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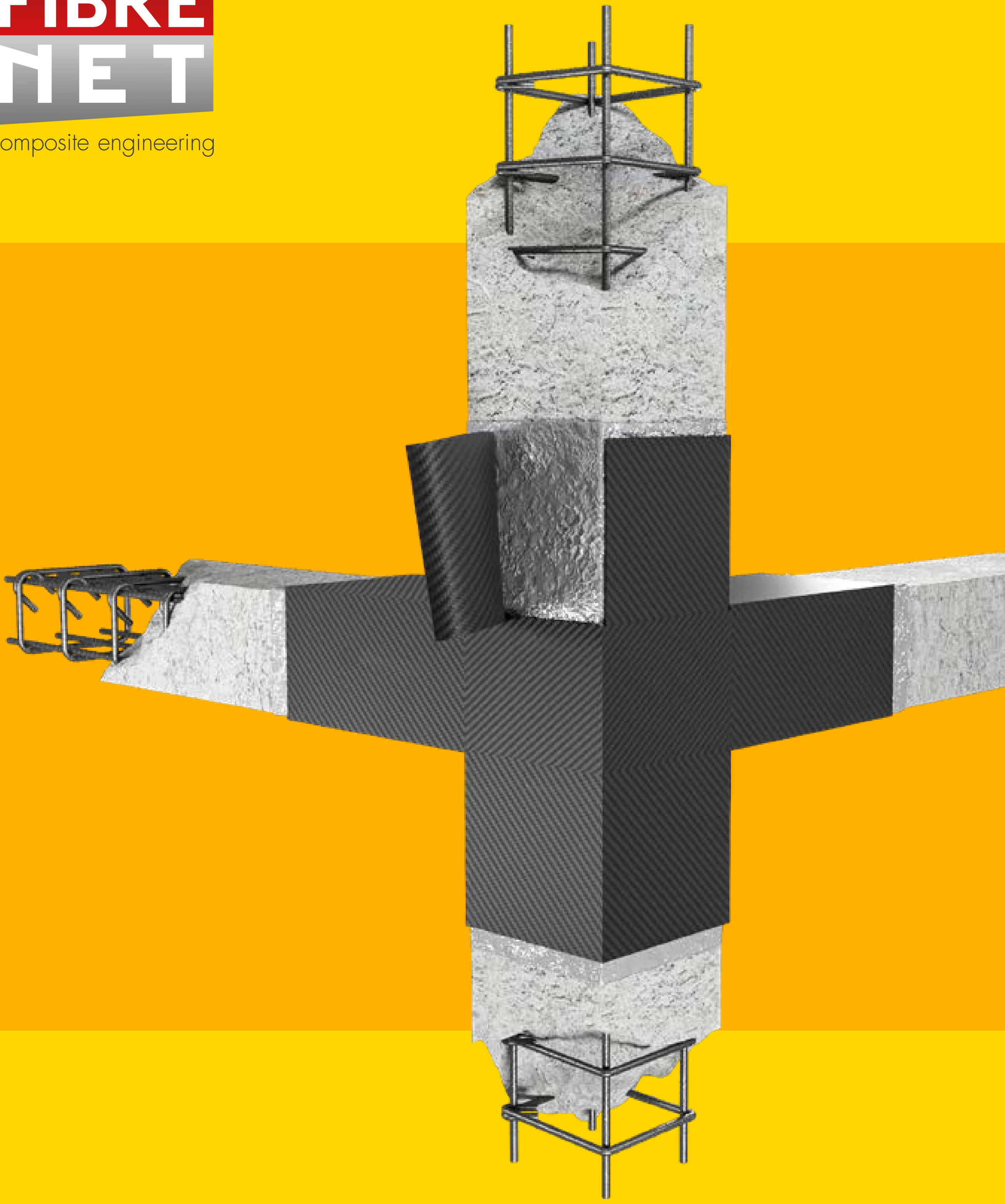

TECHNICAL MANUAL
BETONTEX
FRP SYSTEM

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TECHNICAL MANUAL

BETONTEX

FRP SYSTEM

The “BETONTEX Technical Manual” is intended to serve as a useful and practical working tool for professionals and companies operating in the construction sector.
It is the result of over twenty years of research and experimentation, as well as on-site experiences that have established Fibre Net as an international leader in the field of composite materials applied to construction.

INDEX

1 INTRODUCTION 7

2 BACKGROUND AND TECHNICAL FOUNDATIONS OF THE FIBRE NET BETONTEX FRP SYSTEM 9

2.1 FRP System 9
2.2 FRP systems for the strengthening of masonry structures 13
2.3 FRP in the strengthening of reinforced concrete structures 14
2.4 System components 16

3 RESEARCH AND DEVELOPMENT: EXPERIMENTAL INVESTIGATIONS 21

4 PRACTICAL DESIGN GUIDELINES 23

4.1 Introduction – fundamentals of design with composite materials 24
4.2 Failure mechanisms due to debonding from the substrate 25
4.3 Strengthening of reinforced concrete structures 27

5 SUBSTRATE ASSESSMENT AND APPLICATION CYCLES 47

5.1 Concrete elements 48
5.1.1 Diagnostic techniques on concrete structures 48
5.1.2 Concrete substrate preparation 49
5.1.3 Application cycles 52
5.1.4 Application procedure for preformed FRP reinforcements 56
5.2 Masonry structures 57
5.3 Timber structures 58
5.4 Steel structures 59

6 SUBSTRATE ASSESSMENT AND APPLICATION CYCLES 61

6.1 Strengthening of slabs and floor systems 62
6.2 Strengthening of columns 63
6.3 Flexural strengthening of beams 64
6.4 Shear strengthening of beams 66
6.5 Strengthening of beam-to-column joints 67
6.6 Strengthening of joists 68
6.7 Strengthening of masonry column 70
6.8 External banding at floor slab level 71
6.9 Strengthening of masonry arches and vaults 72
6.10 Strengthening of steel floor slabs 73
6.11 Strengthening of timber floor slabs 74
6.12 Stitching with bars 76
6.13 Connections with bowed bars 77
6.14 Ardfix connection 78

7 SYSTEM PROTECTION AGAINST FIRE AND UV EXPOSURE 81

1

INTRODUCTION

This document is intended to serve as a guide for professionals approaching the use of composite materials in structural rehabilitation works.
While fully acknowledging that FRP (Fiber Reinforced Polymer) systems do not constitute a universal solution for all deteriorated structures requiring strengthening, they often offer a highly effective and technically sound alternative to traditional methods.
Composite materials are particularly suited for applications in which the structural element, or the structure as a whole, is subject to tensile stress conditions, or where the demand for tensile capacity in the reinforcement system is significant.
Their use extends across a wide range of construction typologies, including reinforced and prestressed concrete, masonry, timber, and steel structures.
They are also effective tools to increase the seismic capacity of structures and to upgrade and/or improve aging buildings.
These reinforcement techniques can also represent a valid alternative in the case of protected or heritage buildings. When properly designed and engineered, they can successfully reconcile conservation requirements with structural strengthening needs.
Particular emphasis is also placed on environmental sustainability. This guide provides practitioners with clear references to the Italian Minimum Environmental Criteria (CAM), noting that the Betontex product line complies with these standards through certified Environmental Product Declarations (EPDs).
This technical manual is designed to provide detailed technical, technological, regulatory, and practical information for the execution of structural strengthening interventions in seismic retrofitting, static rehabilitation, restoration, and the conservation of civil structures and infrastructure.


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2

BACKGROUND AND TECHNICAL FOUNDATIONS OF THE FIBRE NET BETONTEX FRP SYSTEM

Fiber-reinforced composite materials established sectors such as aerospace, marine engineering, and motorsport - were introduced into the construction industry in the early 1990s.
Concurrently, leading academic institutions in Italy and abroad undertook extensive experimental campaigns to evaluate the performance of composite systems applied to various structural typologies. The synergy between companies and the academic research community proved instrumental in the formulation of key technical design standards, most notably the CNR-DT 200 Guidelines, now in their second edition.
This document has played a pivotal role in shaping the regulatory and operational framework of the sector.
Fibre Net has been an active contributor to the drafting of these guidelines, participating in all institutional and technical working groups, thereby reaffirming its commitment to innovation, standardization, and the advancement of composite technologies for structural engineering.

2.1 FRP SYSTEM

Fiber Reinforced Polymer (FRP) composites are composed of two main components: the matrix and the reinforcing fibers. The matrix is typically organic in nature, commonly based on thermosetting resins, while the reinforcement consists of continuous fibers such as carbon (CFRP - Carbon Fiber Reinforced Polymer), glass (GFRP - Glass Fiber Reinforced Polymer), aramid (AFRP - Aramid Fiber Reinforced Polymer), or steel (SFRP - Steel Fiber Reinforced Polymer).
FRP systems are employed to enhance the performance of structural elements subjected to both static and seismic actions.
They are particularly effective in strengthening damaged structures, allowing for the restoration of safety conditions that existed prior to the damage.
More broadly, these materials are suitable for all situations where unanticipated load conditions - beyond those considered in the original design - result in increased stress on structural members.
Under specific structural configurations, fiber-reinforced composites represent an unquestionably reliable and efficient alternative to traditional strengthening techniques.

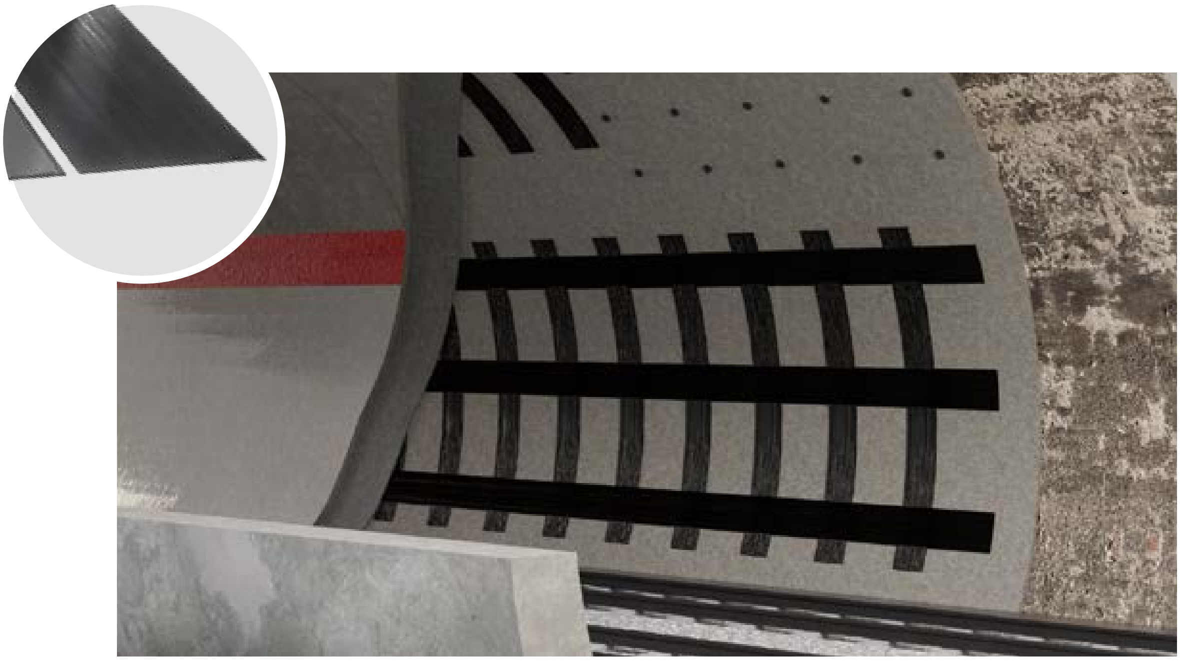
BUILDING CONSTRUCTION

Twenty-five years after their first applications in the construction industry, composite materials the technique has matured and has proven extremely useful for solving even complex structural problems. The Italian building stock is predominantly composed of ageing structures that reflect the design approaches and regulatory frameworks of their original construction era. Many of these structures were conceived to withstand only gravitational loads and, in light of the updated national seismic zoning, now require targeted strengthening interventions.
In such cases, the use of composite materials represents a valuable opportunity that can be considered by designers, contractors, and clients alike. Today, FRP composites also constitute a viable technological solution for historic and protected structures, offering high compatibility with the constraints of heritage preservation.
The versatility of composite materials enables rapid, efficient, and cost-effective strengthening interven tions, with reduced environmental impact. In some cases, reinforcement work can be performed without interrupting the activities taking place inside the structure.

INFRASTRUCTURE

In the infrastructure sector, the most relevant development is the issuance of ministerial guidelines for the safety assessment of existing infrastructure assets. The initial phases of inventory and analysis have revealed that a significant portion of civil works exhibit high levels of attention and risk.
In risk reduction, FRP composite materials can be used to reduce the vulnerability component, with a significant impact also on the durability of the structure and its maintenance, producing direct effects on the Bridge Management System (BMS). Composite materials are therefore a strategic option for both regulatory and functional upgrading of civil infrastructure.

FRP strengthening systems can be broadly classified into two main categories:



Preformed reinforcement systems

Preformed elements of various shapes in which the fiber-matrix combination is manufactured in the factory, while the bonding to the substrate is carried out on site using an adhesive resin.

In-situ laminated strengthening systems

Systems in which both the composite material (matrix + fiber) and the bonding to the substrate are formed directly on site.

2.2 FRP SYSTEMS FOR THE STRENGTHENING OF MASONRY STRUCTURES

Composite reinforcements provide masonry with tensile strength - a property it naturally lacks - thus contributing to the formation of a new material: reinforced masonry. Their application reduces the seismic vulnerability of buildings by increasing their resistance to seismic actions.

Composite materials can be used to strengthen masonry against both in-plane and out-of-plane actions, enhancing the structure's capacity to withstand seismic forces and preventing the activation of local and/or global failure mechanisms.

In general, their use in masonry buildings includes:
▪ ring beams created through external or combined internal/external wrapping connected by anchors;
▪ strengthening of vaults and arches with reinforcing strips;
▪ reinforcement against both in-plane and out-of-plane actions;
▪ confinement of columns to improve strength and ductility.

2.3 FRP IN THE STRENGTHENING OF REINFORCED CONCRETE STRUCTURES

As with masonry buildings, the design of reinforced concrete structures - from the early 20th century until just a few decades ago - focused primarily on resistance to static loads, often neglecting seismic actions, especially in many regions.

These structures typically present the following issues:

- design based solely on gravity loads: characterized by strong beams and weak columns, resulting in poor ductility and promoting brittle failure mechanisms;
- inadequate floor systems: lack of diaphragm action due to the absence of rigid floors.

FRP composite materials are employed for the strengthening and rehabilitation of reinforced concrete structures, particularly for:

- columns and pillars, increasing shear capacity, flexural strength, and ductility;
- beams, enhancing flexural, torsional, and shear strength;
- beam-column joints, improving shear resistance and ensuring the correct hierarchy of strengths under seismic loads;
- slabs and floor plates, increasing flexural and shear strength.

2.4 SYSTEM COMPONENTS

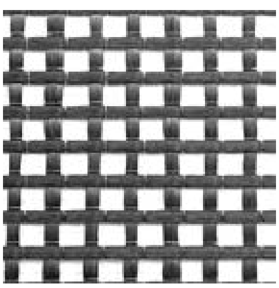
BETONTEX
THERMALLY WELDED UNIDIRECTIONAL FABRIC IN CFRP
Thermally welded unidirectional fabric made of medium-tenacity (MT), high-tenacity (HT), or high-modulus (HM) carbon fiber.

PRODUCT	WEIGHT	ELASTIC MODULUS
MEDIUM TENACITY FABRIC		
FB-GV320U-MT	300 g/m^2	>= 250 GPa
FB-GV420U-MT	400 g/m^2	
FB-GV620U-MT	600 g/m^2	
HIGH TENACITY FABRIC		
FB-GV330U-HT	300 g/m^2	>= 245 GPa
FB-GV420U-HT	400 g/m^2	
FB-GV620U-HT	600 g/m^2	
HIGH MODULUS FABRIC		
FB-GV320U-HM	300 g/m^2	>= 390 GPa
FB-GV420U-HM	400 g/m^2	
FB-GV620U-HM	600 g/m^2	

BETONTEX
MULTI-AXIAL FABRIC IN CFRP
Multidirectional reinforcement thermowelded in high tenacity carbon fiber.

PRODUCT	WEIGHT	ELASTIC MODULUS
FB-Multiax400	400 g/m^2	230 GPa

BETONTEX
BIDIRECTIONAL CARBON FIBER MESH
Bidirectional high tenacity carbon fiber dry mesh.



PRODUCT	MESH SIZE	WEIGHT	ELASTIC MODULUS
FB-RC225-TH12-R8	8 x 8 mm	200 g/m^2	245 GPa
FB-RC225-TH12-R16	16 x 16 mm		

** in release

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BETONTEX
CARBON FIBER LAMINATE
Preformed carbon fiber laminate made of high tenacity (HT) and high modulus (HM) fibers, equipped with double peel-ply film.

PRODUCT	THICKNESS	ELASTIC MODULUS
LAMINATE HIGH TENACITY		
FB-G12L-HT	1,2 mm	170 GPa
FB-G14L-HT	1,4 mm	170 GPa
LAMINATE HIGH MODULUS		
FB-G14L-HM	1,4 mm	200 GPa
LAMINATE ULTRA-HIGH MODULUS		
FB-G14L-HHM	1,4 mm	250 GPa

BETONTEX
CFRP BAR
Prefabricated bar in high tenacity (HT) and high modulus (HM) Carbon Fiber Reinforced Polymer (CFRP), available with smooth or enhanced bond surface, made of chemically resistant carbon fiber and thermosetting resin.

PRODUCT	DIAMETER	ELASTIC MODULUS
HIGH TENACITY SMOOTH BAR		
FB-G_BL-HT	da 6 mm a 16 mm	130 GPa
HIGH TENACITY BAR WITH ENHANCED BONDING SURFACE		
FB-G_BAM-HT	da 6 mm a 16 mm	130 GPa
HIGH MODULUS BAR WITH ENHANCED BONDING SURFACE		
FB-G_BAM-HM	da 6 mm a 16 mm	200 GPa

BETONTEX
DEBOWED CARBON FIBER ROD
Fiber Reinforced Polymer (CFRP), made of chemically resistant carbon fiber and thermosetting resin, featuring unidirectional fiber anchorages on one or both ends for in-situ impregnation.

PRODUCT	ENDS TO BE IMPREGNATED	ELASTIC MODULUS
SINGLE-ANCHOR BAR		
FB-TUP10-CHT1A	n.1 x 20 cm	130 GPa
DOUBLE ANCHOR BAR		
FB-TUP10-CHT2A	n.2 x 20 cm	130 GPa

BETONTEX
CFRP BOW – TUF
High-tenacity or high-modulus carbon fiber bow with external sleeve

PRODUCT	DIAMETER	ELASTIC MODULUS
BOW – TUF HIGH TOUGHNESS		
FB-TUF_CHT	8-10-12 mm	245 GPa
BOW TUF HIGH MODULUS		
FB-TUF_CHM	8-10-12 mm	390 GPa

2.4

BETONTEX
ADHESIVE AND IMPREGNATION RESINS

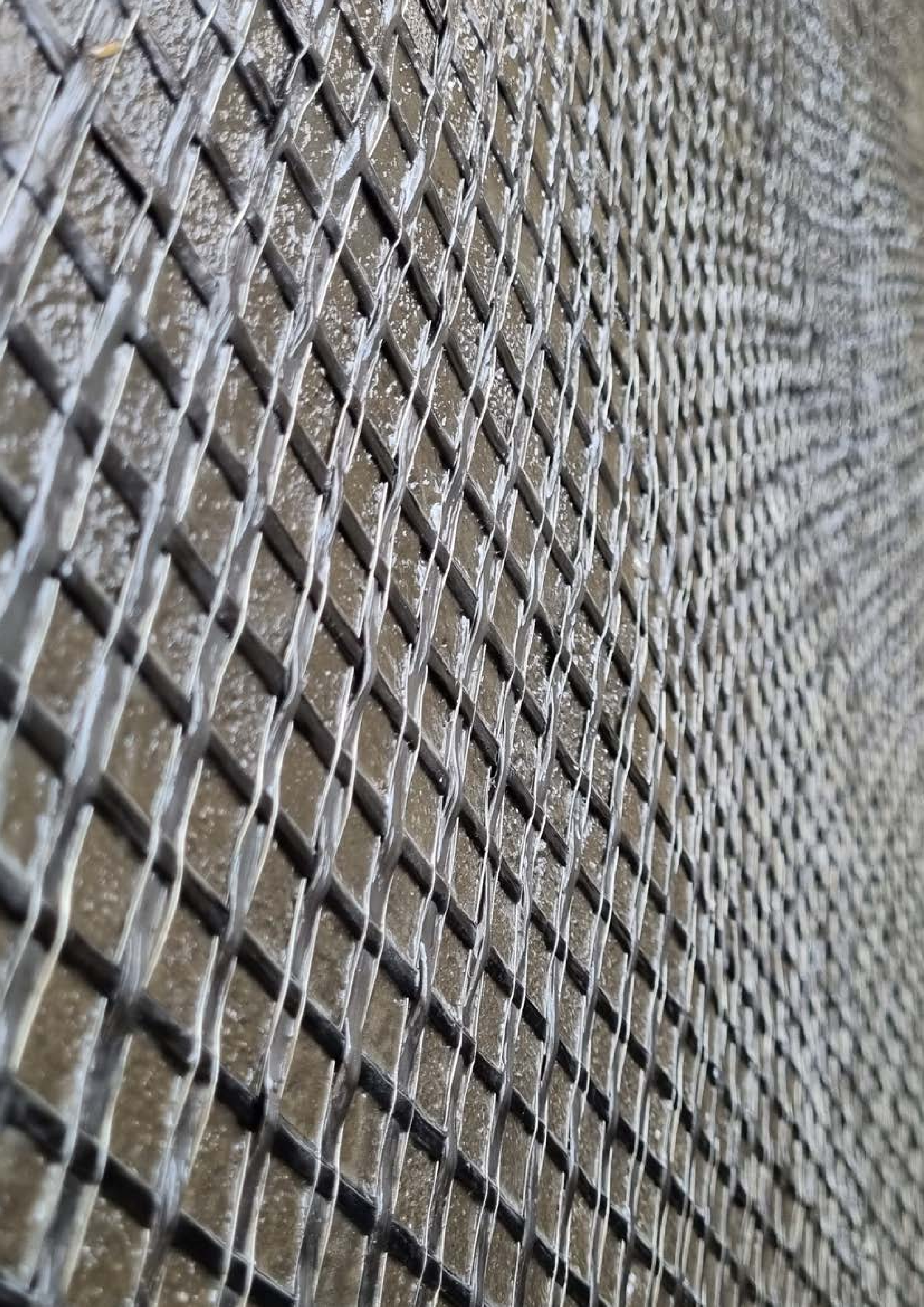
Thermally welded unidirectional fabric made of medium-tenacity (MT), high-tenacity (HT), or high-modulus (HM) carbon fiber.

PRODUCT	APPLICATION	AVERAGE CONSUMPTION	
PRIMER: LOW-VISCOSITY EPOXY RESIN			
FB-RC01	surface preparation	150 ÷ 300 g/m²	
IMPREGNATING AGENT: THIXOTROPIC EPOXY RESIN			
FB-RC02	impregnation of carbon fiber fabrics or meshes	First layer	Subsequent layers
		600 g/m²	300 g/m²
		800 g/m²	400 g/m²
		1200 g/m²	600 g/m²
ADHESIVE: THIXOTROPIC EPOXY RESIN			
FB-RC30/3	bonding of carbon fiber laminates and anchoring of glass fiber bars	3 ÷ 5 kg/m² (laminate) 1,5 ÷ 3 kg/m (bar)	

BETONTEX
ANCHORING RESINS

PRODUCT	DESCRIPTION
INTEGRA FIXA VINYL15	Two-component, vinylester, styrene-free, chemical anchor in cartridges

PRODUCT	DESCRIPTION
FB-RC30/3-600	Thixotropic epoxy resin in cartridges

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RESEARCH AND DEVELOPMENT: EXPERIMENTAL INVESTIGATIONS

Research activities began in the early 1990s with the first experimental campaigns conducted in collaboration with the University of Bologna, which immediately highlighted the high potential of FRP strengthening technology when applied to reinforced concrete structures. These initial studies also helped clarify the mechanical behavior of the system and, in particular, the critical role played by the bond between the FRP reinforcement and the concrete substrate.
The structural effectiveness of externally bonded FRP systems is highly dependent on this bond. When the substrate can no longer transfer stresses to the reinforcement, debonding occurs - a failure mechanism commonly referred to as delamination. Experimental testing has made it possible to analyze this phenomenon in depth and to develop analytical models for the design and prediction of system performance.
Research efforts also contributed to the development of technological solutions that optimize the structural contribution of externally bonded composite reinforcements.
In flexural strengthening applications, the use of anti-debonding devices - typically composite connectors such as fiber anchors or U-wraps, arranged along the element with defined spacing and geometry - has proven particularly effective. These devices allow the full tensile capacity of the reinforcement to be exploited and make it possible to predict the critical failure section. In flexural scenarios, failure tends to occur in regions of maximum moment, where the tensile demand on the reinforcement is greatest.

Flexural tests conducted on reinforced concrete beams, strengthened using longitudinal FRP and equipped with U-wraps or fiber anchors to mitigate delamination, yielded the following key findings:

- the ultimate limit state was governed by rupture of the longitudinal reinforcement in the zone of maximum tensile stress, effectively preventing debonding or delamination;
- beams strengthened with lateral u-wraps achieved slightly higher ultimate moments than beams with connectors; however, failure in these cases occurred due to debonding of the wraps, with no rupture of the longitudinal reinforcement. failure localized in areas subjected to higher shear demands;
- the presence of connectors not only prevented debonding - understood as the propagation of localized detachment - but also enabled reliable prediction of the failure zone.
  this marked a shift from an unpredictable failure scenario to a more controlled and forecastable behavior, with the failure section consistently located at mid-span in the region of maximum flexural demand, corresponding to the tensile capacity limit of the frp.

In addition to structural element testing, all experimental campaigns included comprehensive material characterization, such as:

- mechanical testing on concrete, steel, and frp materials;
- bond tests to evaluate the effectiveness of the interface between reinforcement and substrate.

Experimental investigation proved fundamental not only for the development of analytical design models supporting FRP technology, but also for defining critical technological and execution details.
Among these, particular emphasis was placed on substrate preparation and the operational guidelines necessary to ensure proper surface treatment - topics that will be discussed in detail in the following chapters.
Technological progress also involved both material innovation and production techniques.
By the mid-1990s, ongoing feedback between the market and manufacturers had already identified several practical challenges associated with the application of traditional reinforcement fabrics. Early-generation fabrics were often unstable and difficult to handle, compromising both the ease of installation and the overall performance of the strengthening system.

To address these issues, thermally bonded fabrics were developed, offering the following advantages:

- improved dimensional stability, simplifying installation;
- enhanced handling properties, easing the work of field operators;
- increased reinforcement efficiency, due to more accurate and reliable placement.

These advancements have led to significant improvements in the performance and applicability of FRP systems, thereby enhancing the overall reliability of composite-based structural strengthening technologies.

4

PRACTICAL DESIGN GUIDELINES

Composite materials are increasingly employed in structural rehabilitation and retrofitting applications, owing to a series of distinct advantages:

- high durability, including in aggressive environmental conditions;
- lightweight nature compared to traditional construction materials, allowing for easier application, even in confined or hard-to-reach spaces;
- high tensile strength and stiffness;
- customizable properties, enabling the design of composites tailored to specific structural requirements.

Despite these benefits, designers intending to utilize FRP strengthening systems must carefully account for certain material-specific characteristics.
Unlike steel, which exhibits an elasto-plastic behavior, composite materials respond in a linear-elastic manner up to failure, without any significant plastic deformation or yielding.
As a result, failure modes are brittle, and this must be duly considered during the design process.
The design of FRP reinforcement systems must meet criteria related to serviceability, durability, and ultimate limit state performance.
In fire scenarios, the strength of the reinforcement must be appropriate to the required exposure duration and safety level.
Strengthening systems must be positioned in areas where tensile stresses need to be resisted.
FRP composites should never be relied upon to carry compressive loads, as this is outside the scope of their intended mechanical performance.

4.1 INTRODUCTION – FUNDAMENTALS OF DESIGN WITH COMPOSITE MATERIALS

The strengthening of structures through the bonding of composite materials is an effective technique, provided that the design, detailing, and installation are carried out correctly.

Before selecting and applying such systems, it is recommended to perform preliminary investigations to allow the designer to acquire adequate knowledge of the substrate and, if necessary, to prescribe appropriate repair works.

It is essential to evaluate not only the mechanical properties of the materials involved but also their state of preservation, since the maximum service stress of the composite reinforcement depends on these parameters. If the substrate shows signs of deterioration, it must be repaired beforehand, and the use of properly designed mechanical anchorage systems should be prescribed. If the substrate is deemed unsuitable for reinforcement, alternative strengthening techniques should be considered.

In summary, the fundamental requirements for the selection and design of composite reinforcement systems are:
- achieving a sufficient level of knowledge of the structure to identify and eliminate potential risks;
- inhibiting brittle failure mechanisms and promoting a more ductile structural behavior;
- ensuring chemical-physical and mechanical compatibility between the reinforcement materials and the substrate, in order to extend the service life of the structure.

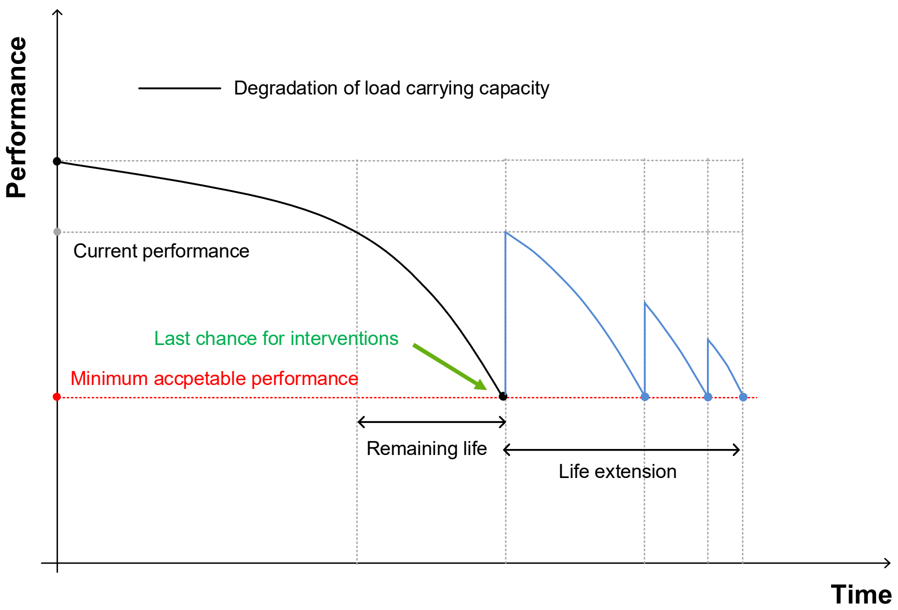

Fig. 01 - *Extension of the service life of the structure following maintenance interventions (e.g., structural strengthening)*

Fig. 02 - *Composite materials can be used to modify the structural failure mode*

4.2 FAILURE MECHANISMS DUE TO DEBONDING FROM THE SUBSTRATE

In strengthening interventions on concrete or masonry elements using laminates or fabrics, the bond between the composite material and the substrate plays a critical role, as debonding failure is inherently brittle in nature.
In principle, debonding can occur within the adhesive layer, at the interface between the adhesive and the substrate, within the substrate itself, or within the reinforcement system (for example, in multi-layer applications). When properly installed, since the shear strength of the adhesive typically exceeds that of the substrate, failure generally occurs by detachment of a layer of the substrate material. In concrete elements, this may include the complete removal of the concrete cover.

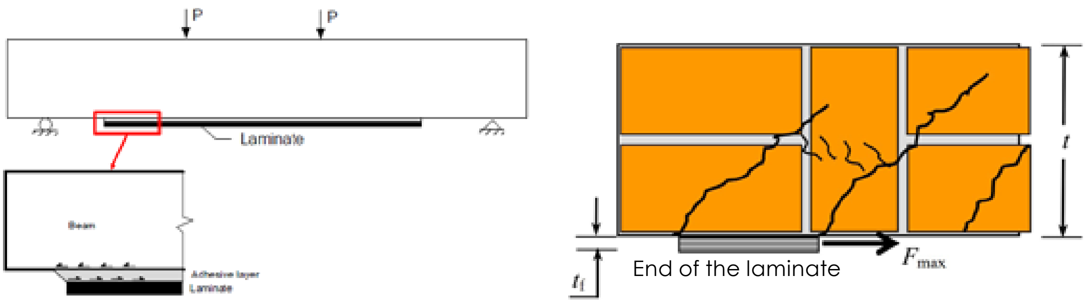

Fig. 03 *- Debonding modes of composite reinforcement from concrete substra*

TYPICAL CAUSES OF DEBONDING FAILURE INCLUDE:

- Attainment of maximum shear strength at the interface - shear leg mechanism
- Development of tensile stresses between the composite and the substrate - peeling effect

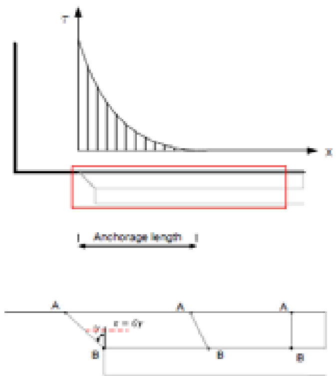

Fig. 04 *- Debonding due to the development of maximum shear strength*

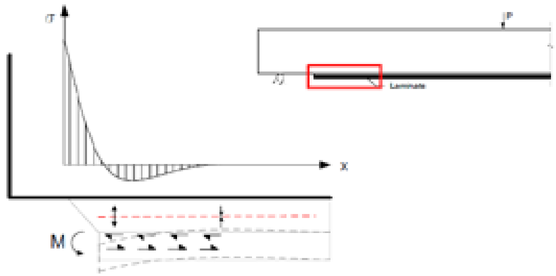

Fig. 05 *- Peeling-induced debonding*

- Attainment of maximum tensile strain in the composite reinforcement.

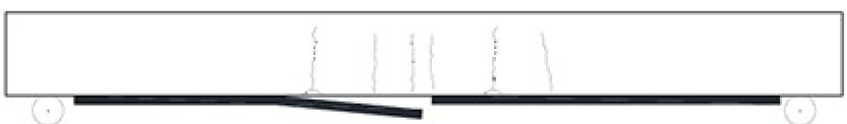

Fig. 06 *- Tensile failure due to the attainment of maximum strain in the composite*

4.2

This final failure mode can only occur if an adequate anchorage system is provided to ensure the transfer of forces from the reinforcement to the substrate-for example, through the use of fiber anchors or external composite stirrups.

The analytical model shows that the magnitude of force transferred from the substrate to the reinforcement depends on the following parameters:

- the mechanical properties of the substrate;
- the elastic modulus of the composite material;
- the thickness of the reinforcement layer.

The graph below illustrates how the bond strength of the composite system varies with changes in the reinforcement thickness:

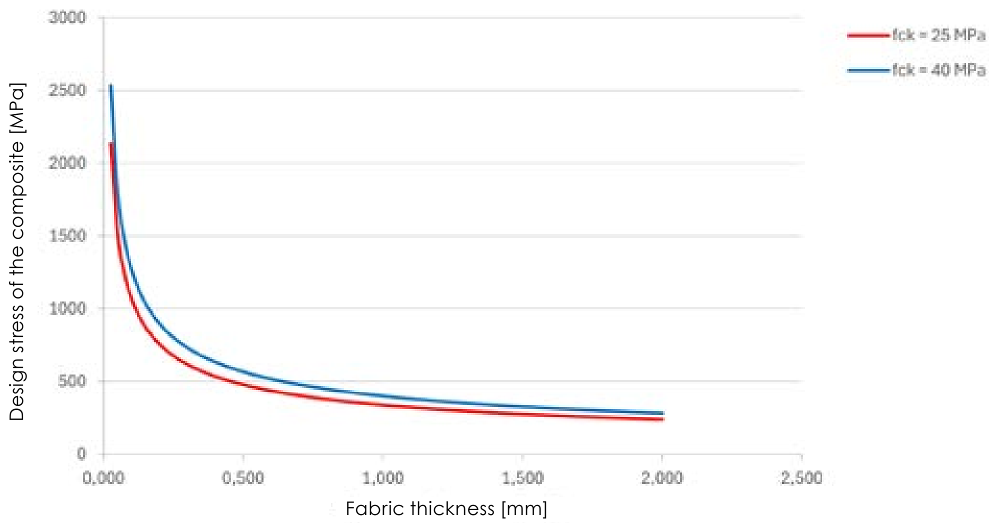

Fig. 07 *- Variation in bond strength with reinforcement thickness* t_f

4.3 STRENGTHENING OF REINFORCED CONCRETE STRUCTURES

The primary objective of using composite materials to strengthen reinforced concrete structures is to increase the ductility of structural elements, with strength enhancement as a secondary goal. For this reason, designers employing these materials must prioritize solutions that promote ductile failure mechanisms, while avoiding the activation of brittle behaviors that could compromise the overall effectiveness of the intervention.

Typical brittle failure modes to be avoided include:
- shear failure;
- tensile failure of the beam–column joint panel;
- buckling of compressed bars;
- loss of bond in lap splice regions.

Design checks must be carried out with reference to both Ultimate Limit States (ULS) - which define the conditions beyond which the structure is no longer able to fulfill its load-bearing function - and, where applicable, Serviceability Limit States (SLS), which ensure acceptable performance under long-term operating conditions. In all cases, the capacity of the strengthened structural element must exceed the demand imposed by design actions.

When evaluating the load-bearing capacity of a strengthened element, it must be noted that the maximum increase achievable compared to the original capacity is limited to 50%. However, this limitation does not apply in the case of exceptional or seismic actions, for which specific design criteria may be adopted.

The design resistance of the strengthened section R_{d} is determined by dividing the calculated section capacity (bending, shear, confinement, etc.) by a partial safety factor γ_{Rd}, whose values are provided in the table below.

The design values of the mechanical properties of the FRP used in structural verifications are calculated using the following expression:

$$X_{\mathrm{d}} = \eta \cdot \frac{X_{\mathrm{k}}}{\gamma_{\mathrm{m}}}$$

Where:

X_{d} design value of strength or strain of the composite;

X_{k} characteristic value of strength or strain of the composite;

η environmental reduction factor;

γ_{m} material partial safety factor.

RESISTANCE MODEL	γ_{Rd}
BENDING / AXIAL-BENDING	1.00
SHEAR / TORSION	1.20
CONFINEMENT	1.10

Tab. 01 *- Table 01 – Partial safety factors* γ_{Rd}

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4.3

In the expressions provided in the following sections, the average value of the axial elastic modulus E_f is adopted. For the design of externally bonded FRP reinforcements, the mechanical property values shown in the following tables shall be used:

CLASS	FIBER TYPE	TENSILE ELASTIC MODULUS (in fiber direction) [GPa]	TENSILE STRENGTH (in fiber direction) [MPa]
E17/B17	Glass/Basalt	17	170
E23/B23	Glass/Basalt	23	240
G38/600 B38/600	Glass/Basalt	38	600
G38/800 B38/800	Glass/Basalt	38	800
G45/B45	Glass/Basalt	45	1000
C120	Carbon	120	1800
C150/1800	Carbon	150	1800
C150/2300	Carbon	150	2300
C190/1800	Carbon	190	1800
C200/1800	Carbon	200	1800
A55	Aramid	55	1200

Tab. 02 *-Mechanical properties of preformed FRP systems*

CLASS	FIBER TYPE	TENSILE ELASTIC MODULUS (in fiber direction) [GPa]	TENSILE STRENGTH (in fiber direction) [MPa]
60G/60B	Glass/Basalt	60	1300
210C	Carbon	210	2700
350/1750C	Carbon	350	1750
350/2800C	Carbon	350	2800
500C	Carbon	500	2000
100A	Aramid	100	2200
180S	High-strength steel	180	2200 (1)
190S	High-strength steel	190	2200 (1)

Tab. 03 *- Mechanical properties of in-situ impregnated FRP systems*

4.3

FLEXURAL STRENGTHENING OF REINFORCED CONCRETE

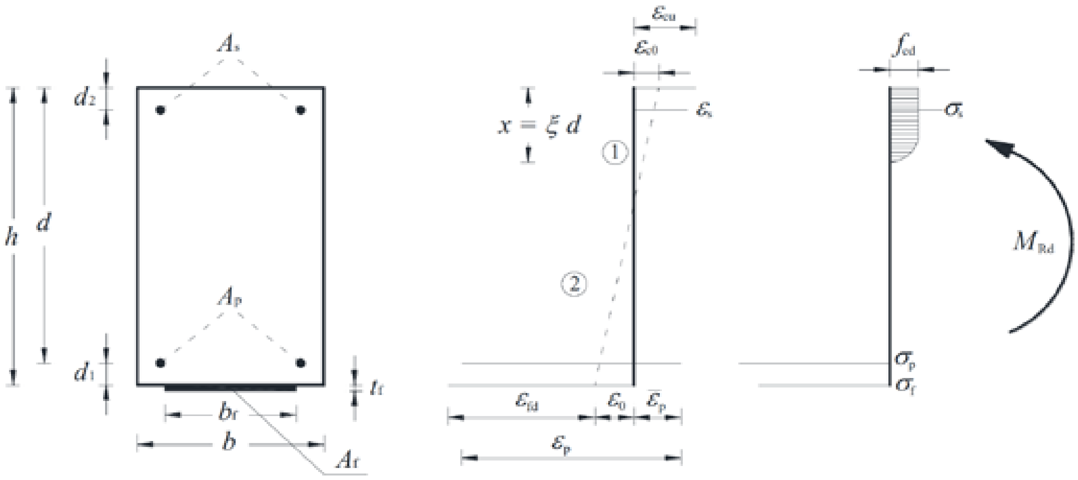
Flexural strengthening of a reinforced concrete (RC) element becomes necessary when the applied bending moment M_{Ed} exceeds the design flexural resistance of the existing section M_{Rd} .

The flexural capacity of the strengthened section is evaluated based on the following assumptions:
- plane sections remain plane up to failure;
- perfect bond exists between all materials (steel–concrete, frp–concrete);
- tensile strength of concrete is neglected;
- the constitutive laws of concrete and steel comply with those prescribed in the relevant technical standards (e.g., ntc);
- the fiber-reinforced polymer (frp) composite behaves as a linear elastic material up to failure.

In calculating the flexural capacity of the strengthened section, failure is assumed to occur either when the ultimate compressive strain of concrete ε_{cu} is reached or when the FRP reaches the debonding strain ε_{fd} which is the ultimate strain associated with detachment from the substrate.
To optimize material use and ensure a ductile structural response, it is recommended to design the FRP strengthening so that debonding occurs after yielding of the internal steel reinforcement. Otherwise, if FRP debonding precedes steel yielding, the section behaves in a brittle manner and, in some cases, the flexural strength of the strengthened section may be lower than that of the unstrengthened configuration.

The flexural resistance of the strengthened section is determined by solving:
- the force equilibrium equation in the vertical direction, which defines the position of the neutral axis;
- the moment equilibrium equation, taken about the centroid of the tensile reinforcement.

Based on the schematic representation below, two distinct failure modes of the section can be identified.



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4.3

CONFINEMENT STRENGTHENING

The design of the reinforcement must not be limited to ensuring that the load-bearing capacity of the element exceeds the demand, but must also improve the rotational capacity of the section in the plastic range.
This objective can only be achieved if the amount of reinforcement applied allows for the full yielding of the steel reinforcement within the reinforced concrete section, preventing premature debonding or failure of the composite.

Fig. 09 *- Buckling of compressed reinforcement bars*

The need to confine structural elements characterized by one dominant dimension relative to the others, such as columns, has long been a solution adopted to improve their compressive performance.
The flow of compression isostatic lines predominantly follows a vertical direction and, consequently, tensile stresses orthogonal to these isostatic lines are generated.
Below is a diagram showing the distribution of isostatic lines and a historical example of hoop strengthening, previously used to reinforce stone columns by means of prefabricated steel elements

Fig. 10 *- Concrete element confined with carbon fiber fabrics*

4.3

The increase in compressive strength and corresponding ultimate strain of concrete confined with FRP depends on the applied confinement pressure.
This pressure is a function of the stiffness of the reinforcement system and the geometry of the cross-section of the confined element.

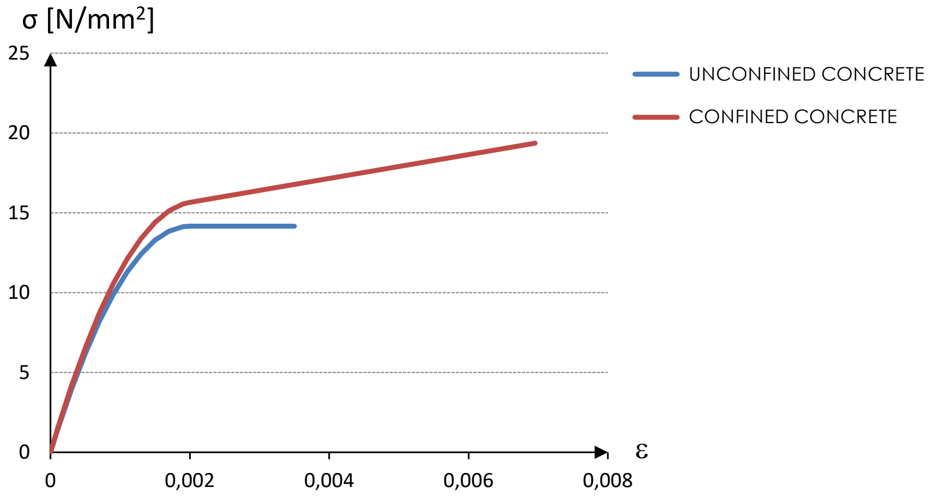


Fig. 11 *- A typical stress–strain (σ–ε) relationship of an FRP-confined concrete element*

Failure of the confined element typically occurs due to rupture of the composite. However, beyond a certain level of axial strain, the confined element effectively loses its functionality, as it can only sustain minimal and negligible transverse stresses.
For this reason, failure is conventionally assumed to occur when the FRP reaches a limiting strain of 0.4%.

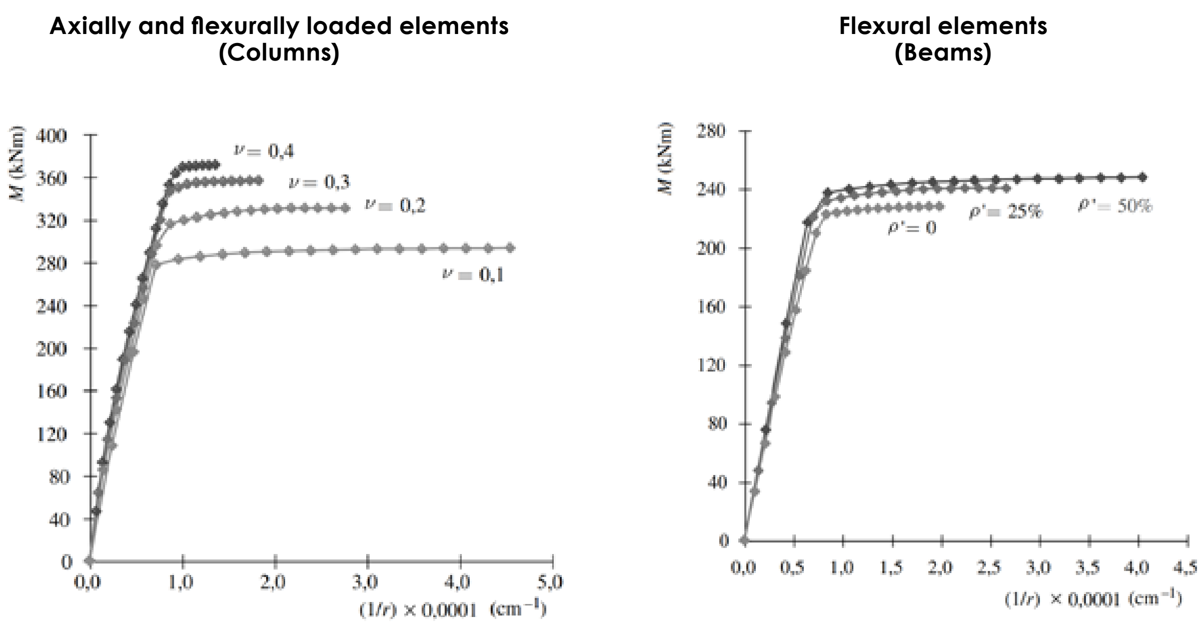


Fig. 12 *-Moment–curvature diagrams for axially loaded (columns) and flexural (beams) sections* **[1]**

FIBRE NET composite engineering

4.3

Existing condition section

The flexural resistance of the existing section is equal to 73.84 kNm.
Below is shown the M–N interaction diagram of the section:

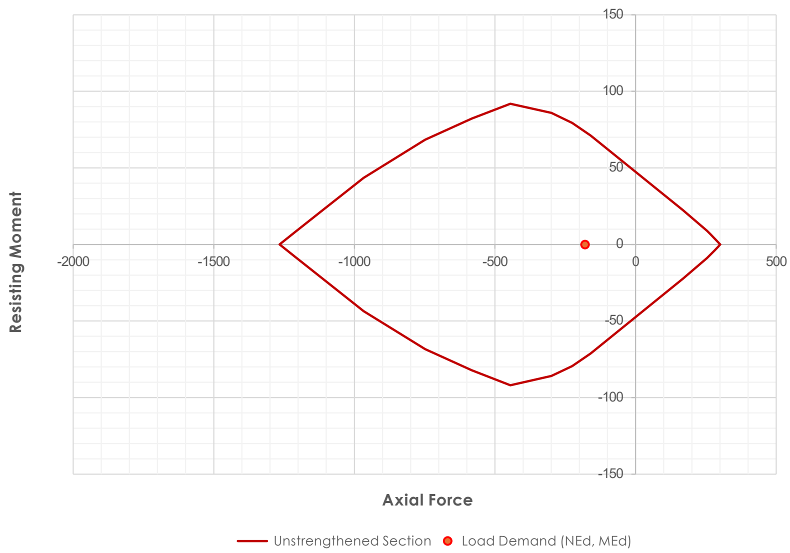


Fig. 13 - *M–N interaction diagram of the existing reinforced concrete section*

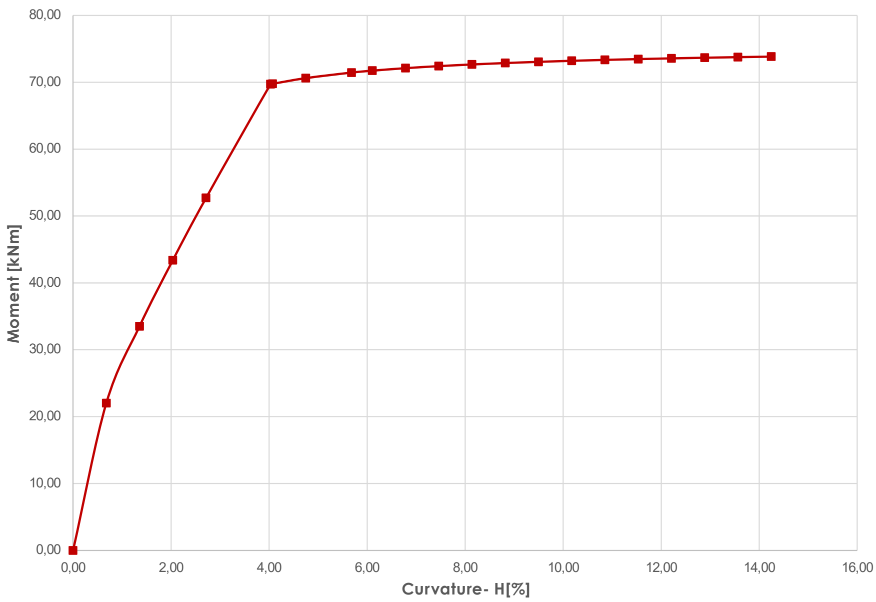


Fig. 14 - *Moment–curvature diagram of the existing section.*

The curvature ductility of the existing section is equal to 3.34.

4.3

Section strengthened with longitudinal cfrp fabrics - Type FB GV620U HM - (Hp. 1)

The structural element is strengthened using CFRP fabrics of type FB GV620U HM, a high-modulus carbon fiber fabric. The flexural resistance of the strengthened section is 114.9 kNm. The M–N interaction diagram of the section is shown below:

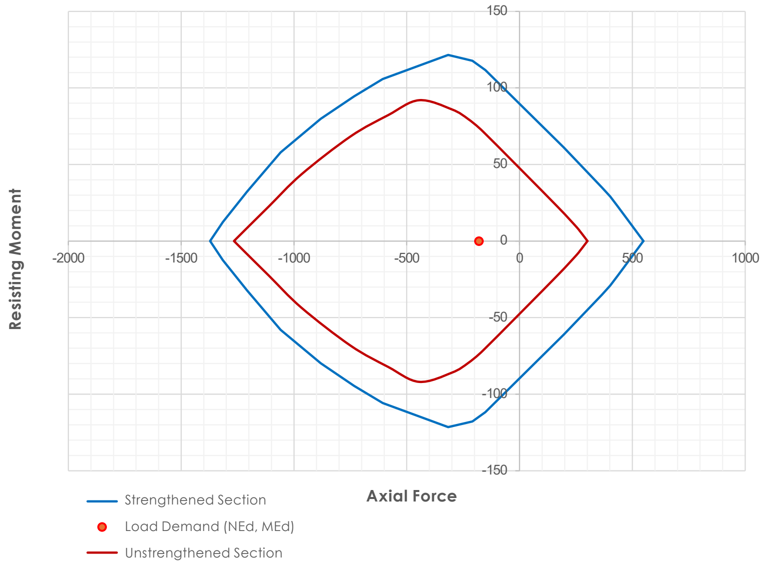


Fig. 15 *- M–N interaction diagram of the strengthened reinforced concrete section*

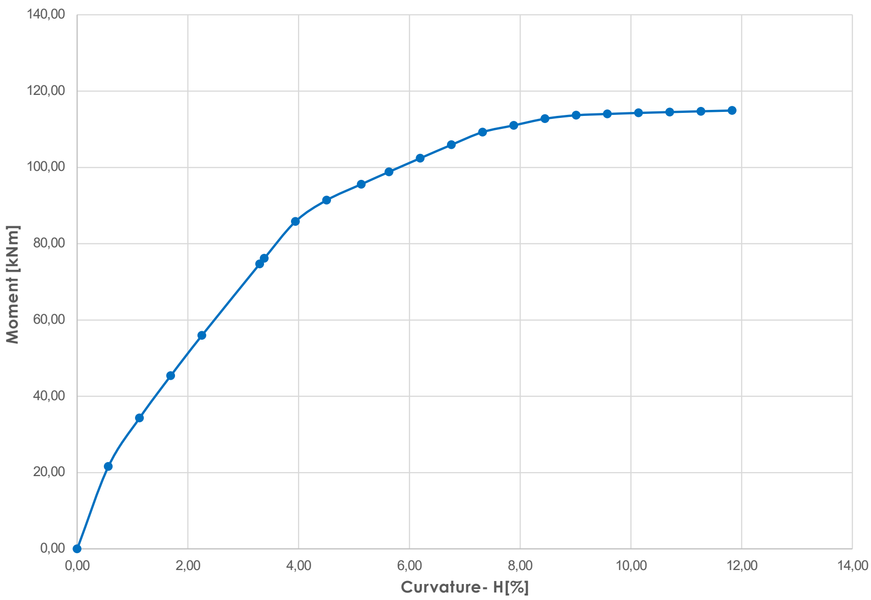


Fig. 16 *- Moment–curvature diagram of the strengthened section*

In this case, the curvature ductility of the strengthened section is equal to 2.33.
As clearly observed, while the flexural strength increases significantly, there is a reduction in the rotational capacity of the section.

4.3

Section reinforced with longitudinal fabrics only (type FB GV330U HT) and transverse fabrics (type FB GV420U HT) applied in three layers - (Hp. 2)

The effect of confinement on the deformation capacity of concrete is calculated:

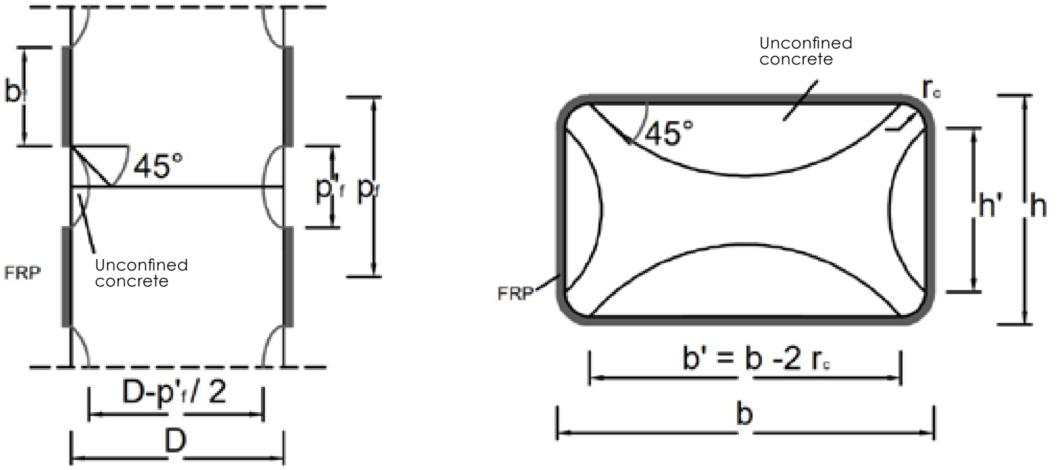


Fig. 17 - *IConfinement intervention on a reinforced concrete section using FRP reinforcements*

GEOMETRICAL AND MECHANICAL PROPERTIES OF THE FRP FABRIC REINFORCEMENT

Type of fabric used: FB GV420U-HT020-RC02 (High-tenacity unidirectional CFRP fabric)

Design Parameter	Symbol	Class Value
Number of reinforcement layers	n	**3**
Tape width	b_f	200 mm
Effective cross-sectional area	A_f	135 mm^2
Thickness of reinforcement system	t_f	0,675 mm
Ultimate tensile strength of the tape	f_{fk}	2700 N/mm^2
Tensile modulus of elasticity of the tape	E_f	210000 N/mm^2
Ultimate strain	ε_{fk}	1,29%
Partial safety factor (range: 1.20–1.50	$\gamma_{f,d}$	**1,20**
Exposure condition		**Indoor**
Will a protective coating be applied to the FRP?		**no**
Environmental conversion factor (Table 3-2)	h_a	0,95
Load type		**Long-term**
Long-term effects conversion factor (Table 3-3)	h_l	0,8
Radius of curvature of reinforced section (0 ≤rc/b ≤ 0,5)	r_c	**30** mm
Spacing between reinforcement layers	p_f	**200** mm
Net distance between reinforcement layers	p'_f	0 mm
Fiber inclination angle relative to longitudinal axis	β	90 °

SHEAR RESISTANCE OF THE FRP-STRENGTHENED SECTION

The design strength of the confined element can be evaluated using the following expression:

$$N_{\mathrm{Rcc,d}} = \frac{1}{\gamma_{\mathrm{Rd}}} \cdot A_{\mathrm{c}} \cdot f_{\mathrm{ccd}} + A_{\mathrm{s}} \cdot f_{\mathrm{yd}}$$

Geometric reinforcement ratio	ρ_f	7,875E-03	
Horizontal efficiency factor	k_H	0,519	
Vertical efficiency factor	k_V	1,000	
Fiber inclination efficiency factor	k_a	1,00	
Fiber orientation (perpendicular to axis)	A_f	0°	
Overall efficiency factor	k_{eff}	0,52	
Reduced design strain of the composite	$\varepsilon_{fd,rif}$	0,004	
Confinement pressure	f_1	3,31	N/mm2
Effective confinement pressure	$f_{1,eff}$	1,72	N/mm2
Design strength of confined concrete	f_{ccd}	20,29	N/mm2

The resulting strengths are:

Unconfined element design strength	N_{Rd}	1389,76	kN
Confined element design strength	$N_{Rcc,d}$	2470,08	kN

The flexural resistance of the section is 96.23 kNm. The M–N interaction diagram of the section is shown below.

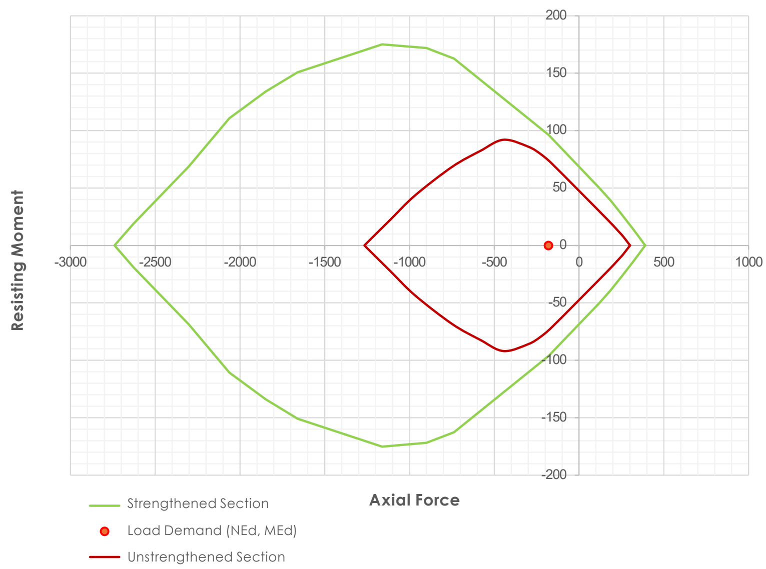


Fig. 18 *- M–N interaction diagram of the strengthened reinforced concrete section*

The moment–curvature diagram of the strengthened section highlights an increase in compressive resistance under high axial loads, due to the confinement effect.

4.3

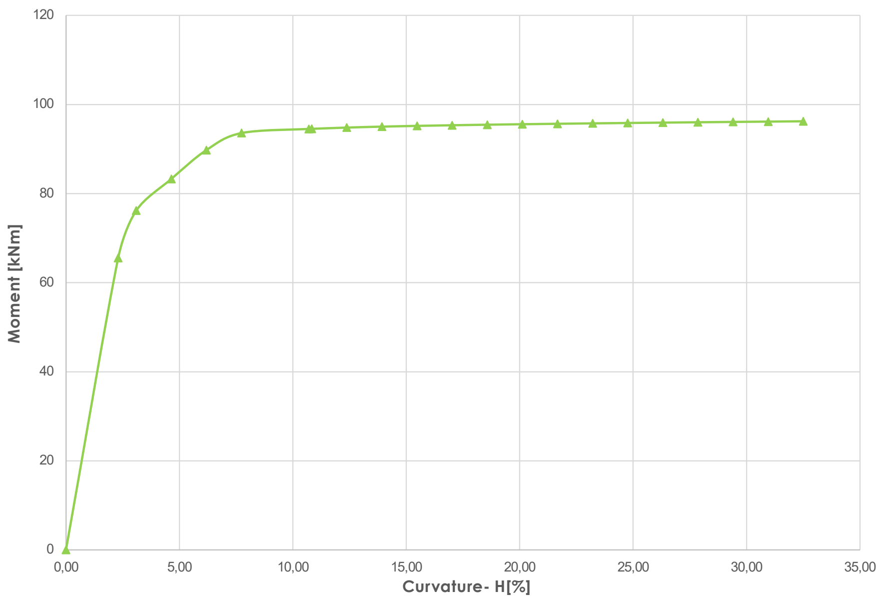


Fig. 19 *- Moment–curvature diagram of the strengthened section (Hp. 2)*

In Hypothesis 2 of structural strengthening, the curvature ductility of the design state is equal to 9.62.

4.3

Section strengthened with only transverse fabrics FB GV 420UHT applied in three Layers (Hp. 3)

The section was strengthened using only transverse fabrics (FB GV 420UHT), applied in a triple layer configuration (Hp. 3). In this scenario, the flexural strength of the reinforced member remains unchanged, while the ultimate bending moment capacity of the section reaches 72.04 kNm.

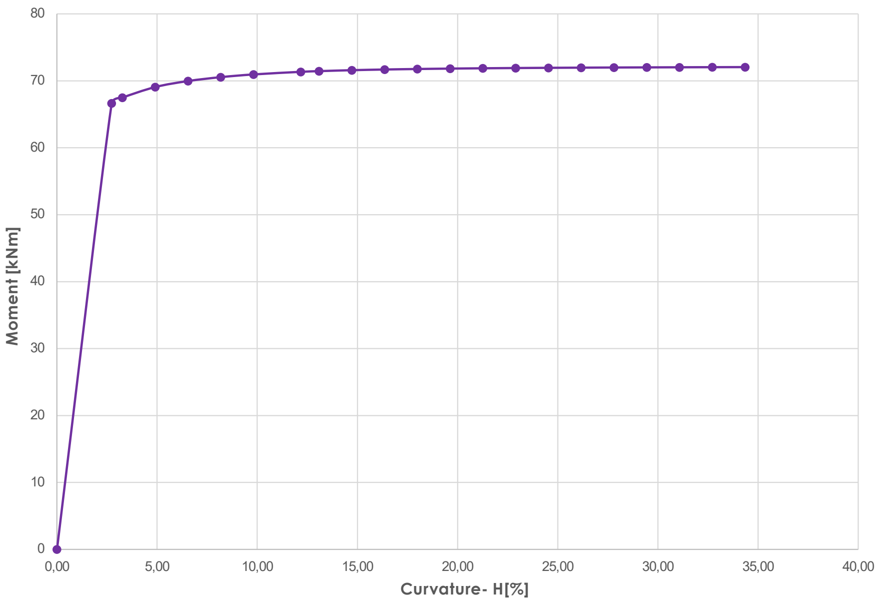


Fig. 20 - Moment-curvature diagram of the section at the design state (Hp. 3)

Under strengthening hypothesis Hp. 3, the ductility at the design state reaches a value of 11.63, which is significantly higher than that obtained with the previously analyzed design strategies. The transverse wrapping of the section leads to a considerable increase in curvature ductility.
A comparison of the moment-curvature diagrams clearly highlights that a strengthening intervention with only transverse wrapping significantly enhances the rotational capacity of the section compared to solutions involving only longitudinal reinforcements.

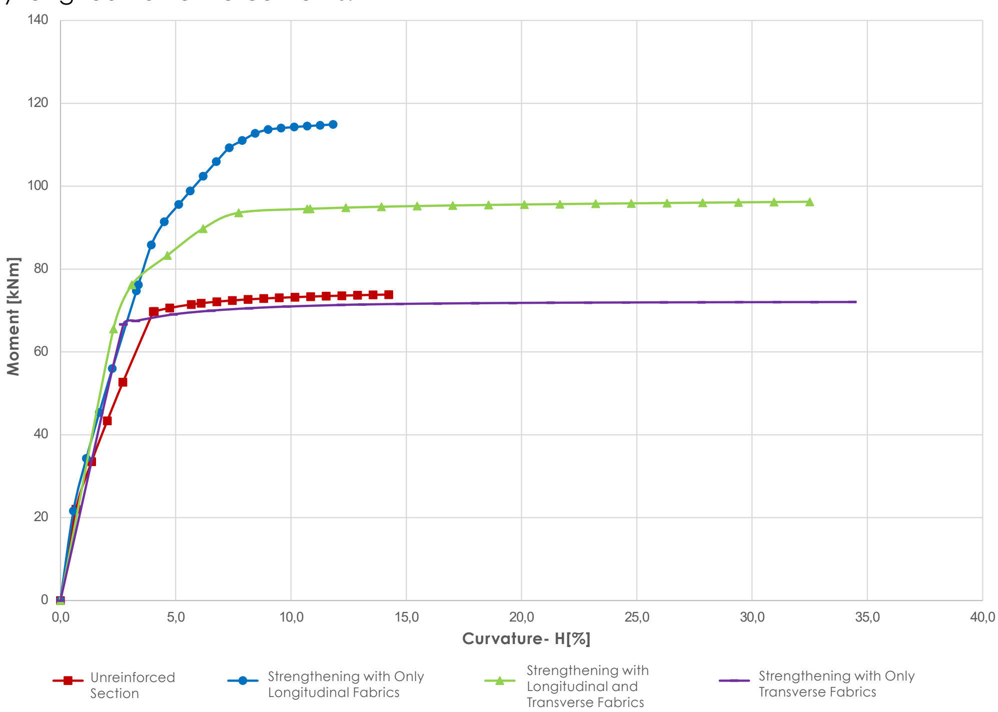


Fig. 21 - Comparison of moment-curvature diagrams: as-built state vs. different design scenarios

4.3

ELIMINATION OF BRITTLE FAILURE MECHANISMS

In seismic design, it is essential to prevent the structure from developing brittle failure modes before the activation of ductile mechanisms. The main brittle failure mechanisms that may affect a reinforced concrete structure include:

- shear failure;
- failure of beam-column joints;
- bond failure of reinforcement bars in lap splice regions;
- buckling of compressed longitudinal bars.

The latter two phenomena can be mitigated through section confinement, achieved by applying a minimum thickness of reinforcement.

SHEAR STRENGTHENING

If the shear strength of a reinforced concrete or prestressed concrete section is lower than the design shear force determined by structural analysis or according to capacity design principles, strengthening is required. In this process, the contributions from both concrete and any existing transverse reinforcement must be taken into account.

FRP composite wraps, applied in full adhesion to the concrete surface, can be installed either continuously or discontinuously. The wrapping configuration can be full - encasing the entire section - or partial, using a so-called "U-wrap".

In the case of partial wrapping, to improve the anchorage of the free ends of the composite material, the use of mechanical anchors and/or composite anchors (e.g., fiber bows) is recommended to enhance effectiveness.

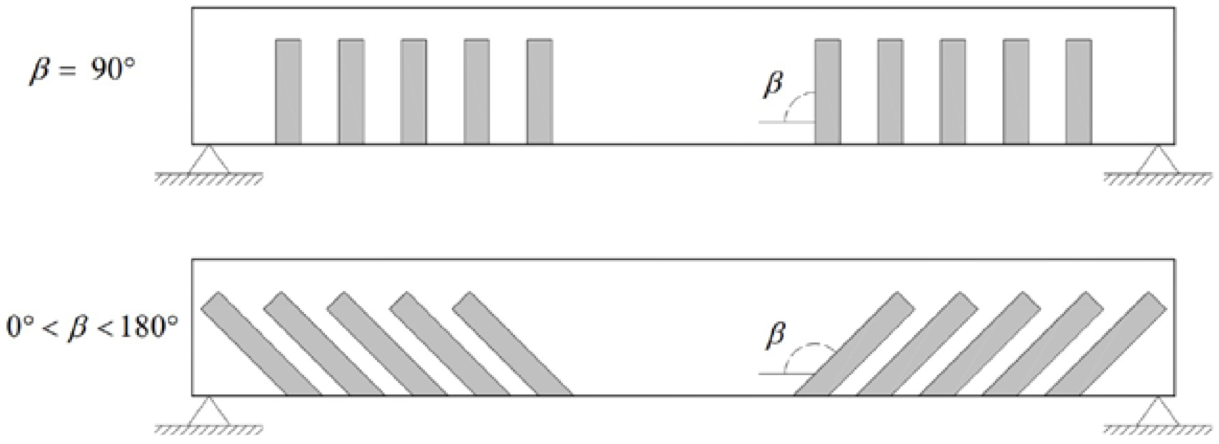


Fig. 22 *- Shear reinforcement orientations using strip layout.*

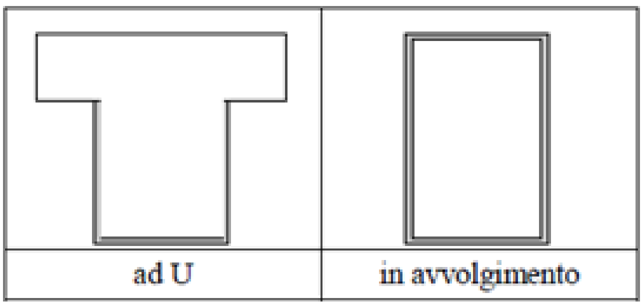


Fig. 23 *- Shear reinforcement arrangement around the section.*

4.3

As in the case of cantilever beams, where the compressed zone is located at the bottom of the beam and a U-wrap (partial wrapping) shear reinforcement has been adopted in the design phase, the installation of appropriate mechanical anchorage devices becomes mandatory.

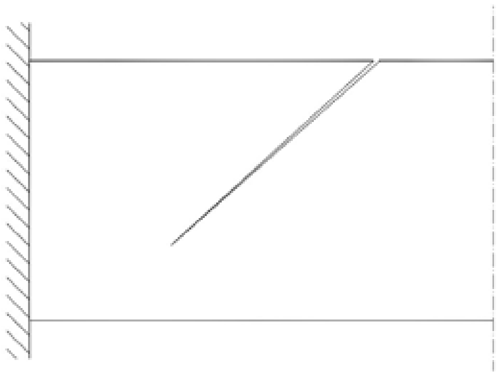


Fig. 24 *- Cantilever beam*

The shear strength of a reinforced section is determined using the following equation:

$$V_{Rd} = \min\{V_{Rd,s} + V_{Rd,f} \, ; \, V_{Rd,c}\}$$

Where:

V_{Rd} design shear resistance of the strengthened section;

$V_{Rd,s}$ shear contribution from the steel transverse reinforcement, calculated according to applicable standards;

$V_{Rd,f}$ shear contribution from the FRP reinforcement, calculated in accordance with paragraph 4.3 of CNR-DT 200 R1

$V_{Rd,c}$ shear contribution from the concrete strut mechanism, calculated according to applicable standards

4.3

STRENGTHENING OF BEAM-COLUMN JOINTS

In reinforced concrete frame structures, the beam-column joint is a critical element, both in terms of regulatory requirements and construction constraints.
The failure mechanism that may develop in these joints - well documented in past seismic events but historically underrepresented in design codes - requires specific assessments and targeted interventions to address inherent design deficiencies.

The proper behavior of the joint panel can be restored through the application of CFRP reinforcements

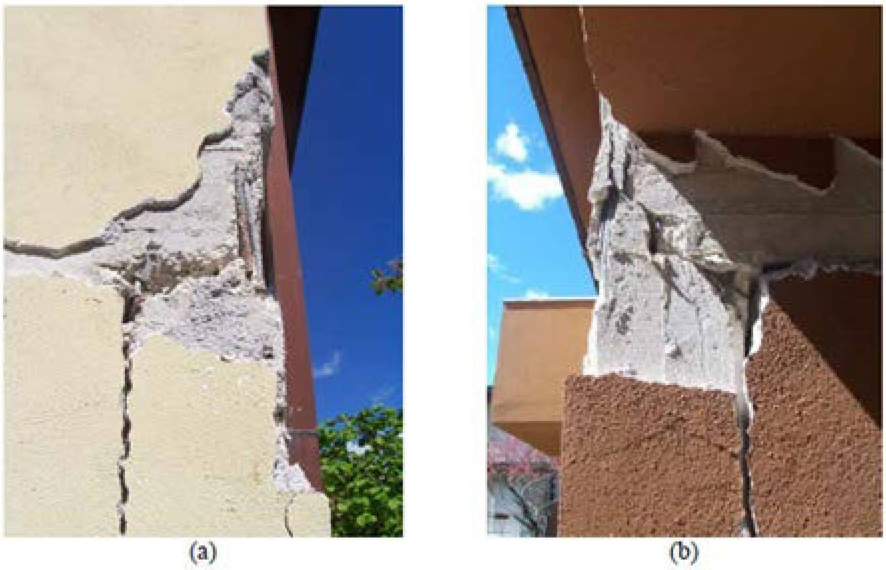


Fig. 25 *- Typical cracking patterns observed in joint panels [01]*

The calculation of the increase in tensile strength achievable in unconfined joint panels must consider the contribution of the fiber-reinforced composite in the direction of the principal tensile stresses.
The effectiveness of the intervention depends on the proper anchorage of the reinforcement ends using suitable construction detailing. Without such anchorage, the reinforcement cannot be considered effective.
The stress state within the joint panel is influenced by several factors, including:

▪ the geometry of the joint;
▪ the internal forces resulting from structural analysis;
▪ the amount of reinforcement present in the beams framing into the joint.

The analysis of beam-column joints cannot be conducted using beam theory (such as the Timoshenko or Euler-Bernoulli models), due to the small dimensions of the joint region.
Therefore, the design is based on a strut-and-tie model, which enables the mechanical behavior of the joint to be evaluated through the identification of compressed struts and tension ties.
This approach is analogous to the Mörsch truss model used for assessing the shear capacity of reinforced concrete members.

The shear capacity of the joint is governed by a truss mechanism which, following diagonal cracking of the joint panel, involves the simultaneous activation of two distinct mechanisms: a shear-compression mechanism and a shear-tension mechanism.

4.3

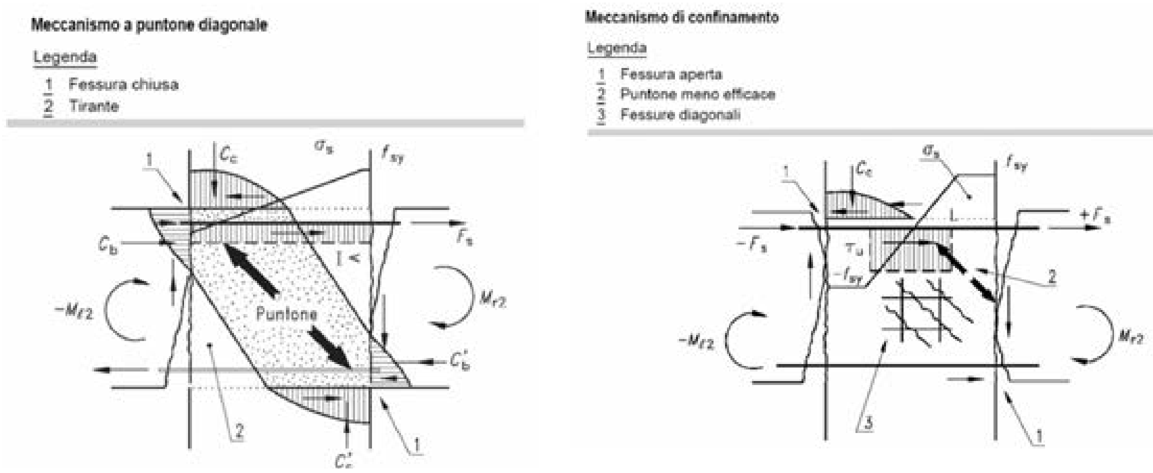


Fig. 26 *- Mechanisms activated in the joint following cracking [02]*

Regarding existing buildings, Circular §C8.7.2.3.6 states that strength verifications must be carried out only for partially confined joints, for which both diagonal tensile and compressive strength must be verified. Specifically, it is assumed that the joint is not transversely reinforced, and the assessment of potential damage is based on the analysis of the principal stresses generated within the joint panel.
An important aspect to consider when verifying joints in existing buildings is that the associated failure mechanism is brittle. Therefore, in accordance with §8.7.2 of NTC18, material strengths must be divided both by partial safety factors [γm] and by the confidence factor [fc]. This is in contrast to ductile mechanisms, for which mechanical properties are divided only by the confidence factor.

The following expressions, based on a stress analysis using Mohr's circle, are used for evaluation:
- For tensile strength:

$$\sigma_{jt} = \left| \frac{N}{2A_j} - \sqrt{\left(\frac{N}{2A_j}\right)^2 + \left(\frac{V_j}{A_j}\right)^2} \right| \leq 0{,}3\sqrt{f_c} \qquad [C8.7.2.11]$$

- For compressive strength:

$$\sigma_{jc} = \frac{N}{2A_j} + \sqrt{\left(\frac{N}{2A_j}\right)^2 + \left(\frac{V_j}{A_j}\right)^2} \leq 0{,}5 f_c \qquad [C8.7.2.12]$$

With $A_j = b_j \cdot h_{jc}$ e f_c expressed in MPa:

Where:
- N axial force acting on the top column;
- V_j total shear force acting on the joint, including both the shear from the axial load in the upper column and the tensile force from the longitudinal reinforcement in the beam;
- b_j effective width of the joint (as defined in Fig. C.7.4.3);
- h_{jc} distance between the outermost reinforcements of the column;
- f_c average compressive strength of concrete, obtained as the average of in-situ test results, divided by the confidence factor and the partial safety factor.

The design of FRP reinforcements consists of sizing the reinforcement by assuming, as the demand, the maximum force that can be transmitted to the joint - namely, equal to the yielding of one of the elements converging into it. This method is based on a design approach outlined in international guidelines, specifically fib Bulletin 90, which - starting from the relationships valid for existing joints as described in §C8.7.2.3.5 - allows for the assessment of the increase in diagonal tensile strength provided by the FRP reinforcement.

4.3

APPROACH [CEB-FIB BULLETIN NO. 90]

Definition of shear demand in the joint panel and axial force in the upper column

$V_j = V_c - (T + T')$ In the absence of detailed data, the tensile forces TTT and T'T'T' are assumed to correspond to the yielding of the longitudinal reinforcement in the converging beams, while the shear force VCV_CVC is derived from the equilibrium of the joint.

N axial force acting in the upper column.;

Definition of principal tensile and compressive stresses and comparison with the concrete-only strength

$$\sigma_{jt} = \left| \frac{N}{2A_j} - \sqrt{\left(\frac{N}{2A_j}\right)^2 + \left(\frac{V_j}{A_j}\right)^2} \right| \leq 0{,}3\sqrt{f_c} \qquad [C8.7.2.11]$$

$$\sigma_{jc} = \frac{N}{2A_j} + \sqrt{\left(\frac{N}{2A_j}\right)^2 + \left(\frac{V_j}{A_j}\right)^2} \leq 0{,}5 f_c \qquad [C8.7.2.12]$$

Assessment of tensile strength enhancement due to reinforcement, evaluated using Equation 8.59 of the fib Bulletin 90 **[04]**

$$\sigma_{\mathrm{jt,f}} = \frac{A_\mathrm{f} \cdot E_\mathrm{f} \cdot \varepsilon_\mathrm{fd}}{b_\mathrm{c} \cdot \left({}^{h_\mathrm{c}}/_{\sin\theta} \right)}$$

Con $\theta = \mathrm{arctg} \dfrac{h_{trave}}{h_c}$

Where:

- A_f equivalent area of fabric applied to the joint
- E_f elastic modulus of the composite
- ε_fd design strain of the composite
- $b_{\mathrm{c}'\mathrm{hc}}$ width and height of the column section
- h_trave beam height

Assuming the use of a quadri-axial carbon fiber fabric for shear reinforcement of the joint panel, the equivalent fabric area is evaluated using Equation 8.57c of fib Bulletin 90 [05].

$$A_f = n_\mathrm{s} \cdot t_\mathrm{f} \cdot h_\mathrm{c} \cdot \cos\theta \cdot (1 + \tan\theta + 2\tan^2\theta)$$

Where:

- n_s number of reinforced faces of the joint panel
- t_f thickness of the fabric in a single direction
- $\theta = \arctan\left({}^{h_b}/_{h_c} \right)$ inclination of the compressed concrete strut

The design strain of the composite, assuming the use of end anchorages on the beams and accounting for intermediate debonding, can be evaluated as follows:

$$\varepsilon_\mathrm{fd} = 34 \left(\frac{{f_\mathrm{cd}}^{2/3}}{A_\mathrm{f} \cdot E_\mathrm{f}} \right)^{0.6}$$

Check of principal tensile stress

$$\sigma_{jt} = \left| \frac{N}{2A_j} - \sqrt{\left(\frac{N}{2A_j}\right)^2 + \left(\frac{V_j}{A_j}\right)^2} \right| \leq 0{,}3\sqrt{f_c} + \sigma_{jt,f}$$

In conclusion, it is essential to emphasize that the design method described is applicable only if proper anchorage of the FRP at its ends is ensured. This can be achieved either by wrapping the ends of the member or by using dedicated anchorage devices.

Fig. 27 *- Strengthening of the joint panel in an unconfined interior joint*

4.3

DESIGN OF ANCHORING BOW CONNECTORS FOR CONCRETE STRUCTURES

The following equations, proposed by del Rey Castillo et al. (2019) [04], account for different possible failure mechanisms of the anchorage system. The figure below illustrates the analyzed failure modes:

- **concrete cone failure** (N_{cc}): Occurs when the anchorage capacity is limited by the tensile strength of the surrounding concrete, leading to the detachment of a conical volume of material around the connector;
- **mixed mode failure** (N_{cb}): A combined mechanism involving both concrete cone breakout and loss of bond between the anchor and the substrate;
- **pull-out failure** (N_{po}): Takes place when the anchor progressively loses bond, resulting in slippage and eventual loss of load-carrying capacity;
- **delamination at interface between the FRP fabric and the bow** (N_{sd}): Occurs when separation forms between the anchor bundle and the FRP fabric, compromising the stress transfer efficiency;
- **fiber bowshear failure** (V_{fr}): Happens when the stress in the bundle exceeds the ultimate strength of the fibers, causing failure by shear or rupture.

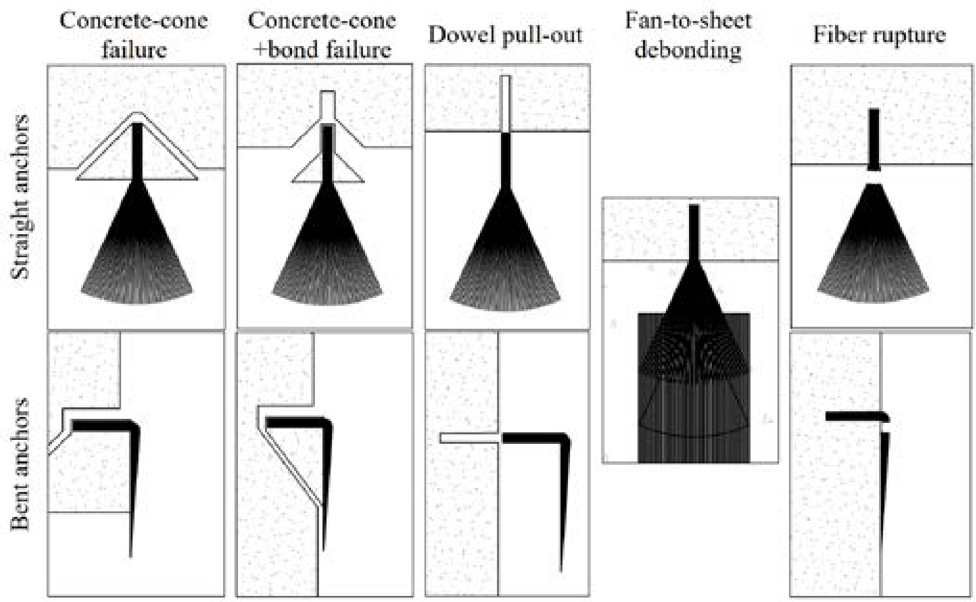


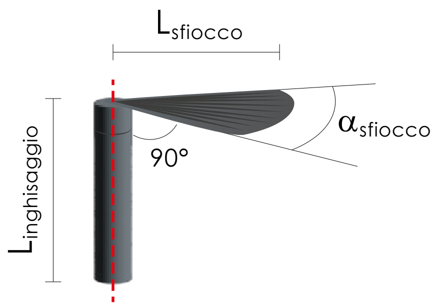
***Fig. 28** - Failure modes of the connector*

The shear strength of the anchorage is the minimum value among the previously listed failure modes:

$$N_{fiocco} = \min(N_{cc}; N_{cb}; N_{po}; N_{sd}; V_{fr})$$

To perform the calculation, the following parameters must be known:

Equivalent diameter of the bow: ϕ_{fiocco}
Achoring length: $L_{inghisaggio}$
Debow length: $L_{sfiocco}$
Debowing opening angle: s_{fiocco}
Hole diameter: ϕ_{foro}
Shear strength of the resin: V_{resina}
Ultimate tensile strength of the fibers: f_{fu}
Fiber volume fraction of the bundle: V_{fibre}



4.3

Concrete cone breakout strength of the anchorage:

$$N_{cc} = 9.68 \cdot \mathrm{L}_{\text{inghisaggio}}^{1.5} \cdot \sqrt{\mathrm{f}_{\text{cm}}}$$

Anchorage Resistance to Mixed Failure:

If the compressive strength of the substrate is fcm < 20 MPa $$N_{cb} = 4.62 \cdot \pi \cdot \phi_{\text{fiocco}} \cdot \mathrm{L}_{\text{inghisaggio}}$$

If the compressive strength of the substrate is fcm ≥ 20 MPa $$N_{cb} = 9.07 \cdot \pi \cdot \phi_{\text{fiocco}} \cdot \mathrm{L}_{\text{inghisaggio}}$$

Pull-Out Resistance of the Anchorage:

$$N_{po} = 0.7 \cdot \mathrm{L}_{\text{inghisaggio}} - 18$$

The following expression, using an anchorage length $L_{inghisaggio}$ in [mm], rprovides a force value in [kN].
Anchorage Resistance to Intermediate Delamination between Fan and FRP Fabric:

$$N_{sd} = 0.35 \cdot V_{\text{resina}} \cdot A_{\text{fan}}$$

Where A_{fan} represents the anchorage area of the bow

$$A_{\text{fan}} = \frac{\pi \cdot L_{sfiocco}^2 \cdot \alpha_{\text{sfiocco}}}{360°}$$

The resistance of the bow to fiber shearing may be assessed either by applying the analytical formulation proposed by Mahrenholtz et al., or by conducting experimental tests on bows subjected to loads orthogonal to the anchorage axis.

$$V_{\text{fr}} = 0.06 \cdot f_{\text{fu}} \cdot V_{\text{fibre}} \cdot \left(\pi \cdot \left(\frac{\phi_{fiocco}^2}{4}\right)\right)$$

REFERENCES

[1] E. Cosenza, G. Manfredi, M. Pecce, Strutture in cemento armato – Basi della progettazione, Milano: Hoepli, 2015.

[2] D. Corritore, "Esercitazione n.7_Corso di Costruzioni in Zona Sismica", A.A. 2019/2020.

[3] O.S. Bursi, T. Dusatti, R. Pucinotti, LINEEE GUIDA PER RIPARAZIONE E RAFFORZAMENTO DI ELEMENTI STRUTTURALI, TAMPONATURE E PARTIZIONI, ReLuis, Dipartimento Protezione Civile.

[4] fib - Task Group 5.1., "fib Bulletin 90: Externally applied FRP reinforcement for concrete structures".

[5] E. del Rey Castillo, et al., "Strengthening RC structures using FRP system anchors in combinations with EBR system", Composite Structures 209, January 2019, pp. 668-685.

5

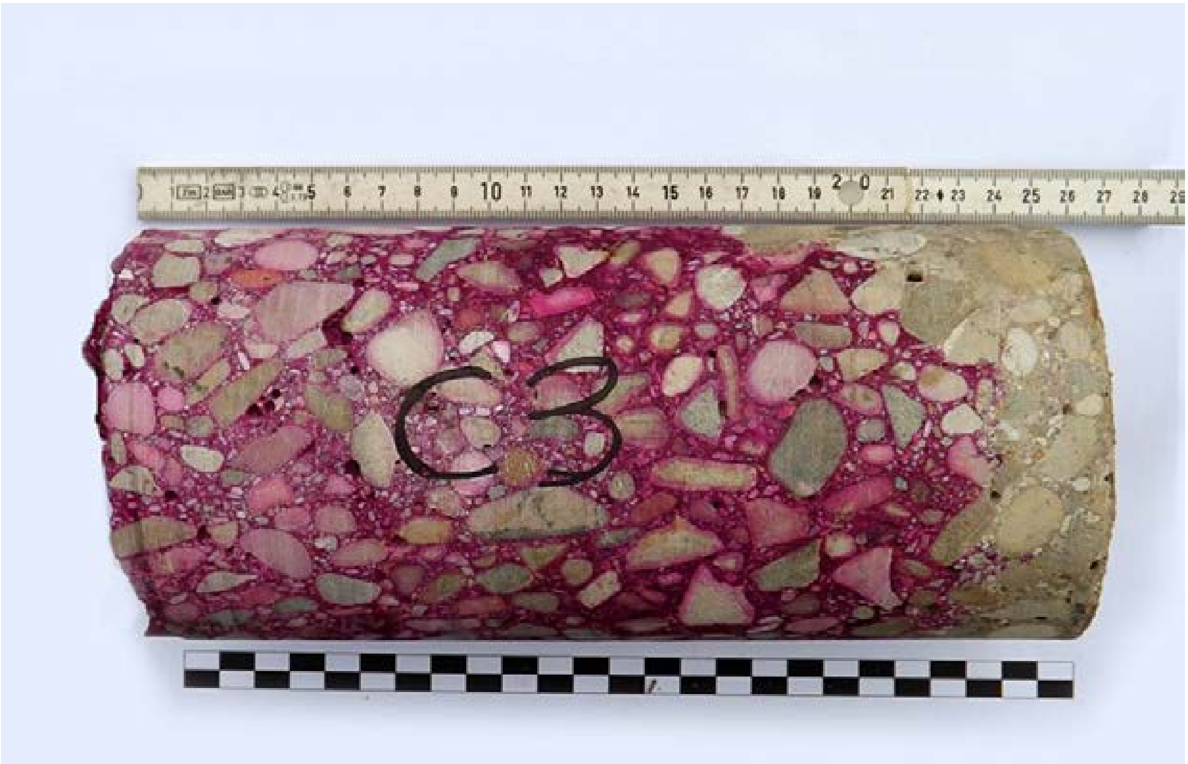
SUBSTRATE ASSESSMENT AND APPLICATION CYCLES

Diagnosis is a fundamental, preparatory, and indispensable phase for proper structural design and, consequently, for improving the durability of structures. This process requires a multidisciplinary and specialized approach, as it is now widely recognized that effective design of structural repair, seismic retrofitting, and strengthening interventions must be based on a thorough diagnostic phase.

However, accurately determining the actual condition of a structure goes beyond evaluating material quality alone.
While this is a relevant factor, it is not sufficient to capture the full complexity of the diagnostic framework.
The path from planning and designing diagnostic activities to structural design includes at least three essential additional phases:

1. historical-critical analysis of the structure (anamnesis) – crucial to understanding the building's evolution and any previous interventions;
2. structural and stress evaluations – taking into account both past conditions and current service conditions;
3. elastomechanical compatibility – between existing substrates and planned interventions, which is essential to ensure the effectiveness and durability of repair, strengthening, and protection works, with the aim of extending the service life of the structure.

In light of these considerations, the main diagnostic techniques listed below are organized according to the type of material to be analyzed. Although not exhaustive, these methods serve as a useful reference for assessing material quality and, when properly integrated into the overall diagnostic framework, can provide critical guidance for planning the necessary maintenance interventions.



5.1 CONCRETE ELEMENTS

5.1.1 Diagnostic techniques on concrete structures

In the specific case of reinforced concrete, the most common investigation methods may also include the assessment of water presence within the structure. Water, together with oxygen, accelerates the chemical and physical degradation processes of the structure, promoting reinforcement corrosion and other forms of deterioration.

In addition to traditional visual inspections - aimed at identifying active or passive moisture stains, cracking, reinforcement corrosion, and structural deformations - various non-destructive tests are employed, including:

- **Ultrasonic testing**
  Used to assess concrete integrity and detect internal defects;
- **Rebound hammer testing**
  Used to evaluate surface hardness and estimate the mechanical strength of concrete;
- **Infrared thermography**
  Useful for detecting thermal anomalies that may indicate internal defects;
- **Acoustic emission testing**
  Used to monitor sound emissions generated by microcracking under load.

These methods are complemented by laboratory tests, which include destructive mechanical testing on concrete samples extracted from the structure.
Chemical and electrochemical investigations play a crucial role in diagnosing the degradation state of reinforced concrete. Monitoring the corrosion potential of the reinforcements, for instance, helps determine the presence and progression of internal corrosion. To detect the presence of typically harmful substances - such as carbon dioxide, chlorides, sulfates, and reactive silica - specific contrast agents are used to identify both the presence and concentration of these chemical agents, which can initiate and propagate corrosion of steel reinforcement.
Finally, the investigation methods also include in-situ load testing, involving the application of known loads to verify the structural response of the system under both static and dynamic conditions.

TEST	EQUIPMENT	PURPOSE / EVALUATION
Photography	Digital camera	Surface imaging
Crack Pattern Monitoring	Digital camera, Crack meter, Caliper, Removable deformometer, Strain gauge, Laser scanner	Monitoring the evolution of crack patterns
Thermography	Thermal camera	Thermographic imaging
Endoscopy	Electronic endoscope	Internal section cavity imaging, Crack magnification
Magnetometry	Cover meter	Detection of metallic reinforcement bars
Gamma Radiography	X-ray scanner	Detection of cracks, voids, or metallic inclusions
Sonic Testing	Sonic source and sensor	Structural integrity of the section
Ultrasonic Testing	Ultrasound device	Structural integrity of the section
Sclerometric Testing	Schmidt hammer	Estimation of compressive strength
Corrosion Potential	Voltmeter with reference electrode	Assessment of reinforcement corrosion state

5.1.2 Concrete substrate preparation

The preparation of concrete surfaces is a complex process influenced by several factors, including the level of knowledge about the structure - namely, the type, extent, and severity of deterioration - as well as operational and economic considerations.
These include the type and quality of equipment used, the method of execution (manual or robotic), the skill level and experience of the operators involved, and the cost and duration of the intervention.

This phase is crucial as it serves as a link between structural diagnostics, design specifications, and the execution of the structural rehabilitation work.
The selection of the preparation techniques must consider the specific structural element to be treated, the risk of damaging the existing substrate, and the final objective in terms of surface roughness, which is directly related to the type of protection, repair, or strengthening intervention specified in the design.

Concrete surfaces must be adequately roughened according to the intended intervention but must also be solid and free from chemical contaminants.
These contaminants may originate from the atmosphere, contact with soil or water, or be inherently present in the concrete matrix.

When cement-based premixed products are to be used for surface levelling or structural reconstruction, it is essential to ensure the surface is saturated surface-dry (SSD).
An excessively wet surface would alter the water-to-mix ratio, compromising the bond with the repair material. Conversely, a dry and porous surface may absorb water from the mortar, leading to the same detrimental effect on adhesion.

Another critical aspect of surface preparation involves the opportunity to better assess the symptoms and extent of structural degradation. This phase allows for the identification of sub-surface or deep cracking, the resolution of surface issues such as staining, efflorescence, biological growth, blisters, or scaling, and the recognition of spalling or delamination phenomena caused by chemical degradation or loss of adhesion.

Given these premises, the main surface preparation techniques most commonly used for reinforced and prestressed concrete structures - whether for protective or structural reconstruction purposes - can be grouped into the following categories:

Sandblasting

Sandblasting blasting involves the projection of abrasive material (typically siliceous aggregates) onto the concrete surface using compressed air or atomized water.
This process removes the superficial cement matrix, exposing the more resistant aggregates and, in some cases, revealing capillary porosity.
The resulting surface irregularity can range from micrometric to millimetric, depending on the repair technology specified.
This treatment is particularly effective in preparing the surface for the application of water-repellent agents, impregnators, protective coatings, or premixed levelling mortars, without compromising the integrity of the existing structure.

5.1

Mechanical bush hammering

Bush hammering is performed using pneumatic hammers equipped with chisels of various geometries and sizes, operated manually to break down the existing concrete.
This method is typically used for localized interventions, as it presents certain limitations, including high physical strain for the operator and the potential for structural damage.
Repeated impact can cause the detachment of large portions of concrete and may compromise the bond between reinforcement bars and the surrounding concrete in the treated areas.

Selective hydrodemolition

Hydrodemolition is one of the most common techniques for treating large concrete surfaces. It involves the use of high-pressure water jets, delivered through manual lances or robotic systems, to remove the superficial concrete layer.
This method allows for varying degrees of surface roughness based on design requirements and is particularly suitable for interventions involving the application of premixed repair mortars.

The choice of hydrodemolition technology depends on several parameters, including:

- the mechanical strength of the structure, determined through appropriate preliminary investigations;
- the water flow rate and operating pressure;
- the type of gun and nozzles used, as well as the tuning of the equipment through dedicated trial areas.

Unlike abrasive blasting, selective hydrodemolition also enables the removal of cohesive portions of concrete, ensuring a high-quality surface roughness.
This method differs from standard hydrodemolition, which employs pressures exceeding 1,500–2,500 bar for the indiscriminate removal of entire concrete layers.

Selective hydrodemolition, on the other hand, allows precise control over the depth of material to be removed, based on the type and extent of chemical degradation present. Moreover, with proper management of operating parameters, it is possible to achieve surface roughness levels ranging from CSP 5 to CSP 10, in accordance with ICRI standards.
This level of preparation is ideal for all types of premixed repair mortars, without compromising the integrity of the existing concrete or any exposed reinforcement.

Intervention Techniques
Concrete surface preparation and substrates

ICRI STANDARD	ROUGHNESS DEPTH (mm)	RISK OF SUBSTRATE FRACTURE*	POSSIBLE PREPARATION TECHNIQUE**	TECHNOLOGICAL FEASIBILITY OF INTERVENTION	REFERENCE PRODUCT UNI EN 1504-2 (method)
CSP 1	0,00 - 0,05	None	Chemical etching	Protection	1504-2 (H - I -C)
CSP 2	0,050 - 0,125	None	Grinding	Protection	1504-2 (H - I -C)
CSP 3	0,075 - 0,250	None - Low	Light sandblasting	Protection	1504-2 (H - I -C)
CSP 4	0,075 - 0,250	Low	Light scarification	Protection	1504-2 (H - I -C)
CSP 5	0,750 - 2,200	None	Abrasive blasting	Protection	1504-2 (I - C)

*** / **** Parameters highly dependent on: type of structural element - quality of the existing substrate - quality of equipment and expertise of the operating personnel

ICRI STANDARD	ROUGHNESS DEPTH (mm)	RISK OF SUBSTRATE FRACTURE*	POSSIBLE PREPARATION TECHNIQUE*	TYPE OF INTERVENTION	REFERENCE PRODUCT *** UNI EN 1504-2 UNI EN 1504-3
CSP 6	1,00 - 3,175	None High None	Sandblasting mechanical bush hammering selective hydro-scarification	Protection	1504-2 (H - I -C)
CSP 7	3,175 - 4,250	None High None	Grinding	Protection	1504-2 (H - I -C)
CSP 8	3,175 - 5,00	High None None	Light scarification	Protection	1504-2 (H - I -C)
CSP 9	5,00 - 6,350	Elevata None None	Light scarification	Protection	1504-2 (H - I -C)
CSP 10	> 6,350	High None None	Light scarification	Protection	1504-2 (I - C)

*** / **** Parameters that may vary depending on: job site conditions – quality of the existing substrate equipment and skill level of the operators involved

5.1

5.1.3 Application Cycles

The application cycle of composite materials varies depending on whether the strengthening involves an in-situ laminated system or a preformed reinforcement.

In the case of in-situ laminates, the composite material is fabricated directly on site, and the polymer matrix serves a dual function: it impregnates the reinforcement while also acting as an adhesive between the reinforcement and the concrete substrate.

For preformed reinforcements, the composite material is manufactured off-site and subsequently applied on-site using an adhesive that ensures bonding between the reinforcement and the existing structure.
An illustrative diagram of the two reinforcement techniques is provided below.
The load-resisting mechanism of external composite reinforcements applied to concrete elements is based on the bond between materials. Except in rare cases, failure of the strengthened element typically occurs due to debonding of the FRP from the substrate, rather than reaching the ultimate strength of the composite material itself.

The effectiveness of FRP strengthening applied to concrete structures is greater when debonding occurs within the concrete itself, resulting in cohesive failure. This is structurally more favorable than adhesive failure at the adhesive-reinforcement interface, which is less effective from a structural standpoint.

In-situ laminated strengthening systems

FABRIC/MESH + EPOXY RESI

Preformed strengthening system

PREFORMED LAMINATE + EPOXY RESIN

The load-bearing mechanism of external composite reinforcements applied to concrete elements is adhesive in nature. Except in rare cases, failure of the strengthened element occurs due to debonding of the FRP from the substrate, and almost never due to the composite material reaching its ultimate strength.

The strengthening effect of FRP materials applied to concrete structures is more effective when debonding occurs within the concrete, resulting in cohesive failure. It is less effective when debonding occurs at the adhesive–reinforcement interface, leading to adhesive failure.

CNR-DT 200/2004

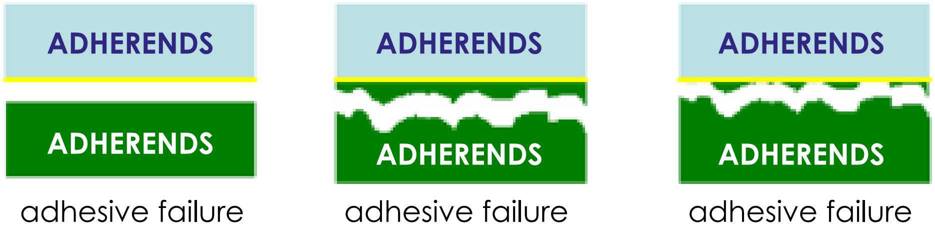


Fig. 2-10 *- Comparison of the different types of failure*

To ensure the maximum mechanical performance of the composite reinforcement, it is essential that the concrete substrate is clean and free of oils, greases, and form-release agents. Cleaning must be carried out mechanically using tools such as a grinder or rotary sander; the use of chemical solvents is not recommended.

The surface designated for reinforcement must be flat, rough, and not smooth, with a roughness index between 0.3 and 0.5 mm, measurable using a profilometer or laser surface scanner. Any surface irregularities must be corrected using structural repair mortars classified as R4 or epoxy skim coats, selected based on the size and nature of the defect. Specifically, epoxy putty is recommended for minor imperfections (up to 1 mm of roughness), while full-surface smoothing with epoxy products is discouraged, as it may hinder proper impregnation of the reinforcement.

When selecting the repair mortar, three key parameters must be considered:
- bond strength to concrete, which must exceed 2 MPa;
- elastic modulus, which must be compatible with that of the substrate;
- aggregate grading, with a preferred d50 not exceeding 2 mm, and finishing performed with a steel trowel rather than a sponge float.

According to the guidelines of the International Concrete Repair Institute (ICRI), the surface is suitable for the application of in-situ laminated reinforcements if it falls within CSP grades 2 to 5, while for pre-formed reinforcements, the acceptable range may extend up to CSP grade 6.

The substrate must be dry, with a surface moisture content between 5% and 10%. If a cementitious repair has been performed, full curing of the mortar must be ensured before applying the reinforcement. The curing time will depend on the type of mortar used, the properties of the substrate, and the site's temperature and humidity conditions.

If the repair only affects the surface layer, it is always advisable to assess the depth of the degradation (e.g., carbonation extent or presence of free chlorides) to tailor the intervention to the actual condition of the structure. If it is not possible to adapt the repair to the real state of deterioration, anti-delamination systems must be installed - at a minimum in anchorage zones - to ensure effective mechanical behavior of the FRP reinforcement.

5.1

Main phases of the application cycle

After removing any deteriorated concrete cover and completing the substrate preparation (see previous section), the main phases of a correct application cycle are as follows:

A. REINFORCEMENT LAYOUT
- Accurately identify and mark the position of the reinforcement on the concrete element, following the project specifications.

B. APPLICATION OF THE EPOXY PRIMER
- If required, apply the two-component primer BETONTEX RC01 at a rate of 300 g/m² on the surface to be treated.
- Distribute the primer evenly using a brush or short-nap roller, ensuring a uniform film is achieved.

C. PRIMER CURING
- Wait at least one hour and no more than three hours before proceeding to the next step.
- The primer must remain tacky; if it dries completely, it must be removed mechanically before continuing.
- The surface must be sticky to the touch before proceeding.

D. REINFORCEMENT CUTTING
- Prepare the reinforcement strips by cutting them to the lengths and widths specified in the project.

E. REINFORCEMENT STORAGE
- Roll the strips and store them in a clean, dust-free container until application.

F. APPLICATION OF THE EPOXY MATRIX BETONTEX FB-RC02
- Apply the first layer of BETONTEX FB-RC02 epoxy adhesive onto the primed substrate, at a rate of approximately 300 g/m² for a 300 g/m² carbon fiber strip.

G. REINFORCEMENT PLACEMENT
- Position the reinforcement according to the exact alignment and orientation specified in the design.
- Even slight misalignment can significantly reduce the reinforcement's effectiveness.

H. ROLLING THE REINFORCEMENT
- Use a special grooved bubble-breaking roller, repeating the operation until the resin from the lower layer begins to emerge slightly on the surface of the strip.
- Rolling must follow the fiber direction.

I. APPLICATION OF ADDITIONAL LAYERS
- Repeat steps F, G, and H for each additional reinforcement layer as specified in the design.

J. SATURATION WITH BETONTEX FB-RC02 EPOXY ADHESIVE
- Apply a second layer of adhesive to fully saturate the fabric, at approximately 300 g/m² for a 300 g/m² carbon strip.

K. SECOND ROLLING OPERATION
- Perform a second rolling pass with the bubble-breaking roller to ensure proper impregnation of the reinforcement.

L. SURFACE FINISHING
- Remove any excess resin and finish the surface using a brush.

M. DRY QUARTZ SAND DUSTING
- Apply dry quartz sand onto the final fresh resin layer to enhance adhesion of any subsequent finishes.

N. PROTECTION AND FINISHING
- Apply a surface protection layer such as a civil plaster or UV-resistant paint (e.g., polyurethane coating), or any other finish as specified in the design.

On-site laminates

Application cycle:

Final considerations

In the case of minor localized irregularities, the application of an epoxy skim coat may be carried out prior to Phase F, in order to ensure a more uniform surface.
The quantities indicated for the primer (RC01) and the adhesive (RC02) are based on standard application conditions and may vary significantly depending on the substrate characteristics and the skill level of the applicators.

5.1

5.1.4 Application procedure for preformed FRP reinforcements

The installation of preformed FRP reinforcements involves a sequence of well-defined steps to ensure proper adhesion of the composite material to the concrete substrate.

Application phases

1. **Reinforcement Layout**
- Precisely locate and mark the reinforcement position on the concrete element, following the project drawings.
2. **Application of Epoxy Primer**
- Apply the two-component epoxy primer to the designated surface at a rate of 300 g/m², where required.
- Spread the primer uniformly using a brush or short-nap roller, working it in until a continuous and even film is achieved.
3. **Primer Curing**
- Allow the primer to cure for at least 1 hour and no more than 3 hours.
- The primer must remain tacky; if it dries completely, it must be mechanically removed before continuing.
- The surface is ready for the next step when it feels tacky to the touch.
4. **Cutting the Reinforcement Laminates**
- Prepare the preformed laminates by cutting them to the dimensions specified in the design.
- Apply a 25 mm masking tape along the cutting line to prevent localized cracking.
- Use an angle grinder with a metal-cutting or diamond blade to perform the cut.
5. **Surface Preparation of the Laminate**
- Lightly sand the bonding surface of the laminate with fine-grit sandpaper (grit 400–600).
- Clean the surface with compressed air to remove dust and debris.
6. **Application of Epoxy Adhesive**
- Apply a first layer of BETONTEX RC30/3 adhesive to the marked area on the concrete surface.
- Apply adhesive to the laminate bonding face as well.
7. **Placement of the Carbon Laminate**
- Precisely position the laminate according to the design orientation.
- Apply gentle pressure using a rigid plastic roller to promote adhesion.
8. **Removal of Excess Resin**
- Remove any excess resin that may affect the performance of the reinforcement.
9. **Finishing and Protection**
- If required, apply an additional layer of epoxy adhesive and broadcast with dry quartz sand, selecting the appropriate grain size for the desired finish.
- Protect the reinforcement with a skim coat or a UV-resistant coating (e.g., polyurethane paint)

Resin mixing instructions

The resins used for the installation of preformed reinforcements are two-component systems composed of:

- **Component A (resin)**
- **Component B (hardener)**

Correct mixing procedure:

1. Use a clean polyethylene container, free of solvents, grease, or oils.
2. Tare the scale and pour the correct amount of Component A.
3. Add Component B according to the weight ratio specified in the technical datasheet.
4. Mix the two components using a low-speed paint mixer to avoid air entrapment.
5. Continue mixing until a uniform, homogeneous, and evenly colored mixture is obtained.

Environmental conditions for application

The application of composite materials must be carried out within a temperature range of 5°C to 30°C. Throughout the entire process, it is essential to ensure that:

- The substrate, primer, and adhesive are not exposed to direct sources of heat or moisture.
- The surfaces to be reinforced are clean and completely dry.
- No condensation is present on the surfaces.
- Ambient humidity is not excessive.

In the three days following the application, stable environmental conditions must be maintained to ensure proper resin curing.
For further details regarding the application procedure, please refer to the specific technical documentation.

5.2 MASONRY STRUCTURES

Diagnosis

In a context marked by significant heterogeneity in construction techniques, the assessment of the mechanical properties of materials (such as the compressive and shear strength of masonry) must be framed within a broader understanding of the entire structural system. Key aspects to be considered include the effectiveness of vertical and horizontal interlocking, the load-distribution capacity of horizontal structures, and the effects of chemical and physical degradation on materials. These elements define a highly complex discipline that requires a thorough, multidisciplinary analysis.

Visual inspection represents the first step of the diagnostic process and aims to identify crack patterns, fissures, delaminations, efflorescence, and signs of moisture. These preliminary assessments can be supplemented with a series of non-destructive tests, including:

- sonic and ultrasonic testing, used to detect internal defects and discontinuities and to evaluate the overall quality of the masonry;
- infrared thermography, which detects thermal anomalies that may indicate voids or hidden moisture not visible to the naked eye;
- flat-jack tests, employed to determine the deformability and strength of the masonry through the application of controlled pressure.

Among the most common and standardized destructive tests are:

- compressive strength tests on bricks or blocks, used to assess the mechanical resistance of the masonry units;
- shear tests, aimed at measuring the shear strength of mortars and the interfaces between masonry units.

In the investigation of existing masonry structures, chemical and mineralogical analyses are also important diagnostic tools. These allow for the examination of:

- inorganic matrices, through the identification of mortar composition to assess compatibility and durability;
- soluble salts, particularly to identify the presence and type of chlorides.

When present above certain thresholds and under specific moisture conditions, these salts may trigger degradation phenomena of varying severity

FIBRE NET composite engineering

5.3 TIMBER STRUCTURES

Diagnosis

As with existing timber structures, attention to the mechanical properties of the material is necessary but not sufficient for a comprehensive assessment. A proper understanding of a timber structure requires a series of on-site inspections - both visual and instrumental - aimed at identifying possible timber defects as well as forms of deterioration and decay due to environmental exposure or service conditions.

Visual inspection is the first tool in the evaluation process, allowing the analysis of the surface condition of the timber elements, the detection of cracks and deformations, and the identification of biological attacks, such as those caused by fungi or wood-boring insects.

This initial assessment can be supplemented by various non-destructive tests, including:
- resistography, used to measure the resistance to needle penetration and assess wood density;
- ultrasonic testing, employed to detect internal defects and evaluate the structural quality of the timber;
- infrared thermography, useful for identifying thermal anomalies that may indicate moisture presence or internal decay.

Destructive testing, on the other hand, may include:
- compression and bending tests, performed on extracted samples to evaluate the material's mechanical strength;
- tensile tests, similar to the above, specifically aimed at estimating the tensile strength of wood.

A critical aspect of the assessment involves biological investigations, which allow for the identification of fungi and xylophagous insects, as well as the type and extent of infestation. In addition, moisture content analysis is fundamental to prevent the risk of biological degradation and to ensure long-term durability of the timber.

Finally, as with concrete and masonry structures, timber structures can also be monitored over time.
Using deformometers and strain gauges, it is possible to measure deformations and stresses over time, ensuring continuous control of the structural condition.

5.4 STEEL STRUCTURES

Diagnosis

The assessment of corrosion onset and other electrochemical degradation processes can be exacerbated by construction defects or natural material aging - particularly when steel is exposed to aggressive environmental agents and lacks protective sacrificial coatings.
To evaluate the condition of steel structures, a range of diagnostic techniques is employed, including visual inspections, non-destructive and destructive testing, electrochemical investigations, and in-service monitoring systems.

1. Visual inspection

Visual examination is the first diagnostic tool and is used to detect early signs of corrosion, deformations, cracking, and welding defects. This preliminary assessment helps identify critical areas that require further investigation through more advanced methods.

2. Non-destructive testing (NDT)

NDT methods allow structural assessment without compromising integrity. Common techniques include:
- radiographic testing: used to detect internal flaws in welds and structural components;
- ultrasonic testing: employed to identify internal defects and measure the residual thickness of corroded sections;
- magnetic particle testing and Eddy Current testing: effective for detecting surface cracks and flaws in ferromagnetic materials.

3. Destructive testing

Destructive tests are carried out to determine the mechanical properties of the material and verify that the structure meets design requirements. These tests include:
- tensile tests: used to measure the tensile strength of steel;
- hardness tests: used to assess the surface hardness and wear resistance of the material.

4. Electrochemical investigations

Electrochemical techniques are used to monitor the corrosion process and estimate its rate. Common investigations include:
- corrosion potential measurement: assesses the likelihood of corrosion in steel components;
- polarization techniques: used to determine the corrosion rate and estimate the remaining service life of the structure.

5. In-Service monitoring

Structural monitoring systems are employed to detect anomalies during the service life of the structure. Key instruments include:
- strain gauges: used to monitor stress and strain in structural elements;
- corrosion probes: used to track corrosion progression over time and quantify material degradation.

When properly integrated, these diagnostic methods provide a comprehensive assessment of the conservation state of steel structures, offering essential data for the planning of maintenance, repair, or strengthening interventions

6

THE BETONTEX SYSTEM

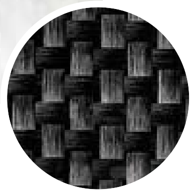
FIELDS OF APPLICATION AND INSTALLATION METHODS

6.1 STRENGTHENING OF SLABS AND FLOOR SYSTEMS

FABRICS AND MESHES

The intervention involves the application of structural strengthening systems in FRP - either unidirectional fabrics or bidirectional carbon fiber meshes - on the extrados of floor systems. The materials used are designed according to the specific project requirements and the safety levels to be achieved, while always preserving the architectural appearance of the structural element.
The resulting strengthening system offers high durability, full reversibility, complete compatibility with traditional materials, negligible increase in dead loads due to the extremely low thickness, and minimal invasiveness on the existing structure.

Example rendering
Strengthening intervention with fabrics and meshes on concrete slabs



INSTALLATION METHOD

1. **SUBSTRATE PREPARATION**
If the slab surface is regular, level, and free of discontinuities, a light sanding or grinding is sufficient. In the presence of degradation, all loose or damaged materials (plasters, cement films, non-adherent surface layers) must be removed, and the original section geometry must be restored using suitable repair mortars.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
Once the substrate is properly prepared, a high-performance cementitious mortar or microconcrete (type CC, class R4) is applied. This material must exhibit appropriate mechanical properties, including compressive strength, flexural strength, elastic modulus, and adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3. **APPLICATION OF PRIMER**
After the surface has dried, an epoxy primer is applied to regulate absorption and promote adhesion of subsequent layers. Where required, anchoring elements - such as carbon fiber bow connectors, rods, or Ardfix connectors - may be installed to ensure effective load transfer to the substrate.

4. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still tacky, apply the first layer of epoxy adhesive.

5. **INSTALLATION OF CARBON FIBER FABRIC OR MESH**
Place the carbon fiber fabrics or meshes onto the fresh resin layer, ensuring proper adhesion to the substrate and avoiding the formation of folds, wrinkles, or air bubbles.

6. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by thorough rolling with a bubble-breaking roller to ensure complete fiber saturation and eliminate voids or discontinuities.

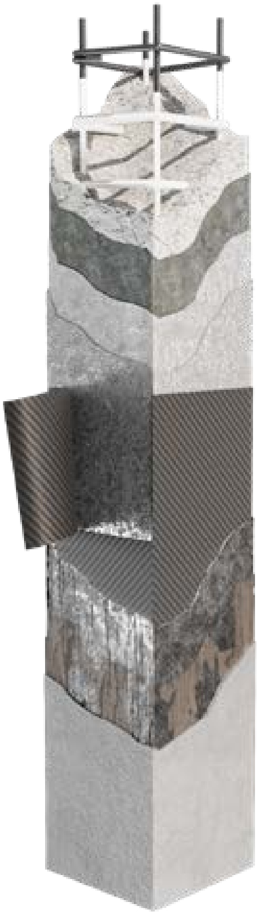
7. **INSTALLATION OF ADDITIONAL LAYERS OF CARBON FIBER FABRIC OR MESH**
If multiple layers of carbon fiber fabric or mesh are specified, repeat steps 4 and 5 accordingly.

8. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
While the resin is still fresh, dry quartz sand may be spread over the surface to promote adhesion of subsequent finishing layers such as plaster or skim coats.

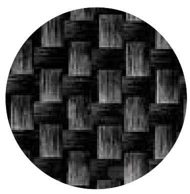
6.2 STRENGTHENING OF COLUMNS

FABRICS

The intervention involves the structural strengthening of columns by wrapping them with FRP systems, using unidirectional fabrics or bidirectional carbon fiber meshes. This technique is primarily intended for the consolidation of compressed or combined compression-bending elements, such as columns, with the aim of increasing their load-bearing capacity and improving their performance under dynamic actions, particularly seismic events.
The resulting reinforcement ensures high durability and provides a significant increase in both ductility and resistance to cyclic loading.



Example rendering
Strengthening intervention with fabrics on a concrete column



INSTALLATION METHOD

1 **SUBSTRATE PREPARATION**
If the surface of the element is regular, and level, a light grinding is performed, followed by rounding of the edges with a curvature radius ≥ 20 mm to prevent stress concentrations in the composite material. In the presence of surface degradation, all loose or damaged portions (plasters, cement laitance, non-adherent materials) must be removed, and the original section geometry restored using appropriate repair mortars.

2 **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
On the properly prepared substrate, a structural mortar of type CC or PCC, with performance class R4 (preferred) or R3, is applied. The mortar must have suitable mechanical properties (compressive and flexural strength, elastic modulus, and bond to the substrate). Alternatively, a two-component epoxy leveling compound may be used.

3 **APPLICATION OF PRIMER**
Once the substrate is dry, an epoxy primer is applied to homogenize the surface and regulate absorption. Where needed, local connectors - such as carbon fiber bow connectors, rods, or Ardfix devices - may be installed to improve the interaction between the reinforcement and the substrate.

4 **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still tacky, apply the first layer of epoxy adhesive.

5 **INSTALLATION OF CARBON FIBER FABRIC OR MESH**
Using the wet-on-wet method, place the carbon fiber fabrics or meshes onto the fresh resin, ensuring continuous adhesion to the substrate and avoiding the formation of air bubbles, wrinkles, or folds.

6 **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure full saturation of the fibers and eliminate any voids..

7 **INSTALLATION OF ADDITIONAL LAYERS OF CARBON FIBER FABRIC OR MESH**
If multiple layers of carbon fiber fabric or mesh are specified, repeat steps 4 and 5 as necessary.

8 **OPTIONAL SPREADING OF DRY QUARTZ SAND**
While the resin is still fresh, dry quartz sand may be spread over the surface to improve adhesion of subsequent finishing layers (such as plaster, skim coat, etc.).

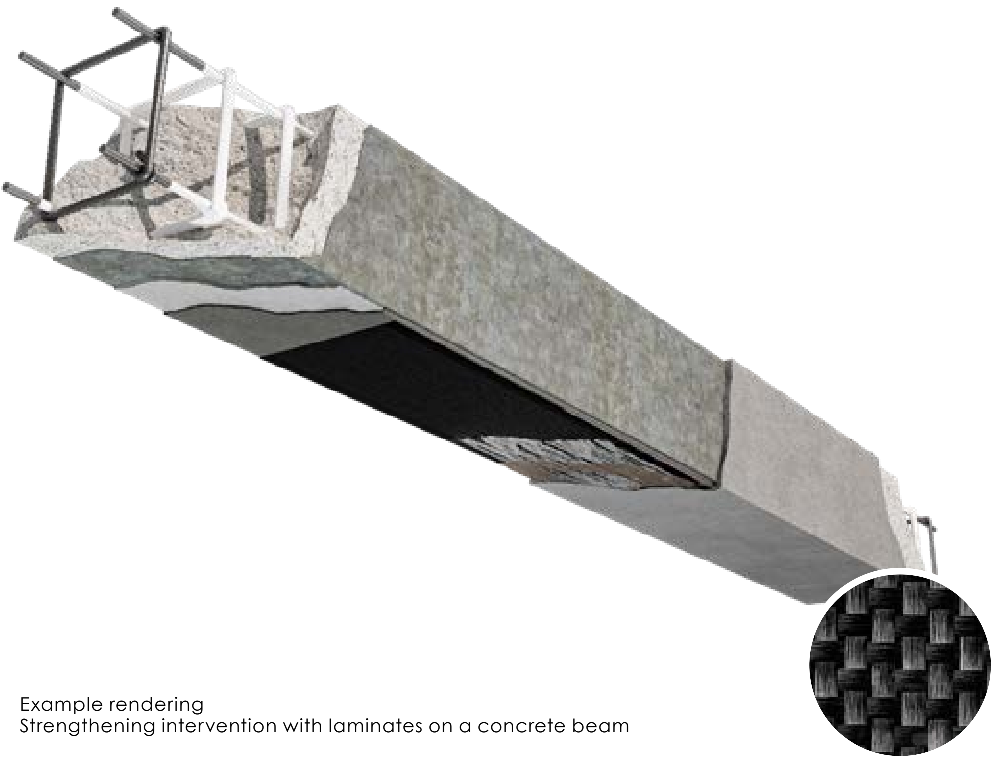
6.3 FLEXURAL STRENGTHENING OF BEAMS

FABRICS

The intervention involves the application of FRP systems to the soffit of beams, using unidirectional fabrics or bidirectional carbon fiber meshes. This technique is aimed at strengthening flexural elements, with the objective of increasing their load-bearing capacity. The reinforcement ensures high durability, improved resistance to cyclic loading, and excellent mechanical performance in terms of stiffness and strength.

PREFORMED LAMINATES

The intervention consists in the structural strengthening of beams by applying FRP systems to the soffit, using preformed or preformed carbon fiber laminates. This technique is particularly suitable for the reinforcement of elements subjected to flexural stresses, such as beams. The resulting strengthening system provides enhanced durability.



Example rendering
Strengthening intervention with laminates on a concrete beam

6.3

INSTALLATION METHOD

INTERVENTION WITH FABRICS

1. **SUBSTRATE PREPARATION**
If the surface of the element is regular, smooth, and level, light grinding is sufficient. In the presence of surface degradation, all loose or damaged materials (plasters, cement laitance, non-adherent layers) must be removed, and the original geometry restored using appropriate repair materials. The surface should be roughened to a texture within the CSP2–CSP5 range.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
Apply a guaranteed-performance cementitious mortar or microconcrete (type CC or PCC), preferably class R4 (minimum R3), with suitable mechanical properties (compressive and flexural strength, elastic modulus, and bond to the substrate). Alternatively, a two-component epoxy leveling compound may be used.

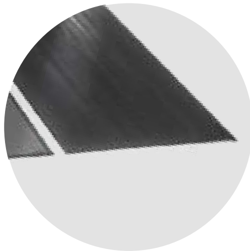
3. **APPLICATION OF PRIMER**
On a dry surface, apply an epoxy primer to homogenize surface absorption and promote adhesion. Where required, local connectors (carbon fiber bow connectors, rods, or Ardfix devices) may be installed to enhance composite-substrate interaction.

4. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still tacky, apply the first layer of epoxy adhesive.

5. **INSTALLATION OF CARBON FIBER FABRIC OR MESH**
Apply the carbon fiber fabrics or meshes to the fresh resin, ensuring continuous adhesion to the substrate and avoiding the formation of air bubbles, wrinkles, or folds.

6. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure complete fiber saturation and eliminate voids.

7. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
While the resin is still fresh, dry quartz sand may be broadcast over the surface to improve adhesion of any subsequent finishes (plaster, skim coat, etc.).



INTERVENTION WITH PREFORMED LAMINATES

1. **SUBSTRATE PREPARATION**
If the surface of the structural element is regular, level, and has an adequate surface roughness in the CSP4–CSP6 range, light grinding is sufficient. In the presence of surface degradation, all loose or damaged materials (plasters, cement laitance, non-adherent layers) must be removed, and the original geometry of the section restored using suitable repair materials.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
On the properly prepared substrate, apply a guaranteed-performance cementitious mortar or microconcrete (type CC or PCC), preferably class R4, or at minimum R3. The material must provide high mechanical performance, including compressive and flexural strength, elastic modulus, and strong adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3. **APPLICATION OF PRIMER**
On a dry substrate, apply an epoxy primer to even out absorption and promote adhesion. Where necessary, local connectors (such as carbon fiber bow connectors, rods, or Ardfix devices) may be used to enhance the interaction between the reinforcement and the substrate.

4. **APPLICATION OF EPOXY ADHESIVE**
While the primer is still tacky, apply the first layer of epoxy adhesive.

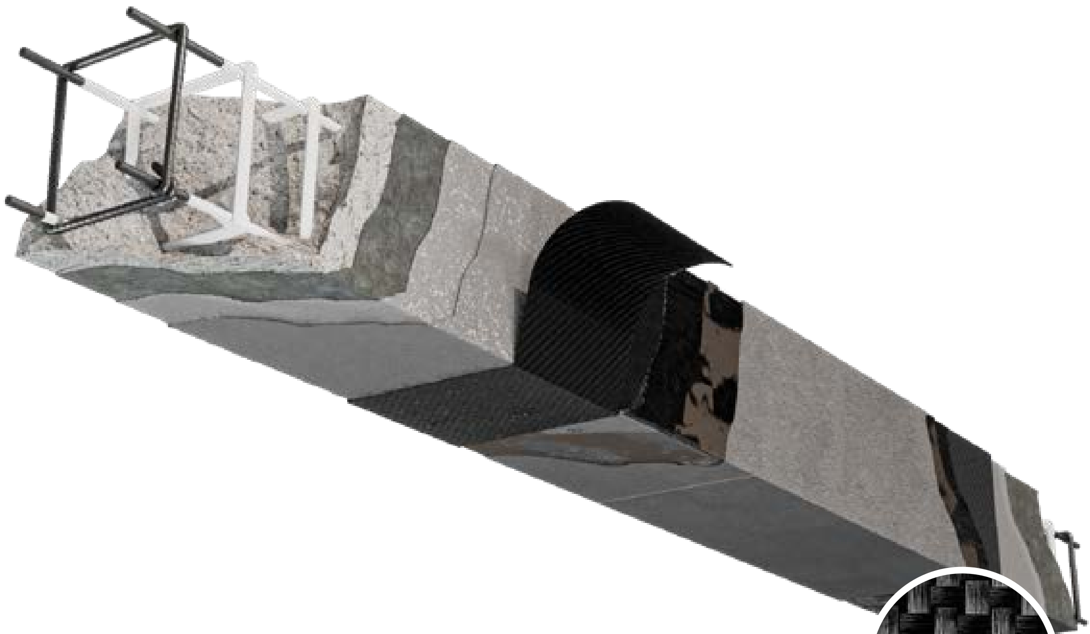
5. **INSTALLATION OF THE PREFORMED OR PREFORMED LAMINATE**
Immediately before installation, remove the peel ply film from the bonding surface of the laminate and lightly sand it with fine-grit sandpaper. Apply a layer of epoxy adhesive and press the laminate gently against the surface using a hard rubber roller to ensure full adhesion. For large spans, temporary propping is recommended during curing.

6. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
Once the intervention is completed, apply an additional layer of epoxy primer over the laminate, followed by a surface spreading of dry quartz sand to improve adhesion of any subsequent finishes (such as plaster or skim coats).

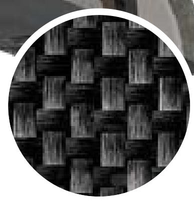
6.4 SHEAR STRENGTHENING OF BEAMS

FABRICS

The intervention consists in the structural shear strengthening of beams through wrapping with FRP systems, using unidirectional fabrics or bidirectional carbon fiber meshes.
This technique is primarily aimed at increasing the transverse reinforcement of the beam, thereby improving the element's behavior under shear forces.
The resulting reinforcement ensures high durability and a significant increase in shear strength.



Example rendering
Shear strengthening intervention with fabrics on a concrete beam



INSTALLATION METHOD

1. **SUBSTRATE PREPARATION**
If the surface of the element is regular and level, perform light grinding, followed by rounding of edges with a curvature radius ≥ 20 mm to avoid stress concentrations in the composite. In the presence of surface degradation, remove all loose or damaged portions (plasters, cement laitance, non-adherent materials) and restore the original section geometry using suitable repair materials.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
Apply a high-performance cementitious mortar or microconcrete (type CC or PCC), preferably class R4 or, alternatively, R3. The material must exhibit adequate mechanical properties: compressive and flexural strength, elastic modulus, and strong adhesion to the substrate. As an alternative, a two-component epoxy leveling compound may be used

3. **APPLICATION OF PRIMER**
On a dry surface, apply an epoxy primer to regulate absorption and promote adhesion. Where required, local connectors (carbon fiber bow connectors, rods, or Ardfix devices) may be installed to improve bond and cooperation between the reinforcement and the substrate.

4. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still tacky, apply the first layer of epoxy adhesive.

5. **INSTALLATION OF CARBON FIBER FABRIC OR MESH**
Apply the carbon fiber fabrics or meshes onto the fresh resin, ensuring continuous adhesion to the substrate and avoiding the formation of air bubbles, wrinkles, or folds.

6. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure full fiber saturation and elimination of voids.

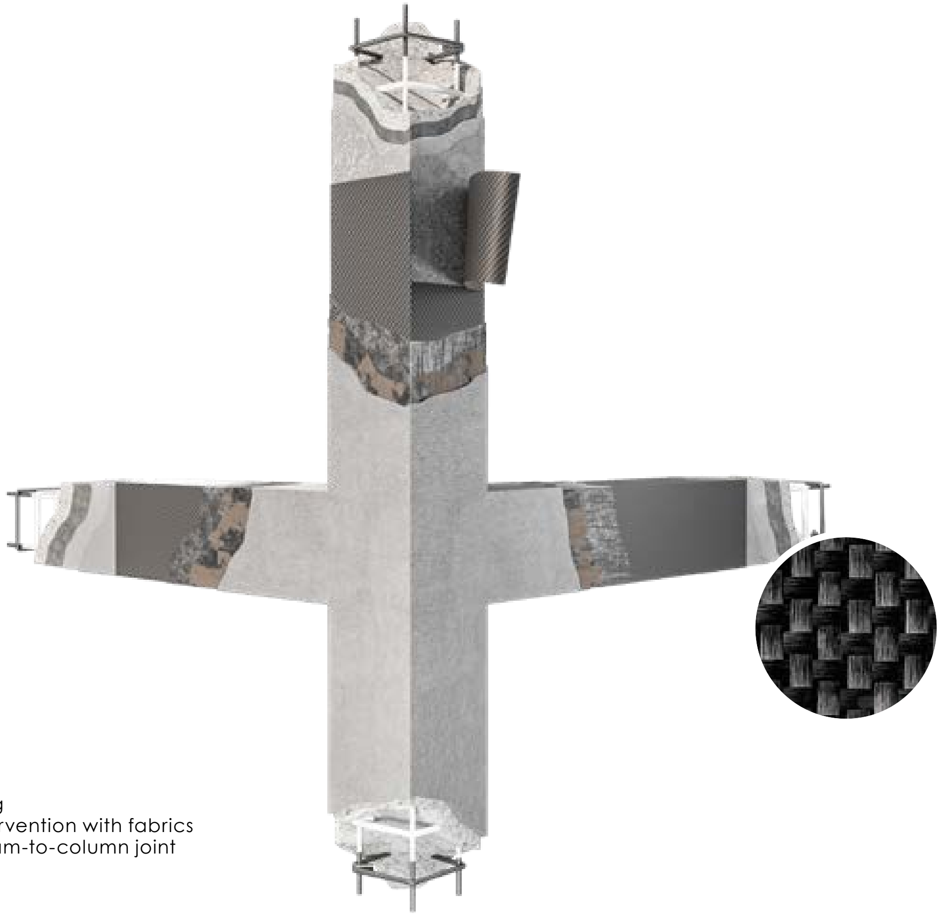
7. **INSTALLATION OF ADDITIONAL LAYERS OF CARBON FIBER FABRIC OR MESH**
In case of multilayer application, repeat steps 4 and 5 for each additional layer.

8. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
While the resin is still fresh, a superficial spreading of dry quartz sand may be applied to enhance adhesion of subsequent finishing layers (plaster, skim coat, etc.).

6.5 STRENGTHENING OF BEAM-TO-COLUMN JOINTS (CORNER AND PERIMETER NODES)

FABRICS

The intervention involves the application of FRP structural strengthening systems, consisting of unidirectional fabrics or bidirectional carbon fiber meshes, at beam-to-column joints. The materials are sized according to the specific design requirements and the required safety level, while always preserving the architectural appearance of the structural element.
The resulting reinforcement system ensures high durability, full reversibility, complete compatibility with traditional materials, negligible increase in self-weight due to the minimal thickness of the materials, and minimal invasiveness on the existing structure.



Example rendering
Strengthening intervention with fabrics on a concrete beam-to-column joint

INSTALLATION METHOD

1 SUBSTRATE PREPARATION
If the surface of the element is regular and level, carry out light grinding, followed by rounding of edges with a curvature radius ≥ 20 mm to prevent stress concentrations in the composite. In case of surface degradation, remove all loose or damaged portions (plasters, cement laitance, non-adherent layers) and restore the original geometry of the section using suitable repair materials.

2 APPLICATION OF A CEMENTITIOUS MORTAR LAYER
Apply a high-performance cementitious mortar or microconcrete (type CC or PCC), preferably class R4 (or at minimum R3), with appropriate mechanical properties: compressive and flexural strength, elastic modulus, and good adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3 OPTIONAL INSTALLATION OF CARBON FIBER CONNECTORS
If specified in the design, drill, clean, and install carbon fiber connectors using cartridge-applied epoxy adhesive to improve the interaction between the reinforcement and the substrate.

4 APPLICATION OF PRIMER
On a dry substrate, apply an epoxy primer to even out surface absorption and promote adhesion.

5 APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN
Apply the first layer of adhesive while the primer is still tacky/fresh.

6 DEBOWING OF CARBON FIBER CONNECTORS
Debow (spread) the ends of the carbon fiber connectors as indicated in the design layout, using impregnating epoxy resin.

7 INSTALLATION OF CARBON FIBER FABRIC
While the resin is still fresh, apply unidirectional or multidirectional carbon fiber fabrics, ensuring full adhesion to the substrate and avoiding the formation of bubbles, wrinkles, or folds.

8 APPLICATION OF THE SECOND LAYER OF RESIN
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure full saturation of the fibers and elimination of voids.

9 INSTALLATION OF ADDITIONAL LAYERS (IF SPECIFIED)
If a multilayer fabric application is specified, repeat steps 5 and 7 for each additional layer.

10 OPTIONAL SPREADING OF DRY QUARTZ SAND
While the resin is still fresh, apply a surface spreading of dry quartz sand to improve adhesion of any subsequent finishing layers (plaster, skim coat, etc.).

6.6 STRENGTHENING OF JOISTS

FABRICS

The intervention consists in the structural strengthening of joists by applying FRP systems - based on unidirectional carbon fiber fabrics - to the soffit. This technique is mainly intended for the consolidation of flexural elements, such as joists and beams, with the aim of enhancing their load-bearing capacity and improving their performance under dynamic actions, particularly those of seismic origin.
The applied reinforcement ensures high durability, a notable increase in ductility and cyclic strength, and outstanding mechanical performance in terms of stiffness and resistance.

PREFORMED LAMINATES

The intervention consists in the structural strengthening of joists by applying FRP systems - specifically preformed or preformed carbon fiber laminates - to the soffit. This technique is primarily aimed at reinforcing flexural elements, such as joists, in order to increase their load-bearing capacity and enhance their response to dynamic actions, particularly seismic events.
The resulting reinforcement provides high durability, a significant increase in ductility and resistance to cyclic loading, as well as excellent mechanical performance in terms of stiffness and strength.

Example rendering
Strengthening intervention with laminates on a clay-concrete composite slab

INSTALLATION METHOD

INTERVENTION WITH FABRICS

1. **SUBSTRATE PREPARATION**
If the surface of the joists is regular and level, perform light grinding. In the presence of surface degradation, remove all loose or damaged portions (plasters, cement laitance, non-adherent materials) and restore the original section geometry using suitable repair materials.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
Apply a guaranteed-performance cementitious mortar (type CC or PCC), preferably class R4, or alternatively R3. The material must have adequate mechanical properties in terms of compressive and flexural strength, elastic modulus, and adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3. **APPLICATION OF PRIMER**
On a dry substrate, apply an epoxy primer to homogenize absorption and promote adhesion. Where necessary, local connectors (carbon fiber bow connectors, rods, or Ardfix devices) may be installed to improve the interaction between the reinforcement and the substrate.

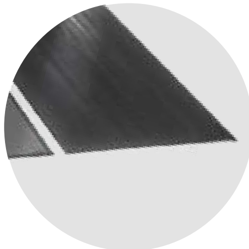
4. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
With the primer still fresh, proceed with the application of the first layer of adhesive.

5. **INSTALLATION OF CARBON FIBER FABRIC**
While the resin is still fresh, apply unidirectional carbon fiber fabrics, ensuring continuous adhesion to the substrate and avoiding the formation of bubbles, wrinkles, or folds.

6. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure full fiber saturation and the elimination of voids.

7. **INSTALLATION OF ADDITIONAL LAYERS (IF SPECIFIED)**
If a multilayer fabric application is required, repeat steps 4 and 5 for each additional layer.

8. **OPTIONAL BROADCASTING OF DRY QUARTZ SAND**
While the resin is still fresh, a surface broadcast of dry quartz sand may be applied to improve adhesion of subsequent finishing layers.



INTERVENTION WITH PREFORMED LAMINATES

1. **SUBSTRATE PREPARATION**
If the surface of the joists is regular and level, perform light grinding.
In case of surface degradation, remove all loose or damaged portions (plasters, cement laitance, non-adherent materials), and restore the original section geometry using suitable repair materials.

2. **APPLICATION OF A CEMENTITIOUS MORTAR LAYER**
Apply a guaranteed-performance cementitious mortar (type CC or PCC), preferably class R4, or alternatively R3. The material must exhibit appropriate mechanical properties in terms of compressive and flexural strength, elastic modulus, and adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3. **APPLICATION OF PRIMER**
On a dry substrate, apply an epoxy primer to regulate absorption and promote uniform adhesion.
Where necessary, local connectors (such as carbon fiber bow connectors, rods, or Ardfix devices) may be installed to improve interaction between the reinforcement and the substrate.

4. **APPLICATION OF EPOXY ADHESIVE**
After the primer has fully cured, apply a layer of epoxy adhesive to the soffit of the joist.

5. **INSTALLATION OF THE PREFORMED OR PREFORMED LAMINATE**
Immediately before installation, remove the peel ply film from the bonding face of the laminate.
Apply an additional layer of epoxy adhesive and press the laminate against the substrate using a hard rubber roller to ensure proper adhesion.
For joists with significant spans, temporary propping is recommended during curing.

6. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
Upon completion of the intervention, an additional layer of adhesive can be applied over the laminate, followed by a surface spreading of dry quartz sand to improve adhesion of subsequent finishing layers.

6.7 STRENGTHENING OF MASONRY COLUMN

FABRICS

The intervention consists in the structural strengthening of masonry columns through wrapping with FRP systems, using unidirectional fabrics or bidirectional carbon fiber meshes. This technique is mainly used to consolidate compressed or flexural-compression elements, such as masonry piers and columns, with the objective of increasing their load-bearing capacity and improving their performance under dynamic actions, particularly seismic loads.
The reinforcement provides high durability, a significant increase in ductility and resistance to cyclic loading, as well as excellent mechanical performance in terms of stiffness and strength.

Example rendering
Strengthening intervention
with fabrics on masonry columns

INSTALLATION METHOD

1. **SUBSTRATE PREPARATION**
If the surface of the element is regular and level, carry out light grinding.
In the presence of surface degradation, remove all loose or damaged materials (plasters, cement laitance, non-adherent layers), and restore the original geometry of the section using suitable repair mortars.

2. **APPLICATION OF A MASONRY MORTAR LAYER**
Apply a guaranteed-performance masonry mortar with adequate mechanical properties, including compressive and flexural strength, elastic modulus, and good adhesion to the substrate. Alternatively, a two-component epoxy leveling compound may be used.

3. **APPLICATION OF PRIMER**
On a dry substrate, apply an epoxy primer to regulate surface absorption and promote adhesion.
Where required, local connectors (carbon fiber bow connectors, rods, or Ardfix devices) may be inserted to improve the bond and cooperation between the reinforcement and the substrate.

4. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
Once the primer has fully cured, apply the first layer of impregnating epoxy resin.

5. **INSTALLATION OF CARBON FIBER FABRIC OR MESH**
While the resin is still fresh, apply the carbon fiber fabrics or meshes, ensuring perfect adhesion to the substrate and avoiding the formation of air bubbles, wrinkles, or folds.

6. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin, followed by rolling with a bubble-breaking roller to ensure complete saturation of the fibers and the elimination of voids.

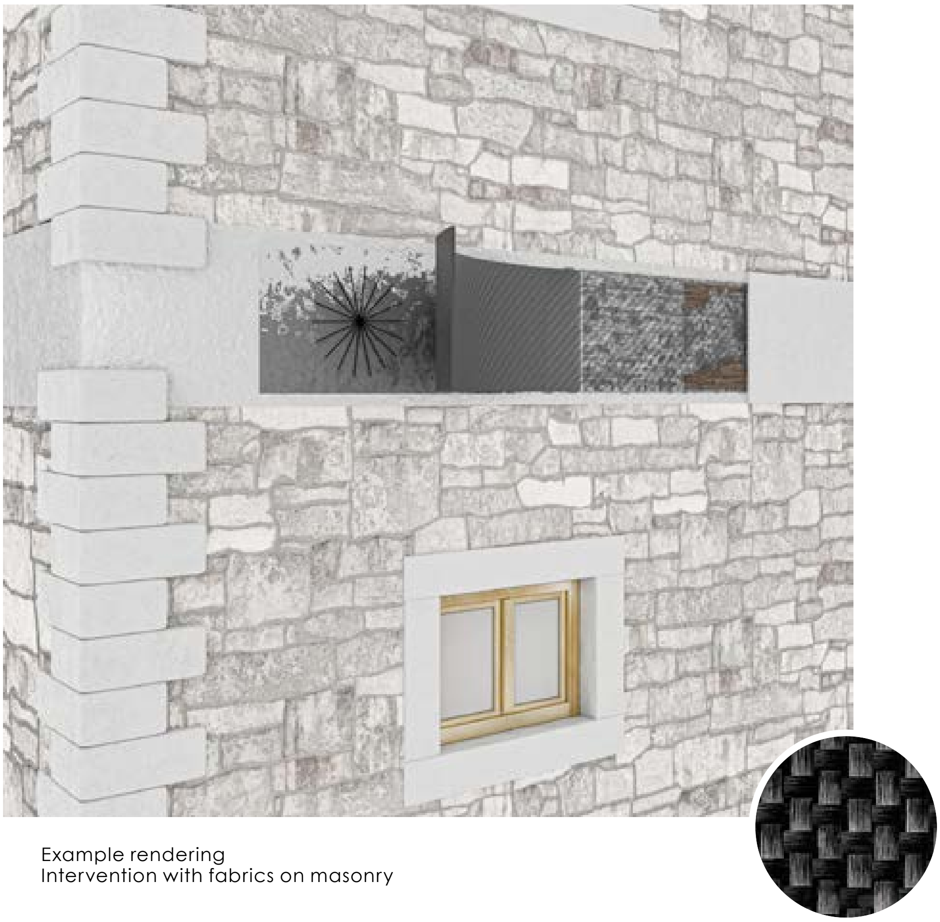
7. **INSTALLATION OF ADDITIONAL LAYERS (IF REQUIRED)**
If a multilayer reinforcement is specified, repeat steps 4 and 5 for each additional layer.

8. **OPTIONAL SPREADING OF DRY QUARTZ SAND**
While the resin is still fresh, dry quartz sand may be spread over the surface to facilitate adhesion of subsequent finishing layers.

6.8 EXTERNAL BANDING AT FLOOR SLAB LEVEL

FABRICS

The intervention consists in the execution of external banding at the level of the floor slabs using FRP systems, typically through the application of unidirectional fabrics or bidirectional carbon fiber meshes, combined with appropriate anchoring and/or connection systems.
This technique is mainly employed to prevent the activation of out-of-plane overturning mechanisms, with the aim of restoring the box-like structural behavior of the masonry building.



Example rendering
Intervention with fabrics on masonry

INSTALLATION METHOD

1. **SUBSTRATE PREPARATION**
If the surface of the element is regular and planar, light sanding is carried out to obtain a roughened surface with a roughness profile corresponding to CSP2–CSP5. All edges must then be rounded with a curvature radius ≥ 20 mm to avoid stress concentrations in the composite.
In case of surface degradation, all loose or deteriorated materials (such as plasters, slurries, or non-adhering layers) must be removed, and the original geometry of the section restored using suitable repair mortars.

2. **APPLICATION OF MASONRY MORTAR LAYER**
On the properly prepared substrate, a performance-guaranteed masonry mortar is applied, featuring adequate mechanical properties in terms of compressive and flexural strength, elastic modulus, and adhesion to the substrate. As an alternative, a two-component epoxy skim coat may be used.

3. **OPTIONAL INSTALLATION OF CARBON FIBER CONNECTORS**
If required by the design, carbon fiber connectors are installed through drilling, cleaning, and bonding with cartridge-applied epoxy adhesive, to enhance the composite-to-substrate interaction.

4. **PRIMER APPLICATION**
Once the substrate is dry, an epoxy primer is applied to even out and regulate surface absorption.

5. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still fresh, the first layer of epoxy adhesive is applied.

6. **DEBOWING OF CARBON FIBER CONNECTORS**
The carbon fiber connectors are debowed as specified in the design, using the same impregnating resin.

7. **APPLICATION OF ADDITIONAL LAYERS (IF REQUIRED)**
While the resin is still fresh, carbon fiber fabrics or meshes are applied, ensuring continuous adhesion to the substrate and avoiding bubbles, folds, or discontinuities.

8. **APPLICATION OF SECOND LAYER OF RESIN**
A second layer of impregnating resin is then applied, followed by bubble-removing roller finishing to ensure full fiber impregnation and void elimination.

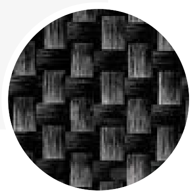
9. **APPLICATION OF FURTHER LAYERS (IF REQUIRED)**
For multi-layer reinforcements, steps 5 and 7 must be repeated for each additional layer specified in the project.

10. **OPTIONAL SPREADING DRY QUARTZ SAND**
While the resin is still fresh, a dry quartz sand spreading may be carried out to improve the adhesion of any subsequent finishes (plasters, skim coats, etc.).

6.9 STRENGTHENING OF MASONRY ARCHES AND VAULTS

FABRICS

The intervention consists in the structural strengthening of masonry arches and vaults through FRP wrapping, using unidirectional fabrics or bidirectional carbon fiber meshes.
The reinforcement can be applied either on the intrados (soffit) or extrados (extradosed surface). The main effect of the intervention is the inhibition of the formation of kinematic hinges, which would otherwise lead to collapse through a mechanism failure. In general, for FRP-strengthened arches and vaults, failure does not occur due to kinematic mechanisms but rather due to the material's strength limits being exceeded. For reinforcements applied to the extrados, particular attention must be paid to end anchorage, which can be achieved using preformed fan-type connectors. For intrados applications, it is necessary to verify the risk of premature debonding due to curvature-induced stresses. This phenomenon can be mitigated by providing adequate mechanical connections using preformed bow connectors.
FRP strengthening of these structural elements enhances both the static and seismic performance of the structure.



INSTALLATION METHOD

1 SUBSTRATE PREPARATION
If the surface of the element is regular, smooth, and planar, a light sanding is performed, followed by edge rounding with a curvature radius ≥ 20 mm to avoid stress concentrations in the composite.
In the presence of surface degradation, all loose or deteriorated portions (such as plasters, slurries, or non-adhering materials) must be removed, and the original geometry of the section restored using suitable repair mortars.

2 APPLICATION OF A MASONRY MORTAR LAYER
On the properly prepared substrate, a performance-certified masonry mortar is applied, characterized by appropriate mechanical properties in terms of compressive and flexural strength, elastic modulus, and substrate adhesion. Alternatively, a two-component epoxy skim coat may be used.

3 OPTIONAL INSTALLATION OF CARBON FIBER CONNECTORS
If required by the project, carbon fiber connectors are installed through drilling, cleaning, and bonding using cartridge-applied epoxy adhesive, in order to improve the interaction between the reinforcement and the substrate.

4 PRIMER APPLICATION
Once the substrate is dry, an epoxy primer is applied to ensure surface uniformity and regulate absorbency.

5 APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN
While the primer is still fresh, the first layer of epoxy adhesive is applied.

6 DEBOWING OF CARBON FIBER CONNECTORS
The carbon fiber connectors are flared as specified in the design, using the same impregnating resin.

7 APPLICATION OF THE CARBON FIBER FABRIC OR MESH
While the resin is still fresh, carbon fiber fabrics or meshes are applied, ensuring full contact with the substrate and avoiding the formation of bubbles, creases, or folds.

8 APPLICATION OF THE SECOND LAYER OF RESIN
A second layer of impregnating resin is applied, followed by bubble-removal rolling to ensure complete fiber impregnation and the elimination of air voids.

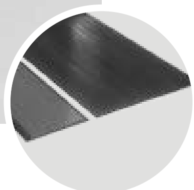
9 APPLICATION OF ADDITIONAL LAYERS (IF REQUIRED)
For multilayer reinforcements, steps 5 and 7 are repeated for each additional layer specified in the project.

10 OPTIONAL SPREADING DRY QUARTZ SAND
While the resin is still fresh, a superficial spreading of dry quartz sand may be applied to improve the adhesion of any subsequent finishing layers.

6.10 STRENGTHENING OF STEEL FLOOR SLABS

PREFORMED LAMINATES

The intervention consists in the structural strengthening of steel beams through the application of FRP systems—specifically preformed or preformed carbon fiber laminates—on the soffit (tension side) of the element.
This technique is primarily intended for the reinforcement of flexural members, with the aim of increasing their load-bearing capacity and improving their performance under static loading conditions.



Illustrative rendering – Intervention with laminates on a steel floor slab

INSTALLATION METHOD

1. **SUBSTRATE PREPARATION**
Remove any existing coatings from the soffit of the steel beams and carry out light sanding or grinding. This operation must be performed immediately before the application of the FRP system to prevent oxidation.

2. **PRIMER APPLICATION**
On a dry substrate, apply an epoxy primer to ensure surface uniformity and control absorption.

3. **APPLICATION OF GALVANIC CORROSION BARRIER**
Apply an epoxy skim coat over the prepared surface, followed by the placement of a fiberglass mesh to prevent galvanic corrosion caused by direct contact between steel and carbon fiber.

4. **APPLICATION OF EPOXY ADHESIVE**
While the primer is still fresh, proceed with the application of the first layer of epoxy adhesive.

5. **APPLICATION OF PREFORMED OR PREFORMED LAMINATE**
Immediately before installation, remove the peel-ply film from the bonding face of the laminate.
Apply an additional layer of epoxy adhesive, then press the laminate into place using a hard rubber roller to ensure proper adhesion to the substrate.
In the case of beams with large spans, it is advisable to provide temporary propping.

6. **OPTIONAL SPREADING DRY QUARTZ SAND**
Once the intervention is completed, an additional layer of epoxy adhesive may be applied over the laminates, followed by a surface spreading of dry quartz sand to improve adhesion for any subsequent finishing layers.

6.11 STRENGTHENING OF TIMBER FLOOR SLABS

FABRICS

The intervention consists of the structural reinforcement of wooden beams through the application of FRP systems, using carbon fiber fabrics applied to the underside (intrados) of the element. This technique allows for simultaneous improvement of both bending and shear behavior, enhancing the overall performance of the timber element. The reinforcement applied in this way ensures high durability, excellent mechanical performance in terms of stiffness and strength, a significant increase in ductility, and a greater capacity to withstand dynamic actions, particularly seismic ones.

Illustrative rendering - intervention with laminates on timber floor slab

PREFORMED LAMINATES

The intervention consists in the structural strengthening of timber beams through the application of preformed carbon fiber laminates on the soffit (tension side) of the elements.
The objective is to increase the load-bearing capacity of the timber members and enhance their resistance to static loads.

INSTALLATION METHOD

INTERVENTION WITH FABRICS

1. **SUBSTRATE PREPARATION**
Remove all coatings and surface irregularities from the soffit of the timber beams. Then carry out light sanding or grinding to obtain a surface suitable for the application of the reinforcement.

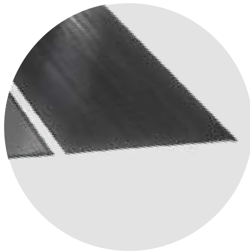
2. **PRIMER APPLICATION**
On a dry and properly prepared substrate, apply an epoxy primer to ensure surface uniformity and regulate absorbency. Where specified in the design, connection elements (such as fan anchors, rods, or Ardfix carbon fiber devices) may be installed.

3. **APPLICATION OF THE FIRST LAYER OF IMPREGNATING RESIN**
While the primer is still fresh, apply the first layer of epoxy adhesive.

4. **APPLICATION OF THE CARBON FIBER FABRIC OR MESH**
While the resin is still fresh, apply the carbon fiber fabrics or meshes, ensuring continuous adhesion to the substrate and taking care to avoid wrinkles, folds, or air bubbles.

5. **APPLICATION OF THE SECOND LAYER OF RESIN**
Apply a second layer of impregnating resin and follow with bubble-removal rolling to ensure complete fiber saturation. In the case of multilayer reinforcement, repeat steps 4 and 5 for each additional layer.

6. **OPTIONAL SPREADING DRY QUARTZ SAND**
Once the intervention is completed, and while the resin is still fresh, a surface spreading of dry quartz sand may be applied to ensure adequate adhesion for any subsequent finishing layers (plasters, skim coats, etc.).



INTERVENTION WITH PREFORMED LAMINATES

1. **SUBSTRATE PREPARATION**
Remove any coatings or finishing layers from the soffit of the timber beams and perform light sanding or grinding to prepare the surface.

2. **CUTTING OF THE TIMBER BEAMS**
According to design specifications, perform a longitudinal incision in the beam using a flexible cutting tool. The width and depth of the notch must be dimensioned to accommodate the insertion of preformed laminates. Where required, connection elements (such as bowed anchors, rods, or Ardfix carbon fiber devices) may be included. Carefully collect the sawdust generated during cutting for use in the final sealing stage.

3. **CLEANING OF THE NOTCH**
After cutting, blow out the notch thoroughly with compressed air to remove all dust and sawdust residues.

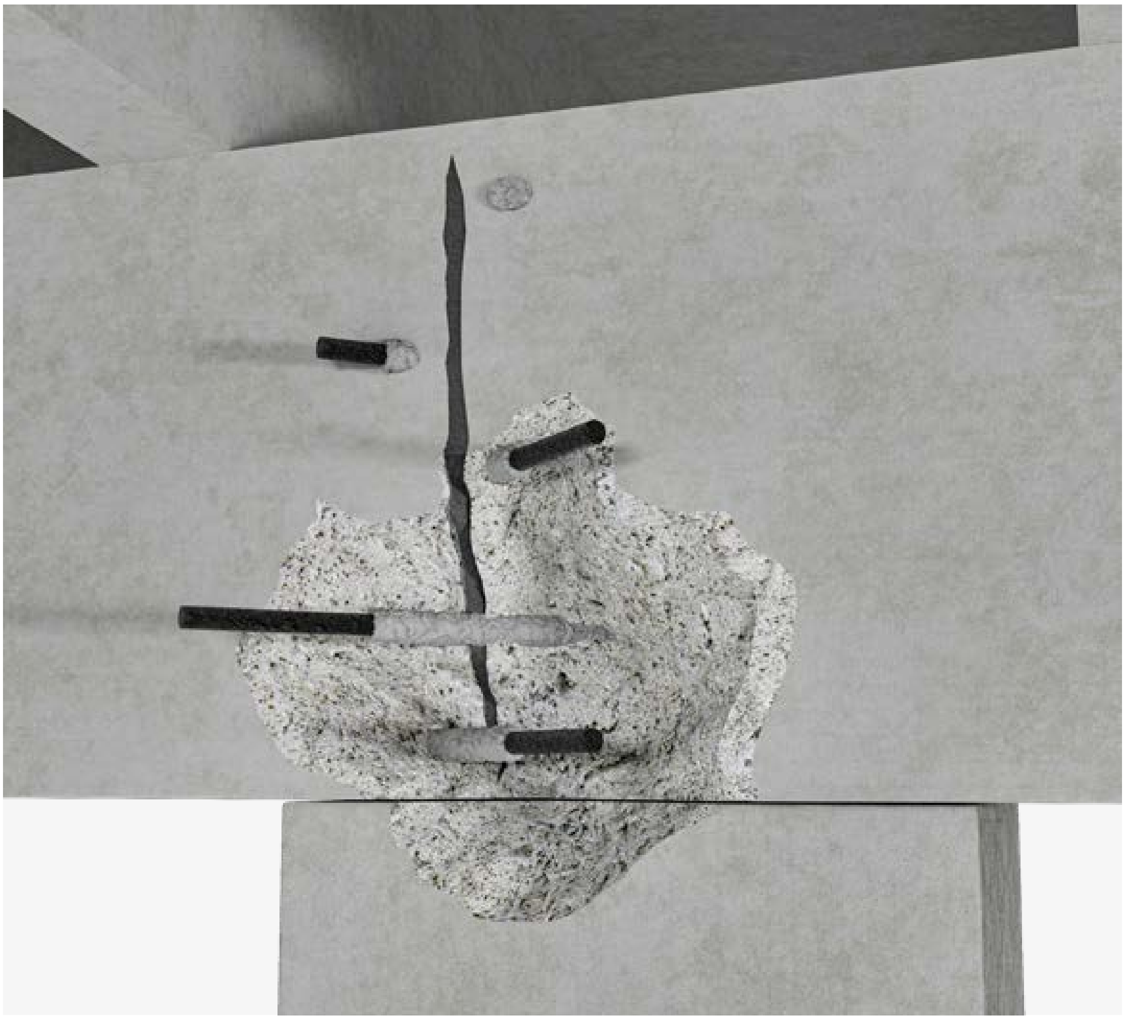
4. **APPLICATION OF THE FIRST LAYER OF EPOXY ADHESIVE**
Apply a layer of epoxy adhesive inside the notch, ensuring an even and uniform distribution.

5. **APPLICATION OF THE PREFORMED OR PREFORMED LAMINATE**
Immediately before installation, remove the peel-ply film from the bonding face of the laminate.
Apply a layer of epoxy adhesive to the laminate and insert it into the notch, applying light pressure to ensure proper adhesion to the timber.

6. **FINAL SEALING OF THE TIMBER BEAM**
Upon completion of the intervention, seal the notch with a mixture of epoxy adhesive and the previously collected sawdust, in order to achieve a finish that is both compatible and visually homogeneous with the timber element.

6.12 STITCHING WITH BARS

The intervention consists in the execution of stitching, connections, anchorages, and structural ties on reinforced concrete elements using preformed CFRP (Carbon Fiber Reinforced Polymer) bars.
This technique, when combined with resin injection, restores structural continuity in the presence of cracks or fractures.



Illustrative rendering – Intervention on concrete

INSTALLATION METHOD

1. **IDENTIFICATION OF THE CRACK OR DAMAGE**
Remove any plaster covering the affected area, then clean the substrate thoroughly to eliminate dust and debris.

2. **DRILLING OF HOLES**
Mark the drilling points on both sides of the crack, perform the drilling, and proceed with thorough cleaning of the holes.

3. **APPLICATION OF EPOXY SEALER**
Apply epoxy sealer along the entire length of the crack to seal and prepare the surface for resin injection.

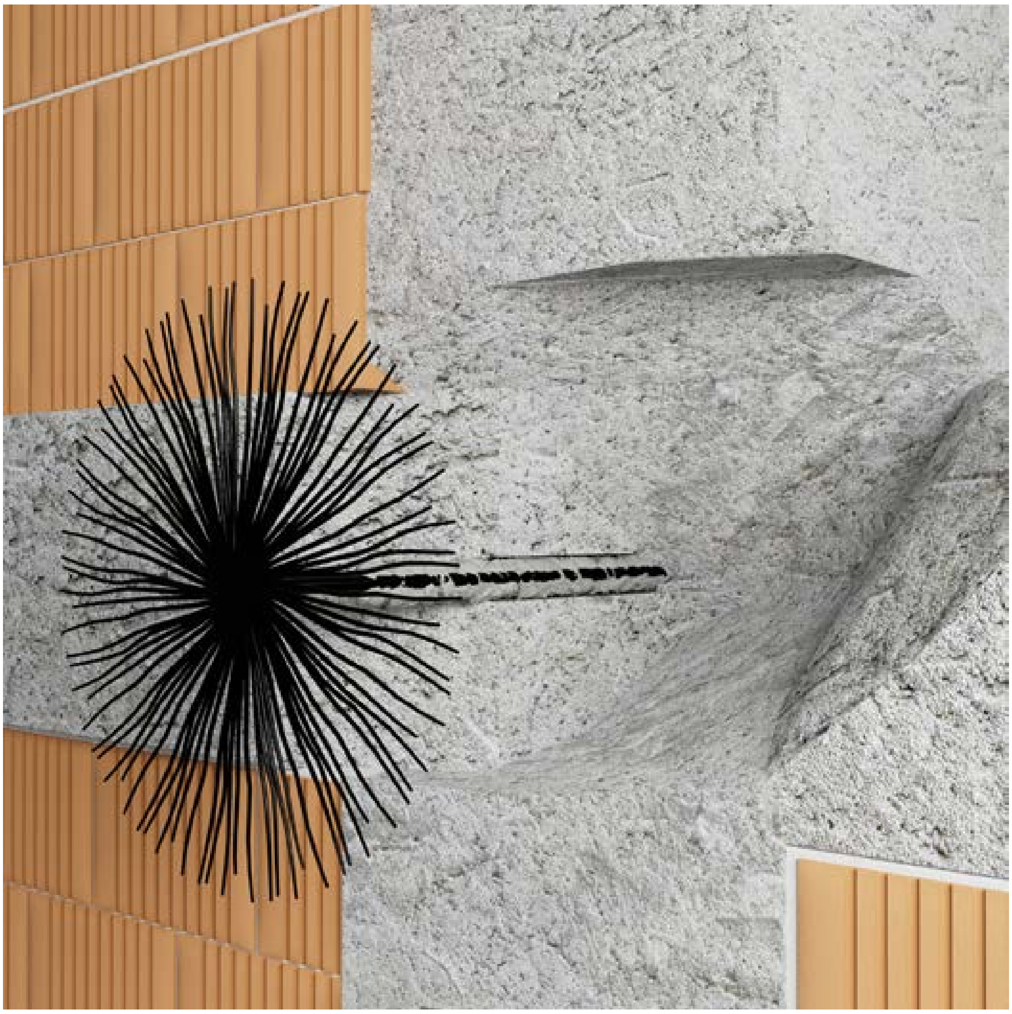
4. **RESIN INJECTION**
Inject fluid epoxy resin into the pre-drilled holes to fill the internal voids and promote bonding across the crack.

5. **INSERTION OF PREFORMED BARS**
Insert the CFRP bars into the holes while applying a light rotational movement to ensure optimal adhesion within the epoxy-filled cavity.

6. **FINAL SEALING**
Complete the intervention by sealing the holes with appropriate resins or repair mortars, ensuring a flush and durable finish

6.13 CONNECTIONS WITH BOWED BARS

The intervention consists in the installation of through or blind connections between the FRP reinforcement (carbon fiber fabrics, meshes, or laminates) and the existing structure, using preformed carbon fiber connectors with one or two bowed ends.
The connectors, made of high-strength carbon fiber, are sized according to project requirements and the specified safety level.



Illustrative Rendering – Intervention on Concrete

INSTALLATION METHOD

1. **REMOVAL OF PLASTER**
If present, remove any existing plaster and perform mechanical cleaning of the substrate. Assess the condition of the substrate for potential degradation.

2. **COVER METER SURVEY (PACOMETRIC TESTING)**
Carry out pacometric surveys to detect existing reinforcement and minimize interference with the placement of new connectors.

3. **DRILLING OF HOLES**
Mark the drilling location, drill the hole with the diameter and depth specified in the project, then clean the hole thoroughly.

4. **PRIMER APPLICATION**
Apply the epoxy primer to the internal surfaces of the drilled hole.

5. **RESIN INJECTION**
Inject fluid epoxy resin into the previously drilled hole.

6. **INSTALLATION OF THE CONNECTOR**
Insert the connector into the hole with a slight twisting motion to ensure optimal adhesion to the resin and the surrounding substrate.

7. **APPLICATION OF IMPREGNATING RESIN**
After protecting the ends of the bar, apply impregnating resin over the area where the splaying will occur.

8. **BAR DEBOWING**
Debow (spead) the bar onto the previously applied resin, arranging the filaments as specified in the design.
Apply a second layer of resin and impregnate the fibers using a bubble-breaking roller to ensure complete saturation and bonding.

6.14 ARDFIX CONNECTION

The intervention consists in the installation of ARDFIX-type connection systems, in which the bond between the FRP reinforcement and the substrate is ensured by the reinforcing fabric integrated into the connector itself. The primary objective is to enable effective load transfer and eliminate the risk of delamination.
The ARDFIX connection system is composed of unidirectional carbon fiber fabrics and preformed carbon fiber bars.

Illustrative Rendering – Intervention on Concrete

INSTALLATION METHOD

1. **OPTIONAL SUBSTRATE PREPARATION**
If necessary, remove any plaster present and carry out mechanical cleaning of the substrate. Assess the condition of the substrate for any degradation.

2. **DRILLING OF HOLES**
Mark the hole location, drill according to the diameter and depth specified in the project, and clean the hole thoroughly.

3. **PREPARATION OF THE PREFORMED BAR**
Cut the carbon fiber preformed bar to a length based on the required minimum anchorage length.

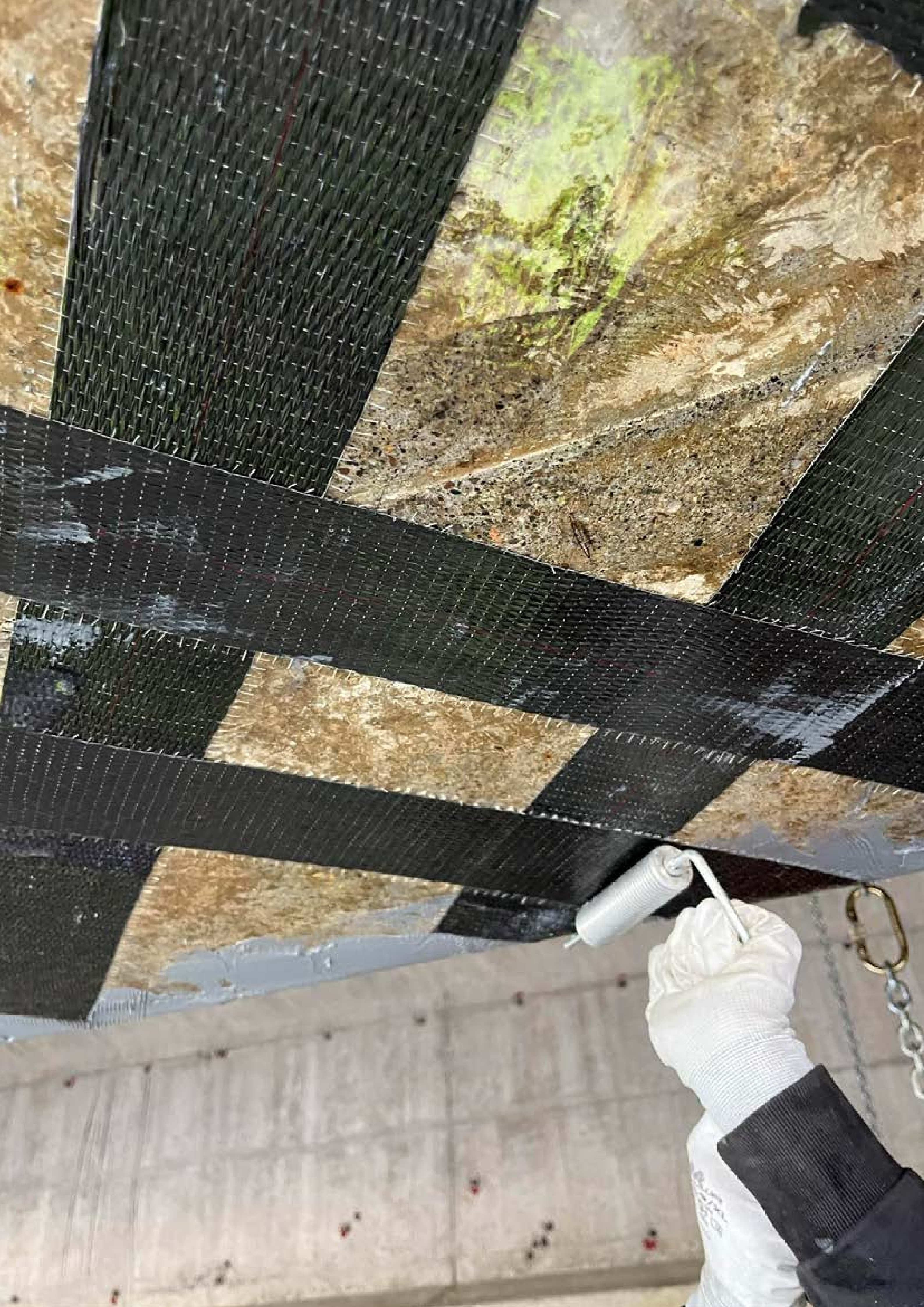
4. **PREPARATION OF UNIDIRECTIONAL FABRIC**
Prepare two strips of unidirectional carbon fiber fabric and impregnate them with epoxy resin.

5. **RESIN INJECTION**
Inject fluid epoxy resin into the previously drilled hole.

6. **INSTALLATION OF THE CONNECTION**
Position the two fabric strips in a cross configuration over the hole and insert the carbon fiber preformed bar.
Remove any excess resin that emerges from the hole.

7. **FOLDING OF THE UNIDIRECTIONAL FABRIC**
The four ends of the fabric strips should protrude by at least 15 cm. Fold them back over the substrate and impregnate with epoxy resin.

8. **OPTIONAL APPLICATION OF ADDITIONAL REINFORCEMENT (PATCH)**
Apply a unidirectional carbon fiber fabric patch longitudinally over the connection area on the substrate to enhance load transfer.



7

SYSTEM PROTECTION AGAINST FIRE AND UV EXPOSURE

Fire protection

FRP reinforcements must be protected in all situations where their structural contribution is required during fire exposure to ensure safety. Fire protection can be either active or passive.
In the case of passive protection, the use of calcium silicate boards and/or intumescent protective plasters is recommended. The thickness of these boards and/or plaster layers must be defined through precise analytical and/or experimental evaluations. All protective materials must be accompanied by appropriate certifications.
When using boards installed with mechanical fasteners over the reinforcement, it is essential to avoid cutting or piercing the fibers with the fixing system.
For protective plaster applications, it is necessary to ensure adequate adhesion properties under thermal stresses such as those generated during a fire event.
The choice of fire protection system must consider:

- the expected fire exposure conditions and duration;
- the simultaneous occurrence of fire and structural loading that the reinforcement must withstand.

UV protection

Prolonged exposure to UV radiation can compromise the durability of the reinforcement system by degrading the physical and mechanical properties of the epoxy matrix. This degradation leads to matrix embrittlement (known as "sclerotization") and noticeable surface yellowing.
UV protection can be effectively achieved by:

- applying a protective polyurethane coating, such as INTEGRA PROTECTION - F 440 PU, with a recommended thickness of approximately 400 μm;
- applying a fine cementitious skim coat, such as STRUTTURA RASO FINO - RF 248, with a thickness of 1 - 2 mm, over a layer of dry quartz sand broadcast onto the fresh outer epoxy layer of the reinforcement.

Implementing proper protection systems is essential to preserve the long-term performance of FRP reinforcements, ensuring safety, structural efficiency, and durability of the intervention.

NOTES

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