FUTURE DEVELOPMENT FOR POST-INSTALLED REBAR FROM REGULATION ASPECT

December 17, 2021

Structural Division

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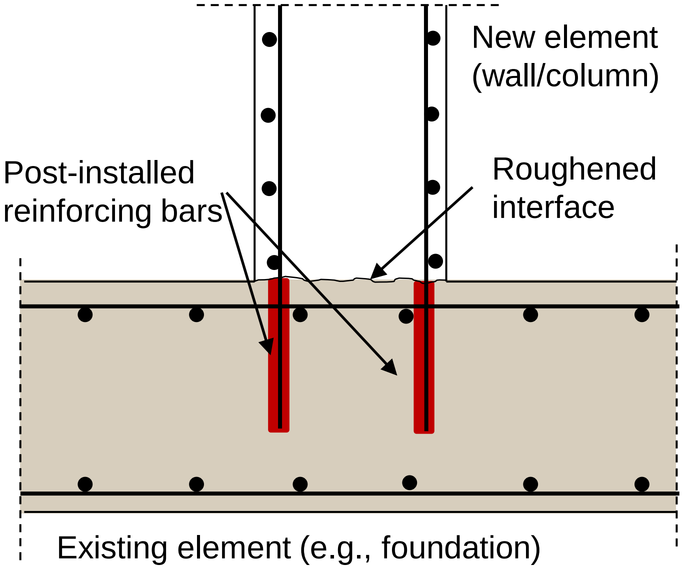
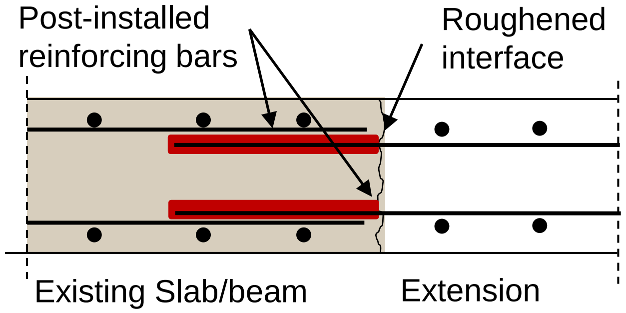
TYPICAL APPLICATIONS WITH PIR

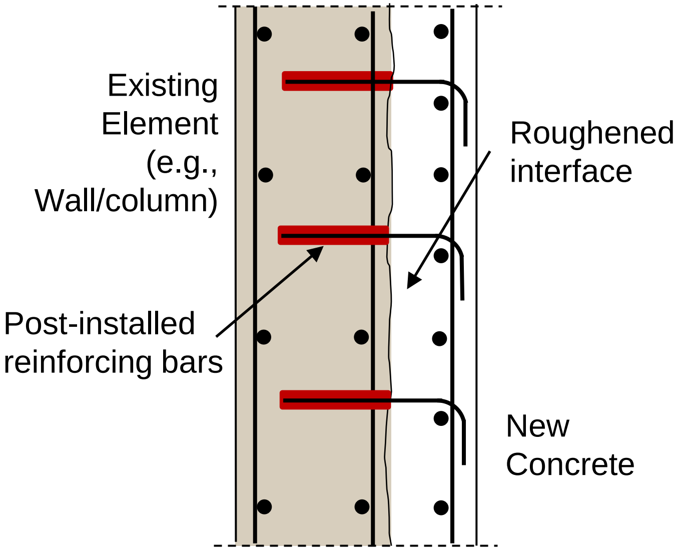
Starter bars in rigid nodes



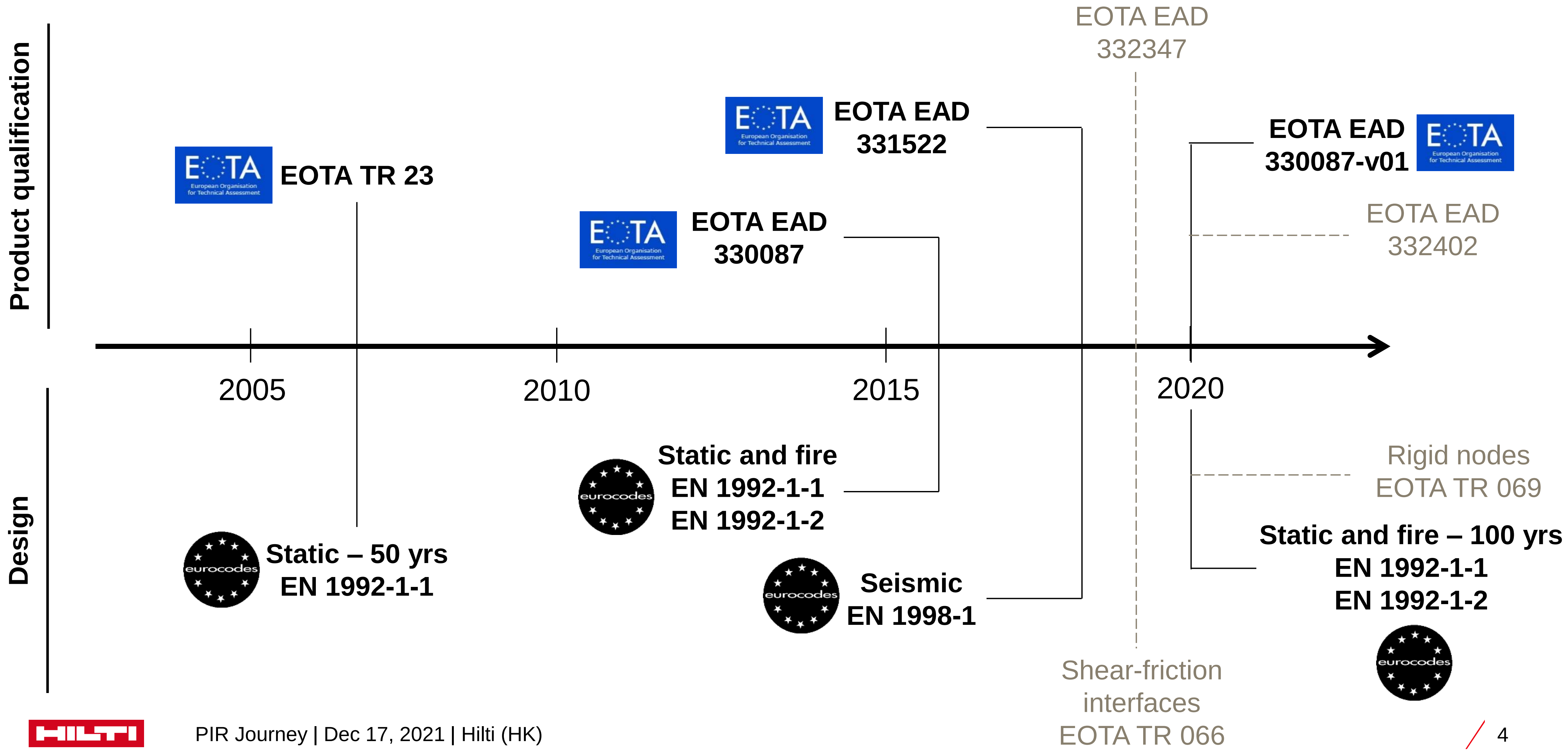
Lap splices



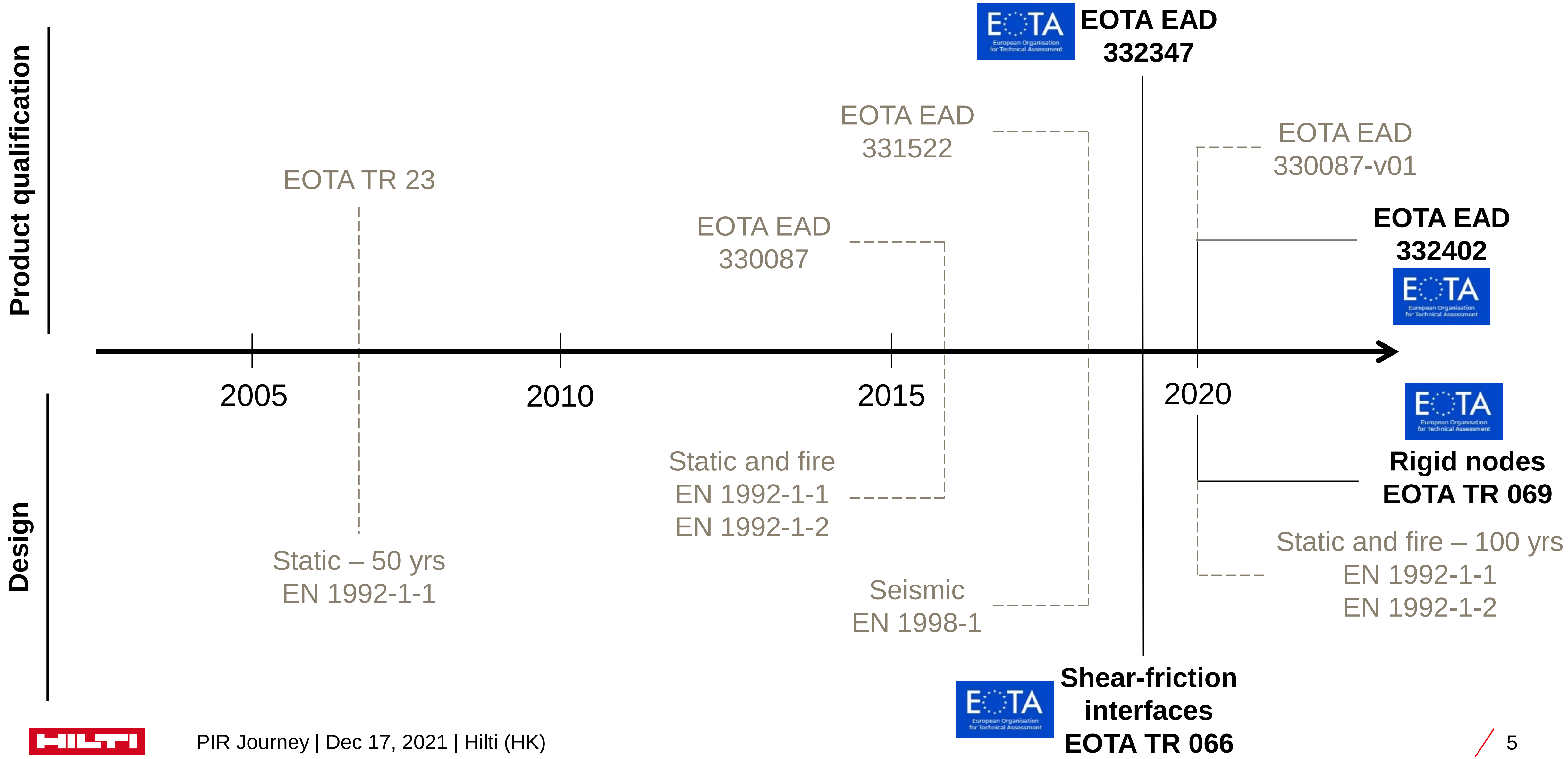
Shear dowels



EUROPEAN CODE DEVELOPMENTS IN THE PAST 20 YEARS



OUTLOOK ON RECENT AND ONGOING DEVELOPMENTS



EUROPEAN REGULATORY FRAMEWORK FOR POST-INSTALLED REBAR

Post-installed rebar

	Static	Fire	Seismic
Product Qualification	EAD 330087 EAD 332402	EAD 330087	EAD 330087
Technical data	ETA I ETA II	ETA I	ETA I
Design method	EC2 TR069	EC2	EC8

SBP

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

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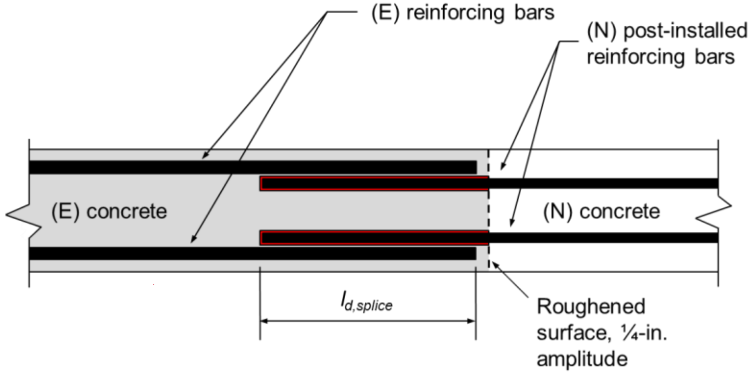
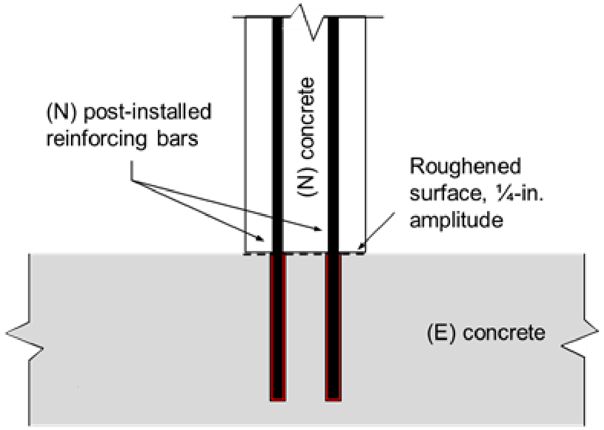
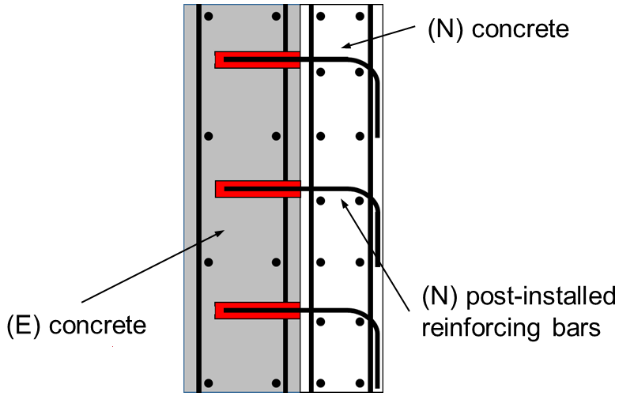
THE EAD 330087-00-0601 PROVIDES A SOLUTION FOR SPLICES. STRUCTURAL JOINTS ONLY AS SIMPLY SUPPORTED

Splices	Structural joints	Concrete overlay

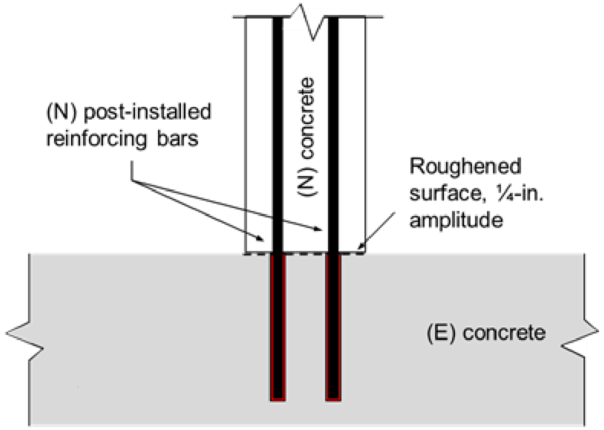






STRUCTURAL JOINTS CAN BE DESIGNED FOLLOWING 3 OPTIONS

Structural joints



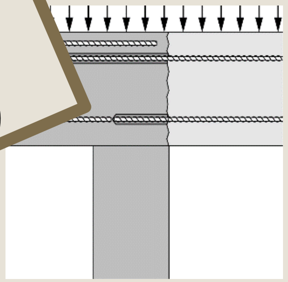
Designed as simply supported: no bending moment. The design can follow EC2 and same formula as splices

Hilti HIT Rebar Design Method

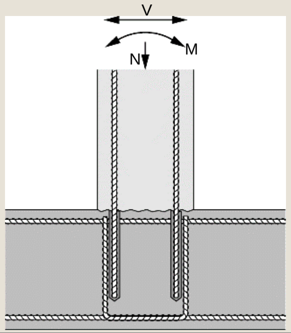
TR069

RIGID NODES CAN BE DESIGNED BY FOLLOWING THE NEW APPROACH…

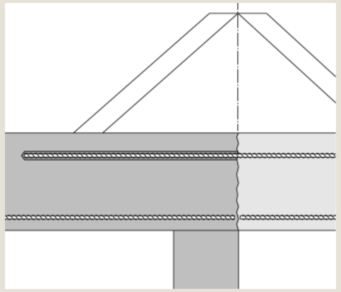
EC2 / EAD 330087 (PIR=CIR)



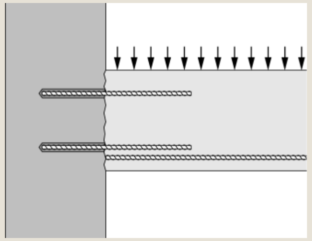
Overlap joint for rebar connections of slabs and beams



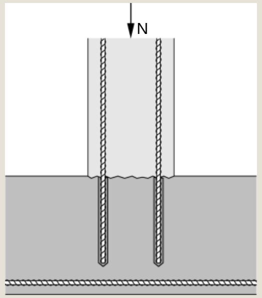
Overlap joint at a foundation of a column or wall



Anchoring of reinforcement to cover the line of acting tensile force

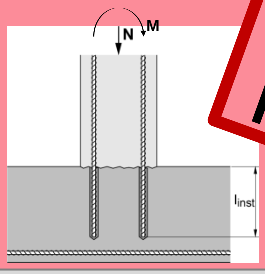


End anchoring of slabs or beams (simply supported)



Components stressed primarily in compression

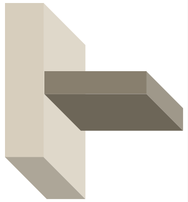
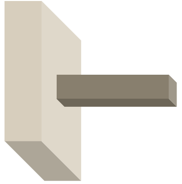
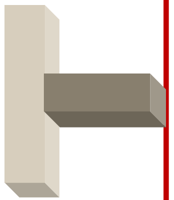
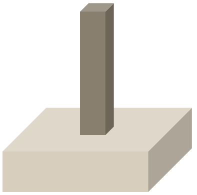
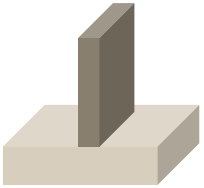
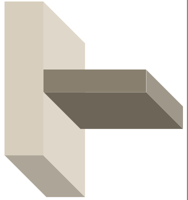
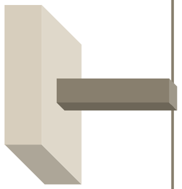
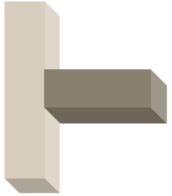
New design / New EAD



Components subjected to bending moment

IN STRUCTURAL JOINTS: WITH HY200 R V3 YOU CAN COVER 5 MORE APPLICATIONS!!

ONLY WITH BEYOND CAST-IN!!!

		1	2	3	4	5	6	7	8
									
	Connection type	Simply supported	Simply supported	Simply supported	Rigid	Rigid	Rigid	Rigid	Rigid
	Members connected	Slab to wall	Beam to wall	Beam to column	Column to foundation	Wall to foundation	Slab to wall	Beam to wall	Beam to column
Today	**Current Design Method**	EC2	EC2	EC2	X	X	X	X	X
Future	**Design with beyond cast-in**	EC2	EC2	EC2	**Beyond CI**	**Beyond CI**	**Beyond CI**	**Beyond CI**	**Beyond CI**

However, if we really want to follow EC2, in case of simply supported 25% of the bending moment in the middle of the span should be considered at the support → it is designed as rigid!!

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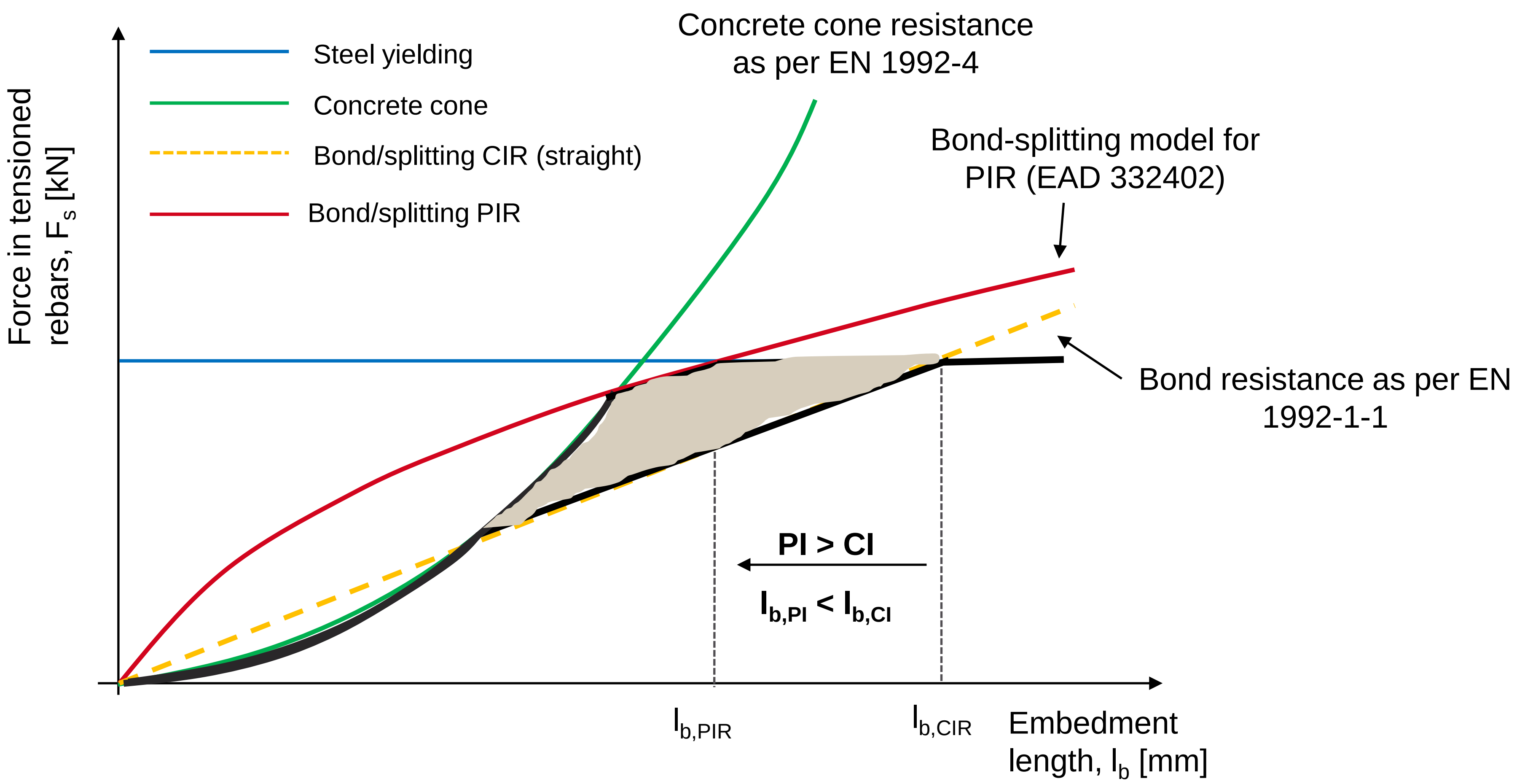
DESIGN OF RIGID CONNECTIONS WITH PIR: TR 069



THE DESIGN IS BASED ON THE HIERARCHY OF RESISTANCES

Design resistance to yielding

Design bond splitting resistance

$$R_d \leq \min\left(N_{Rd,y}; N_{Rd,c}; N_{Rd,sp}\right)$$

Design concrete cone break out resistance

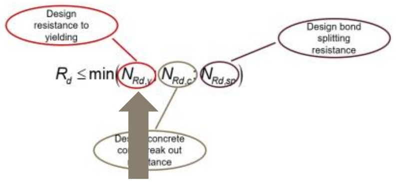
NOTE: Do you know the principles of anchor theory? Then, the rebar design is easy for you….

WHAT TO KEEP IN MIND

- Splices applications are designed based on EC2: post-installed rebar performs equal to cast-in rebars

- Structural joints are designed based on TR069: post-installed rebar performance beyond cast-in rebars

1) THE RESISTANCE TO YIELDING IS FUNCTION OF REBAR DIAMETER AND STEEL STRENGTH

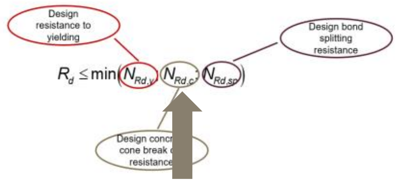


$$R_d \leq \min\left(N_{Rd,y};\, N_{Rd,c};\, N_{Rd,sp}\right)$$

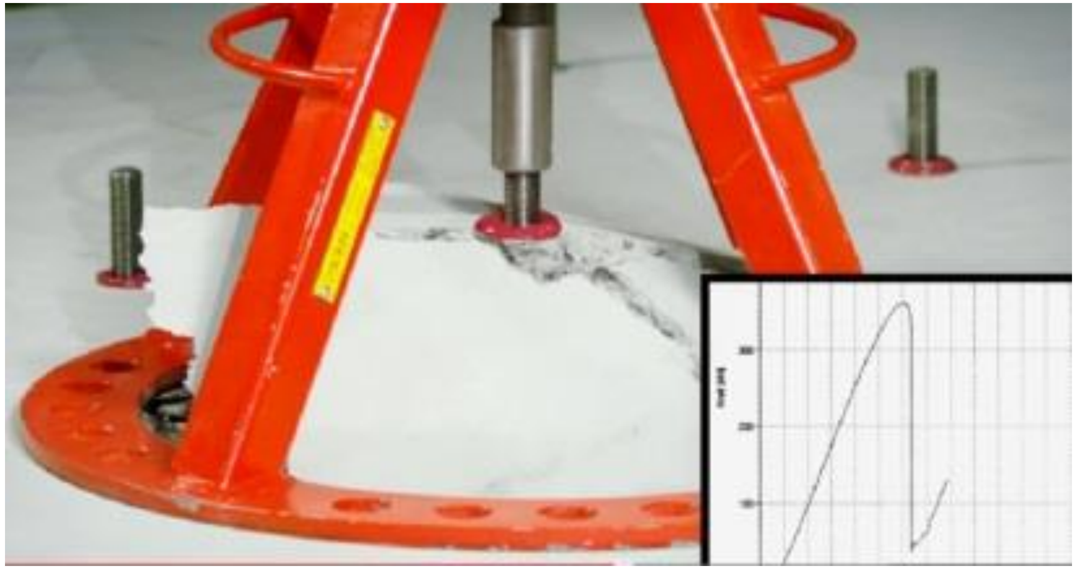
$$N_{Rd,y} = N_{Rk,y} / \gamma_{Ms}$$

$$N_{Rk,y} = A_s \cdot f_{yk}$$

2) THE RESISTANCE TO CONCRETE CONE IS FUNCTION OF SEVERAL PARAMETERS



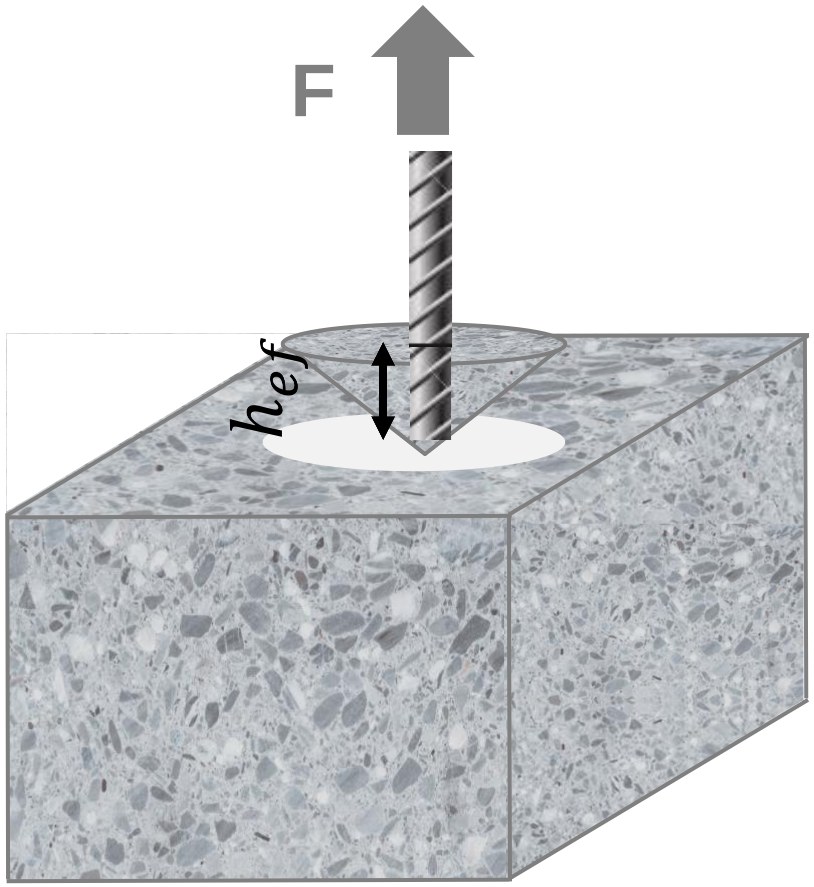
$$R_d \leq \min\left(N_{Rd,y}; N_{Rd,c}; N_{Rd,sp}\right)$$



$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{ec,N} \cdot \psi_{re,N} \cdot \psi_{M,N}$$

Please note: concrete cone failure formula is exactly the same used for anchor design!

ANCHORAGE LENGTH IS THE KEY FOR CONCRETE CONE STRENGTH



Group anchor acting surface

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

Single anchor maximum area

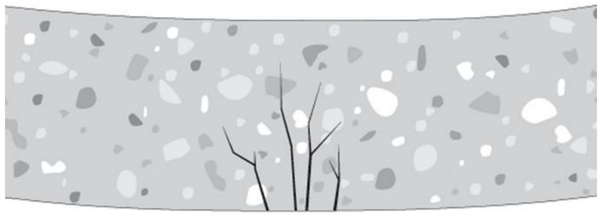
Characteristic Strength of Single Anchor

$$N^0{}_{Rk,c} = k_1 \sqrt{f_{ck}}\ h_{ef}{}^{1,5}$$

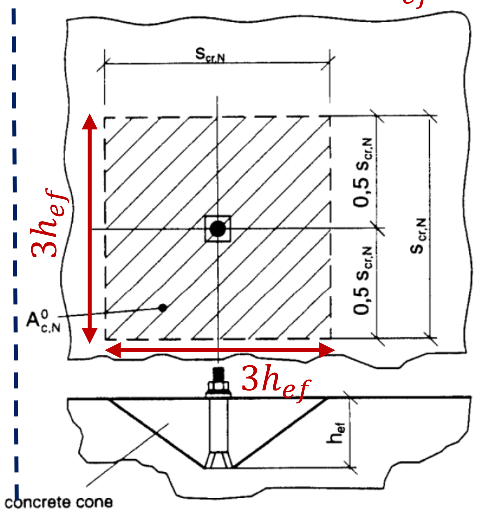
k_1 : Concrete crack coefficient (Uncracked : 7,7 | Cracked : 11,0)

h_{ef} : Effective anchorage length

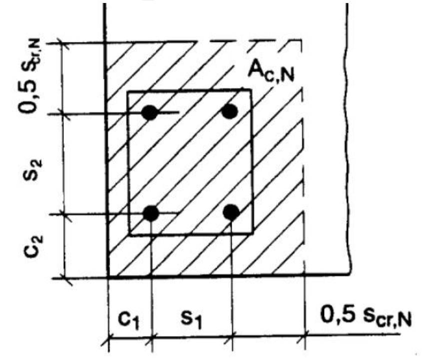
f_{ck} : Characteristic cylindrical concrete strength



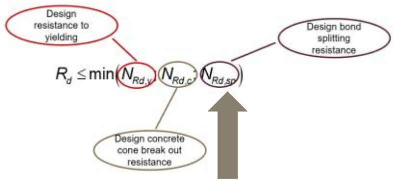
$$A^0_{c,N} = s_{cr,N} \cdot s_{cr,N} = 3h_{ef} \times 3h_{ef} = 9h_{ef}^2$$



$$A_{c,N} = (c_1 + s_1 + 0,5\ s_{cr,N}) \cdot (c_2 + s_2 + 0,5\ s_{cr,N})$$



3) THE RESISTANCE TO SPLITTING IS FUNCTION OF PRODUCT PERFORMANCE



$$R_d \le \min\left(N_{Rd,y};\, N_{Rd,c};\, N_{Rd,sp}\right)$$

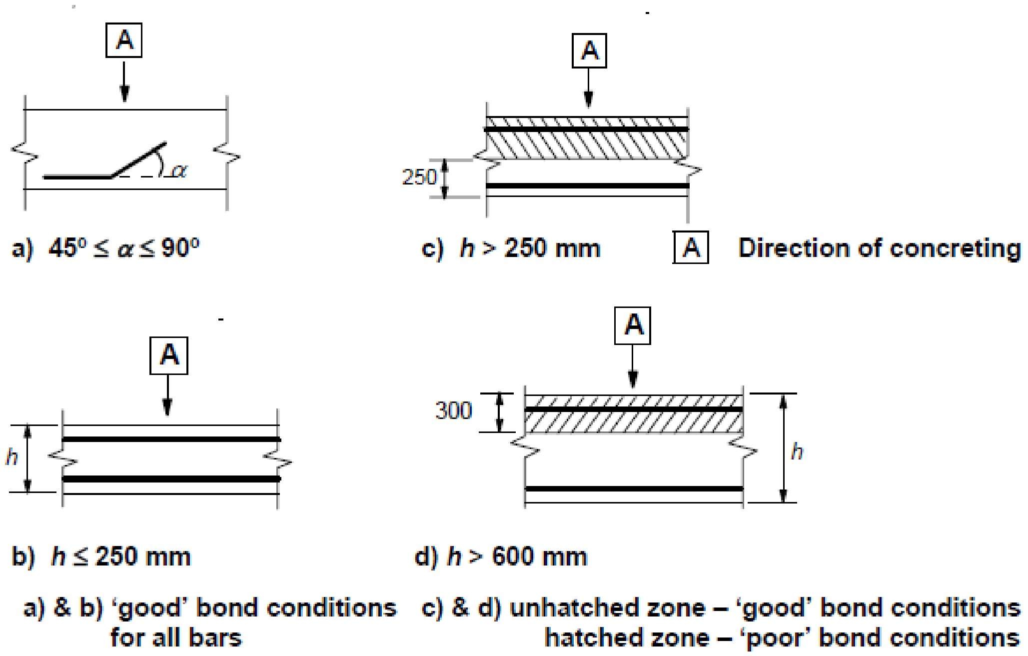
$$N_{Rk,sp} = \tau_{Rk,sp} \cdot l_b \cdot \phi \cdot \pi$$

$$\tau_{Rk,sp} = \eta_1 \cdot A_k \cdot \left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_{min}}{\phi}\right)^{sp3} \cdot \left(\frac{c_{max}}{c_{min}}\right)^{sp4} + k_m \cdot K_{tr}\right] \cdot \left(\frac{7\phi}{l_b}\right)^{lb1} \cdot \Omega_{p,tr}$$

$$\le \tau_{Rk,ucr} \cdot \Omega_{cr} \left| \Omega_{p,tr} \right. \cdot \psi_{sus} \qquad 7\phi \le l_b \le 20\phi$$

$$\le \tau_{Rk,ucr} \cdot \left(\frac{20 \cdot l_b}{\phi}\right)^{lb1} \cdot \Omega_{cr} \left| \Omega_{p,tr} \right. \cdot \psi_{sus} \qquad l_b > 20\phi$$

η_1 IS THE COEFFICIENT RELATED TO GOOD OR POOR BOND CONDITIONS BASED ON EC2



= 1.0 when "good" conditions are obtained as per EN 1992-1-1, Figure 8.2 [4]

= 0.7 in all other cases

SOME PARAMETERS ARE FROM THE NEW ETA…

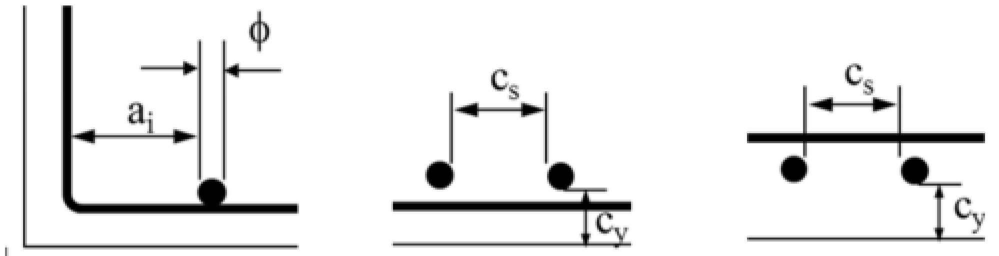
A_k, sp1, sp2, sp3, sp4, Ω_{cr} and lb1 are taken from the product ETA and are product related

K_m TAKES INTO ACCOUNT THE TRANSVERSE REINFORCEMENT

= 12 where rebars are confined inside a bend of links passing round the bar of at least 90° .

= 6 where a rebar is more than 125 mm and more than 5 bar diameters from the nearest vertical leg of a link crossing the splitting plane in an approximately perpendicular direction

= 0 if a splitting crack would not intersect transverse reinforcement, either because the transverse reinforcement is positioned inside the bars, or the clear spacing between anchored or pairs of lapped rebars is less than 4 times the bottom cover, and hence a crack through the plane of the rebars would form without intersecting transverse reinforcement



$a_i \leq 125$ mm or $a_i \leq 5\phi$: $k_m = 12$
$a_i > 125$ mm and $a_i > 5\phi$: $k_m = 6$

$a_i > 125$ mm and $a_i > 5\phi$ and $c_s < 4c_y$: $k_m = 0$

$k_m = 0$

K_{tr} TAKES INTO ACCOUNT THE EFFECT OF REINFORCEMENT ON SPLITTING FAILURE MODE

$K_{tr} = (n_t \ A_{st}) / (n_b \ f \ s_b) \leq 0.05$

where:

n_t is the number of legs of confining reinforcement crossing a potential splitting surface

A_{st} is the cross-sectional area of one stirrup leg

n_b is the number of anchored or lapped bars in the potential splitting surface

s_b is the spacing between the confining reinforcement

Note: in the case of cracked concrete, in equations (4.11b) and (4.11c) only W_{cr} applies and $W_{p,tr}$ shall not be applied.

$\Omega_{p,tr}$ TAKES INTO ACCOUNT TRANSVERSE PRESSURE PERPENDICULAR TO THE AXIS OF THE REBAR

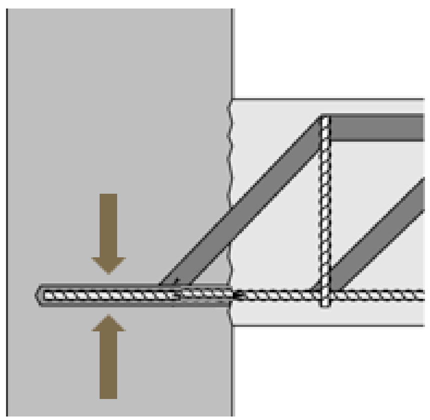
$$\Omega_{p,tr} = 1.0 - \frac{0.3 \cdot p_{tr}}{f_{ctm}} \qquad \text{for} \quad f_{ctm} \geq p_{tr} \geq 0 \quad (\text{tension})$$

$$\Omega_{p,tr} = 1.0 - \tanh\left[0.2 \cdot \frac{p_{tr}}{0.1 \cdot f_{cm}}\right] \quad \text{for} \quad f_{cm} \geq p_{tr} \geq 0 \quad (\text{compression})$$

Where

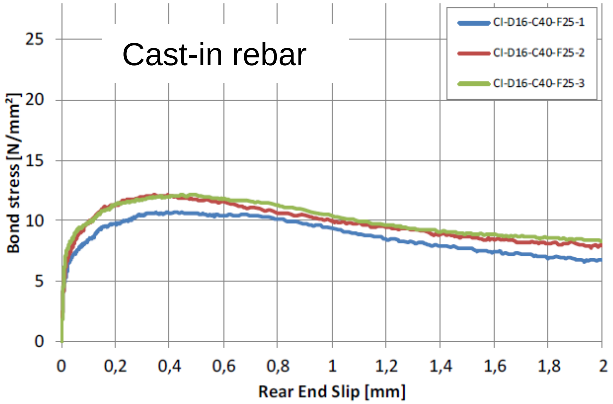
f_{cm} and f_{ctm} shall be taken according to EN 1992-1-1 [4] for the concrete strength class under consideration.

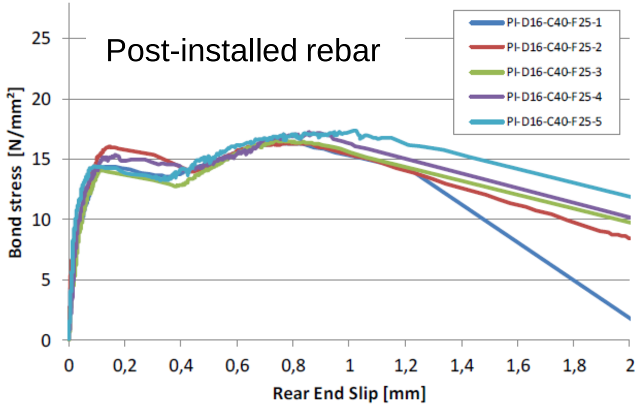
p_{tr} is calculated as mean stress in the concrete (orthogonal to the bar axis) averaged over a volume around the bar with a diameter of 3f.

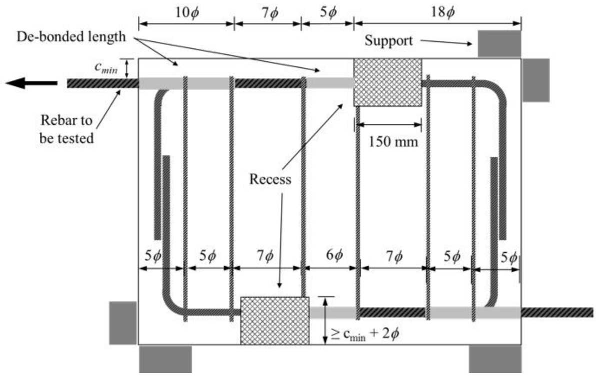


ASSESSMENT OF REALISTIC BOND-SPLITTING RESISTANCE OF PIR (EAD 332402)

Derivation of local bond model







Assessment of shear lag effect

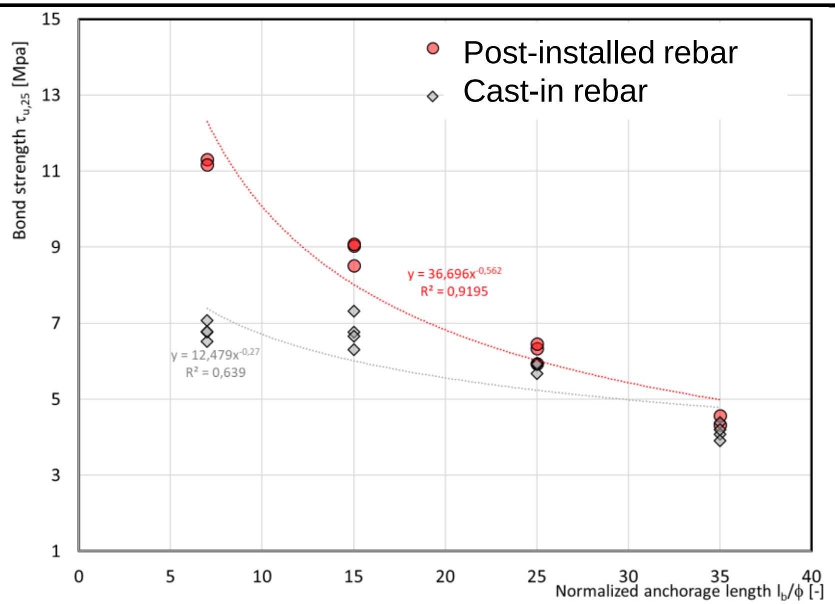
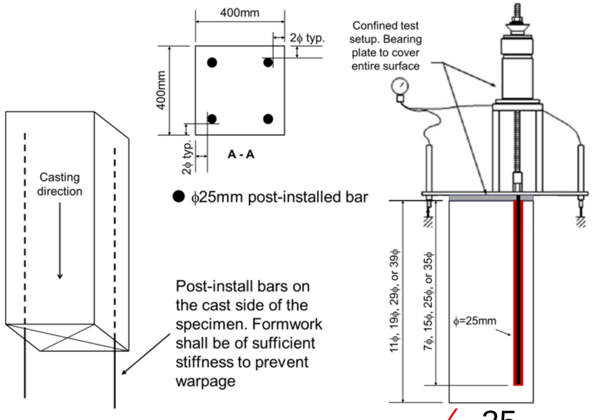
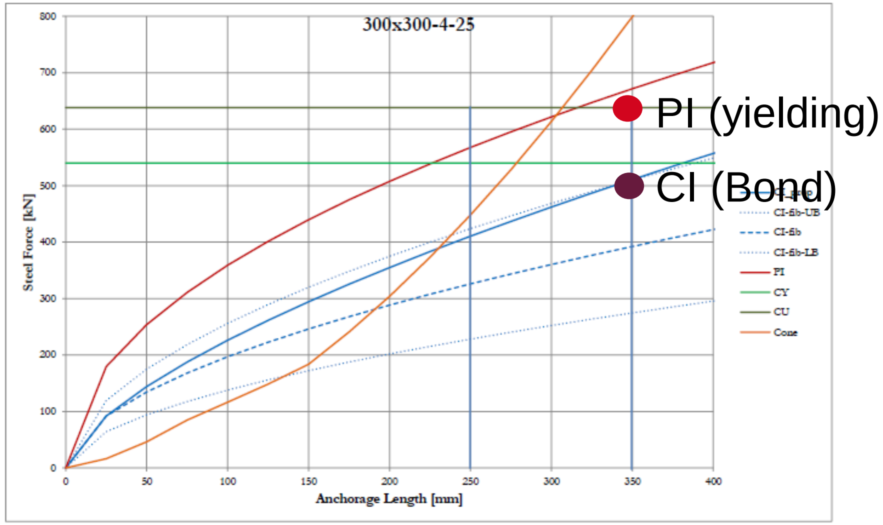


Figure 5.2 Tested specimen – G1-HY200-1,G2-HY200-1, G3-HY200-1, G4-HY200-1



EXPERIMENTAL VALIDATION OF DESIGN FOLLOWING THE PROVISIONS OF TR069

Monotonic tests on column-foundation joints



	CI	PI	Units
Expected Steel Force at Failure	510	638	kN
Column Moment at Failure	114	137	kN-m
Point of application of load	2.045	2.047	m
Expected Failure Load	**55.75**	**66.93**	kN

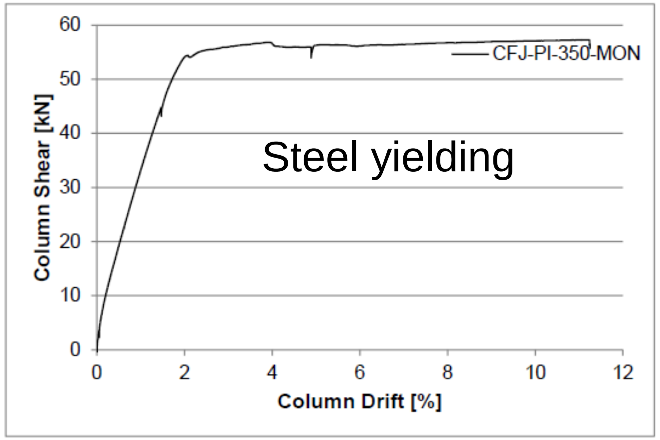
University of Stuttgart

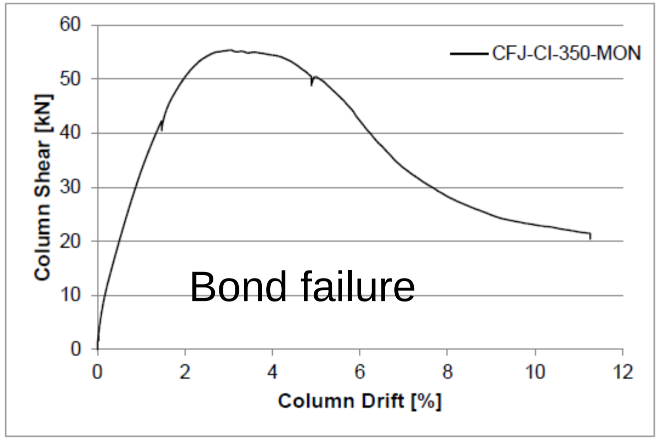
CFJ-PI-350-MON

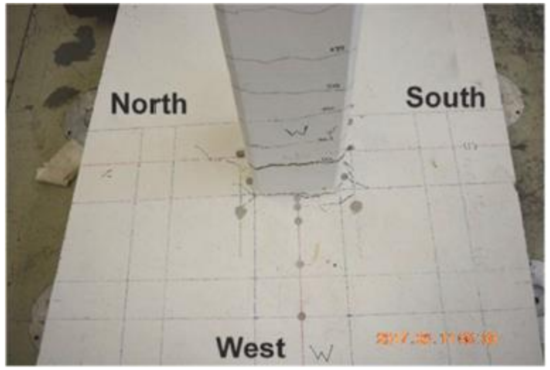
1. Yielding of Column
2. Test Terminated prior to failure
3. Max. Load = 57.25kN (*Pre:66.93*)
4. Moment induced deformation

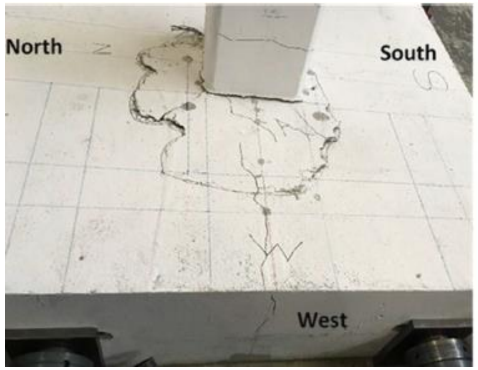
CFJ-CI-350-MON

1. Pull out + Cone in Foundation
2. Final Failure Observed
3. Max. Load = 55.36kN (*Pre:55.75*)
4. Rigid Body Rotation









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CONCLUSIONS

- Post-installed reinforcing bar systems is extensively used in the market, however due to regulation limitation the strength of the system did not fully utilize

- The future development of PIR system will focus on more extensive applications (moment joint) as well as better bond strength calculation and hence the strength of the system can be further unleashed

- The performance of post-installed reinforcing bar systems can be superior to the cast-in bars under specific conditions

- More research and regulation development are expected in coming years and the coverage of PIR system will be further enhanced from equal to cast-in to better than cast-in

THANK YOU