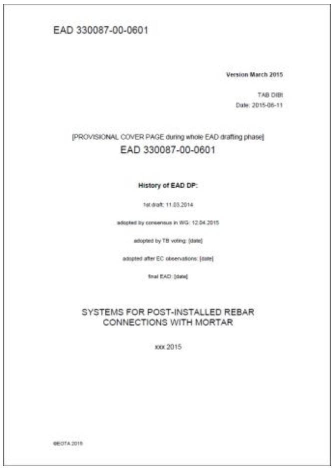
QUALIFICATION OF POST INSTALLED REBAR SYSTEM

Ir Ng Beng Hooi
24th September 2018

CONTENTS

- 1.0 The New ETA and Consideration behind EAD
- 2.0 Design life for Post Installed Rebar and Anchor
- 3.0 Fire Design for Post Installed Rebar
- 4.0 Seismic for Post Installed Rebar

EAD 330087 INCLUDES THE KEY APPLICATIONS WHICH CAN BE DESIGNED WITH POST-INSTALLED REBAR


EAD 330087-00-0601

Version March 2015

TAB DIBt

Date: 2015-06-11

[PROVISIONAL COVER PAGE during whole EAD drafting phase]

EAD 330087-00-0601

History of EAD DP:

1st draft: 11.03.2014

adopted by consensus in WG: 12.04.2015

adopted by TB voting: [date]

adopted after EC observations: [date]

final EAD: [date]

SYSTEMS FOR POST-INSTALLED REBAR CONNECTIONS WITH MORTAR

xxx 2015

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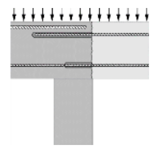
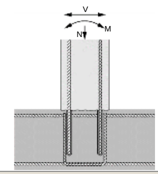
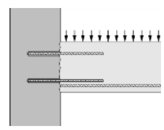


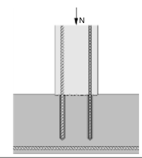
Overlap joint for rebar connections of slabs and beams



Overlap joint at a foundation of a column or wall

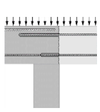
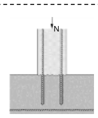
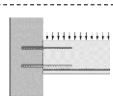
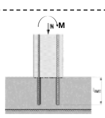


End anchoring of slabs or beams (simply supported)

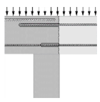
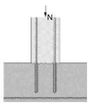
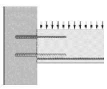
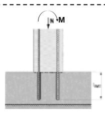


Components stressed primarily in compression

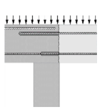
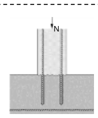
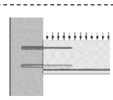
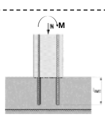
SUMMARY OF QUALIFICATION AND DESIGN AS PER EAD 330087 FOR EACH APPLICATION

	Application	Qualification	Design
Splices		**EAD**	**Eurocode 2**
Compres.		**EAD**	**Eurocode 2**
Simply supp.		**EAD**	**Eurocode 2**
Rigid connect.			

CURRENT APPLICATION OF HILTI METHOD: SIMPLY SUPPORTED AND RIGID CONNECTIONS

	Application	Qualification	Design	Hilti design
Splices		EAD	Eurocode 2	
Compres.		EAD	Eurocode 2	
Simply supp.		EAD	Eurocode 2	HIT Rebar Method first version for HY200 and RE500V3
Rigid connect.				Hilti frame node model based on EC2 + HIT Rebar Method first version for HY200 and RE500V3

CURRENT APPLICATION OF HILTI METHOD: SIMPLY SUPPORTED AND RIGID CONNECTIONS

	Application	Qualification	Design	Hilti design
Splices		EAD	Eurocode 2	
Compres.		EAD	Eurocode 2	
Simply supp.		EAD	Eurocode 2	HIT Rebar Method first version for HY200 and HIT Rebar Method second version for RE500V3
Rigid connect.				Hilti frame node model based on EC2 + HIT Rebar Method first version for HY200 and HIT Rebar Method second version for RE500V3

LIST OF RELEVANT EOTA DOCUMENTS FOR QUALIFICATION OF POST-INSTALLED REBAR

Document	Organisation	Roles and functions	Remarks
EAD 330087 (2018)	EOTA	Qualification of post-installed reinforcement in Europe under static loading and fire exposure.	Replacing EOTA TR 023 (2006). Design as per MS EN 1992-1-1 (2010) and EN 1992-1-2 (2004).
EAD 331522 (endorsed draft 2018)	EOTA	Post-installed rebar with mortar under seismic action	Publication expected 2019. Design as per MS EN 1992-1 (2010).
EAD 330499 (2017)	EOTA	Qualification of post-installed anchors in Europe under static loading.	Replacing ETAG 001, Part 5 (2006). Design according to EN 1992-4 (2018).
EOTA TR 049 (2016)	EOTA	Qualification of post-installed anchors in Europe under seismic loading.	Design according to EN 1992-4 (2018) or EOTA TR 045 (2013).

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BACKGROUND

Where do service life requirements come from?

1. Eurocode 1990 "working life category 5" - infrastructure

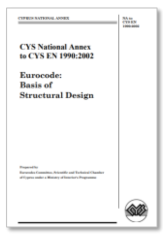
Adapted from EN 1990 Table 2.1 —"Indicative design working life"

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures
2	10-25	Replaceable structural parts
3	15-30	Agricultural and similar structures
4	50	Buildings and other common structures
5	**100**	**Monumental buildings, bridges, and other civil structures**

Image source: Hilti image bank

2. National standards

Examples: UK, Italy, Cyprus



Hyperlinks to documents embedded in image

3. Owners

Example: Burj Khalifa

Image source: CNN

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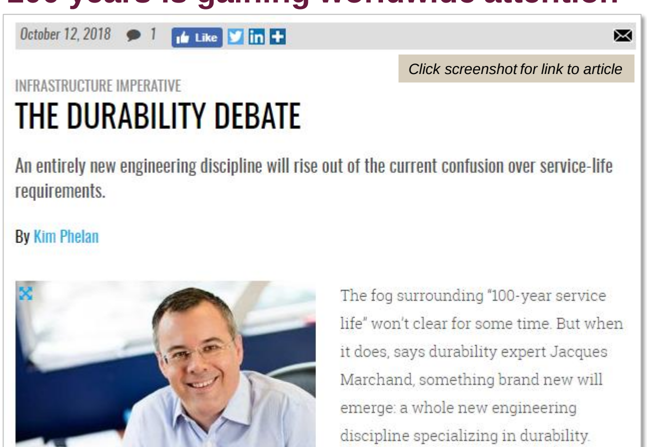
BACKGROUND

100 years is gaining worldwide attention – and confusion



October 12, 2018 1 Like

Click screenshot for link to article

INFRASTRUCTURE IMPERATIVE

THE DURABILITY DEBATE

An entirely new engineering discipline will rise out of the current confusion over service-life requirements.

By Kim Phelan

The fog surrounding "100-year service life" won't clear for some time. But when it does, says durability expert Jacques Marchand, something brand new will emerge: a whole new engineering discipline specializing in durability.

Article summary

- 100 years is a hot topic right now, but there is no guidance for how to address it
- Owners must be more clear about their expectations up-front in order to meet them
- "Durability" is a vague word that nobody has seriously considered for service life

Service life for anchors/PIR

- Assessment of anchors and rebar has always implied a 50-year service life
- Where 100 years is needed, it has been handled on a case-by-case basis
- No harmonized standards have accounted for service life, leaving confusion about how to extend it

With the first ETA for 100-year assessment of anchors, Hilti is taking the first step to clearing up the confusion in our industry and taking a role in the bigger conversation about service life.

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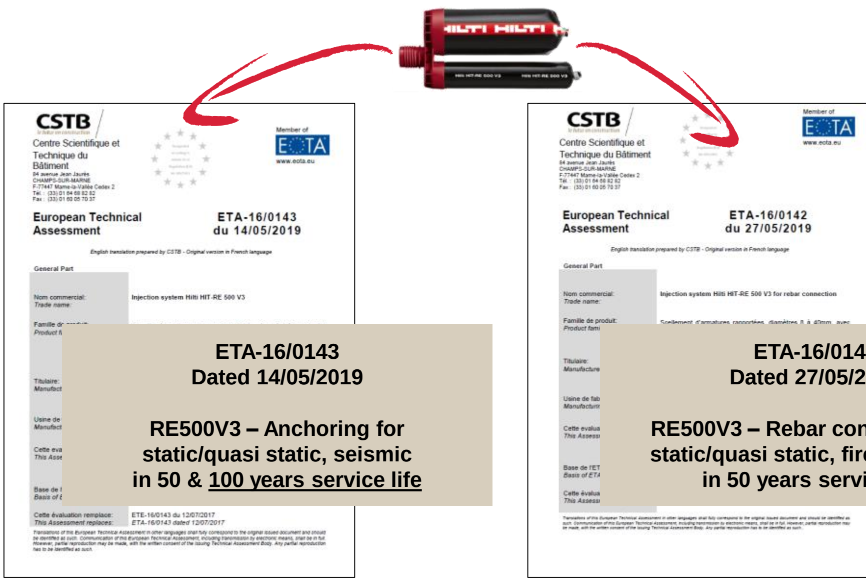
NEW ETA ADDRESSING THE 100YR SERVICE LIFE TOPIC WHICH FOLLOW A NEW EAD



ETA-16/0143
Dated 14/05/2019

RE500V3 – Anchoring for static/quasi static, seismic in 50 & <u>100 years service life</u>

ETA-16/0142
Dated 27/05/2019

RE500V3 – Rebar connection for static/quasi static, fire & seismic in 50 years service life

TESTING FOR 50 YEARS

Scope, EAD 330499 (bonded fasteners): *The performance characteristics are consistent with the design provisions of EN 1992-4 and* ***are based on a design working life of 50 years*** *.*

So, which tests actually connect to 50 years?

time/cycle-independent tests

- reference tests
- “robustness” (dry, wet, flooded, poorly mixed)
- max long/short-term temp.
- maximum torque moment
- installation direction
- service condition tests

→ *not relevant for service life*

time/cycle-dependent tests

- freeze/thaw
- durability (alkalinity/sulfur)
- seismic tests

→ *testing/assessment not tied to 50 years*

- sustained load
- crack movement

→ *testing/assessment are tied to 50 years*

Must be considered in a 100-year EAD

IS DIFFERENCE PULL OUT TEST AT SITE AND SUSTAINED LOAD TEST IN LABORATORY

CONTENTS

WHY IS FIRE DESIGN IMPORTANT? FUNDAMENTAL REQUIREMENTS ACCORDING TO EC2

When subjected to fire exposure construction elements performances are reduced causing fall of structures→ Fire causes significant costs losses and deads

In the event of fire have adequate resistance for the required period of time exposure: concrete structure shall be designed and constructed in a way that they maintain their load bearing function during the relevant fire exposure.
(Eurocode 2 provisions)

EUROPEAN REGULATORY FRAMEWORK FOR POST-INSTALLED REBAR

"Rebar theory"
"Design of rebar as a rebar"

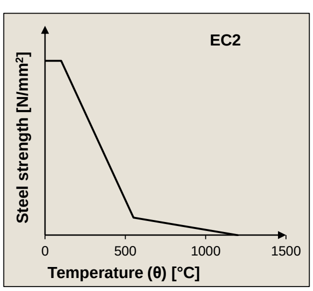
	Static	Fire	Seismic
Product Qualification	EAD	EAD	x
Technical data	ETA	ETA	CSTB regional approval
Design method	EC2	EC2	EC2 based

WHICH ARE THE PARAMETERS TO BE DEFINED FOR A FIRE DESIGN BASED ON EC2?

1. Fire resistance criteria
2. Time exposure
3. Design approach
4. External fire action
5. Fire structural resistance

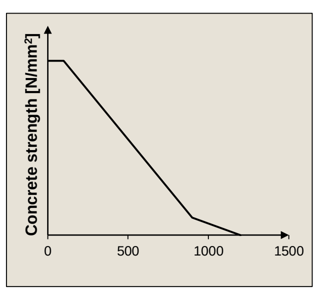
WHEN SUBJECTED TO FIRE EXPOSURE CONSTRUCTION ELEMENTS RESISTANCE IS REDUCED

Steel



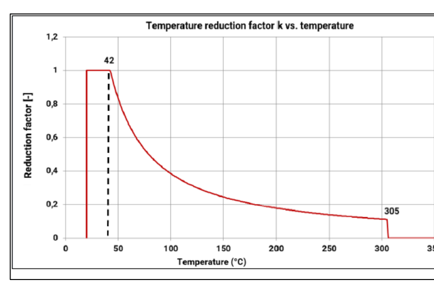
- Reduction of strength when subjected to high temperatures

Concrete



- Efficiently behaviour in fire conditions
- Non-combustible
- No emissions of smoke
- Good thermal insulation

Mortars



- Mortars have high sensitivity to temperatures, it should be part of the consideration in our PIR design

IN THE REGULATORY FRAMEWORK OF REBAR THEORY A NEW EAD FOR FIRE IS AVAILABLE

	Old!	New!
Qualification (“testing”)	**CSTB, DIBt, Efectis, CTICM have internal qualification criteria*** (National level)	NEW **EAD «Rebar Fire»** (European level)
Tech. Data (“approval”)	**DIBt / Efectis / CTICM / CSTB reports**	**ETA** (for post-installed rebar) **e.g. ETA 15/0297**
Design	**Local design recommendations**	**EN 1992-1 (Eurocode 2 - Part 1.2)**

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

THE NEW EAD INCLUDES METHODS AND CRITERIA FOR ASSESSING THE FIRE PRODUCT PERFORMANCE

The **European Assessment Document (EAD)** is a harmonised technical specification in the sense of Regulation (EU) No 305 /2011 (CPR).

It contains, at least,

- a general description of the construction product and its intended use (Chapter 1 - Scope),
- the list of essential characteristics relevant for the intended use (Chapter 2) and
- methods and criteria for assessing the performance of the product (Chapter 2),
- principles for the applicable factory production control (Chapter 3 - AVCP).

An **EAD-format** has been agreed with the European Commission in March 2015 which is used by all EAD writers aiming at consistency and comparability of the information provided.

Adopted EADs are used by Technical Assessment Bodies organized in EOTA for issuing European Technical Assessments (ETA). Titles of adopted EADs according to Annex II.7 to the CPR are announced on this website under “Publications/EADs” once an ETA is issued.

The reference of **final EADs** is published by the European Commission in the Official Journal of the European Union (OJEU) and provided in NANDO. Once the EAD reference is published in the OJEU, EOTA provides final EADs for download on this website.

Member States or the European Commission may raise **formal objections** against EADs.

Products are tested according to a specific established procedure.

IN THE REGULATORY FRAMEWORK OF REBAR THEORY FIRE PERFORMANCE IS INCLUDED IN THE ETA

	Old!	New!
Qualification ("testing")	CSTB, DIBt, Efectis, CTICM have internal qualification criteria* (National level)	EAD «Rebar Fire» (European level) NEW
Tech. Data ("approval")	**DIBt / Efectis / CTICM / CSTB reports**	**ETA (for post-installed rebar) e.g. ETA 15/0297** NEW
Design	Local design recommendations	EN 1992-1 (Eurocode 2 - Part 1.2)

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

DIBT AND CSTB REPORTS INCLUDE TABULATED VALUES OF BOND STRENGTH OR LOAD FOR FEW APPLICATIONS

HILTI HIT-HY 200-A&R	Bonding stress (MPa)					
Concrete cover (mm)	R 30	R 60	R 90	R 120	R 180	R 240
10	0.2					
20	0.4	0.2				
30	0.8	0.3	0.2			
40	1.7	0.5	0.2	0.2		
50	3.3	0.8	0.4	0.3	0.2	
60	6.4	1.2	0.6	0.4	0.2	
70	9.7	2.0	0.9	0.5	0.3	0.2
80	12.0	3.3	1.3	0.8	0.4	0.3

- Wall to wall connections
- Only member analysis possible
- R criteria

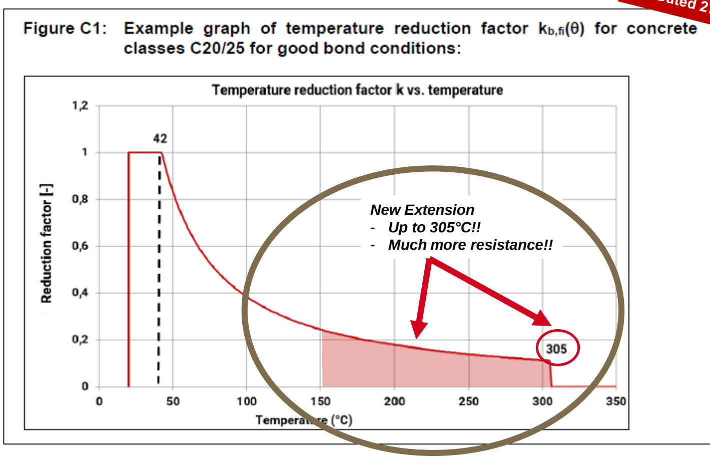
HILTI HIT-HY 200-A&R									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
			80	5.8	2.4	1.4	1.2	1.0	1.0
			90	7.8	3.4	2.0	1.6	1.3	1.3
			100	9.9	4.8	2.7	2.1	1.6	1.6
			110	12.2	6.4	3.7	2.8	2.1	1.9
			120	14.6	8.3	5.0	3.7	2.6	2.3
			130	16.2	10.3	6.5	4.9	3.3	2.8
			140		12.4	8.2	6.2	4.1	3.4
			150		14.7	10.1	7.8	5.2	4.1
			160		16.2	12.1	9.5	6.4	4.9

- Slab to wall connections
- Only member analysis possible
- R criteria

THE NEW ETA PROVIDES A BOND STRENGTH AS FUNCTION OF TEMPERATURE

THE FIRE CURVE IS NOW EXTENDED TO 305°C.

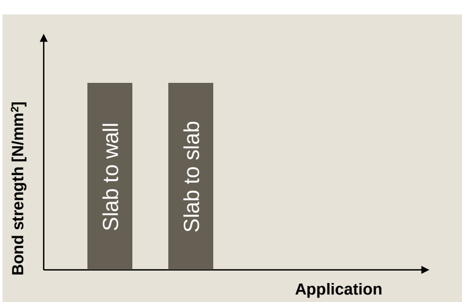
NEW ETA-16/0142
Dated 27/05/2019



- *The fire curve shows the mortar behavior in fire*
- *The reduction factor calculated based on temperature is applied to the characteristic bond strength in order to calculate the fire bond strength*

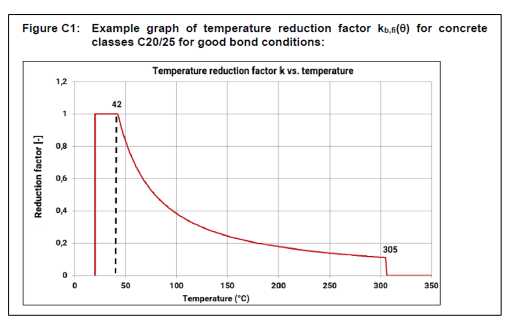
IN THE PAST, THE BEHAVIOR OF THE MORTAR WAS FUNCTION OF APPLICATIONS

Old!



Bond strength as function of application

New!



Bond strength as function of temperature: every application is covered!

THE EC2 PROVIDES THE GUIDELINES FOR THE DESIGN OF CONCRETE STRUCTURES IN FIRE CONDITIONS

	Old!	New!
Qualification ("testing")	CSTB, DIBt, Efectis, CTICM have internal qualification criteria* (National level)	EAD «Rebar Fire» (European level) NEW
Tech. Data ("approval")	DIBt / Efectis / CTICM / CSTB reports	ETA (for post-installed rebar) e.g. ETA 15/0297 NEW
Design	**Local design recommendations**	**EN 1992-1 (Eurocode 2 - Part 1.2)**

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

THE NEW DESIGN VALUES TAKE INTO ACCOUNT DIFFERENT CONDITIONS

Old

- Only conditions assumed in the testing phase are taken into account
- Unknown safety concept developed by CSTB/DIBt internally
- Safety concept not aligned with EC2 safety margins

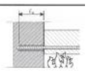
New

- The same logic of cold design is applied and as a consequence several different conditions are taken into account (in a cold design):
  - Robusteness of the mortar
  - Robusteness of the installation
  - Long term behavior
  - Corrosion
  - Cyclic temperatures
  - Cracked concrete
- Safety concept in line with EC2

THE CONCRETE COVER IS A PARAMETER CONSIDERED IN THE FIRE DESIGN TABLES FOR HIT-RE 500 V3

Old

Tabelle 1a: Bemessungswert der Zugkraft $N_{Rd,fi}$ beim Nachweis entsprechend Abschnitt 3.3 zur Einordnung in Feuerwiderstandsklassen; Bewehrungsanschluss senkrecht zur brandbeanspruchten Oberfläche in Platten und Wänden



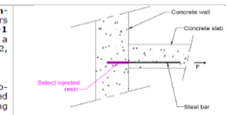
Stabdurchmesser	Setztiefe	Feuerwiderstandsklasse				
		R30	R60	R90	R120	R180
d_s	ℓ_v	$N_{Rd,fi(30)}$	$N_{Rd,fi(60)}$	$N_{Rd,fi(90)}$	$N_{Rd,fi(120)}$	$N_{Rd,fi(180)}$
mm	cm	kN	kN	kN	kN	kN
8	8,0	2,4	1,0	0,5	0,3	0,0
	9,5	3,9	1,7	0,9	0,6	0,1
	11,5	7,3	3,1	1,7	1,1	0,4
	15,0	16,2	8,2	4,6	3,1	1,4
	18,0		16,2	10,0	6,7	2,9
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,1
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7,0
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16,2
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,7
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,3
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,6
	19,5		25,3	17,6	12,2	5,1
	22,0			25,3	20,7	8,7
	23,5				25,3	11,6
	28,0					25,3
12	12,0	12,8	5,3	3,0	2,0	0,8
	15,0	25,2	12,2	6,9	4,7	2,1
	18,0	36,4	24,3	15,0	10,1	4,4
	21,0		36,4	27,4	20,6	8,5
	23,5			36,4	31,0	14,2
	25,0				36,4	19,1
	29,5					36,4
14	14,0	24,6	10,9	6,1	4,2	1,9
	17,0	39,1	23,5	13,5	9,2	4,1
	19,5	49,6	35,6	24,7	17,1	7,2
	22,5		49,6	39,2	31,3	13,5
	25,0			49,6	43,4	22,3
	26,5				49,6	29,5
	31,0					49,6

Concrete cover is not a parameter

New

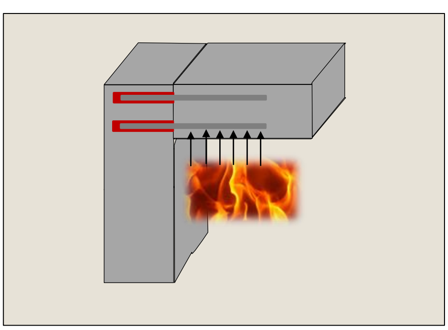
The table presents design load resistances for a **Beam-Wall connection** using **C20/25 concrete** and rebars with a yield strength **f_y=500 N/mm²** in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for a **concrete cover of 40 mm** and for diameters 8, 10, 12, 14, 16, 20, 25, 28 and 32 mm

The design load values may be used safely for a slab-wall connection. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.

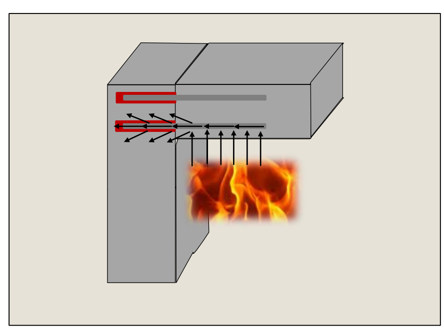


Concrete Cover = 40 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
8	100	4.9	1.8	0.8	0.4	0.0	0.0
	140	8.4	5.0	2.9	1.9	0.7	0.2
	180	11.9	8.5	6.2	4.5	2.3	1.3
	220	15.4	11.9	9.7	8.0	4.9	3.1
	240	16.8	13.7	11.4	9.7	6.6	4.3
	280		16.8	14.9	13.2	10.1	7.6
	310			16.8	15.8	12.7	10.2
	330				16.8	14.4	11.9
	360					16.8	14.5
	390						16.8
10	110	7.3	3.1	1.5	0.9	0.0	0.0
	150	11.6	7.3	4.5	3.0	1.3	0.6
	190	15.9	11.7	8.9	6.7	3.5	2.1
	230	20.3	16.0	13.2	11.0	7.2	4.6
	290	26.2	22.5	19.7	17.5	13.7	10.5
	330		26.2	24.0	21.9	18.0	14.9
	350			26.2	24.0	20.2	17.0
	370				26.2	22.3	19.2
	410					26.2	23.6
	440						26.2

CONCRETE COVER AFFECTS THE HEATING TRANSFER ALONG THE ANCHORAGE LENGTH

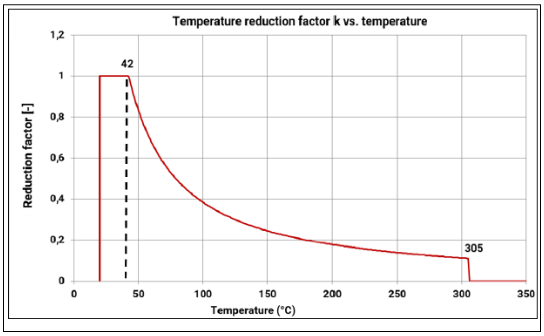


Heat is transferred to the rebar via concrete cover



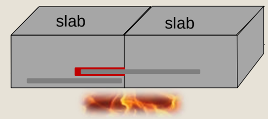
Rebar transfers heat to the mortar

TO SIMPLIFY THE RESISTANCE DESIGN, HILTI PROVIDES DESIGN DATA FOR THE MOST COMMON APPLICATIONS



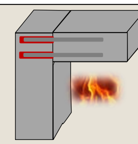
Bond strength or bond loading for limited/specific cases

Slab-to-slab connections



Constant temperature

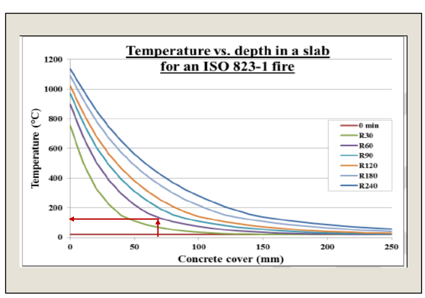
Slab-to-wall connections



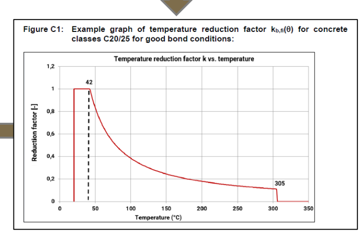
Not-constant temperature

IN PARALLEL CASE THE BOND LOADING CAPACITY CAN BE EASILY CALCULATED IN CASE OF FIRE EVENT

Concrete cover
Exposure time
(parameters coming from the designers)



Temperature



Reduction factor

Reduced bond strength
$f_{bd,fi} = f_{bk} \cdot k_b(\theta_{cr})/\gamma_{M,fi}$

Reduced bond loading capacity ($F_{bd,fi} = f_{bd,fi} \cdot \pi \cdot \phi \cdot l_{bd}$)

DESIGN VALUES FROM HILTI TABLES ARE USED IN THE FIRE DESIGN OF SYSTEM CONNECTIONS BASED ON EC2

- $E_{d,fi} \leq R_{d,t,fi}$
  - $E_{d,fi}$ = design effect of actions for fire situation

    $$E_{d,fi} = \eta_{fi} \, E_d$$

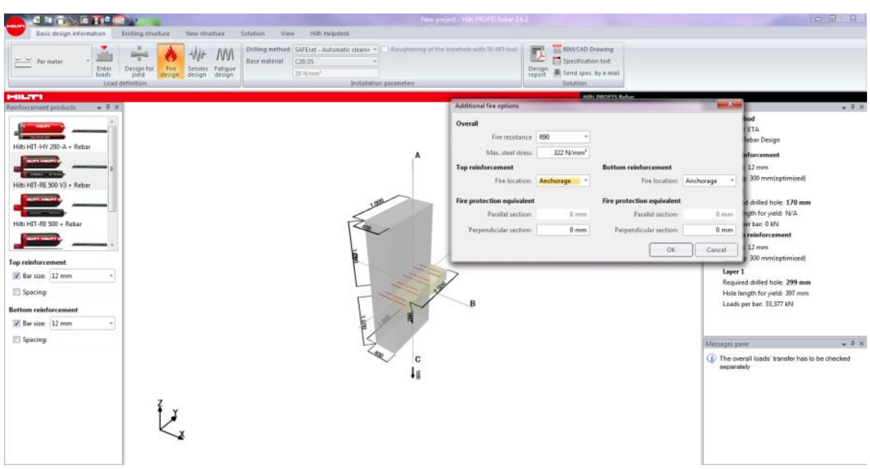
    - η_{fi} = reduction factor for the design load level for the fire situation (recommended simplified value = 0,7)
    - E_d = design value of the corresponding force or moment for normal temperature design, for a fundamental combination of actions
  - $R_{d,t,fi}$ = design resistance in the fire situation

    $$R_{d,t,fi} = \min(F_{bd,fi}; F_{s,fi})$$

    - $F_{bd,fi}$ = fire bond resistance
    - $F_{s,fi}$ = fire steel resistance

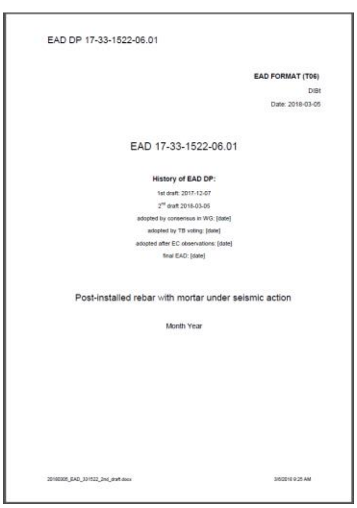
    → $F_{bd,fi} < F_{s,fi}$

PROFIS PROVIDES SOLUTIONS FOR POST-INSTALLED REBAR SYSTEM CONNECTIONS SUBJECTED TO FIRE



CONTENTS

NEW DEVELOPMENT OF THE QUALIFICATION CRITERIA FOR REBAR IN SEISMIC



EAD DP 17-33-1522-06.01

EAD FORMAT (T06)

DIBt

Date: 2018-03-05

EAD 17-33-1522-06.01

History of EAD DP:

1st draft: 2017-12-07

2nd draft 2018-03-05

adopted by consensus in WG: [date]

adopted by TB voting: [date]

adopted after EC observations: [date]

final EAD: [date]

Post-installed rebar with mortar under seismic action

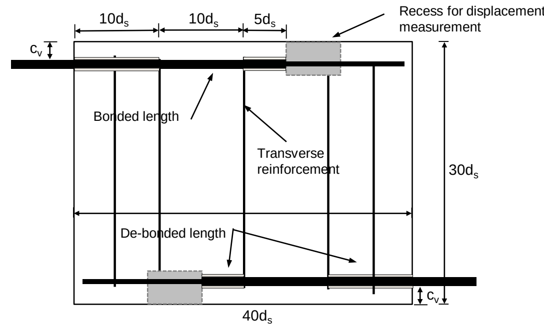
Month Year

This European Assessment Document (EAD) covers post-installed rebar under seismic loading conditions which are assessed in accordance with EAD 330087 [1] for static loading.

This EAD covers post-installed reinforcing bar (rebar) connections designed in accordance with EN 1992-1-1 [2] and EN 1998-1 [3].

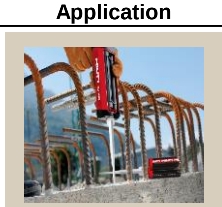
The post-installed rebar connection comprises of a mortar and an embedded straight ribbed (deformed) reinforcing bar complying with EN 1992-1-1 Annex C, classes B and C.

MORE THAN 2 YEARS OF WORK…WITH HUNDREDS OF TESTS!

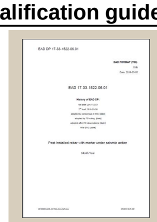


THE QUALIFICATION PROCEDURE ENSURES THAT THE PRODUCT IS TESTED AS PER THE GUIDELINE

Application



Qualification guideline



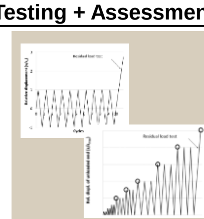
Products

TAB*

CSTB
Centre Scientifique et Technique du Bâtiment

Deutsches Institut für Bautechnik
DIBt

Testing + Assessment

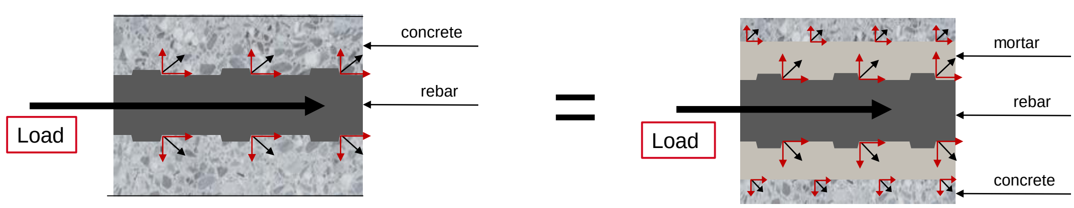


ETA

*: Technical Assessment Body

BASED ON THE QUALIFICATION PROCESS, PIR SHOULD BEHAVE SIMILARLY TO CAST-IN IN SEISMIC

Cast-in rebar | **Post-installed rebar**



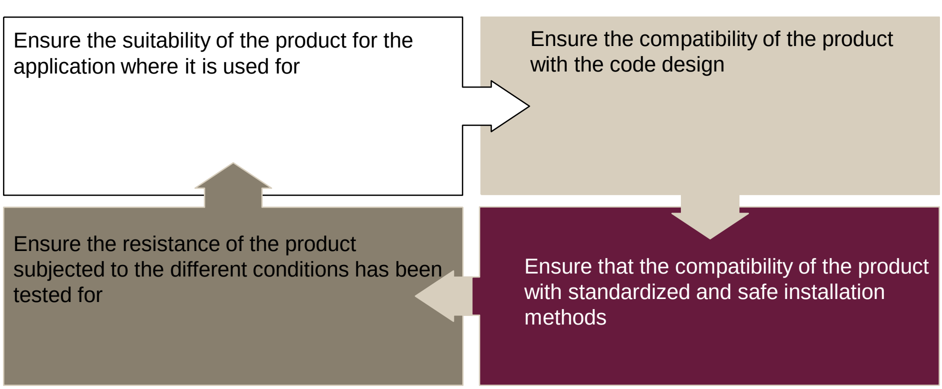
Cast-in rebar

1. Load transferred by **mechanical interlock** provided by the rebar ribs.
2. Mechanical interlock develops **compression struts**
3. Struts lead to rotational tensile stresses **perpendicular** to the **loading direction**.

Post-installed rebar

1. Load from the rebar **transferred to the concrete via the mortar** at the interface
2. Transfer occurs due to **adhesion and micro-interlock** at the rough interface caused by the drilled hole.

THE QUALIFICATION ENSURES THAT THE PRODUCT IS SUITABLE FOR SEISMIC APPLICATIONS

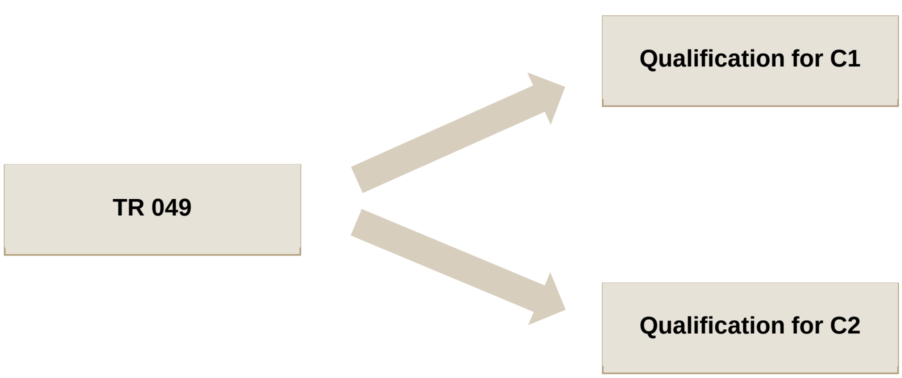


EUROPEAN REGULATORY FRAMEWORK FOR POST INSTALLED REBAR

"Rebar theory"
"Design of rebar as a rebar"

	Static	Fire	Seismic
Product Qualification	EAD		EAD
Technical data	ETA	ETA	ETA
Design method	EC2	EC2	EC8 based

ETAG QUALIFICATION FOR ANCHORS CONSIDERS TWO CONDITIONS C1 AND C2



PEAK GROUND ACCELERATION AND BUILDING CATEGORY ARE DIFFERENT FOR C1 AND C2

Seismicity level[a]		Importance Class acc. to EN 1998-1:2004, 4.2.5			
Class	$a_g \cdot S$ [c]	I	II	III	IV
Very low[b]	$a_g \cdot S \leq 0{,}05\,g$	No additional requirement			
Low[b]	$0{,}05\,g < a_g \cdot S \leq 0{,}10\,g$	C1	C1 [d] or C2 [e]		C2
> low	$a_g \cdot S > 0{,}10\,g$	C1	C2		

[a] The values defining the seismicity levels are may be found in the National Annex of EN 1988-1.

[b] Definition according to EN 1998-1:2004, 3.2.1.

[c] a_g = design ground acceleration on Type A ground (EN 1998-1:2004, 3.2.1),
S = soil factor (see e.g. EN 1998-1:2004, 3.2.2).

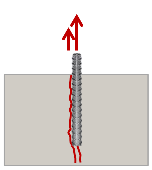
[d] C1 for Type 'B' connections (see 5.1)

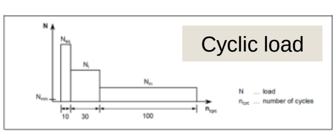
[e] C2 for Type 'A' connections (see 5.1)

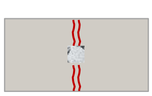
Category C1 or C2 is function of seismicity level (PGA) and importance class of the building

SEISMIC C1 QUALIFICATION CONSIDERS CYCLIC LOADING AND STATIC CRACKING (ANCHOR IS IN THE CRACK)

Tensile test

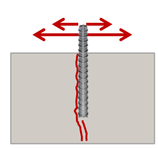


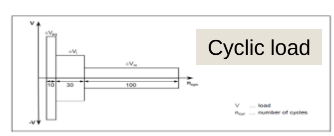


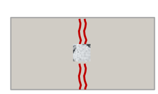


Static crack opened at 0.5 mm

Shear test

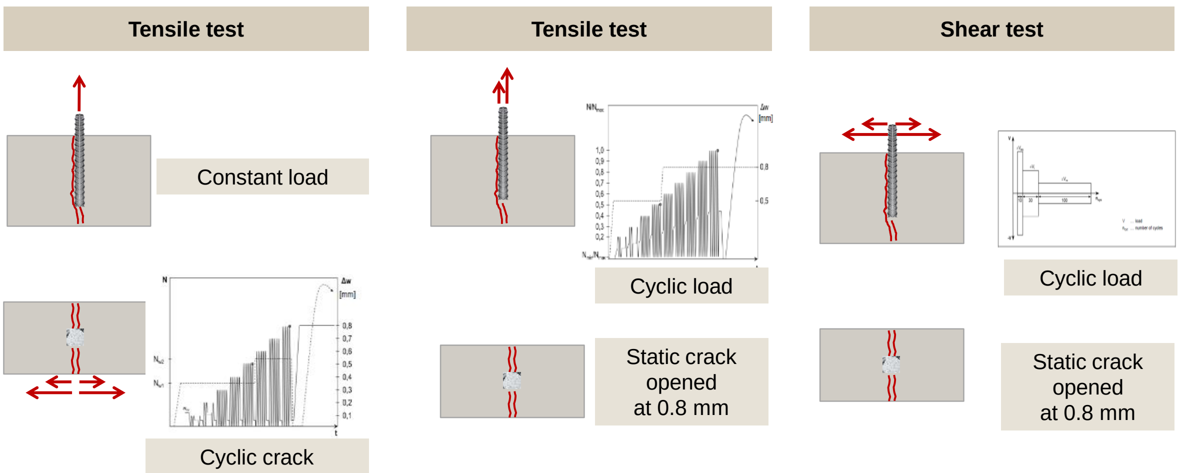




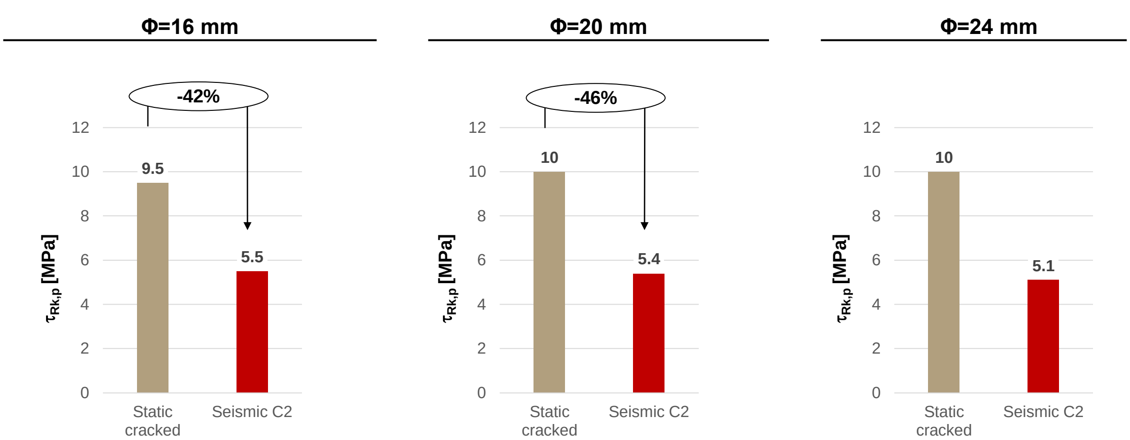


Static crack opened at 0.5 mm

SEISMIC C2 QUALIFICATION CONSIDERS CYCLIC LOADING AND CYCLIC CRACKING (ANCHOR IS IN THE CRACK)

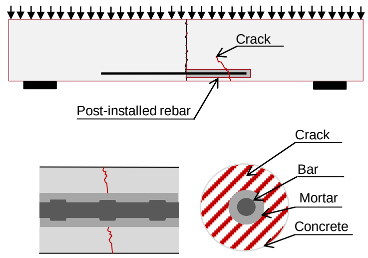


THE CYCLIC ACTION CAN SIGNIFICANTLY AFFECT THE PERFORMANCE

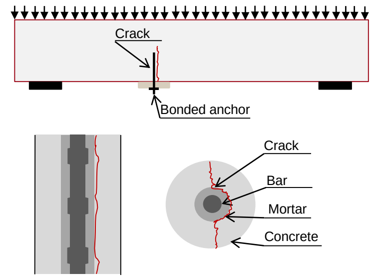


WHY THE QUALIFICATION IS DIFFERENT FOR REBAR? 1) BECAUSE THE CRACK IS NOT PARALLEL TO A REBAR!

“Rebar theory”
“Design of rebar as a rebar”



“Anchor theory”
“Design of rebar as an anchor”



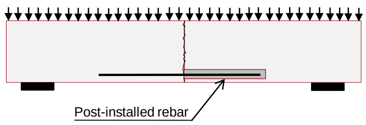
2) BECAUSE THE REBAR IS NOT A SINGLE POINT OF CONNECTION

“Rebar theory”
“Design of rebar as a rebar”

“Anchor theory”
“Design of rebar as an anchor”

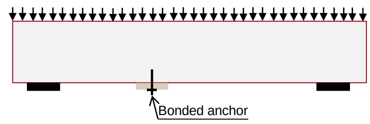
3) ANCHORAGE LENGTH OF REBAR IS IN GENERAL MUCH LONGER THAN AN ANCHOR’S

“Rebar theory”
“Design of rebar as a rebar”



$l_{b,min} = \max(0.3 l_{brqd}, f_{yd}; 10\phi; 100mm) \le l_{bd} \le 60\ \phi$

“Anchor theory”
“Design of rebar as an anchor”



$4\phi \le h_{eff} \le 20\phi$

CAST-IN FAILS FOR YIELDING, SPLITTING AND PULL OUT: IS PIR EQUAL TO CAST-IN WHEN SUBJECTED TO CYCLIC?

Static failure modes

Splitting

Pull out

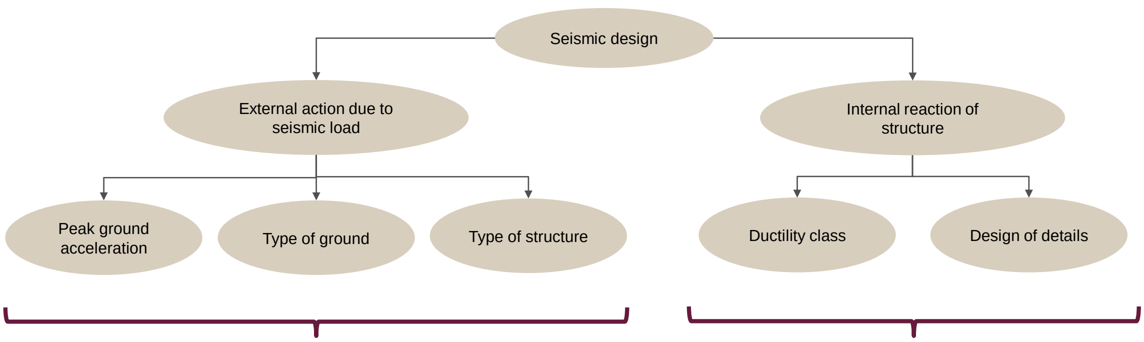
Yielding

Scope of qualification

Assess the equivalence of post-installed rebar with cast-in in terms of bond strength degradation and energy dissipation:

- In splitting: the bar is very close to the edge
- In pull-out: the bar is far from the edge

AS PER CAST-IN BAR, PIR BOND STRENGTH IS NOT FUNCTION OF SEISMIC ZONE (1/2)



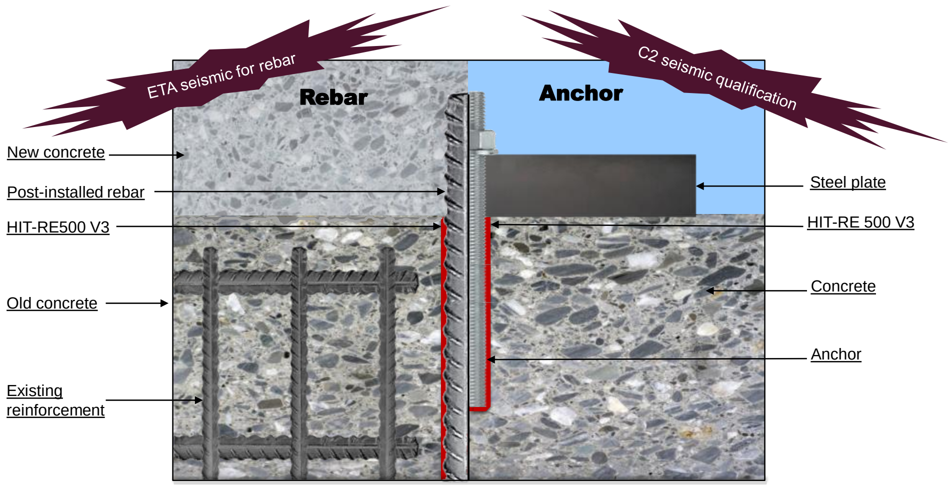
The action on the structure is function of seismic zone

The reaction is a consequence of how the structure has been designed (same logic as per cast-in design)

AS PER CAST-IN BAR, PIR BOND STRENGTH IS NOT FUNCTION OF SEISMIC ZONE (2/2)

Anchor design	Rebar design
Position of the anchor The anchor is installed in the crack. The performance of the anchor in cracked concrete is lower than non-cracked concrete.	**Position of the rebar** In general situations the crack does not develop along the rebar. Rebar connections are not a single point of connection, but rather a multiple connection system. Embedment depth of rebar is significanlty higher than anchors.
C1 and C2 qualification The two categories take into account the performance of the anchor installed in into a crack subjected to loading displacement. C2 is the category for structural elements.	**Seismic qualification** The seismic qualification takes into account the performance of a post-installed rebar subjected to cyclic loading/displacement.
Seismic zone is not considered in the reaction Seismic zone is not considered in the performance of the anchor. The anchor is tested under standardized displacement/force which does not consider the position of the building.	**Seismic zone is not considered in the reaction** Seismic zone is not considered in the performance of the rebar. The rebar is tested under standardized displacement/force which does not consider the position of the building.

REBAR THEORY AND ANCHOR THEORY ARE DIFFERENT THEORIES



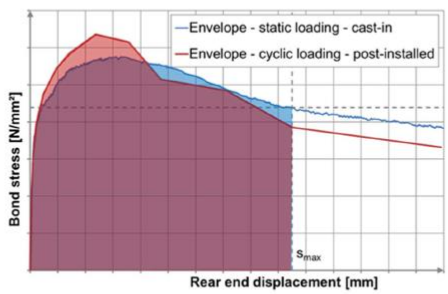
REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

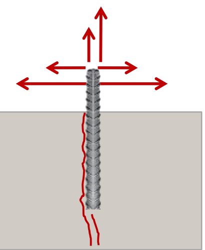
	"Rebar theory" Post-installed rebar	"Anchor theory" Bonded anchor
Seismic qualification	To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.	To assess the performance in cracked concrete subjected to cyclic loading.

REBAR THEORY: EQUIVALENCE WITH CAST IN BAR
ANCHOR THEORY: PERFORMANCE IN CRACKED CONCRETE

"Rebar theory"
"Design of rebar as a rebar"

"Anchor theory"
"Design of rebar as an anchor"





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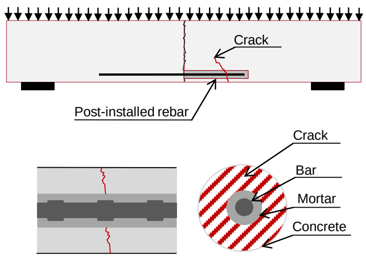
Seismic qualification	To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.	To assess the performance in cracked concrete subjected to cyclic loading.
Position of anchor/rebar with respect to the crack	Uncracked concrete	Parallel to the crack

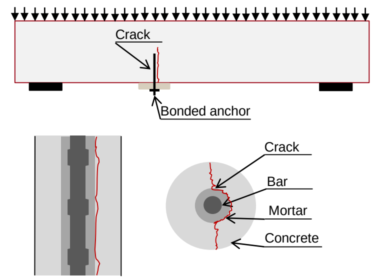
CONCRETE CONDITIONS: UNCRACKED VS. CRACKED

"Rebar theory"
"Design of rebar as a rebar"

"Anchor theory"
"Design of rebar as an anchor"



The crack does not develop parallel to the rebar!



REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

	"Rebar theory" **Post-installed rebar**	**"Anchor theory"** **Bonded anchor**
Seismic qualification	To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.	To assess the performance in cracked concrete subjected to cyclic loading.
Position of anchor/rebar with respect to the crack	Uncracked concrete	Parallel to the crack
Type of tests	1) Bond strength with constant cyclic loading and 2) splitting test with increasing cyclic loading	1) Tensile tests with constant/cyclic crack/loading 2) shear tests with cyclic loading and static crack

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

	"Rebar theory" Post-installed rebar	**"Anchor theory" Bonded anchor**
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Test set up	Confined / unconfined (splitting is not affected by confinement)	Confined

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

	"Rebar theory" Post-installed rebar	**"Anchor theory" Bonded anchor**
Seismic qualification	To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.	To assess the performance in cracked concrete subjected to cyclic loading.
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Test set up	Confined / unconfined (splitting is not affected by confinement)	Confined
Edge distance	Based on the ETA	Based on the ETA

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

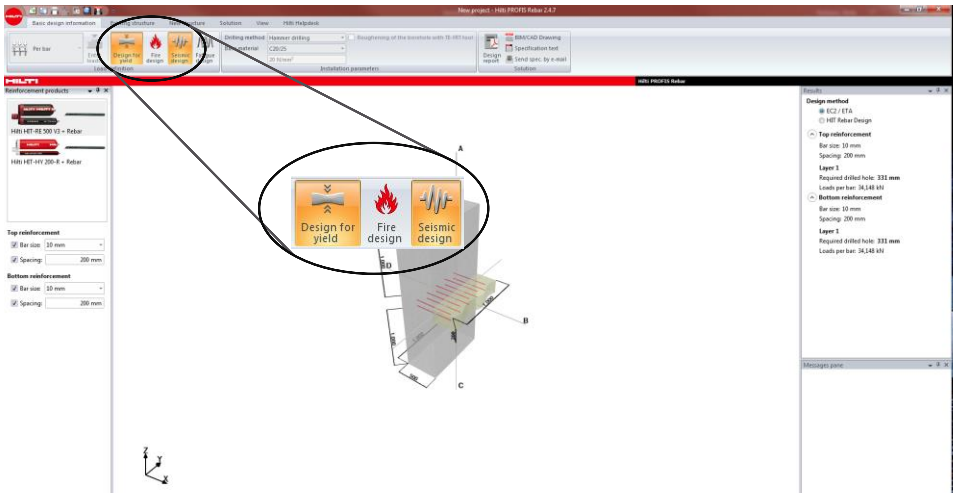
	"Rebar theory" **Post-installed rebar**	**"Anchor theory"** **Bonded anchor**
Seismic qualification	To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.	To assess the performance in cracked concrete subjected to cyclic loading.
Position of anchor/rebar with respect to the crack	Uncracked concrete	Parallel to the crack
Type of tests	1) Bond strength with constant cyclic loading and 2) splitting test with increasing cyclic loading	1) Tensile tests with constant/cyclic crack/loading 2) shear tests with cyclic loading and static crack
Test set up	Confined / unconfined (splitting is not affected by confinement)	Confined
Edge distance	Based on the ETA	Based on the ETA
Failure modes	**Steel Yielding**, pull out, splitting	Steel Yielding (usually lesser ductility), concrete cone failure, pull out, splitting

THE DESIGN ANCHORAGE LENGTH IS FUNCTION OF REQUIRED ANCHORAGE LENGTH AND FACTORS α_I

$$F_{bd} = f_{bd} \cdot \pi \cdot \Phi \cdot l_{bd} \quad \longrightarrow \quad l_{bd} = \alpha_1\, \alpha_2\, \alpha_3\, \alpha_4\, \alpha_5\, l_{b,rqd} \geq l_{b,min}$$

Parameter	**Value (-)**
α_1	1
α_2	0,7 - 1
α_3	1 (always even in the presence of transverce reinforcement)
α_4	1
α_5	0,7 - 1
$l_{b,rqd}$	$l_{b,rqd} = (\phi/4)(\sigma_{sd,seism}/f_{bd,seism})$ → using f_{yd} instead of $\sigma_{sd,seism}$ is strongly recommended
$l_{b,min}$	max($0.3 l_{brqd,fyd}$; 10ϕ; 100mm) → end bars
γ_s	1

IN PROFIS REBAR: SELECT SEISMIC DESIGN TO TAKE INTO ACCOUNT REDUCTION OF PERFORMANCE



THANK YOU