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ADHESION AT HIGH TEMPERATURE OF FRP BARS STRAIGHT OR BENT AT THE END OF CONCRETE SLABS

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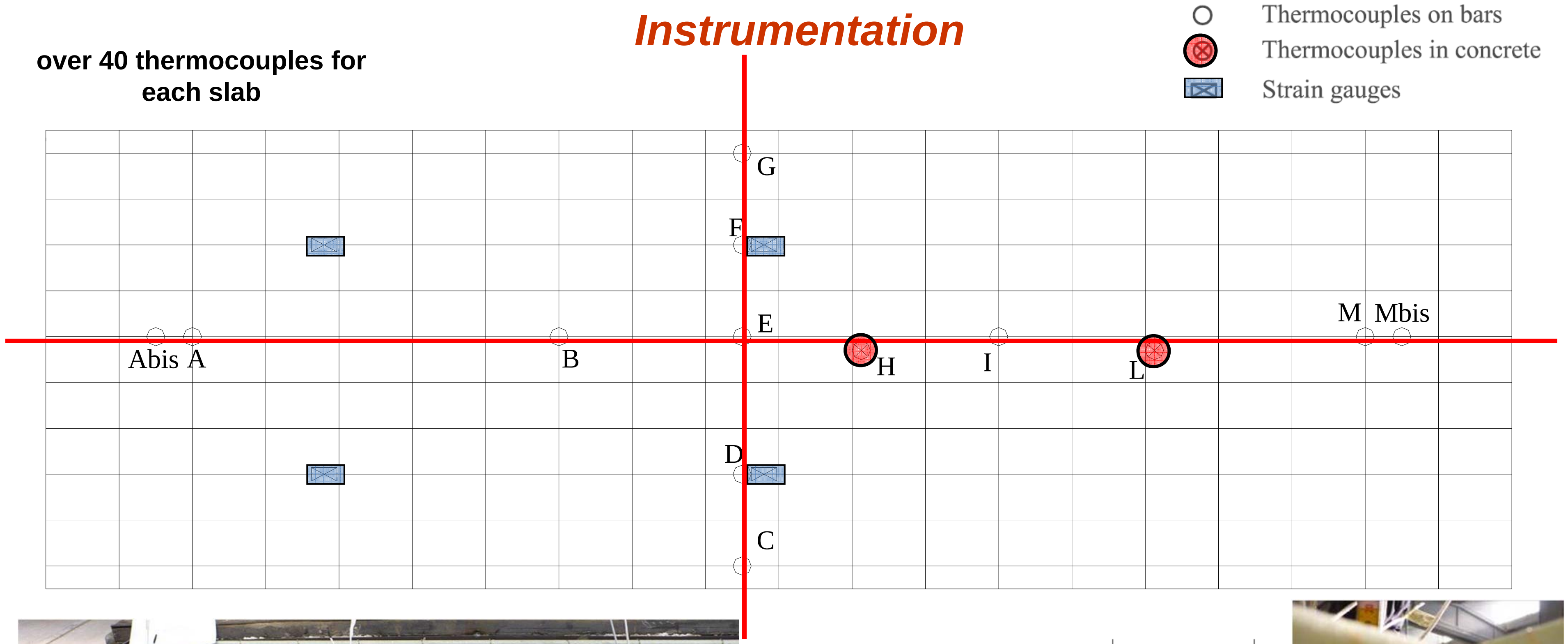
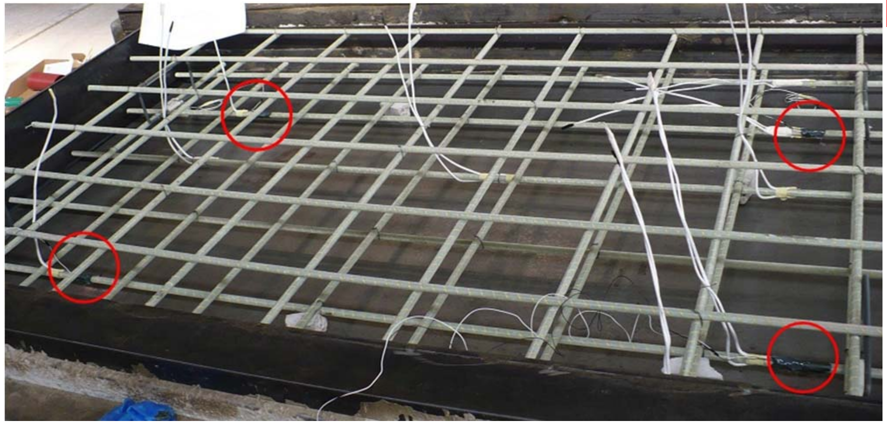
- The paper deals with the structural behaviour of concrete slabs reinforced with FRP bars or grids in the case of **high temperatures**, due to fire event.
- The **mechanical properties** of FRPs deteriorate when high temperatures arise in those materials, resulting in a significant **decrease of performances** of the FRP-reinforced structural members.
- Even if several international codes are available for the design of concrete structures reinforced with FRP bars, few provisions and calculation models taking account of fire condition are suggested.

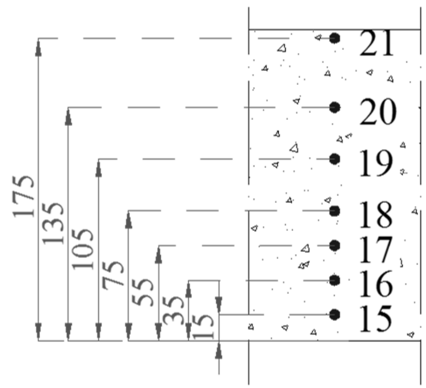
- Within a research program the authors have already tested in fire condition **six concrete slabs** reinforced with GFRP bars, characterized by different values of **concrete cover** and **anchoring length**, by exposing them to heat in a furnace according to the time-temperature curve ISO834.
- Based on such results, **three further fire tests** have been recently carried out on three slabs reinforced with GFRP **bars bent at the end** of the member, in order to improve the anchorage of the bars within the short zone not directly exposed to fire.
- In the following the results of all the fire tests are summarized making possible a comparison between the different anchorage efficiency

Instrumentation

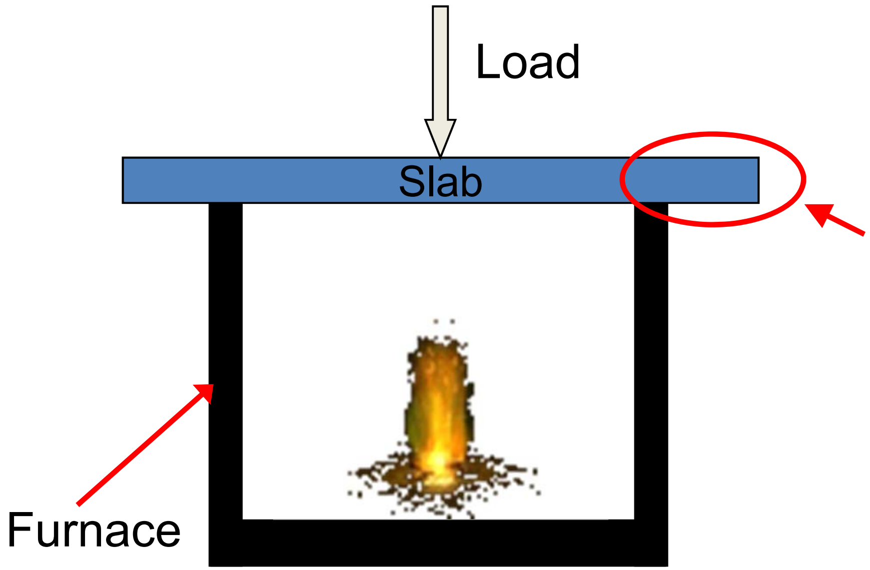
over 40 thermocouples for each slab







Test setup



Parameters

- Concrete cover
- Length of zone outside the furnace
- Bars type (straight or bent)
- Fire load level $\eta_{fi} = M_{Ed,fi}/M_{Rd}$

End zone of slab not directly exposed to fire → Anchorage length

Note: A continuous reinforcement from side to side of the concrete element is used .

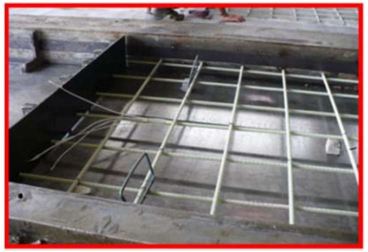
Test matrix

Geometrical properties
Slabs thickness = 180 mm
Slabs width = 1250 mm
Span length = 3200 mm

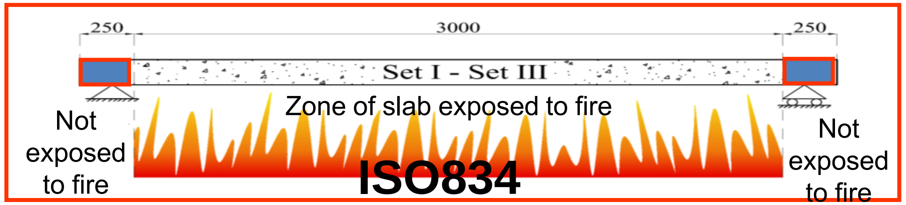
Materials
Concrete C35/45
GFRP bars (E glass fibers and ortophtalic polyester resin, T_g = 100°C)

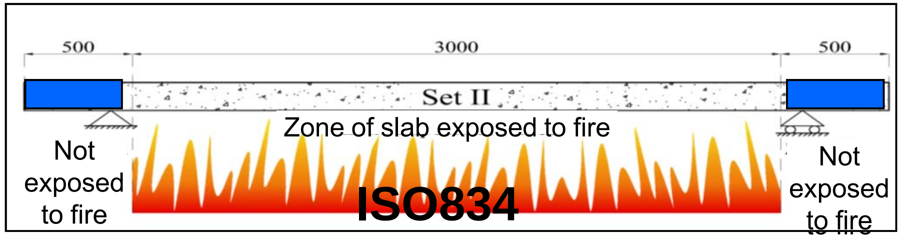
Set	Slab	Concrete cover *[mm]*	Anchorage length *[mm]*	Longitudinal (diameter/ spacing) *[mm/mm]*	Longitudinal Bars no.	M_{Rd} *[kNm]*
I	S1	32	250 straight bars	Φ12/150	9	65
	S2					
	S3			Φ12/225	6	46
II	S4	51	500 straight bars	Φ12/125	10	65
	S5					
	S6			Φ12/200	7	46
III	S7	32	250 bent bars	Φ12/150	9	65
	S8					
	S9			Φ12/225	6	46

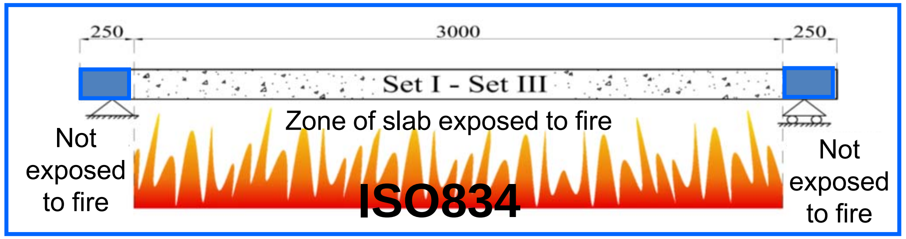
straight bars



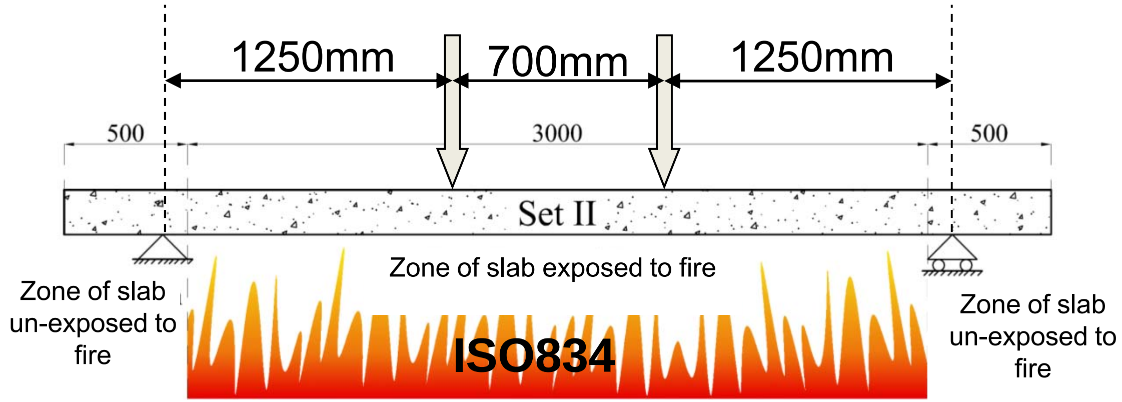
bent bars

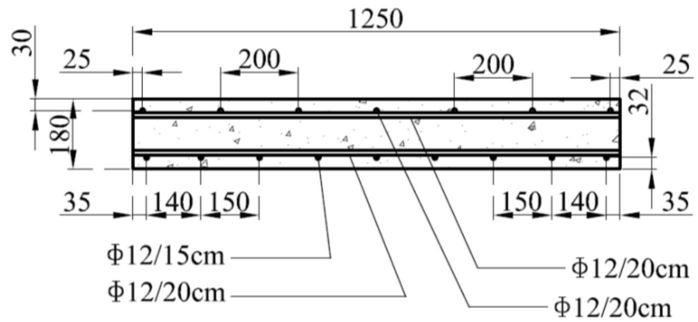






Load





Fire Load level → $\eta_{fi} = M_{Ed,fi,t}/M_{Rd}$

S1, S4, S7 → 10% of M_{Rd} (own weight)

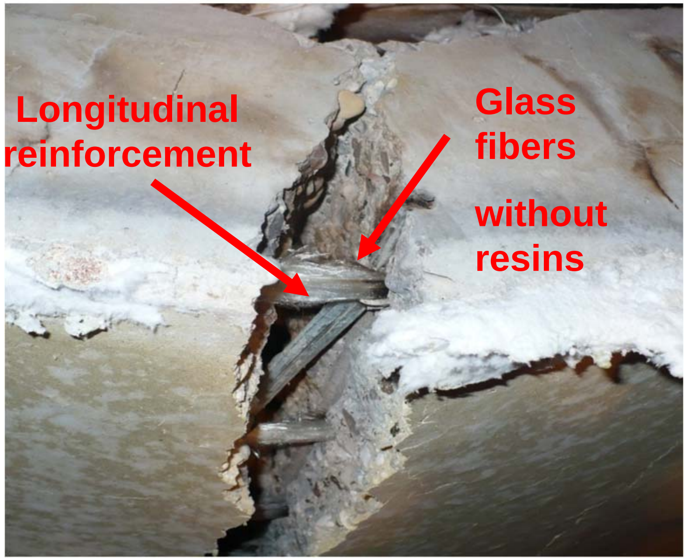
S2, S5, S8 → 40% of M_{Rd} (F=17.5kN)

S3, S6, S9 → 60% of M_{Rd} (F=17.5kN)

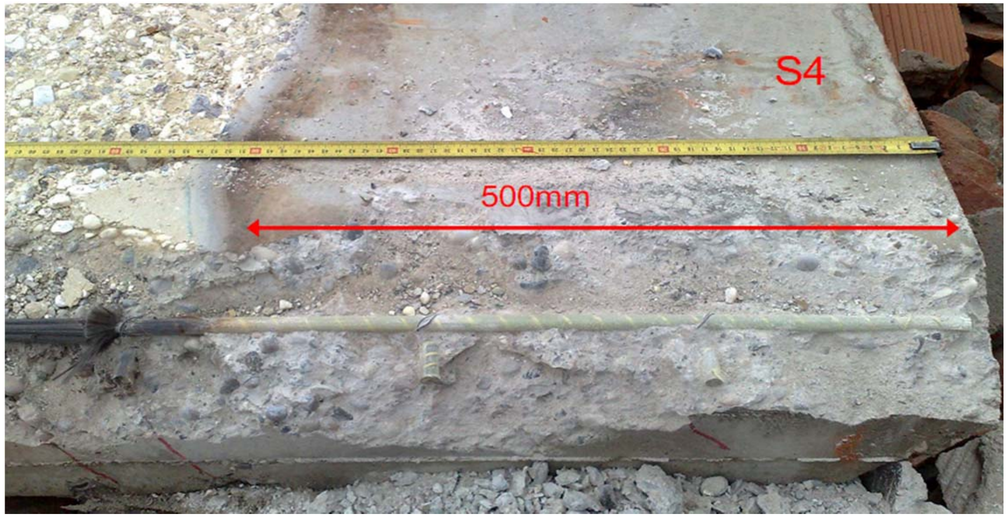
Observations after tests

Slabs S4-S5-S6: Fiber failure at midspan

Inside the furnace: bars $c = 51mm, L_{unexp} = 500mm$



Section: end of slab

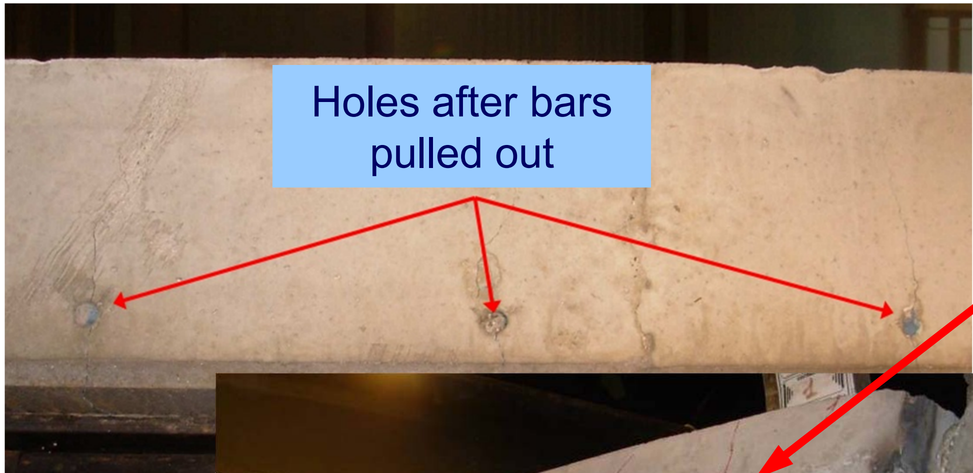


Observations after tests concerning the anchorage zone – STRAIGHT BARS

Slabs S1-S2-S3: Pull out of bars

$c = 32mm, L_{unexp} = 250mm$

Section: end of slab



Cracks on transverse section at the end of the slab (correspondence crack/bar)

Bar

Coating

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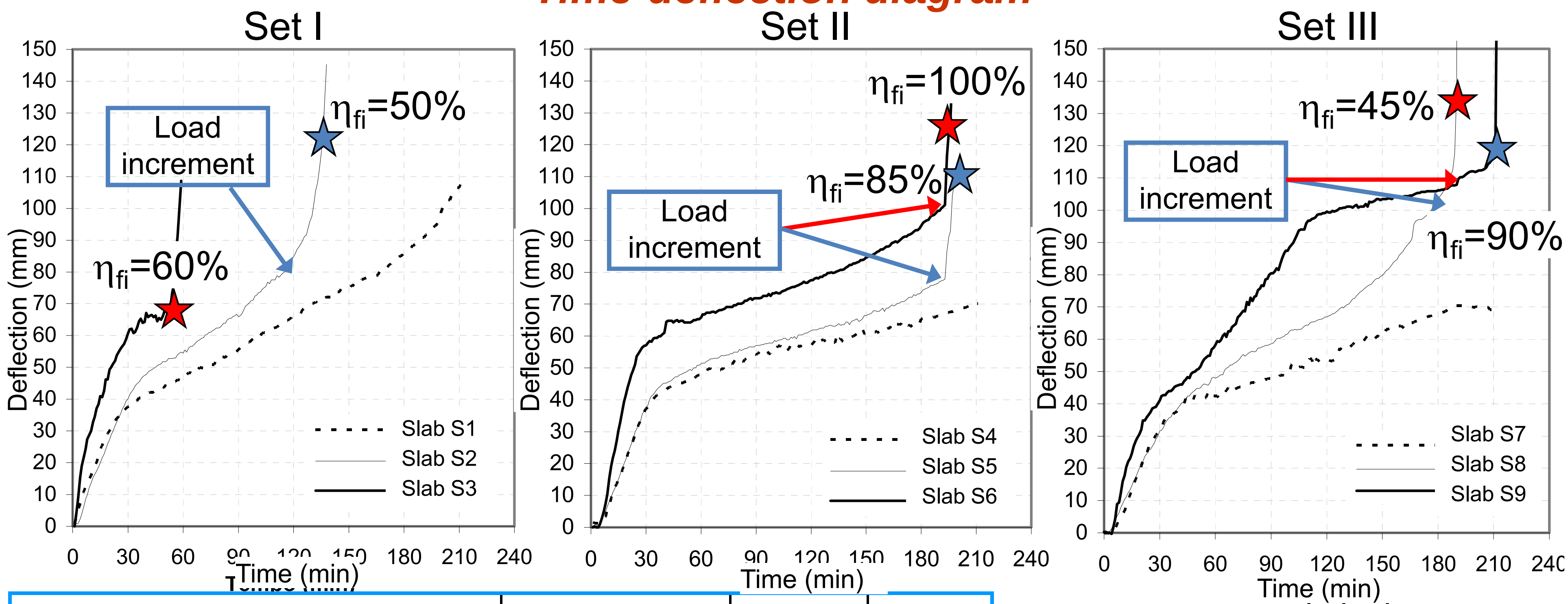
Observations after tests concerning the anchorage zone – BENT BARS

Slabs S7-S8-S9: no pull out of bars
c = 32mm, L_{unexp} = 250mm

Cracks on transverse section at the end of the slab in correspondence of each bar without pull out.

Time-deflection diagram



Set	Slab	*c* *[mm]*	*L_{unexp}* *[mm]*	Bar's end	STAGE 1 *η_{fi}* *[%]*	STAGE 1 *t_e* *[min]*	STAGE 2 *η_{fail}* *[%]*	Type of failure
I	S1	32	250	Straight	10	>180	55 *	Bars pull out
	S2				40	120	50	
	S3				60	60	-	
II	S4	51	500	Straight	10	>180	100 *	Bars rupture
	S5				40	>180	85	
	S6				60	>180	100	
III	S7	32	250	Bent	10	>180	60 *	Bars rupture
	S8				40	>180	45	
	S9				60	>180	90	

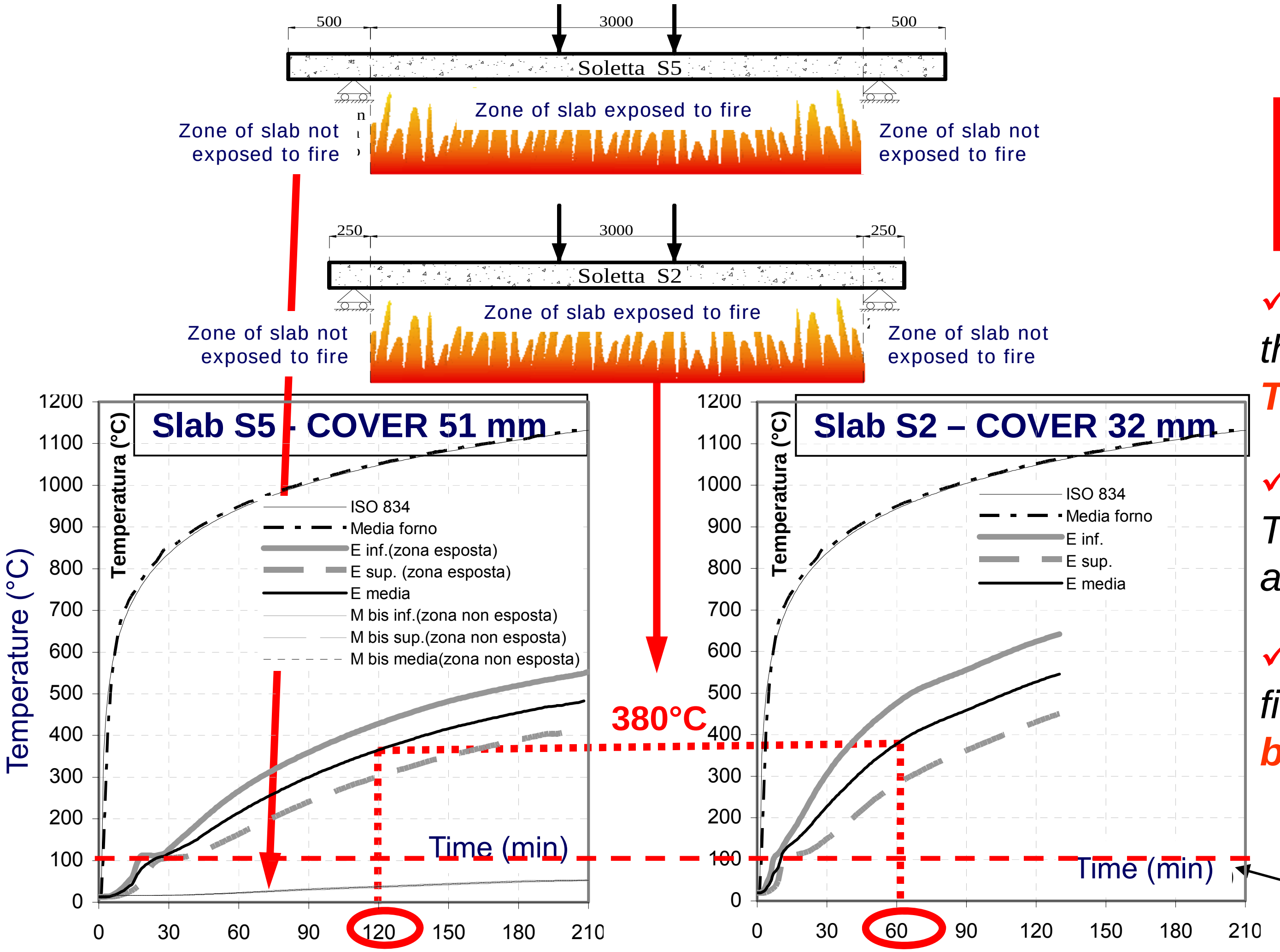
STAGE 1: constant load
STAGE 2: increasing load

c = concrete cover
L_{unexp} = un-exposed length
$\eta_{fi} = M_{Ed,fi,t}/M_{Rd}$ (constant load)
$\eta_{fail} = M_{Ed,fi,t}/M_{Rd}$ (at failure)

* *Residual strength*

Main remarks on temperature levels and concrete cover

Comparison between thermal field in two typologies of slabs



Cover

T_g after about 15min for S2

T_g after about 25min for S5

✓*Cover thickness affects the time needed to achieve **T_g in the bars***

✓*In the **unexposed zone** T_g in the bars is not achieved*

✓*In the zone exposed to fire the **overlapping of bars** cannot be used*

Thermal behaviour

- ✓ ***Concrete cover*** ***was confirmed particularly meaningful for the protection provided to FRP bars, allowing to delay the attainment of high temperature values in the bars.***
- ✓ ***In a part of the zone not directly exposed to fire (as a function of fire exposure time) the bars didn't attain the glass transition temperature T_g.***

Mechanical behaviour

- ✓ ***When the bars temperature achieves the glass transition value, there is a significant reduction of bond between FRP bars and concrete.***
- ✓ ***The mechanical behaviour of tested slabs has been characterized by the migration of bars stresses from the zone directly exposed to fire to the anchorage zone (i.e. the zone not directly exposed to fire action).***
- ✓ ***When the glass transition temperature is achieved in the zone directly exposed to fire, the structural behaviour depends mainly on the length of unexposed zone (anchorage length) and on the bars type (straight or bent).***

Structural details

- ***The anchorage obtained simply by bending bars at the end of member in a short zone (250mm) allowed to attain a good structural behavior in case of fire, equivalent to that shown by slabs characterized by a large anchoring length (500mm).***
- ***The production process allowing the bar to be bent is easily implemented by FRP bars manufacturers owing technologically advanced systems.***