POLYTECHNIC UNIVERSITY OF MILAN

Master Degree in Civil Engineering

POLITECNICO DI MILANO

Study of an Experimental Anchor System - Staple Anchors - for Externally Bonded Frp Laminates Used for the Consolidation and Retrofitting of Reinforced Concrete Structures through an Innovative Double Shear Test Method

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Master Thesis of

Thomas CADENAZZI

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   - Failure mode analysis
   - Flat Staples
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5. Comparisons: Staples vs. Spikes
6. Recommendation on Preliminary Design Previsions

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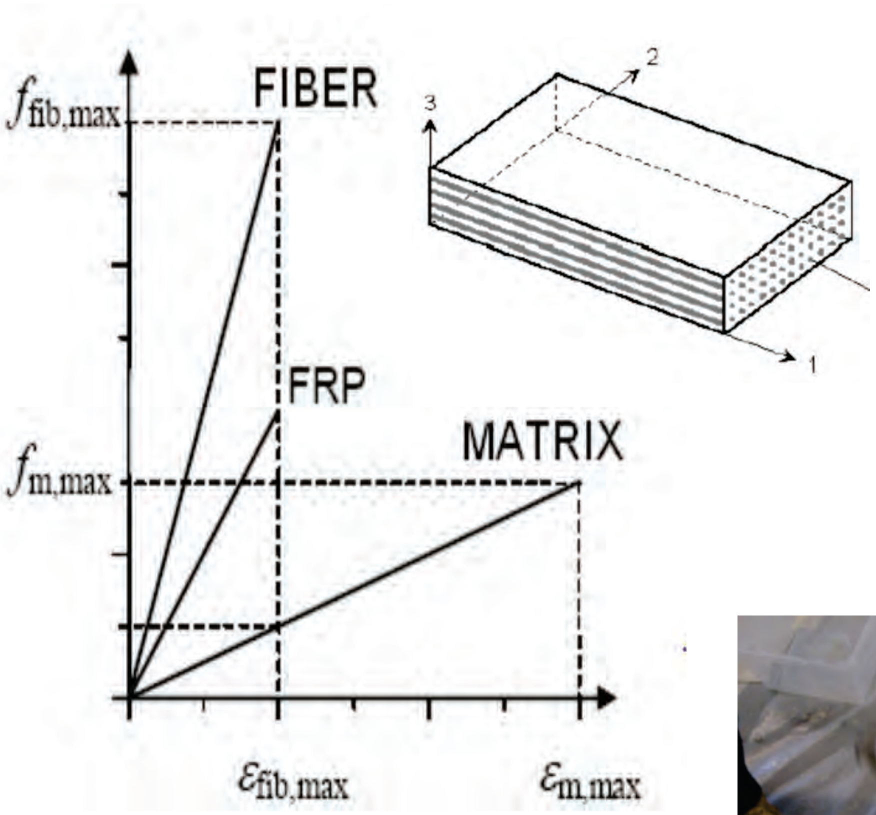
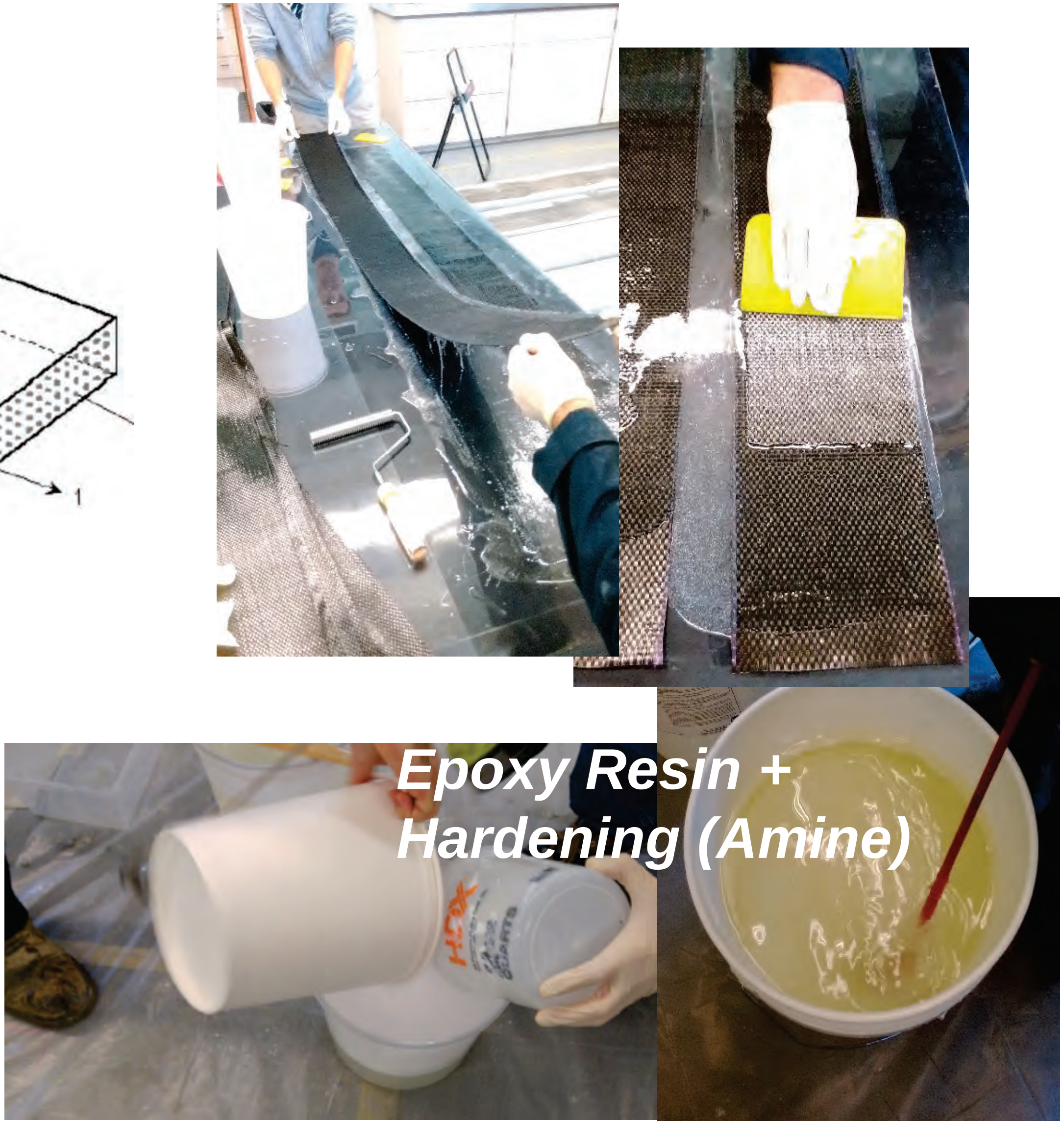
FRP Laminates for Rehabilitation Purposes

(Nanni, 2000) (Alkhrdaji, 2015)

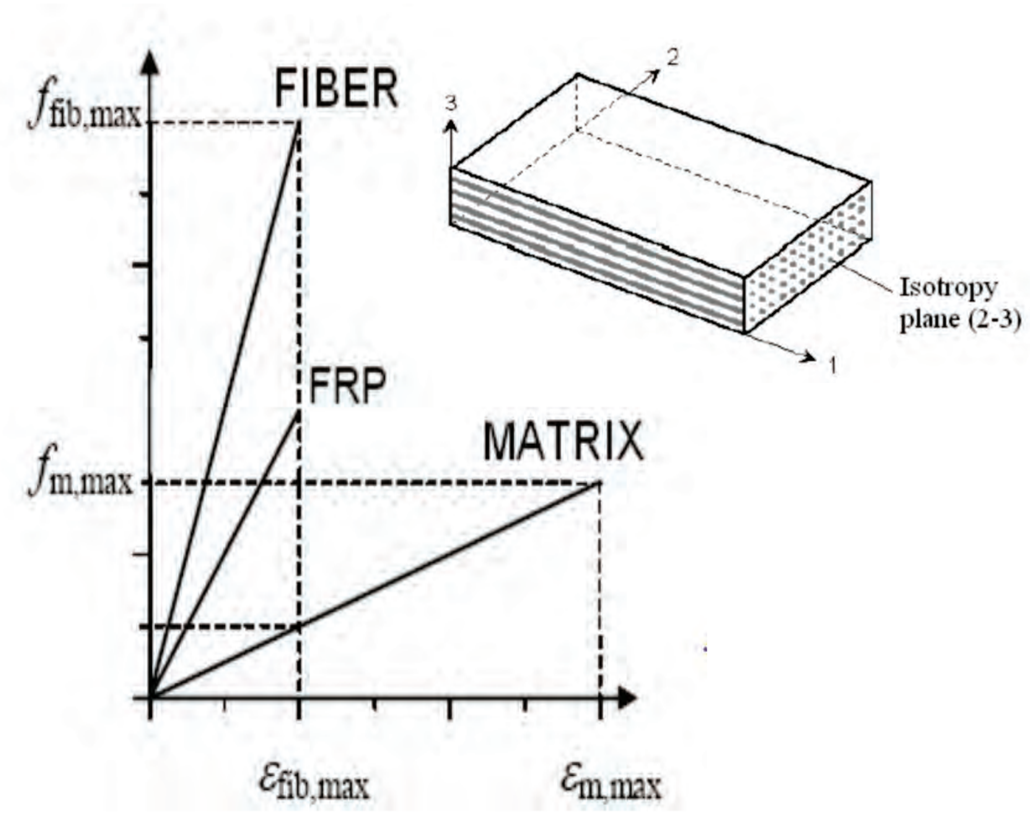
The Material: Impregnation



(CNR, 2014)



The Material: Fiber Reinforced Polymers



(CNR, 2014)

Carbon Fibers

Epoxy Resin

High Mechanical Properties

High Specific Resistance

Immunity to Corrosion

High Environmental Resistance

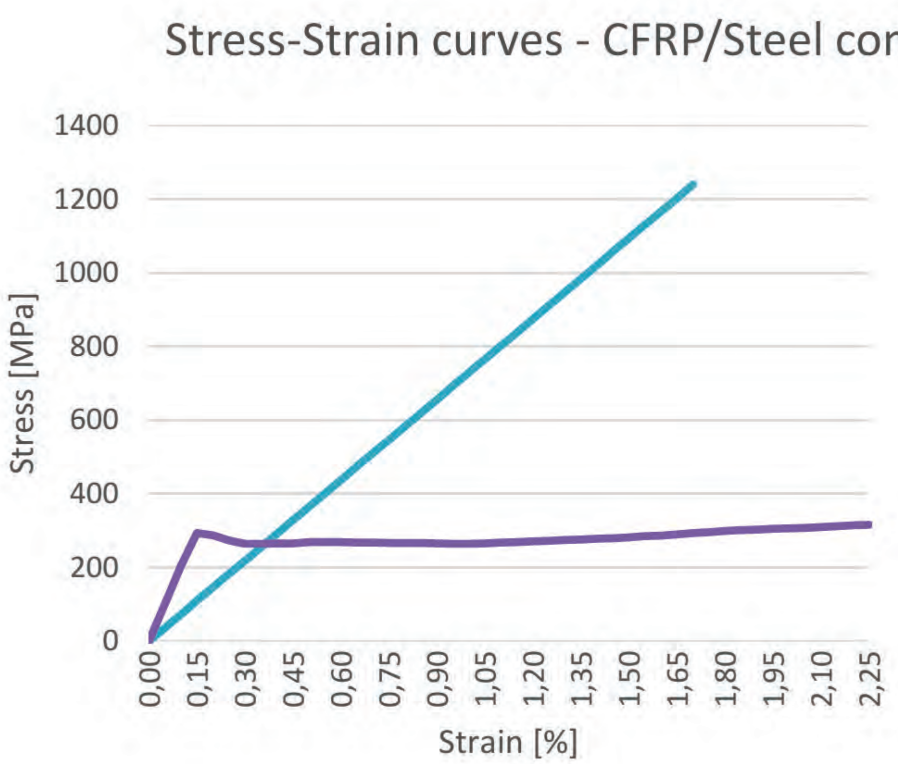
Lightness

Cheapness

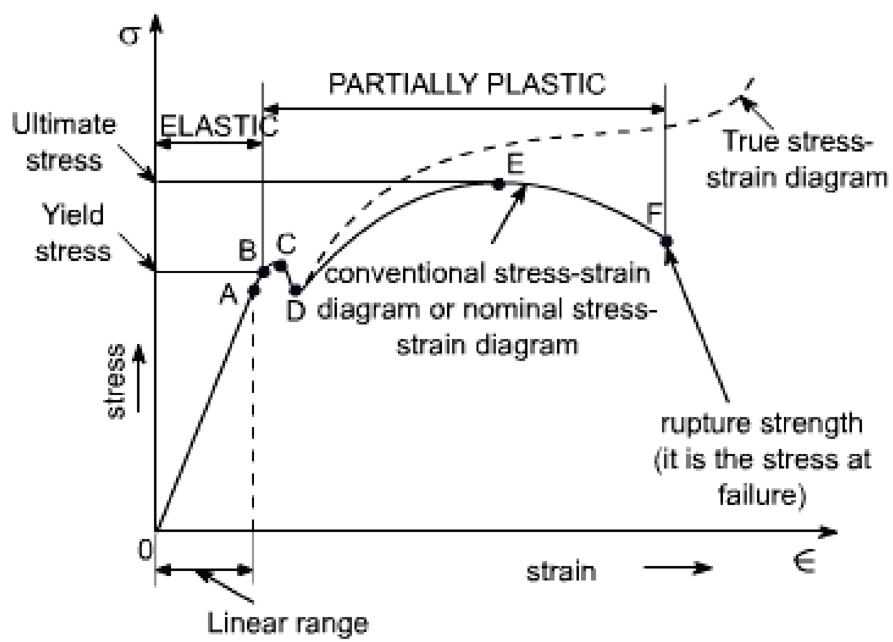
Easy to use

High Adesion

CFRP Laminate properties



- Lightness
- High Mechanical Properties
- Immunity to Corrosion



- Elastic modulus CFRP 200H: 77,04 GPa
- Elastic modulus steel: 210 GPa

The Debonding Problem

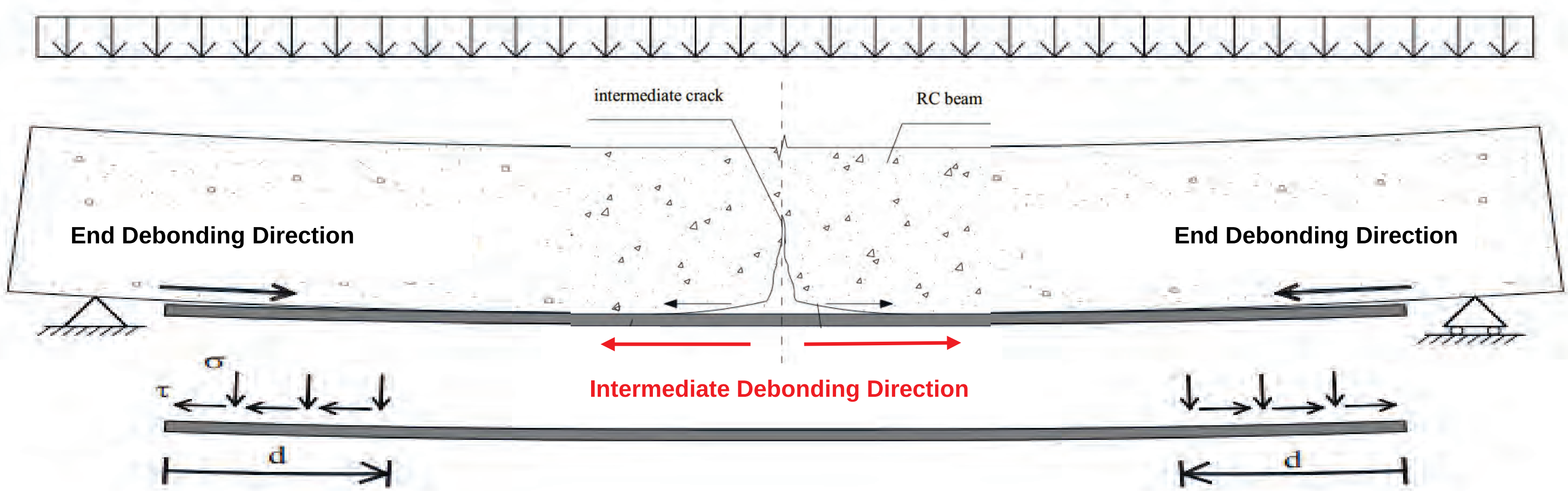
The debonding is the loss of adhesion of a thin concrete layer at strain levels much smaller than the ultimate capacity of the composite. Four types of debonding

1) **End Debonding**

2) **Intermediate Debonding**

3) **Debonding caused by diagonal shear cracks**

4) **Debonding caused by irregularities and roughness of concrete surface**



(Adapted from CNR, 2014)

Anchorage System Purposes

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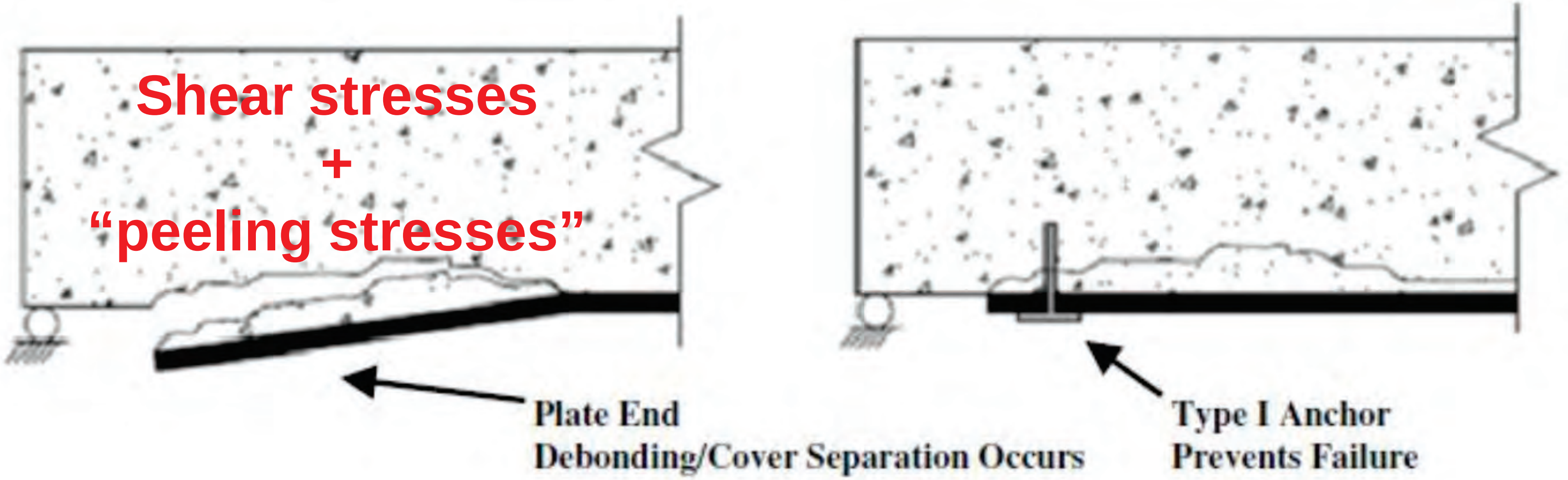
Prevent or delay the interfacial crack opening at the starting of debonding or failure of the concrete substrate



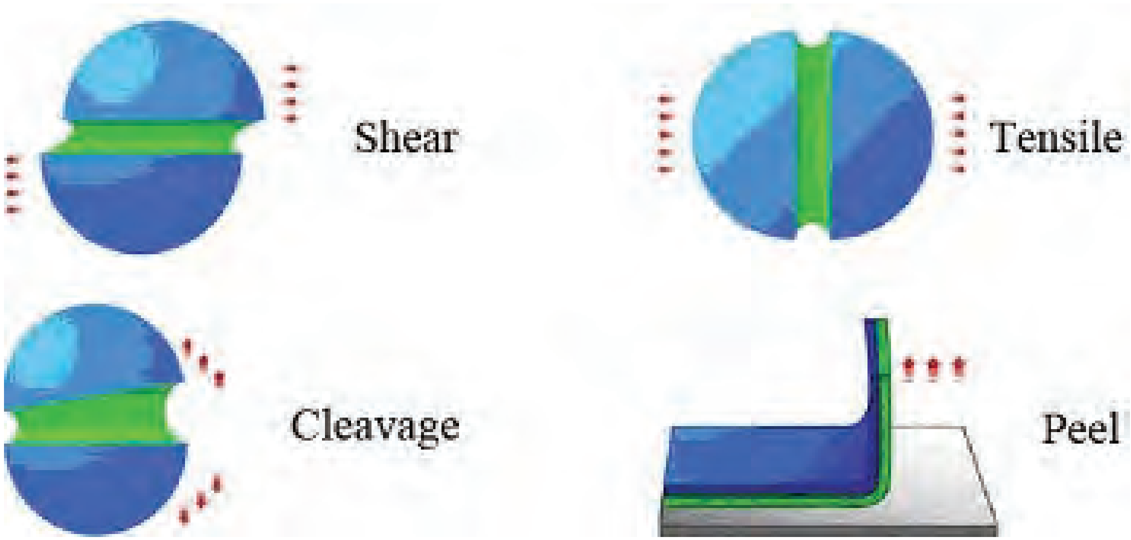
(Grelle & Sneed, 2013)

Anchorage System Purposes

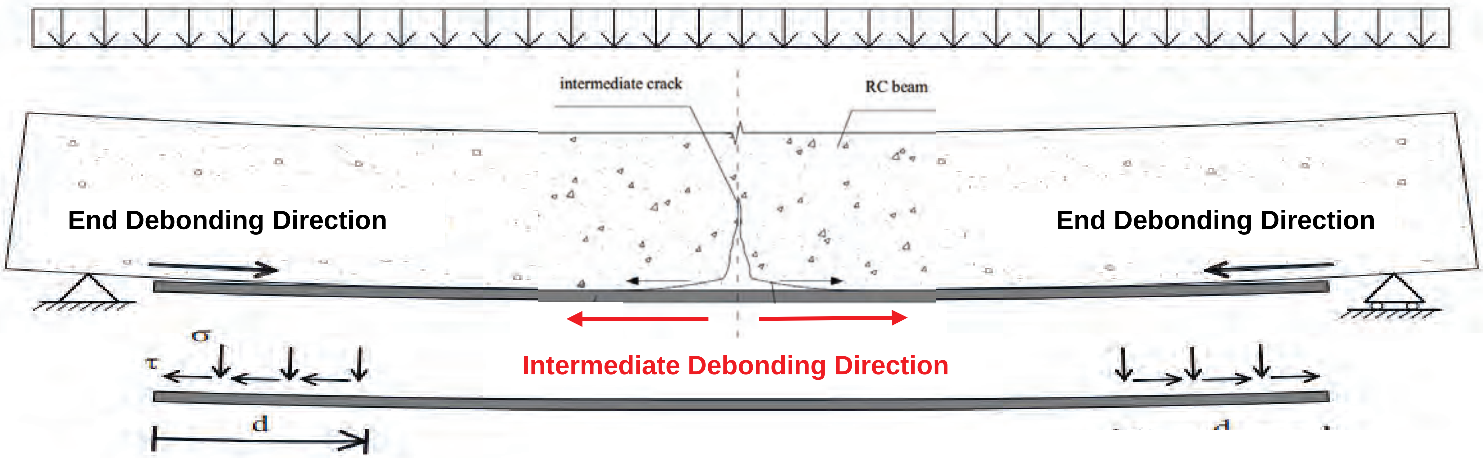
It should be kept in mind that in flexural elements, peeling stresses also develop along the FRP-concrete interface and their interaction with shear stresses can lead to a reduction in the bond strength of the strengthening system

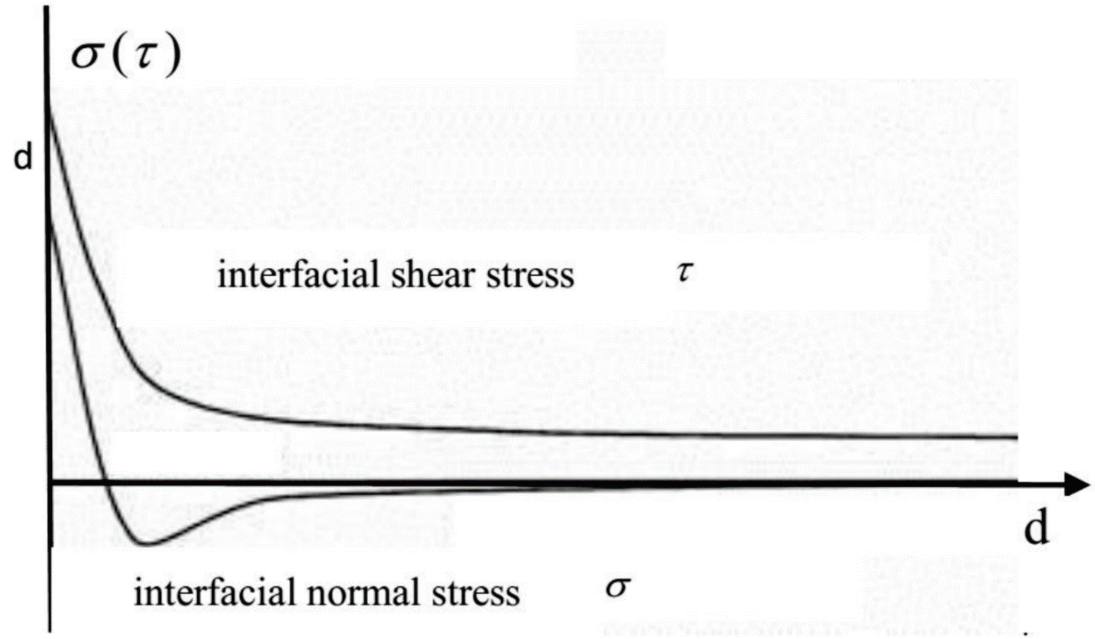
Peeling stresses: Depending on

Anchorage system DEPTH



Anchorage System Purposes

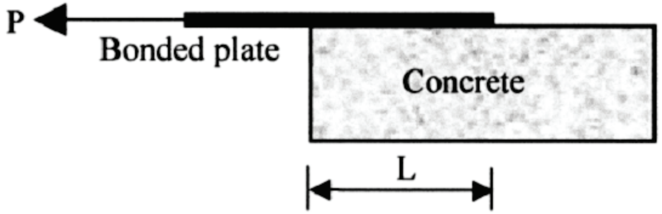




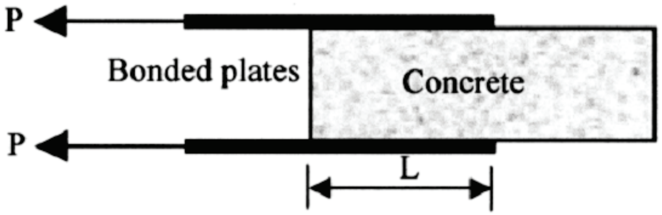
(CNR, 2014)

Double-shear test, test of anchorage system characterization

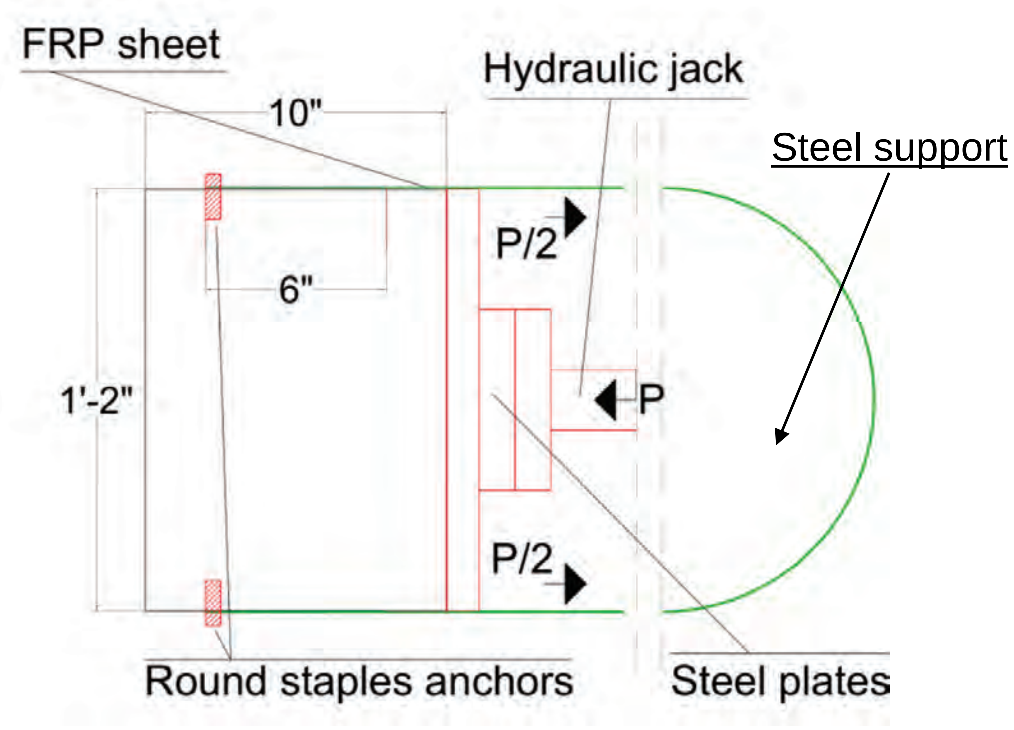
The **force transfer** between FRP plate and concrete substrate takes place primarily through **shear stresses** → **shear tests** are **adopted** to determine the **maximum debonding force**



a) Single shear test



b) Double shear test



Due to symmetry and for better control of induced normal stresses, the double-shear test is generally preferred over the single shear test.

Existing types of FRP anchorage systems

1. Anchor Spikes

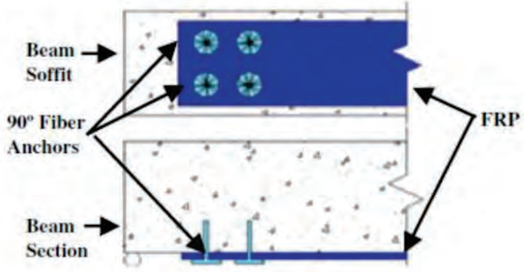
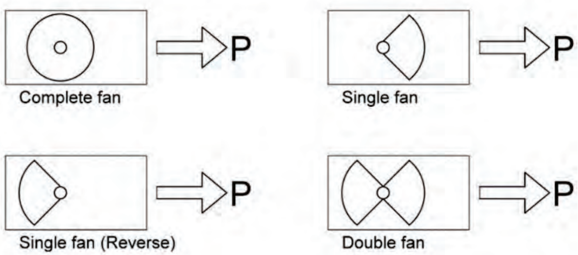
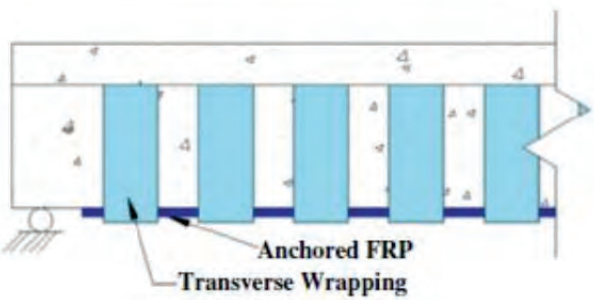


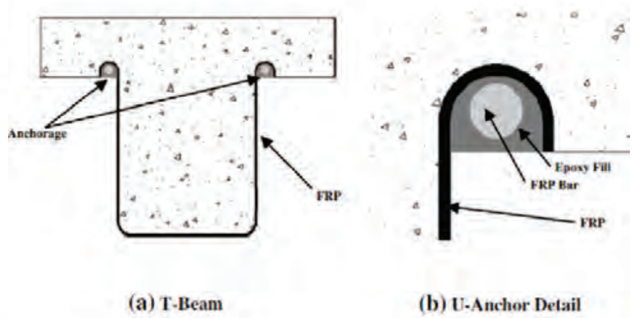
Figure 1.9 - 90° anchor spikes



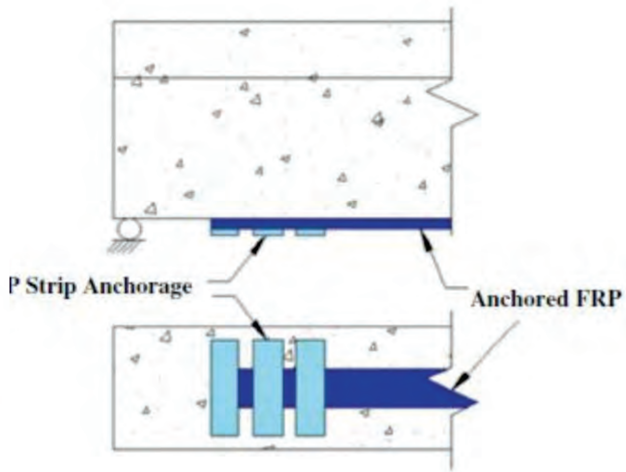
2. Transverse Wrapping



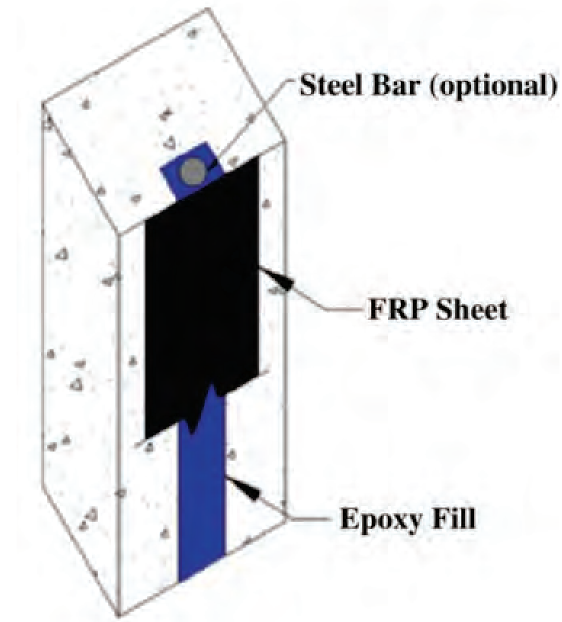
3. U-Anchors



4. FRP Strips

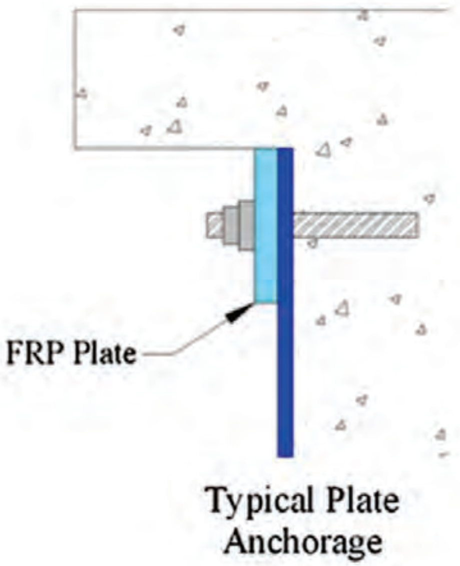


5. Longitudinal Chase

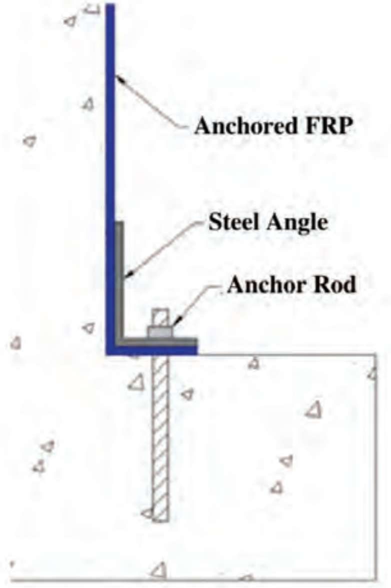


Existing types of FRP anchorage systems

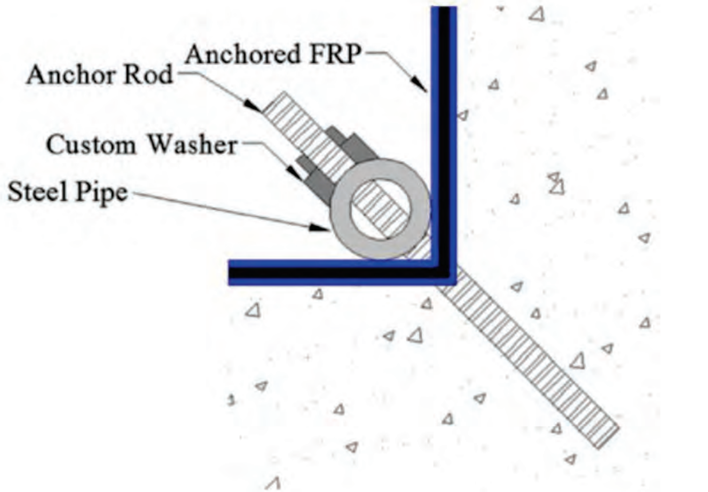
6. Plate Anchors



7. Bolted Angles

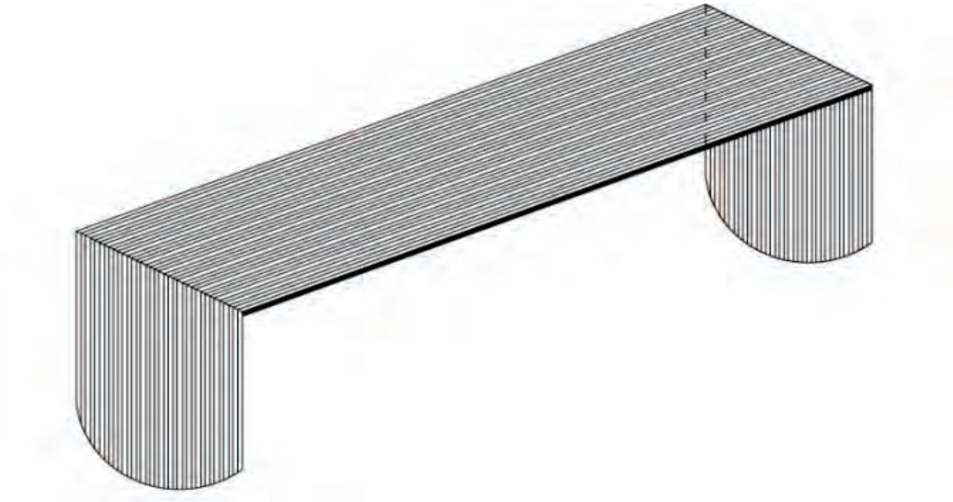


8. Cylindrical Hollow Section

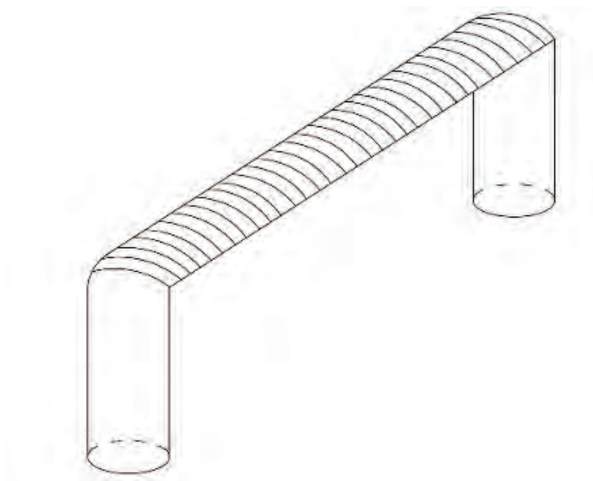


Staple Anchors – Preformed anchorage systems

1) FLAT STAPLE



2) ROUND STAPLE



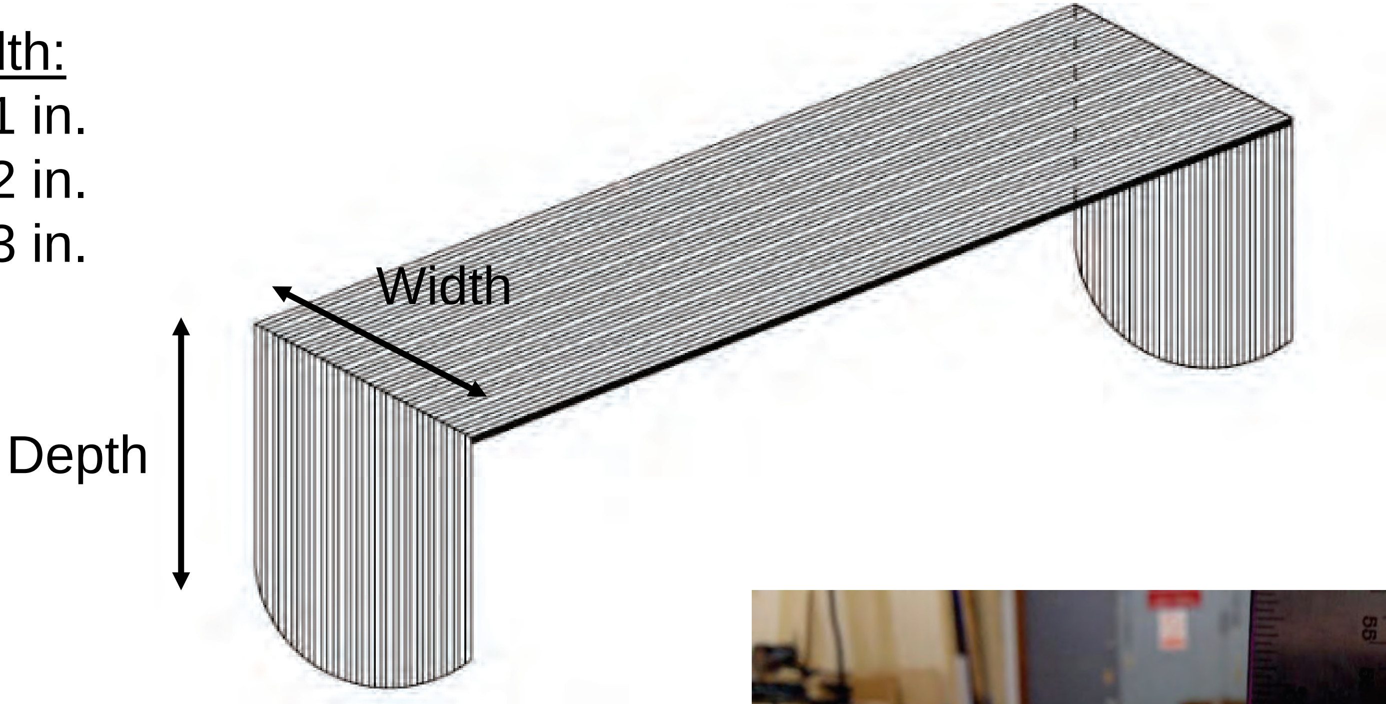
competitive

1. Low manufacturing costs
2. Easy to apply (preformed elements)
3. High mechanical properties

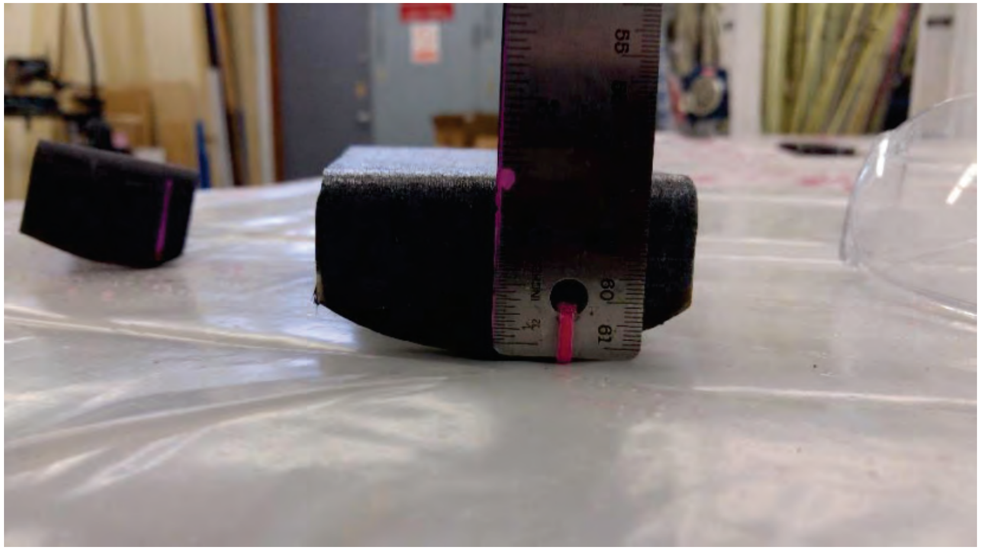
Flat Staples

Width:

- 1 in.
- 2 in.
- 3 in.



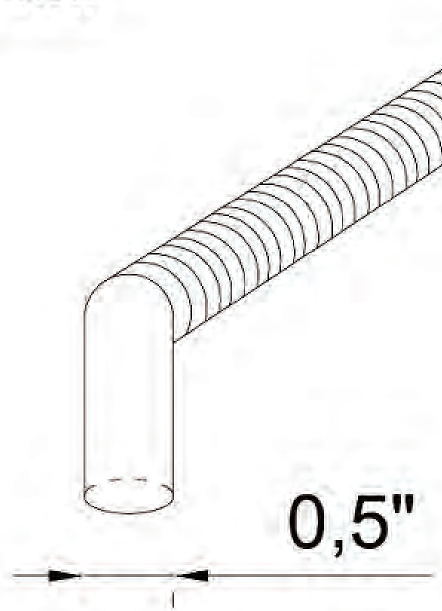
With the uni-directional fibers of the anchor aligned in a longitudinal way to the flexural FRP sheet, the flat staple anchor is made by carbon fibers pre-impregnated with a particular synthetic resin



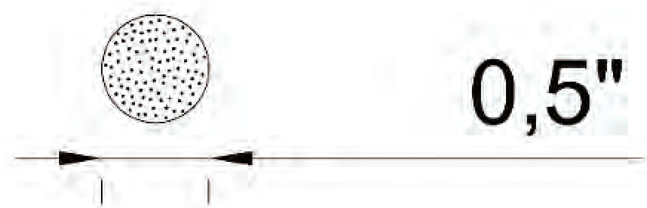
Round Staples – 1st Design Idea - Prototype

The uni-directional fibers of the anchor are aligned in a longitudinal way to the flexural FRP sheet, covered by an epoxy layer (matrix) that keeps the fibers together.

3D View

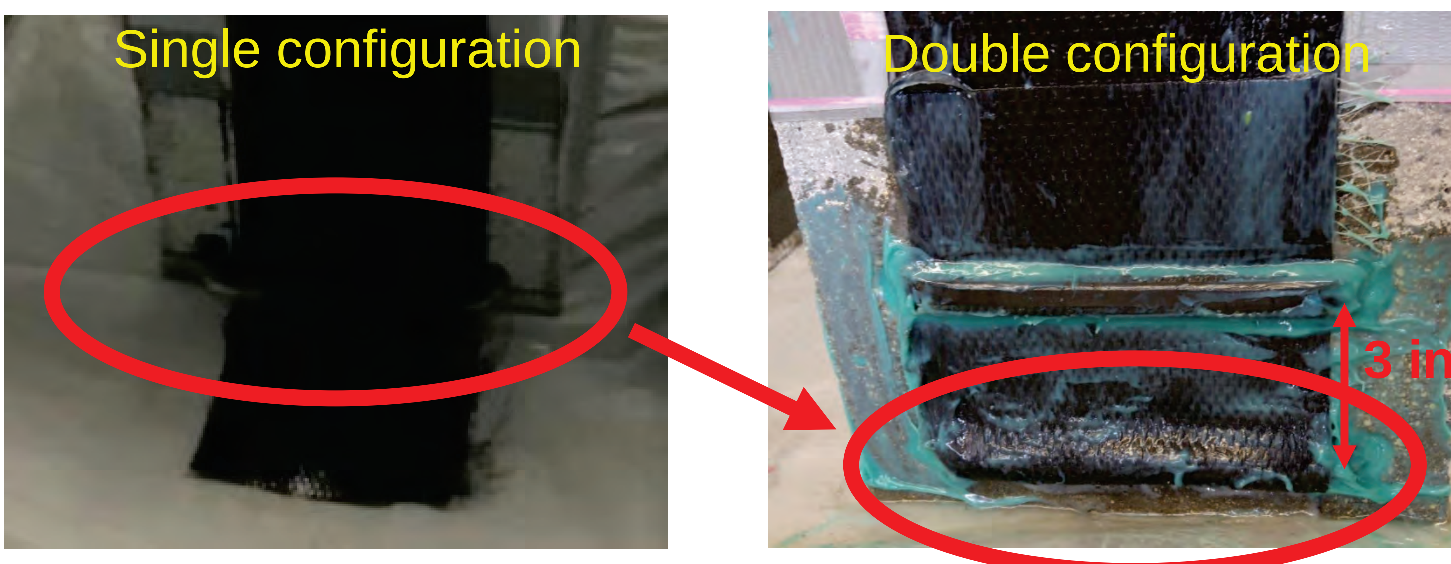


Cross-section

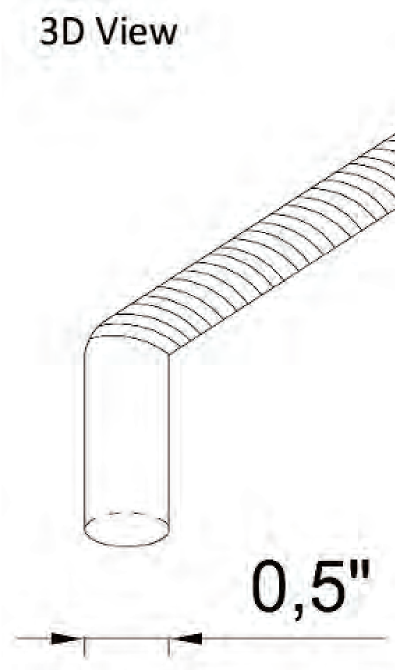


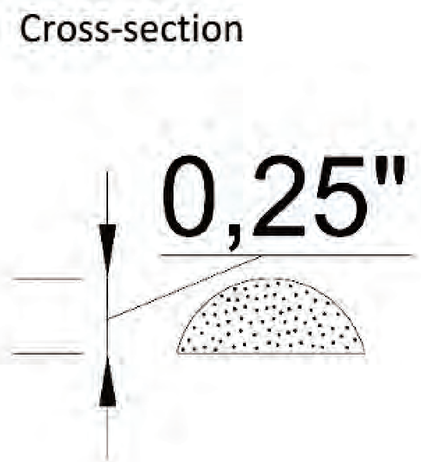
Round Staples – 2nd Design Idea

1) The **under part** of the anchor is **flat**, increasing the area in contact with the FRP laminate
2) The **upper part** of the anchor is **elliptical**. This shape allows the squeezed epoxy in excess to come out laterally, by the legs sides of the anchor.
3) More fibers were concentrated on the bend radius, improving the resistance in this location, where the stresses are more concentrated.



Round Staples – 2nd Design Idea





Specimen Preparation & Experimental Program

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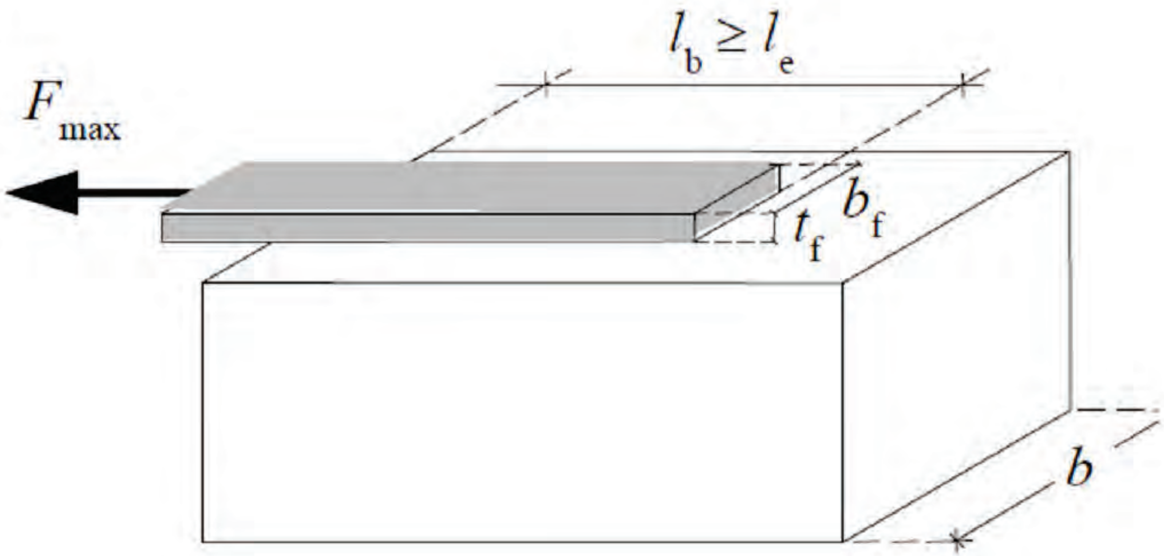
Shear Test Program



(CNR DT200, 2013)

The length **l_e** is called **optimal bond length** and corresponds to the minimal bond length able to carry the maximum anchorage force

$$l_{ed} = \max\left\{\frac{1}{\gamma_{Rd} \cdot f_{bd}}\sqrt{\frac{\pi^2 \cdot E_f \cdot t_f \cdot \Gamma_{Fd}}{2}};150 \text{ mm}\right\}$$

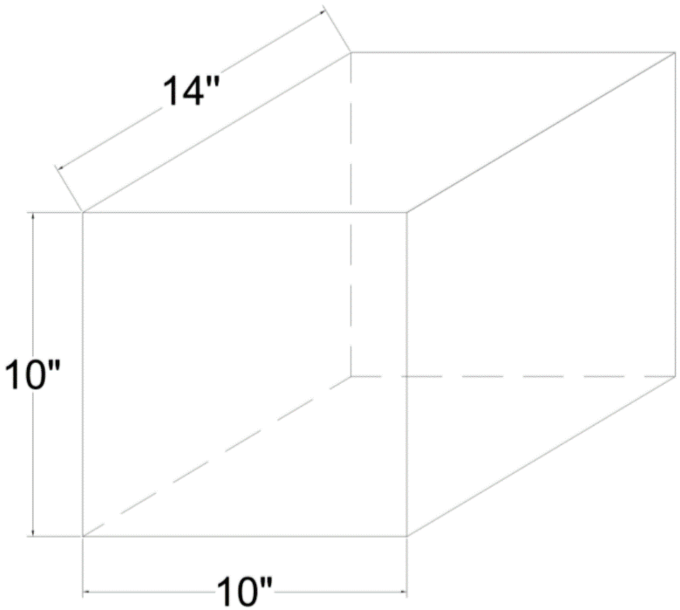
Shear Test Program

Data			
Ef	Elastic Modulus FRP	77040,00	Mpa
tf	thickness of FRP	1,02	mm
FC	Confidence factor	1,00	
bf	width	152,40	mm
b	length	254,00	mm
Kb	geometrical corrective factor	0,94	-
KG	additional corrective factor for wet lay-up systems	0,04	mm
fctm	concrete tensile strength	4,13	Mpa
fcm	concrete compressive strength	59,00	Mpa
Γfd	Design fracture energy	0,41	Mpamm
su	design bond strength between FRP and concrete	0,25	-
YRd	Corrective factor (standard)	1,25	-
fbd	factor fbd	3,27	Mpa

$$L_{ed} = 97{,}25\, mm \;(= 3{,}83\; in.)$$

Concrete Properties

Calculations on **concrete characterization** and **blocks size**



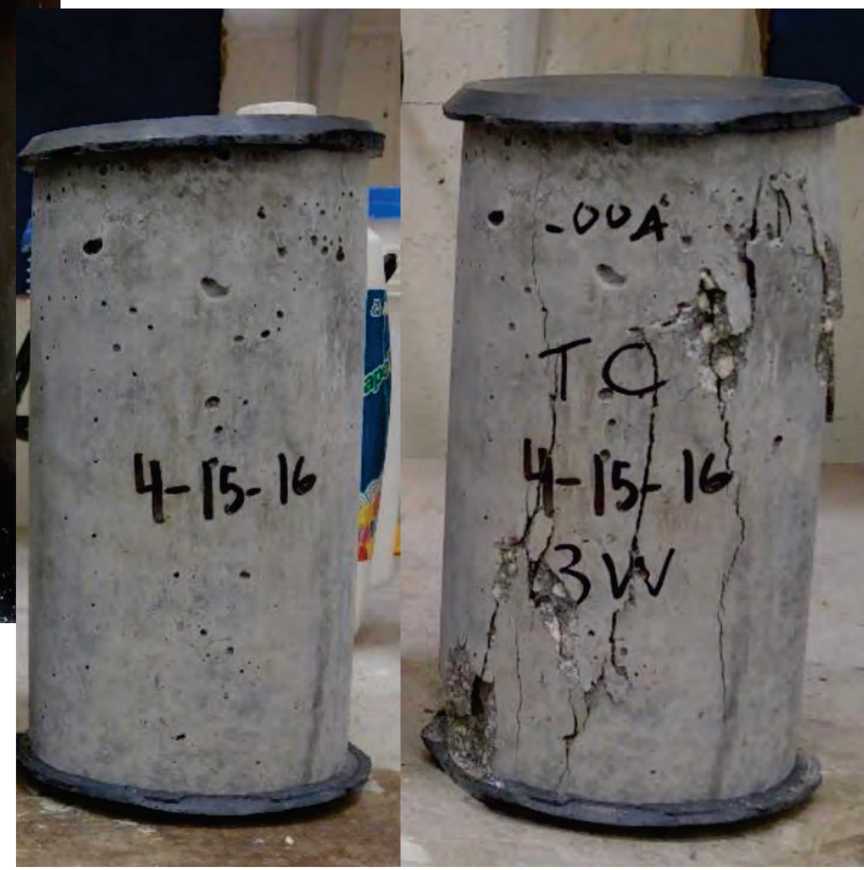
$$f'_t = 0,7\ \frac{0,27(f'_c)^{2/3}}{1,5} = 0,7\ \frac{0,27(59,84)^{2/3}}{1,5} = 1,93\ MPa$$

$$A = 10\ in\ \cdot 10\ in =$$

$$= 254\ mm\ \cdot\ 254\ mm\ = 64,516\ mm^2$$

$$P_{max,th} = \frac{f'_t}{1000}\ [KPa] \cdot A = \frac{1,93}{1000} \cdot 64,516 = 124,36\ KN$$

Specimen Preparation: Concrete Casting & Sandblasting



$$f'_c = \frac{P_m[N]}{A\,[mm^2]} = \frac{491869\ N}{8202\ mm^2} = 59{,}84\ MPa$$

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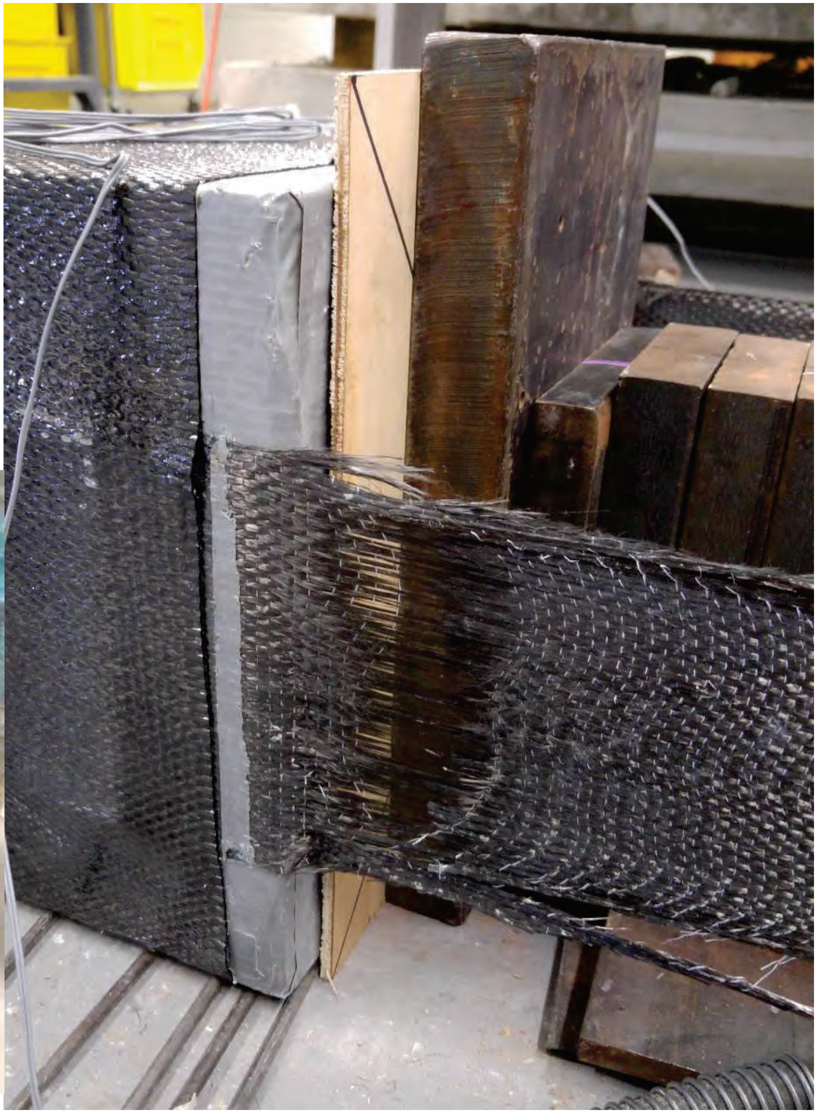
Test 1 – Dry CFRP testing

Test 1 – Dry CFRP testing

INSUFFICIENT RESULTS AND NOT RELIABLE



Results test 1

NOT RELIABLE RESULTS

- **Different stresses distribution on the dry CFRP**, caused by the not perfectly centered applied load, that brought to a rip in the most stressed fiber, causing the cracking start. It is important to remind that in the dry CFRP, as soon as a little crack occur, this immediately propagate toward the closest dry fibers, leading to the crack of the entire CFRP sheet.
- **The unevenness of adhesive on CFRP sheet out of the bond area**, leading to uneven stress distribution in the CFRP fibers.
- The application of the epoxy resin on CFRP sheet out of the bond area, leading again to uneven stress distribution in the CFRP fibers.
- The **low unbounded area** furnished on the concrete surface (only 1 inch), which could have caused again an **uneven stress distribution** in the CFRP fibers, just out of the bonded area where most of the ruptures occurred.

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Aims

I. Find a test which is reliable, repeatable, easy to perform and able to represent the stress state in the real applications

II. Anchors characterization in different configurations

III. Spike anchors comparison

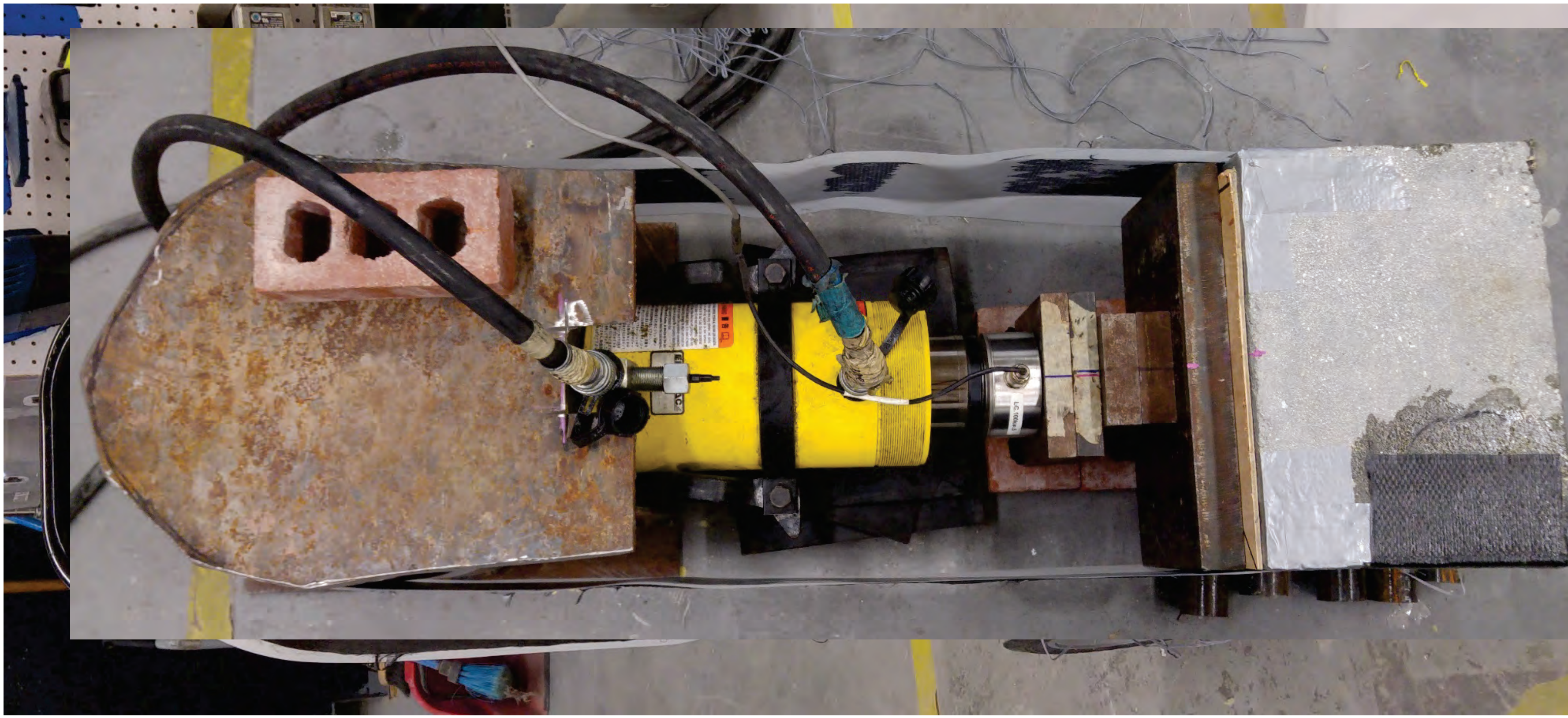
- Peak load
- Strains
- Failure modes

EPS FOAM SHAPES

Mylar sheet

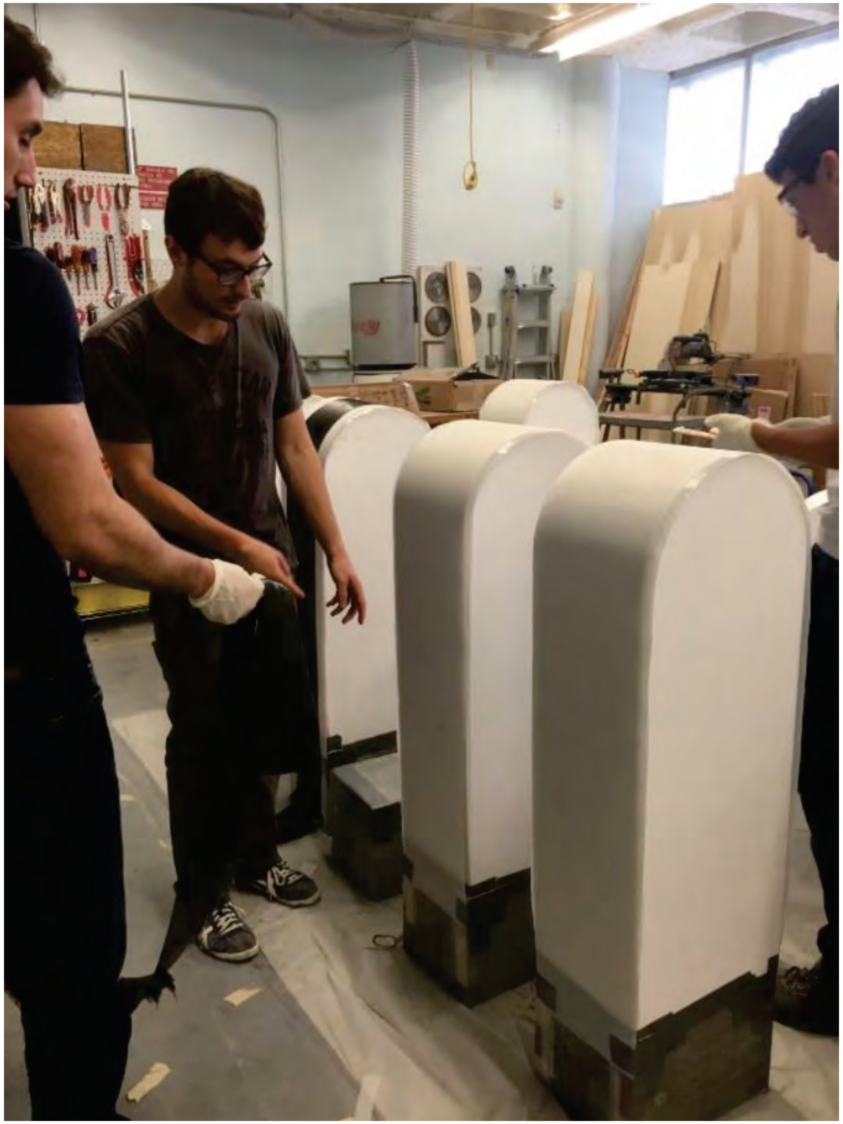
Test 2 – Wet CFRP test preparation

EPS FOAM SHAPES

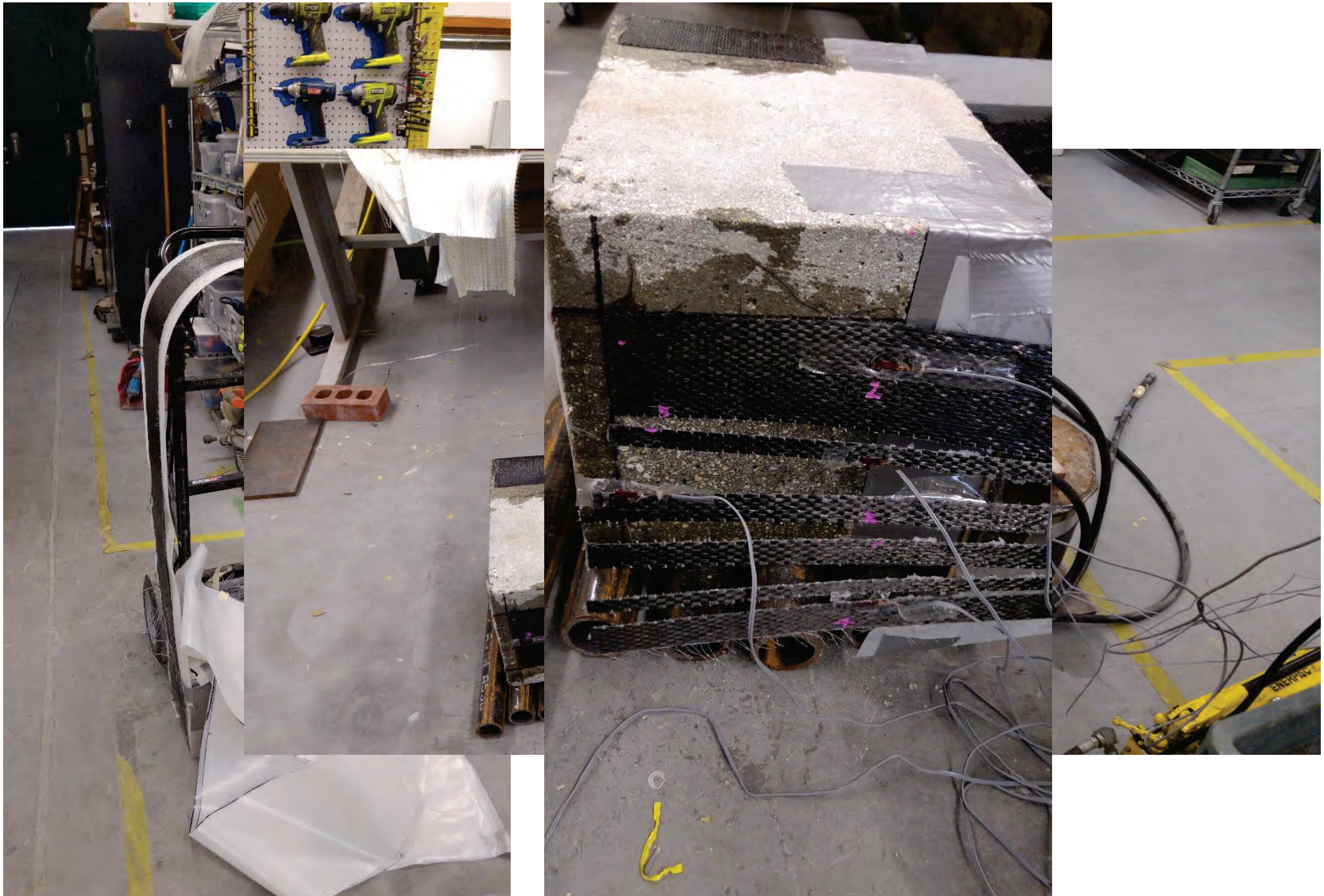


Test 2 – Wet CFRP test preparation

EPS FOAM SHAPES



Test 2 – Wet CFRP test



Dry and Wet CFRP Installation - Differences

1) It represents exactly the **real application** when the system acts in situ. An interrupted strip of wet CFRP acts as a continuum system.

2) impregnating the carbon fibers with an **epoxy resin** allows the latter to behave as a **matrix**, which means to keep the fibers straight, **transferring evenly the stresses** to them, avoiding intensifications or different stresses distribution along all the CFRP strip.

Results

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Failure mode analysis

6 Failure modes:

A. Rupture as delamination of the CFRP sheet
B. Slippage of the CFRP sheet beneath the anchor, without their ruptures
C. Slippage of the CFRP sheet beneath the anchor, with the rupture of the CFRP sheet
D. Rupture of the anchor with the delamination of the CFRP
E. Rupture of the concrete substrate and rupture of the anchor
F. Rupture of the concrete substrate without the rupture of the anchor

Failure mode analysis

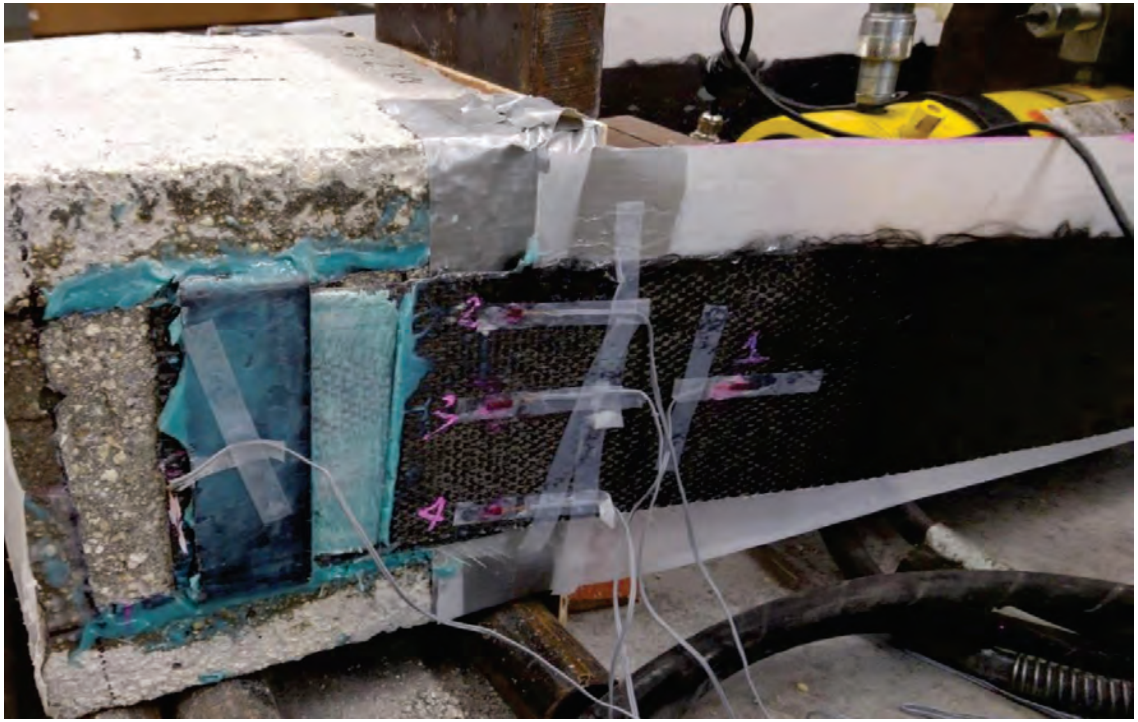
A. Rupture as delamination of the CFRP sheet

Rupture by debonding of the CFRP sheet at the adhesive-to-concrete interface.
Only the benchmarks presented this type of failure. That is due to the fact that of the absence of an anchorage system.

PREVALENT ON BENCHMARKS

Failure mode analysis

B. Slippage of the CFRP sheet beneath the anchor, without their ruptures

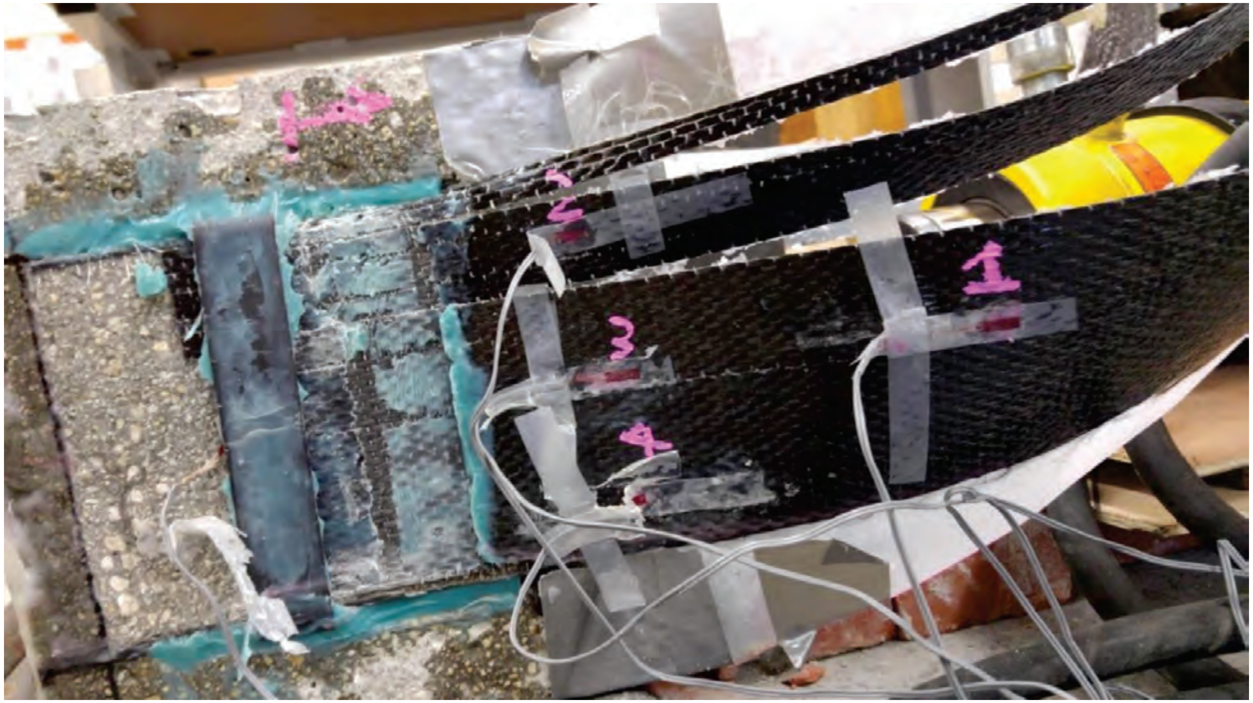


ACCIDENTAL, OBSERVED ONLY IN ONE SPECIMEN

Debonding of the CFRP sheet at the adhesive-to-concrete interface, followed literally by a slippage of the CFRP sheet beneath the anchor, as to mean an insufficient adhesive-to-concrete and anchor-to-CFRP interface.

Failure mode analysis

C. Slippage of the CFRP sheet beneath the anchor, with the rupture of the CFRP sheet

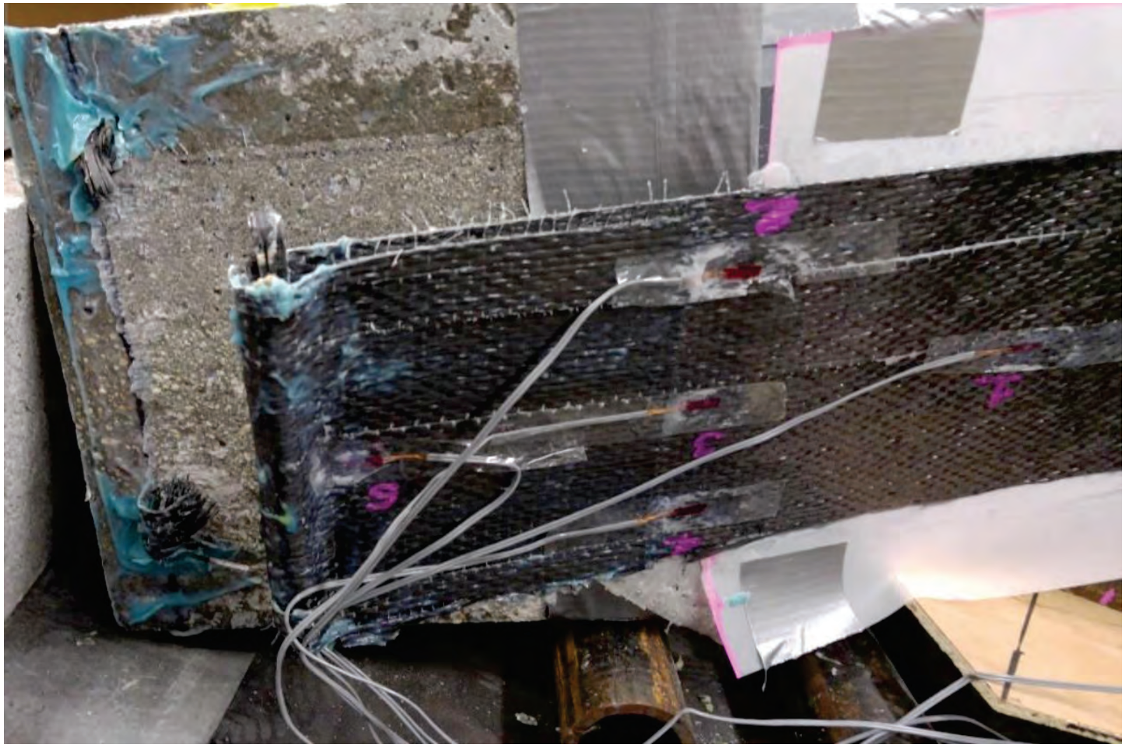


PREVALENT ON FLAT STAPLES _ 2W

The sheet has developed its full strength (readings of good strains level around 0.7-0.8%), with a good anchor resistance. ***The failure mode C is ideal for determining the sufficiency of the anchors*** *and develop guidelines for anchor design.*

Failure mode analysis

D. Rupture of the anchor with the delamination of the CFRP



ONLY IN THE ROUND STAPLE PROTOTYPES (1° DESIGN IDEA) AT SINGLE CONFIGURATION

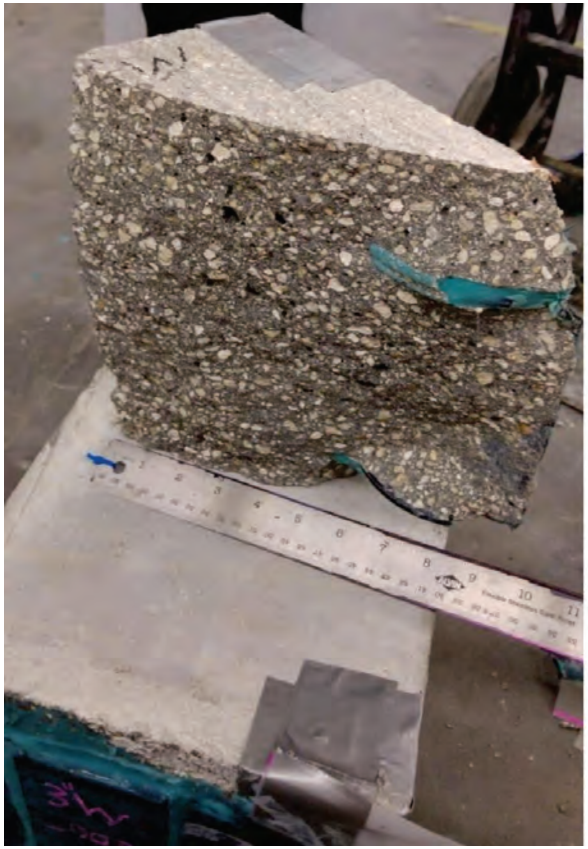
The failure of the anchor indicates that anchors do not have sufficient capacity to develop the full strength of the CFRP sheet and is generally an undesirable failure mode. Failure mode D was observed only for the round staple anchor.

E. Rupture of the concrete substrate and rupture of the anchor

PREVALENT ON THE NEW ROUND STAPLES AT SINGLE CONFIGURATION

The rupture of the concrete always initiated first at one end, where the leg of the round staple was embedded; after this, immediately the opposite leg of the anchor took the entire stress, breaking again the anchor along the bend radius.

F. Rupture of the concrete substrate without the rupture of the anchor



The failure was due entirely to the rupture of the concrete substrate. Since the maximum shear capacity of the non-reinforced concrete was reached, the anchor was still performing well, assuming that it could have been achieved a higher load.

PREVALENT ON FLAT STAPLE_3W

Results

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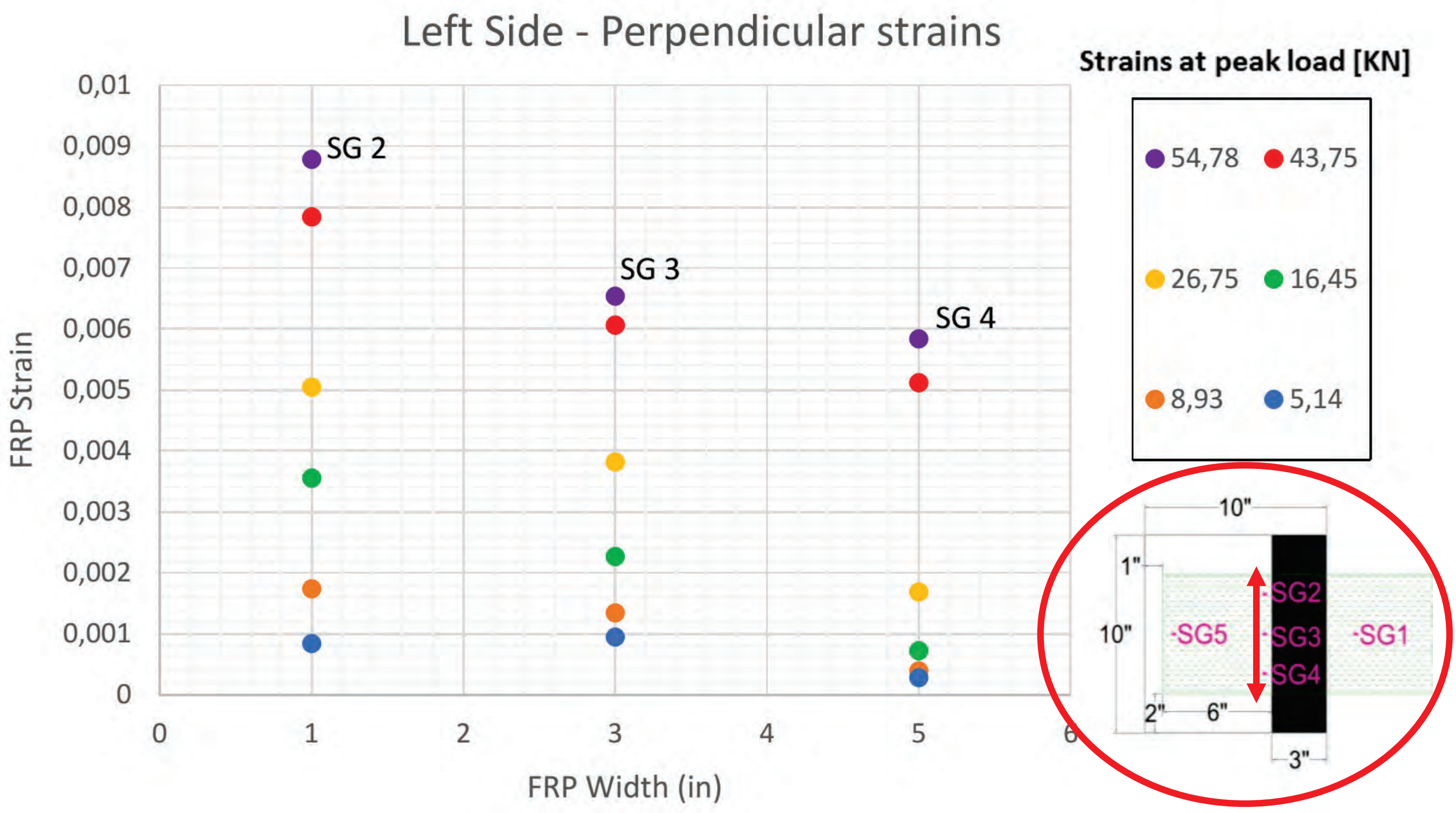
Results test 2 - Flat staples

Shear test n.2 (WET FRP)				
	Specimen ID	Anchor's dimensions	P/2 [KN]	Increase in Peak Load [%]
BENCHMARKS	T2_BM_001	No anchor	29,01	-19,68%
	T2_BM_002	No anchor	37,88	4,91%
	T2_BM_003	No anchor	41,45	14,77%
		Average	36,11	**0,00%**
FLAT STAPLES	T2_FS_3W_001	3''W - 1''D	55,37	53,34%
	T2_FS_3W_002	3''W - 1''D	62,26	72,41%
	T2_FS_3W_003	3''W - 1''D	81,62	126,01%
		Average	66,42	**83,92%**
	T2_FS_2W_001	2''W - 1''D	54,78	51,69%
	T2_FS_2W_002	2''W - 1''D	66,98	85,49%
	T2_FS_2W_003	2''W - 1''D	64,88	79,65%
		Average	62,21	**72,28%**
	T2_FS_1W_001	1''W - 1''D	57,18	58,34%
	T2_FS_1W_002	1''W - 1''D	55,69	54,21%
	T2_FS_1W_003	1''W - 1''D	59,17	63,84%
		Average	57,35	**58,80%**

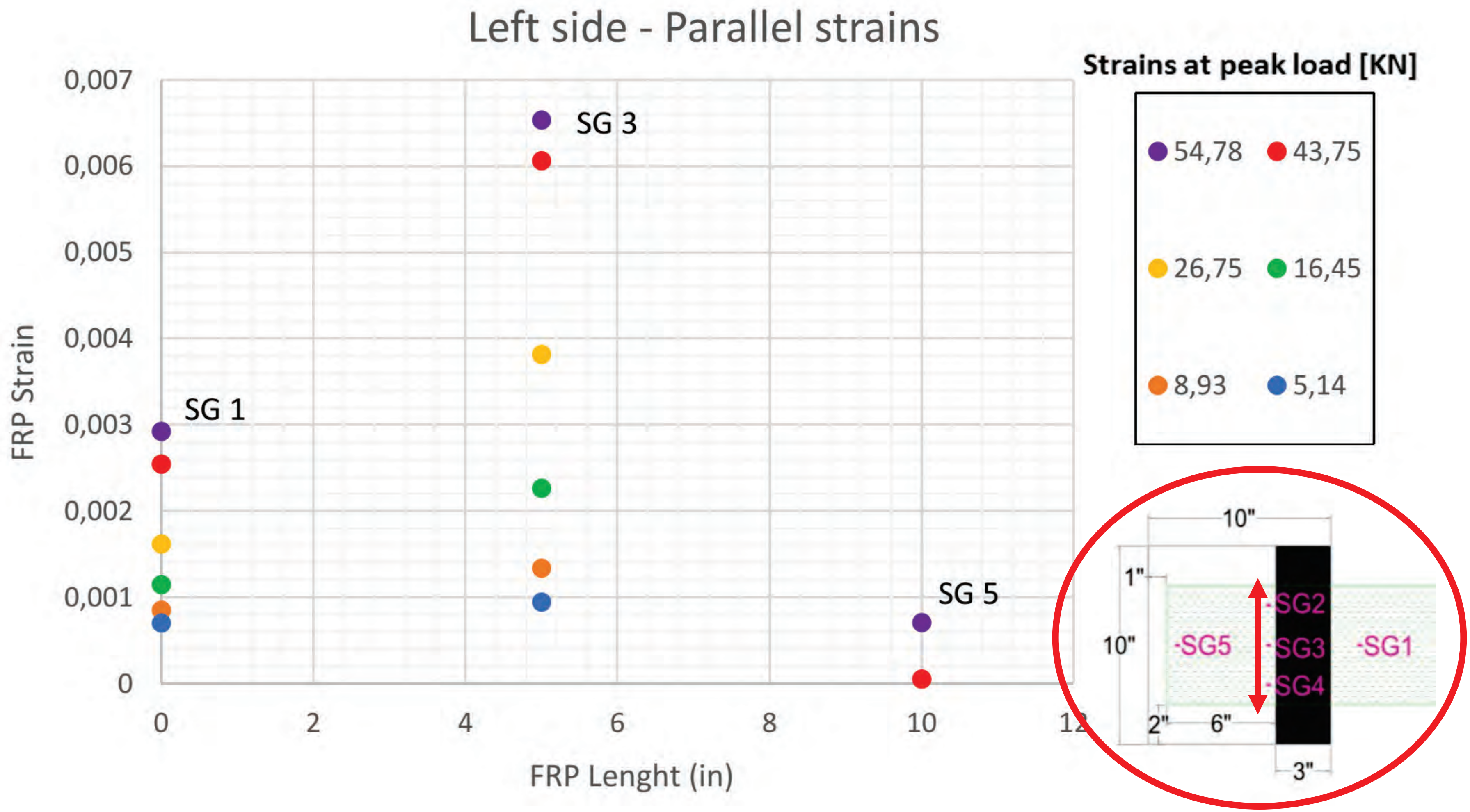
Results test 2

FLAT STAPLE 2W_1D_001



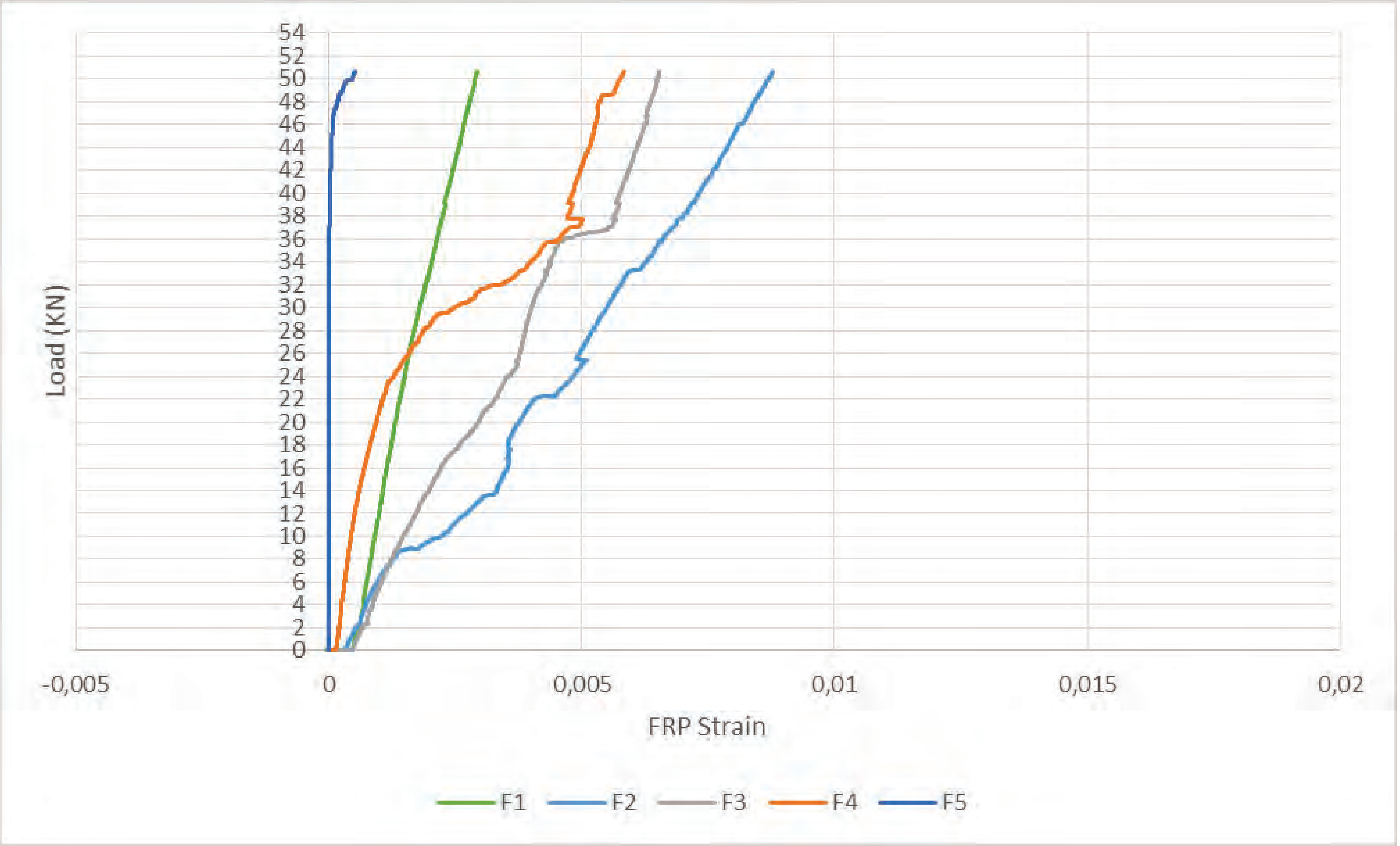
Results test 2

FLAT STAPLE 2W_1D_001



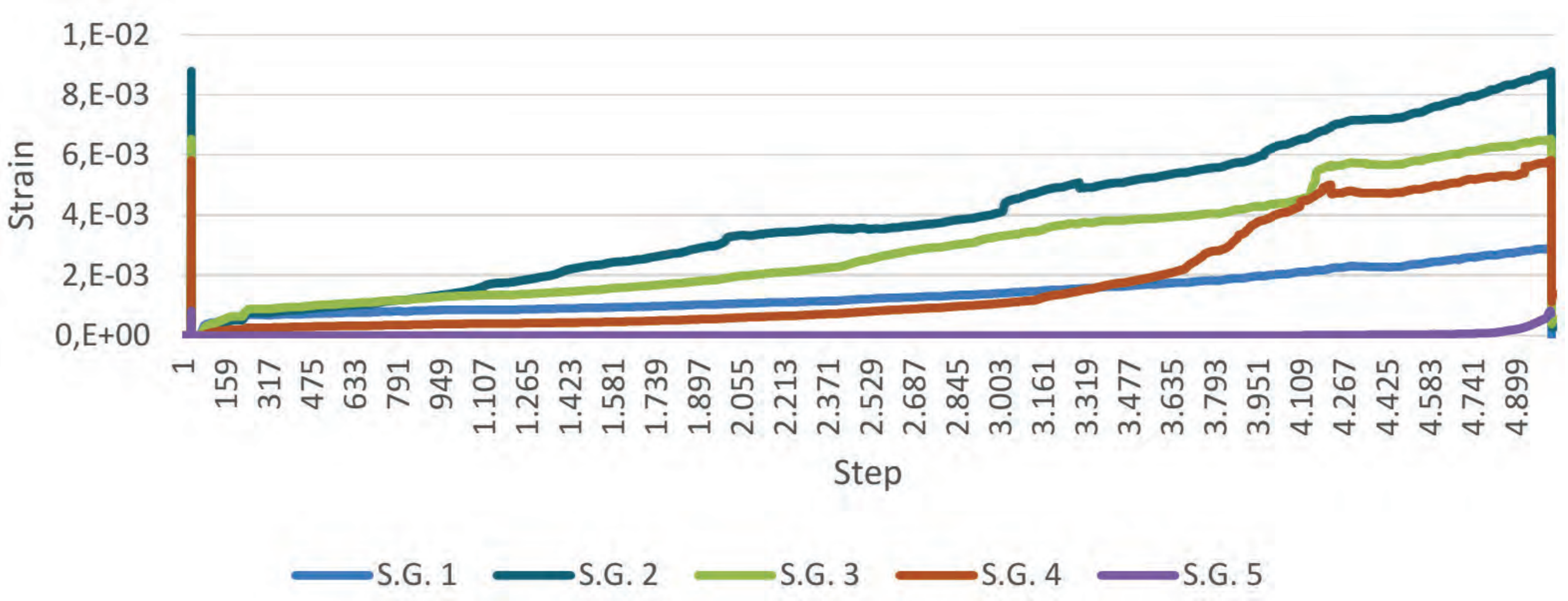
Results test 2

FLAT STAPLE 2W_1D_001



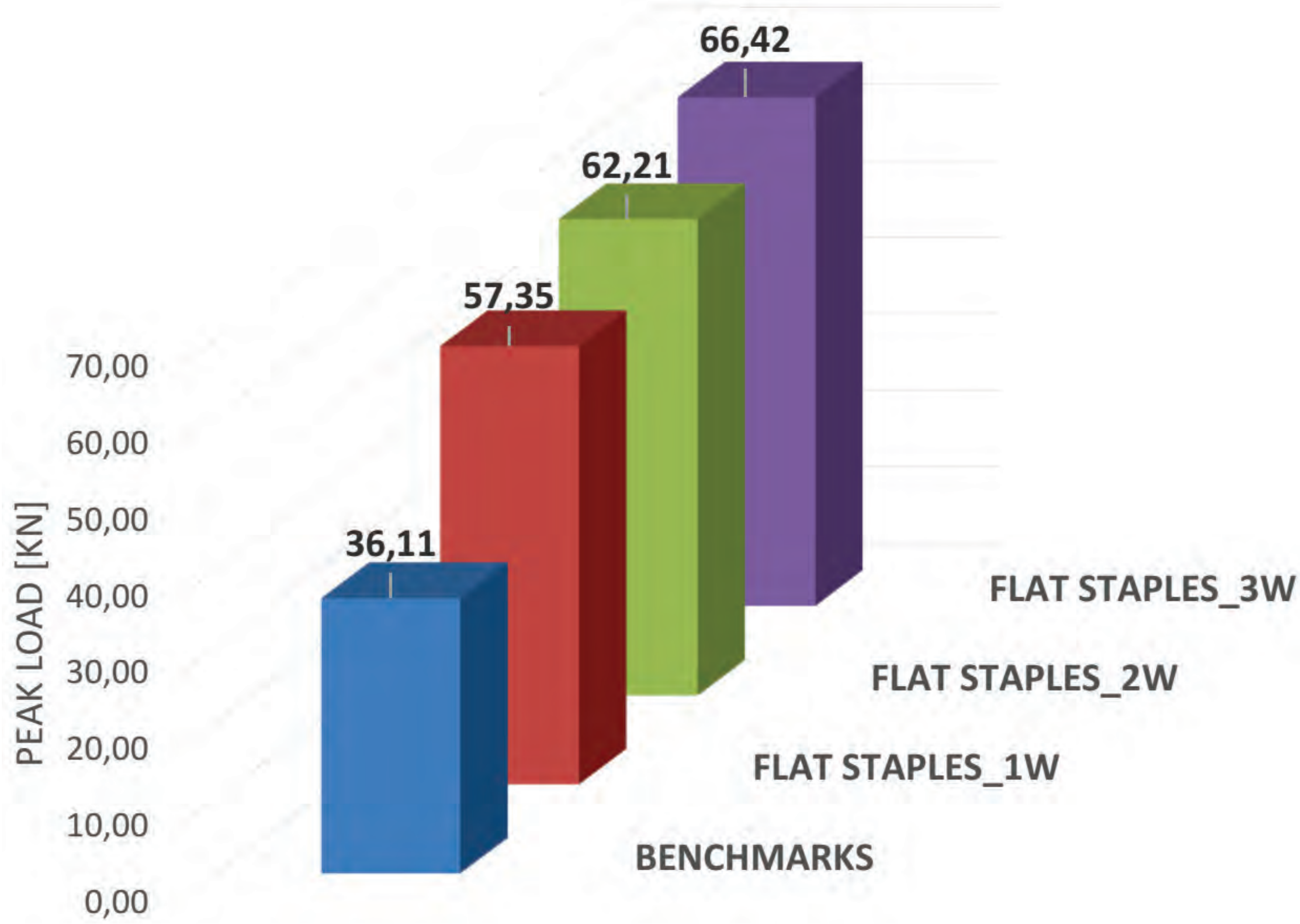
Results test 2

FLAT STAPLE 2W_1D_001

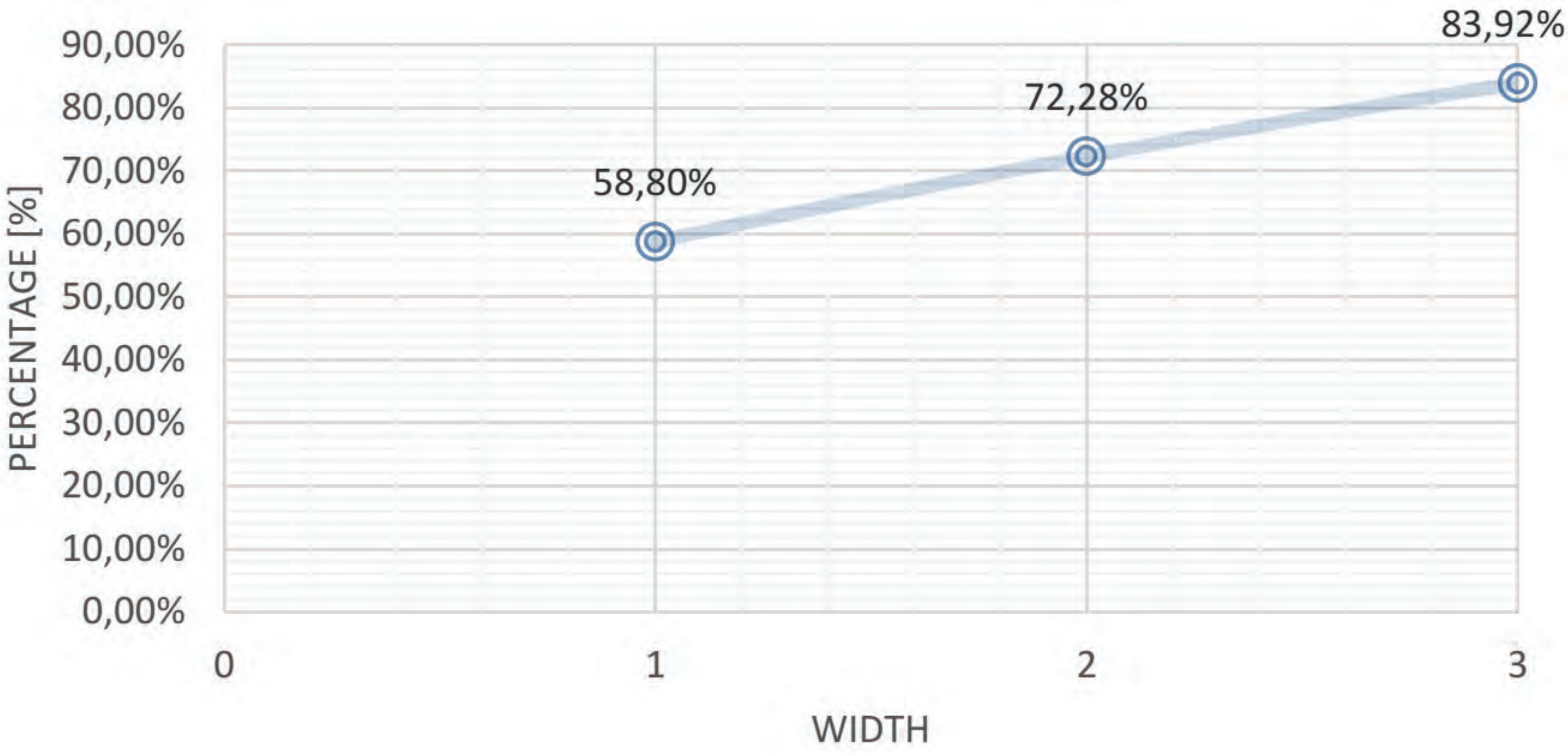


Progressive behavior of the debonding crack, which initiated at the loaded end (readings of the SG2, SG3, SG4) and propagated towards the free end, behind the anchor as the reading of the SG5.

AVERAGE INCREASE – PEAK LOADS



PERCENTUAL INCREASE - PEAK LOADS



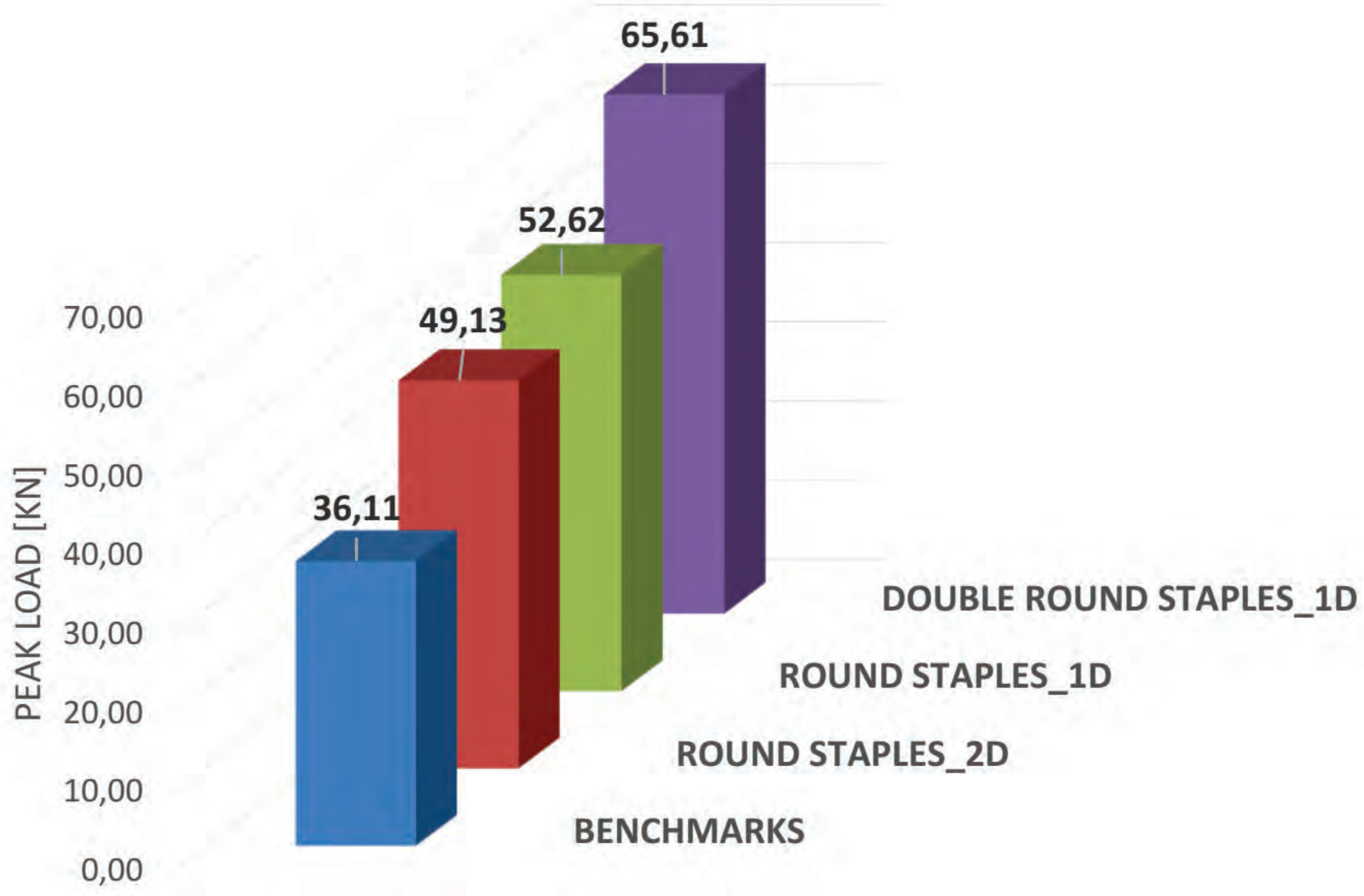
Results

1. FRP Laminates for Rehabilitation Purposes.
2. FRP Anchorage System Purposes
3. Specimen Preparation & Experimental Program
   - Test 1 – Dry CFRP testing
   - Test 2 – Wet CFRP testing (innovative method)
4. Results
   - Failure mode analysis
   - Flat Staples
   - Round Staples
5. Comparisons: Staples vs. Spikes
6. Recommendation on Preliminary Design Previsions

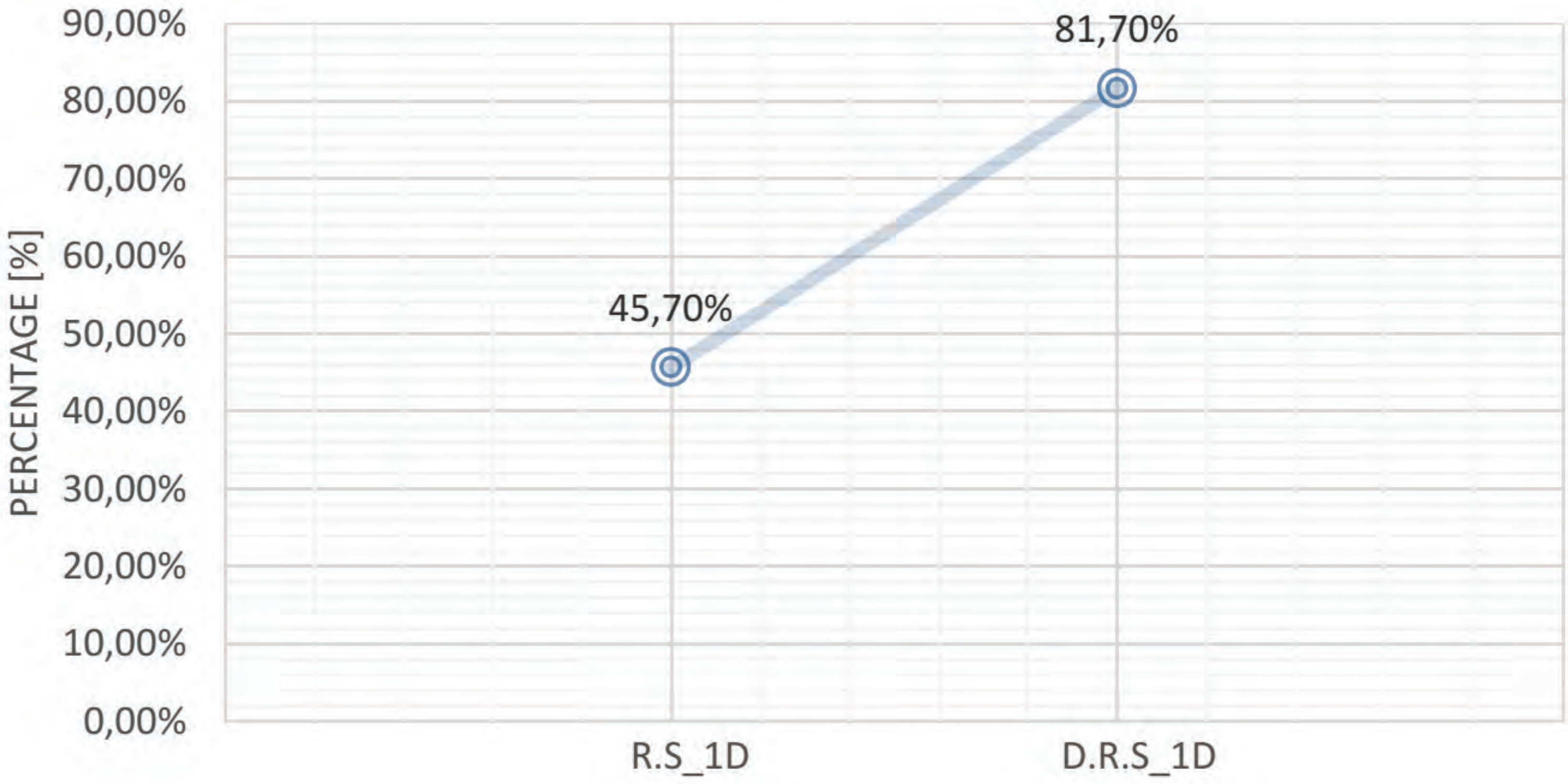
Results test 2 - Round staples

Shear test n.2 (WET FRP)				
	Specimen ID	Anchor's dimensions	P/2 [KN]	Increase in Peak Load [%]
BENCHMARKS	T2_BM_001	No anchor	29,01	-19,68%
	T2_BM_002	No anchor	37,88	4,91%
	T2_BM_003	No anchor	41,45	14,77%
		Average	36,11	**0,00%**
ROUND STAPLES	RS_2D_001	2''D_OLD	30,75	-14,86%
	RS_2D_002	2''D_OLD	36,49	1,05%
	RS_2D_003	2''D_NEW	49,13	36,06%
		Average	49,13	**36,06%**
	RS_1D_001	1''D_NEW	46,34	28,31%
	RS_1D_002	1''D_NEW	59,20	63,94%
	RS_1D_003	1''D_NEW	52,31	44,86%
		Average	52,62	**45,70%**
	DRS_1D_001	1''D_NEW	65,13	80,35%
	DRS_1D_002	1''D_NEW	68,88	90,73%
	DRS_1D_003	1''D_NEW	62,84	74,02%
		Average	65,61	**81,70%**

AVERAGE INCREASE – PEAK LOADS



PERCENTUAL INCREASE - PEAK LOADS



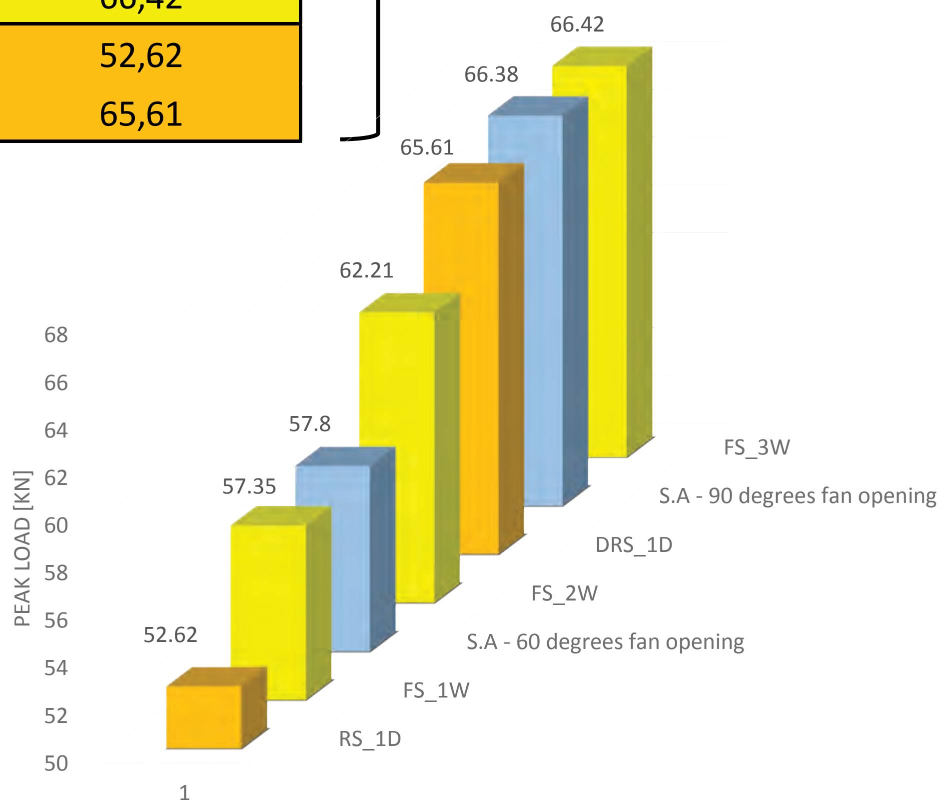
Comparisons: Staples vs. Spikes

1. ***FRP Laminates for Rehabilitation Purposes.***
2. ***FRP Anchorage System Purposes***
3. ***Specimen Preparation & Experimental Program***
   - ***Test 1 – Dry CFRP testing***
   - ***Test 2 – Wet CFRP testing (innovative method)***
4. ***Results***
   - ***Failure mode analysis***
   - ***Flat Staples***
   - ***Round Staples***
5. ***Comparisons: Staples vs. Spikes***
6. ***Recommendation on Preliminary Design Previsions***

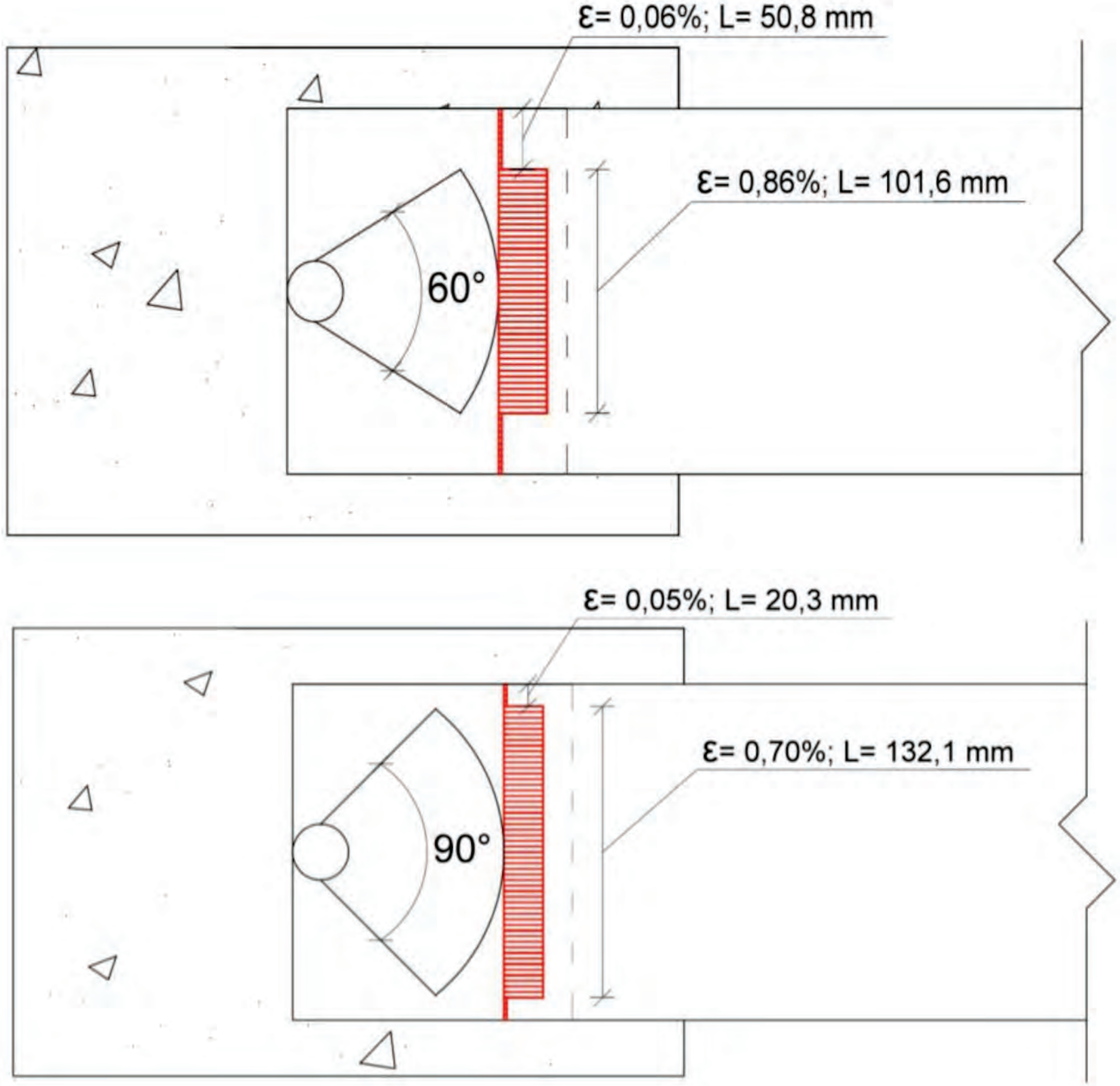
Peak load interpretation

Anchor's type	Anchor's Configuration	Peak Load [KN]
Spike anchors	60 degrees fan opening	57,8
	90 degrees fan opening	66,38
Flat staple anchors	1 in. width – 1 in. depth	57,35
	2 in. width - 1 in. depth	62,21
	3 in. width - 1 in. depth	66,42
Round staple anchors	Single conf. - 1 in. depth	52,62
	Double conf. - 1 in. depth	65,61

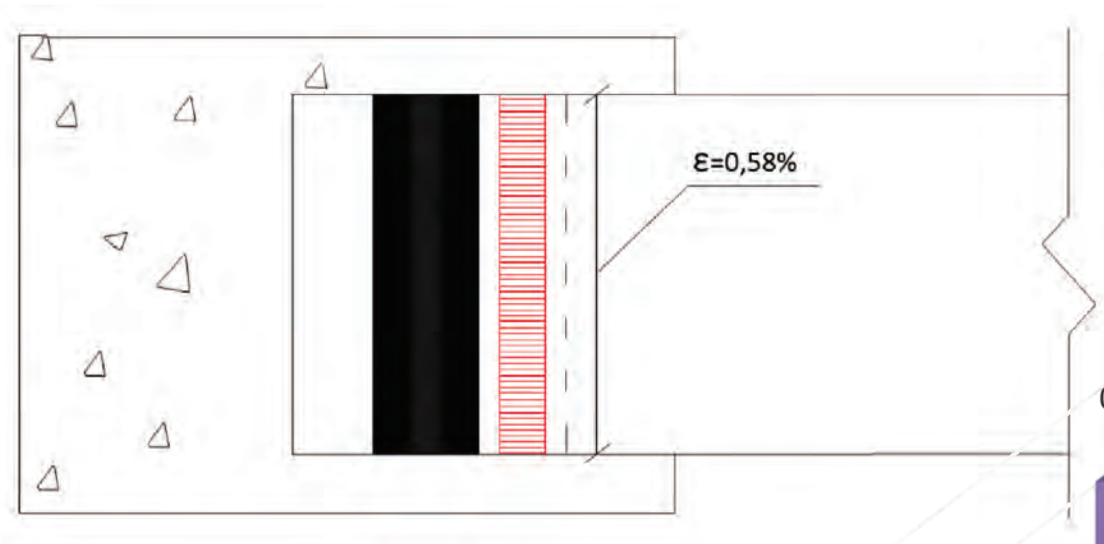
RESEARCH TOPIC



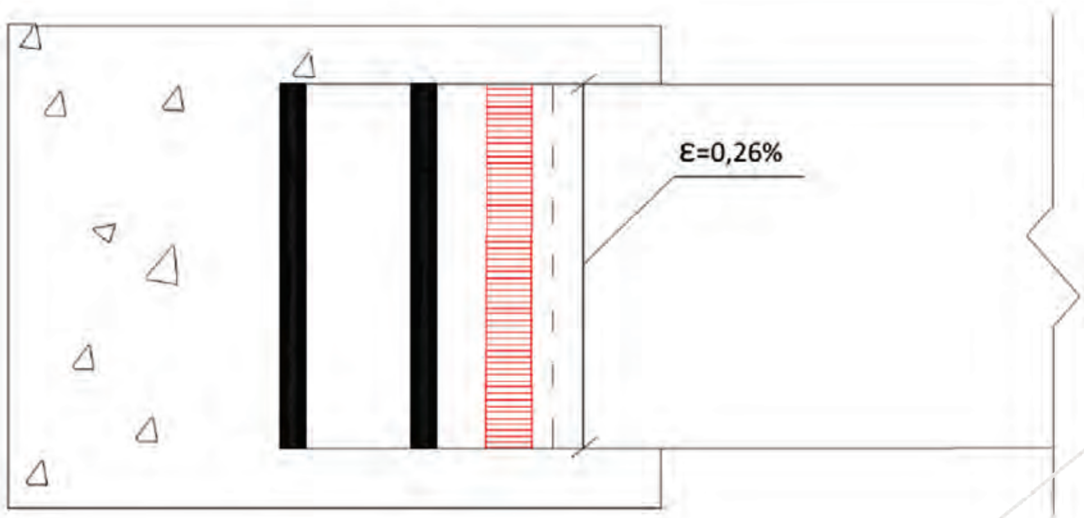
Strain interpretation – Spike anchors

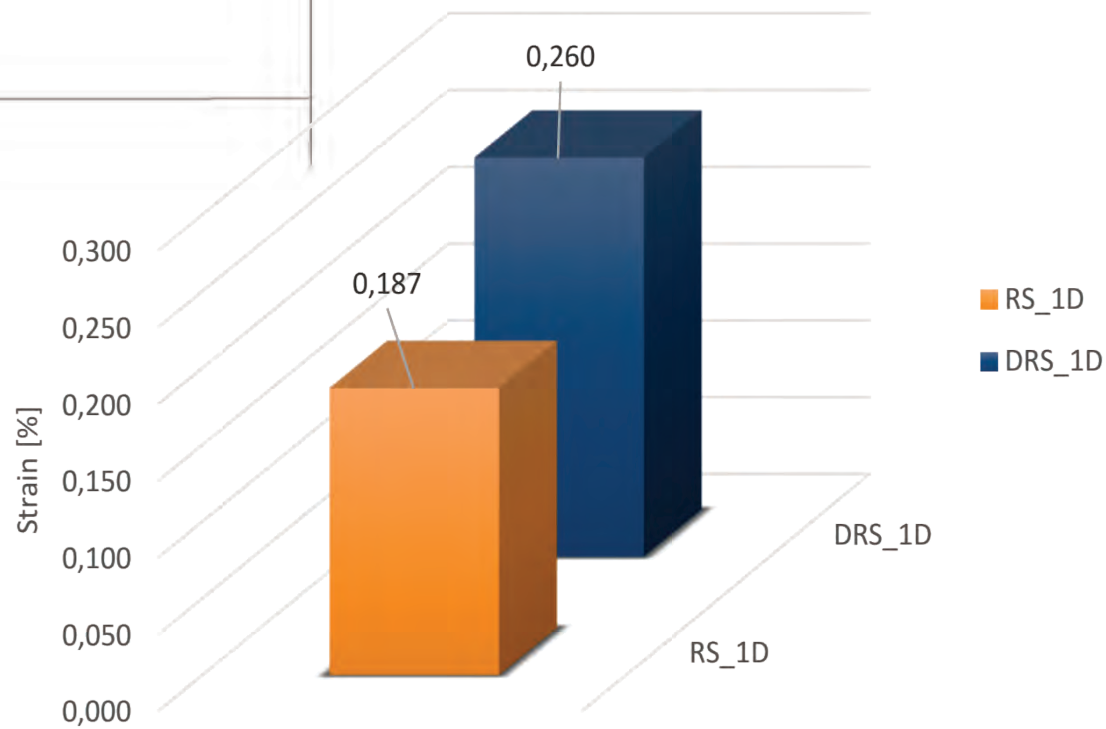


Strain interpretation – Flat staples



Strain interpretation – Round staples





Failure modes - comparison

SPIKE ANCHORS

FLAT STAPLE

Recommendation on Preliminary Design Previsions

1. FRP Laminates for Rehabilitation Purposes.
2. FRP Anchorage System Purposes
3. Specimen Preparation & Experimental Program
   - Test 1 – Dry CFRP testing
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Results - Discussions

Based on:

- **Dispersion of the results** (a low COV observed mainly in the 2-inches flat staple anchorage system).
- **Type of rupture** (the ideal failure mode is the failure mode C, which represents the full strength developed by the CFRP laminate).
- **Strains interpretation** (highest values of the strains are obviously preferred).
- **Peak load significantly high.**

We can say that the best configurations are:

- **The 2-inches width, 1-inch depth anchor, for the flat staple anchorage system.**

- **The double round staple configuration, with 1-inch depth, for the round staple anchorage system.**

Results - Discussions

FLAT STAPLES: 2-inches width

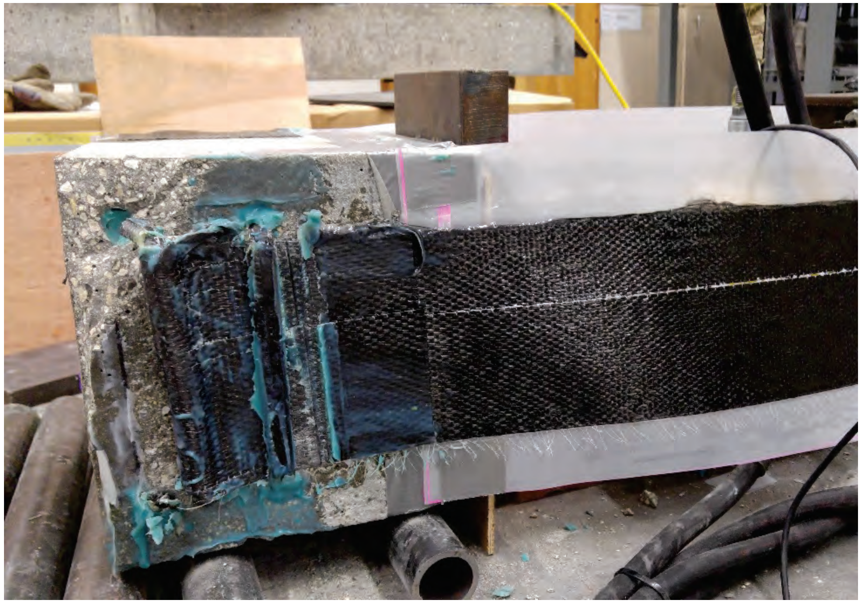
- 3-inches width anchor → **Concrete failure** (high concrete strenght! 59MPa of f'c)
- The 2-inches width anchor → Delamination and rupture of the FRP laminate, without the anchor rupture (in two cases: mixed rupture of concrete and the FRP laminate).
- Excellent stresses distribution and relevant values of the strains

→ 2-inches width anchor is sufficient to develop the full strength of the FRP laminate

Results - Discussions

ROUND STAPLES: The double round staple configuration

- 24,7% increase of peak load compared to the single configuration
- Increase of the strain values → develop the full strength of the FRP laminate
- Better resistance through the work of both the anchors (without their rupture)



Future studies

- Changing values of depth → **Pull-out stresses**

Finally, thanks to the results obtained in this research, tests should be conducted on beams, as follows:

- One anchor 2-inches width, 1-inch depth on each end, on a 6” FRP sheet width.

- A double round staple configuration, 1-inch depth on each end, always on a 6” FRP sheet – width.

Aims

I. Find a test which is reliable, repeatable, easy to perform and able to represent the stress state in the real applications

II. Anchors characterization in different configurations

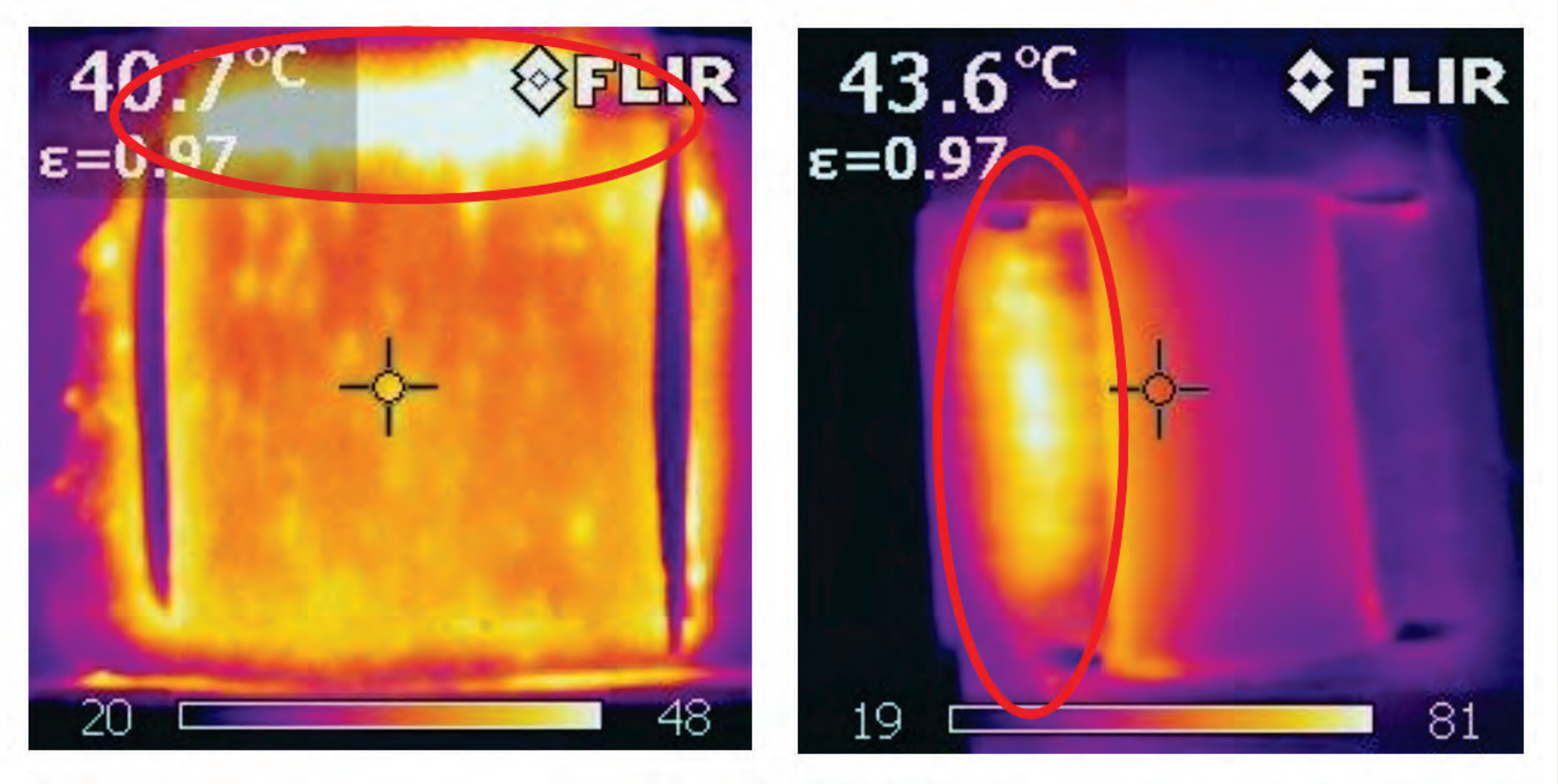
III. Spike anchors comparison

- Peak load
- Strains
- Failure modes

Thank You

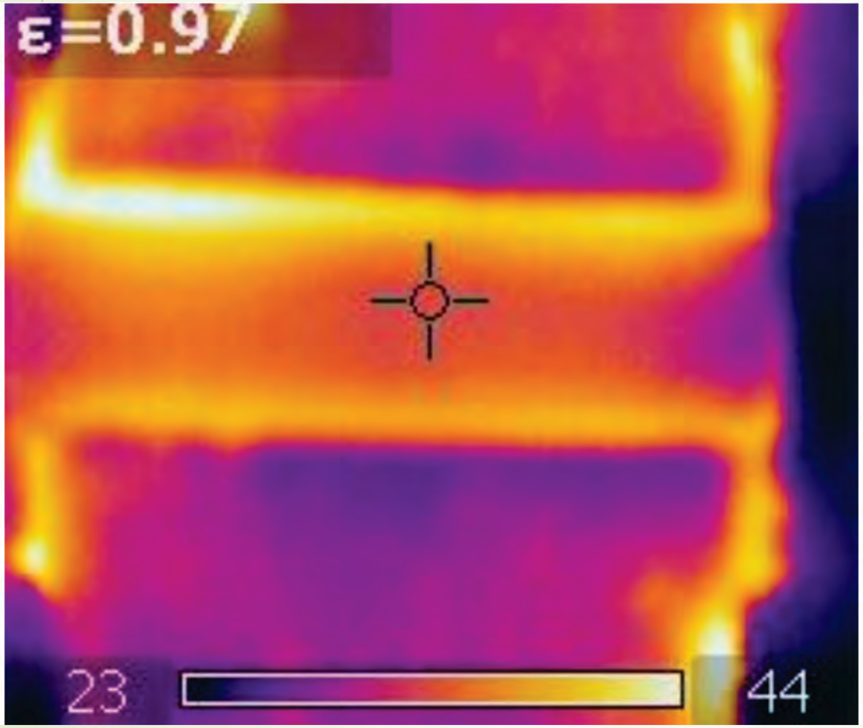
Thank you for your attention

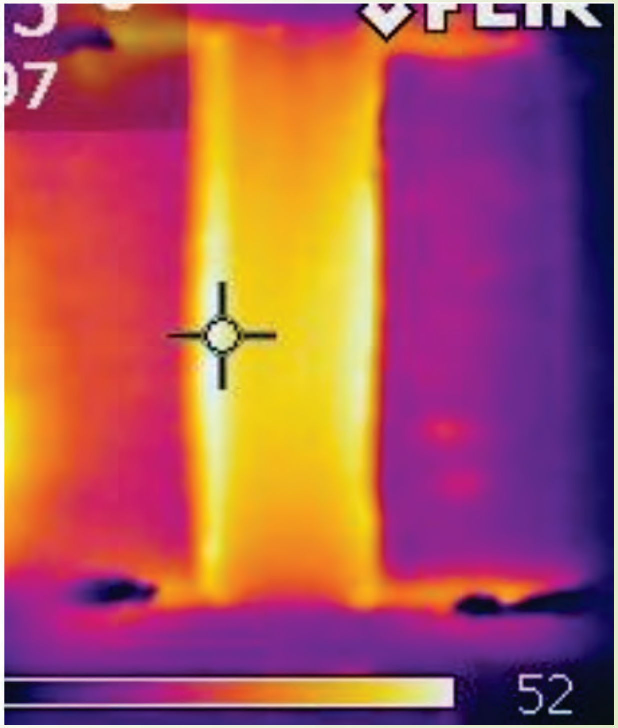
Thermal Camera



Voids & Durability Hazard

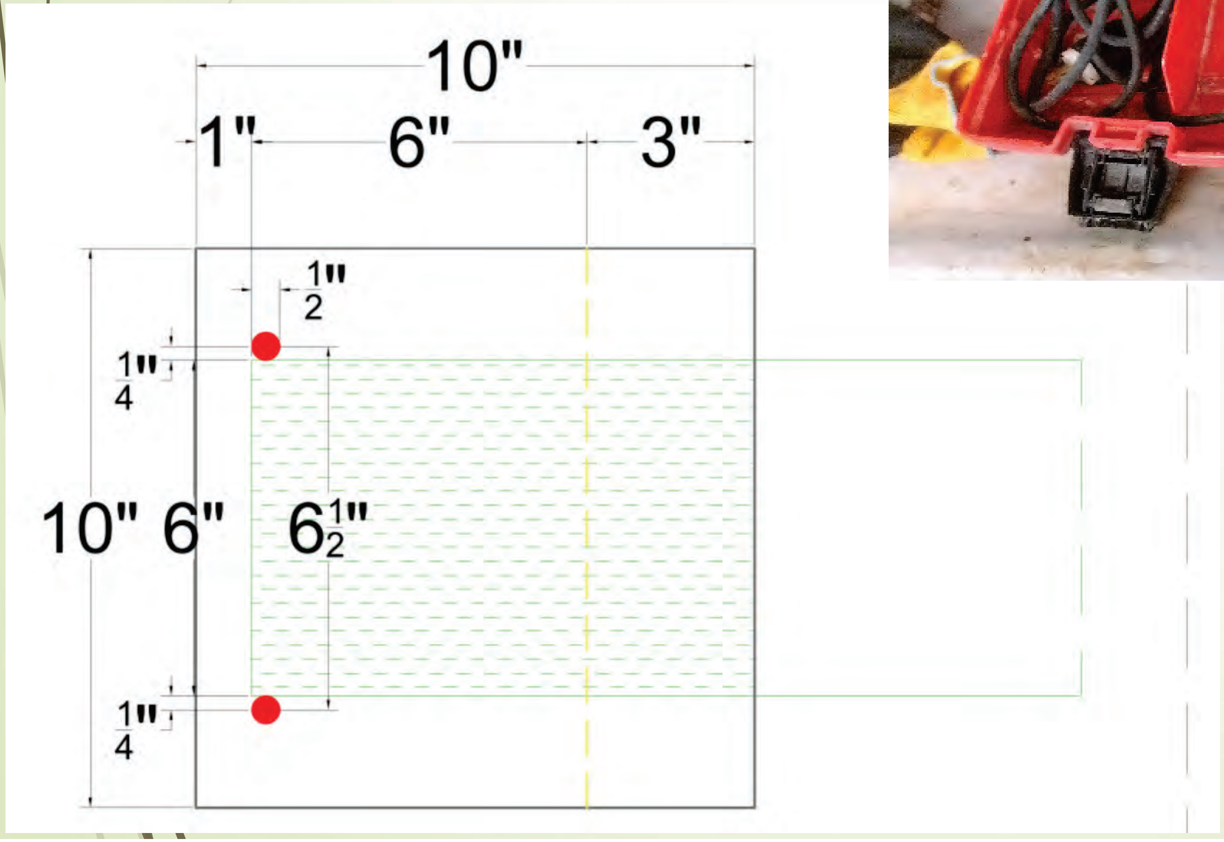
Thermal Camera



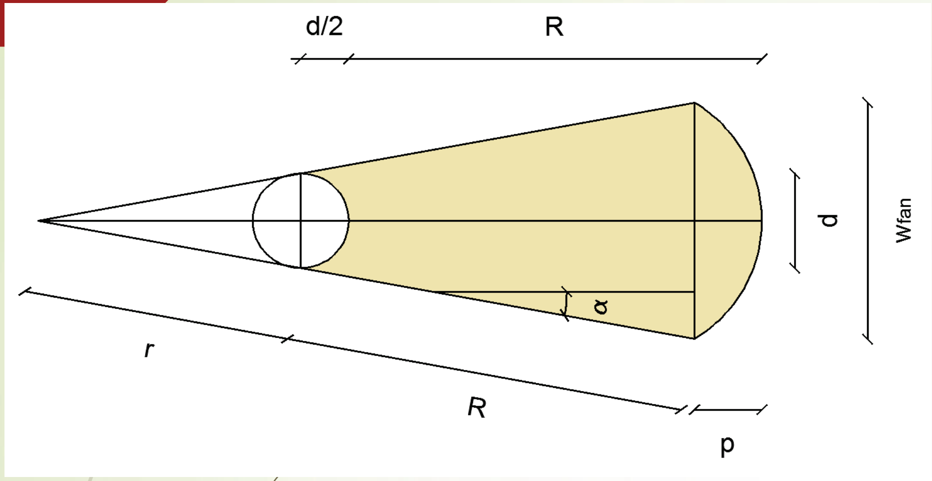


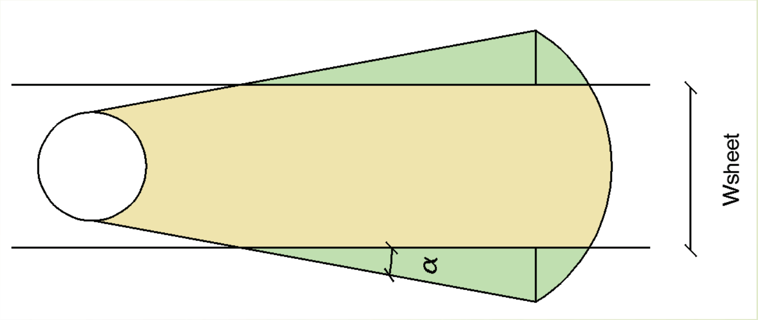
Surface and anchors' hole preparation

Surface and anchors' hole preparation



Anchors sizes





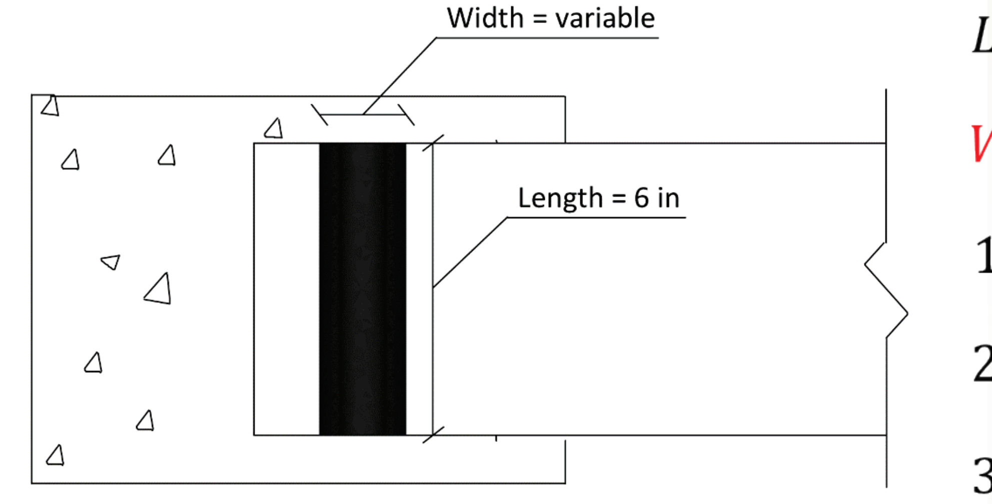
$$A_{fan} = \frac{(r+R)w_{fan}}{2}\cos\left({}^{\alpha}\!/_{2}\right) - \frac{rd}{2}\cos\left({}^{\alpha}\!/_{2}\right) - \frac{\pi d^2}{8} + \frac{2}{3}\,pw_{fan}$$

$$Area_{60\ degrees\ fan\ opening} = 7{,}55\ in^2 = 48{,}71\ cm^2$$

$$Area_{90\ degrees\ fan\ opening} = 10{,}15\ in^2 = 65{,}48\ cm^2$$

Anchors sizes

Flat staples



$$Length = 6\,in. = 15{,}24\ cm$$

$$Width = Variable = ?$$

1) $Width = 1\ in = 25{,}4\ cm$

2) $Width = 2\ in = 5{,}8\ cm$

3) $Width = 3\ in = 7{,}62\ cm$

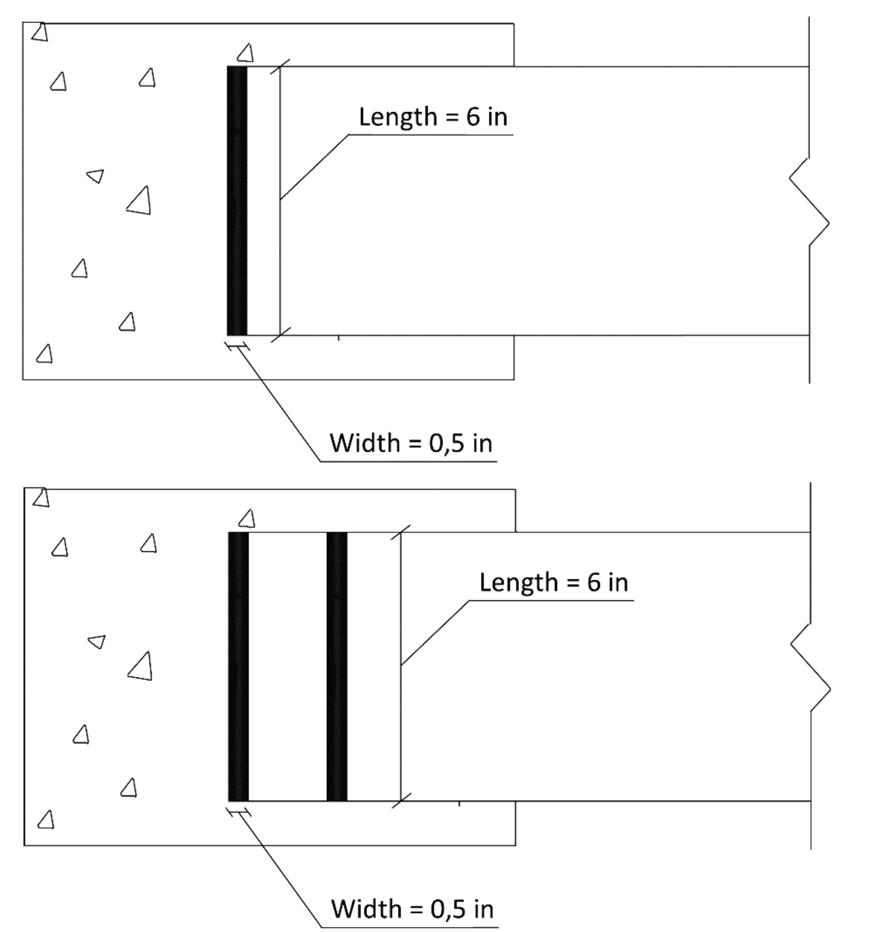
$$Area_{1\ in.width} = 6\ in^2 = 38,71\ cm^2$$

$$Area_{2\ in.width} = 12\ in^2 = 77,42\ cm^2$$

$$Area_{3\ in.width} = 18\ in^2 = 116,13\ cm^2$$

Anchors sizes

Round staples



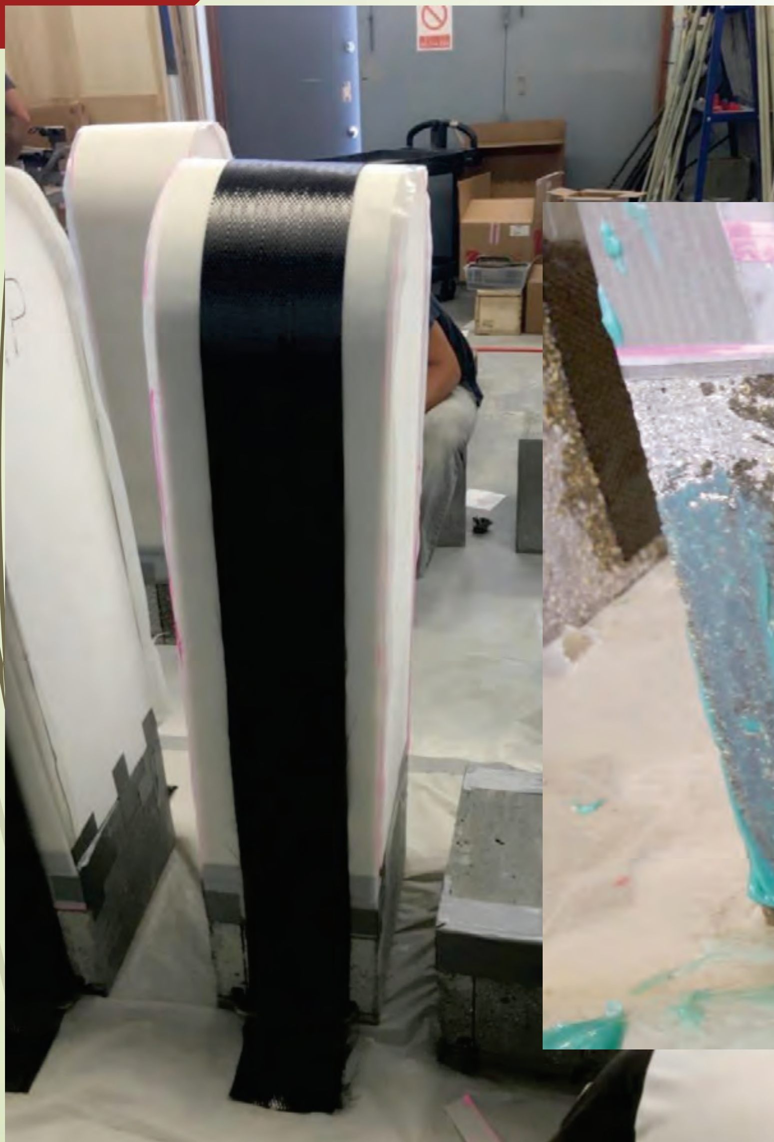
$$Length = 6\,in. = 15{,}24\ cm$$

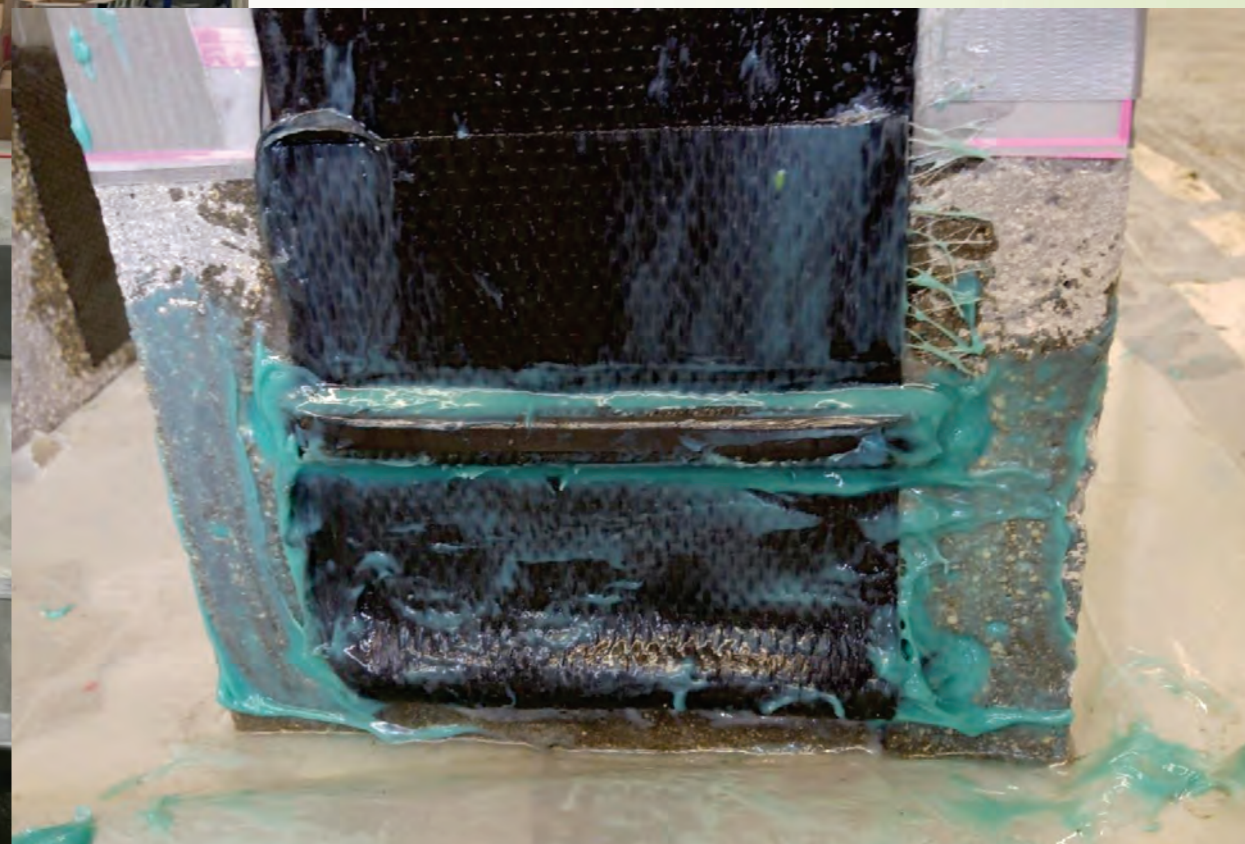
$$Width = 0{,}5\,in. = 1{,}27\ cm$$

$$Area\ = 3\,in^2 = 19{,}35\,cm^2$$

Sandwich configuration

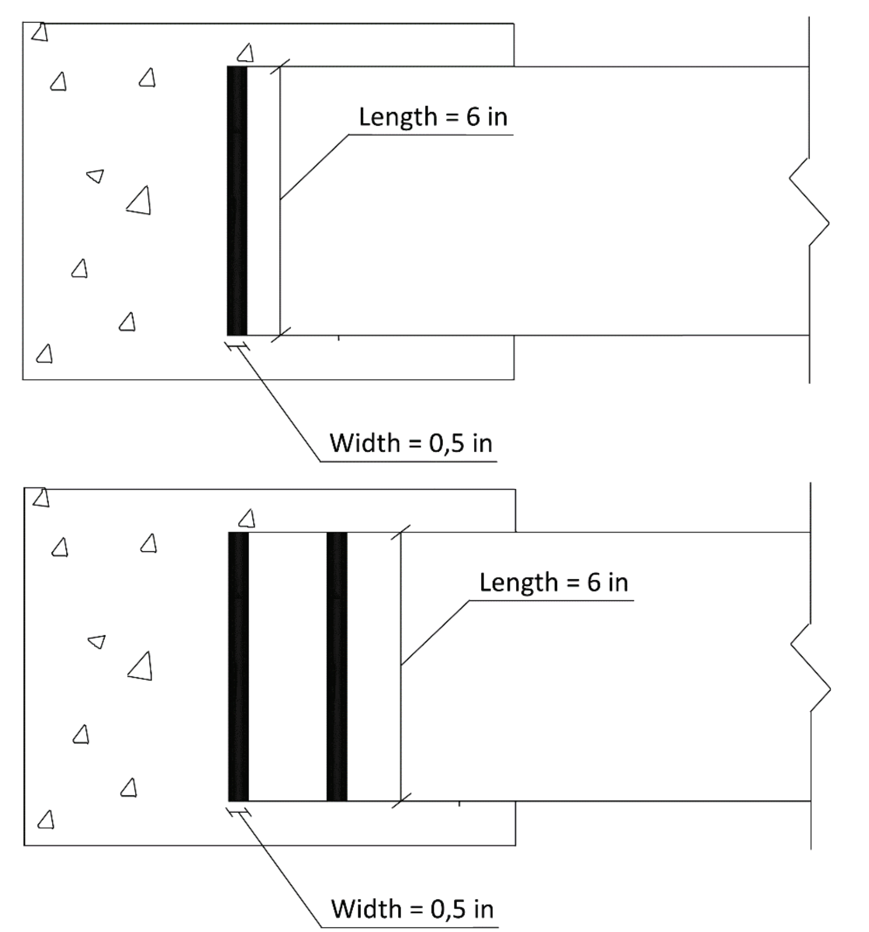
Sandwich configuration – round staples





Anchors sizes

Round staples



$$Length = 6\,in. = 15{,}24\ cm$$

$$Width = 0{,}5\,in. = 1{,}27\ cm$$

$$Area\ = 3\,in.^2 = 19{,}\,35\,cm^2$$

Sandwich configuration

$$\sigma = E \cdot \varepsilon \rightarrow \frac{P}{A} = E \cdot \varepsilon$$

$$\rightarrow P = E \cdot \varepsilon \cdot A$$

$$A \uparrow \quad \rightarrow \quad P \uparrow$$

$N.B.\,CFRP\ sheet\ thickness = 1\ mm$

Anchors sizes

DEPTH ?

Country	Concrete Code	Range of Concrete Cover (mm)
UK	BS:8110	25-50
EU	EN 1992 (EC2)	diameter +10 - 55
USA	ACI:318	40-50
Australia	AS:3600	15-78

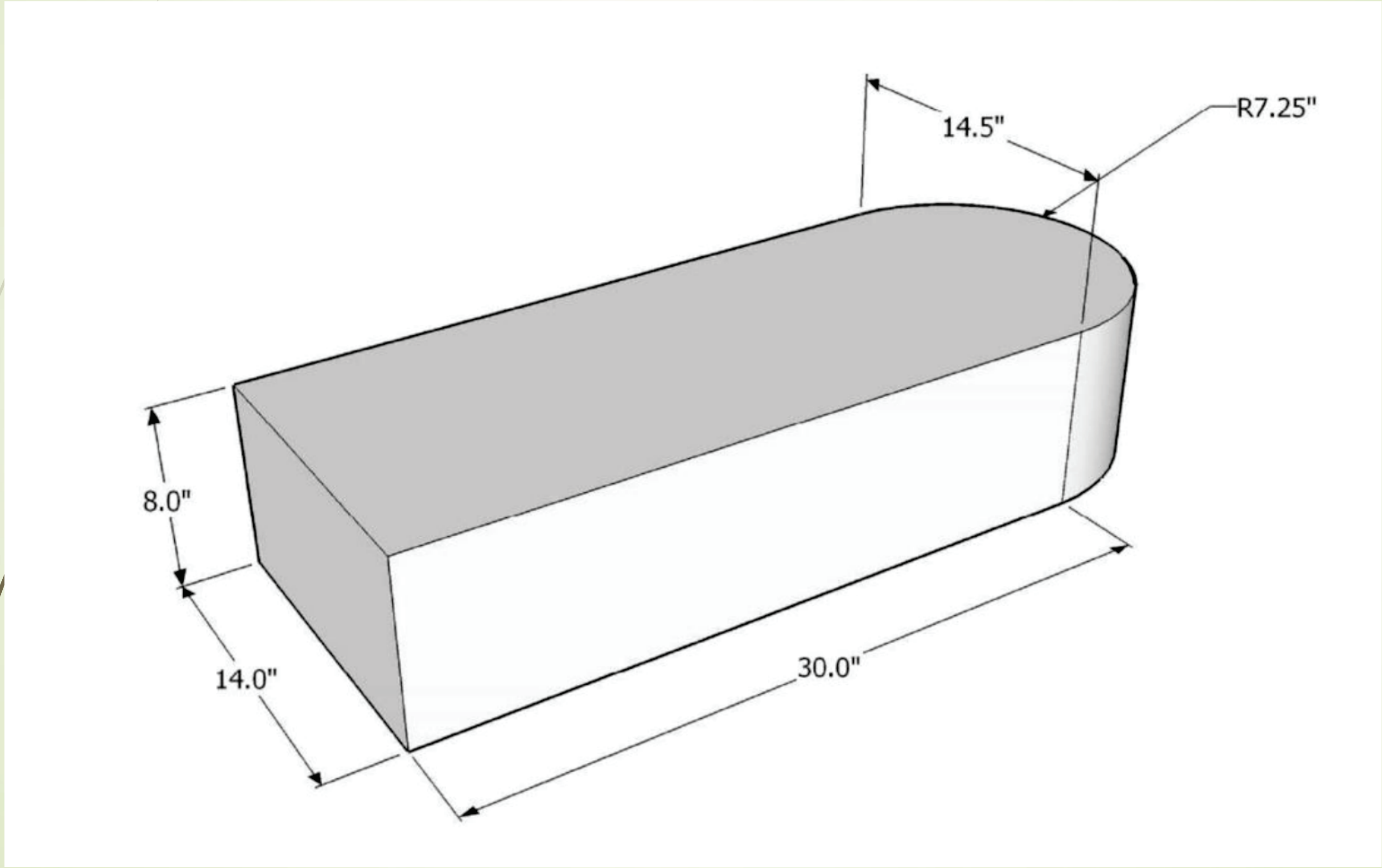
N.B: 1 in = 25,4 mm

Fixed at 1’’. Infact 1’’ of anchors depth is sufficient and ideal for a main reason:

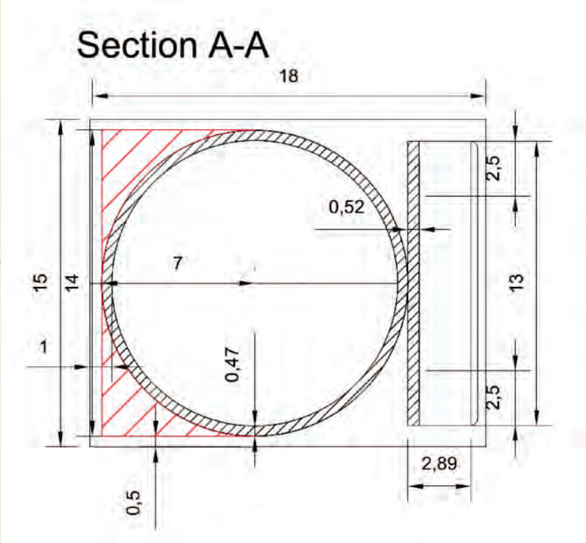
The rebars interaction!

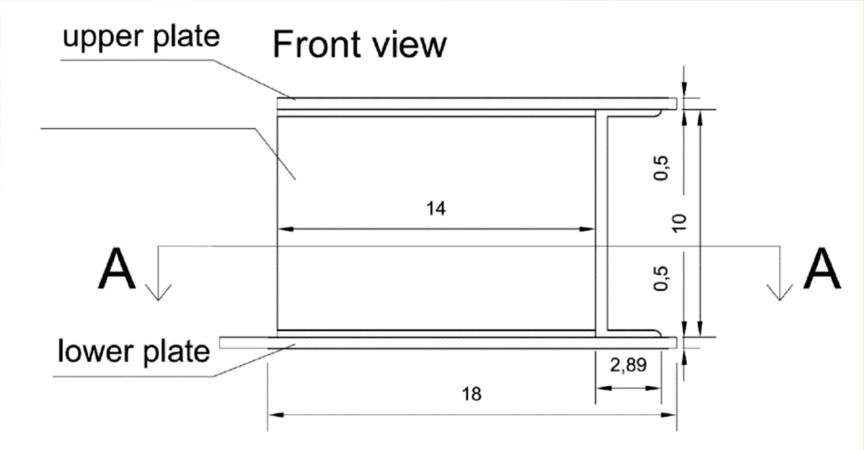
Since most of the worldwide regulations give some minimum requirements for the concrete cover (see table 4.1), a 1’’ depth, while anchoring an FRP reinforcement, would not be a problem of interact and damage the internal reinforcement of a slab.

EPS FOAM SHAPES



Steel support cut





Existing types of FRP anchorage systems

1. Anchor Spikes
2. Transverse Wrapping
3. U-Anchors
4. FRP Strips
5. Longitudinal Chase
6. Plate Anchors
7. Bolted Angles
8. Cylindrical Hollow Section

Anchor Spikes

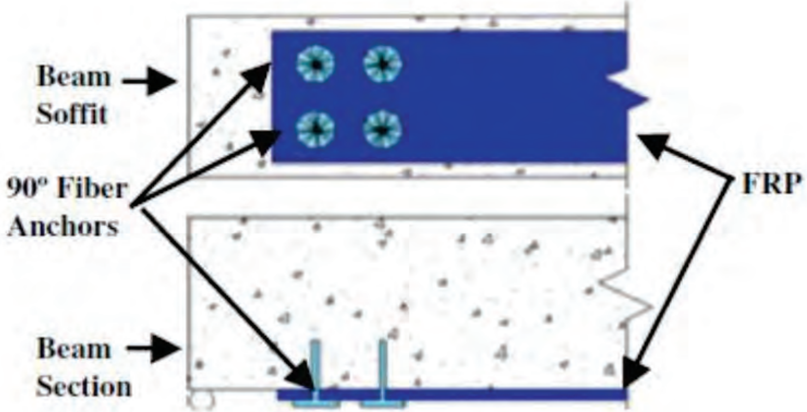
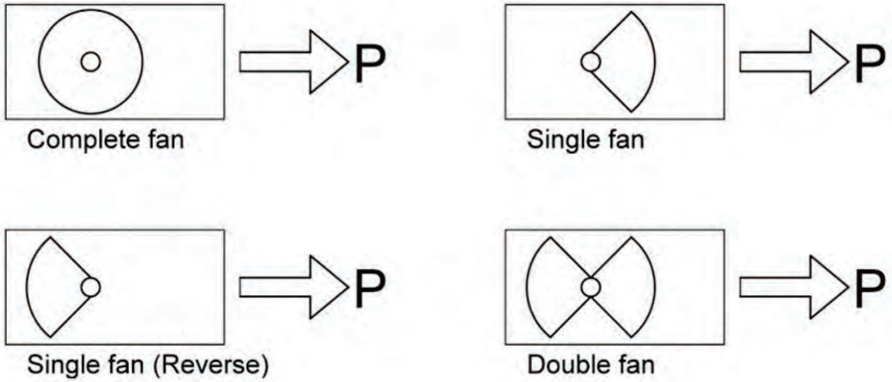
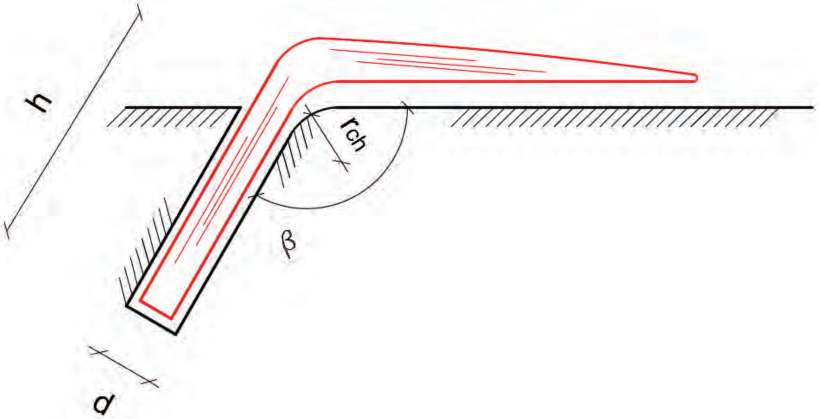


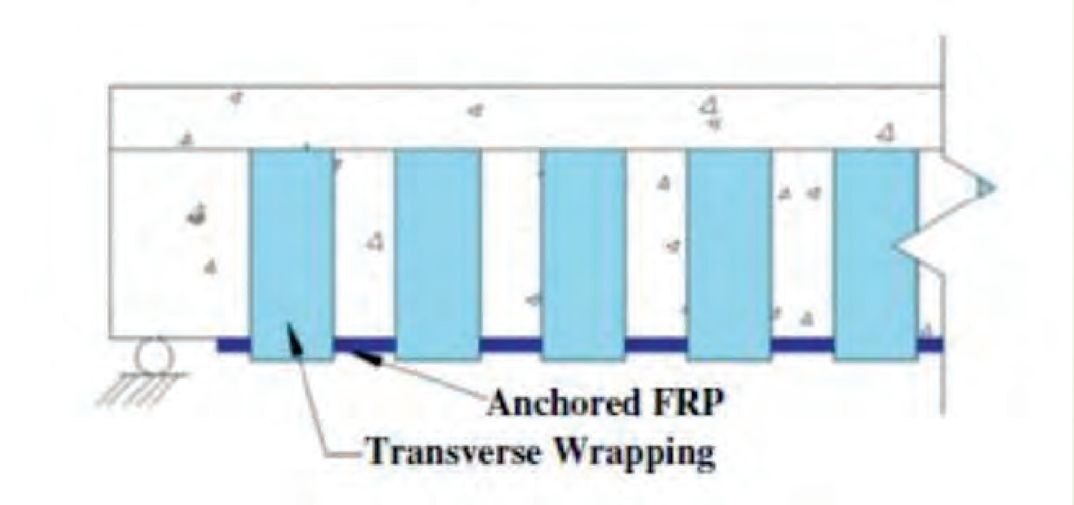
Figure 1.9 - 90° anchor spikes





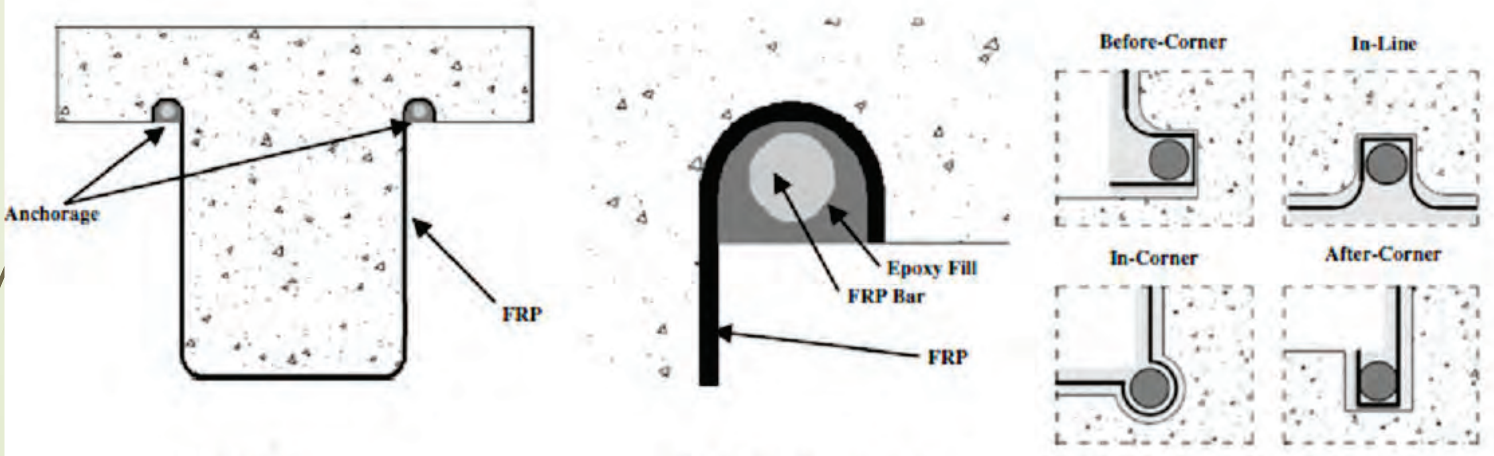
Transverse wrapping

Transverse wrapping is usually in the form of discrete strips situated along the laminate length or at its end. The fiber orientation can be perpendicular to the longitudinal axis or inclined whit a certain angle.



U-Anchors

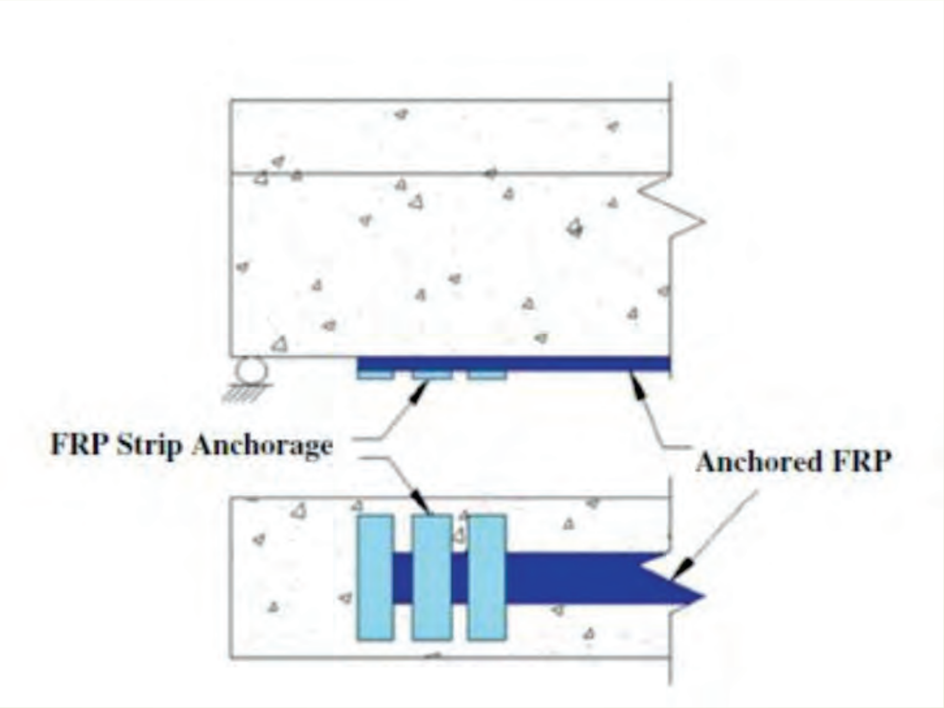
A U-Anchor is installed in a groove made in the concrete surface onto which or adjacent to where the strengthening FRP sheets are placed. The FRP sheets are then pressed into the groove that is filled with epoxy, sometimes in combination with steel bars.



(a) T-Beam (b) U-Anchor Detail (c) U-Anchor Types

FRP Strips

Fiber reinforced polymer strips are a very simple type of anchorage, installed on the top of the FRP sheet used to strengthen the reinforced concrete member. They are typically installed perpendicular to the direction of the force of the strengthening FRP sheets and for this reason they have limited efficiency.



Longitudinal Chase

The groove is filled in with epoxy resin and, in some cases, a steel or FRP bar is embedded. The FRP sheet is bonded to the concrete and over the top of the groove. This anchorage system is based on the concept that the interfacial shear stresses are better distributed to a larger area of concrete through the mechanical properties of the epoxy resin poured into the groove.

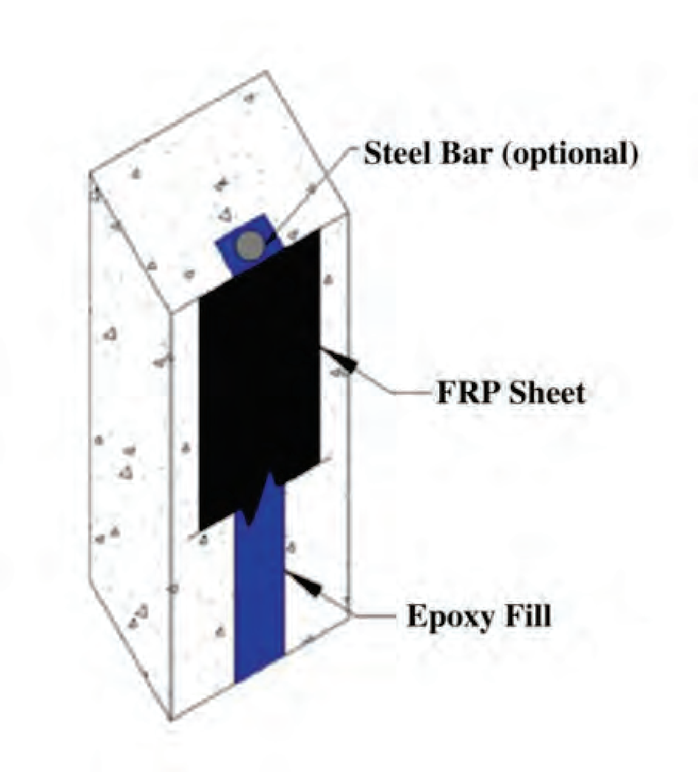
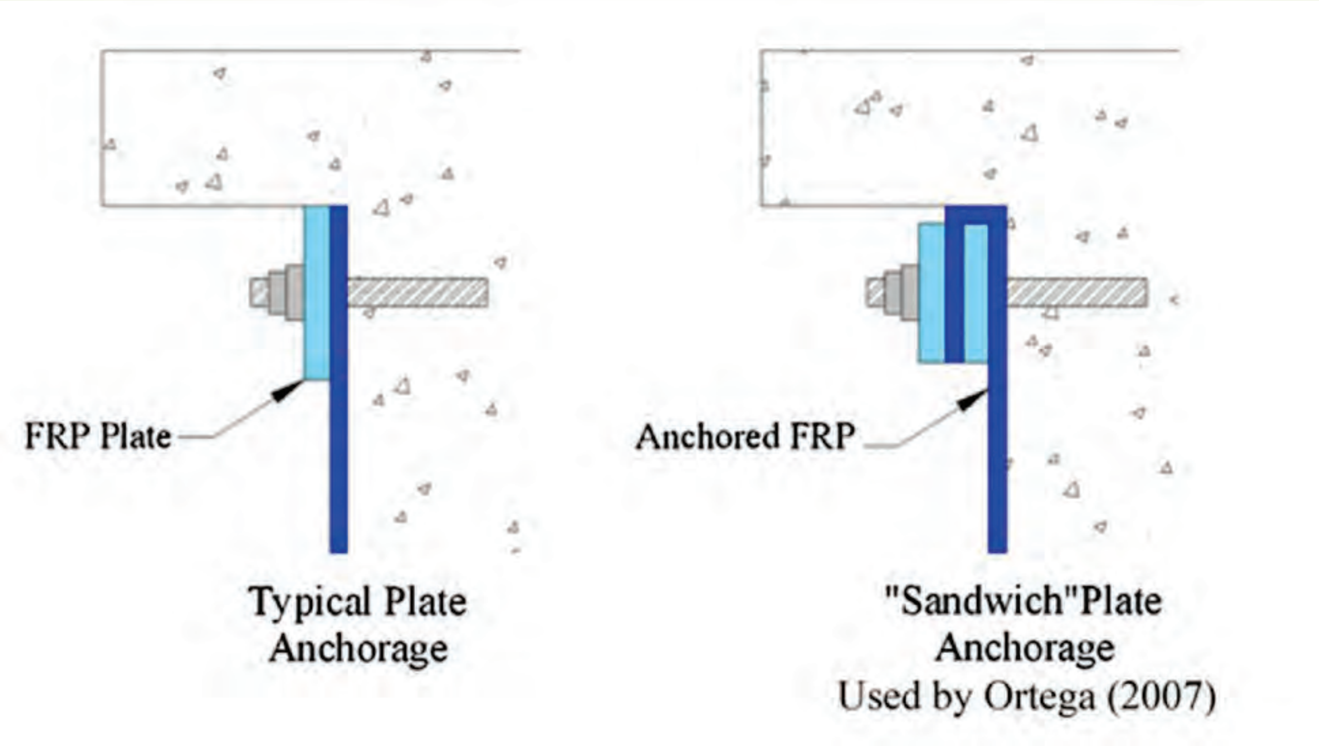


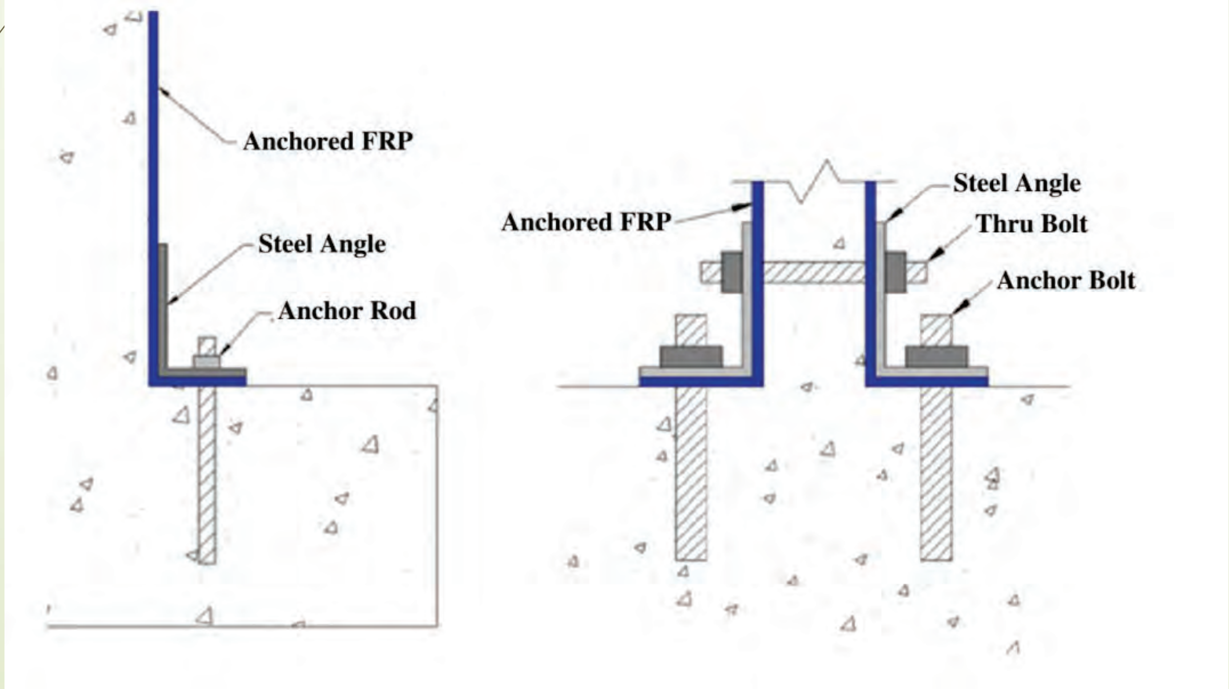
Plate Anchors

This anchorage system is made up of FRP sheets anchored to the plates (metallic or composite plates), which are either bolted or bonded to the concrete substrate. This configuration allows transferring the shear stress to the FRP–plate interface.



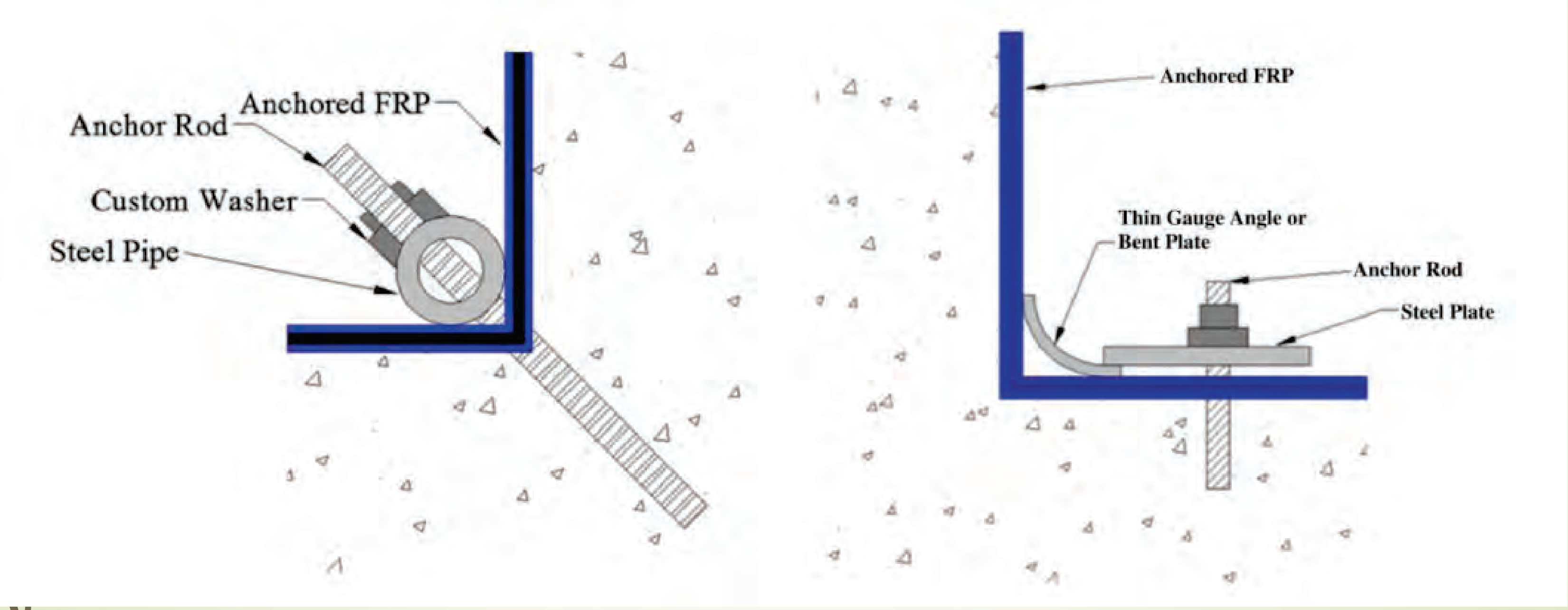
Bolted Angles

Installed in 90° joints. Usually, the FRP is laid around the joint, the angle is bonded to the FRP in the joint and bolted to the concrete either through or around the FRP sheet. Even if bolted angles have several limitations, as the problem of corrosion (they are made of steel) or the problem of stress concentration in the FRP (due to the 90° corner), they are frequently used because steel angle shapes are easy to obtain and require little fabrication.



Cylindrical Hollow Section

Designed for 90° joints applications, this type of anchorage is composed a steel pipe is bolted through the FRP at a 45 angle in order to eliminate the potential for local stress concentrations at the 90° corner.



Influence of anchorage

1. **prevent or delay the interfacial crack opening at the starting of debonding or failure of the concrete substrate**

2. **increases the total available interfacial shear stress transfer**

↓

transfer length is less than the effective bond length, usually due to the geometric conditions of the structural member

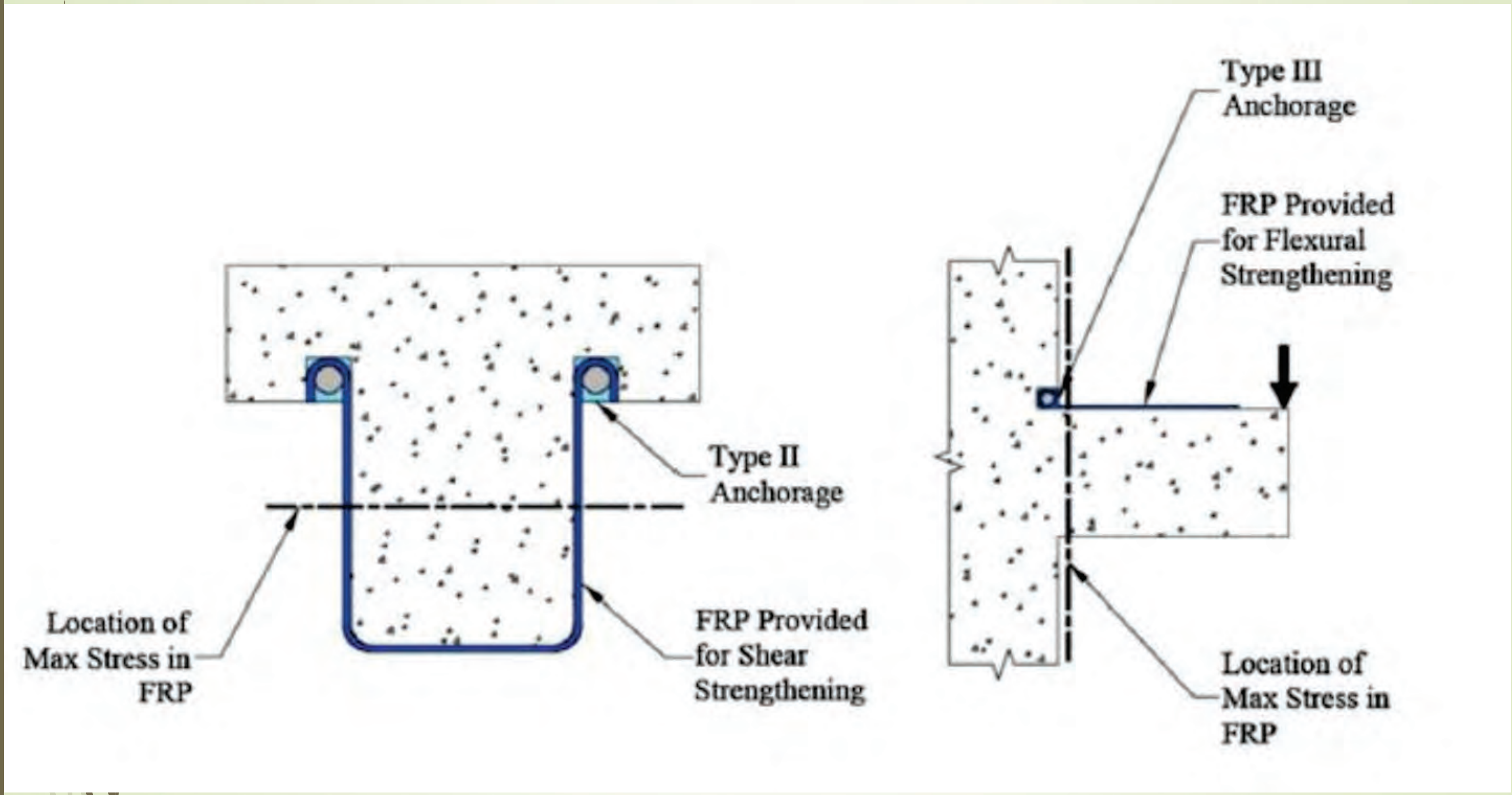
Influence of anchorage

1. prevent or delay the interfacial crack opening at the starting of debonding or failure of the concrete substrate

2. increases the total available interfacial shear stress transfer

3. provides a load transfer mechanism at critical locations of structural members (such as at the location of an interface between two orthogonal structural members) where no bond length is available beyond the critical section.

Anchorage System Purposes



(CNR, 2014)

Results test 1

Shear test n.1 (DRY CFRP)						
	Specimen ID	Anchor's dimensions	P [KN]	P/2 [KN]	Increase in Peak Load [%]	Rupture Type
BENCHMARKS	T1_BM_001	No anchor	45,80	22,90	34,53%	G
	T1_BM_002	No anchor	22,29	11,15	-34,53%	G
		Average	34,05	17,02	**0,00%**	
FLAT STAPLES	T1_FS_3W_2D_001	3''W - 2''D	32,33	16,16	-5,06%	G
	T1_FS_3W_2D_002	3''W - 2''D	88,04	44,02	158,57%	G/C
	T1_FS_3W_2D_003	3''W - 2''D	61,16	30,58	79,62%	G
		Average	60,51	30,25	**158,57%**	
	T1_FS_3W_1D_001	3''W - 1''D	67,11	33,56	97,11%	G
	T1_FS_3W_1D_002	3''W - 1''D	83,55	41,78	145,40%	G/C
	T1_FS_3W_1D_003	3''W - 1''D	67,31	33,65	97,68%	G
		Average	72,66	36,33	**145,40%**	
	T1_FS_1,5W_2D_001	1,5''W - 2''D	61,60	30,80	80,91%	G
	T1_FS_1,5W_2D_002	1,5''W - 2''D	34,25	17,12	0,59%	G
	T1_FS_1,5W_2D_003	1,5''W - 2''D	86,35	43,18	153,62%	G/C
		Average	60,73	30,37	**153,62%**	
	T1_FS_1,5W_1D_001	1,5''W - 1''D	59,67	29,83	75,25%	G
	T1_FS_1,5W_1D_002	1,5''W - 1''D	86,41	43,20	153,78%	G/C
	T1_FS_1,5W_1D_003	1,5''W - 1''D	64,89	32,44	90,57%	G
		Average	70,32	35,16	**153,78%**	

3 in. larghezza (width) e 2 in. profondità (depth)

Thank You

Thank you for your attention