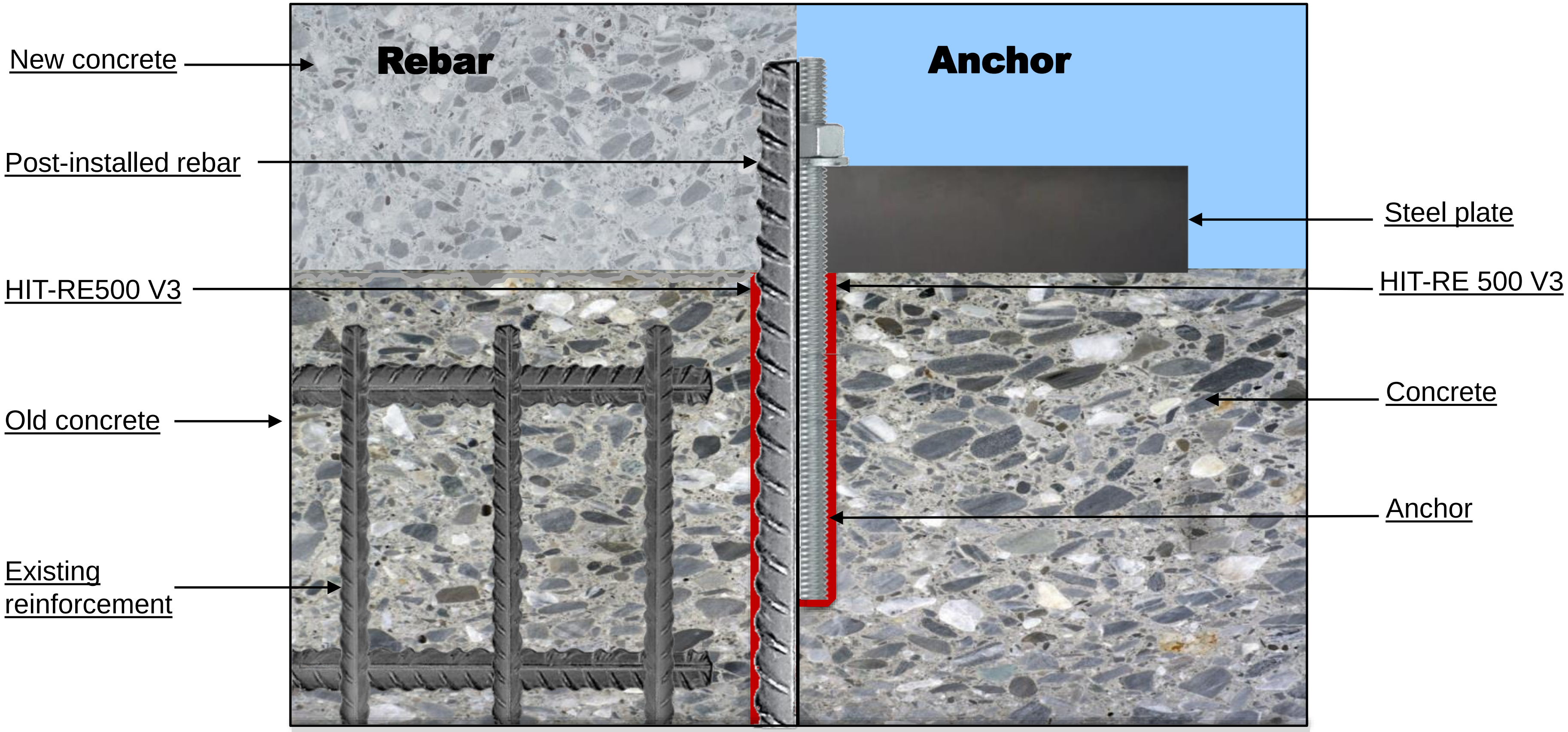
POST-INSTALLED REBAR DESIGN

Stella Nerbano

May, 2017

CONTENTS

REBAR APPLICATIONS VS. ANCHOR APPLICATIONS

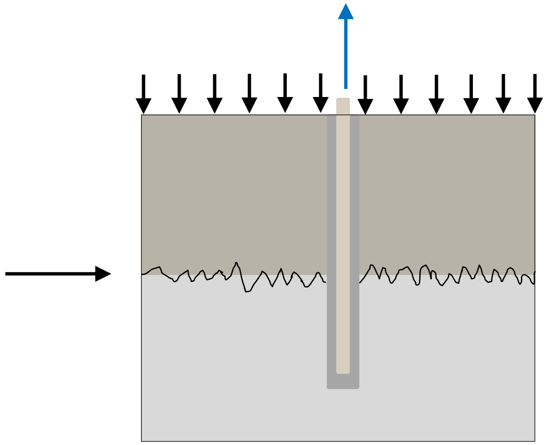


REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

	"Rebar theory" **Post-installed rebar**	**"Anchor theory"** **Bonded anchor**
Load on the bar	Tension (roughness of joint critical for the shear transfer)	Tension, shear, combination of both

INFLUENCE OF THE JOINT: SMOOTH VS. ROUGH

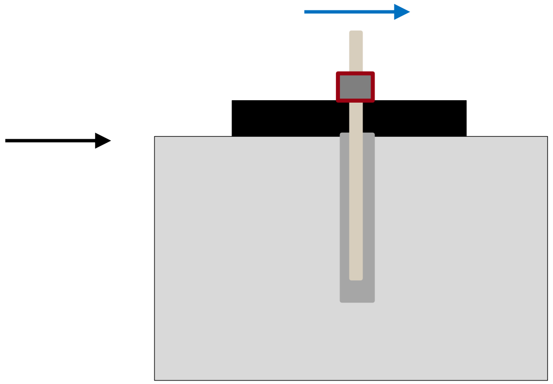
"Rebar theory"
"Design of rebar as a rebar"



- The post-installed rebar clamps the two faces together, enabling shear transfer through friction acting over the interface surface area. The roughness of the interface surface is critical.
- The post installed rebar acts in tension only.
- Carbonated layer should be removed

(Palieraki et al. 2014; EC2:EN1992-1-1:2004 (6.2.5))

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



- The anchor takes up the shear load.
- The roughness of the interface surface does not play any role.

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Load transfer mechanism	Equilibrium with local or global concrete struts	Utilization of concrete tensile strength

CONFINED VS. UNCONFINED CONCRETE

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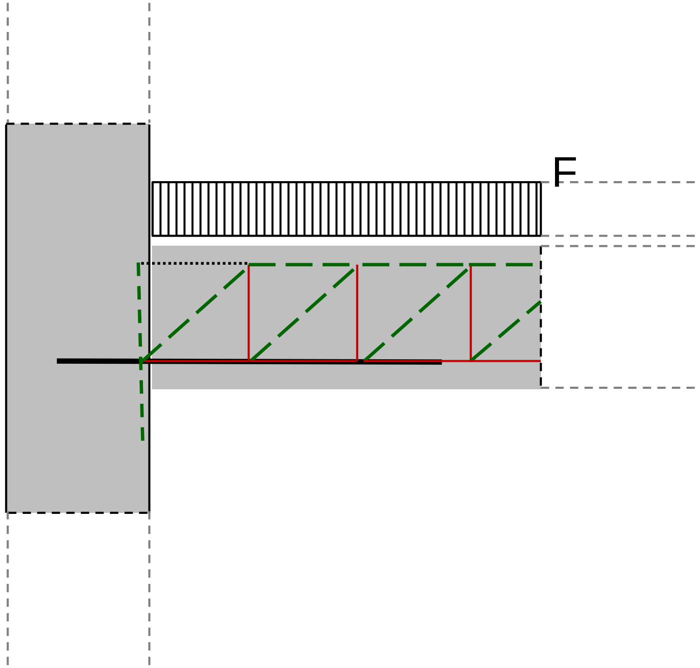
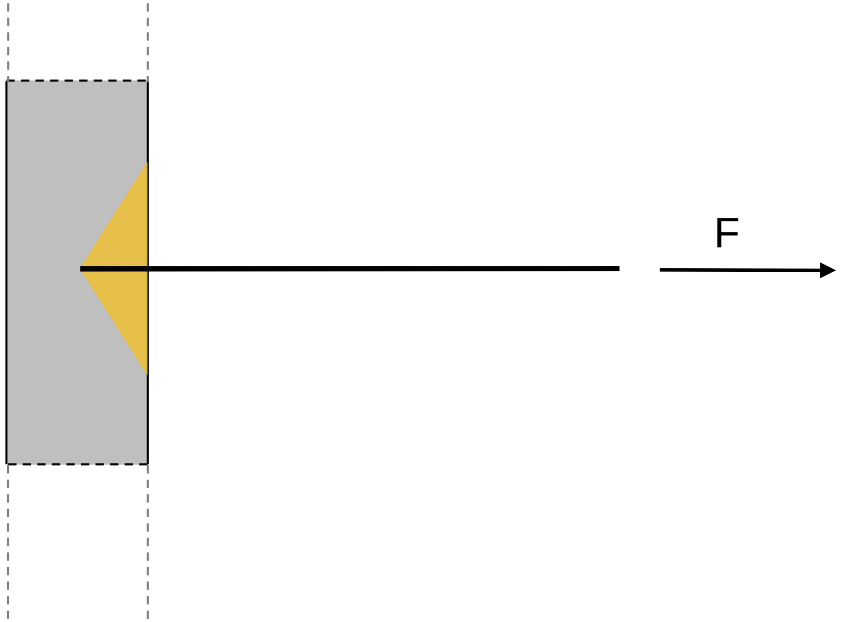
“Design of rebar as a rebar”



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



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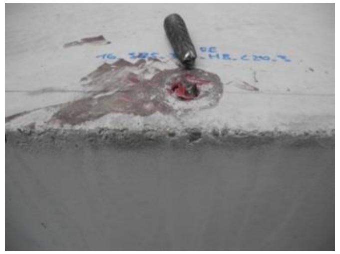
Failure modes	Steel yielding, pull out, splitting	Steel failure, concrete cone failure, pull out, splitting

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

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

Splitting

Steel failure



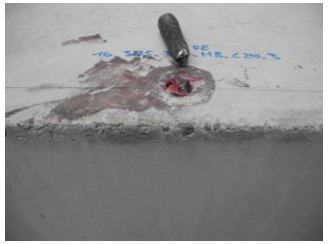
Pull out

The compression strut prevents the concrete cone failure

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

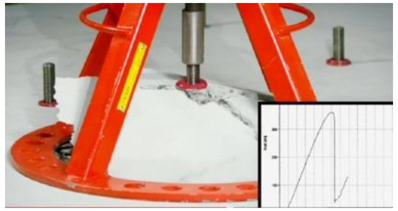
Splitting

Steel failure



Pull out

Concrete cone



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Minimum concrete cover (min (spacing; edge distance))	According to EC2	According to ETA

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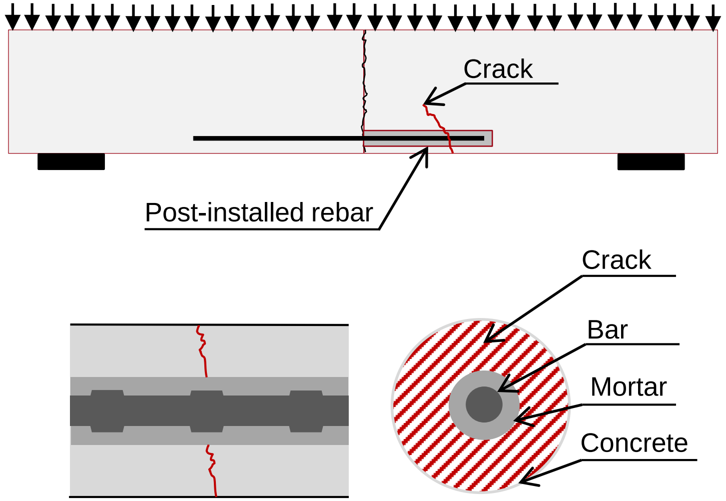
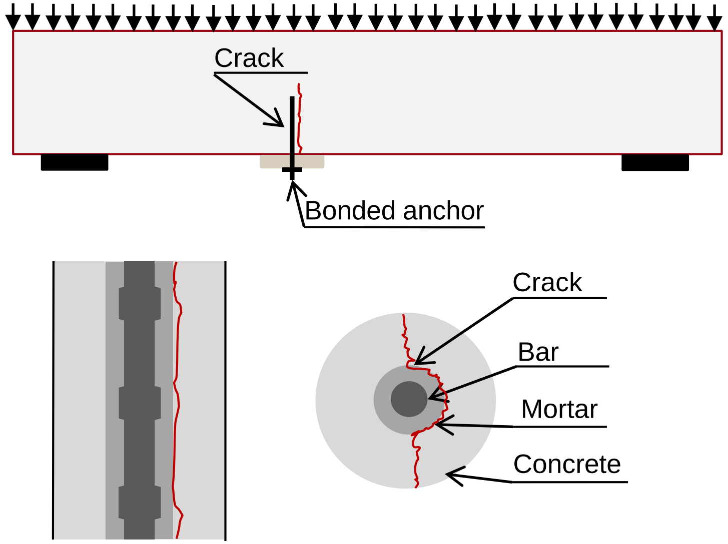
Concrete	Uncracked/craked	Cracked/uncraked

CONCRETE CONDITIONS: UNCRACKED VS. CRACKED

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



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



EUROPEAN REGULATORY FRAMEWORK FOR POST-INSTALLED REBAR

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

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

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

	Static	Fire	Seismic
Product Qualification	ETAG 001 – part 5	x	TR 049
Technical data	ETA	CSTB/DIBt regional approval	ETA
Design method	TR 029 (EN 1992-4)	Local regulations	TR 045 (EN 1992-4)

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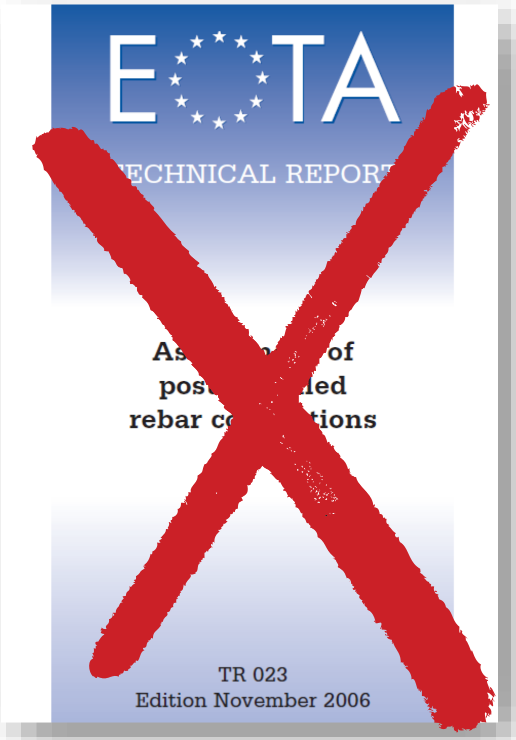
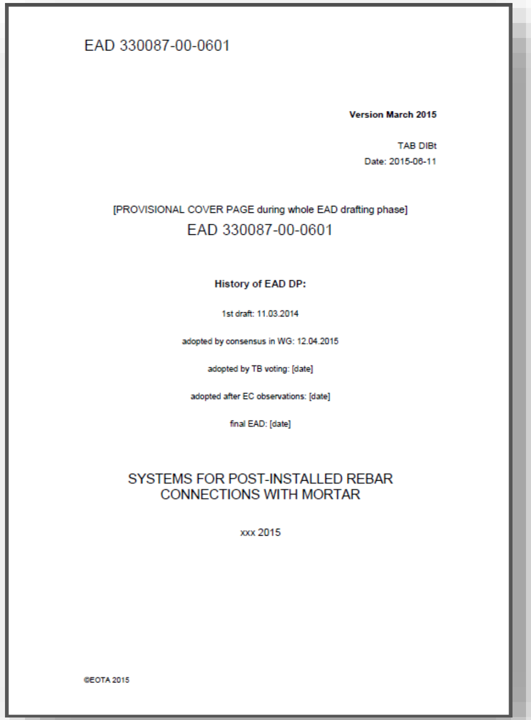
Design method	TR 029 (EN 1992-4)	Local regulations	TR 045 (EN 1992-4)

EAD 330087-00-0601 INCLUDES THE ASSESSMENT OF STATIC AND FIRE PERFORMANCE OF P.I. 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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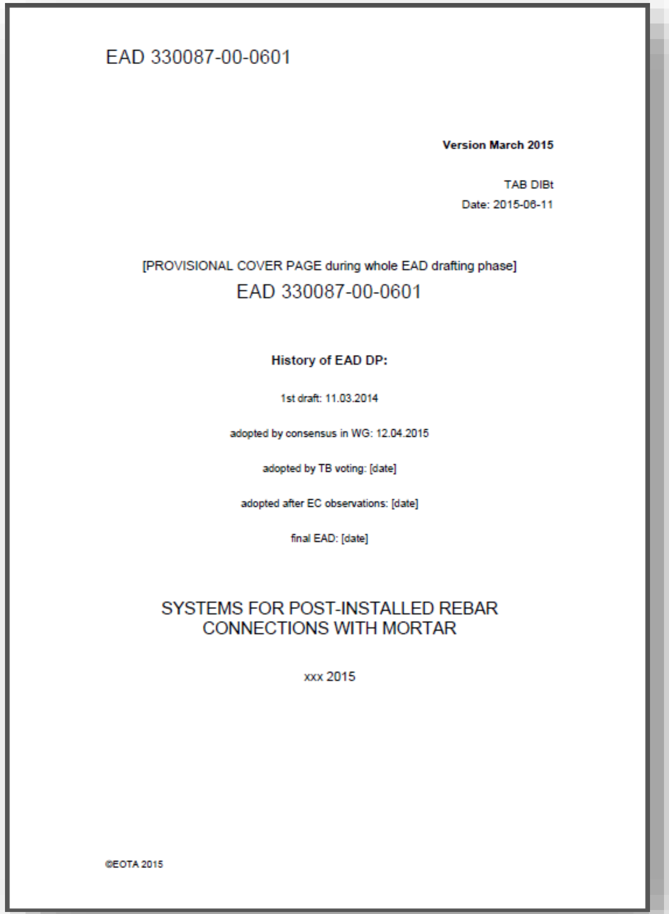
EAD RESTRICTS THE RANGE OF P.I. REBAR APPLICATIONS TO CASES WHERE CONCRETE CONE IS PREVENTED



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SYSTEMS FOR POST-INSTALLED REBAR CONNECTIONS WITH MORTAR

xxx 2015

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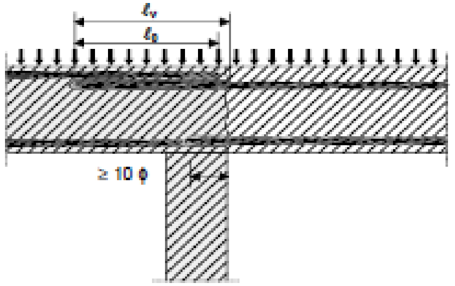


Figure 1.1 Overlap joint for rebar connections of slabs and beams

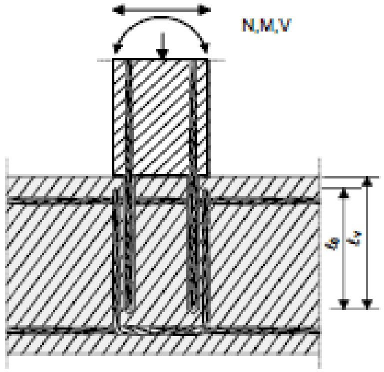


Figure 1.2 Overlap joint at a foundation of a column or wall where the rebar is stressed in tension

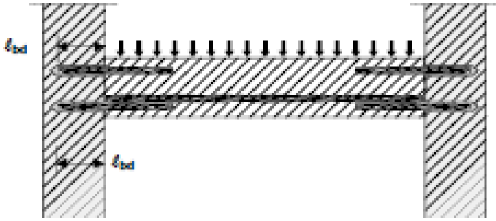


Figure 1.3 End anchoring of slabs or beams, designed as simply supported

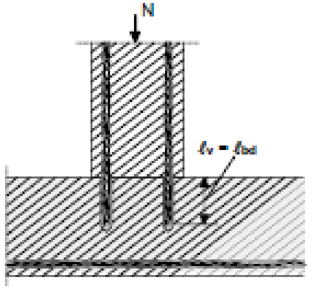
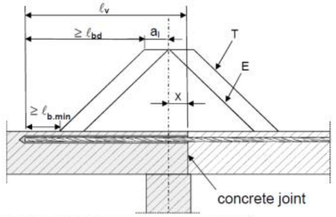


Figure 1.4 rebar connection for components stressed primarily in compression; rebar is stressed in compression



(only post-installed rebar is plotted)

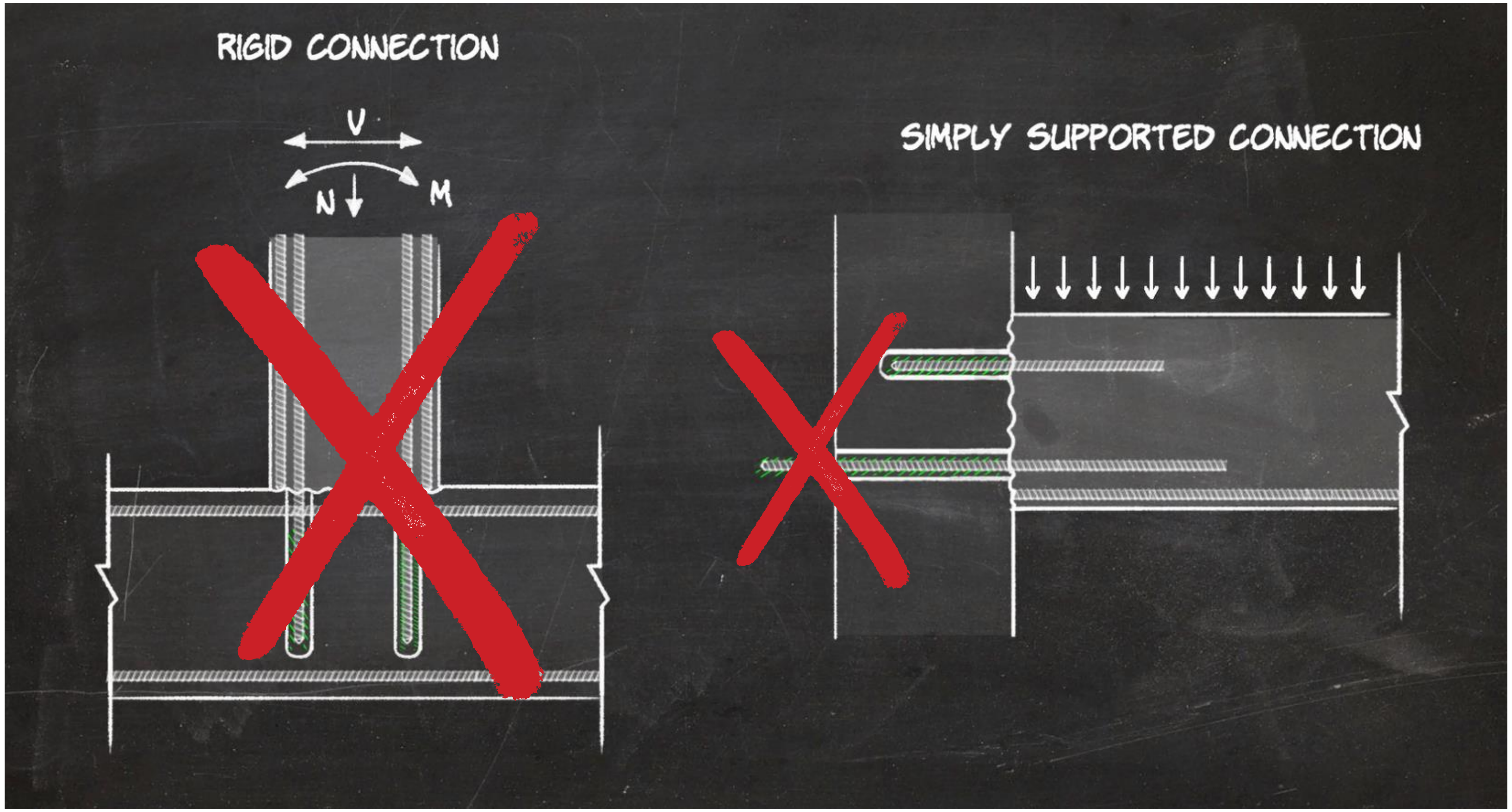
Figure 1.5 Anchoring of reinforcement to cover the

BASED ON THE EAD P.I. REBAR AND CAST-IN HAVE THE SAME BEHAVIOR

It shall be shown by the tests according to Table 2.4 that the post-installed rebar system can develop the same bond resistance with the same safety margin as cast-in-place rebar according to EN 1992-1-1. In EN 1992-1-1 no requirements for testing are given, but the values for f_{bd} can be calculated according to EN 1992-1-1, 8.4.2. The required values of bond resistance $f_{bm,rqd}$ to show equivalence to the bond strength used in design according to EN 1992-1-1 are given in Table 2.6 as a function of the concrete class.

Concrete strength class	Required bond resistance for post-installed rebar $f_{bm,rqd}$ [N/mm^2]	Design value of the ultimate bond stress according to EN 1992-1-1**) f_{bd} [N/mm²]
C12/15	7,1	1,6
C16/20	8,6	2,0
C20/25	**10,0**	2,3
C25/30	11,6	2,7
C30/37	13,1	3,0
C35/45	14,5	3,4
C40/50	15,9	3,7
C45/55	17,2	4,0
C50/60	**18,4**	4,3

TWO MAIN PROBLEMS: RIGID CONNECTIONS CANNOT BE DESIGNED AND SOLUTIONS CAN BE UNFEASIBLE

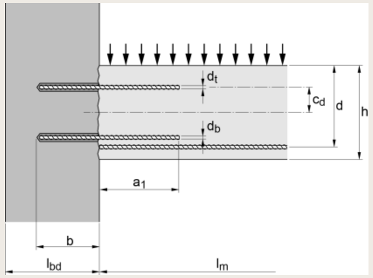


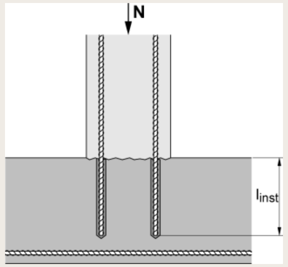
HILTI DEVELOPED A UNIQUE HIT REBAR METHOD THAT EXTENDS EC2 DESIGN AND COVERS MORE APPLICATIONS

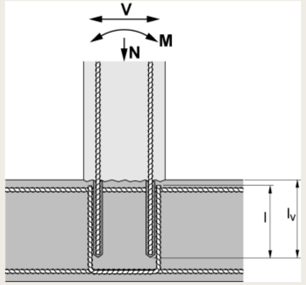
HIT Rebar design Method is based on Rebar theory but extends the range of EC2 applications, based on Hilti own testing:

1. Allows reduction of anchorage lengths for some applications considered in EOTA TR 023
2. Provides a Hilti own design method for moment resisting connections (frame node).

Reduction of anchorage length

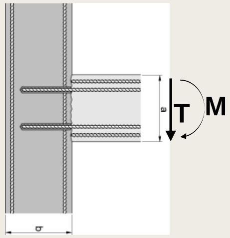






Reduction of anchorage length is possible when edge distance and spacing are large enough based on Hilti own testing. The anchorage length is **reduced up to 70%** compare to the EC2 design.

Design solution



Moment connection: solution possible **with Hilti** design method (based on Hilti own testing).
Not coverd by EC2/TR023 cause concrete cone failure is assumed.

HILTI HIT REBAR DESIGN METHOD

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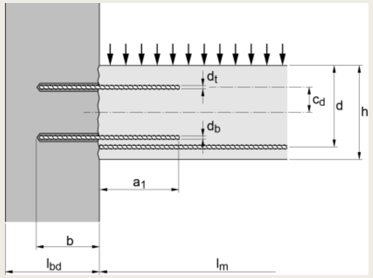
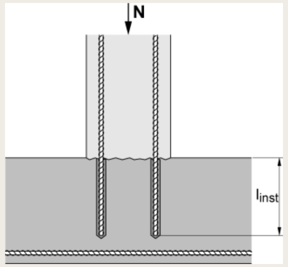
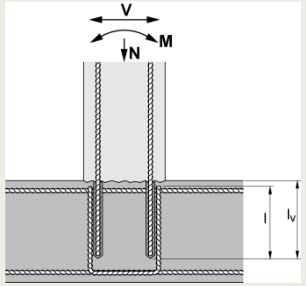
Reduction of anchorage length







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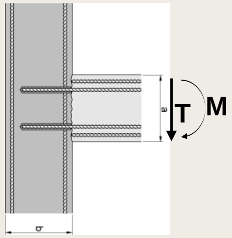

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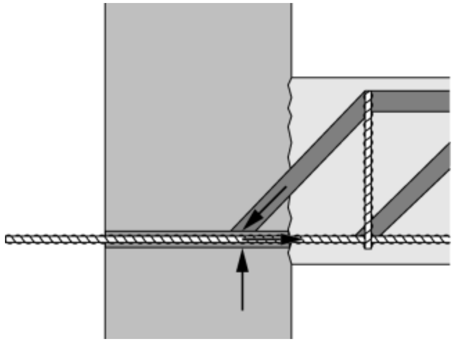
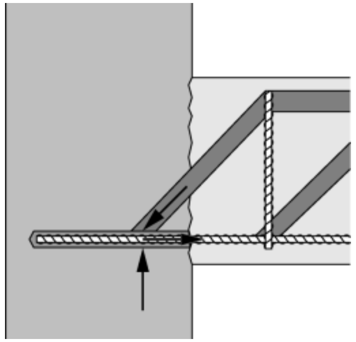
HIT REBAR DESIGN METHOD 1ST PILLAR: REDUCTION OF THE ANCHORAGE LENGTH

PROBLEM



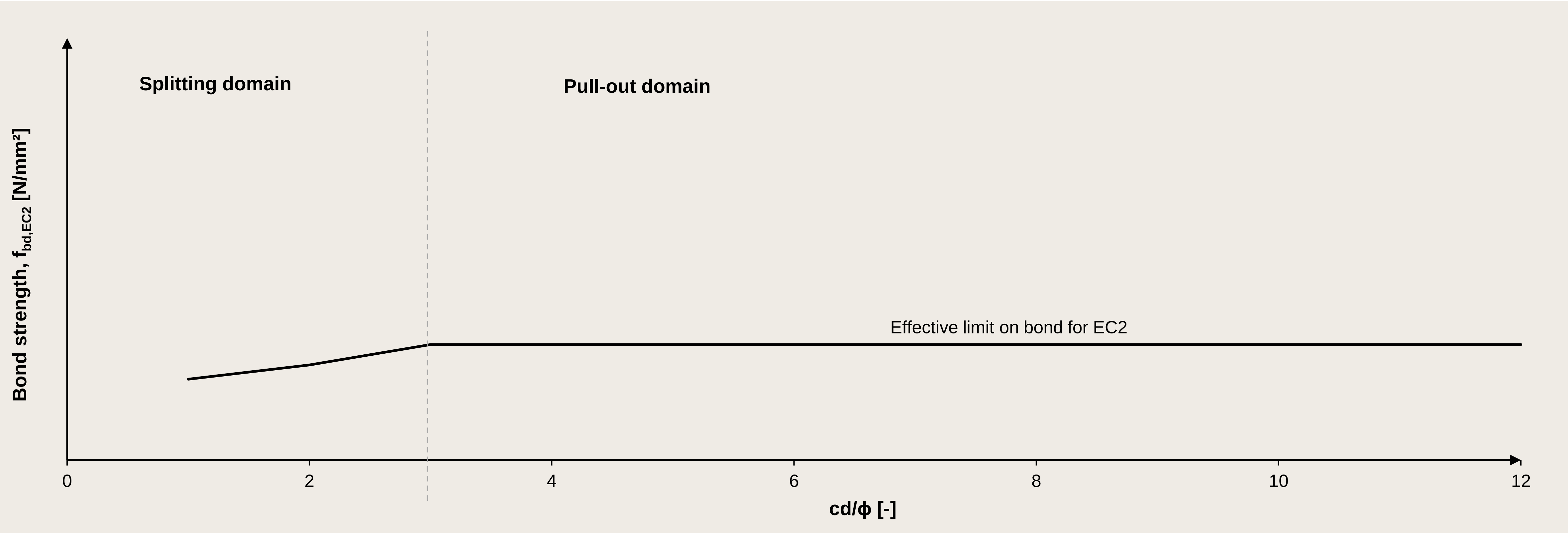
Unfeasible solution

SOLUTION



Feasible solution

BOND STRENGTH OF P.I. REBAR IS LIMITED TO THAT OF CAST-IN REBAR



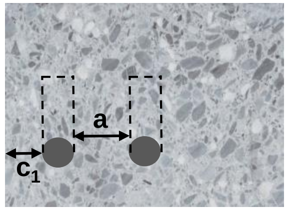
$f_{bd,EC2} = f_{bd}/\alpha_2$

[EC2:EN1992-1-1:2004]

α_2 TAKES INTO ACCOUNT THE MINIMUM CONCRETE COVER C_D

Cast in rebars

Bent or hooked bars

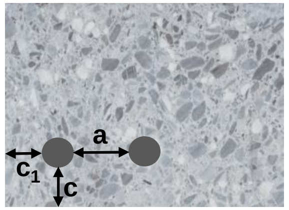


$c_d = \min(a/2, c_1)$

$0.7 \leq \alpha_2 \leq 1$

Post-installed rebars

Straight bars

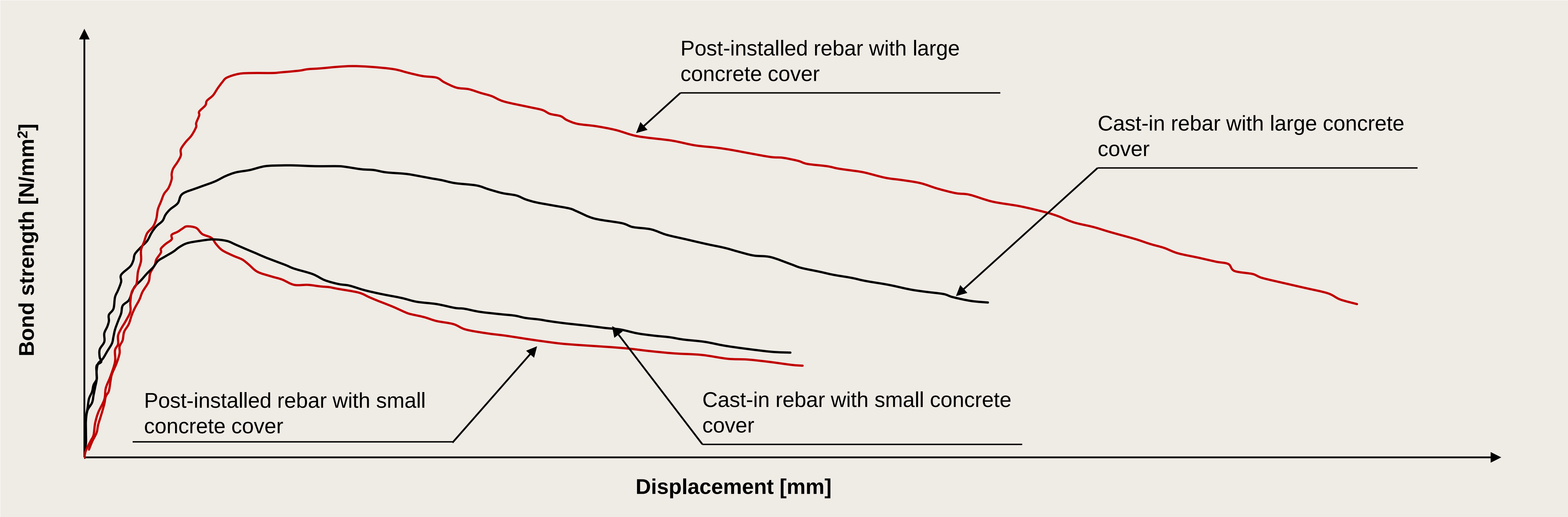


$c_d = \min(a/2, c_1, c)$

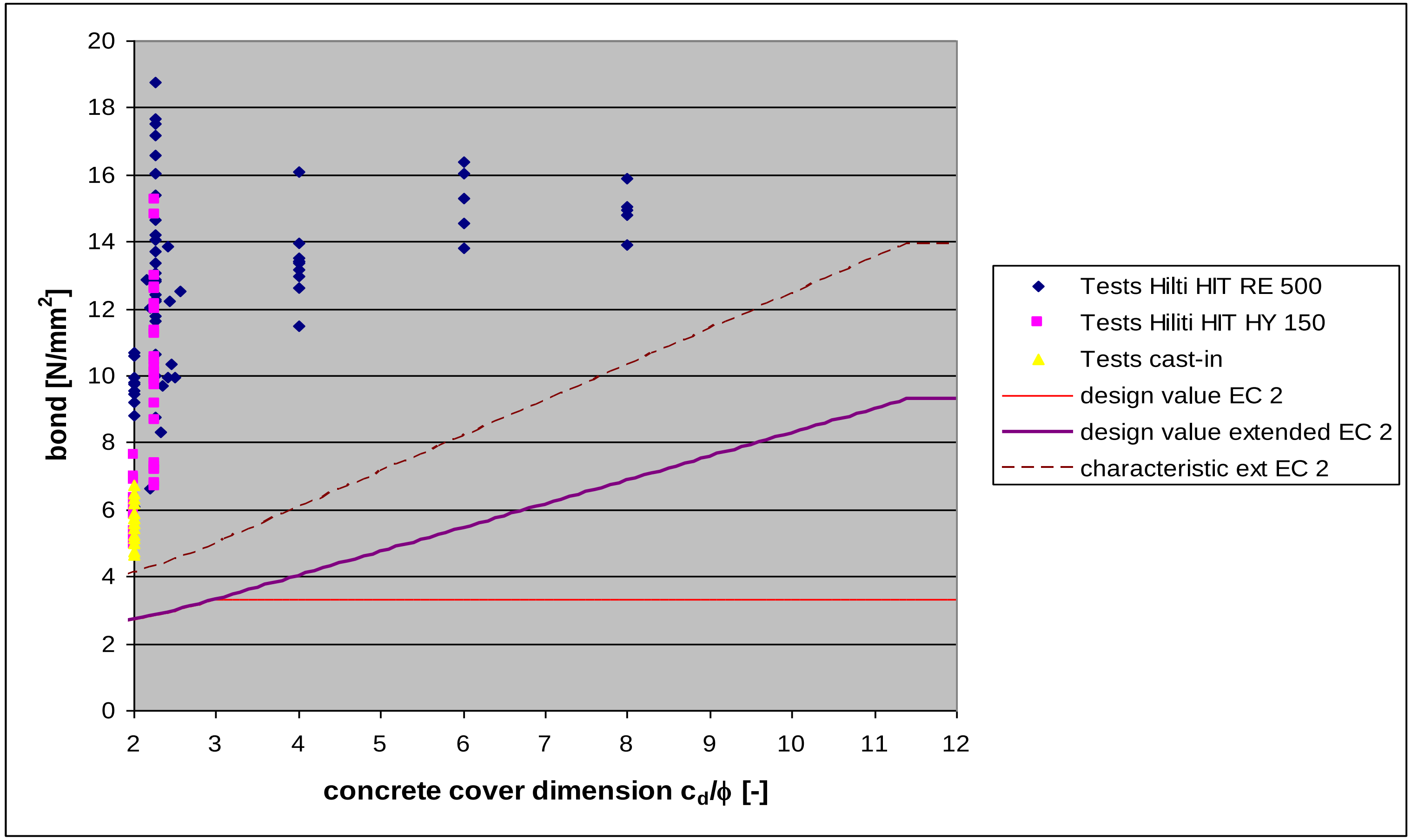
$0.7 \leq \alpha_2 \leq 1$

(EC2:EN1992-1-1:2004 (8.4.4)

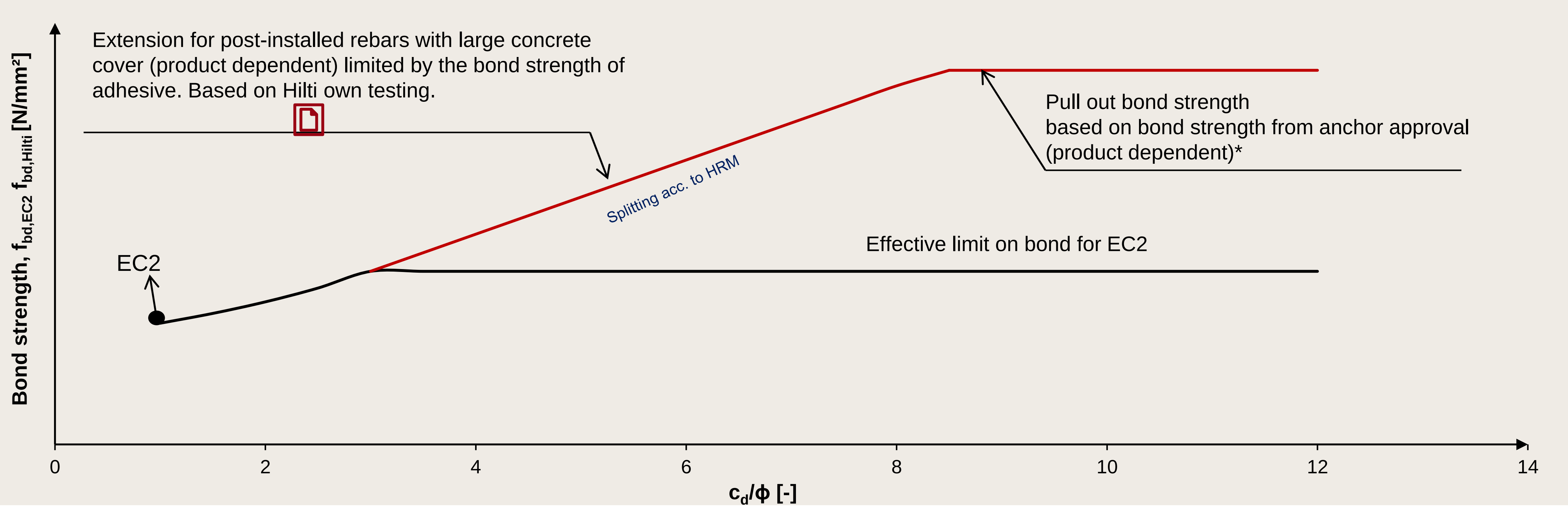
EXPERIMENTAL BEHAVIOR IN A CONFINED TEST SET UP OF A P.I. REBAR INSTALLED WITH HILTI'S MORTARS



EXPERIMENTAL BEHAVIOR IN A CONFINED TEST SET UP OF P.I. REBAR AND CAST-IN



THE HIT REBAR DESIGN METHOD RESULTS FROM EXPERIMENTAL ANALYSIS



$f_{bd,EC2} = f_{bd}/\alpha_2$

$f_{bd,Hilti} = f_{bd}/\alpha'_2$ ➡ $\alpha_2' = \dfrac{1}{\dfrac{1}{0.7} + \delta \cdot \dfrac{c_d - 3\phi}{\phi}}$

*: bond strength for cracked concrete: cracks parallel to the rebar; bond strength for uncracked concrete: cracks perpendicular to the rebar

THE PULL-OUT BOND STRESS COMES FROM THE ANCHOR APPROVAL

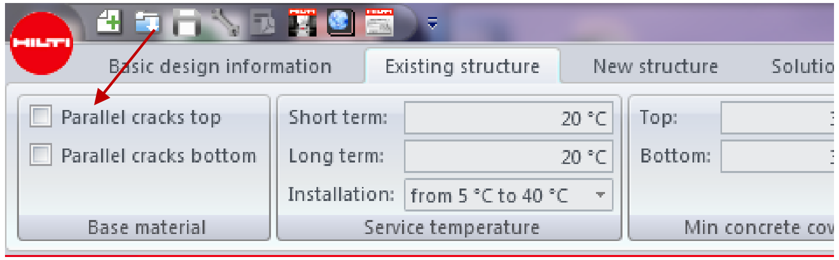
Uncracked concrete (RE500V3)

Reinforcing bar (rebar)			ϕ 10	ϕ 12	ϕ 14	ϕ 16	ϕ 20	ϕ 25	ϕ 28	ϕ 30	ϕ 32
Installation safety factor											
Hammer drilling	$\gamma_2^{1)} = \gamma_{inst}^{2)}$	[-]	1,0								
Hammer drilling with Hilti hollow drill bit TE-CD or TE-YD	$\gamma_2^{1)} = \gamma_{inst}^{2)}$	[-]	-	1,0						-	
Diamond coring	$\gamma_2^{1)} = \gamma_{inst}^{2)}$	[-]	1,2			1,4					
Diamond coring with roughening with Hilti roughening tool TE-YRT	$\gamma_2^{1)} = \gamma_{inst}^{2)}$	[-]	-		1,0					-	
Hammer drilling in flooded holes	$\gamma_2^{1)} = \gamma_{inst}^{2)}$	[-]	1,4								
Steel failure rebars											
Characteristic resistance	$N_{Rk,s}$	[kN]	43	62	85	111	173	270	339	388	442
Partial safety factor	$\gamma_{Ms,N}$	[-]	1,4								
Combined pullout and concrete cone failure											
Characteristic bond resistance in non-cracked concrete C20/25 in hammer drilled holes and hammer drilled holes with Hilti hollow drill bit TE-CD or TE-YD and diamond cored holes with roughening with Hilti roughening tool TE-YRT											
Temperature range I: 40°C / 24°C	$\tau_{Rk,ucr}$	[N/mm²]	14	14	14	14	14	13	13	13	13
Temperature range II: 70°C / 43°C	$\tau_{Rk,ucr}$	[N/mm²]	11	11	11	10	10	10	9,5	9,5	9,5
Characteristic bond resistance in non-cracked concrete C20/25 in diamond cored holes.											
Temperature range I: 40°C / 24°C	$\tau_{Rk,ucr}$	[N/mm²]	9	9	9	9	9	9	9,5	9,5	9,5
Temperature range II: 70°C / 43°C	$\tau_{Rk,ucr}$	[N/mm²]	6,5	6,5	6,5	6,5	7	7	7	7	7
Characteristic bond resistance in non-cracked concrete C20/25 in hammer drilled holes and installation in water-filled holes											
Temperature range I: 40°C / 24°C	$\tau_{Rk,ucr}$	[N/mm²]	12	12	12	12	12	11	11	11	11
Temperature range II: 70°C / 43°C	$\tau_{Rk,ucr}$	[N/mm²]	9	9	9	9	8,5	8,5	8,5	8	8
Factor acc. to section 6.2.2.3 of CEN/TS 1992-4:2009 part 5	k_8	[-]	10,1								

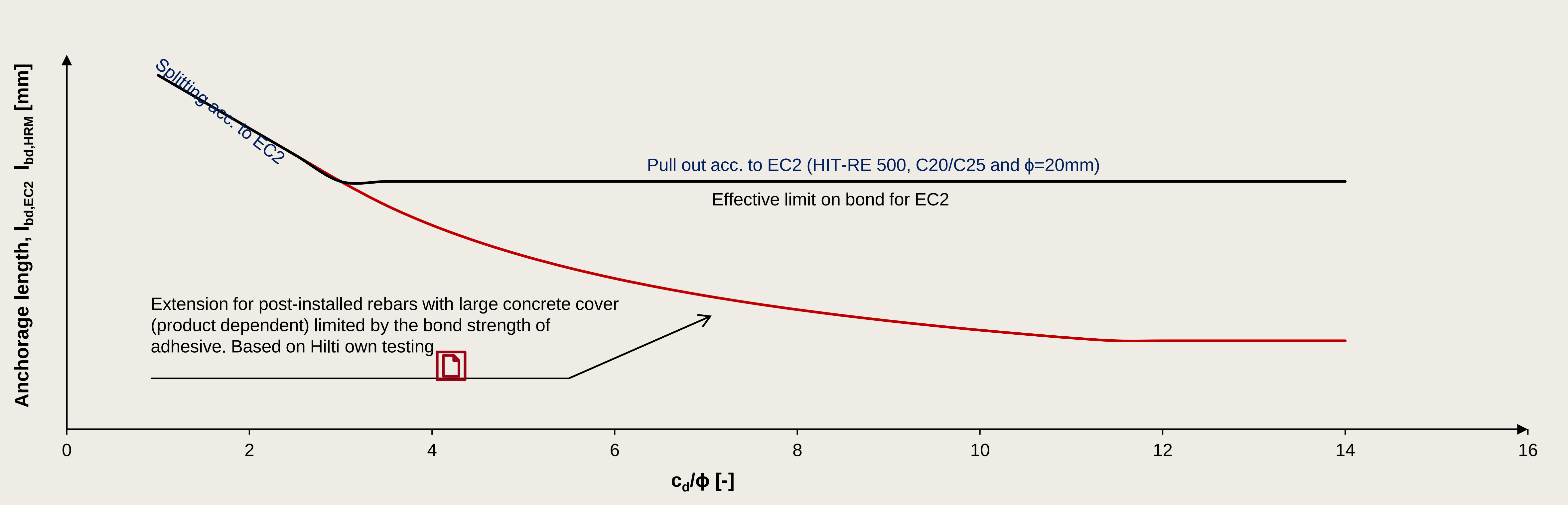
Cracked concrete (RE500V3)

Reinforcing bar (rebar)			ϕ 10	ϕ 12	ϕ 14	ϕ 16	ϕ 20	ϕ 25	ϕ 28	ϕ 30	ϕ 32
Combined pullout and concrete cone failure (continued)											
Characteristic bond resistance in cracked concrete C20/25 in hammer drilled holes and hammer drilled holes with Hilti hollow drill bit TE-CD or TE-YD and diamond cored holes with roughening with Hilti roughening tool TE-YRT											
Temperature range I: 40°C / 24°C	$\tau_{Rk,cr}$	[N/mm²]	8,5	9,5	9,5	9,5	10	10	11	11	11
Temperature range II: 70°C / 43°C	$\tau_{Rk,cr}$	[N/mm²]	7	8	8	8	8	8	8	8	8

PROFIS



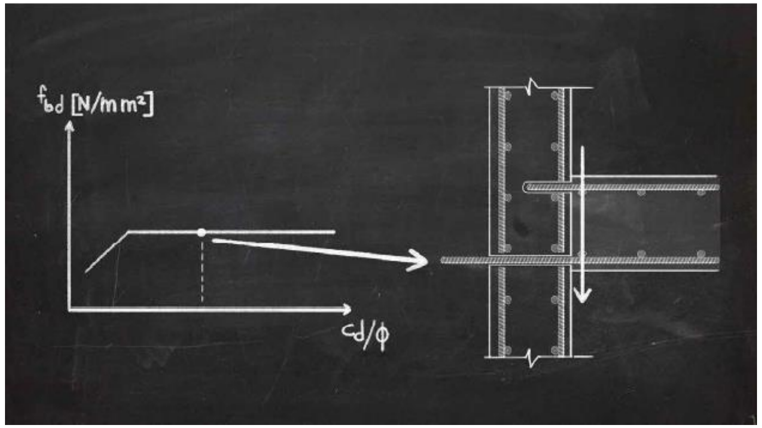
HIGHER BOND STRENGTH WITH HIT REBAR METHOD: REDUCTION OF THE ANCHORAGE LENGTH



$l_{bd,EC2}=(\phi/4)(f_{yd}/f_{bd,EC2})$

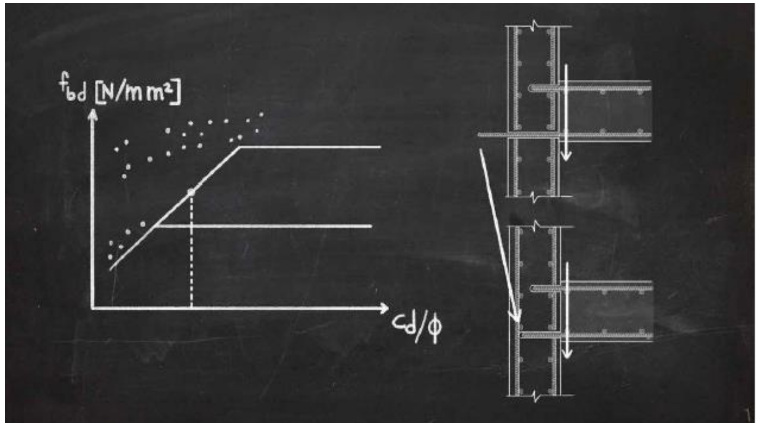
$l_{bd,HRM}=(\phi/4)(f_{yd}/f_{bd,Hilti})$

DESIGN A POST-INSTALLED REBAR ACCORDING TO HIT REBAR DESIGN METHOD FOLLOWING THE EC2 DESIGN



EC2 restricts the use of bond strength to that of cast-in.

$$\alpha_2 = 1 - 0.15 \cdot \frac{c_d - \phi}{\phi} \qquad l_{bd,spl} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} \cdot \alpha_2$$

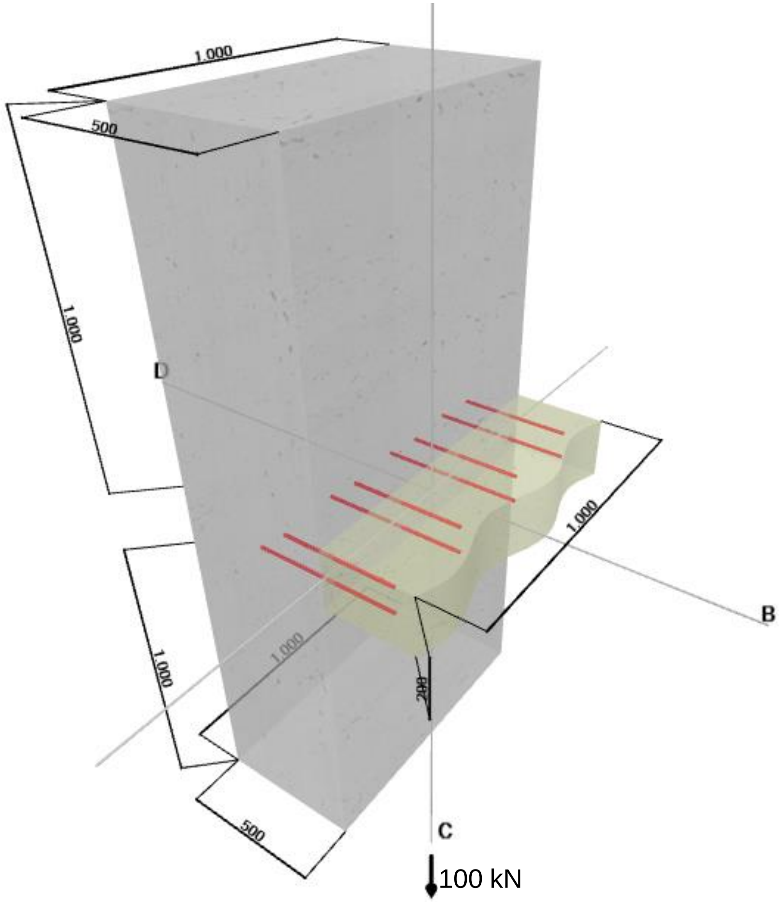


HIT Rebar Method through Hilti's extensive in-house research provided benefit for $c_d/\phi > 3$.

It allows higher bond strength thus reducing embedment depths.

$$\alpha_2' = \frac{1}{\frac{1}{0.7} + \delta \cdot \frac{c_d - 3 \cdot \phi}{\phi}} \qquad l_{bd,spl} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} \cdot \alpha_2'$$

SLAB TO WALL: SIMPLY SUPPORTED CONNECTION: HIT REBAR DESIGN METHOD BENEFITS



case

simply supported

Modeling in Profis Rebar

Simply supported wall/slab

Anchorage length

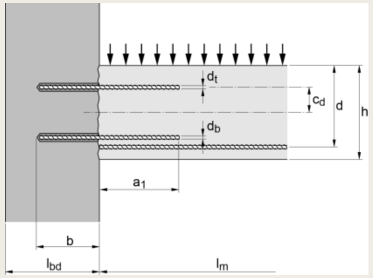
	EC2	HRM
Product	HIT-RE 500 V3	
Φ [mm]	12	12
$l_{bd,bottom}$ [mm]	269	170
$l_{bd,top}$ [mm]	170	170
Average saving [%]		18.5

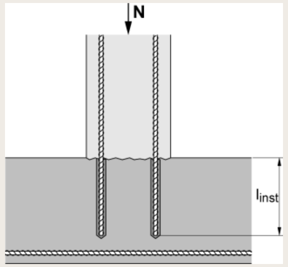
HILTI DEVELOPED A UNIQUE HIT REBAR METHOD THAT EXTENDS EC2 DESIGN AND COVERS MORE APPLICATIONS

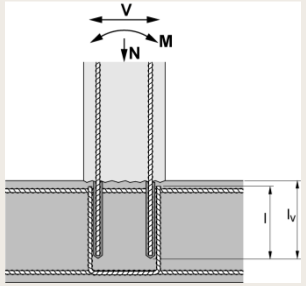
HIT Rebar design Method is based on Rebar theory but extends the range of EC2 applications, based on Hilti own testing:

1. Allows reduction of anchorage lengths for some applications considered in EOTA TR 023
2. Provides a Hilti own design method for moment resisting connections (frame node).

Reduction of anchorage length

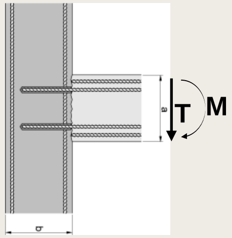






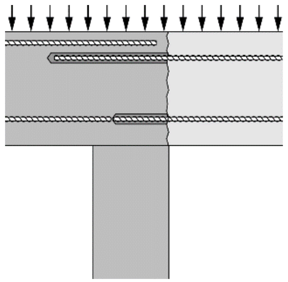
Reduction of anchorage length is possible when edge distance and spacing are large enough based on Hilti own testing. The anchorage length is **reduced up to 70%** compare to the EC2 design.

Design solution

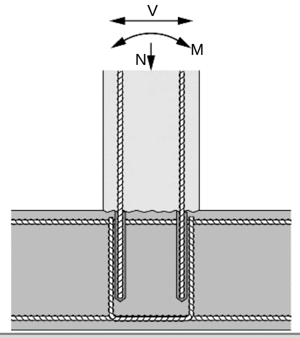


Moment connection: solution possible **with Hilti** design method (based on Hilti own testing).
Not coverd by EC2/TR023 cause concret cone failure is assumed.

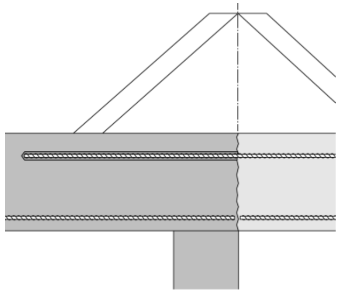
TR023 LIMITS THE APPLICATIONS TO CASES WHERE THE CONCRETE CONE FAILURE IS PREVENTED



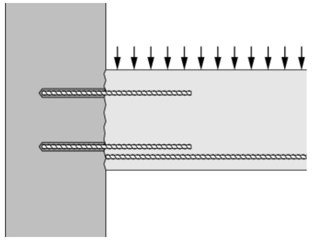
Overlap joint for rebar connections of slabs and beams



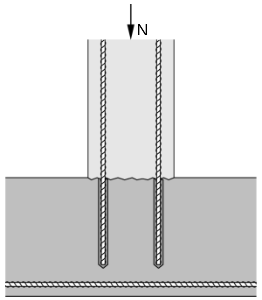
Overlap joint at a foundation of a column or wall



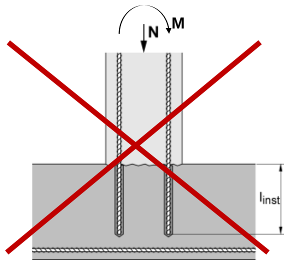
Anchoring of reinforcement to cover the line of acting tensile force



End anchoring of slabs or beams (simply supported)



Components stressed primarily in compression

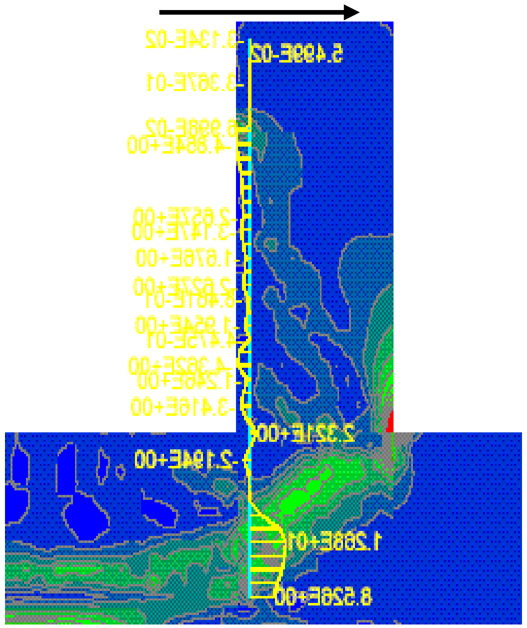


Components subjected to bending moment

TO OVERCOME THE DESIGN LIMITATIONS BY EC2, HILTI DEVELOPED A SOLUTION FOR FRAME NODES

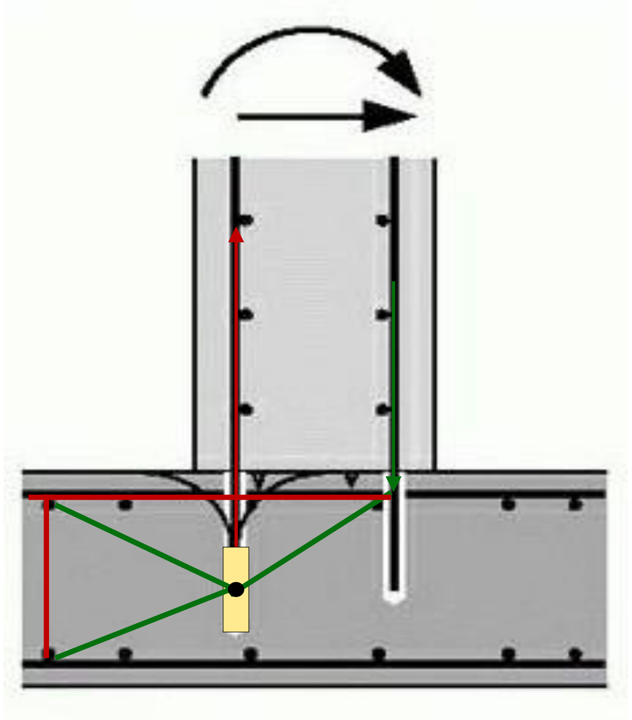
Numerical analysis

The force flow in the frame node is assessed by means of Finite Element Analysis (Hilti research).

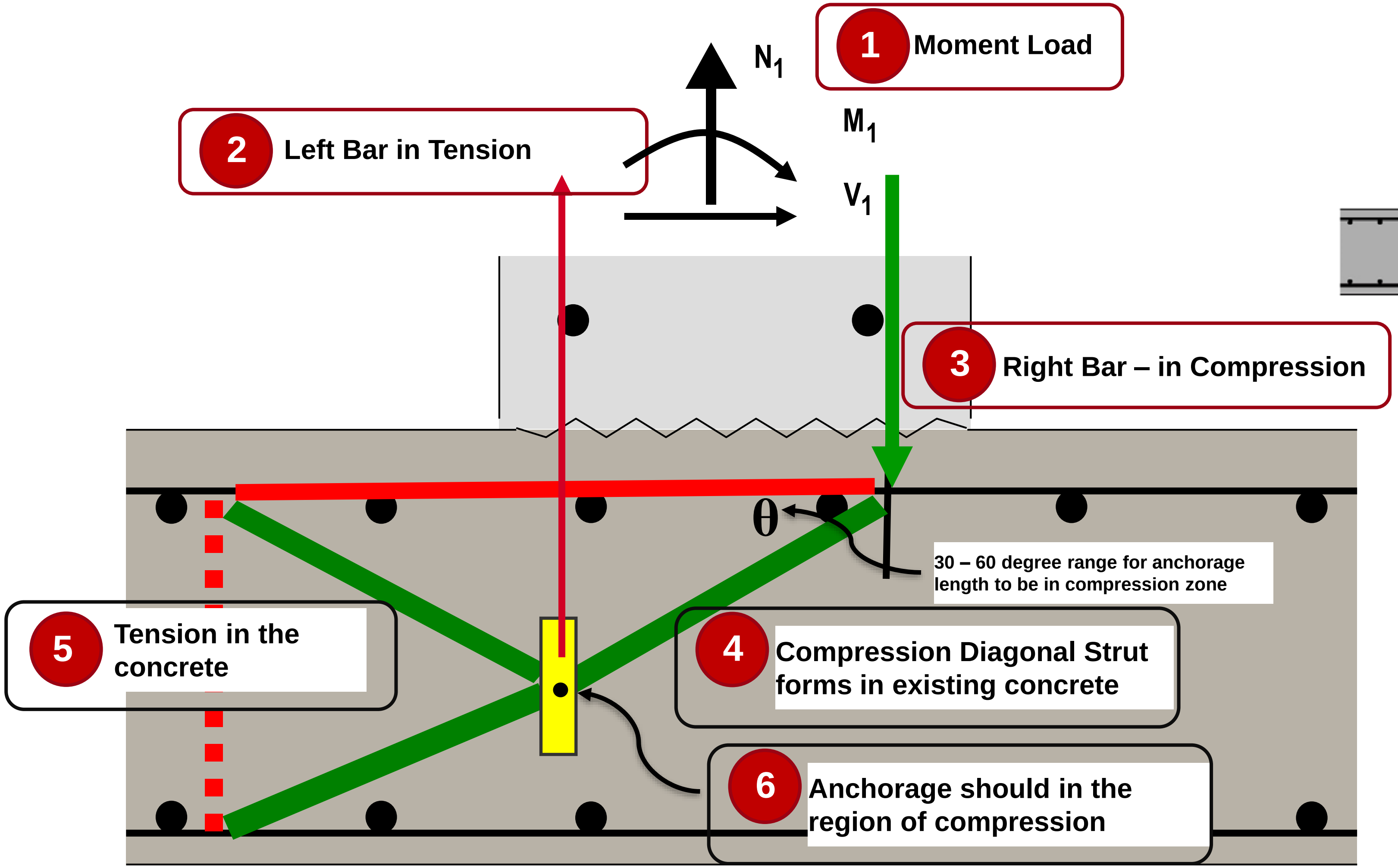


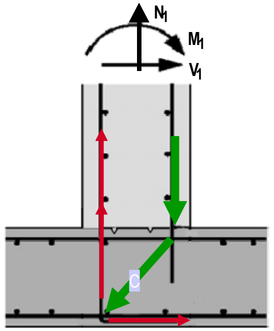
Strut and tie model

The strut and tie model is developed for straight bars (Hilti research)



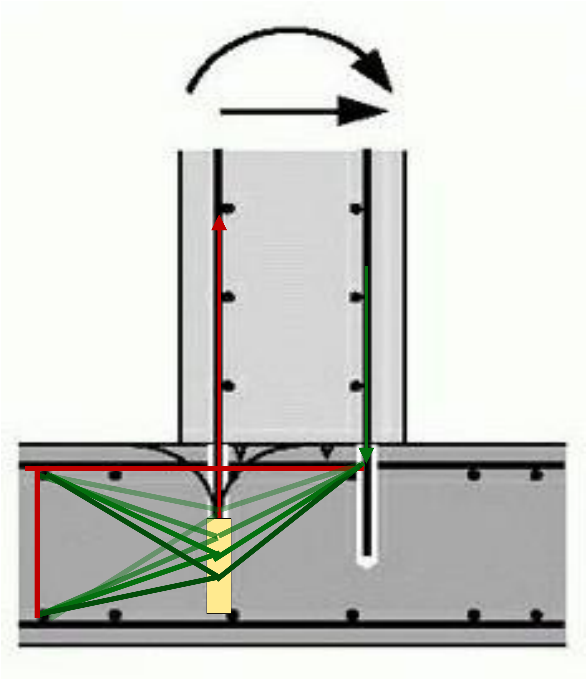
THE HIT REBAR DESIGN METHOD (HRM) IS BASED ON THE STRUT AND TIE MODEL FOR CAST-IN CONNECTIONS





STRESS IN THE NODE IS AFFECTED BY THE STRUT ANGLE

Strut and tie model

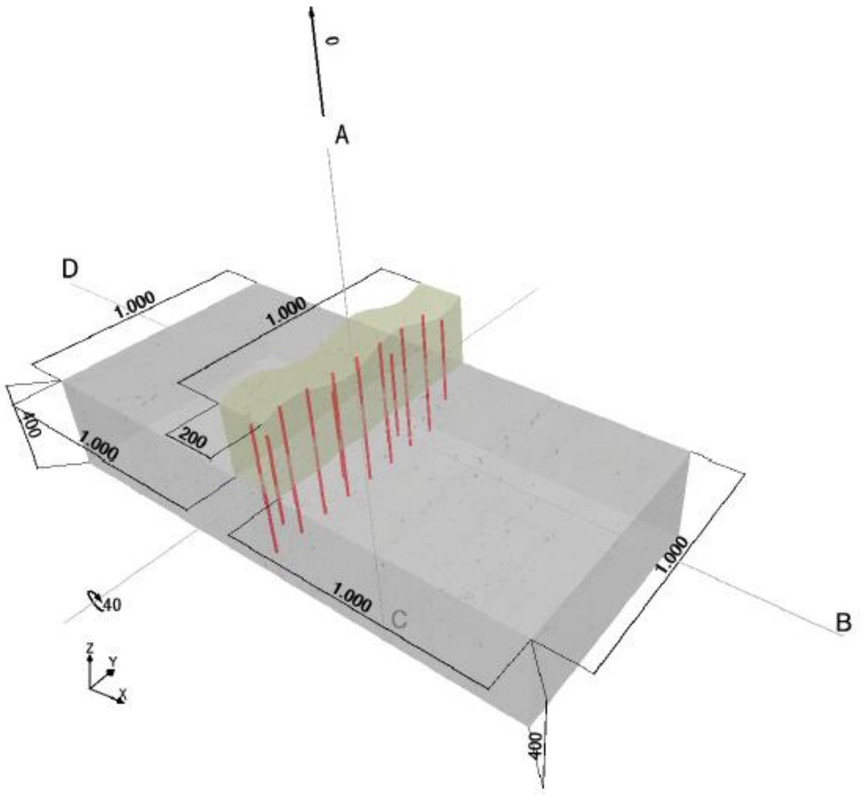


Stress to be checked in the design

1. Anchorage post-installed reinforcement
2. Compressive strut in node
3. Splitting force in transition area
4. Tension reinforcement in node

THE FRAME NODE ANGLE IS REDUCED: REINFORCEMENT REQUIRED IN THE EXISTING SLAB INCREASES

Design example



Design parameters

Frame node angle	60°
Drilled hole length	366 mm
Compression in strut direction	411 kN/m
Splitting stress	0,208 N/mm2
Additional tensile force	105 kN/m

Frame node angle	45°
Drilled hole length	284 mm
Compression in strut direction	503 kN/m
Splitting stress	0,291 N/mm2
Additional tensile force	256 kN/m

CONTENTS

THANK YOU