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# Rivestimento in anelli di conci prefabbricati di gallerie realizzate con TBM: armature alternative

## EVENTO ON LINE – 18 Marzo 2021

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**INTRODUZIONE**
**ESEMPI**
**NORMATIVE, LINEE GUIDA, RACCOMANDAZIONI**

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PRO ITER
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**CON IL PATROCINIO DI**

fib CEB-FIP
Fédération Internationale du Béton

Società Italiana Gallerie
Italian Tunnelling Society

# Introduzione

- Scavo meccanizzato
- Armatura tradizionale
- Armature alternative
- FRC
- Confronti steel rebar vs FRC / GFRP rebar
- Aspetti non direttamente evidenziabili dai confronti

# Esempi

- Modellazione 3D
- Danni ai conci
- GFRP

# Normative, Linee Guida e Raccomandazioni

- FRC
- GFRP
- Precast concrete tunnel segments
- Precast tunnel segments FRC


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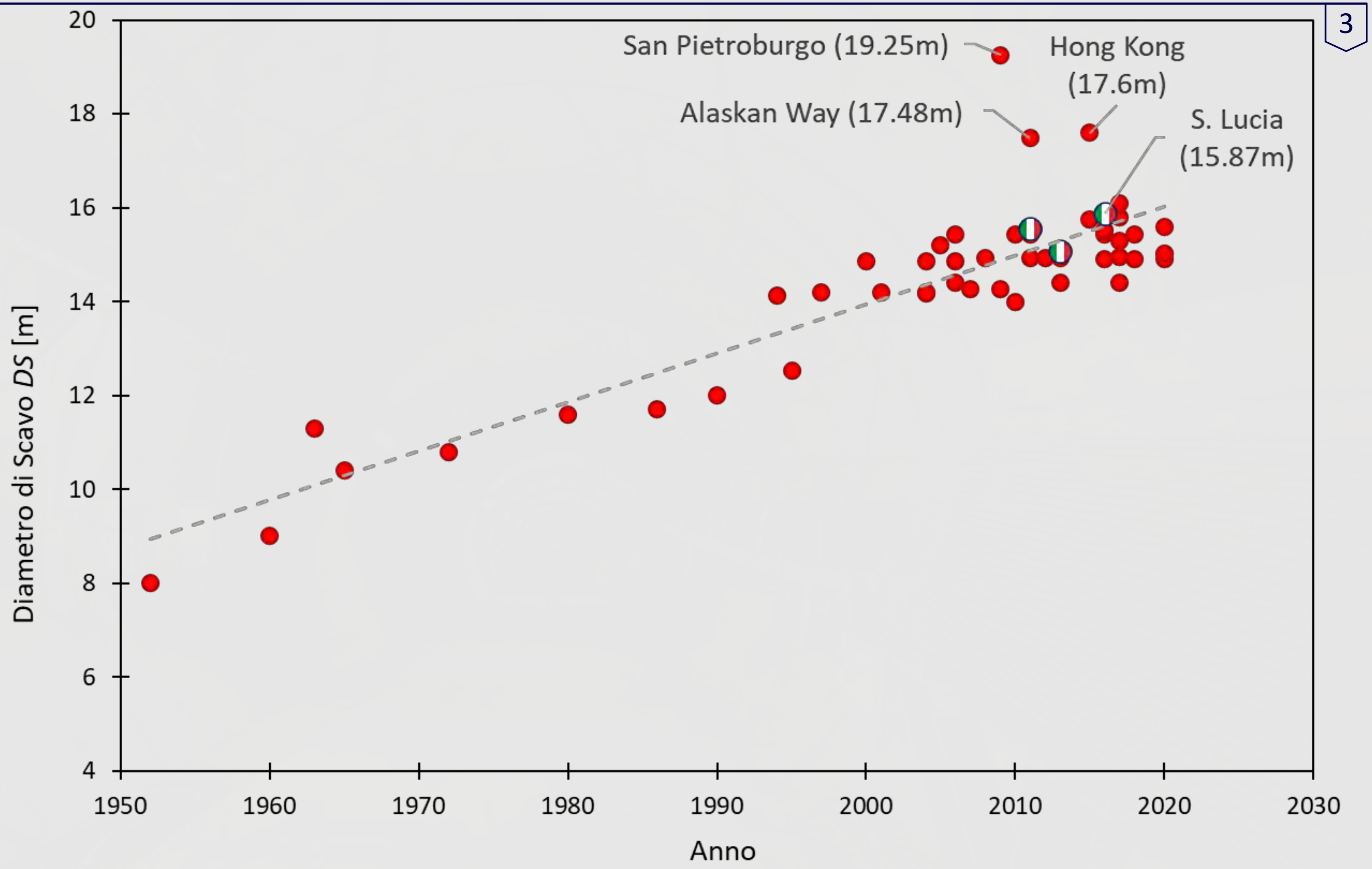
# Introduzione

## Scavo meccanizzato

### *Evoluzione del diametro di scavo nel tempo*

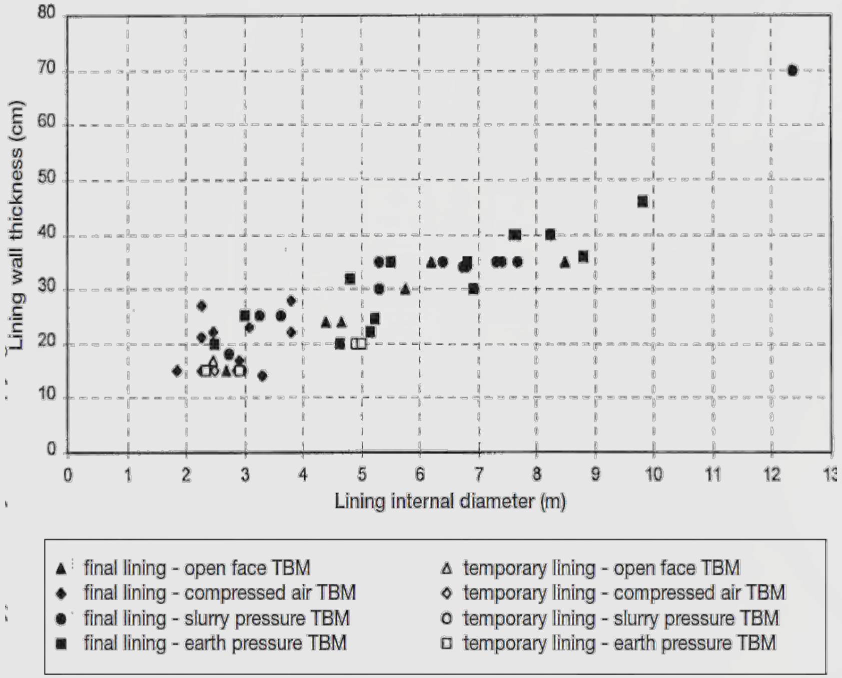
| IN ITALIA | |
|---|---|
| Galleria Caltanissetta | *DS* = 15.08m |
| Galleria Sparvo | *DS* = 15.55m |
| Galleria S. Lucia | *DS* = 15.87m |
| **NEL MONDO** | |
| Tuen Mun – Chek Lap Kok Link (Hong Kong) | *DS* = 17.60m |
| Orlovsky Tunnel (San Pietroburgo) in progetto | *DS* = 19.25m |

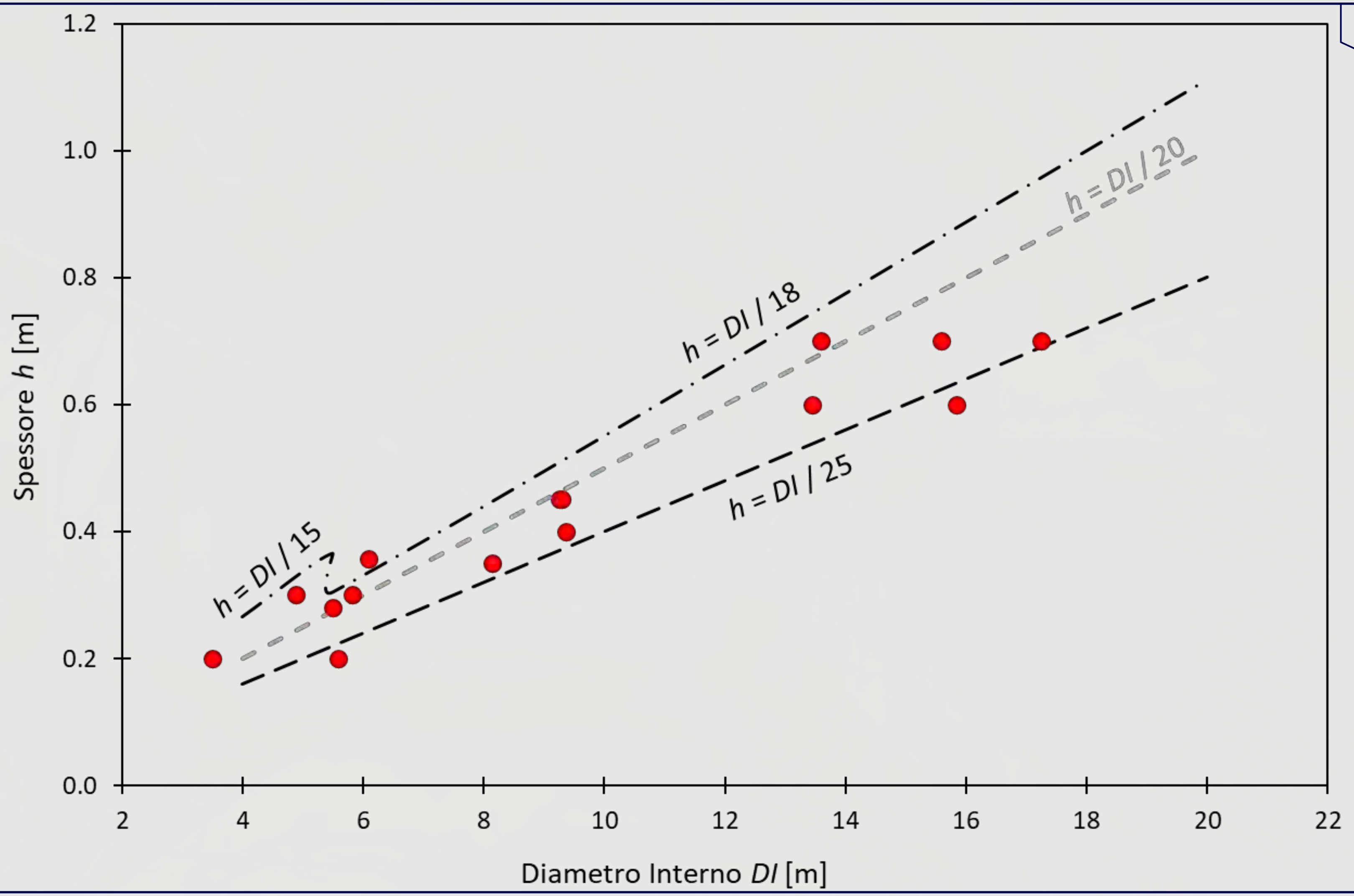


# Introduzione

## Scavo meccanizzato

### *Legame tra il diametro interno e lo spessore del rivestimento*



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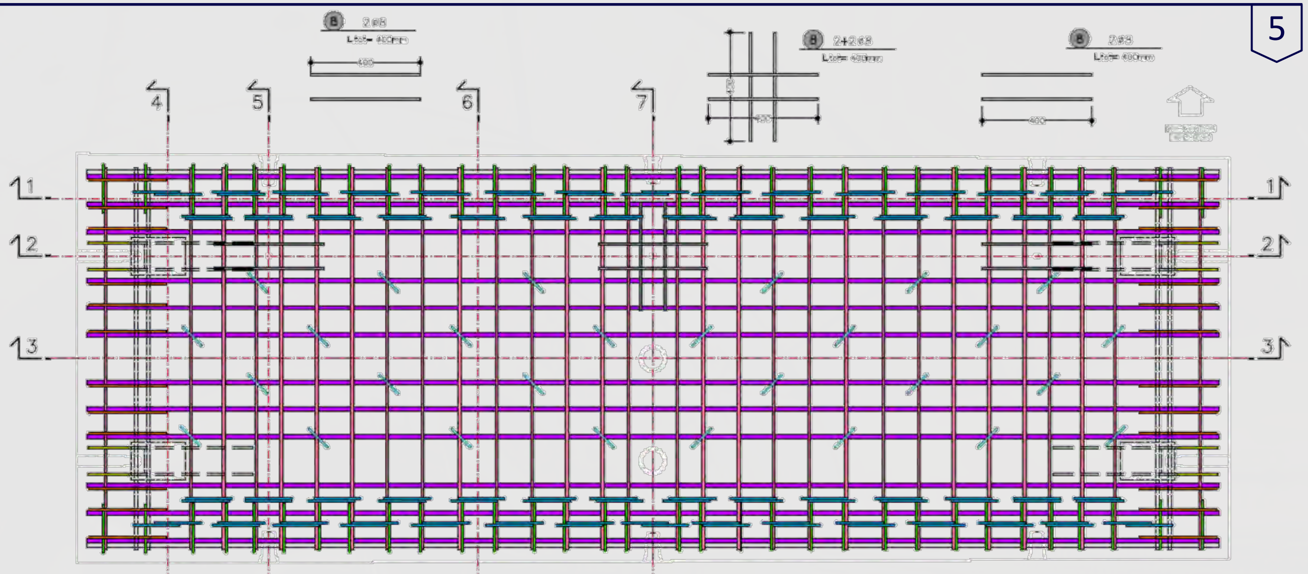
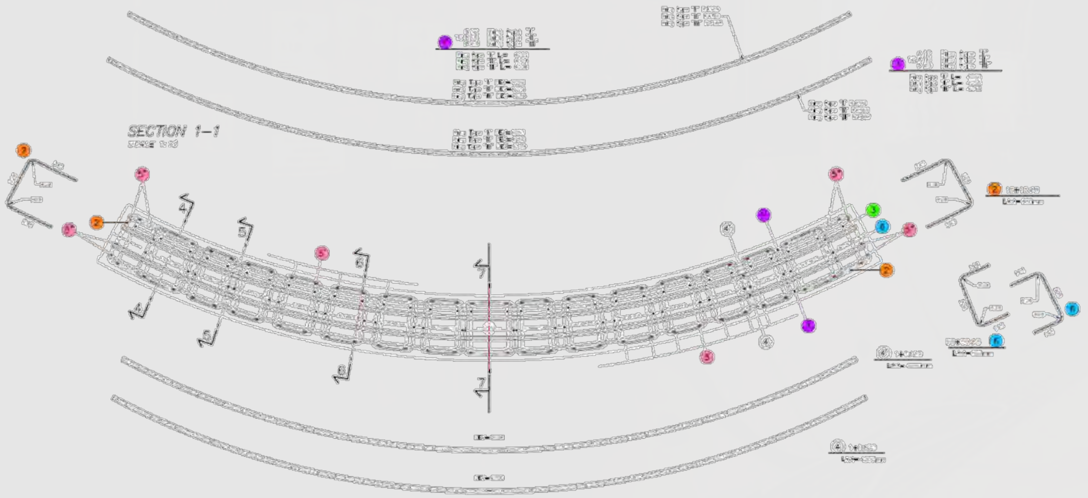
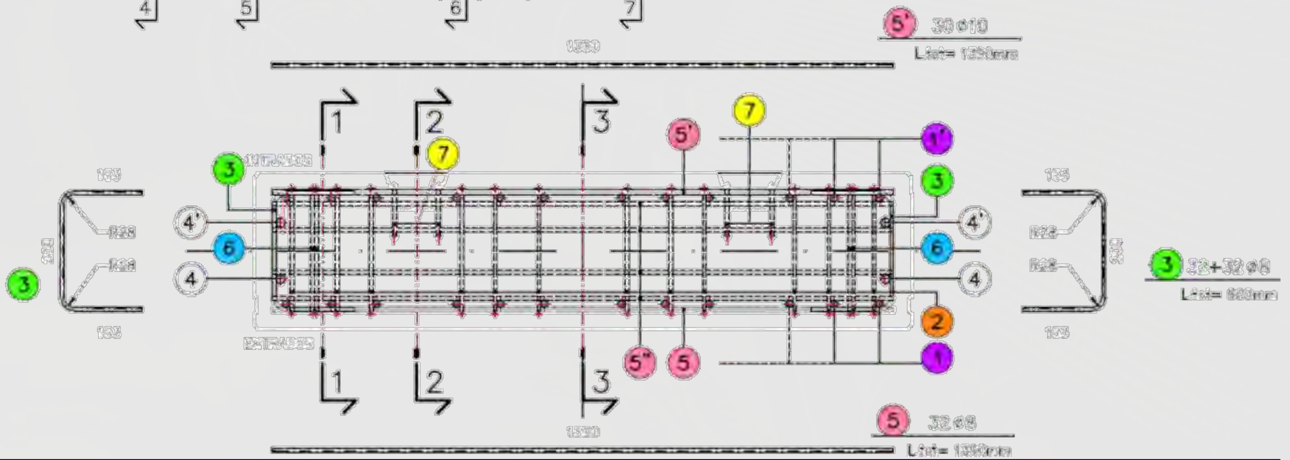
# Introduzione

## Armatura tradizionale: componenti

*a) Principale (circonferenziale)*
*b) Ripartizione (longitudinale)*
*c) A taglio (radiale)*
*d) Frettaggio (perimetro, tasche, boccole, inserti ecc.)*





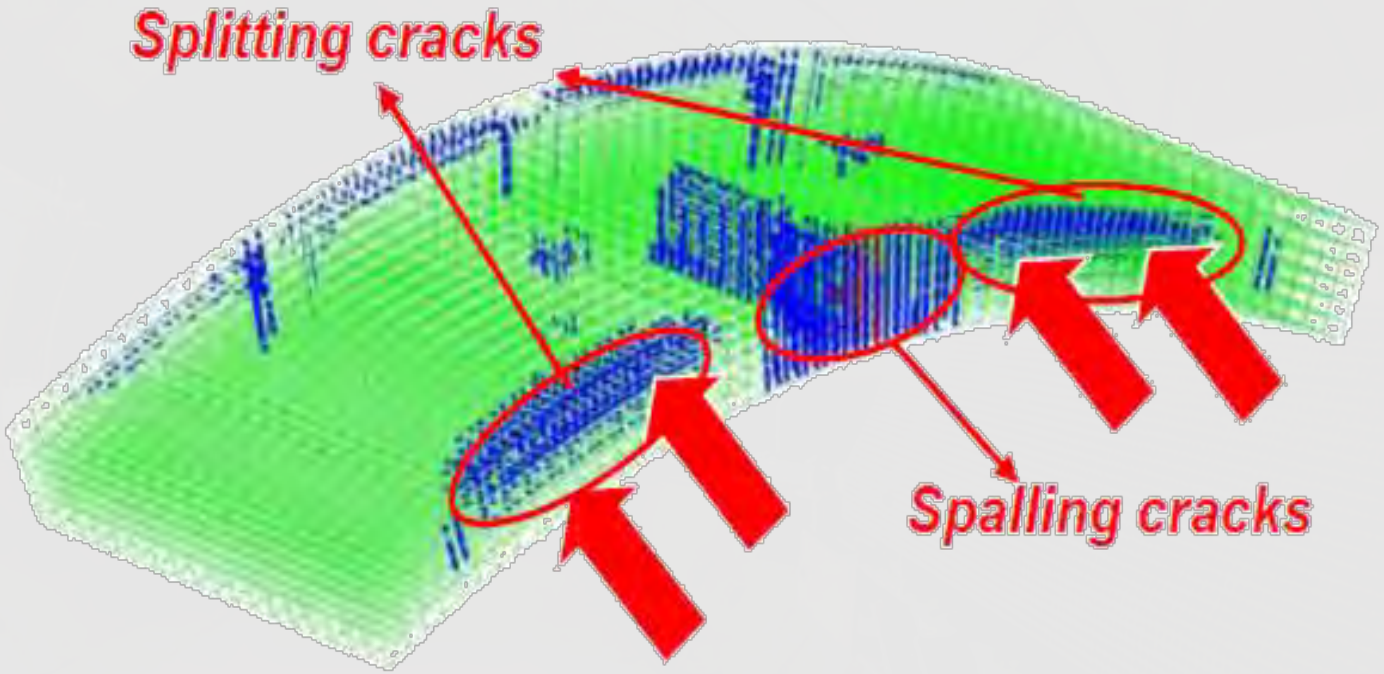
# Introduzione



## Armatura tradizionale: componente d)

**Spalling stresses :**
local tensile stresses that arise in the lining in the region between the thrust jack plates (thrust shoes) because of the interaction of adjacent jacks or couple of jacks;

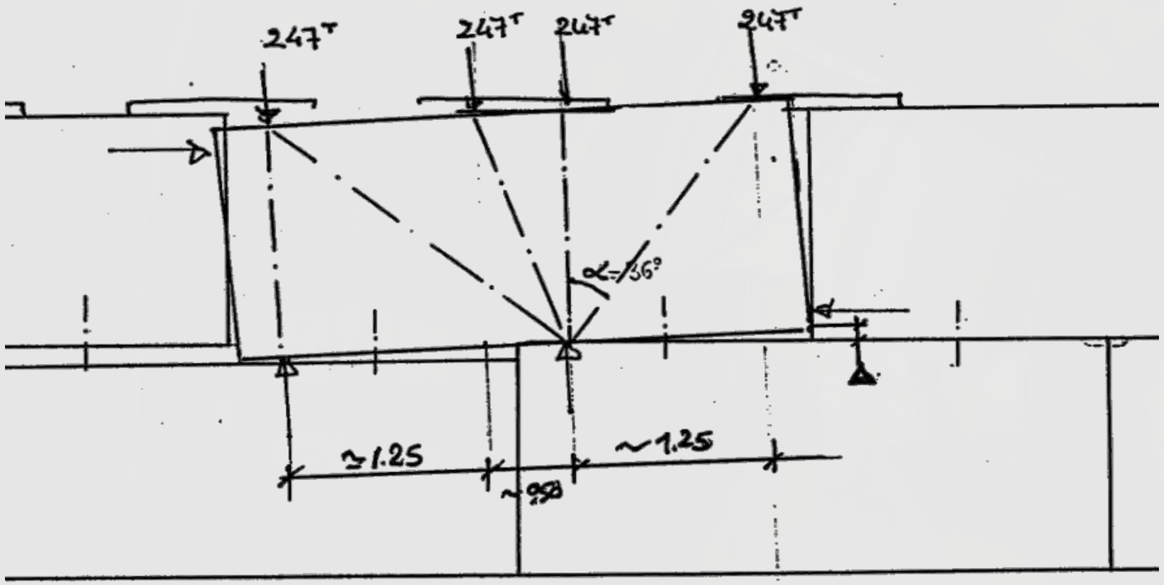
**Splitting stresses :**
local tensile stresses (also called bursting stresses) which arise during the jacks thrust in tunnel segments under their loading areas in transverse direction (perpendicular to the axis of the applied forces);

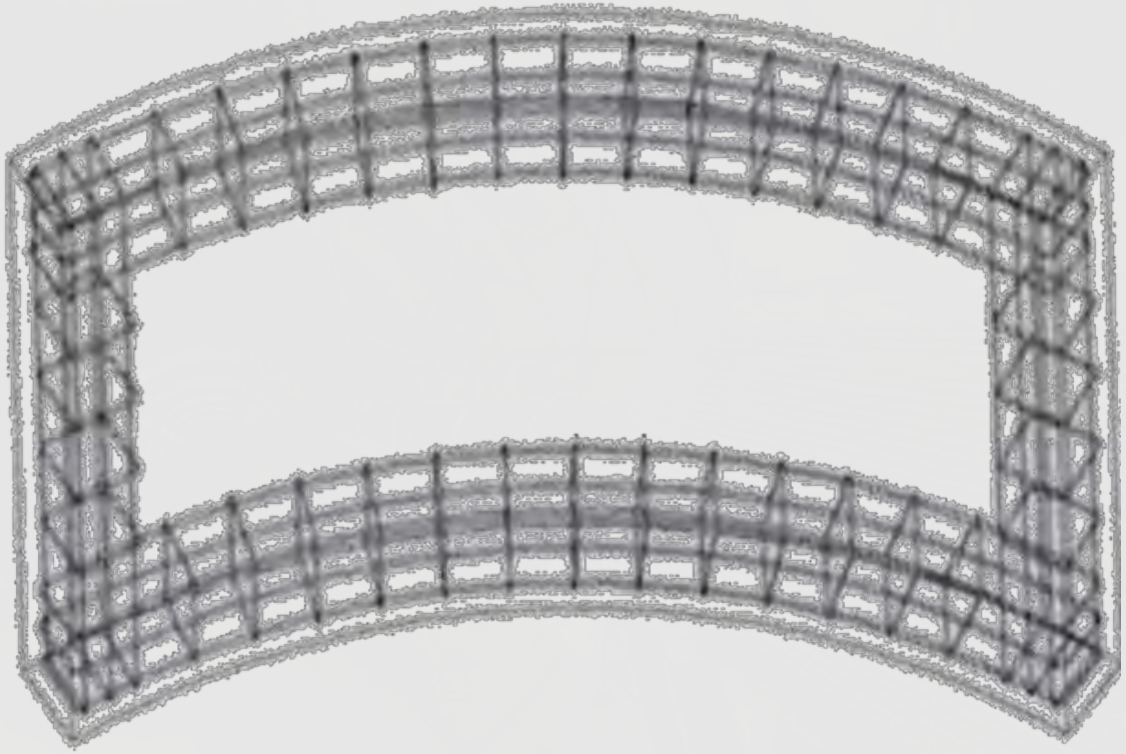


# Introduzione



## Armatura tradizionale: componente d)



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# Introduzione

## Armatura tradizionale: componenti

Le prime tre componenti (**principale, ripartizione, a taglio**) sono quelle deputate a far fronte agli sforzi diffusi: M, N – circonferenziale e longitudinale – T).

Le **fibre** (armature diffusa) rappresentano una buona alternativa nel caso sforzi diffusi.

L'**armatura di frettaggio** contrasta invece l'effetto degli sforzi localizzati.

Le **barre** (in acciaio o GFRP) sono la migliore armatura per sforzi localizzati.

# Introduzione

## Armature alternative

### Armature fibrose

Acciaio

Alluminio

Vetro

Carbonio

Polipropilene

### Barre in GFRP

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# Introduzione

## Armature alternative

| | Lunghezza [mm] | $\varnothing_{medio}$ [µm] | $f_t$ [MPa] | E [GPa] |
|---|---|---|---|---|
| **Fibre in acciaio** | 30 ÷ 60 | 500 | ≥ 1100 | 210 |
| **Fibre in polipropilene** | 6 ÷ 24 | 20 ÷ 400 | 340 ÷ 500 | 8.5 ÷ 12.5 |
| **Fibre in carbonio** | 10 ÷ 20 | 8 ÷ 10 | > 2000 | 180 ÷ 240 |
| **Fibre in vetro** | ≅ 12 | 14 | - | 72 |

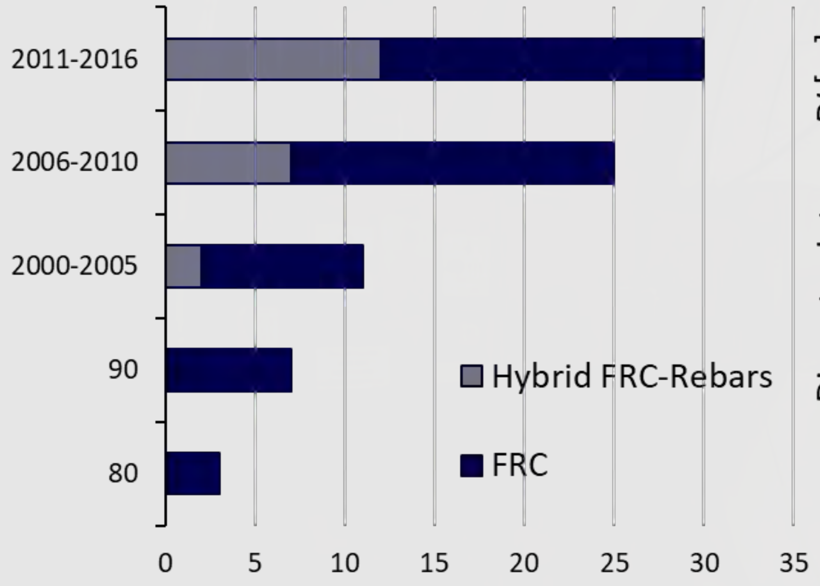


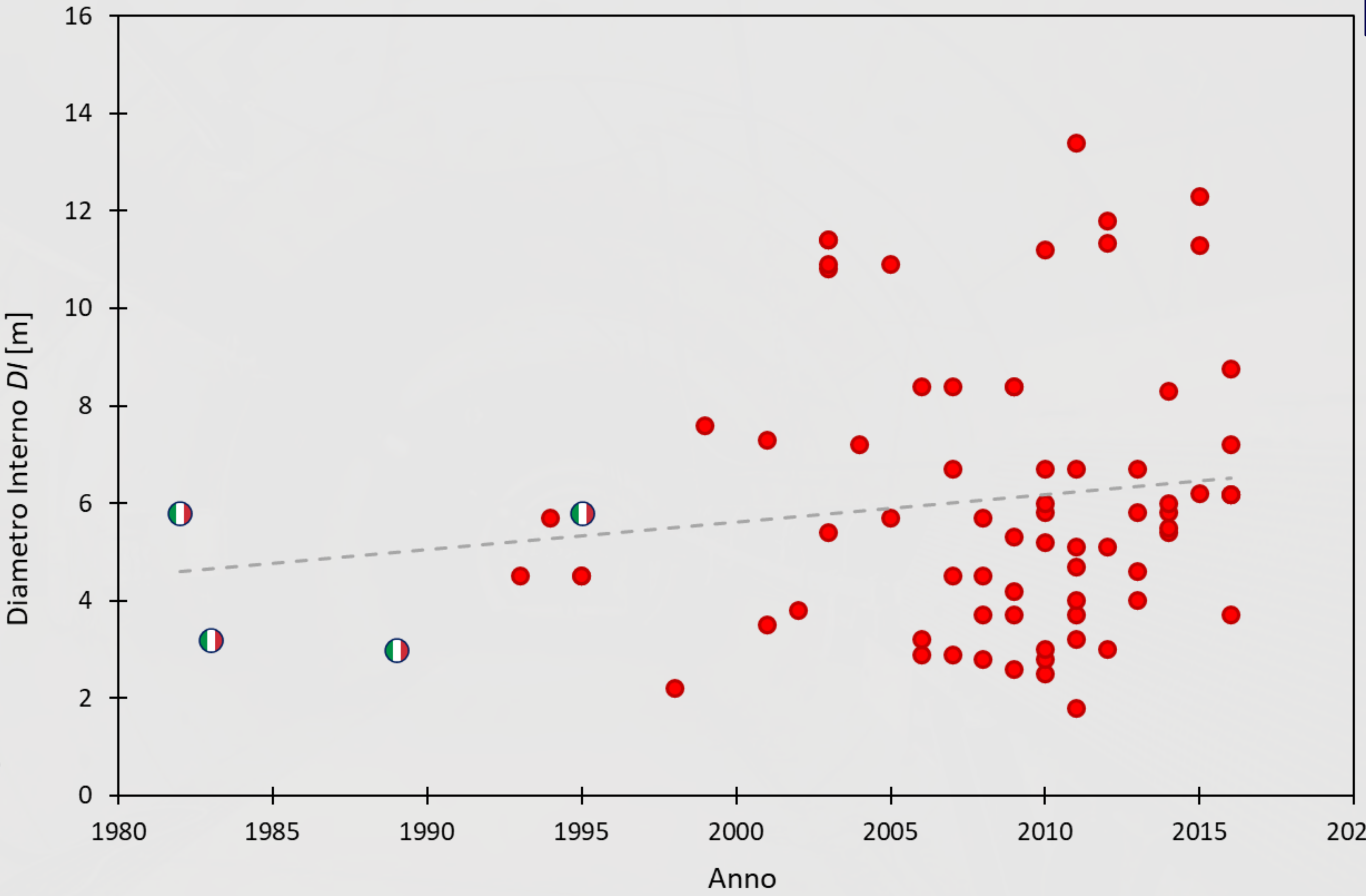

| | Peso [kg/m³] | $\tau_{ad}$ [MPa] | $f_{yk}$ [MPa] | E [GPa] |
|---|---|---|---|---|
| **Barre in GFRP** | 1’900 | 5 ÷ 8 | 700 ÷ 1000 | 35 ÷ 40 |

# Introduzione

## FRC

### *Evoluzione dell'uso di conci in FRC nel tempo*




dati da bollettino *fib* n. 83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# Introduzione

## FRC

### *Uso di conci in FRC per gallerie con diverse funzioni*

| Funzione | Diametro Interno *DI* [m] | Spessore [m] | % |
|---|---|---|---|
| Servizio | 2.0 – 5.0 | 0.15 – 0.30 | 10 |
| Idraulica | 2.0 – 7.0 | 0.20 – 0.35 | 39 |
| Metropolitane | 6.0 – 9.0 | 0.25 – 0.35 | 21 |
| Ferrovie | 8.0 – 12.0 | 0.30 – 0.40 | 18 |
| Strade | 9.0 – 15.0 | 0.40 – 0.60 | 12 |

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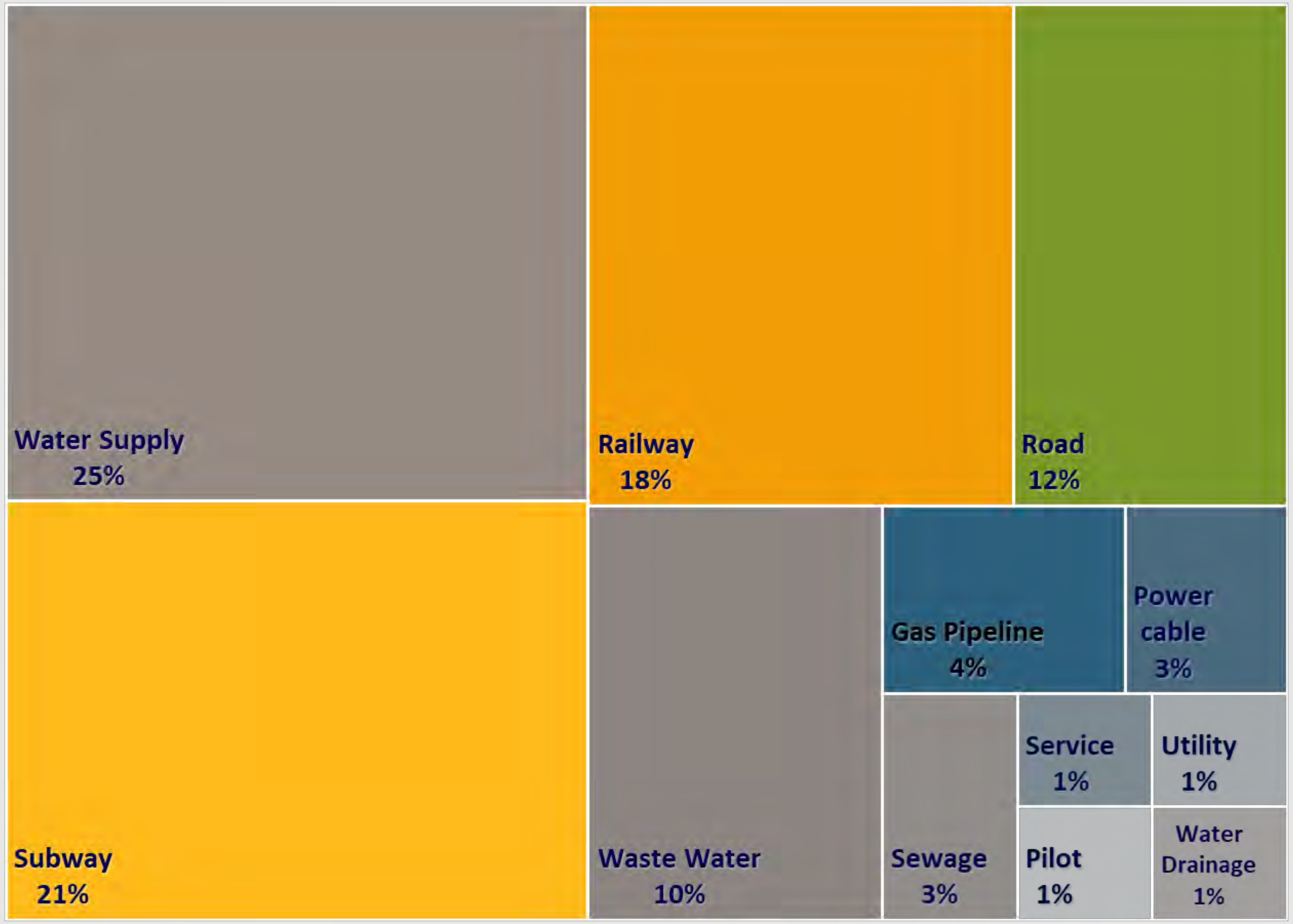



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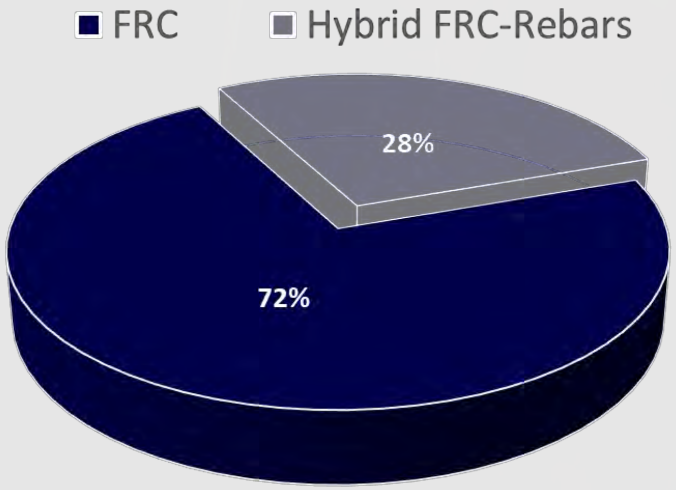
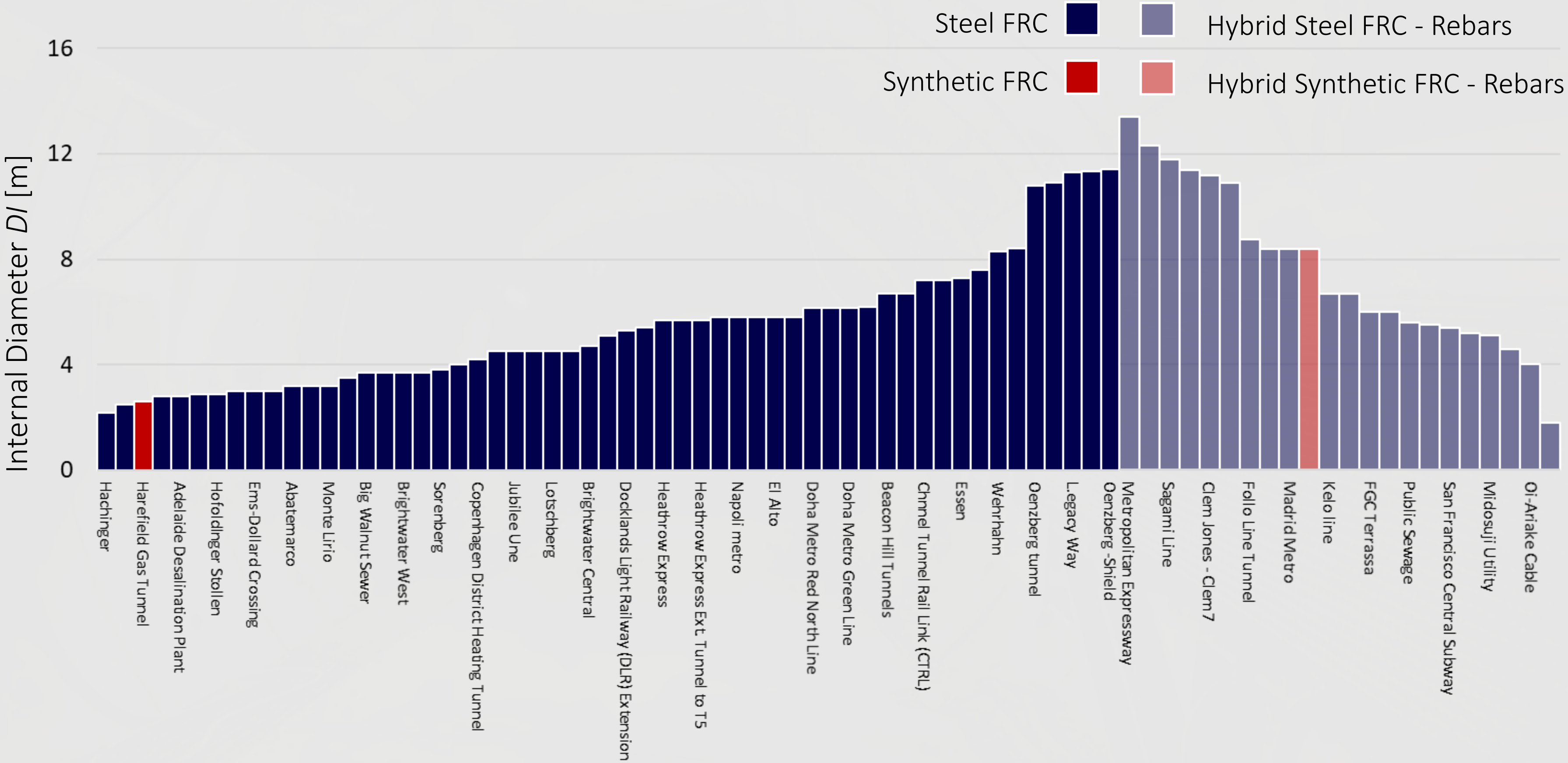
# Introduzione

## FRC

### *Uso di conci in FRC in funzione del diametro*

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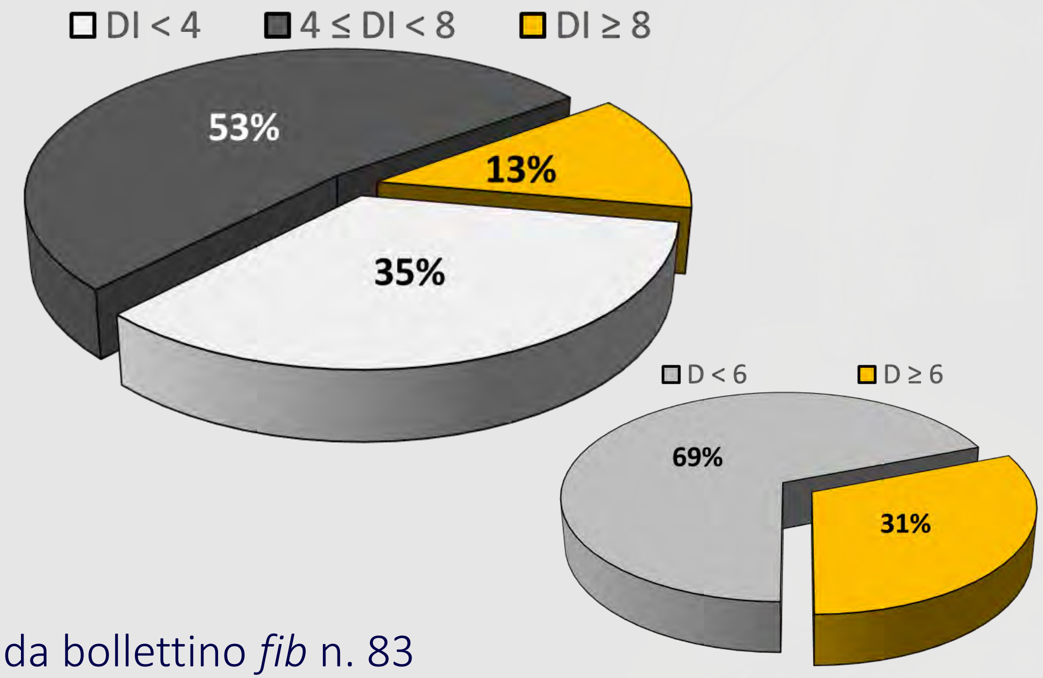
# Introduzione

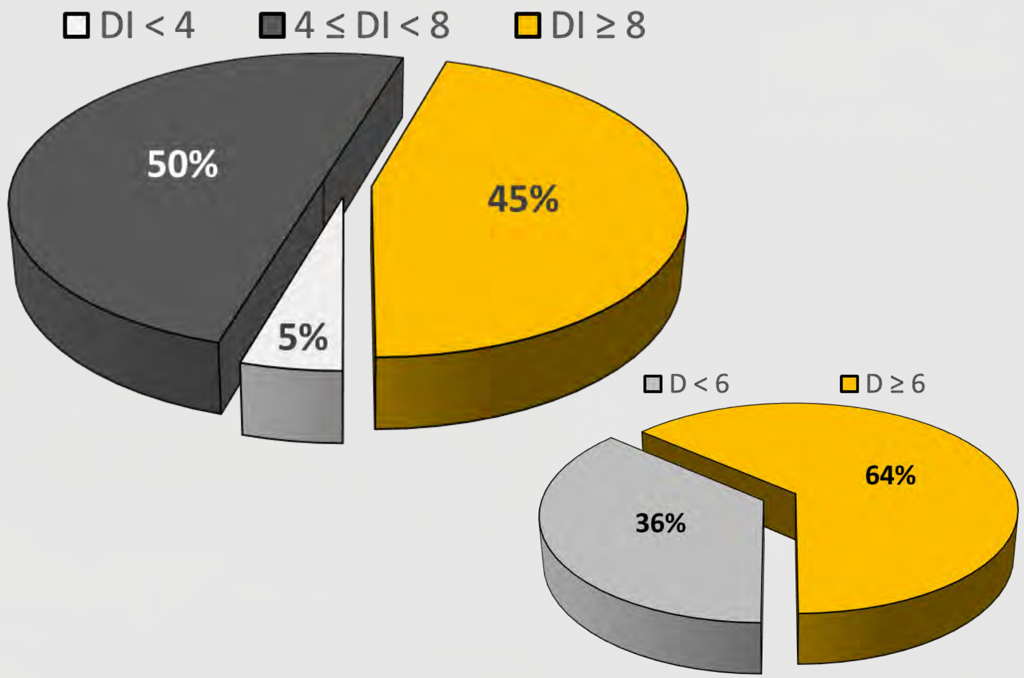
## FRC

### *Uso di conci in FRC in funzione del diametro interno DI*

**FRC**




**HYBRID FRC-REBARS**

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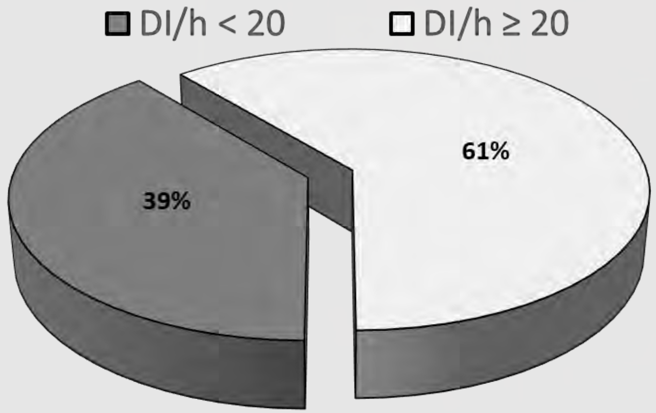
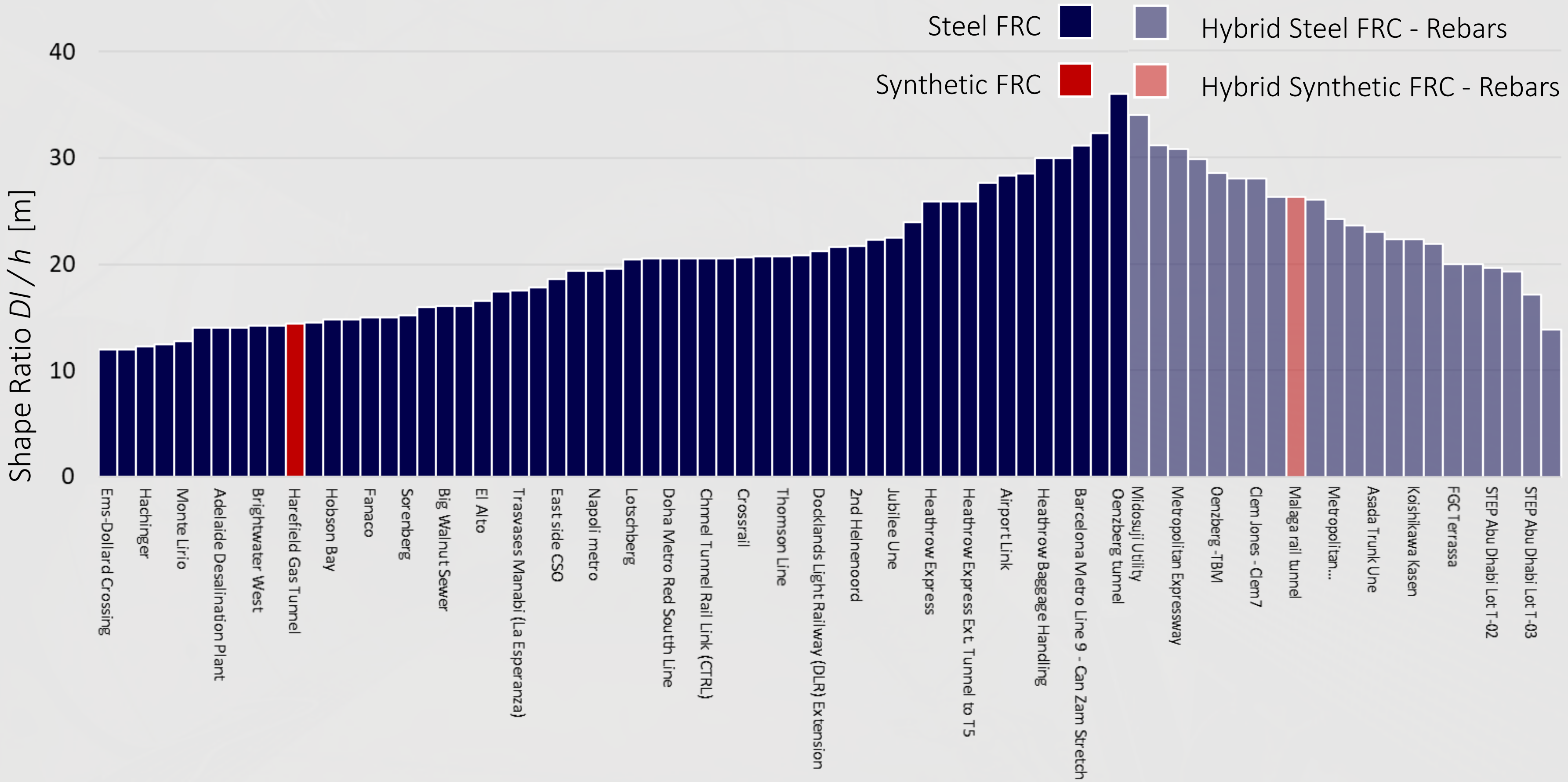
# Introduzione

## FRC

*Uso di conci in FRC in funzione del rapporto di forma DI / h*

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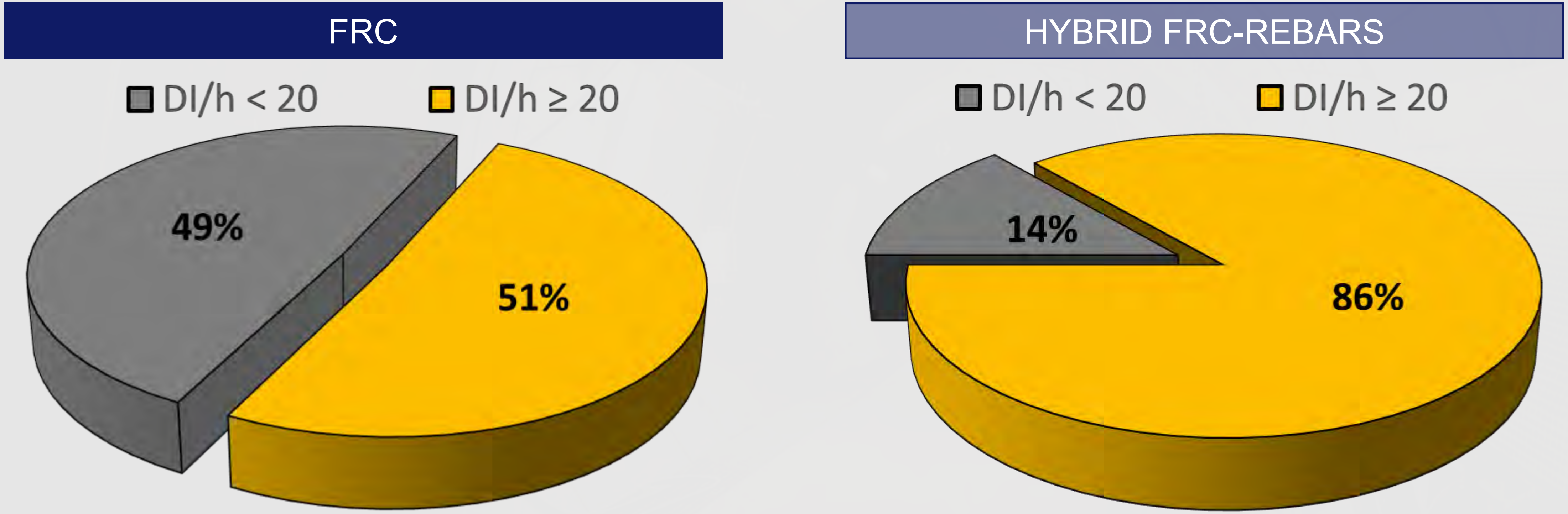
# Introduzione

## FRC

### *Uso di conci in FRC in funzione del rapporto di forma Dl / h*

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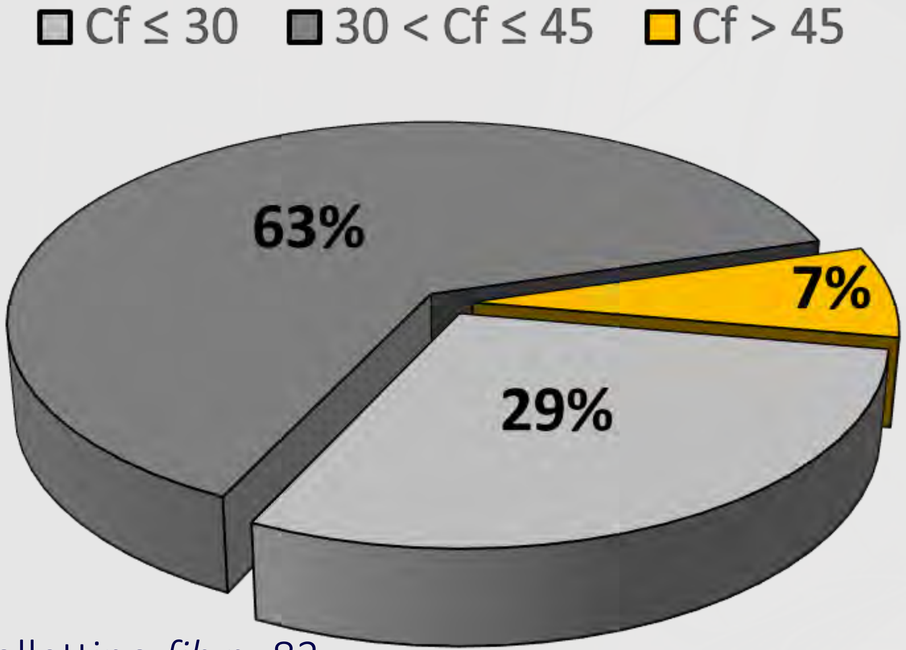
# Introduzione

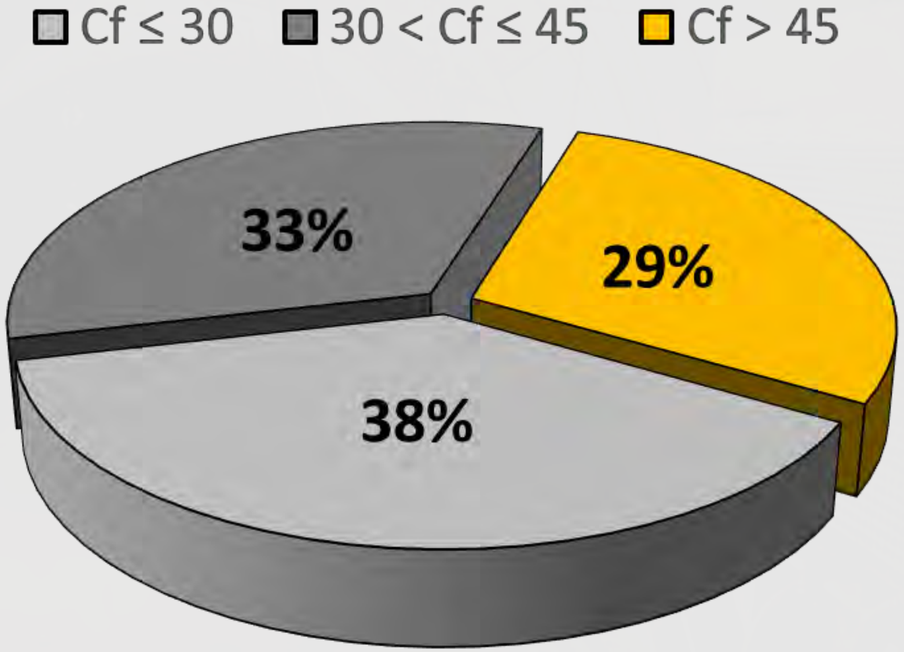
## Steel FRC

### *Dosaggio delle fibre*

**FRC**




**HYBRID FRC-REBARS**

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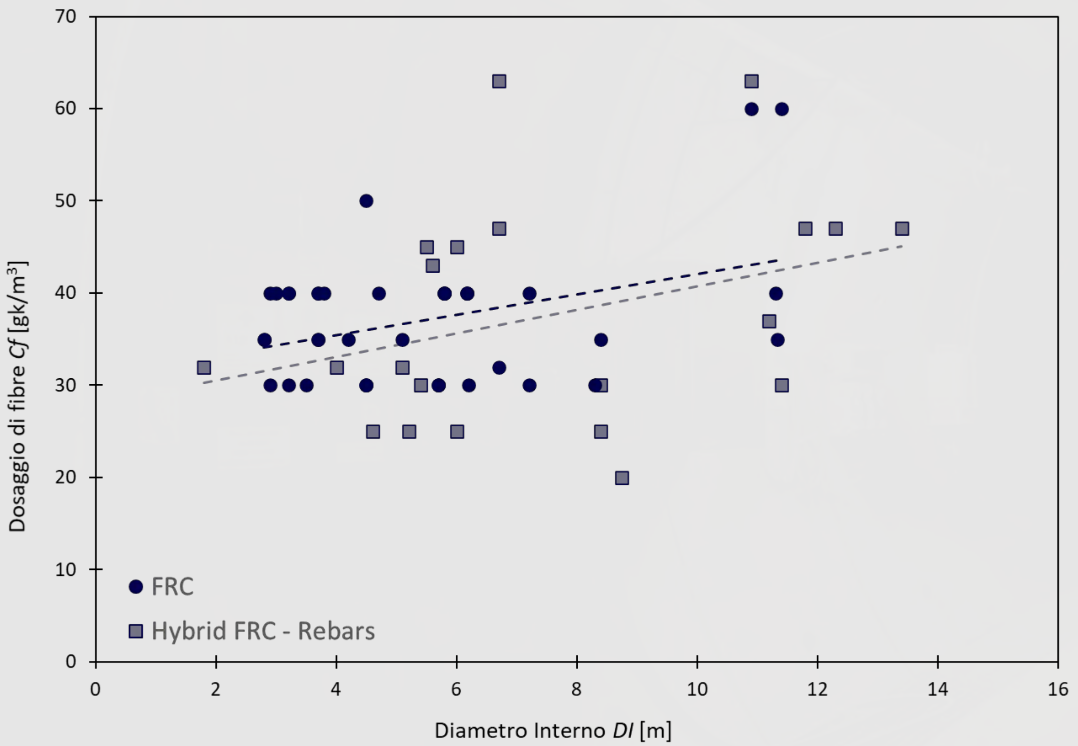
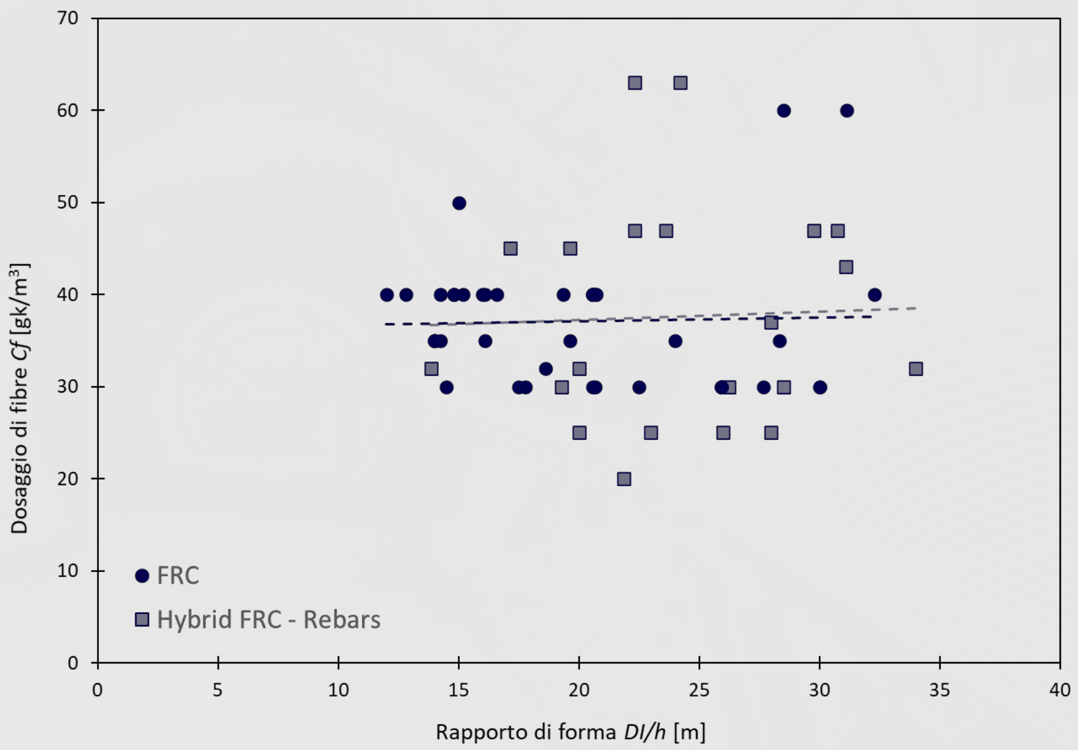
# Introduzione

## Steel FRC

### *Dosaggio delle fibre*

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# Introduzione



## FRC: *Sintesi delle statistiche del bollettino fib n. 83*

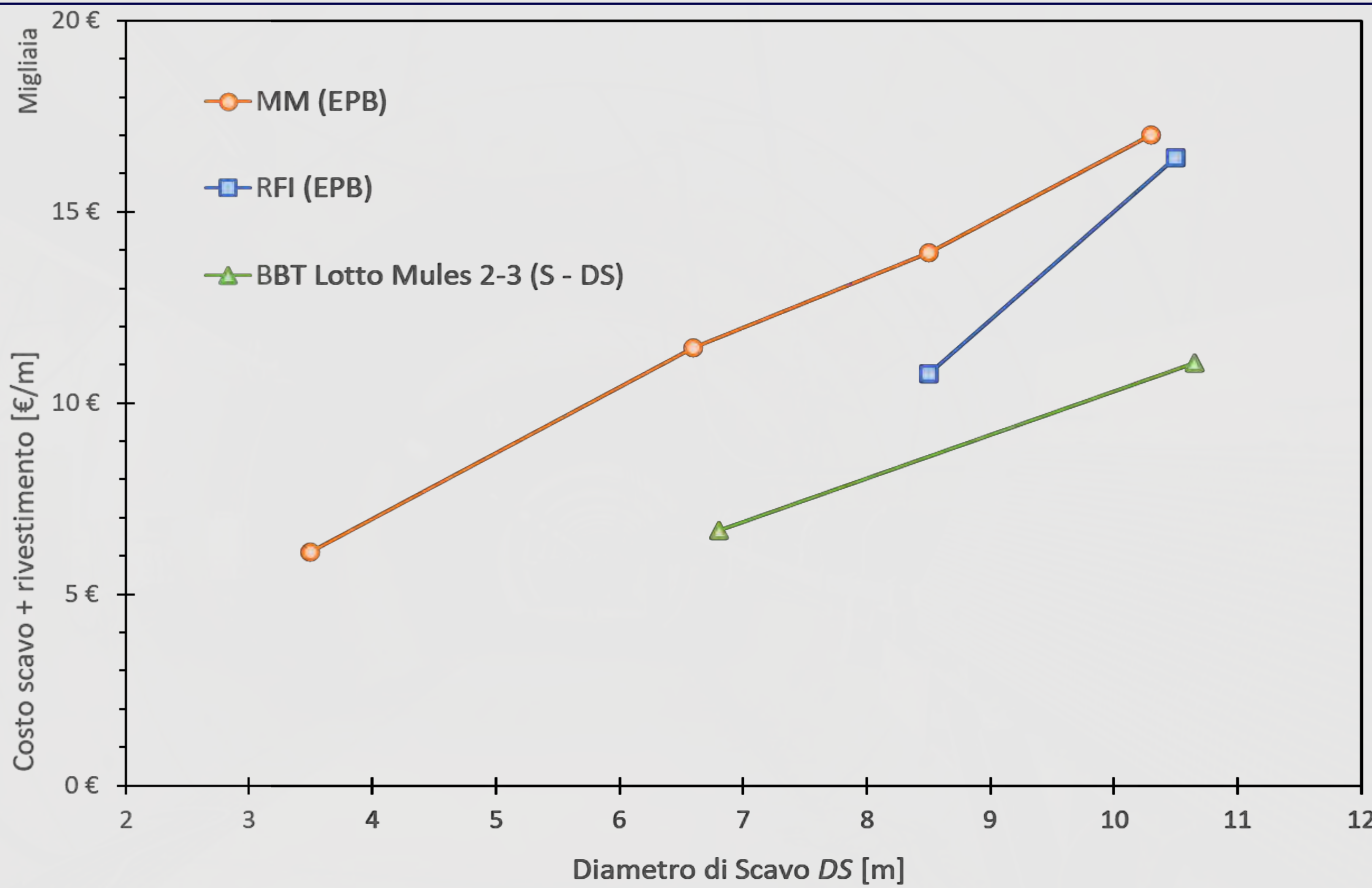
| Steel FRC | n. casi [-] | n. casi [%] | *DI* > 6m [%] | *DI* > 8m [%] | *DI/h* > 20 [%] | $C_f \leq 30$ kg/m³ [%] | 30 kg/m³ < $C_f \leq 45$ kg/m³ [%] | $C_f > 45$ kg/m³ [%] |
|---|---|---|---|---|---|---|---|---|
| **Solo FRC** | 55 | 73% | 31% | 13% | 51% | 29% | 63% | 7% |
| **Hybrid FRC – Rebars** | 20 | 27% | 64% | 45% | 86% | 38% | 33% | 29% |
| **Totale** | 75 | 100% | 40% | 22% | 60% | 31% | 55% | 13% |

- L'armatura fibrosa è stata usata per Diametri Interni *DI* fino a 13.4m.
- Nel 27% dei 75 casi riportati l'armatura fibrosa in acciaio è stata accoppiata con un'armatura in barre tradizionali (armatura ibrida). Questa percentuale sale al 50% (un caso su due) per le fibre sintetiche.
- L'armatura ibrida è stata utilizzata preferenzialmente per diametri DI maggiori e per maggiori rapporti di forma DI/h (conci più snelli).
- Il contenuto/dosaggio in fibre Cf sembra non dipendere né da DI né da DI/h ma si nota una percentuale di casi con dosaggi elevati (Cf > 45 kg/m$^3$) tra quelli di armature ibride (per DI maggiori, si predilige un DI/h maggiore rispetto a una minore incidenza di armatura complessiva)

# Introduzione

## Confronti: steel rebar

*Legame tra il diametro di scavo DS e il costo complessivo (scavo + rivestimento)*




Costi parametrici:

- TBM con fronte pressurizzato: da 1’300 a 1’700 €/m / m di *DS*
- TBM con fronte non pressurizzato: 1’000 €/m / m di *DS*

# Introduzione

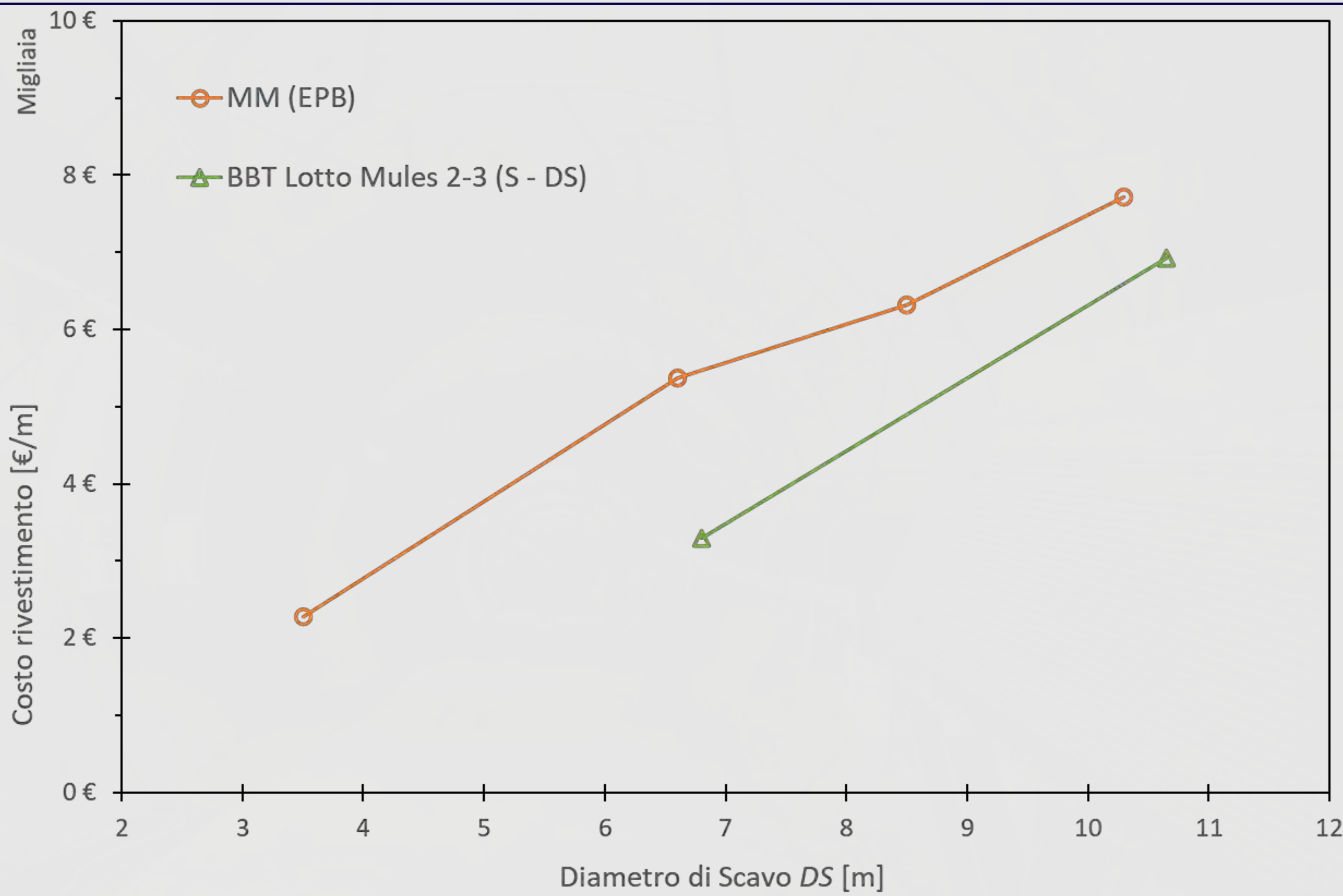
## Confronti: steel rebar

*Legame tra il diametro di scavo DS e il costo del rivestimento*

*(incluso intasamento a tergo)*

Costi parametrici:

- TBM con fronte pressurizzato: da 650 a 750 €/m / m di *DS*
- TBM con fronte non pressurizzato: da 500 a 650 €/m / m di *DS*





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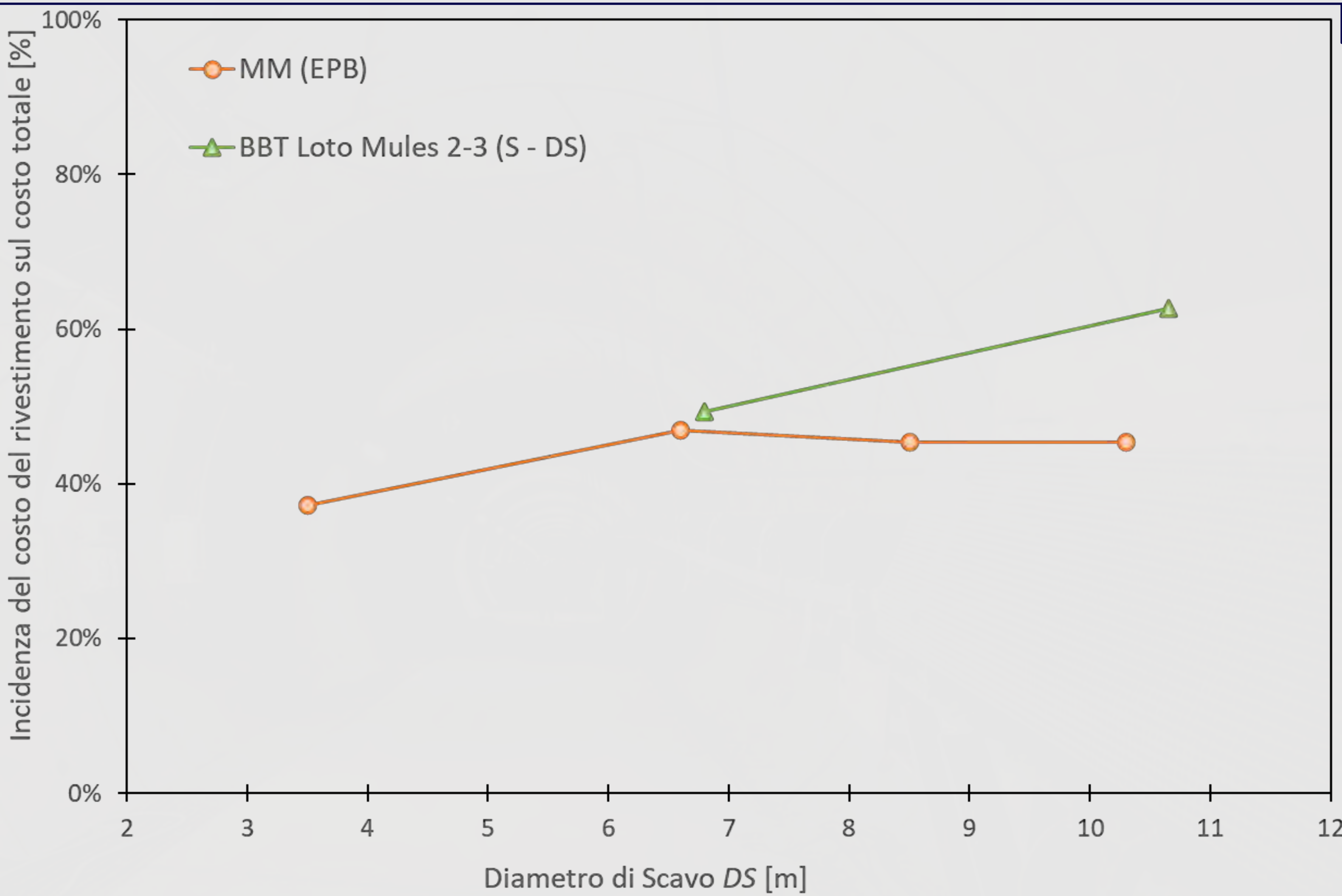
# Introduzione

## Confronti: steel rebar

*Legame tra il diametro di scavo DS e il costo del rivestimento*

*(incluso intasamento a tergo)*

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# Introduzione

## Confronti: steel rebar

*Incidenza delle diverse categorie di armatura tradizionale*

Incidenze massime e minime:

- Totale: da 100 a 180 kg/m$^3$
- Escluso frettaggio: da 80 a 150 kg/m$^3$

| **Incidenza** [kg/m$^3$] [%] | **Galleria 1** Anello 1 | **Galleria 1** Anello 2 | **Galleria 1** Anello 3 | **Galleria 2** | **Galleria 3** | **Galleria 4** Anello 1 | **Galleria 4** Anello 2 |
|---|---|---|---|---|---|---|---|
| **Totale** | 112 **100%** | 143 **100%** | 183 **100%** | 124 **100%** | 126 **100%** | 111 **100%** | 160 **100%** |
| **Tutto escluso frettaggio (circonferenziali, longitudinali, taglio)** | 79 **65%** | 110 **73%** | 150 **79%** | 103 **83%** | 80 **64%** | 91 **82%** | 129 **81%** |
| | | | | | | | |
| **Armatura di frettaggio** | 33 **35%** | 33 **27%** | 33 **21%** | 21 **17%** | 46 **36%** | 20 **18%** | 31 **19%** |


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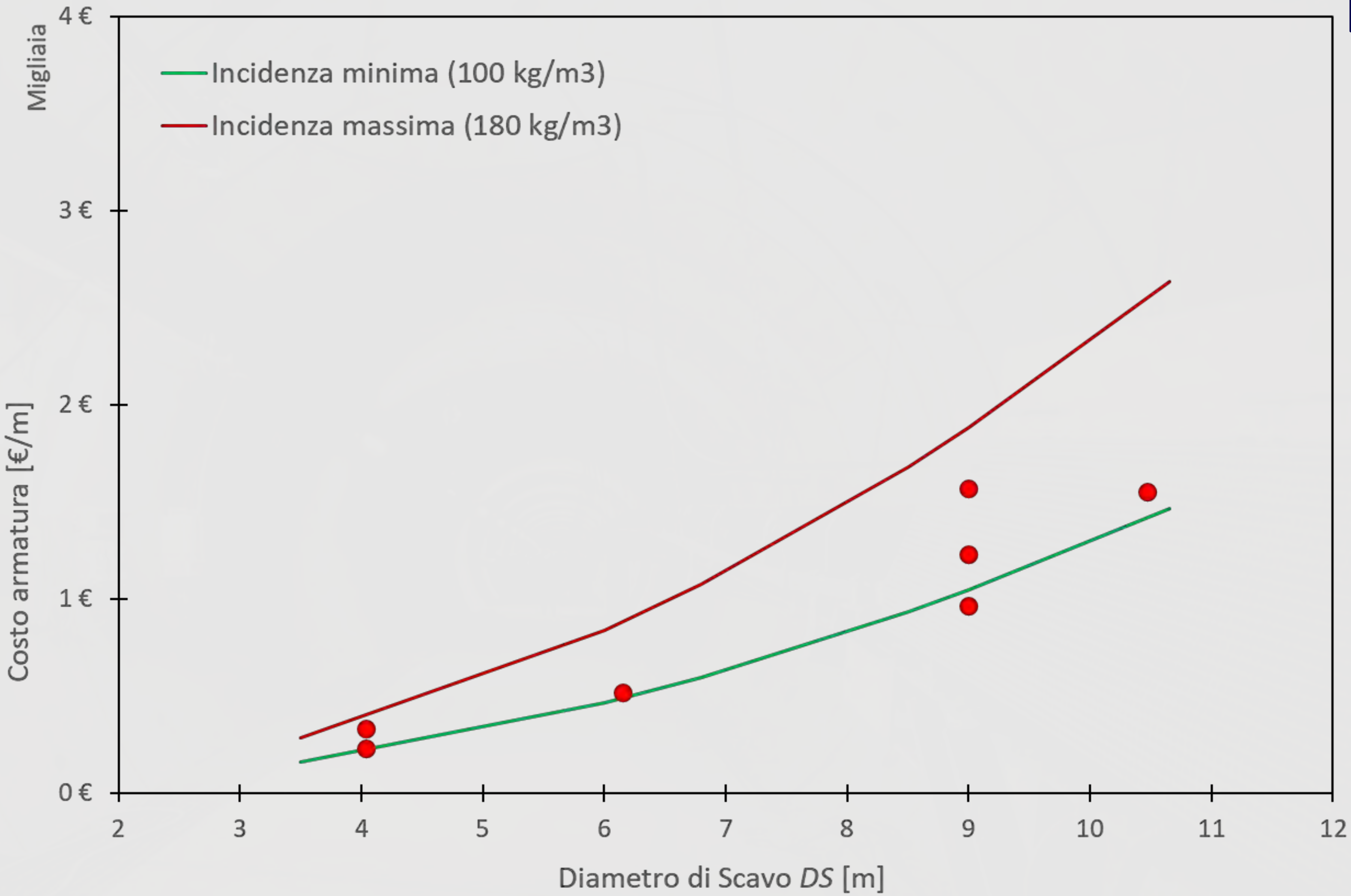
# Introduzione

## Confronti: steel rebar

*Legame tra il diametro di scavo DS e il costo dell'armatura tradizionale*
*(costo acciaio 1 €/kg*
*spessore dei conci h = DI/20 con DI ~ DS/1,13)*

Costi parametrici:

- Incidenza minima: (13·*DS*[m]) €/m / m di *DS*
- Incidenza massima: (23·*DS*[m]) €/m / m di *DS*





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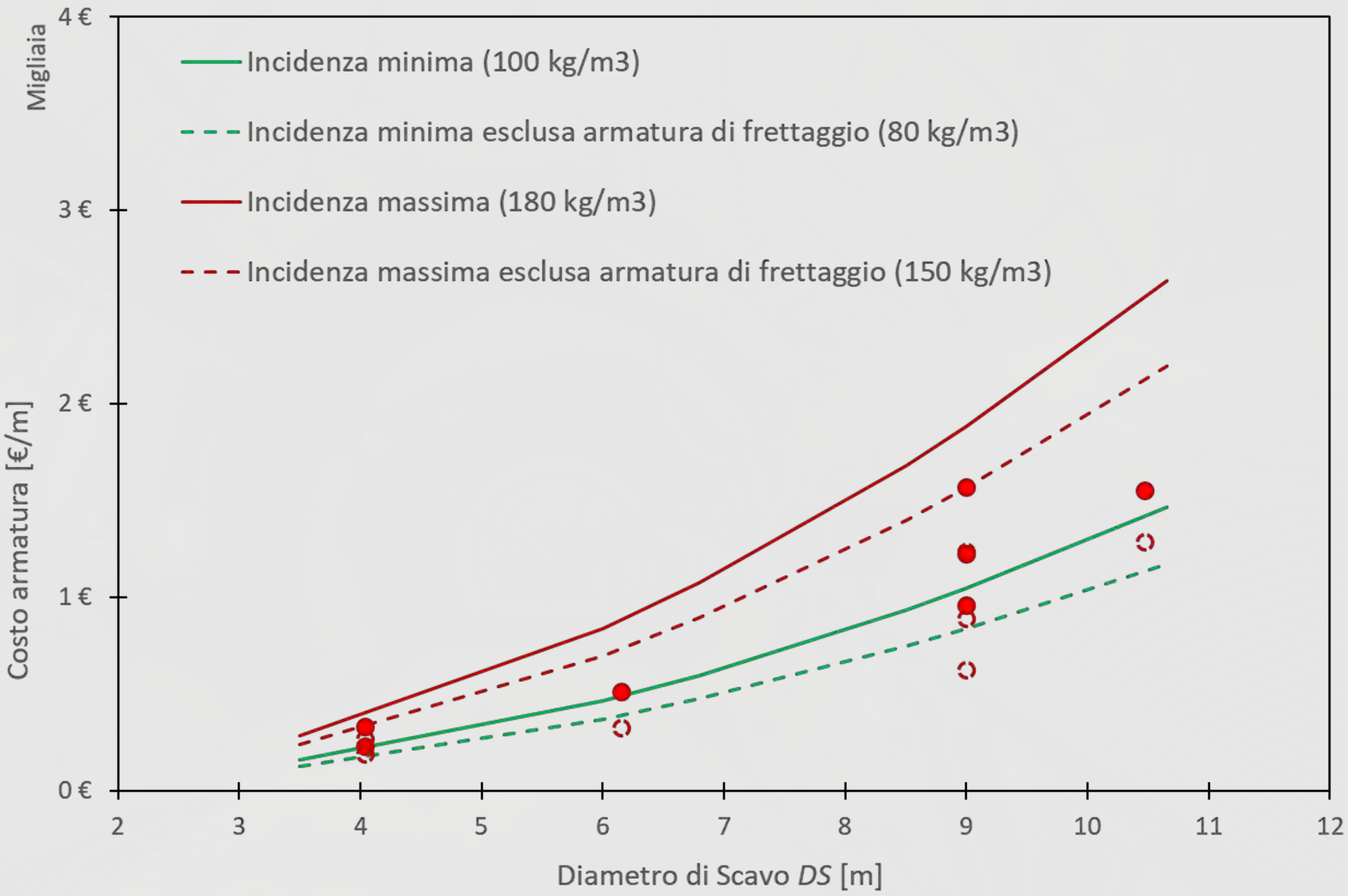
# Introduzione

## Confronti: steel rebar

*Legame tra il diametro di scavo DS e il costo dell'armatura tradizionale esclusa quella di frettaggio*
*(costo acciaio 1€/kg*
*spessore dei conci h = DI/20 con DI ~ DS/1,13)*

Costi parametrici:

- Incidenza minima: (10·*DS*[m]) €/m / m di *DS*
- Incidenza massima: (19·*DS*[m]) €/m / m di *DS*



# Introduzione

## Confronti: steel rebar

### *Costo parametrico dell'armatura*

| | Costo parametrico [€/m / m di *DS*] | Esempio 1 *DS* = 6m | Esempio 2 *DS* = 9m |
|---|---|---|---|
| **Scavo e rivestimento** TBM pressur. – non pressur. | **1'000 ÷ 1'700** | **6'000 ÷ 10'200** | **9'000 ÷ 15'300** |
| **Solo rivestimento** TBM pressur. – non pressur. | 500 ÷ 750 | 3'000 ÷ 4'500 | 4'500 ÷ 6'750 |
| **Armatura (totale)** Incidenza minima 100 kg/m$^3$ / massima 180 kg/m$^3$ | 13·*DS*[m] / 23·*DS*[m] | 500 ÷ 900 | 1000 ÷ 1900 |
| **Armatura (esclusa frettaggio)** Incidenza minima 80 kg/m$^3$ / massima 150 kg/m$^3$ | 10·*DS*[m] / 19·*DS*[m] | 350 ÷ 700 | 850 ÷ 1600 |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# Introduzione

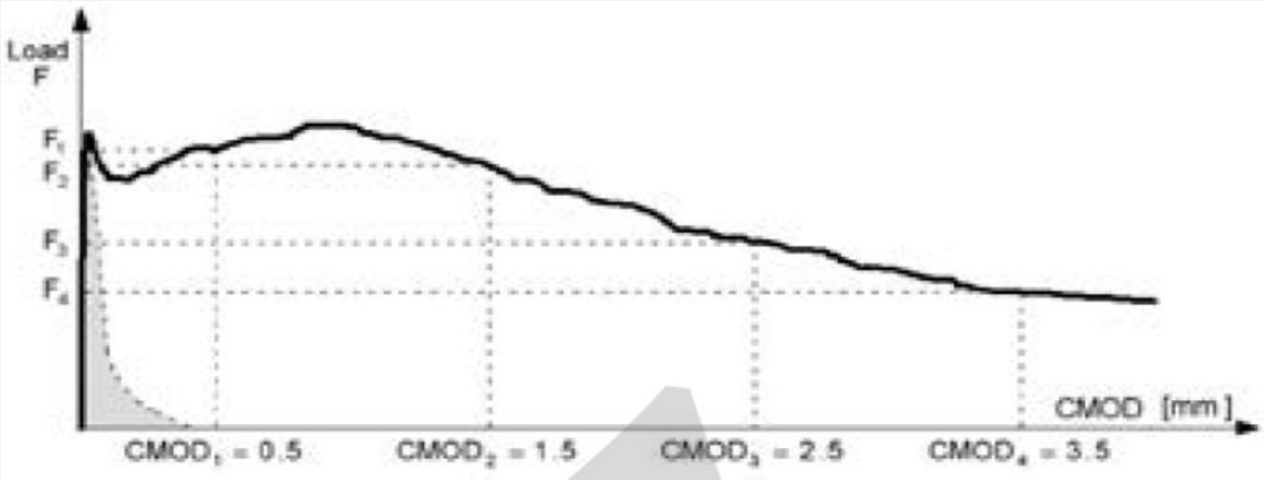
## Confronti: FRC

### *Caratteristiche meccaniche delle fibre*

Denominazione **FRC $f_{ck}$ $f_{R1k}$ $f_{R3k}/f_{R1k}$**

Per esempio **FRC 50 4c** :

- $f_{ck}$ resistenza caratteristica a compressione del cls su provino cilindrico (esempio: 50 MPa per C50/60)
- $f_{R1k}$ resistenza a flessione del FRC per apertura di una fessura di 0.5mm (esempio: 4 MPa)
- $f_{R3k}/f_{R1k}$ performance delle fibre in termini di duttilità, definito da una lettera (esempio: c), con
- $f_{R3k}$ resistenza del FRC a flessione per apertura di una fessura di 2.5mm.




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

È evidente **l'assenza di qualsiasi riferimento diretto al contenuto in fibre nella definizione delle caratteristiche meccaniche dell'armatura fibrosa**, che, pertanto deve essere determinata con apposite prove di carico su travette prismatiche standard.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# Introduzione

## Confronti: FRC

### *Dosaggio delle fibre*

- Armatura in barre in acciaio: 1.00 €/kg
- Armatura in fibre in acciaio: 2.50 €/kg
- Armatura in fibre sintetiche: 10.00 €/kg

80 – 150 kg/m$^3$ di armatura (non comprendenti l’armatura di frettaggio) in barre in acciaio corrispondono a:

- 32 – 60 kg/m$^3$ di armatura in fibre in acciaio
- 8 – 15 kg/m$^3$ di armatura in fibre sintetiche


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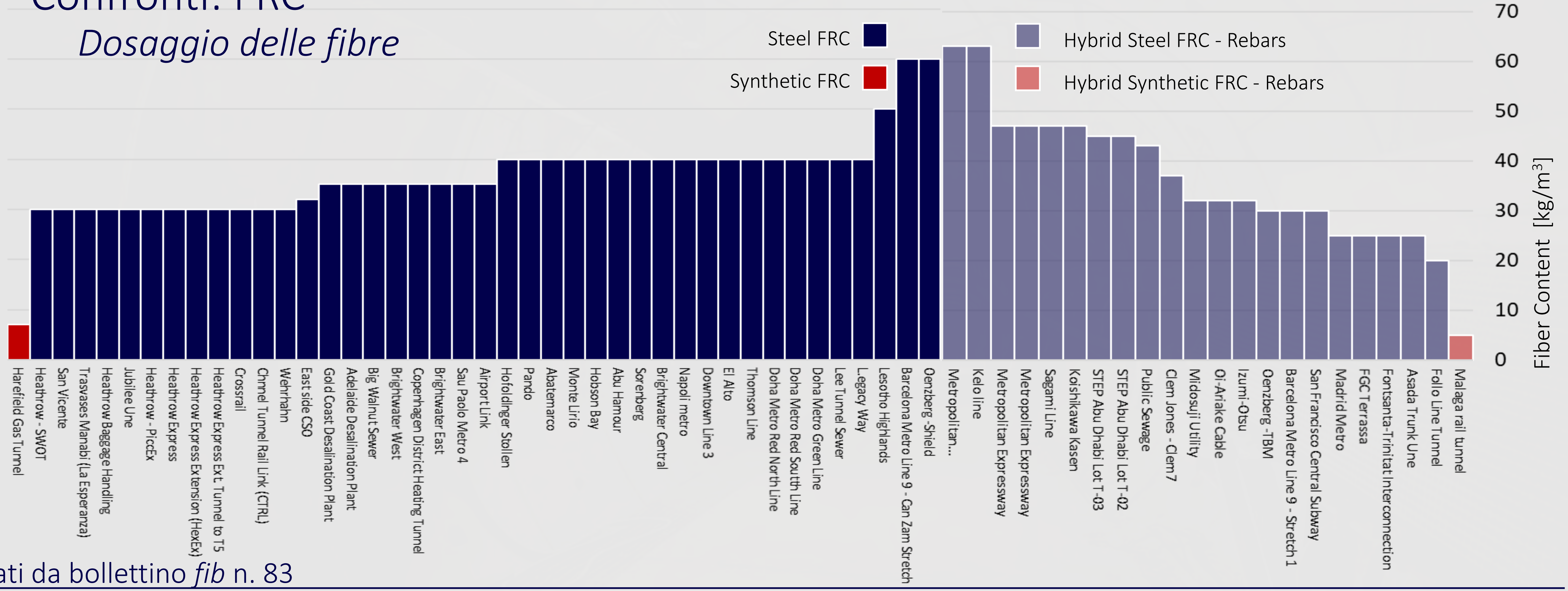
# Introduzione

## Confronti: FRC

### *Dosaggio delle fibre*




dati da bollettino *fib* n. 83

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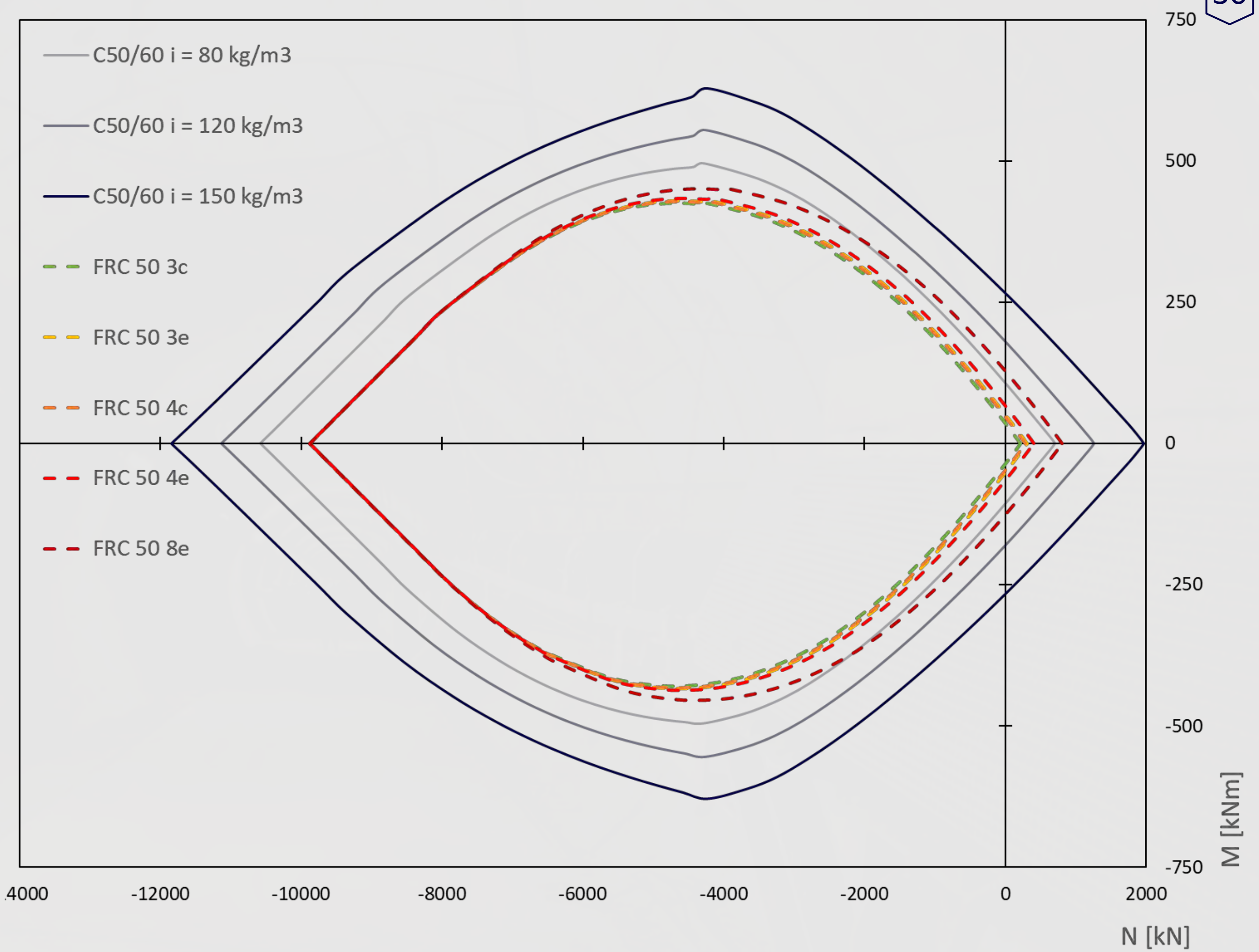
# Introduzione

## Confronti: FRC

Conci in C50/60, spessore 35cm, armati con:

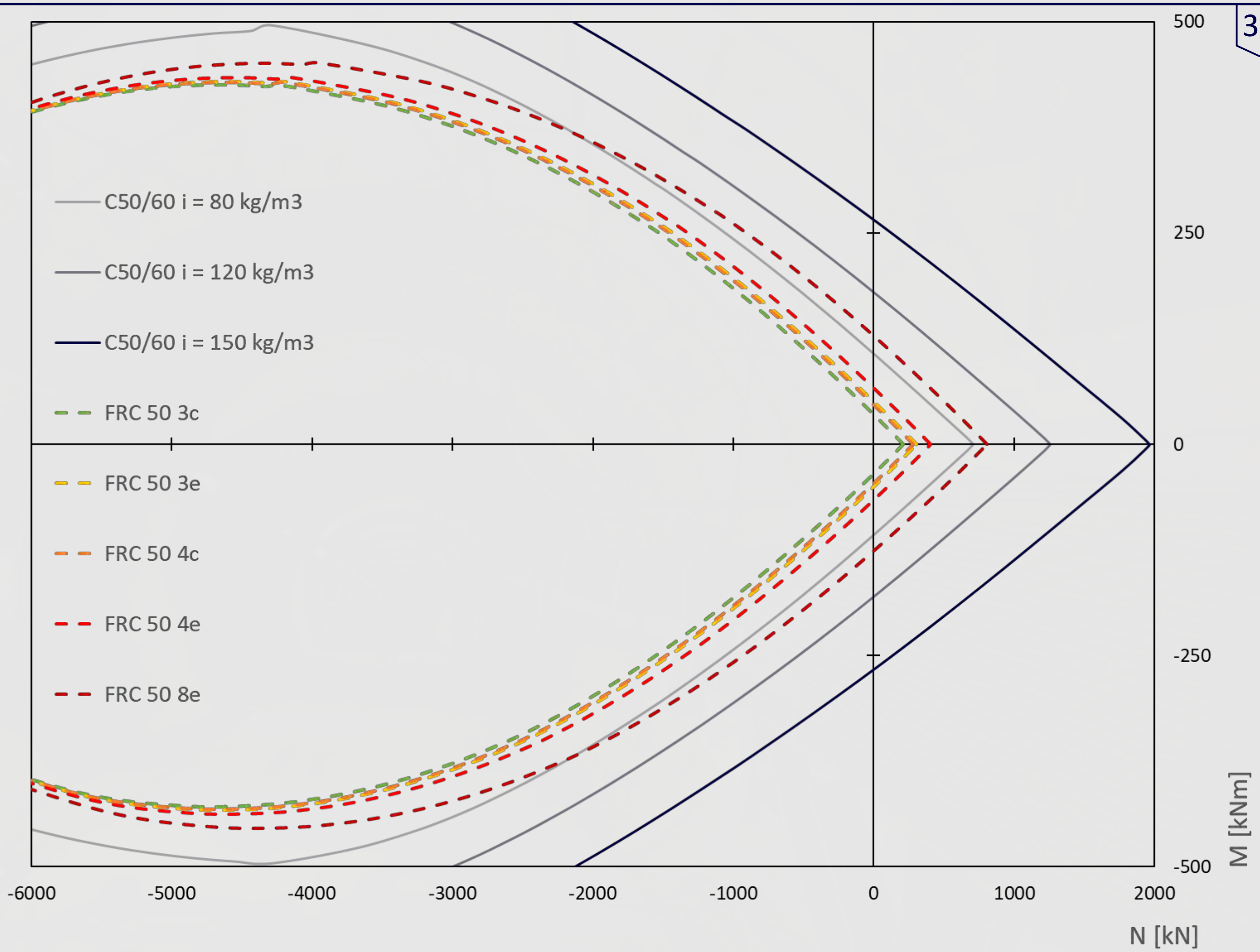
- Ø12 passo 12.5cm (i = 80 kg/m$^3$)
- Ø16 passo 12.5cm (i = 120 kg/m$^3$)
- Ø20 passo 12.5cm (i = 150 kg/m$^3$)
- FRC 50 3c
- FRC 50 4c
- FRC 50 3e
- FRC 50 4e
- FRC 50 8e



# Introduzione
## Confronti: FRC

Conci in C50/60, spessore 35cm, armati con:

- Ø12 passo 12.5cm (i = 80 kg/m$^3$)
- Ø16 passo 12.5cm (i = 120 kg/m$^3$)
- Ø20 passo 12.5cm (i = 150 kg/m$^3$)
- FRC 50 3c
- FRC 50 4c
- FRC 50 3e
- FRC 50 4e
- FRC 50 8e



# Introduzione

## Confronti: GFRP

- Sulla base delle attuali esperienze, **l'incidenza in peso di armatura in barre in GFRP nei conci è pari a circa il 50% di quella in acciaio** (il 25% considerando la sola armatura principale).
- Per le armature in barre in GFRP, quindi, un confronto basato sull'equivalenza statica rispetto all'armatura tradizionale evidenzia un'inefficienza economica:

| | |
|---|---|
| Armatura in acciaio: | 1.00 €/kg |
| Armatura in barre GFRP: | 10.00 €/kg |
| $i_{acciaio} = 100\ kg/m^3$ | $100\ €/m^3$ |
| $i_{GFRP} = 0.5\ i_{acciaio} = 50\ kg/m^3$ | $500\ €/m^3$ |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# Esempi

## GFRP

### 2 Design of GFRP reinforcements replacing the ordinary steel cage

The design of GFRP reinforced segments can be carried out by means of bending moment - axial force envelopes (M-N). The actions due to transient load conditions (demoulding, storage, transport, etc.) and final condition (ground pressure) are compared with M-N envelopes defined for the different stages. Furthermore, the TBM thrust loading condition can be analysed considering the tensile force in the bars according to the models available in the literature.

For M-N envelopes definition, different guidelines can be followed (ACI 2006, CNR-DT 203 2007, Fib Bulletin 40, 2007). In the following the method suggested in CNR-DT 203 (Italian Guidelines) is proposed.

Regarding the concrete behaviour, the design is the same as ordinary steel reinforced concrete while the GFRP rebar behaviour differs significantly from the steel one. The GFRP rebar shows a linear-elastic behaviour up to failure. Limits in terms of both strength and deformation are imposed:

$$f_f = E_f \varepsilon \quad (1)$$

$$f_{fd} = \eta_a \eta_l \frac{f_{fk}}{\gamma_f} \quad (2)$$

$$\varepsilon_{fd} = 0.9 \eta_a \frac{\varepsilon_{fk}}{\gamma_f} \quad (3)$$

where $f_{fd}$ e $\varepsilon_{fd}$ are the design strength and ultimate deformation respectively; $E_f$ is the average Young's modulus; $\eta_a$, $\eta_l$ e $\gamma_f$ are the environmental reduction factors ($\eta_a$=0.7 for wet environment and $\eta_a$=0.8 for dry environment), the long-term loading coefficient ($\eta_l$=1 for provisional structures) and the partial safety factor for GFRP ($\gamma_f$ = 1.5). Furthermore, no resistance of GFRP rebar in compression is considered.

M-N envelopes can be drawn considering the ordinary rules for sectional analyses (sections planarity and concrete and GFRP rebar relation).

A case study is now considered to show typical M-N envelopes for GFRP reinforced segments. The geometry is given in Figure 2. left side. The reinforcement is: 12Ø12 mm at the extrados and 12Ø14 mm at the intrados. Two envelopes have been drawn (Figure 2. right side), first in demoulding condition and then at the final stage. The material properties are reported in Table 1.

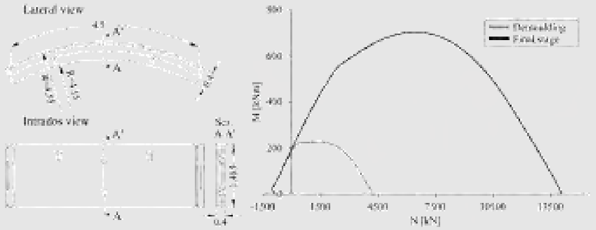


Figure 2. Segment geometry (left); M-N- envelopes at demoulding and at final stage (right)

Table 1. Material properties

| | | |
|---|---|---|
| Concrete cylindrical strength at demoulding | $f_{ck,\,t0}$ | 12 MPa |
| Concrete cylindrical strength final stage | $f_{ck,\,28d}$ | 40 MPa |
| Concrete partial safety coefficient | $\gamma_c$ | 1.5 |
| GFRP strength | $f_{fk}$ | 755 MPa |
| Young's modulus | $E_f$ | 40 GPA |
| Ultimate deformation | $\varepsilon_{fk}$ | 0.019 |
| Environmental reduction factor | $\eta_a$ | 0.7 |
| Long-term loading coefficient | $\eta_l$ | 1 |
| Concrete partial safety coefficient | $\gamma_f$ | 1.5 |

### 3 Design of GFRP reinforcement integrating the ordinary steel cage

The segments edges can often be subjected to cracking and/or breakages caused by collisions during transportation, handling and overturning, or by stress concentration during the thrust phase of the TBM, or even during service.

The concrete compressive stresses and the resulting tensile stresses must be verified.

According to UNI EN 1992-1-1:2005, the concrete compressive stresses must be checked by the following formula:

$$\sigma_d = \frac{N_{Ed}}{b_1 \cdot d_1} < \sigma_{Rd} \quad (4)$$

where $N_{Ed}$ is the design axial load (thrust of the jacks on the transversal joints and compression due to the axial forces on the longitudinal joints), $b_1 \cdot d_1$ is the load application area deriving from the reduction of the section of the joint due to the eccentricity of the load (Figure 3.), $\sigma_{Rd}$ is the concrete design resistance, equivalent to:

$$\sigma_{Rd} = f_{cd} \cdot \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3 \cdot f_{cd} \quad (5)$$

$f_{cd}$ is the concrete cylindrical strength, $A_{c0}$ is the area of the load application (= $b_1 \cdot d_1$) and $A_{c1}$ is the maximum load diffusion area (Figure 3.)

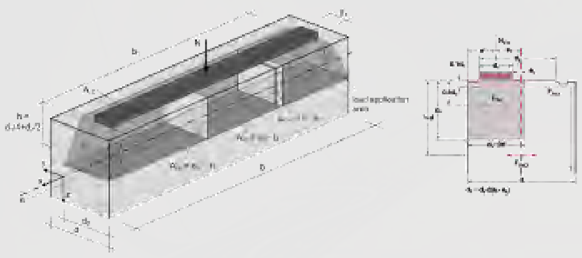

Figure 3. Schematic diagram of load dispersion across the segment thickness at raised partial surface pressure with definition of the mathematical distribution areas (DAUB, 2013)

Parallel to the compression loads, the tensile loads orthogonal to the direction of the application of the load can be defined by methods well known in the literature (Leonhardt, 1986) or by numerical methods (Figure 4.).

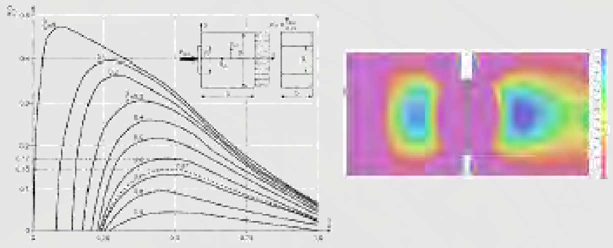

Figure 4. Joint tensile stresses (Analitic solution on the left and FEA solution on the right)

Knowing the distribution of tensile loads in the section, minimum reinforcement is defined taking into account the steel or the GFRP reinforcements strength properties. In any case, it is important to observe that the GFRP reinforcements can be positioned at a much lower distance from the segments' external surface than the steel ones. This leads to a drastic reduction of the cracks opening that, as well known, decreases with decreasing of concrete covers, and ensures an increase of the structure life.

Armature en barre en fibre de verre pour voussoirs de revêtement des tunnels mécanisés

GFRP reinforcement for segmental lining of mechanized excavations

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# Introduzione

## Confronti: GFRP

- Questo tipo di armatura non può essere considerato sostitutivo a quella in barre tradizionali se non per casi specifici che ne giustificano l'impiego anche a fronte di un maggior costo:
    - Necessità di demolizione selettiva dei conci in corrispondenza di nicchie, innesti di by-pass o passaggi a vuoto (*soft eye*)
    - Elevato rischio di attacco chimico (*waste water*, terreni aggressivi) o elettrico (*stray currents)* alle armature tradizionali.
    - Riduzione del copriferro e, di conseguenza, dei danni da trasporto e installazione.

| Acciaio | GFRP |
| --- | --- |


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# Introduzione

## Aspetti non direttamente evidenziabili dai confronti rispetto a steel rebars

| **ADAVANTAGES** (with respect to steel rebars) | **STEEL FRC** | **SYNTHETIC FRC** | **GFRC REBARS** |
|---|---|---|---|
| **Overall strength** | | | |
| **Enhancend durability** | | | |
| **Production efficency** | | | |
| **Crack & fissures width control** | | | |
| **Enhanced impact / shock resilience** | | | |
| **Seismic ductility** | | | |
| **Concrete cover reduction** | | | |
| **Dielectric disconnection** | | | |
| **Fire spalling control** | | | |
| **Ease of demolition** | | | |

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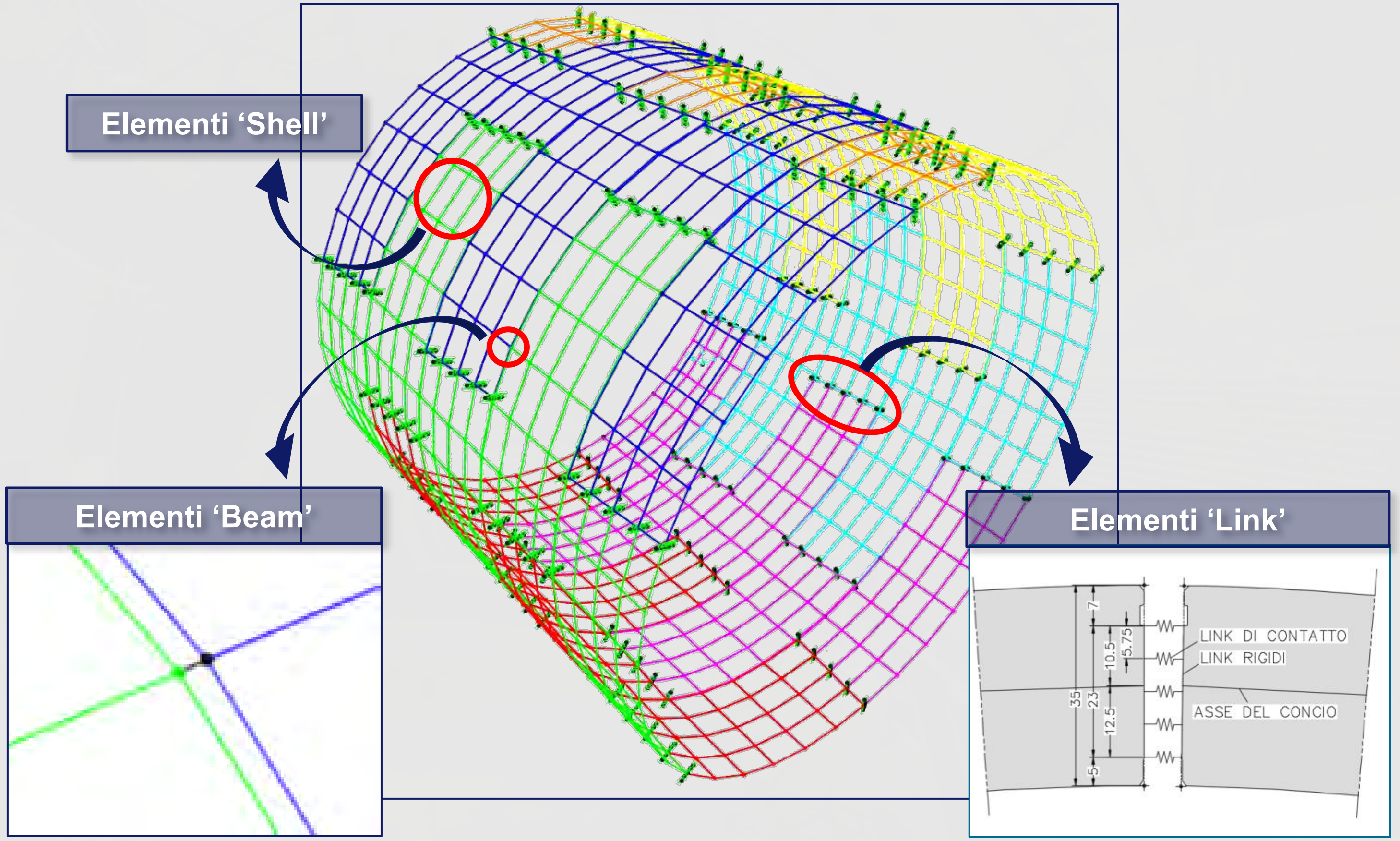
# Esempi

## Modellazione 3D

The models have been loaded with an almost uniform load schematizing the back-fill pressure with an asymmetric load (Figure 17) with variable entity to analyse the behaviour of the system and to define the limit load of the lining. Analyses have shown a concentration of loads at the segments edges with consequent breakage of the first link of the system right at the edge. A significant increase of the asymmetric limit load of the lining is noticed in case of GFRP reinforcement extended to the entire perimeter of the segment and not only at the corner.

Moreover, GFRP reinforcements produce beneficial effects in case of incorrect installation of the segments. If the contact between two segments is limited to only one corner - case that, though not desirable, may happen during the installation of the segments - the asymmetric limit load rises proportionally with respect to the "stress-strain" law assigned to the links that schematizes the joint, deducted from the laboratory tests previously illustrated.

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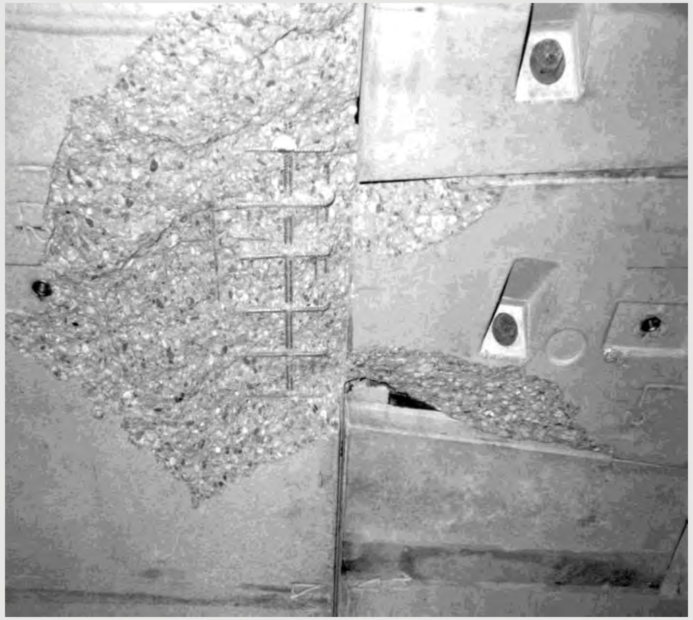
# Esempi

## Danni ai conci

| Chipping of sides and corners | Splitting / Bursting |
|---|---|

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# Esempi

## Danni ai conci

**Spalling**

**Fire Spalling**

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# Esempi

## Danni ai conci: SIG WG2 Report


SIG Working Group 2 - Research
Demages of segmental linings
Table 1 - Technological damages

Società Italiana Gallerie
Italian Tunnelling Society

| Rev. 01.06.2017 | CHAPTERS' REFERENCE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PHASE | 4. Type of damage | | 5. Damage causes | 6. Modelling | 7. Mitigations | 8. Repairs | Reference Documents (Regulations / Guide Lines / Papers) | Pictures |
| POST-CASTING, DEMOLDING, HANDLING, OVERTURNING, STORAGE | Concrete surface defects differentiated among intrados, perimetric surfaces and gasket groove, extrados | Hollow > 5 mm on intrados, extrados and perimetric surface | Incorrect mix design. Poor Vibration, excessive segregation, poor workability Inadequate thermal cycling, curing and post-treatment | - | Mix design, casting process, aging cycle, curing and post-treatment adjustments | Surface cleaning and leveling with liquid mortar cement plaster upon bonding primer application and subsequent shaving | Stuva | Picture T1.1.1 |
| | | Hollow > 1 mm on gaskets groove | | | | | | Picture T1.1.2 |
| | | Irregularities (voids, exposed aggregates and reinforcement) | | | | In the worst cases, rheoplastic mortar pouring (if the reinforcement is exposed it must be treated with a passivating corrosion inhibitor before pouring the above-mentioned admixture) | | |
| | | Removal of concrete skin on rather extensive surface | Demolding agent non homogeneus distribution on the formwork surfaces | - | Demolding agent application by hand pump and consequent spreading over the formwork surfaces with sponges and rubber brushes. Preventive measure to be taken for inserts and anchored gaskets installation, paying specific attention to the formwork groove cleaning in case the demolding agent goes through it (the groove lubrication reduces friction between the gasket and the steel and that can lead to gasket deviation from theoretical position during the vibration phase) | To be carried out, if considered repairable by contract, with repairing mortar | | Picture T1.1.4 |
| | Defects due to inserts presence | Grout or grease leakage in dowels sockets | Incorrect coupling between socket and the related lodging; grease improperly applied as a demolding agent. Grease or grout inside the socket teeth drastically reduce the pull-out performances and can lead to an excessive joint gap and therefore to further leakages | - | Define and apply a tightening torque | Grease and grout have to be removed without damaging the insert. Grout can be removed with the use of acidulated water. | | |
| | | Insert unscrewing / disconnection and absorption in the casting itself | The coupling between the insert and the related lodging is not correct | - | Define and apply a tightening torque. If an unsatisfactory value of the tightening torque has been reached (insert / lodging blockage not guaranteed) a threads dimensional inspection is required (within design tolerances) both for female and male pieces. | Segmental lining coring, new insert installation and bi-component resin fixing. | Maccaferri Tunneling internal SQ procedure for inserts | Picture T1.2.2 |
| | Gaskets (anchored or glued) damaging | Malpositioning Gasket sinking in the concrete Corners deformation Gasket detachments | | - | | Lift the gasket from its groove with a screwdriver and keep it lifted at the correct height with some thicknesses. Fill with an epoxy anchoring gel underneath the gasket to fix it in its correct position. Level the restored gasket with a straight iron or wooden edge. | | Picture T1.3.1 |
| | | Gasket damaging and / or breaking | | | | Cut the damaged gasket area and remove it from its groove. Take a new piece of gasket 5% longer than the damaged part. Cut the base of the gasket. Apply a glue along the empty part of the groove and on the new piece ends. After few minutes insert the gasket into the groove, ensuring the fitting. Be careful to match perfectly the two extremities. Remove the extra glue. Level the restored gasket with a straight iron or wooden edge. | | Picture T1.3.2 |
| | | Gasket and concrete damaging | | | | See the previous two corrective actions | Maccaferri Tunneling internal SQ procedure for concrete + gasket | Picture T1.3.3 |
| | | Concrete damaging | | | | Clean the part to be recovered and apply mortar with a spatula, ensuring the incorporation of the gasket base. Apply the appropriate restraint with a support to maintain the mortar in place during the aging. Clean the gasket. | | Picture T1.3.4 |
| | | Concrete damaging around a wide gasket groove area | | | | Cut the gasket damaged area and recover the groove with a proper mortar. For further corrective actions see the description above. | | Picture T1.3.5 |
| | Chipping of sides and corners | < 25 mm | Collisions. Incorrect demolding agent distribution on the edges and boards which are the most critical areas to be treated. | - | Improvement of the demolding, handling, overturning and storage processes. Guarantee of the correct reinforcement concrete cover. GFRP mesh or steel fiber reinforcement See also Concrete surface defects. | Surface cleaning possibly with compressed air not to have residuals or unstable parts; Application of an epoxy adhesive on the construction joint on which will be laid a one-component thixotropic cementitious mortar, with good workability that hardens without shrinking. | | Picture T1.4 |
| | | 25 - 50 mm | | | | Surface cleaning until a solid, resistant and coarse base is reached; Application of an epoxy adhesive on the construction joint on which will be laid a one-component thixotropic cementitious mortar, shrinkage-compensated, sulphate-resistant and with suitable hardening timings. | | |
| | | > 50 mm | | | | Surface cleaning until a solid, resistant and coarse base is reached; Application of an epoxy adhesive on the construction joint on which will be laid a ready-mixed mortar composed of highly resistant cements, selected aggregates, special admixtures and synthetic fibres. When mixed with water becomes a highly fluid mortar, suitable for pouring into formwork and its workability lasts for about 1 hour. | | |
| HANDLING AND INSTALLATION OF THE RING | Gasket damaging (expulsion or pull out) | | Collisions, rubbings, inadequate bonding grip, inadequate anchorage in the concrete | - | Improvement of handling, transport and installation methods of the ring. Friction reduction using suitable lubricants. Execution of comparison tests | If the expulsion occurs before the installation of the segment, see corrective actions for gasket damages above | | Picture T2.1 |
| | Chipping of sides and corners | See the relevant previous phase | Collisions, Incompressibility of the gasket corner | - | Improvement of the handling, transport and installation methods of the ring. Check the concrete cover. GFRP mesh or steel fibers reinforcement. Check the suitability of the gasket corner. | See corrective actions for cracks above | | Picture T2.2 |
| THRUST PHASE | Gasket compression from jacks' plates | | Segment jack's plate overcomes the gasket | - | Avoid segment jack's plate gasket overcoming and gasket compression. Usage of gasket tested for not performance losing if compressed by jack's plate | - | | |
| | Excessive Gap and Offset | | The connection's systems (dowels / bolts) don't guarantee the sufficient gaskets' compression. Segments' geometric inaccuracies. Geometric inaccuracies during the segments' launch | - | Manufactoring tolerances reduction. Segments' launch and connections' systems improvements. | Joint injecting with epoxy, acrylic or polyurethane resins. Intrados joint's groove sylicon or cement water-plug plastering. | Stuva, BTS, AFTES | Picture T4.1 |
| GROUTING AND SERVICE PHASES | Water likages from joints and bolts' sockets | | Non performing gaskets | - | Gasket and / or connection systems improvement. Lab tests under service conditions of gaskets and / or connection systems, taking into account gap and offset | Joint injecting with epoxy, acrylic or polyurethane resins. Intrados joint's groove sylicon or cement water-plug plastering. | Stuva; BTS; AFTES; Master Politecnico of Torino | Picture T4.2 |
| | Concrete's damages due to aggressive water | | Lack of knowledge about the environmental conditions | - | Use of HSR concrete Proper dimensioning of the reinforcement concrete cover Application of protective coating at the extrados | For local damages, where possible, removal of the worn parts, cleaning, casting a reoplastic mortar: if some steel rebar is visible, it shall be protected by a passivating before the casting of the mortar. Structural reinforcements if required | | |
| | Gaskets' damages due to hydrocarbons or fire | | Lack of knowledge about the potential risk Fire | - | Use of Hydrocarbon-resistant gaskets Sealing of the joints with Fire-resistant mastics and/or Chemical agent-resistant products with high resistance to relaxation | Injections in the joints of polyurethane (or epoxy or acrylic) resins Sealing of the joints | | |
| | Bolts nuts unscrewing | | Vibrations - Insufficient tightening | - | Use of washers and anti-slip attachments Proper tightening | Washers and anti-slip attachments Replace of the bolts and proper tightening | | |
| TO BE FURTHER DEVELOPED | Steel reinforcement corrosion caused by stray currents | | | - | | | | |
| | Damage of PEHD or other material protective coating | | | - | | | FAMA internal procedure | Picture T5.2 |



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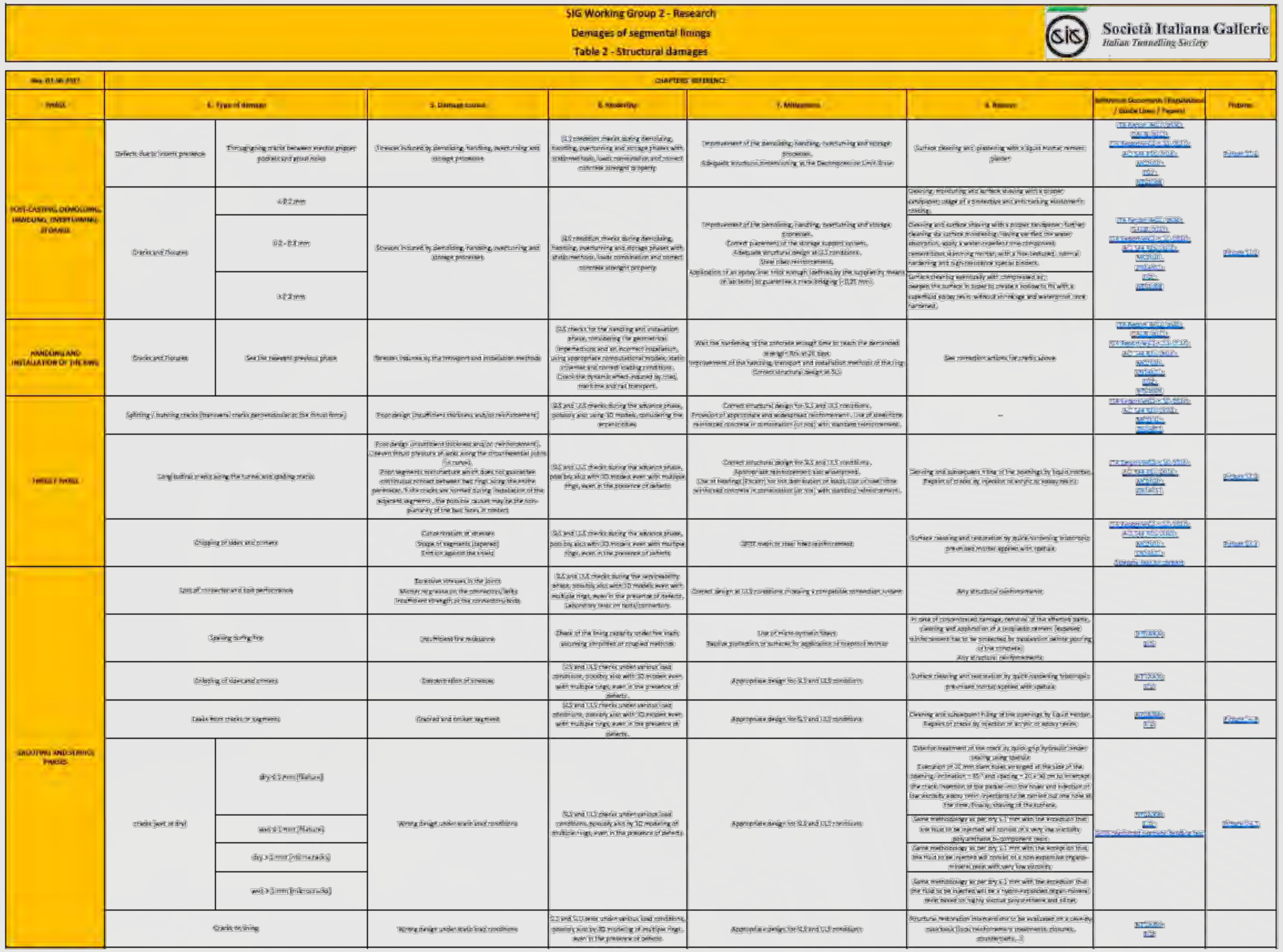
# Esempi

## Danni ai conci: SIG WG2 Report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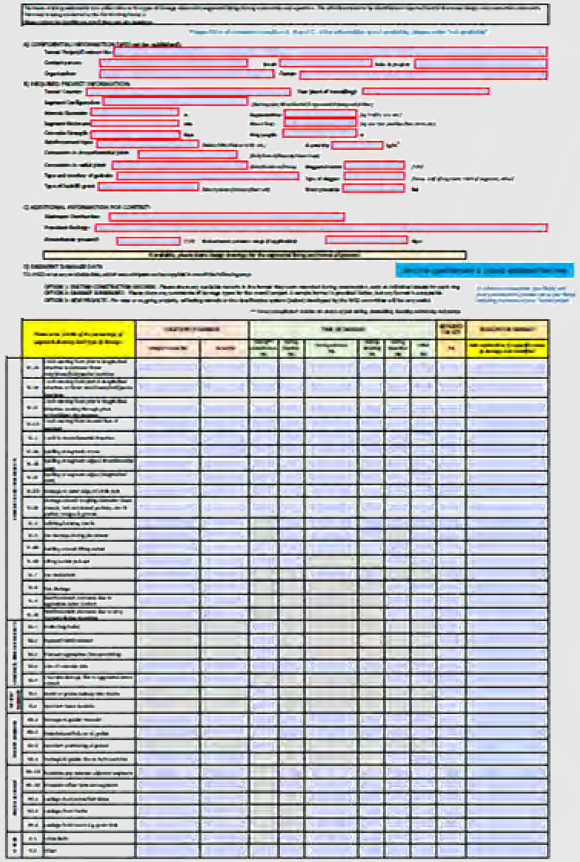
# Esempi

## Danni ai conci: ITA WG 2 (ongoing Report on Segment Damages & Survey)

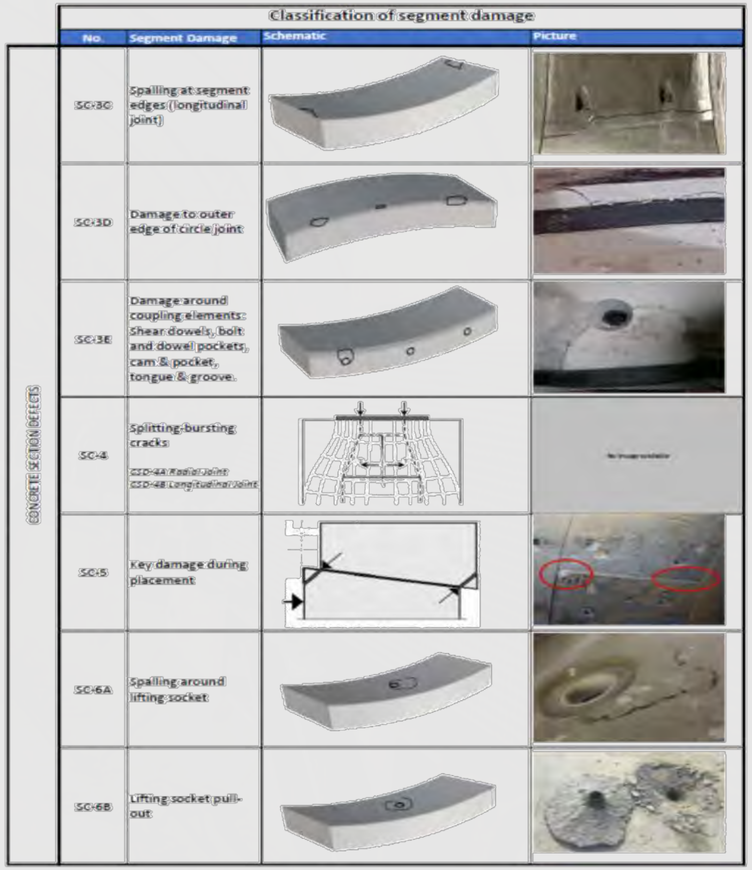
**Damage survey sheet**



**Damage classification**

Classification of segment damage

| | No. | Segment Damage | Schematic | Picture |
|---|---|---|---|---|
| CONCRETE SECTION DEFECTS | SC-1A | Crack starting from joint in longitudinal direction in-between thrust ram/dowel/bolt/ packer locations | | |
| | SC-1B | Crack starting from joint in longitudinal direction at thrust ram/dowel/bolt/ packer locations | | |
| | SC-1C | Crack starting from joint in longitudinal direction running through grout socket/shear pin recesses | | |
| | SC-1D | Crack starting from internal face of segment | | |
| | SC-2 | Crack in circumferential direction | | |
| | SC-3A | Spalling at segment corner | | |
| | SC-3B | Spalling at segment edges (circumferential joint) | | |



Classification of segment damage

| | No. | Segment Damage | Schematic | Picture |
|---|---|---|---|---|
| CONCRETE SECTION DEFECTS | SC-3C | Spalling at segment edges (longitudinal joint) | | |
| | SC-3D | Damage to outer edge of circle joint | | |
| | SC-3E | Damage around coupling elements: Shear dowels, bolt and dowel pockets, cam & pocket, tongue & groove. | | |
| | SC-4 | Splitting-bursting cracks<br>CSD-4A Radial Joint<br>CSD-4B Longitudinal Joint | | |
| | SC-5 | Key damage during placement | | |
| | SC-6A | Spalling around lifting socket | | |
| | SC-6B | Lifting socket pull-out | | |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# Esempi

## Danni ai conci: ITA WG 2 (ongoing Report on Segment Damages & Survey)

**Damage classification**

Classification of segment damage

| | No. | Segment Damage | Schematic | Picture |
|---|---|---|---|---|
| CONCRETE SECTION DEFECTS | SC-7 | Key movement<br>CSD-7A - longitudinal (towards TBM),<br>CSD-7B - radial (into tunnel),<br>CSD-7C - combination of above | Movement of key out of completed ring during erection or during build of subsequent ring | key segment |
| | SC-8 | Fire damage | | |
| | SC-9 | Reinforcement corrosion due to aggressive water contact | | |
| | SC-10 | Reinforcement corrosion due to stray currents during operation | | |
| CONCRETE SECTION DEFECTS | SU-1 | Voids (bug holes) | (>5mm dia on any surface, at any location on gasket groove) | |
| | SU-2 | Exposed reinforcement | Reinforcement exposed after casting | |
| | SU-3 | Exposed aggregates (honeycombing) | | |

Classification of segment damage

| | No. | Segment Damage | Schematic | Picture |
|---|---|---|---|---|
| SURFACE DEFECTS | SU-4 | Loss of concrete skin | Generally occurs during demolding when concrete surface bonds with the mold | |
| | SU-5 | Concrete damage due to aggressive water contact | | |
| INSERT DEFECTS | ID-1 | Grout or grease leakage into inserts | Bolt, dowel or other insert filled during casting process. | |
| | ID-2 | Incorrect insert location | Bolt, dowel or other insert placed incorrectly during casting process | |
| GASKET DAMAGE | GD-1 | Damage to gasket material | Rips, tears or punctures to gasket | |
| | GD-2 | Detachment/Pull-out of gasket | Gasket loose or pulled out of groove due to collision, glue weakening, poor anchoring, rubbing/poor gasket lubrication, | SEGMENT BEING PLACED / PREVIOUSLY PLACED SEGMENT |
| | GD-3 | Incorrect positioning of gasket | Includes poorly dimensioned gaskets that do not fit segment, anchored gaskets that detach from mold during casting and are depressed into concrete, and glued gaskets that are incorrectly positioned (e.g. corners misplaced) | |

Classification of segment damage

| | No. | Segment Damage | Schematic | Picture |
|---|---|---|---|---|
| GASKET DAMAGE | GD-4 | Damage to gasket due to hydrocarbons | Loss of gasket performance due to contact with hydrocarbons and/or high temperatures | |
| WATER LEAKAGE DEFECTS | WL-1A | Excessive gap between adjacent segments | | |
| | WL-1B | Excessive offset between segments | | |
| | WL-2 | Leakage from joints/bolt holes | | |
| | WL-3 | Leakage from cracks | | |
| | WL-4 | Leakage from insert e.g. grout hole | | |
| OTHER | O-1 | Loose Bolts | Loose bolts immediately after ring build, or after TBM advance. Excessive looseness only, minor looseness is normal. | |
| | O-2 | Other | Other damage during manufacture or construction not included in previous classifications (please provide description) | |



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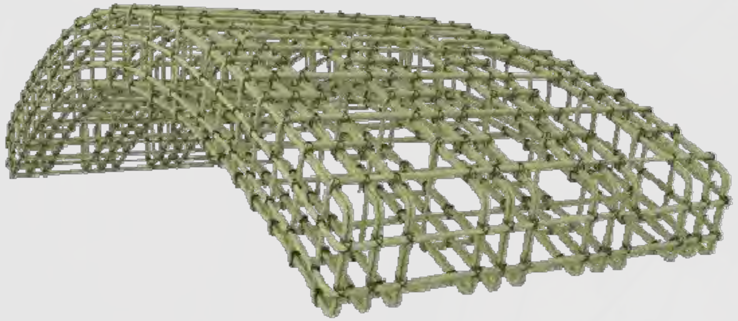
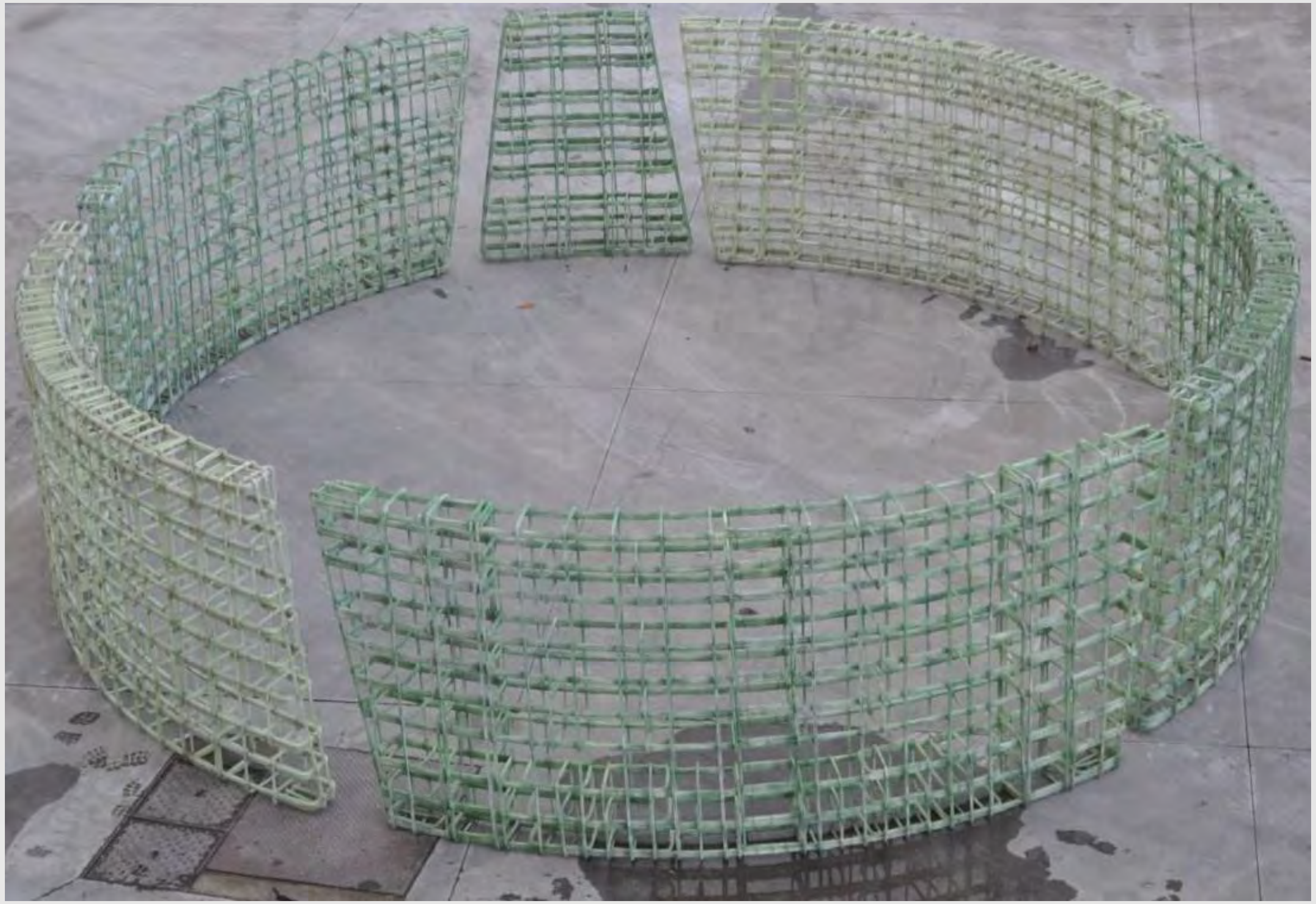
# Esempi

## GFRP





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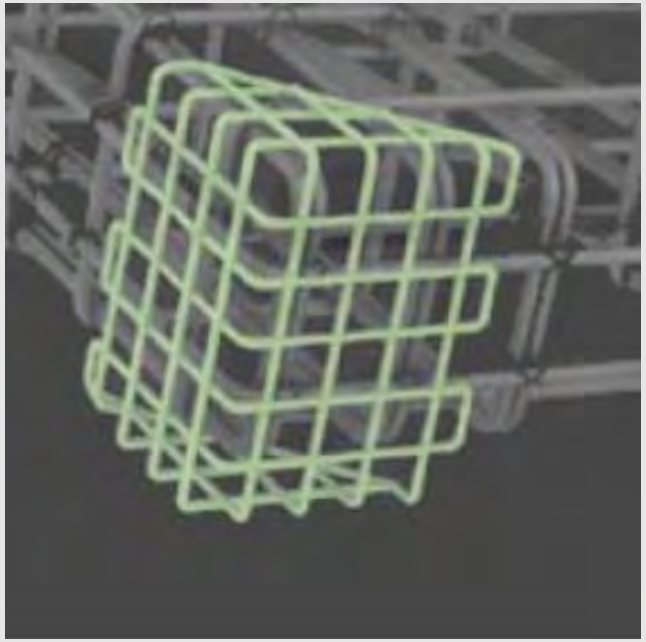
# Esempi



## GFRP

I rinforzi in GFRP, sugli spigoli e/o su tutto il contorno, possono fornire un contributo significativo alla resistenza in caso di urti o di concentrazioni di sforzi generate da difetti geometrici o di montaggio.



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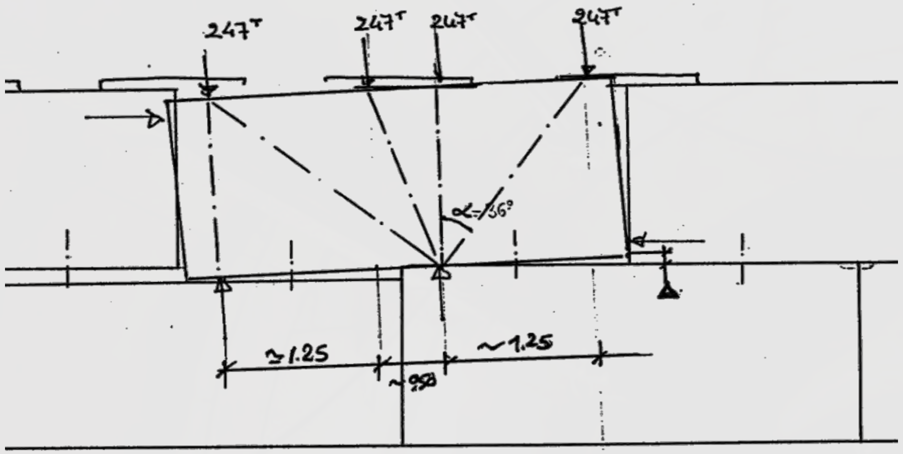
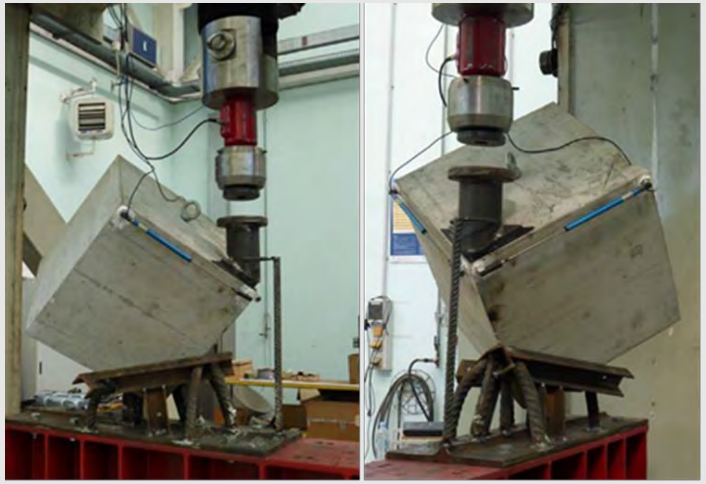
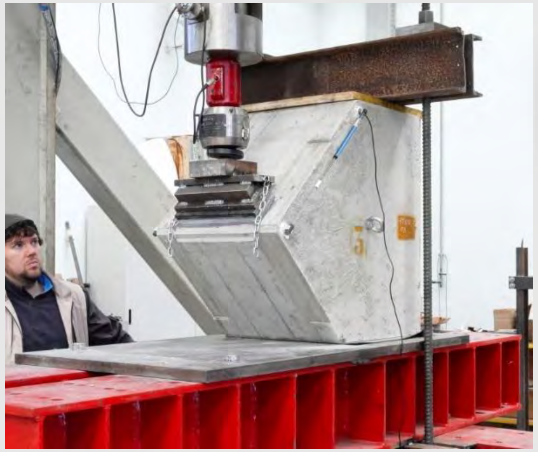
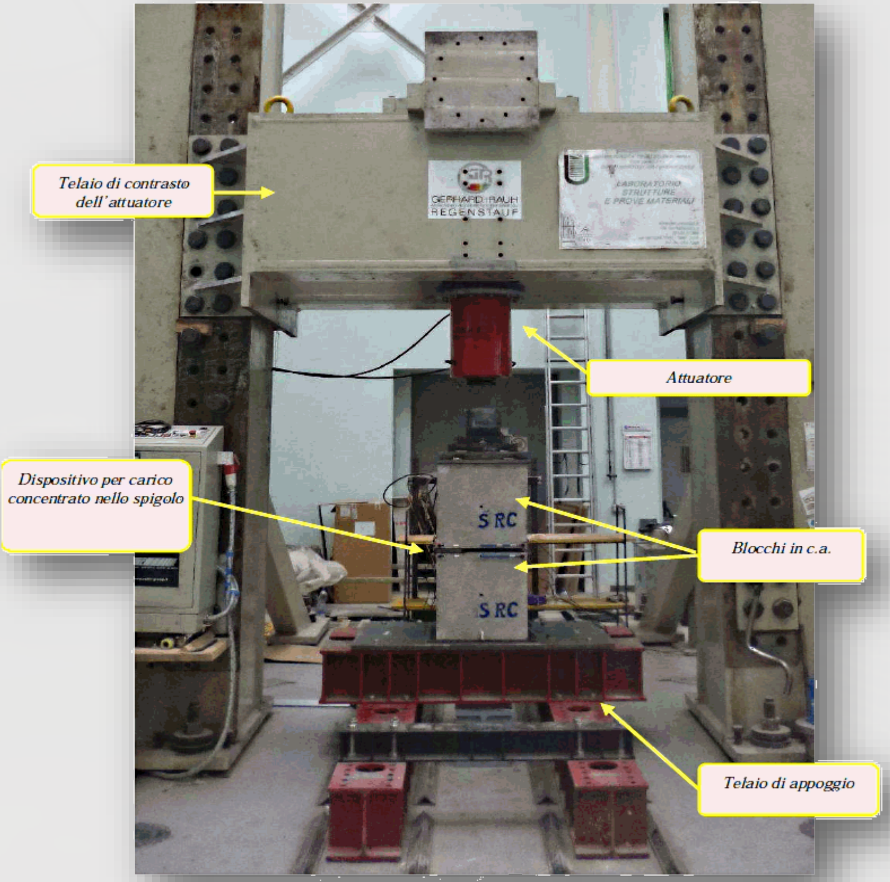
# Esempi

## GFRP







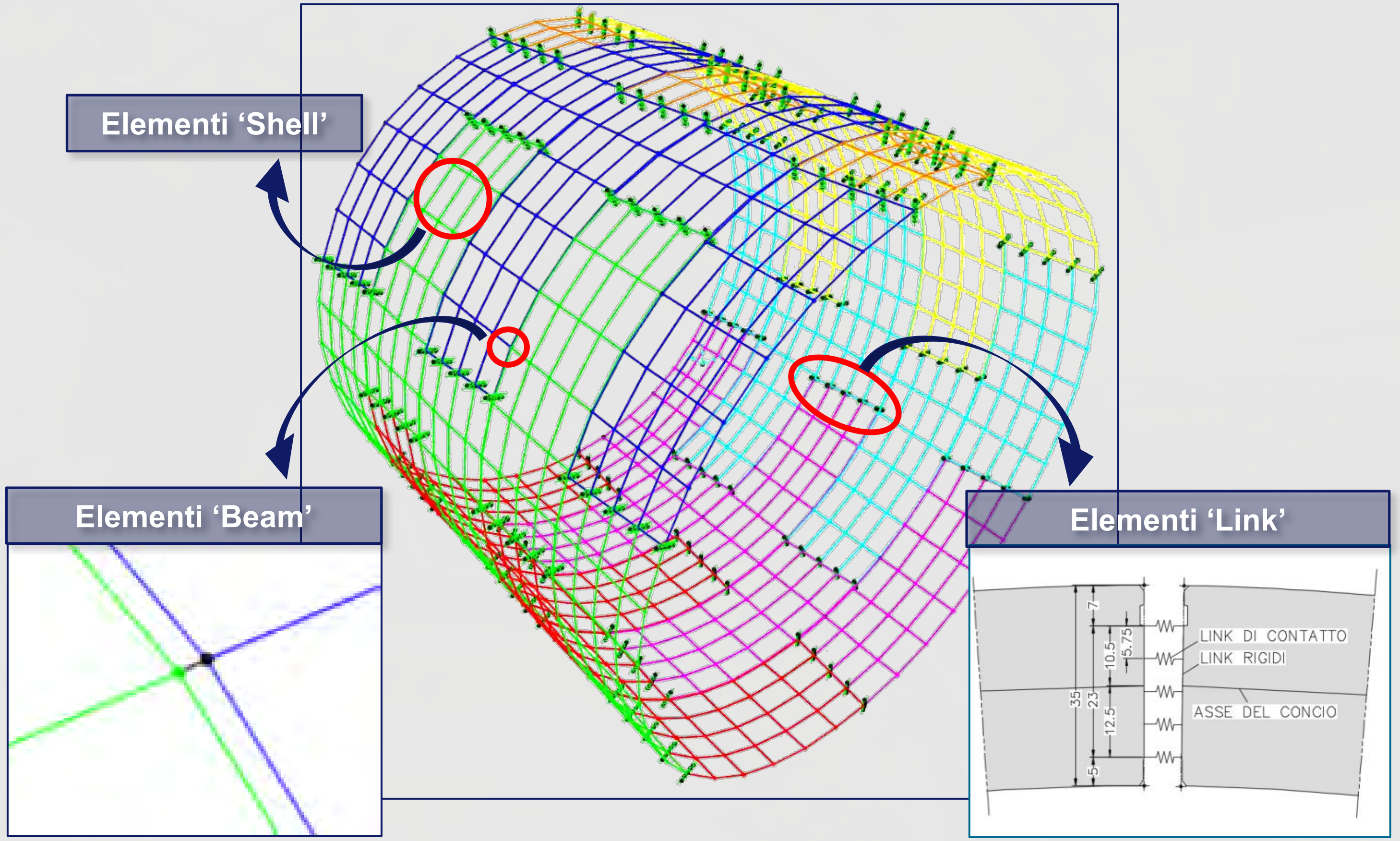

Telaio di contrasto dell'attuatore
Attuatore
Dispositivo per carico concentrato nello spigolo
Blocchi in c.a.
Telaio di appoggio

# Esempi

## Modellazione 3D

The models have been loaded with an almost uniform load schematizing the back-fill pressure with an asymmetric load (Figure 17) with variable entity to analyse the behaviour of the system and to define the limit load of the lining. Analyses have shown a concentration of loads at the segments edges with consequent breakage of the first link of the system right at the edge. A significant increase of the asymmetric limit load of the lining is noticed in case of GFRP reinforcement extended to the entire perimeter of the segment and not only at the corner.

Moreover, GFRP reinforcements produce beneficial effects in case of incorrect installation of the segments. If the contact between two segments is limited to only one corner - case that, though not desirable, may happen during the installation of the segments - the asymmetric limit load rises proportionally with respect to the "stress-strain" law assigned to the links that schematizes the joint, deducted from the laboratory tests previously illustrated.

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# Esempi
## GFRP



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# Esempi

## GFRP

Examples of works where rings fully reinforced with GFRP were adopted are:

- Milan Metro Line 4: n. 3 rings have been realized equipped with instrumentation to check the performance of the GFRP reinforcement used as a dielectric joint at entrance and exit of stations. Before the installation, two segments reinforced with GFRP have been tested under bending loads and for the simulation of the load of the TBM's jacks. The tests have been compared with those of segments reinforced with steel rebar, with positive results. During the installation of the rings any problem arose and any behavioural deviation was noticed. After the installation, the monitoring instruments have shown a reinforcement performance in line with the rest of the tunnel.
- IDRIS Doha (Qatar) Project: segments reinforced with GFRP have been adopted for all sections to be later demolished.

Integrative GFRP edge and corner reinforcements have been planned for the following jobs:

- Santa Lucia Tunnel, Barberino del Mugello (Firenze, Italy, A1 Highway Milan – Rome: 16 m diameter of excavation, 55 cm thick segments; GFRP reinforcement placed at 2 cm from the surface of the edges.
- Brenner Basis Tunnel: 11 m diameter of excavation, 45 cm thick segments.
- Hydraulic Tunnel in Tokyo with hexagonal segments: the GFRP reinforcements will be placed at the sharp corners of the closing segments.
- Esenboga - Havaalani (Turkey) railway tunnel.
- Rijnland Route COMOL5 (Nederland) highway tunnel: GFRP reinforcements have been forecasted to protect the steel reinforcement's concrete cover of 70 mm disposed to guarantee a high fire resistance.

- Rome Metro Line C: 6.7 m diameter of excavation, 35 cm thickness
- London underground
- Thames Tideway


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# Normative, Linee Guida, Raccomandazioni

## FRC

GAZZETTA UFFICIALE
DELLA REPUBBLICA ITALIANA

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

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N. 8

MINISTERO DELLE INFRASTRUTTURE
E DEI TRASPORTI

DECRETO 17 gennaio 2018.

**Aggiornamento delle «Norme tecniche per le costruzioni».**

**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.

*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)***

*Consiglio Superiore dei Lavori Pubblici*

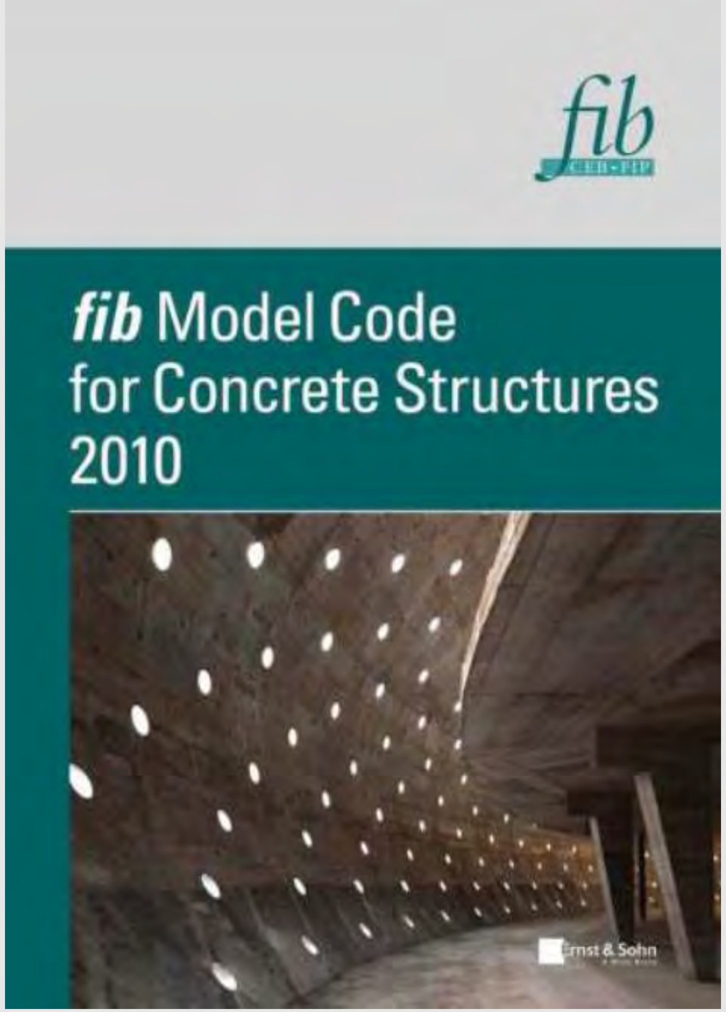
*Servizio Tecnico Centrale*

***Linee guida per la progettazione, messa in opera, controllo e collaudo di elementi strutturali in calcestruzzo fibrorinforzato FRC (Fiber Reinforced Concrete)***

# Normative, Linee Guida, Raccomandazioni

## FRC

- 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.
- 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.



# Normative, Linee Guida, Raccomandazioni

## GFRP

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DECRETO 17 gennaio 2018.

**Aggiornamento delle «Norme tecniche per le costruzioni».**

Capitolo 11 delle NTC 2018

Identificazione e qualificazione di materiali e prodotti per uso strutturale

A tal fine le norme predette prevedono che **i materiali e i prodotti da costruzione per uso strutturale**, *quando non marcati CE ai sensi del Regolamento (UE) n.305/2011 o non provvisti di un ETAss (European Technical Assessment) ai sensi dell'art. 26 del Regolamento (UE) n. 305/2011*, **debbano essere in possesso di un Certificato di Valutazione Tecnica (CVT)** rilasciato dal Sevizio Tecnico Centrale (STC), anche sulla base di linee guida approvate dal Consiglio Superiore dei Lavori Pubblici.



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# Normative, Linee Guida, Raccomandazioni

## GFRP

| ACI 440.1R-15 / 2015 | CSA Standard S806-12 / 2012 | Bullettin *fib* 40 / 2007 | Istruzioni CNR DT203 / 2006 |
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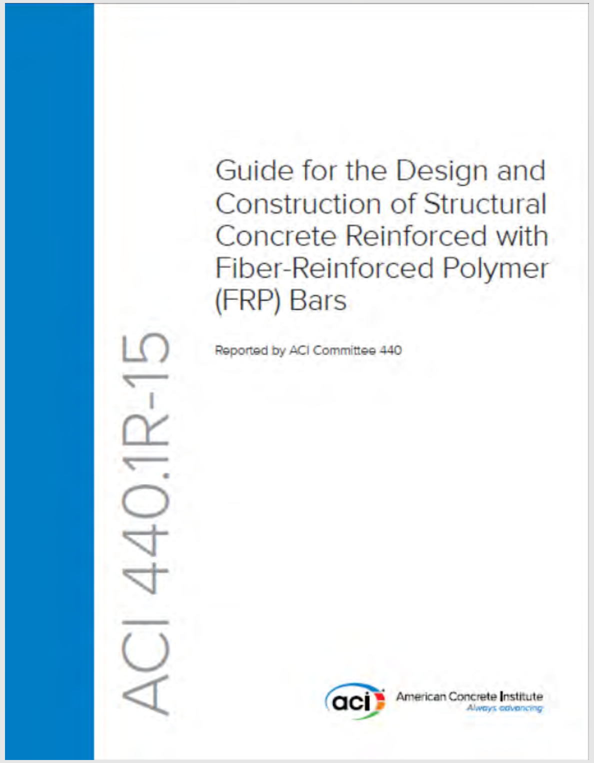


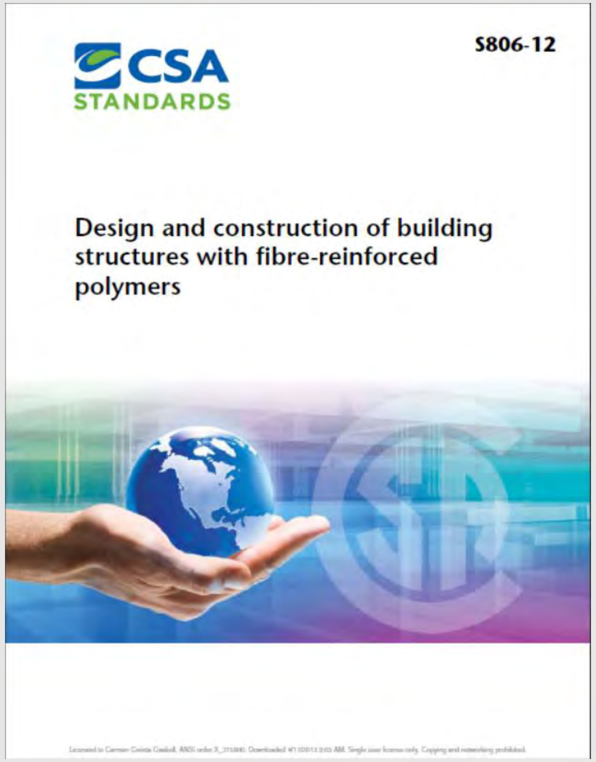



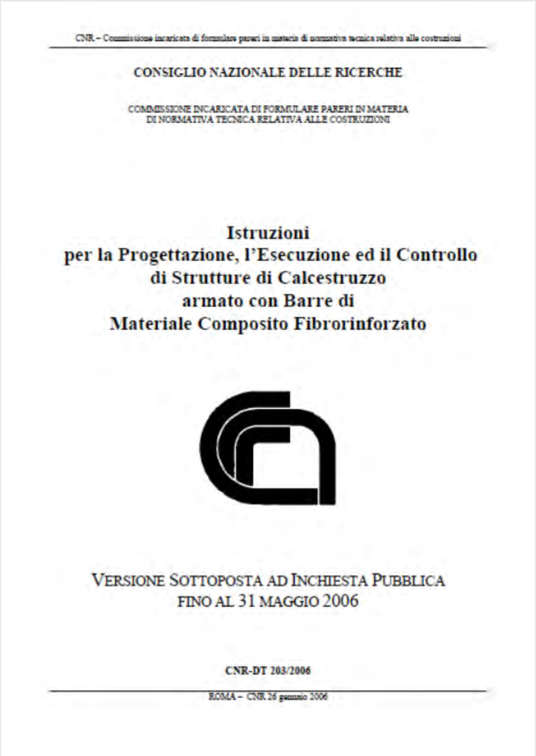




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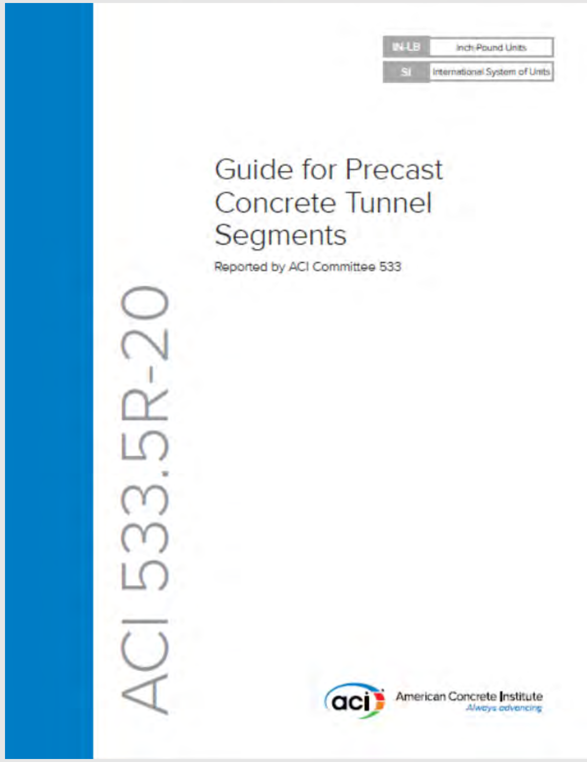
# Normative, Linee Guida, Raccomandazioni

## Precast concrete tunnel segments

| ACI 533.5R-20 / 2020 | ITA WG 2 Report n° 22 / 2019 | SIG WG 2 Report / 2019 | AFTES Rec. / 1998 |
| --- | --- | --- | --- |





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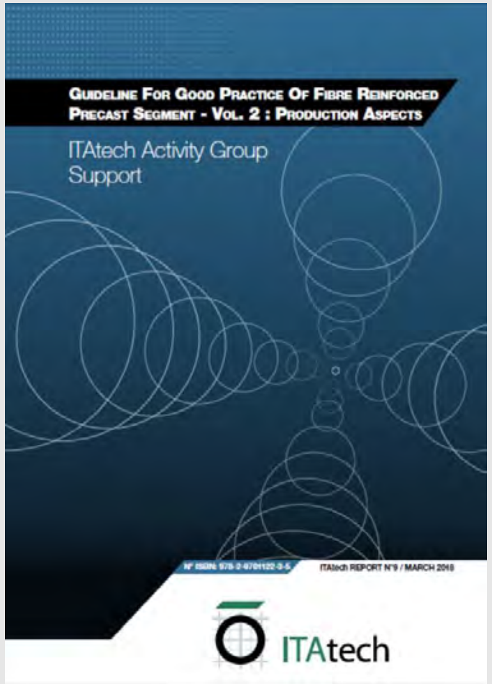
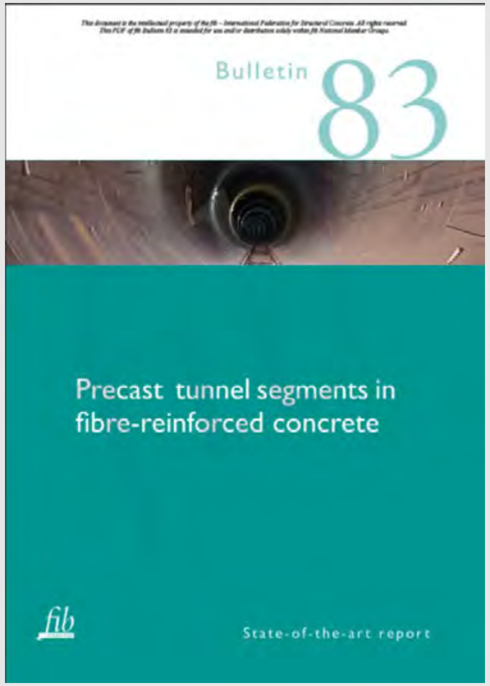
# Normative, Linee Guida, Raccomandazioni

## Precast tunnel segments FRC

ITAtech report n° 9 / 2018



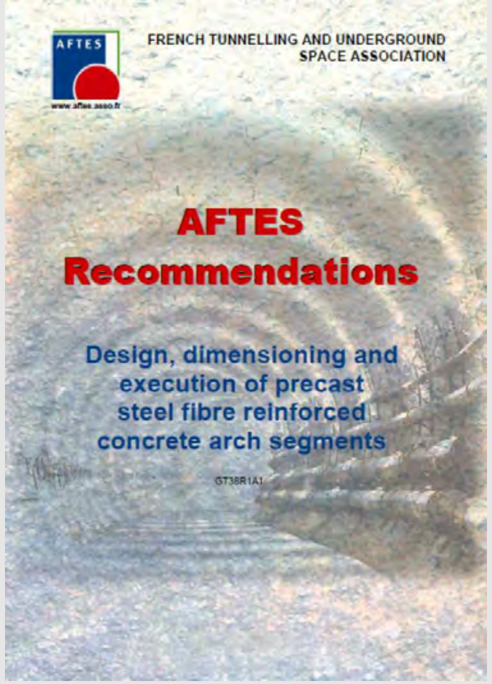

Bullettin *fib* 83 / 2017




ITAtech report n° 7 / 2016


ITA report n° 16 / 2016


AFTES Rec. / 2013



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