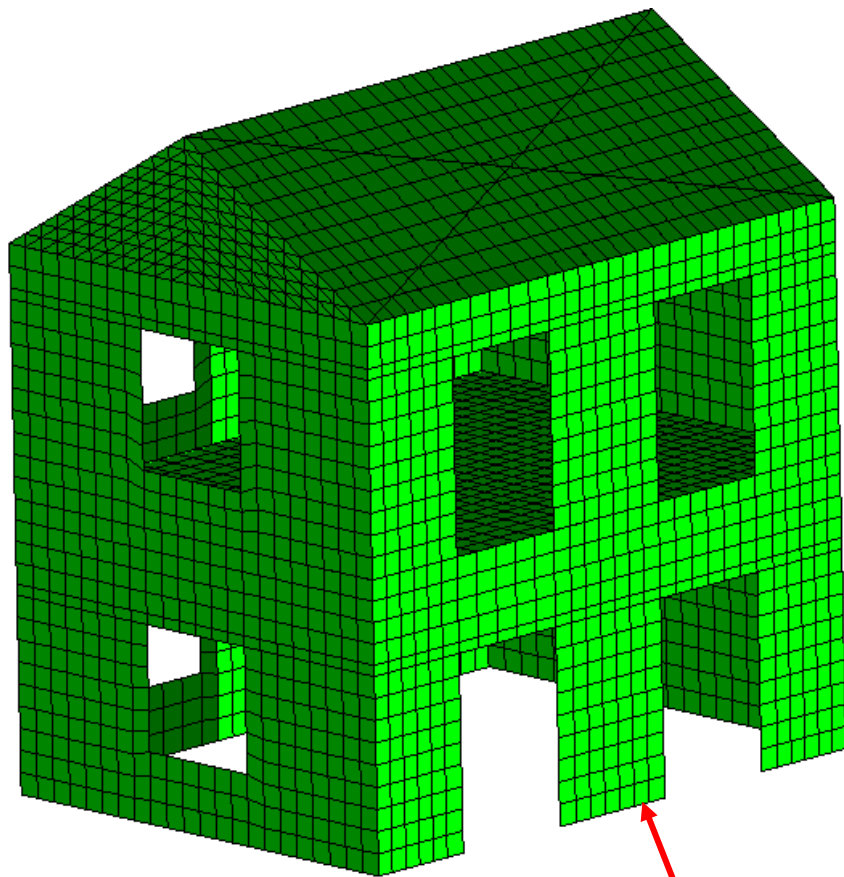
introduzione al FRCC e principali aspetti normativi

Il confronto mette in evidenza come l'impiego dell'intonaco abbia consentito di minimizzare i danneggiamenti per taglio originariamente osservati nei sopraporta e nei maschi murari 'tozzi' dell'edificio;

oltre ai benefici legati al miglioramento della resistenza nel piano della muratura, è importante ricordare come l'intonaco consenta di migliorare sensibilmente il comportamento fuori piano dei maschi murari

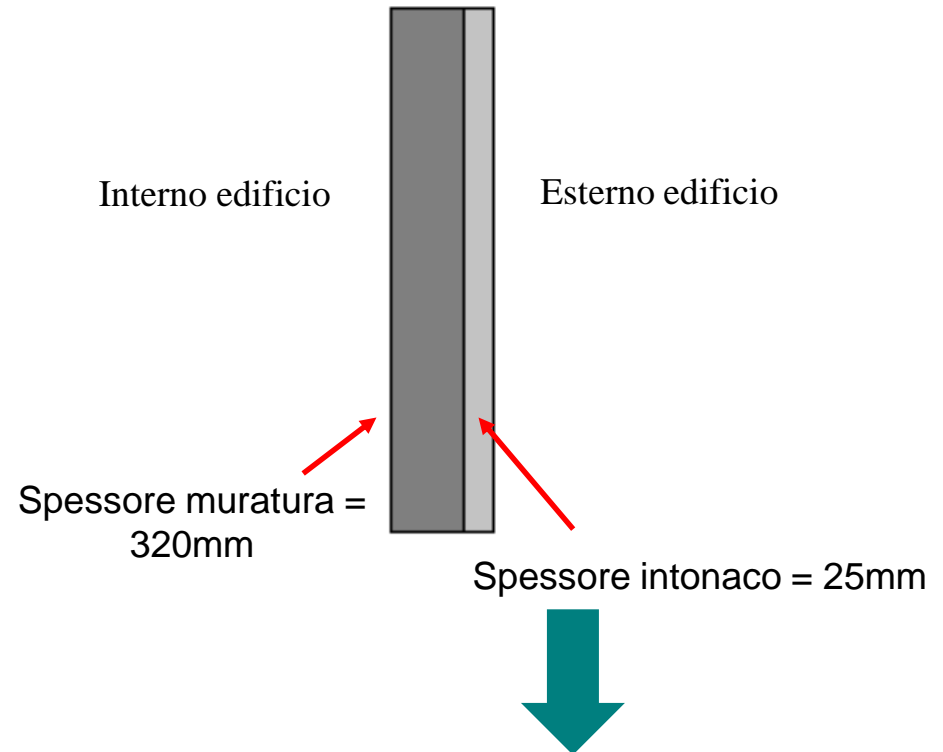


Analisi "pushover" con programma ad elementi finite Diana 9.4



Elementi finiti tipo shell 'layered'

Elemento finito shell



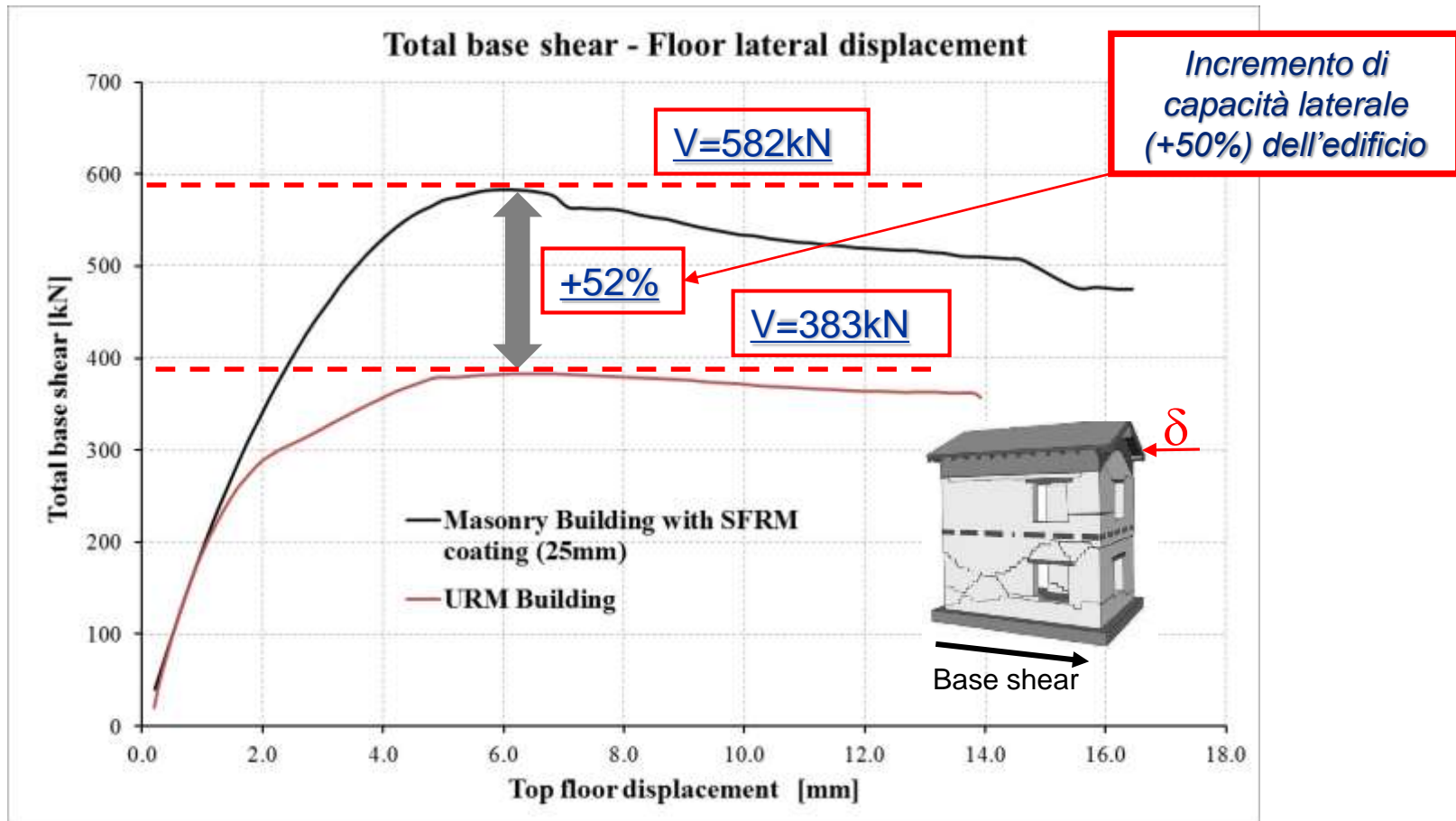
Spessore muratura =
320mm

Spessore intonaco = 25mm

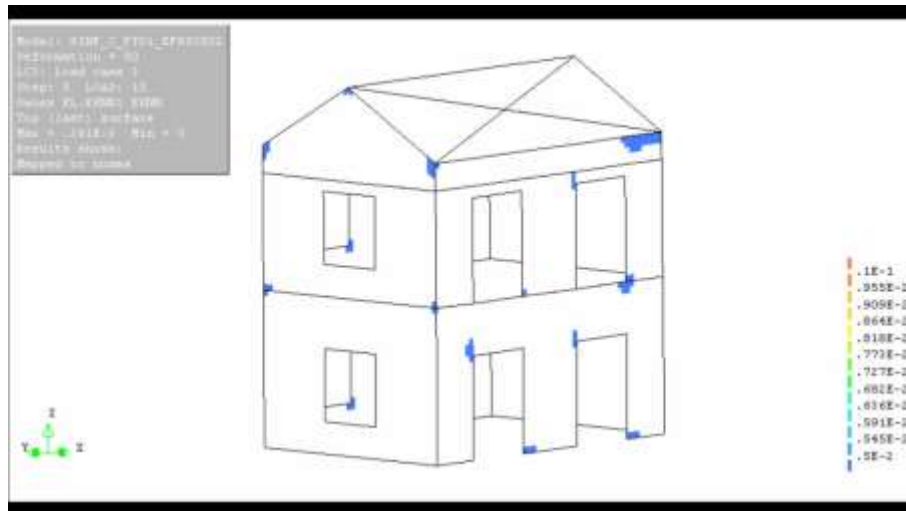
Intonaco: malta nanocomposita rinforzata
con fibre d'acciaio ad elevata resistenza

Risultati della simulazione numerica

Confronto tra la curva di capacità sperimentale dell'edificio senza intonaco e quella numerica relativa all'edificio rinforzato con intonaco fibrorinforzato

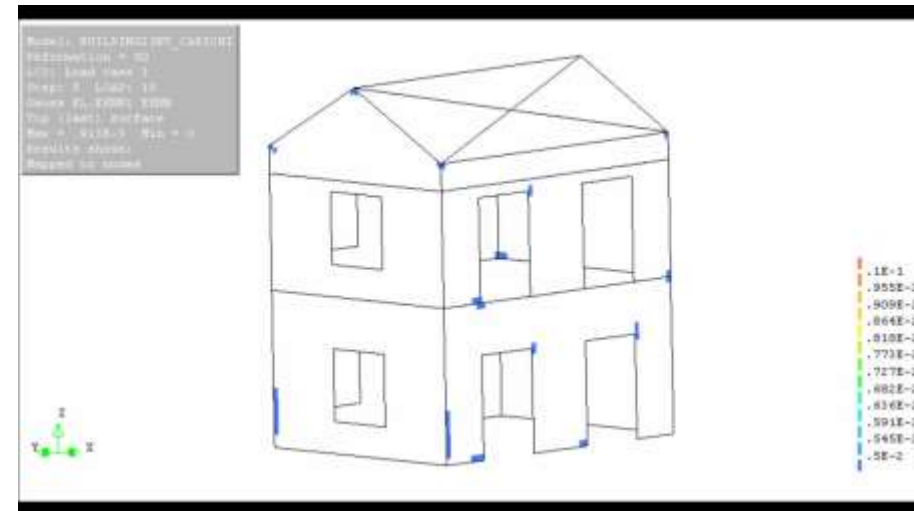


Edificio non rinforzato



**FESSURAZIONE A TAGLIO DI MASCHI
E FASCE MURARI**

Edificio con intonaco fibrorinforzato



**ELIMINAZIONE DELLE FESSURE A
TAGLIO
FESSURE AGLI ANGOLI DELLE
APERTURE**

Test su edificio in scala reale

APPLICAZIONE DELLA TECNICA DI RINFORZO CON SFRM AD UN EDIFICIO IN SCALA REALE



STRUTTURA

- Muratura in mattoni forati
- Impalcati e copertura in legno
- Cappa e cordoli in C.A. per riprodurre un diaframma di piano

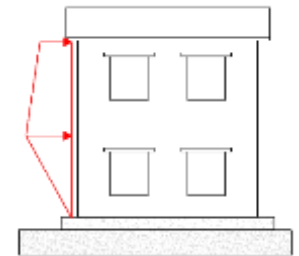
AZIONE SISMICA

- Applicazione quasi statica di carichi orizzontali tramite un martinetto elettromeccanico fissato alla torre di contrasto e opportuni ripartitori verticali

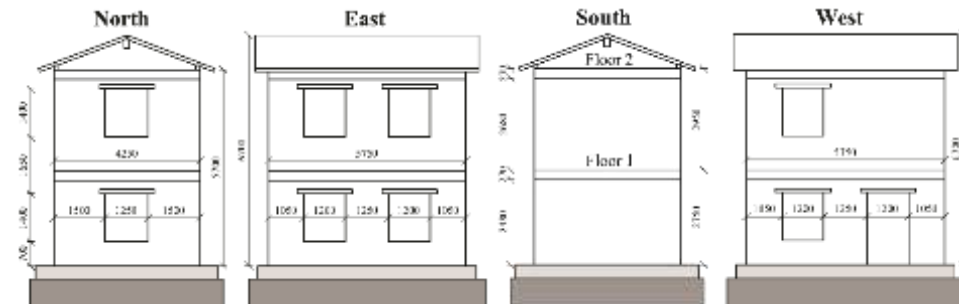
Caratteristiche dell'edificio



Spessore=200mm;
Foratura 60%



Proporzionale alla
massa di piano

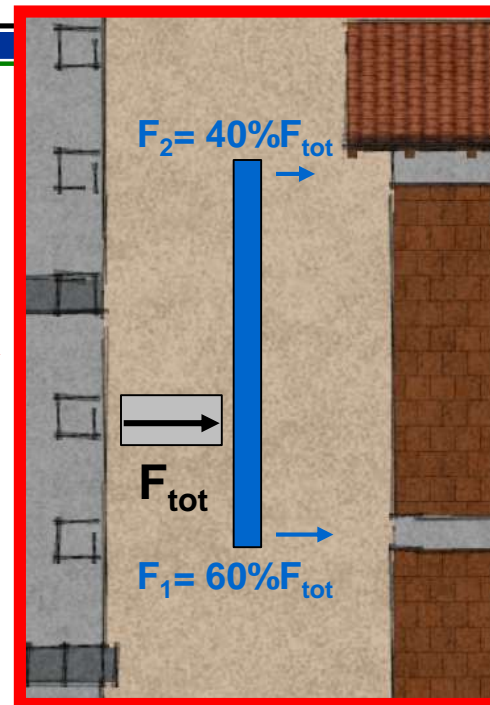
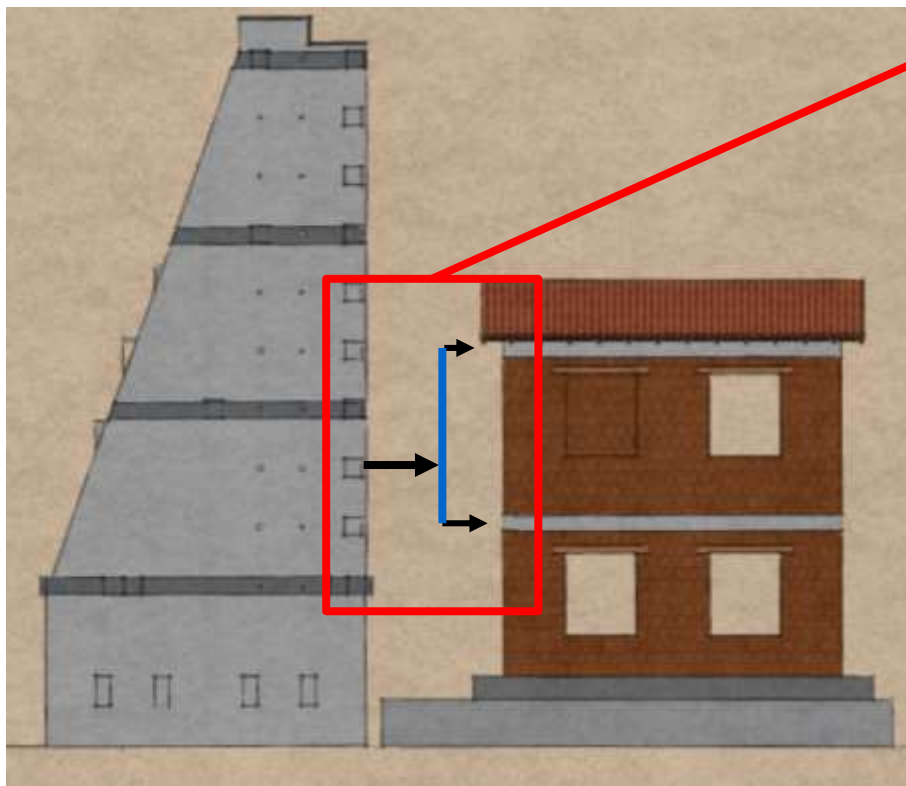


1 porta + 8 finestre

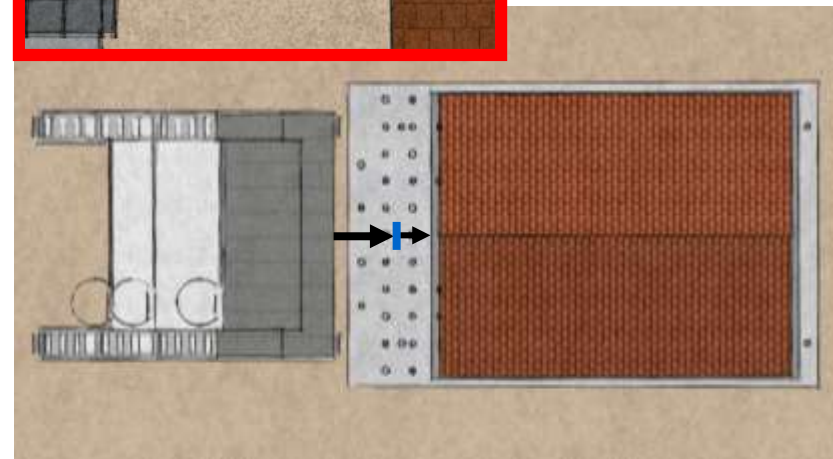
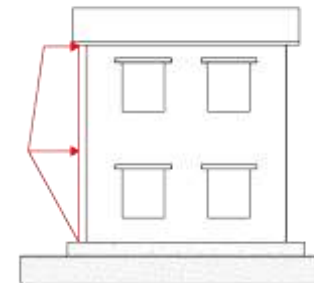
Sistema di carico

□ MARTINETTO ELETTROMECCANICO

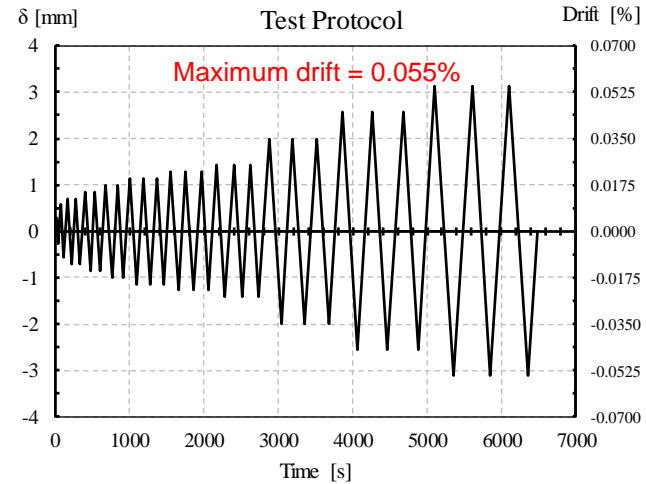
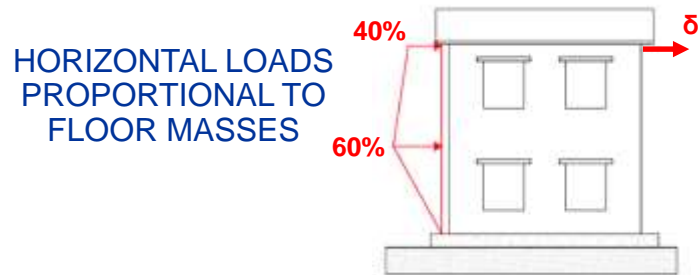
■ RIPARTITORE VERTICALE



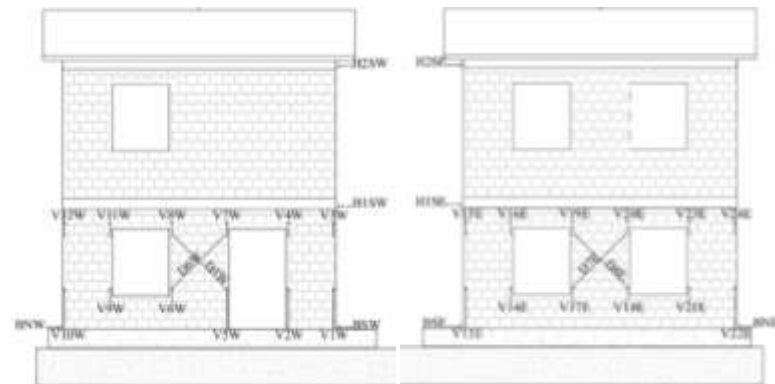
GRUPPO 2
(Proporzionale alla distribuzione di massa)



Test setup and protocol

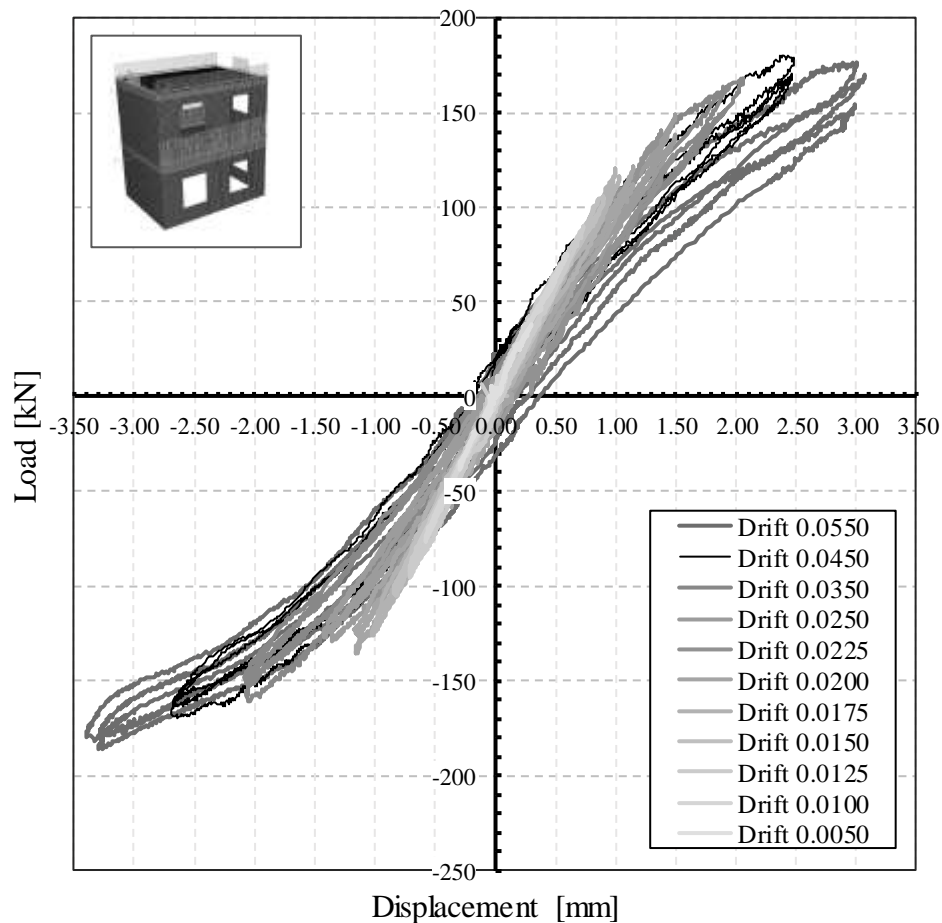


LONGITUDINAL WALLS INSTRUMENTATION



Experimental results

CYCLIC RESPONSE OF UNSTRENGTHENED BUILDING



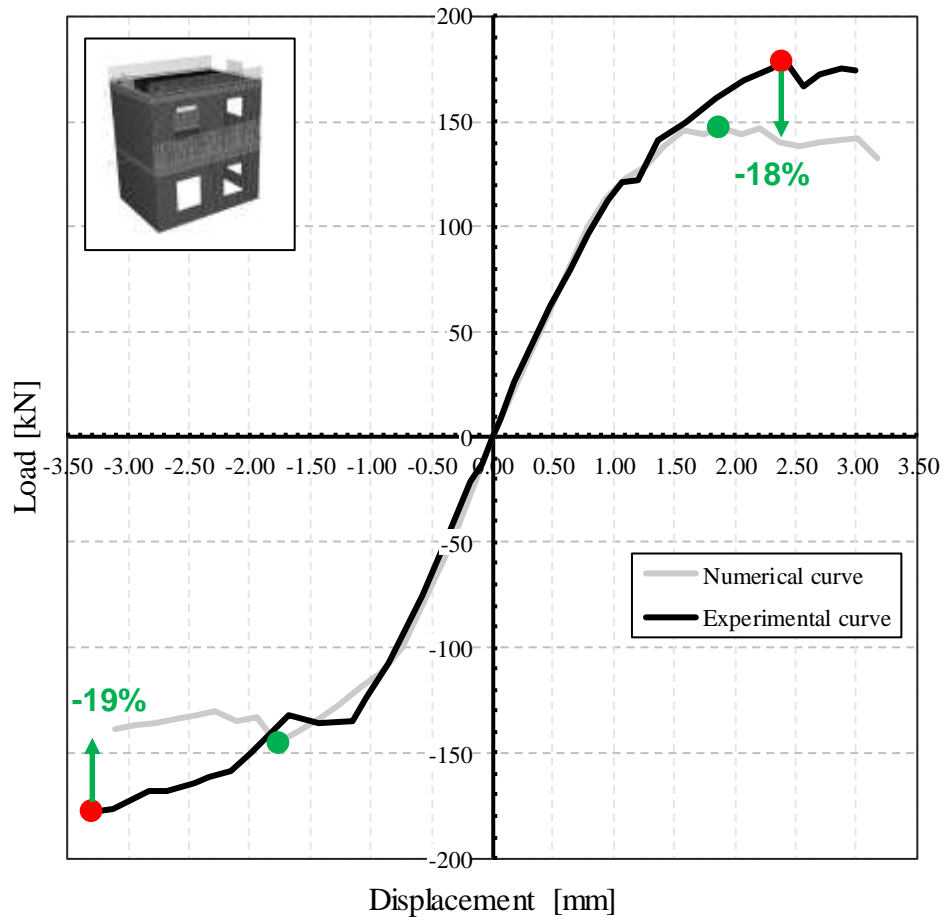
	Positive loading direction	Negative loading direction
K_S [kN/mm]	134	128
V_{cracking} [kN]	120	128
V_{peak} [kN]	180	179
δ_{peak} [kN]	2.4	3.4



FAILURE MODE:
In-plane longitudinal walls response
Diagonal shear failure of masonry piers at ground floor

Experimental vs numerical results

LATERAL LOAD – DISPLACEMENT ENVELOPE

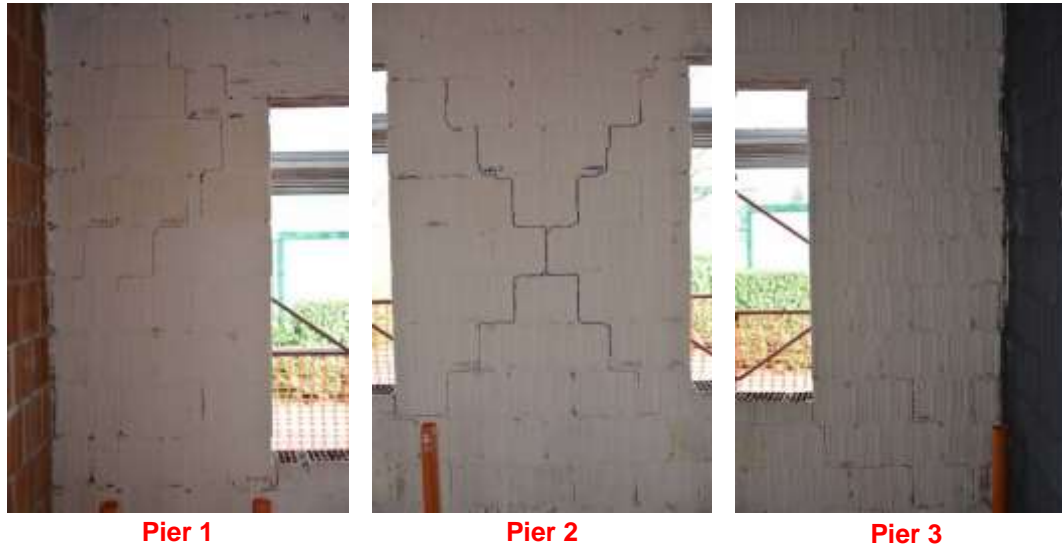


	Experimental	Numerical
K_S^+ [kN/mm]	134	129 (-4%)
K_S^- [kN/mm]	128	153 (+20%)
$V_{cracking}^+$ [kN]	120	114 (-5%)
$V_{cracking}^-$ [kN]	128	112 (-12%)
V_{peak}^+ [kN]	● 180	● 147 (-18%)
V_{peak}^- [kN]	● 179	● 145 (-19%)

Numerical initial stiffness closed to the experimental one

First cracking and maximum numerical loads slightly underestimated

Experimental vs numerical results



Pier 1

Pier 2

Pier 3

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



FAILURE MODE:

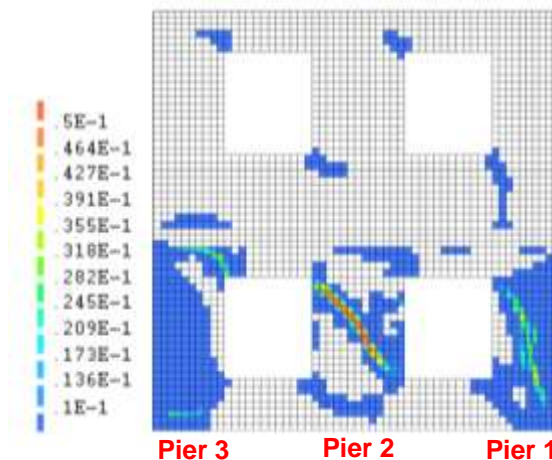
Diagonal shear failure of
central pier (Pier 2)

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

Incipient diagonal shear
crack of Pier 1



TENSILE CRACKING
STRAIN AT THE COLLAPSE
OF NUMERICAL ANALYSIS
(outside view of east façade):

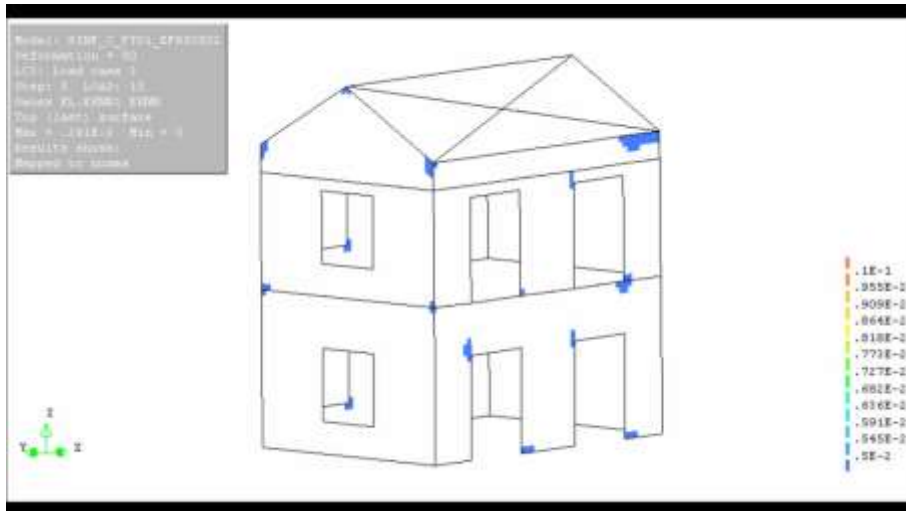


Pier 3

Pier 2

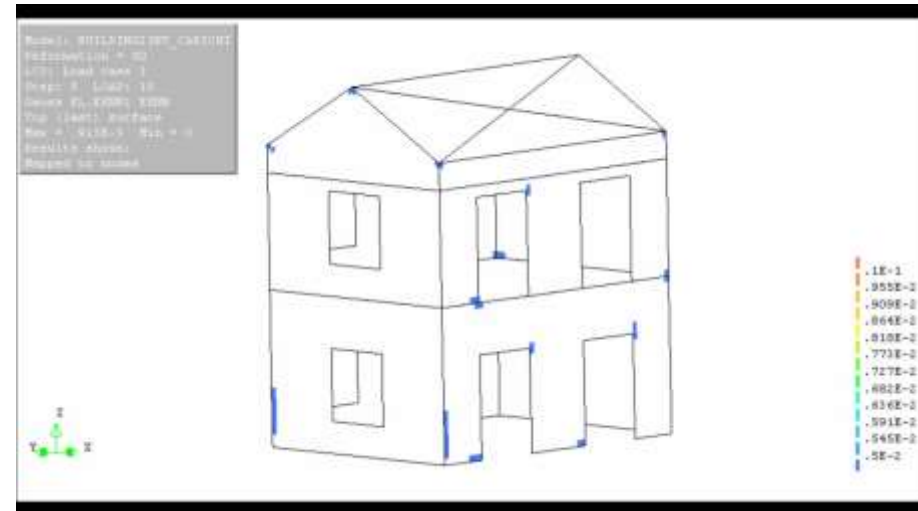
Pier 1

Unstrengthened building



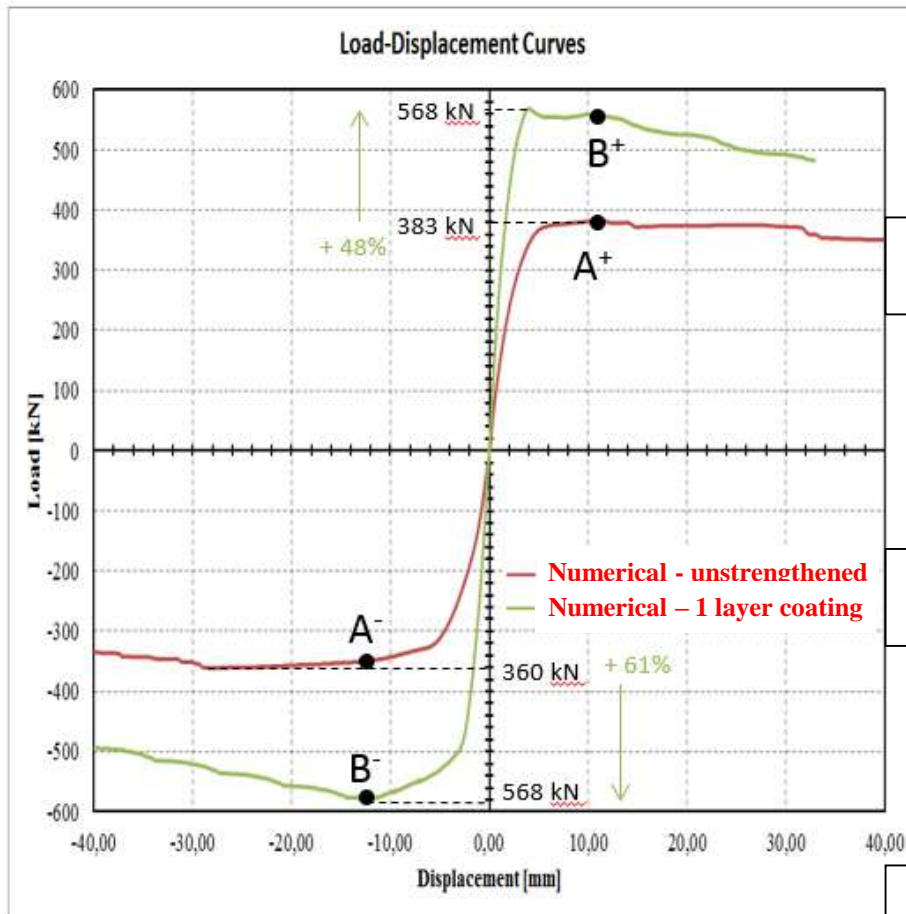
SHEAR CRACK IN MASONRY WALLS

Strengthened building



**NO MORE SHEAR CRACKS
CRACK FROM THE WINDOW
CORNERS**

Numerical simulation of the masonry building strengthened with 1 layer of SFRM



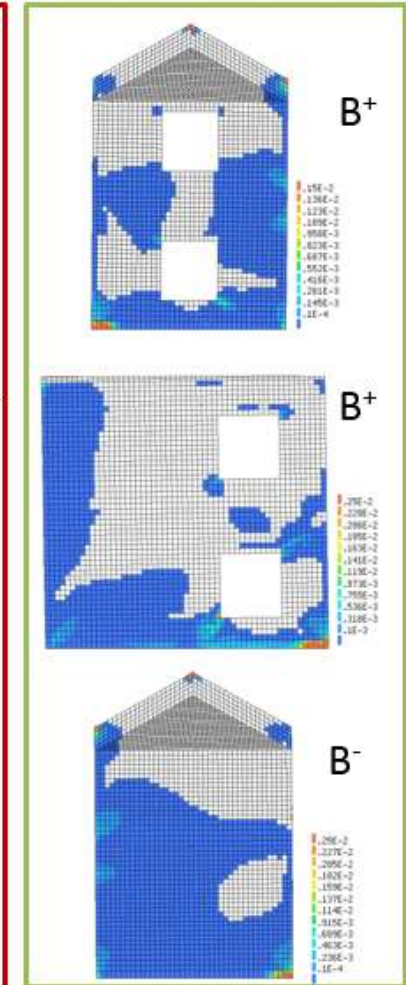
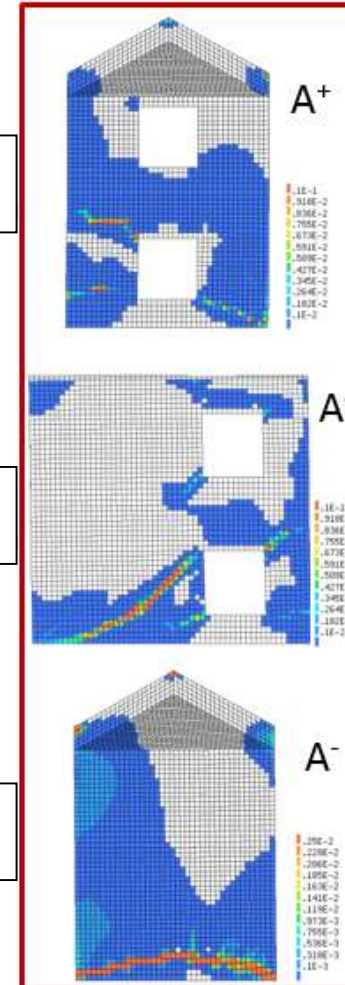
North side

East side

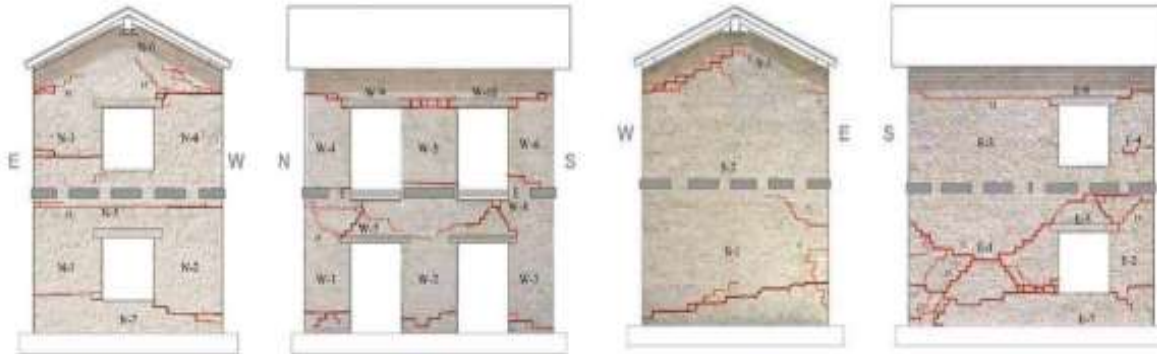
South side

No coating

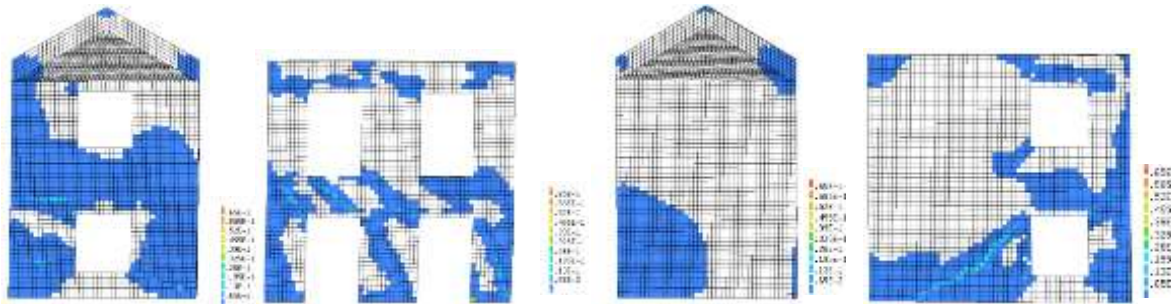
1 layer of SFRM



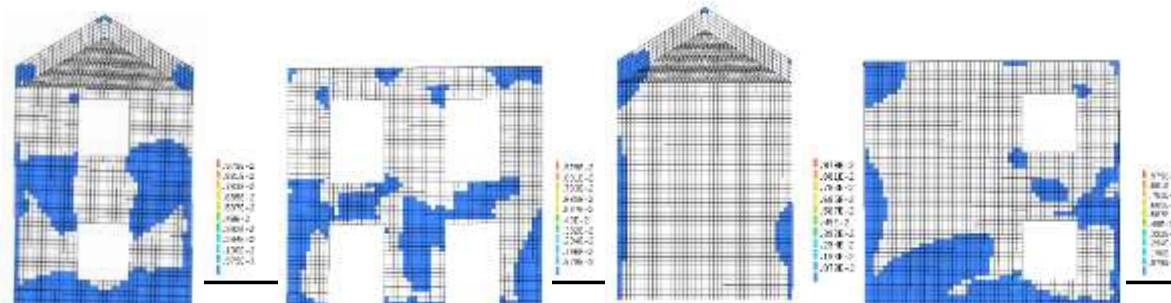
Results of the finite element analyses



Damage pattern after the experimental test



Numerical crack pattern of the unstrengthened specimen



Numerical crack pattern of the specimen strengthened with 1 layer of SFRM



Thank you for your kind attention!



University of Brescia, Italy



Documents regarding FRC tunnel segments



ACI 544.7R-16

Report on Design and Construction of Fiber-Reinforced Precast Concrete Tunnel Segments

Reported by ACI Committee 544

Emerging Technology Series

aci American Concrete Institute
Always advancing

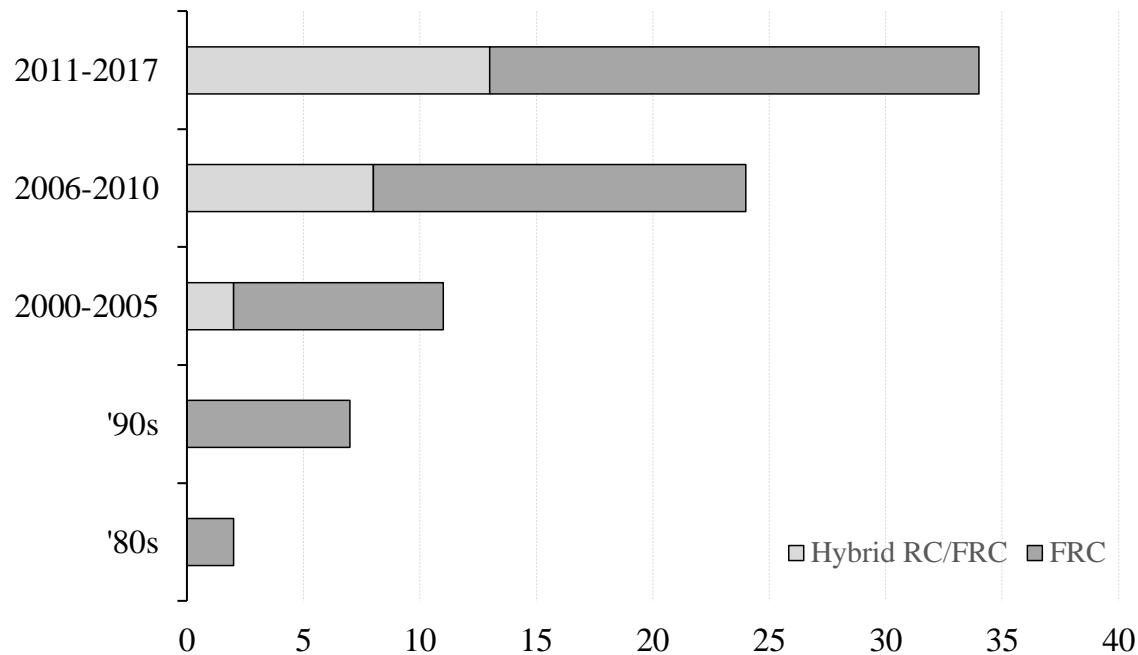
- **ITA report n. 16 (2016)**, “*Twenty years of FRC tunnel segments practice: lessons learnt and proposed design principles*”, April 2016, ISBN 978-2-970-1013-5-2, 71 p.
- **ACI Committee 544 (2016)**. “*Report on Design and Construction of Fiber Reinforced Precast Concrete Tunnel Segments*”, ACI 544.7R-16, American Concrete Institute, Farmington Hills, MI, pp. 36.
- **fib Working Party 1.4.1**. “*Tunnels in fiber reinforced concrete*”, under publication.

Fiber Reinforced Concrete, FRC

The use of FRC for precast tunnel segments:

from '80s → 78 tunnels

FRC & RC/FRC (Hybrid) precast tunnel segments: case studies over the years

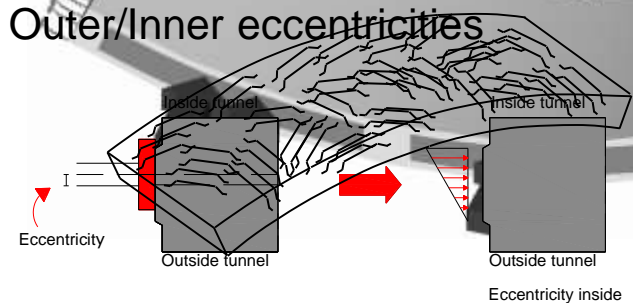


Segmental lining

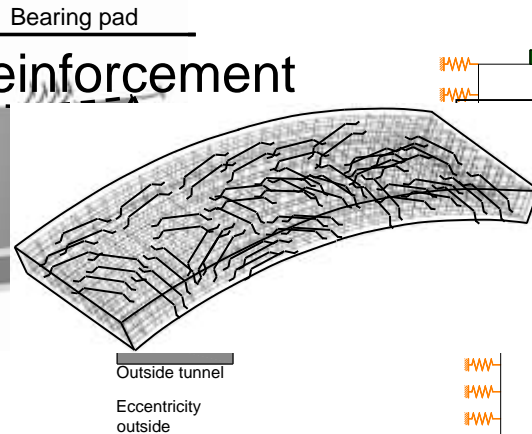


Design features in tunnel segments

- Modelling the loading/boundary conditions generally adopted by designers
- Modelling the loading/boundary conditions representing possible irregularities
- Design of an optimized reinforcement



50/1,0- $V_f=0,57\%$ →45 kg/m³
 50/0,75- $V_f=0,32\%$ →25 kg/m³



RC+50/0,75- $V_f=0,32\%$ →122 kg/m³
 RC→97 kg/m³

