EUROCODE 2 FOR ANCHOR DESIGN

Dursun Fethi Aktaş
Regional Community / Technical Marketing Manager
Middle East, Turkey, Africa

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EVOLUTION OF POST-INSTALLED ANCHORS REGULATIONS IN EUROPE

THE REGULATORY FRAMEWORK FOR CONSTRUCTION PRODUCTS IS GIVEN BY THE CPR, FORMERLY BY THE CPD

No L 40/12   Official Journal of the European Communities   11. 2. 89

COUNCIL DIRECTIVE

of 21 December 1988

on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products

(89/106/EEC)

4.4.2011   EN   Official Journal of the European Union

REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 9 March 2011

laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC

(Text with EEA relevance)

CPD: Construction Products Directive, 1989
- Principle: ensure free movement of construction products in the EU, by harmonizing national laws, with respect to health & safety requirements.
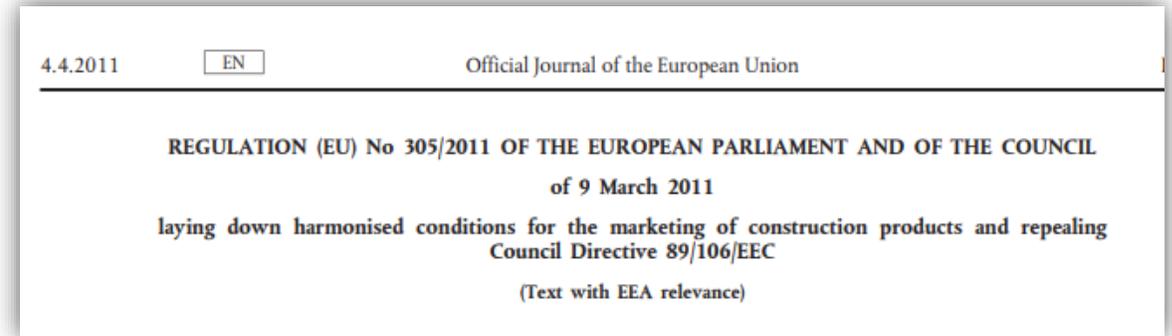
CPR: Construction Products Regulation, 2011
- Replaced CPD to simplify, clarify, as well as improve transparency and effectiveness.
- But the basic principle remain!

https://ec.europa.eu/growth/sectors/construction/product-regulation_en

CPD/CPR LAID THE FRAMEWORK AND DEFINED ROLES & RESPONSIBILITIES OF DIFFERENT ORGANISATIONS

CEN: European Committee for Standardization

- in charge to develop **European Standards** (**ENs**) in many areas, (not only construction products) in particular the **Eurocodes**.

Design Standards

EOTA: European Organisation for Technical Assessment (all TABs)

- in charge to develop **European Assessment Documents (EADs)** in the area of construction products.
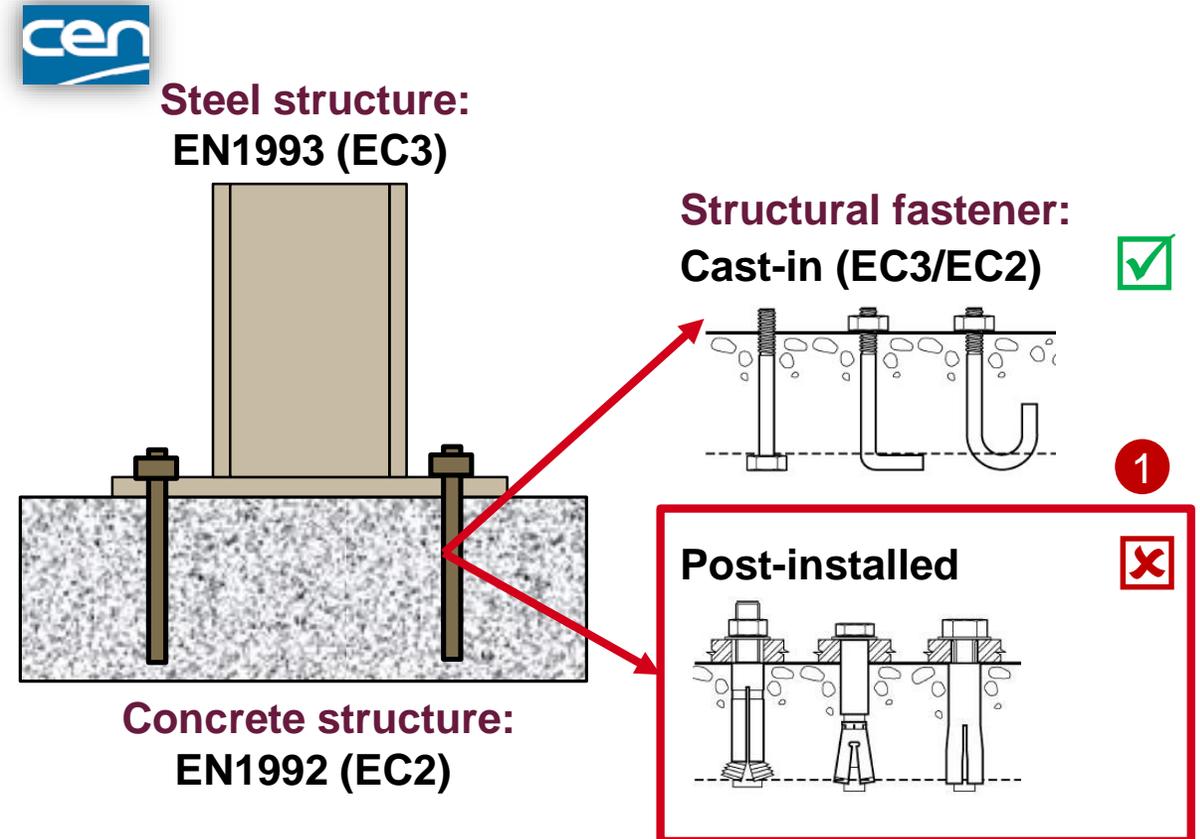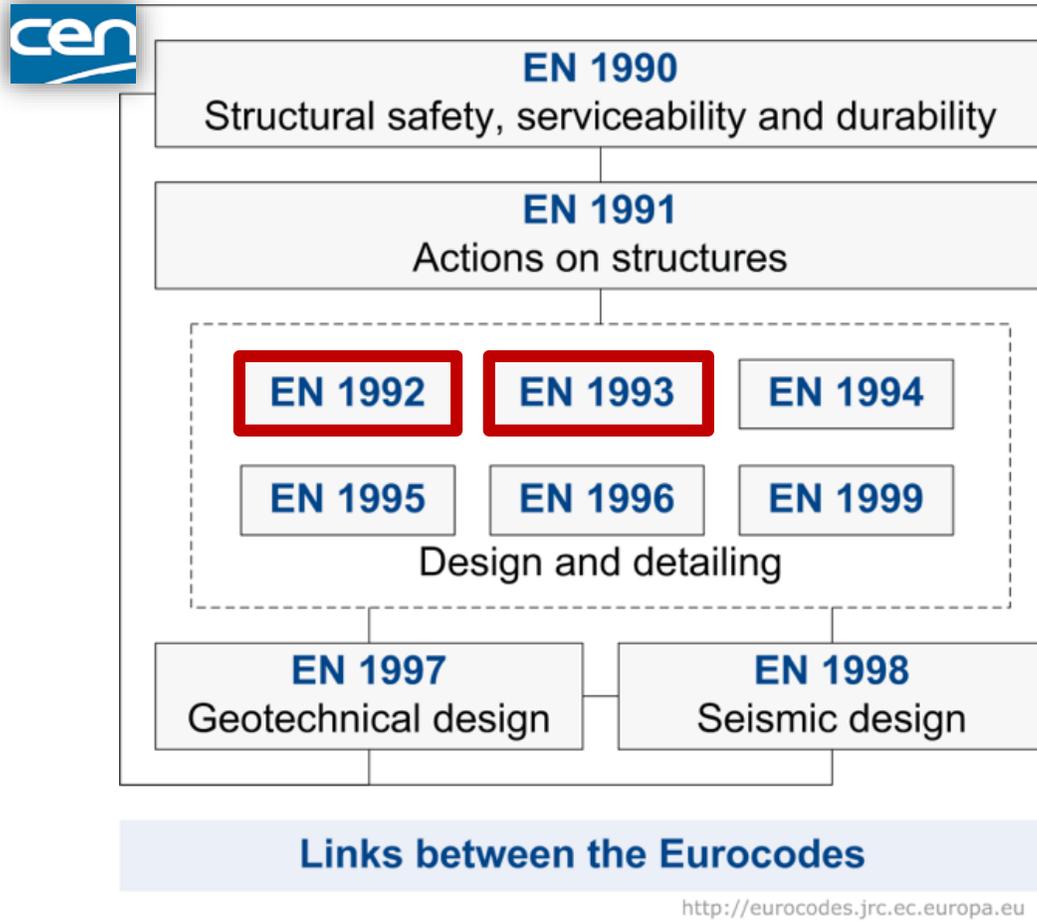
Product Assessment Criteria

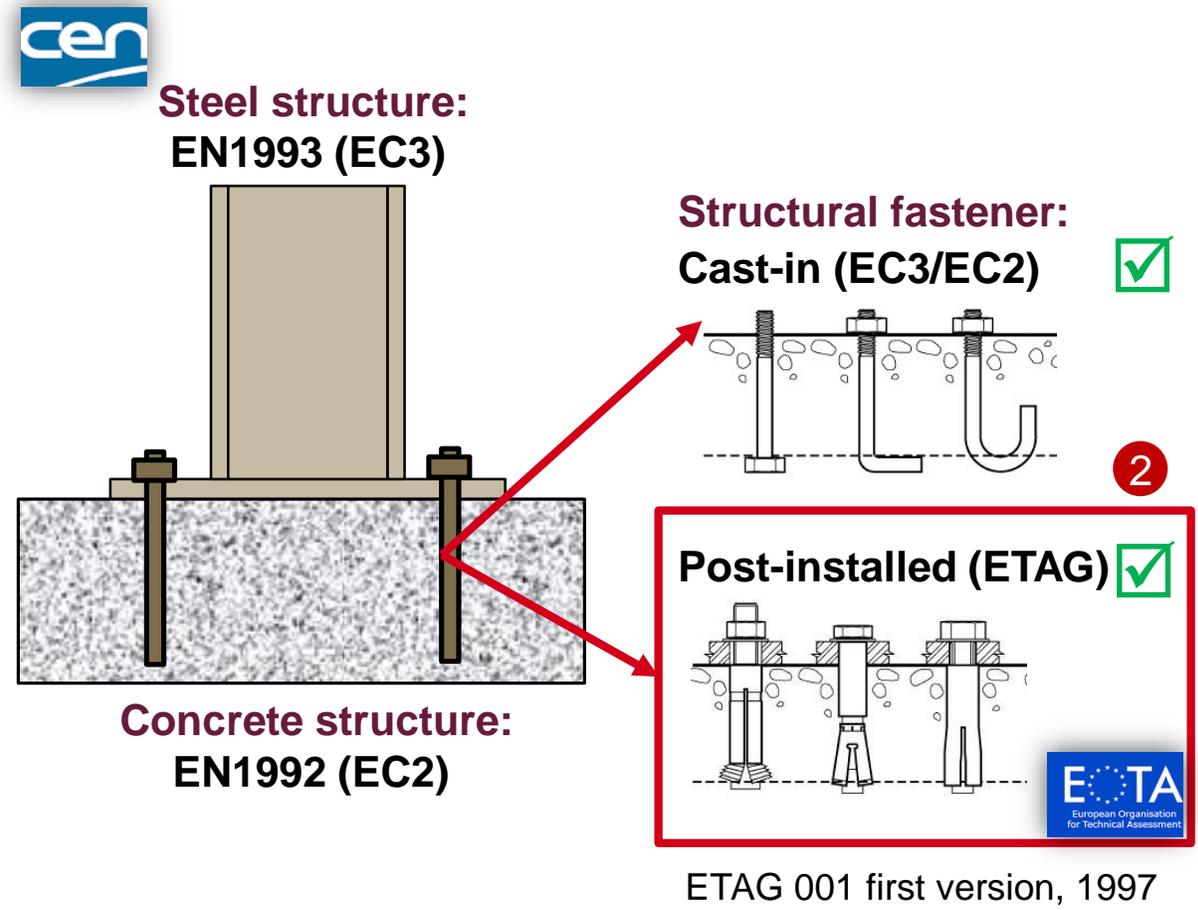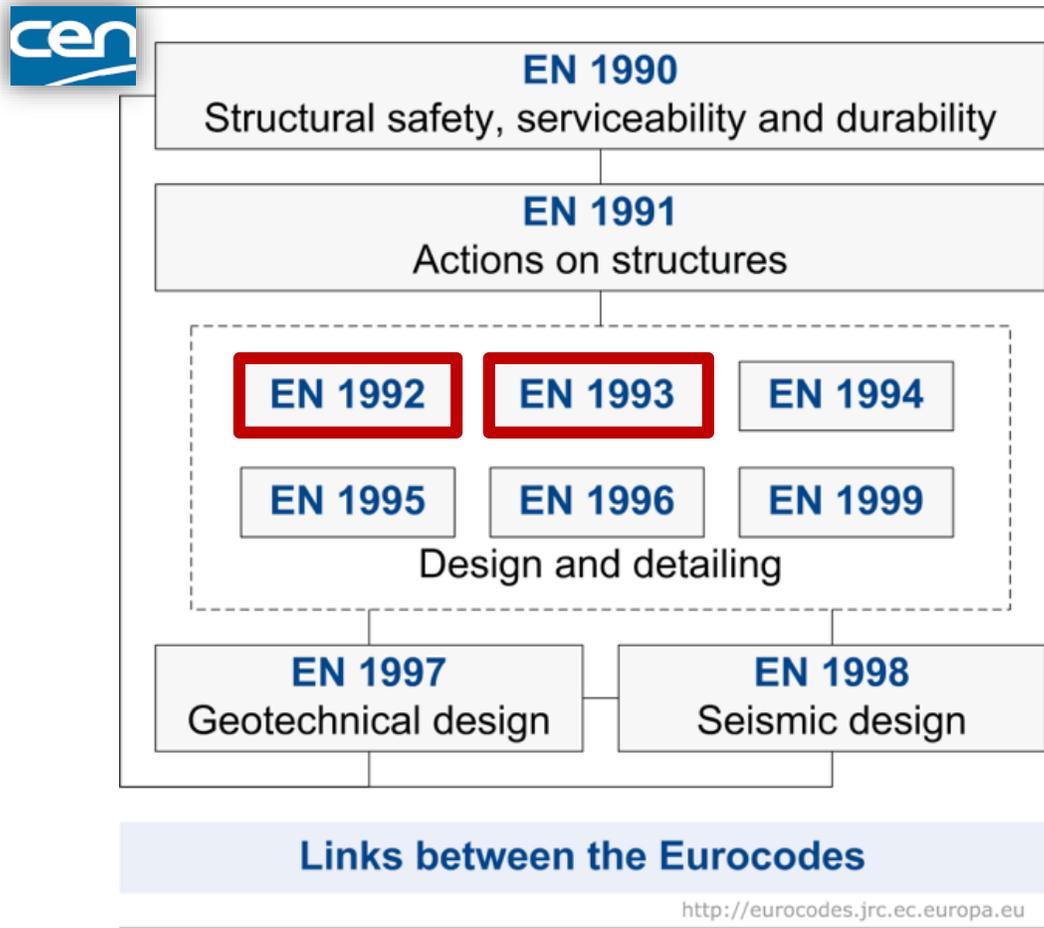**TABs:** Technical Assessment Bodies (e.g. DIBt, CSTB)

- in charge of the **European Technical Assessment (ETAs)** of construction products.

Product Assessment

① WHEN CEN GOT MANDATE TO DEVELOP THE EUROCODE STANDARDS, POST-INST. ANCHOR DESIGN WASN'T MATURE

EN 1990 — Structural safety, serviceability and durability

EN 1991 — Actions on structures

EN 1992 · **EN 1993** · **EN 1994**

EN 1995 · **EN 1996** · **EN 1999**

Design and detailing

EN 1997 — Geotechnical design

EN 1998 — Seismic design

Links between the Eurocodes

http://eurocodes.jrc.ec.europa.eu

Steel structure: EN1993 (EC3)

Concrete structure: EN1992 (EC2)

Structural fastener: Cast-in (EC3/EC2) ✓

Post-installed ✗

② SO, <u>EOTA</u> GOT MANDATE TO DEVELOP POST-INST. ANCHOR DESIGN PROVISIONS UNDER AND <u>ETAG "GUIDELINE"</u>

EN 1990
Structural safety, serviceability and durability

EN 1991
Actions on structures

| EN 1992 | EN 1993 | EN 1994 |

| EN 1995 | EN 1996 | EN 1999 |
Design and detailing

EN 1997
Geotechnical design

EN 1998
Seismic design

Links between the Eurocodes

http://eurocodes.jrc.ec.europa.eu

Steel structure:
EN1993 (EC3)

Concrete structure:
EN1992 (EC2)

Structural fastener:
Cast-in (EC3/EC2) ☑

② **Post-installed (ETAG)** ☑

ETAG 001 first version, 1997

③ NOW, MATURE ENOUGH, POST-INST. ANCHOR DESIGN PROVISIONS GET BACK TO CEN AS PART OF EUROCODE 2

EN 1990
Structural safety, serviceability and durability

EN 1991
Actions on structures

| EN 1992 | EN 1993 | EN 1994 |
| EN 1995 | EN 1996 | EN 1999 |

Design and detailing

EN 1997
Geotechnical design

EN 1998
Seismic design

Links between the Eurocodes

http://eurocodes.jrc.ec.europa.eu

Steel structure:
EN1993 (EC3)

Concrete structure:
EN1992 (EC2)

Structural fastener:
Cast-in (EC3/EC2) ☑

③ **Post-installed (EC2-4)** ☑

EC2-4 (EN1992-4) lastest date of publication, Mar 2019

ASSESSMENT CRITERIA, TECHNICAL DATA AND DESIGN METHOD HAVE TO BE UNDERSTOOD AS A «SYSTEM»

Assessment Criteria

(EADs)
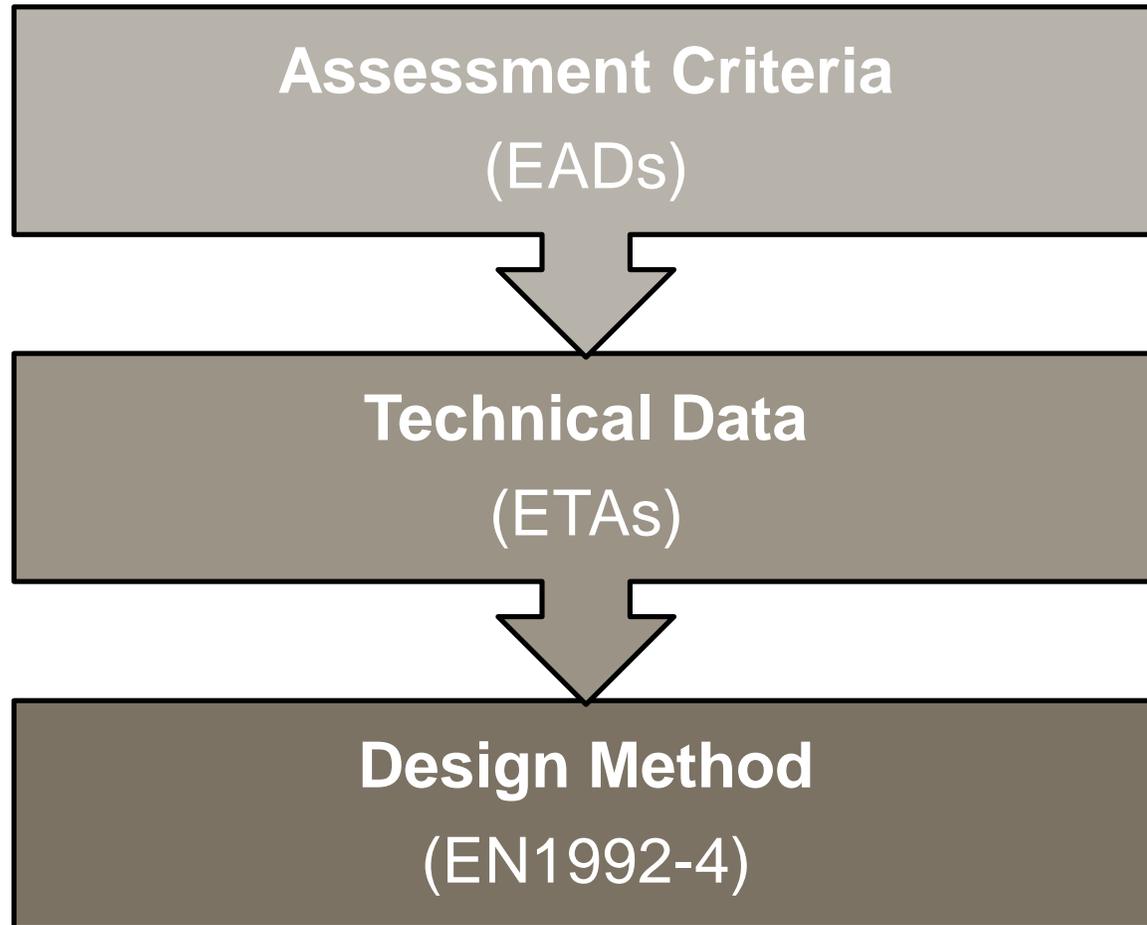
**European Assessment Document (EAD)** provides the methods and criteria for the assessment of the performance of a construction product in relation to its essential characteristics.

Technical Data

(ETAs)

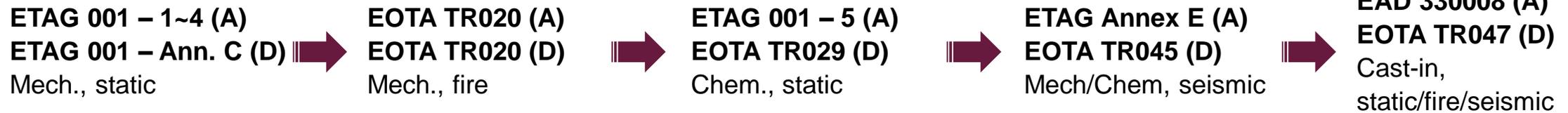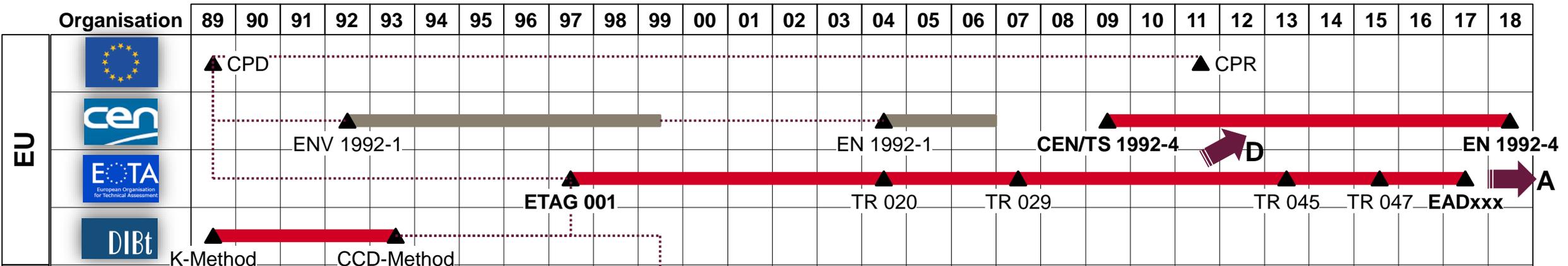**European Technical Assessment (ETA)** provides information about the performance of a construction product in relation to its essential characteristics, according to the respective EAD.

Design Method

(EN1992-4)

EN1992-4 provides a design method for fastenings (connection of structural/non-structural elements to structural components), which are used to transmit actions to the concrete.

THE LONG 30-YEAR JOURNEY TO EC2-4 (EN1992-4): FROM A LOCAL GUIDELINE TO A EUROPEAN STANDARD

2019 >
EN1992-4

European Standard

1997-2018
ETAG 001

European Guideline

1989-1997
K / CCD
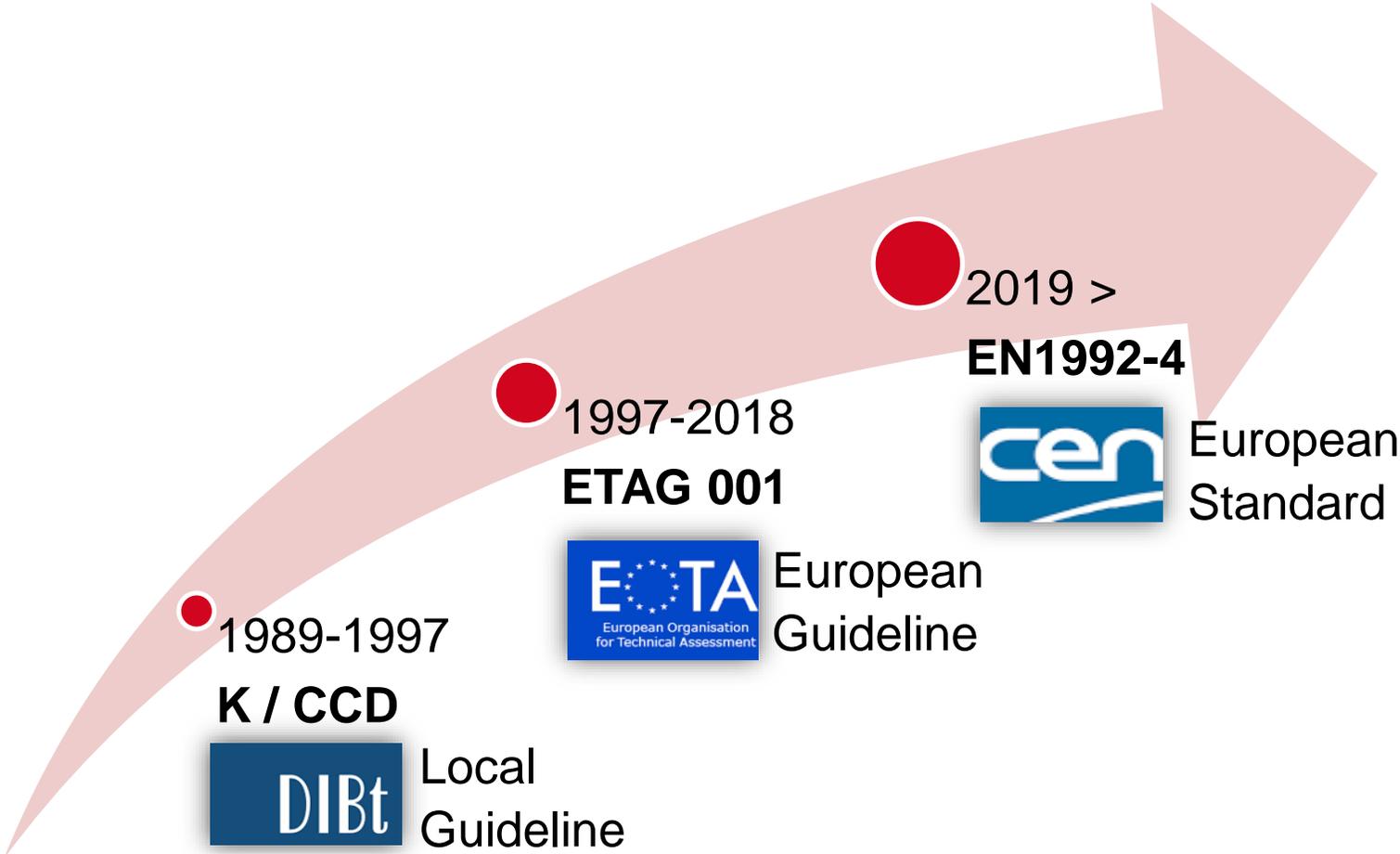
Local Guideline

# THE LONG 30-YEAR JOURNEY TO EC2-4 (EN1992-4): FROM A LOCAL GUIDELINE TO A EUROPEAN STANDARD (DETAILS)

ETAG 001 – 1~4 (A)
ETAG 001 – Ann. C (D)
Mech., static

EOTA TR020 (A)
EOTA TR020 (D)
Mech., fire

ETAG 001 – 5 (A)
EOTA TR029 (D)
Chem., static

ETAG Annex E (A)
EOTA TR045 (D)
Mech/Chem, seismic

EAD 330008 (A)
EOTA TR047 (D)
Cast-in,
static/fire/seismic

- Structural concrete
- Post-installed anchors

(A): Assessment Criteria
(D): Design Guideline

https://www.eota.eu/en-GB/content/etags-used-as-ead/26/

ANCHOR FASTENER SPECIFICATION AND INSTALLATION

ANCHOR FASTENER PERFORMANCE IS HIGHLY LINKED TO CONCRETE MEMBER LOADING STATUS
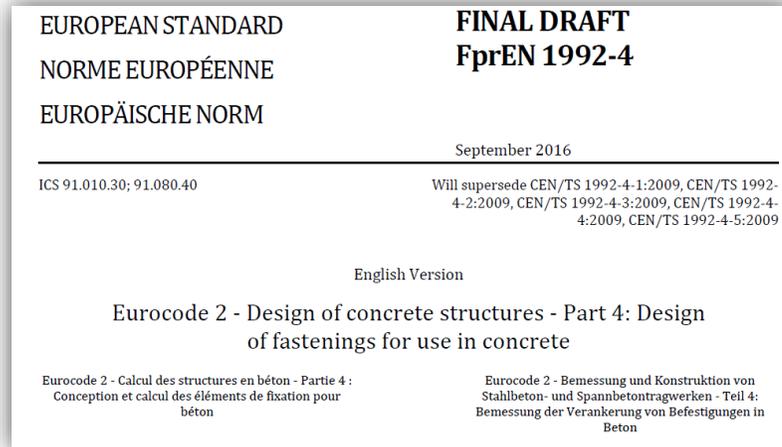

Compression

Tension
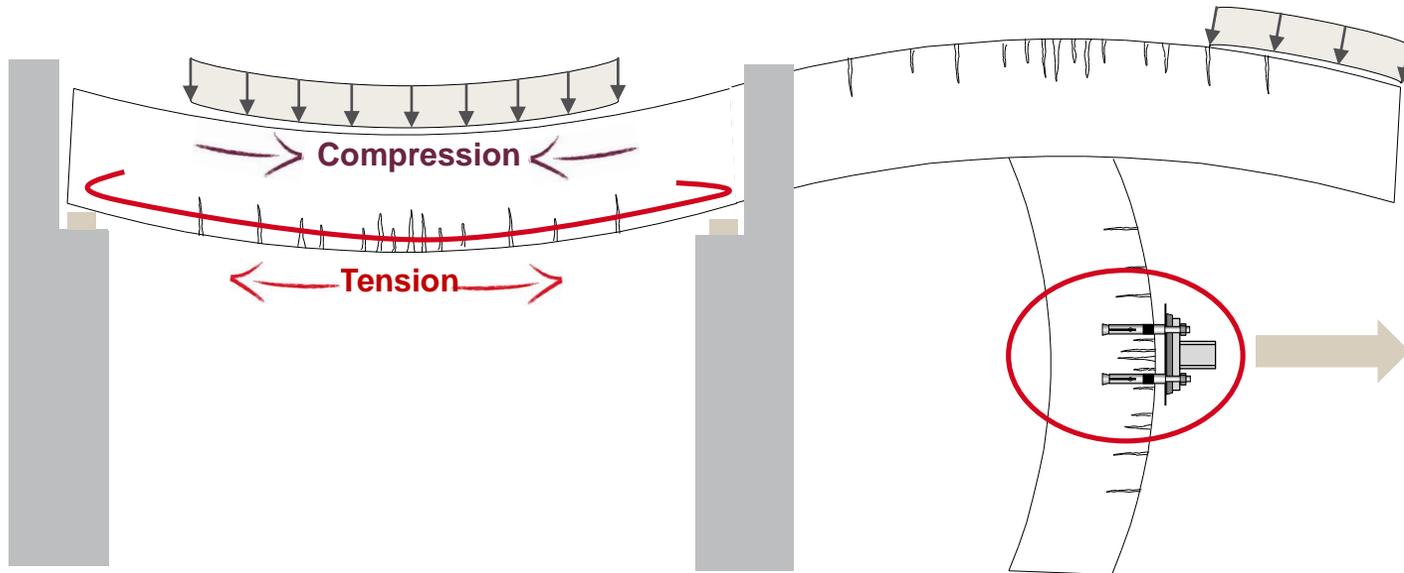
Anchor fastener selection has to consider concrete member status.

- Cracked vs. uncrack?
- Subject to seismic or fatigue load?
- Fire resistance needed?

Every design situation is different that's why you should specify products while taking the concrete situation into account as well.

EUROPEAN STANDARD ENFORCES THE USAGE OF CRACKED CONCRETE DESIGN

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

FINAL DRAFT
FprEN 1992-4

September 2016

ICS 91.010.30; 91.080.40

Will supersede CEN/TS 1992-4-1:2009, CEN/TS 1992-4-2:2009, CEN/TS 1992-4-3:2009, CEN/TS 1992-4-4:2009, CEN/TS 1992-4-5:2009

English Version

Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

Eurocode 2 - Calcul des structures en béton - Partie 4 : Conception et calcul des éléments de fixation pour béton

Eurocode 2 - Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 4: Bemessung der Verankerung von Befestigungen in Beton

4.5 Project specification

(1) The project specification shall typically include the following.

a) Strength class of the concrete used in the design and indication as to whether the concrete is assumed to be cracked or not cracked. If uncracked concrete is assumed, verification is required (see 4.7).

- Eurocode 2-4 requires additional laborious efforts if un-cracked concrete is assumed

- Considering crack concrete is safe and more efficient for designer and contractor

- Full adoption of cracked concrete as in Germany 15 years ago after same provisions reflected in local building regulations ("in case of doubt" cracked is always assumed)

- As per Dec 2018 Germany internal data, 92.4% of designs are done with cracked concrete

SAFETY COMES FROM A PROPER DESIGN + PROPER SPECIFICATION + CORRECT INSTALLATION

EN1992-4 has dedicated chapters for project specification and installation of fasteners.

4.5 Project specification

(1) The project specification shall typically include the following.

a) Strength class of the concrete used in the design and indication as to whether the concrete is assumed to be cracked or not cracked. If uncracked concrete is assumed, verification is required (see 4.7).

b) Environmental exposure assumed in design (see EN 206).

c) A note indicating that the number, manufacturer, type and geometry of the fasteners or manufacturer, type and geometry of anchor channel or channel bolts shall not be changed unless verified and approved by the responsible designer.

d) Construction drawings or supplementary design documents should include:

    1) location of the fasteners or anchor channels in the structure, including tolerances;

    2) number and type of fasteners (including embedment depth) or type of anchor channels and channel bolts;

    3) spacing and edge distance of the fastenings or anchor channels including tolerances (normally these should be specified with positive tolerances only);

    4) thickness of fixture and diameter of the clearance holes (if applicable);

4.6 Installation of fasteners

The resistance and reliability of fastenings are significantly influenced by the manner in which the fasteners are installed. The partial factors given in 4.4 are valid only when the conditions and the assumptions given in Annex F are fulfilled.

Annex F
(normative)

Assumptions for design provisions regarding execution of fastenings

F.1 General

In this EN the following assumptions have been made in respect of installation and execution of the relevant type of fastener and regarding welding design of headed fasteners. The installation instructions should reflect the assumptions stated below for the corresponding type of fastener.

F.2 Post-installed fasteners

a) Concrete has been compacted adequately in the area of the fastening. This should be checked prior and during installation, e.g. by visual inspection.
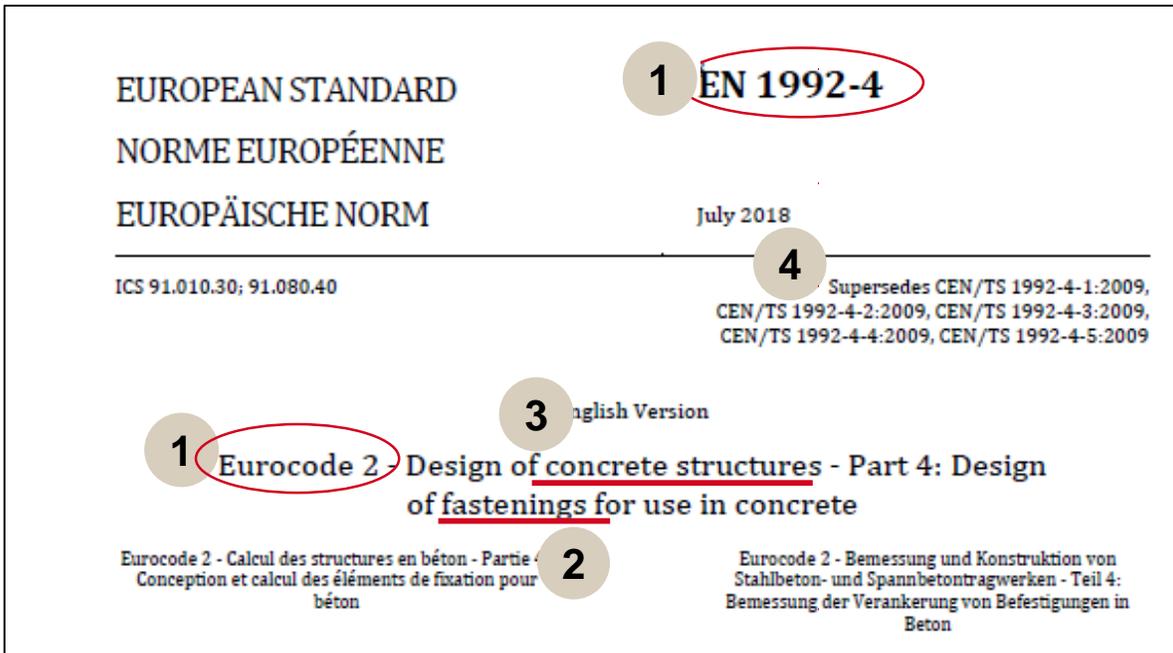
Requirements for drilling operation and bore hole are fulfilled when:

    1) Holes are drilled perpendicular to the surface of the concrete unless specifically required otherwise by the manufacturer's installation instructions.

    2) Drilling is carried out according to the manufacturer's installation instructions.

    3) Hammer-drill bits which comply with ISO (e.g. ISO 5468) or National Standards are used.

    4) The diameter of the segments for diamond core drilling complies with the prescribed diameter.

    5) Holes are cleaned according to the manufacturer's installation instructions which are typically given in the European Technical Product Specifications.

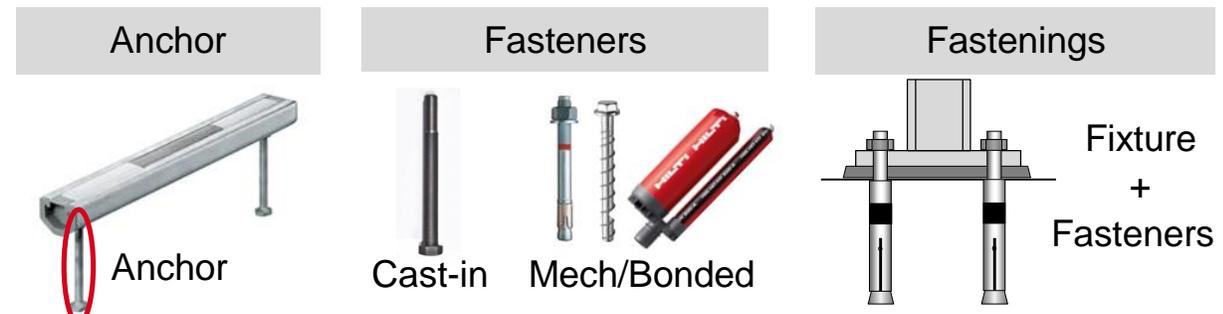# MAIN TECHNICAL DIFFERENCES BETWEEN ETAG & EC2 FOR ANCHOR DESIGN

HILTI

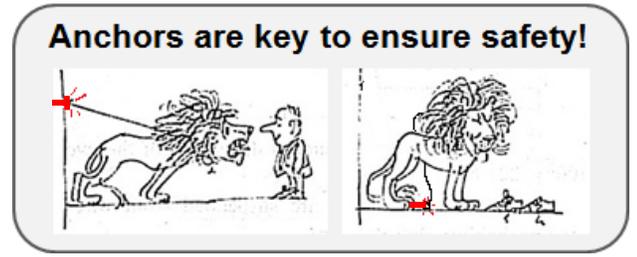# EC2-4: SOME BASIC TAKEAWAYS, JUST BY LOOKING AT THE COVER PAGE…

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

July 2018

1 EN 1992-4

ICS 91.010.30; 91.080.40

4 Supersedes CEN/TS 1992-4-1:2009, CEN/TS 1992-4-2:2009, CEN/TS 1992-4-3:2009, CEN/TS 1992-4-4:2009, CEN/TS 1992-4-5:2009

3 English Version

1 Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

Eurocode 2 - Calcul des structures en béton - Partie 4 - Conception et calcul des éléments de fixation pour béton

2

Eurocode 2 - Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 4: Bemessung der Verankerung von Befestigungen in Beton

1 EN1992-4 = Eurocode 2 - Part 4 = EC2-4

2 Anchor ≠ Fastener ≠ Fastening

Anchor	Fasteners	Fastenings
Anchor	Cast-in Mech/Bonded	Fixture + Fasteners

3 Fastenings have the same importance as the concrete structure itself

Anchors are key to ensure safety!

4 EN1992-4 supersedes CEN/TS 1992-4

EC2-4 COVERS POST-INST. & CAST-IN FASTENERS, AS WELL AS ANCHOR CHANNELS UNDER SEVERAL LOAD CASES

Before EC2-4 published	EC2-4

Design method for fastenings is spread in many different documents (seismic, bonded fasteners, fire, fatigue, etc.)
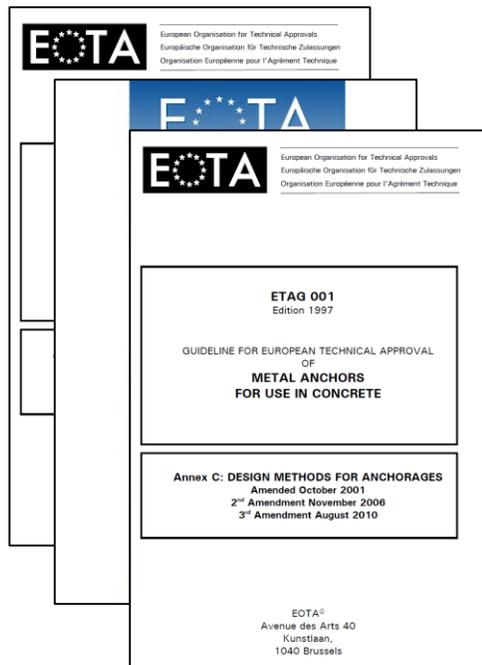
Design method for fastenings is covered in one single document

ETAG 001
Edition 1997

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL
OF
METAL ANCHORS
FOR USE IN CONCRETE

Annex C: DESIGN METHODS FOR ANCHORAGES
Amended October 2001
2nd Amendment November 2006
3rd Amendment August 2010

EOTA©
Avenue des Arts 40
Kunstlaan,
1040 Brussels

	Cast-in fasteners	Anchors Channels	Post-installed fasteners Mechanical	Post-installed fasteners Bonded
Static	☐	☐	☐	☐
Seismic	〰		〰	〰
Fatigue	〰	N/A	〰	〰
Fire	🔥	🔥	🔥	* 🔥

*qualification criteria not available yet

POST-INSTALLED FASTENERS IN EC2-4: BEFORE WE LOOK AT THE DIFFERENCES, LET'S LOOK AT THE SIMILARITIES

Table of content

1. **Scope**

2. **Normative References**

3. **Terms, definitions, symbols, abbreviations**

4. **Basis of design**

5. **Durability**

6. **Derivation of forces acting on fasteners**

7. **Verification of ULS (static)**

8. Verification of ULS (fatigue)

9. Verification of ULS (seismic)

10. Verification of ULS (fire)

11. **Verification of SLS**

Comments on similarity between EC2-4 and ETAG001

1. Normal concrete, with limited configurations of fasteners

2. Link to other EN standards

3. Many symbols like N_{rk}, N_{rd}, are the same.

4. **Rigid** baseplate assumption, **partial** safety factor concept

5. Stated in **ETA** or by national requirement

6. No change

7~10 Verification per different **failure modes**, resistance of certain failure modes shall come from **ETA**.

11. **Linear** function, link to ETA

CONFIGURATIONS OF FASTENINGS: EC2-4 OFFERS A WIDER SCOPE THAN ETAG 001

Gap filled?   Shear load?   Near to an edge?

ETAG 001

Y/N   Y   Y

New in EC2-4

N   Y   Y

Y   Y   Y

New in EC2-4
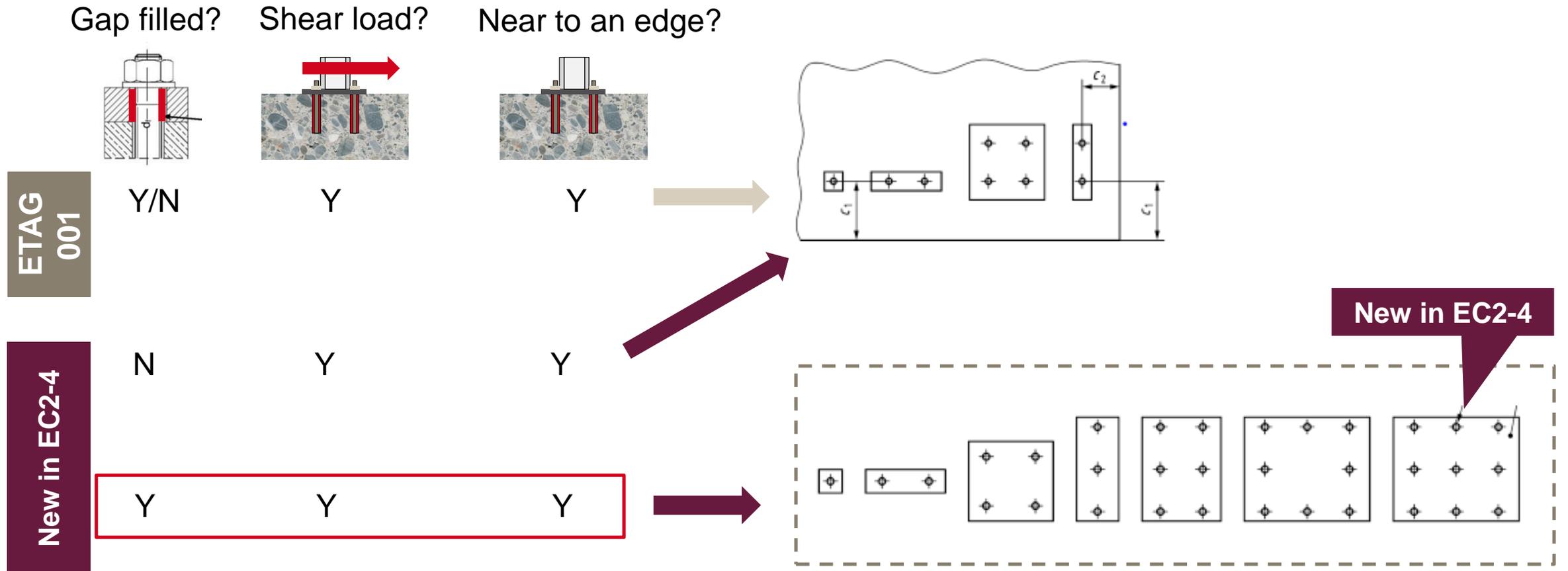
CONCRETE STRENGTH: EC2-4 ALLOWS TO CONSIDER HIGH/LOW STRENGTH CONCRETE GRADES

| C 12/15 | C 16/20 | C 20/25 | C 25/30 | C 30/37 | C 35/45 | C 40/50 | C 45/55 | C 50/60 | C 55/67 | C 60/75 | C 70/85 | C 80/95 | C 90/105 |

ETAG 001 - Annex C

EN1992-4

Current EAD scope — Will probably be extended later on
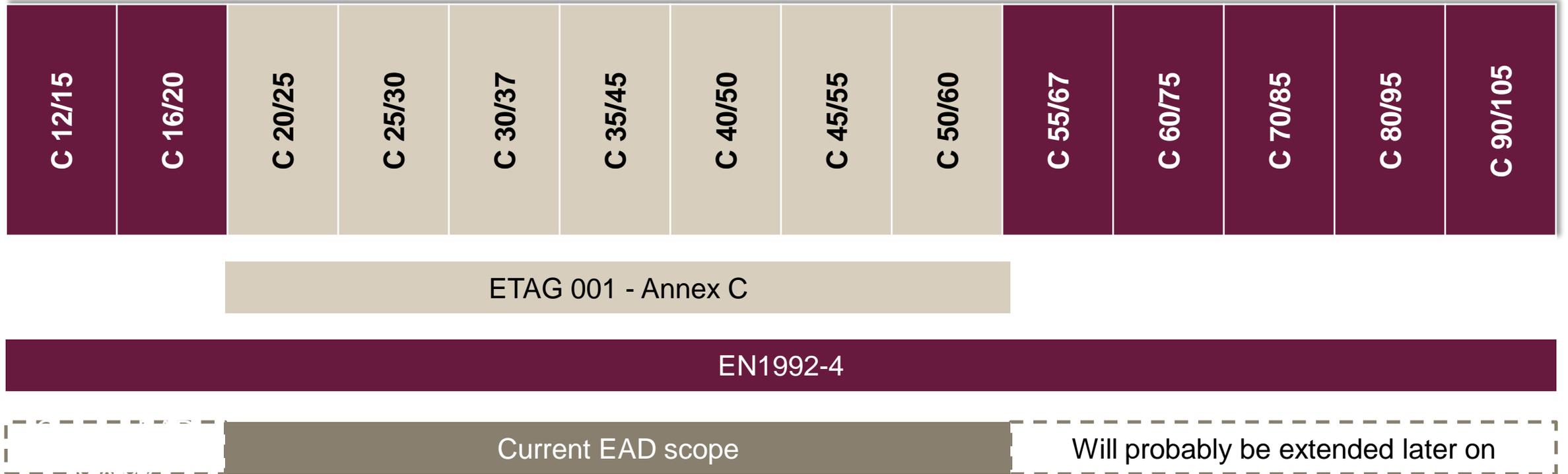
CONCRETE STRENGTH: EC2-4 USES CYLINDER INSTEAD OF CUBE STRENGTH LEADING

Concrete strength can be measured in different ways

C 30 / 37

cylinder's strength
f_{ck}=30 MPa

cube's strength
f_{ck}=37 MPa

300 mm
150 mm
150 mm
150 mm
150 mm
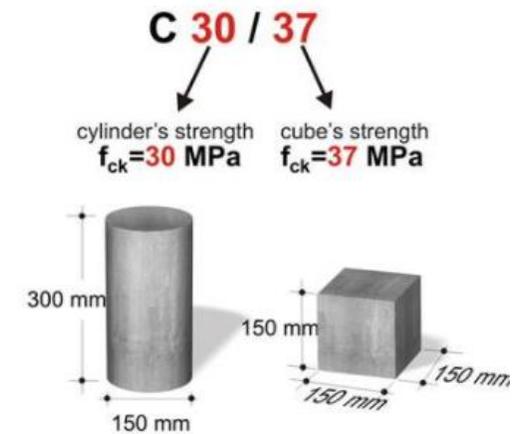
EC2-4   ETAG001

To be in line with other parts of EC2

Most concrete strength relevant formulas have a minor change

Example:
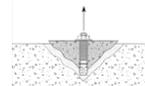
Concrete cone failure

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

Pull-out/Cone failure (Bonded anchors)
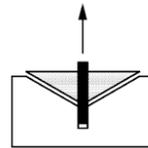
$$\psi^0_{g,Np} = \sqrt{n} - (\sqrt{n} - 1)\left(\frac{\tau_{Rk}}{\tau_{Rk,c}}\right)^{1,5} \geq 1$$

$$\tau_{Rk,c} = \frac{k_3^* \sqrt{h_{ef}\ f_{ck}}}{\pi\ d}$$

ETAG001	EC2-4
k_1, k_3 = 7,2 (cracked) 10,1 (uncracked)	k_1, k_3= 7,7 (cracked) 11,0 (uncracked)

> **EC2-4 shows slightly lower resistance (~5%) for some concrete relevant failure modes versus ETAG 001 Annex C / EOTA TR 029**

RESISTANCE DETERMINATION

1. TENSION LOADS

HILTI

REQUIRED VERIFICATIONS FOR POST-INSTALLED FASTENERS IN TENSION

Table 7.1 — Required verifications for headed and post-installed fasteners in tension

Failure mode		Single fastener	Group of fasteners	
			most loaded fastener	group
1	Steel failure of fastener	No change		
2	Concrete cone failure	$N_{Ed} \leq N_{Rd,c} = \dfrac{N_{Rk,c}}{\gamma_{Mc}}$		$N_{Ed}^{g} \leq N_{Rd,c} = \dfrac{N_{Rk,c}}{\gamma_{Mc}}$
3	Pull-out failure of fastener [a]	No change		
4	Combined pull-out and concrete failure [b]	$N_{Ed} \leq N_{Rd,p} = \dfrac{N_{Rk,p}}{\gamma_{Mp}}$		$N_{Ed}^{g} \leq N_{Rd,p} = \dfrac{N_{Rk,p}}{\gamma_{Mp}}$
5	Concrete splitting failure	$N_{Ed} \leq N_{Rd,sp} = \dfrac{N_{Rk,sp}}{\gamma_{Msp}}$		$N_{Ed}^{g} \leq N_{Rd,sp} = \dfrac{N_{Rk,sp}}{\gamma_{Msp}}$
6	Concrete blow-out failure [c]	Cast-in relevant		
7	Steel failure of reinforcement	$N_{Ed,re} \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Ed,re}^{h} \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$	
8	Anchorage failure of reinforcement	$N_{Ed,re} \leq N_{Rd,a}$	$N_{Ed,re}^{h} \leq N_{Rd,a}$	

[a] Not required for post-installed bonded fasteners.
[b] Not required for headed and post-installed mechanical fasteners.
[c] For cases which require verification see 7.2.1.8 (1).

Resistance of EC2-4 v.s ETAG

$\psi_{M,N}$ **1** New bending/compression force factor

ψ_{sus} **2** New sustained load factor
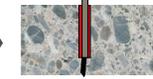
3 More conditions are allowed to omit the splitting verification
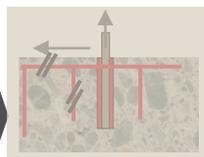
Supplementary reinforcement can also benefit to post-installed fasteners

COMPRESSION FORCE RESULT FROM BENDING MOMENT IS TAKEN INTO ACCOUNT FOR CONCRETE CONE FAILURE

(1)

Pushing back concrete cone

Many test results were available, but not consolidated in ETAG001

Now this factor is considered in EC2-4

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

= 1 for the following cases:

— fastenings with an edge distance $c < 1,5\,h_{ef}$;

— fastenings with $c \geq 1,5\,h_{ef}$ loaded by a bending moment and a tension force with $C_{Ed}/N_{Ed} < 0,8$ where C_{Ed} is the resultant compression force between fixture and concrete (taken as absolute value) and N_{Ed} is the resultant tension force of the tensioned fasteners ; or

— fastenings with $z/h_{ef} \geq 1,5$

$$= 2 - \frac{z}{1,5\,h_{ef}} \geq 1 \text{ for all other cases.}$$

When can this factor be very helpful to the resistance?
- Deep embedment
- Close fastener spacing
- Large bending moments

Structural baseplate

PROFIS EXAMPLE

HY200+HIT-V 8.8 M16X300 Cracked C25/30
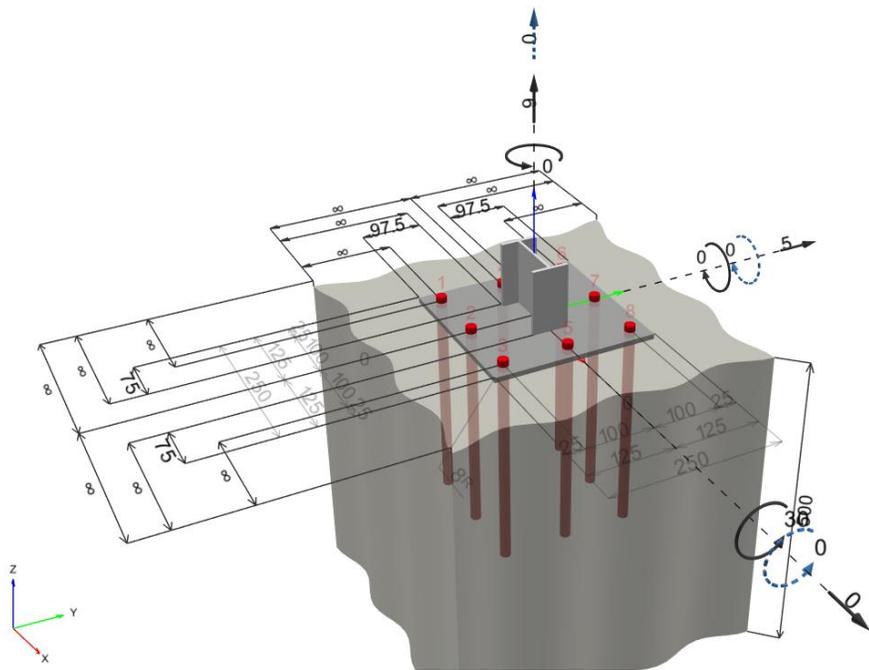
ETAG001 Annex C

ANCHOR DESIGN

Tension

Steel		54%
Concrete breakout		88%
Combined pullout and concrete breakout		96%
Splitting		72%

EC2-4

ANCHOR DESIGN

Tension

Steel		54%
Concrete breakout		56%
Bond		97%
Splitting		0%

CREEP ISSUE OF CHEMICAL FASTENERS IS FURTHER EMPHASIZED IN EC2-4 BY A NEW SUSTAINED LOAD FACTOR

2006 Boston tunnel accident
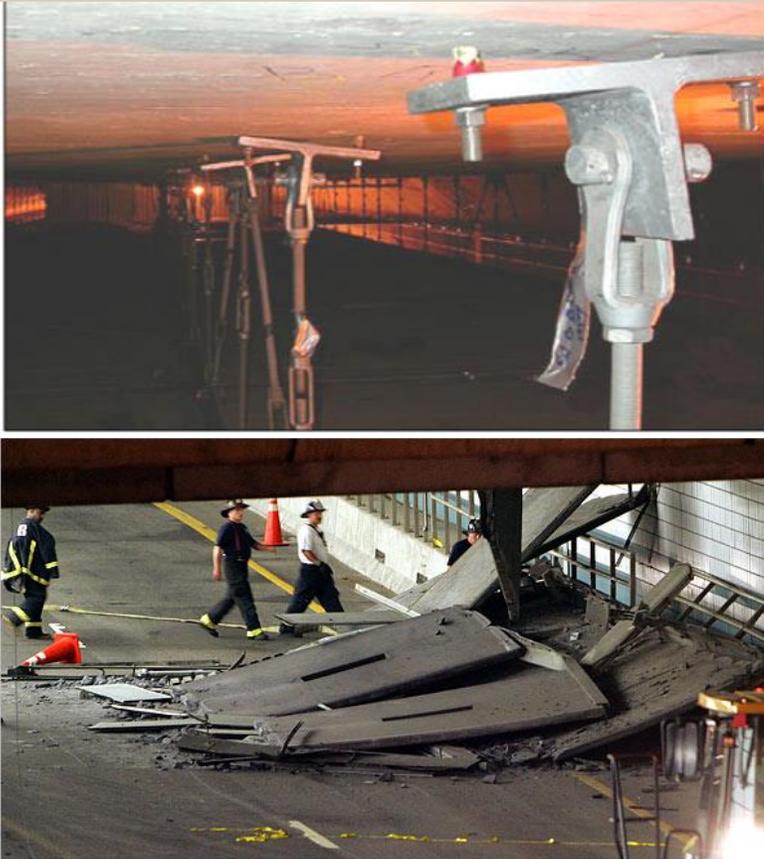
2008 Amendment on ETAG

EC2-4

- Creep behavior was included in the qualification criteria (ETAG 001 Part 5)

- **Pass/Fail** type of sustained load test based on tension design resistance published in ETA.

- No additional consideration in **design**

- Includes a reduction factor to consider creep behavior in the design resistance (pull-out)

- New test/evaluation method under development (EAD) to assess this performance-dependent factor
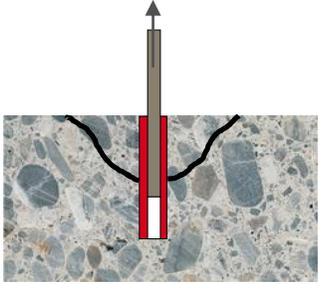
Combined concrete cone and pull out failure (bonded failure)

$$N^0_{Rk,p} = \tau_{Rk}\, \pi\, d\, h_{ef}\, \boxed{\psi_{sus}}\quad \text{New}$$

Typical sustained load relevant applications: tunnel equipment, suspended ceiling;
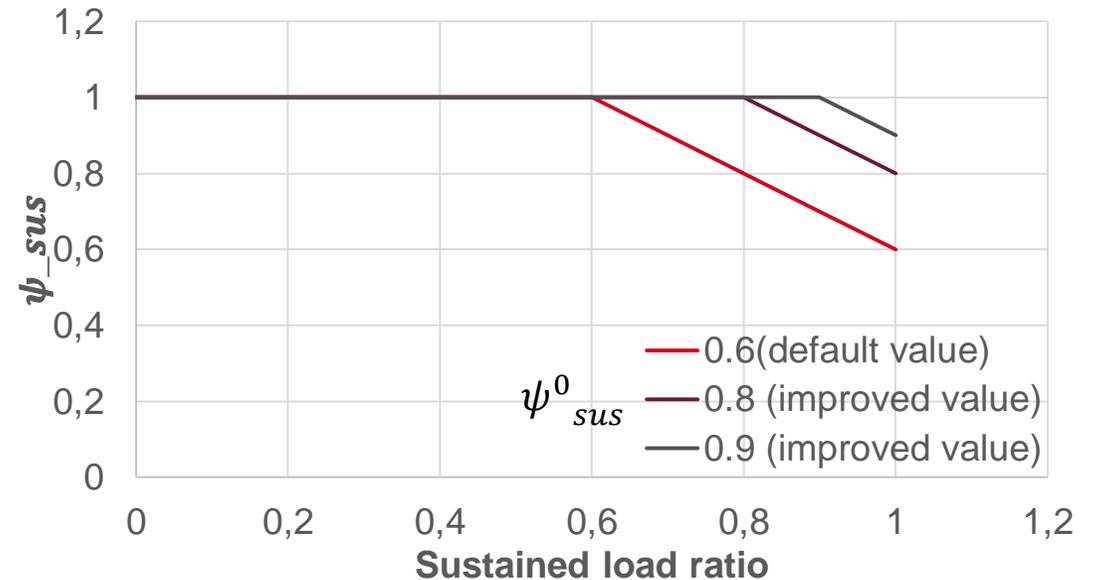
New influencing factor for sustained loads

If $\alpha_{sus} \leq \psi^0_{sus}$:

- $\psi_{sus} = 1$

If $\alpha_{sus} > \psi^0_{sus}$:

- $\psi_{sus} = \boxed{\psi^0_{sus}} + 1 - \boxed{\alpha_{sus}}$

α_{sus} = Value of sustained actions / the value of total actions (ULS)

ψ^0_{sus} = **Product performance dependent factor,** default value is 0.6. (a higher value can be given in the **ETA**)

Chart axes: y-axis ψ_sus (0 to 1,2), x-axis **Sustained load ratio** (0 to 1,2)

ψ^0_{sus}
— 0.6 (default value)
— 0.8 (improved value)
— 0.9 (improved value)
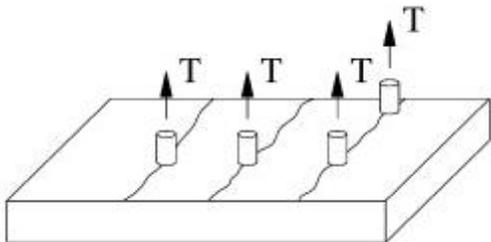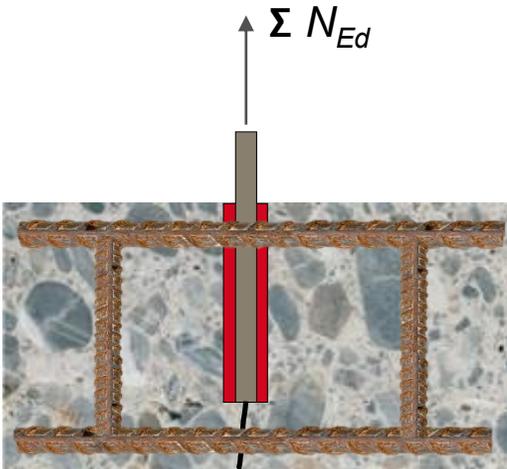
Splitting failure verification can be omitted **if one of** this conditions are fulfilled:

- Do **cracked concrete design** and concrete crack width limited by existing rebar is within 0.3 mm.

- In all directions $c \geq 1{,}2\ c_{cr,sp}$ and $h \geq 2\ h_{ef}$;   ETAG001 Annex C

- In all directions $c \geq 1{,}0\ c_{cr,sp}$ for single fastener and $c \geq 1{,}2\ c_{cr,sp}$ for a group of fasteners, and $h \geq h_{min}$ EC2-4

- **Benefit in thin slab application**

$\Sigma\ N_{Ed}$

2. SHEAR LOADS

REQUIRED VERIFICATION FOR POST-INSTALLED FASTENERS IN SHEAR

Table 7.2 — Required verifications for headed and post-installed fasteners in shear

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	Steel failure of fastener without lever arm	**Theoretical calculation change, as the value is usually provided in ETA – changes are ignorable**		
2	Steel failure of fastener with lever arm	$V_{Ed} \leq V_{Rd,s,M} = \dfrac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V_{Ed}^{h} \leq V_{Rd,s,M} = \dfrac{V_{Rk,s,M}}{\gamma_{Ms}}$	
3	Concrete pry-out failure	**In relation to concrete cone**		
4	Concrete edge failure	$V_{Ed} \leq V_{Rd,c} = \dfrac{V_{Rk,c}}{\gamma_{Mc}}$		$V_{Ed}^{g} \leq V_{Rd,c} = \dfrac{V_{Rk,c}}{\gamma_{Mc}}$
5	Steel failure of supplementary reinforcement [b]	$N_{Ed,re} \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Ed,re}^{h} \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$	
6	Anchorage failure of supplementary reinforcement [b]	$N_{Ed,re} \leq N_{Rd,a}$	$N_{Ed,re}^{h} \leq N_{Rd,a}$	

[a] Exception see 7.2.2.4 (4).

[b] The tension force acting on the reinforcement is calculated from V_{Ed} according to Formula (6.6).

Resistance of EC2-4 v.s ETAG
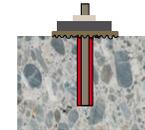
Alternative method for uncracked concrete situation
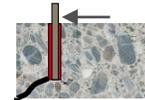
several detail changes
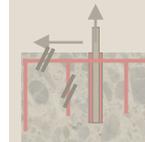
Supplementary reinforcement can also benefit to post-installed fasteners

POSSIBLE HIGHER STEEL RESISTANCE IN GROUTING SITUATION

Steel column application

→ Grout/Mortar bed
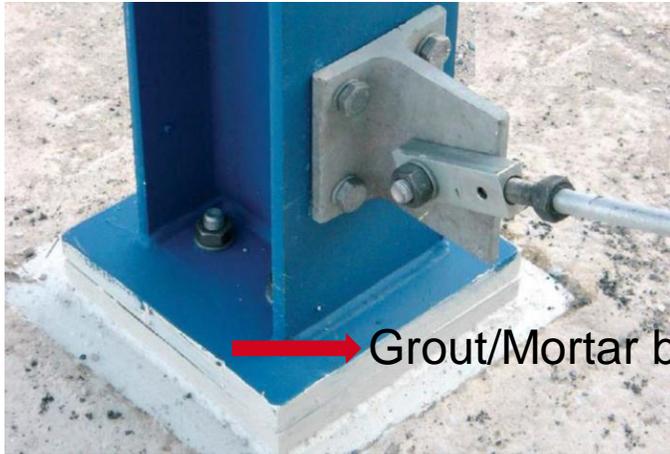
- Often result in big diameter due to shear resistance reduction

- EJ often required/ designer omit the stand off

EN 1992-4 vs. ETAG design (for e.g. d = 16 mm).

Ratio between Shear resistance with lever arm and without lever arm

$$V_{Rk,s} = \left(1 - 0{,}01 \cdot t_{grout}\right) \cdot k_7 \cdot V_{Rk,s}^0$$

— EN 1992-4 design
- - - ETAG design

thickness of grout layer [mm]
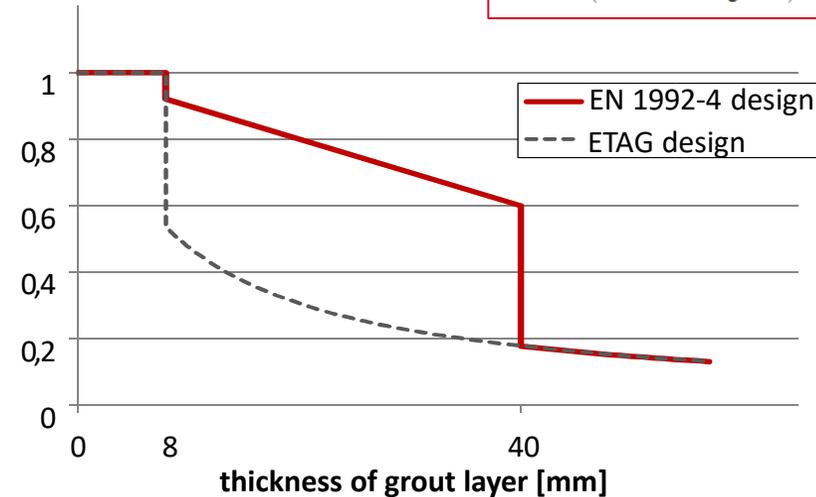
*Key restrictions: 1) at least 2 anchors in group; **2) no tension/moment; 3) uncracked concrete situation**; 4) t_grout is no bigger than 40mm and ≤ 5d. 5) grout strength>30 Mpa, and rough surface

Engineering Judgement is still needed, but we have a better foundation to do so with EC2-4

PROFIS EXAMPLE

HST3 M12X70 uncracked C25/30
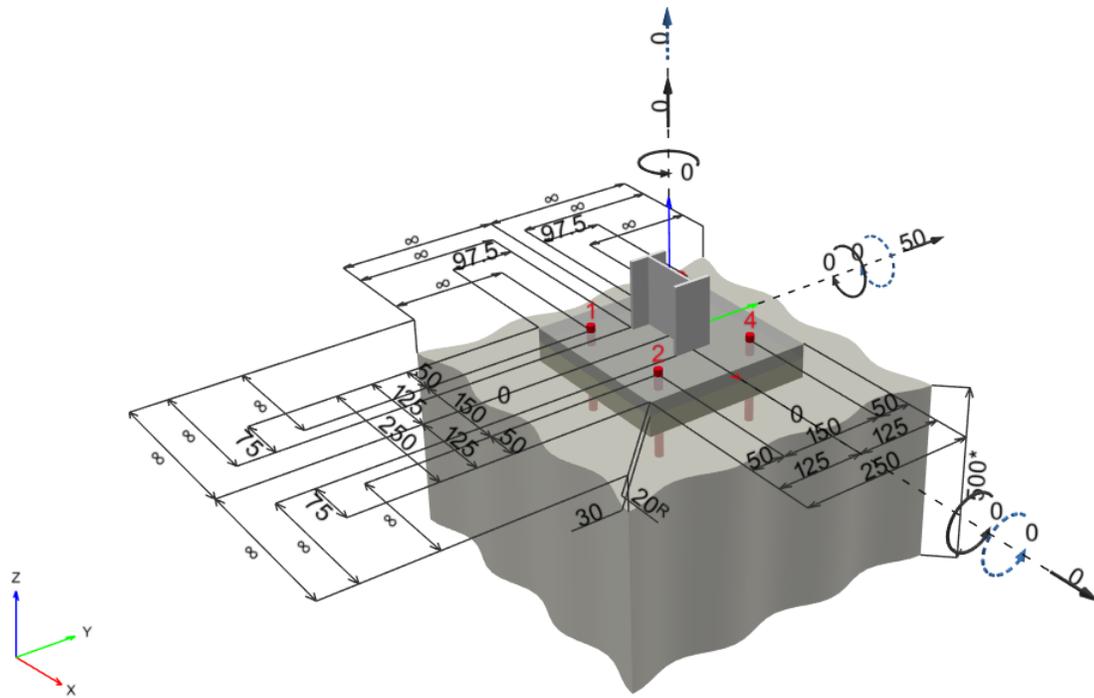
ETAG001 Annex C		EC2-4	
Shear		**Shear**	
Steel	**343%**	Steel	**64%**
Concrete edge breakout	0%	Concrete edge breakout	0%
Pryout	29%	Pryout	29%

EC2-4 HAS SEVERAL CHANGES IN CONCRETE EDGE FAILURE RESISTANCE

Scope	Effective edge failure length(l_f)	Existing rebar influence	Shear force direction influence factor
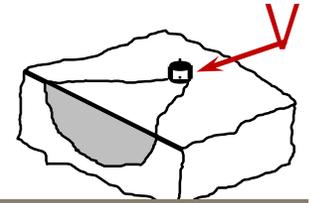
Scope
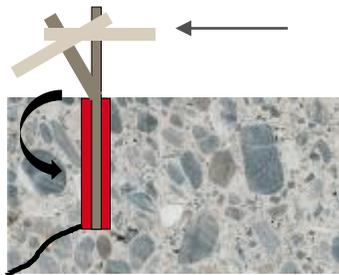
Lever arm close to edge is not explicitly included in EC2-4

Effective edge failure length(l_f)

ETAG: $l_f = h_{ef}$

EC2-4 add additional limitation

$\leq 12\, d_{nom}$ in case of $d_{nom} \leq 24$ mm

$\leq \max\left\{8\, d_{nom}\,;\, 300 \text{ mm}\right\}$ in case of $d_{nom} > 24$ mm

Existing rebar influence

(Not supplementary reinforcement)
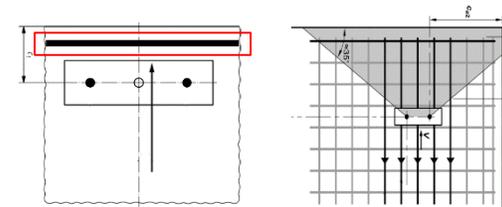
$\psi_{re,V} \neq 1.2$ $\psi_{re,V} = 1.4$

Not valid anymore in EC2-4

Shear force direction influence factor

$\alpha_V = 90°$

V_{ed}

$$\Psi_\alpha = \sqrt{\frac{1}{(cos\alpha_v)^2 + (0.4 sin\alpha_v)^2}}$$

EC2-4: 0.5

Possibly big impact on hand rail application

Minor impact as most ETAs already taken into that account

Minor impact as designers usually don't consider this anyway as per our research.
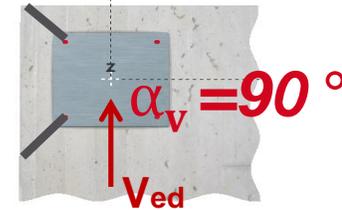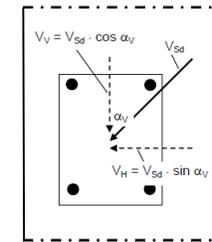
May result in 20% reduction for edge failure parallel with shear; but this is normally not governing failure mode

3. COMBINED LOADS

SEPARATE INTERACTION FOR STEEL AND CONCRETE FAILURE IS NOW USED

Governing Tension failure mode	Governing Shear failure mode	
Concrete	Concrete	**No change**
Steel	Steel	
Concrete	Steel	**EC2: separate interaction curve**
Steel	Concrete	

Example

Resistance: $N_{rd,c} = 7kN$, $N_{rd,S} = 10kN$

$V_{rd,c} = 14kN$, $V_{rd,s} = 6kN$

Action: $N = 6kN$, $V = 4kN$
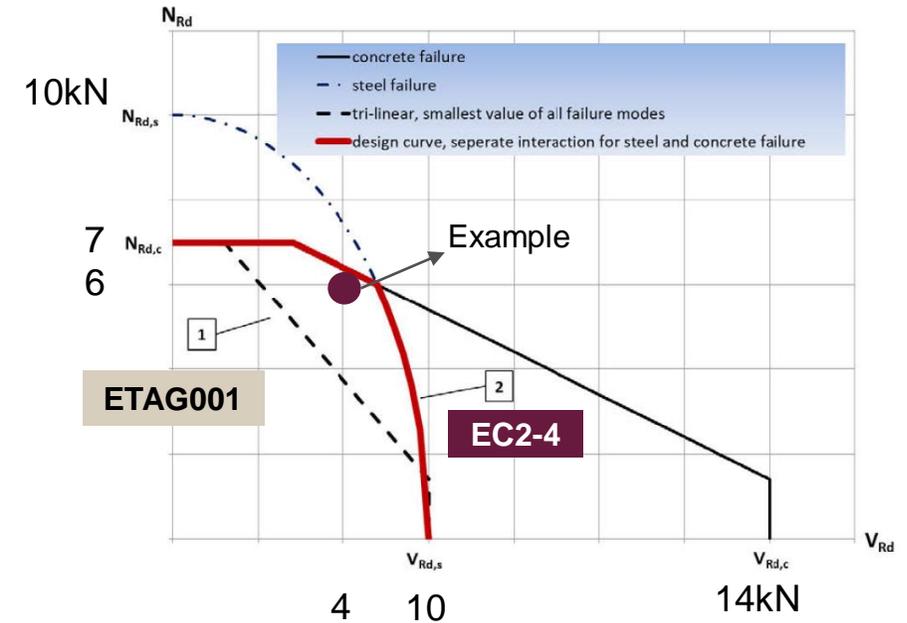
ETAG001 ❌

EC2-4 ✅

PROFIS EXAMPLE

HY200+HIT-V 5.8 M16X200 Cracked C25/30
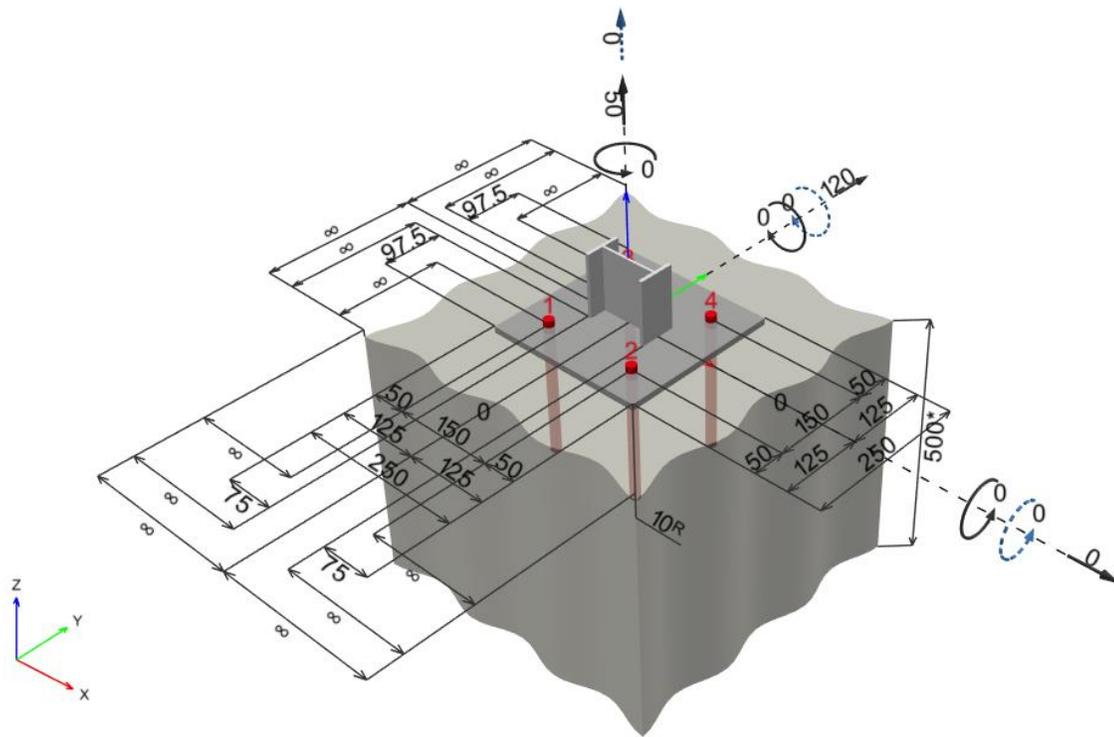
ETAG001 Annex C

ANCHOR DESIGN

Tension

	Steel	24%
	Concrete breakout	44%
	Combined pullout and concrete breakout	49%
	Splitting	0%

Shear

	Steel	96%
	Concrete edge breakout	0%
	Pryout	59%

Combination

	121%

EC2-4

ANCHOR DESIGN

Tension

	Steel	24%
	Concrete breakout	45%
	Bond	50%
	Splitting	0%

Shear

	Steel	96%
	Concrete edge breakout	0%
	Pryout	59%

Combination

	Steel	97%
	Concrete	80%

SUMMARY

1. EN1992-4 is the state of art for concrete anchor fastening design, and in lined with other ENs (Eurocodes)

2. EN1992-4 includes all type of fastenings under static, seismic, fatigue and fire conditions

3. There is no fundamental changes for design concept for post-installed fasteners.

4. Other than a wider scope, some differences between EN1992-4 and ETAG are given in the determination of the resistance:

   - **Tension:** Concrete cone failure, bonded failure and splitting failure

   - **Shear:** Steel failure with lever arm and edge failure.

   - **Combined tension and shear:** better resistance when governing failure mode type is different in tension and shear

THE BASIS OF CONCRETE ANCHOR FASTENING DESIGN

HILTI

DID YOU DO PROPER DESIGN FOR CONCRETE ANCHORS?
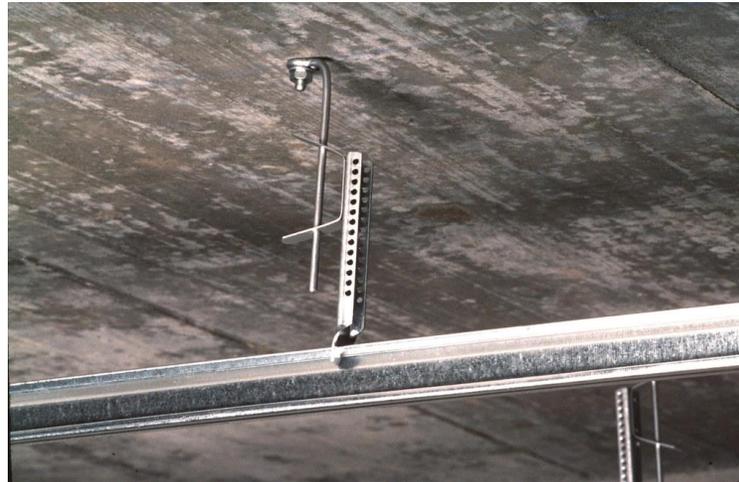
Concrete anchors are widely used in both structural and non-structural elements.
All of them are directly or in directly link to the safety of human being or economic investment

CONSEQUENCE FOR NOT TREATING THEM SERIOUSLY

2014, Shanghai, Rainshelter fell
Because anchor was pull out in a
rainly day

2011, San Marcos
Rough design by project site
engineer

2006, Boston, ceiling slab collapsed.
Improper Installation and sustained load
are the main reason

EN1992-4 FOCUSES ON FASTENERS AND COVERS BOTH STRUCTURAL AND NON-STRUCTURAL APPLICATIONS

Applications leads to serious consequence	Fasteners only

Structural

Precast 🚫

CEN/TR15728

Non-structural (Safety relevant)
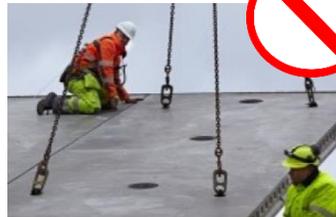
Steel structure: EN1993 (EC3)

ETA available[1]

compacted normal weight concrete without fibers C12/15 to C90/105 (EN206)
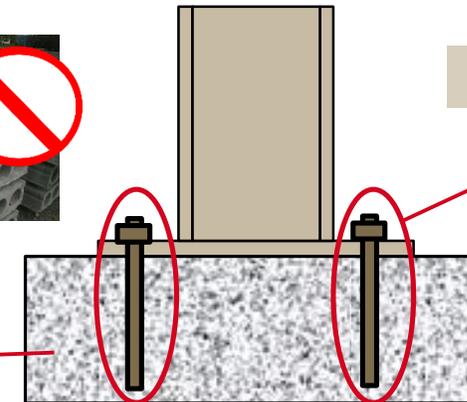
$M6^2$~$M60^3$
h_{ef}: 40^2mm~20d

Concrete structure: EN1992 (EC2)

1. EN, ETA for fastener or anchor channel based on a EAD or a transparent and reproducible assessment that complies with all requirements of the relevant EAD
2. Can be slightly smaller for non structural application in certain cases
3. No limit for tension, M60 is limited for shear loading.

DESIGN AS PER EN1992-4 RELIES ON THE EUROPEAN TECHNICAL PRODUCT SPECIFICATION (ETA)

European technical product specification

EN1992-4 (3.1.27) European Standard (EN), European Technical Assessment (ETA) for fastener or anchor channel based on a European Assessment Document (EAD) or a transparent and reproducible assessment that complies with all requirements of the relevant EAD

EN standards			
	ETA	Transparent and reproducible assessment	
	EAD		

Table E.1 — Characteristics used for the design of fastenings under static loading to be taken from a European Technical Product Specification

Characteristic	Referenced in	Type of fastener			
		Post-installed		Cast-in	
		Mechanical	Bonded	Headed fastener	Anchor channel
h_{ef}	1.3 (2)	x	x	x	x
limitation re concrete strength class	1.5	x	x	x	x
γ_{inst}	4.4.2.1				
E_s (optional)	6.2.1				
$N_{Rk,s}$	7.2.1.3				
$k_{cr,N}$; $k_{ucr,N}$	7.2.1.4 (2); 7.4.1.5 (3)				
$c_{cr,N}$	7.2.1.4 (3)				
$N_{Rk,p}$	7.2.1.5; 7.4.1.4				
ψ^0_{sus}; $\tau_{Rk,cr}$; $\tau_{Rk,ucr}$	7.2.1.6 (2)				
c_{min}; s_{min}; h_{min}	7.2.1.7 (1); 7.4.1.6 (1)				
$c_{cr,sp}$	7.2.1.7 (2); 7.4.1.6 (2)				
$N^0_{Rk,sp}$	7.2.1.7 (2)				
A_h	7.2.1.8 (2)				
$V^0_{Rk,s}$	7.2.2.3.1 (1)	x	x	x	
k_7	7.2.2.3.1 (2)	x	x	x	

- Design resistance per load condition,
- Suitability
- Edge/spacing info,
- Safety factor,
- Corresponding installation method,
- …

EN1992-4 IS BASED ON FASTENING DESIGN THEORY INSTEAD OF REINFORCED CONCRETE THEORY
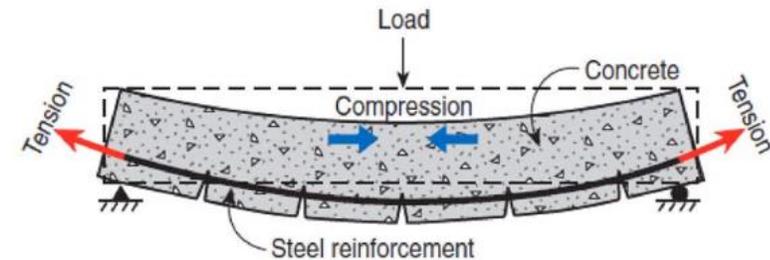
Fastening design theory (EN1992-4)	Reinforced concrete theory (EN1992-1~3)
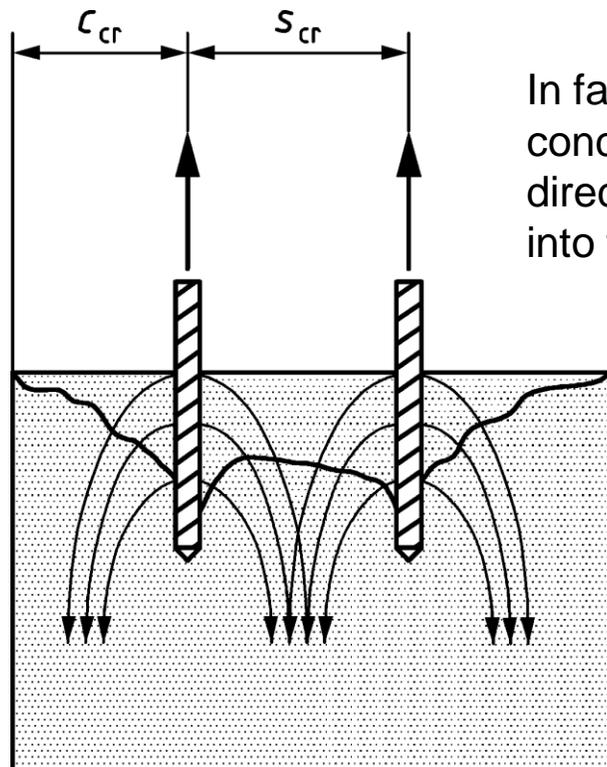
In fastener design theory the concrete tensile capacity is directly used to transfer loads into the concrete component.

≤20d

If 20d is exceeded a linear bond stress distribution or concrete cone calculation method may not be conservative enough

Concrete is used for compression, while tension is taken by rebar assuming concrete always cracks in tension.

* Rebar theory (rebar as rebar): It belongs to reinforced concrete theory, only steel failure, no concrete cone failure, meaning not considering the tensile capacity of concrete

BASIS OF DESIGN

WHAT ARE THE REQUIRED VERIFICATIONS IN EN1992-4?

Ultimate limit state (ULS)	Service limit state (SLS)	Durability
Anchor fastener shall sustain all load actions during execution and use.	Anchor fastener shall not deform to an inadmissible degree	Anchor fastener shall remain fit for use taking into account the environmental conditions for the structure.

* For applications which subject to potential accidental events, additional requirements may need to be fulfilled. (Earthquake is not classified as an accidental event, details are described in EC1)
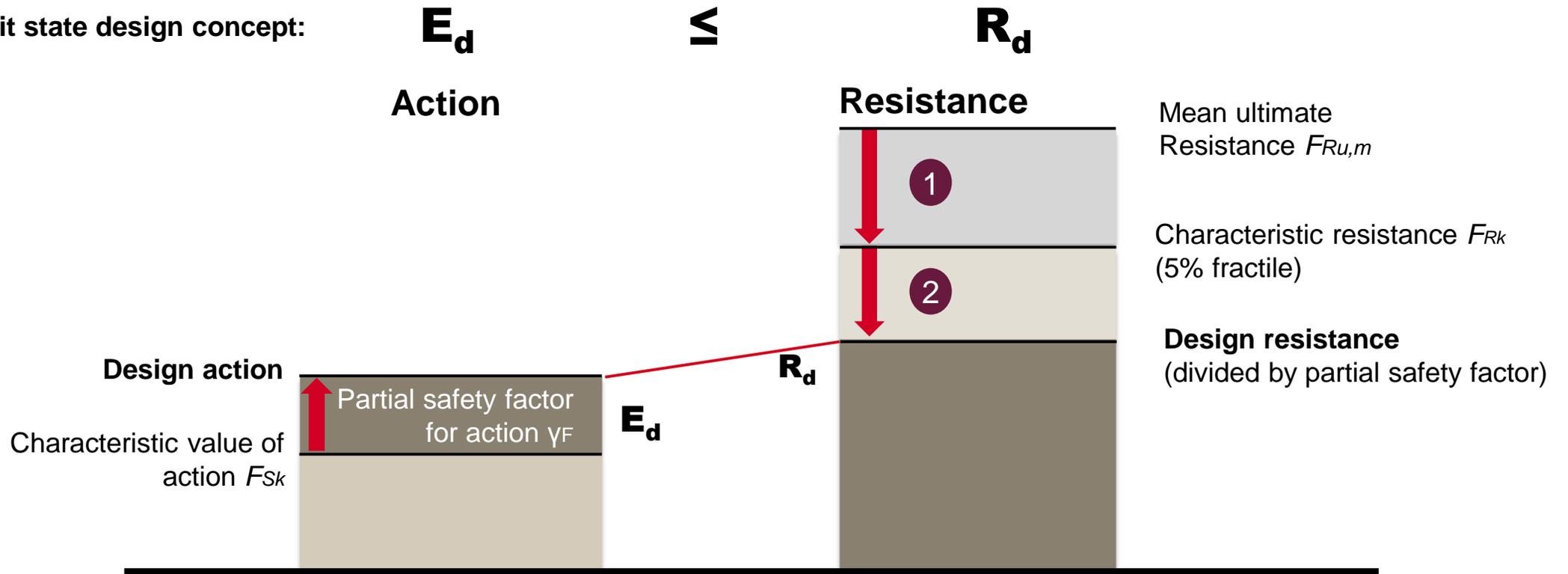
DESIGN RULES ULTIMATE LIMIT STATE

Design action ≤ design resistance

$$E_d \leq R_d$$

SAFETY CONCEPT COMES FROM AMPLIFYING THE ACTION AND LOWERING THE RESISTANCE WITH SAFETY FACTORS

Ultimate limit state design concept:

$$E_d \leq R_d$$

Action

Resistance

Mean ultimate Resistance $F_{Ru,m}$

Characteristic resistance F_{Rk} (5% fractile)

Design resistance (divided by partial safety factor)

Design action

Partial safety factor for action γ_F

E_d

R_d

Characteristic value of action F_{Sk}

* Partial factors for actions are in accordance with EN 1990.

WHY CAN'T WE USE THE MEAN VALUE?

WHICH ONE IS
BETTER?

Product A		Product B	
Test results		Test results	
No.1	10kN	No.1	12kN
No.2	10kN	No.2	11kN
No.3	10kN	No.3	10kN
No.4	10kN	No.4	9kN
No.5	10kN	No.5	8kN
Average:	**10kN**	**Average:**	**10kN**

$F_{Rk} = 10kN$

$F_{Rk} =$ ❓ *4.62kN*

F
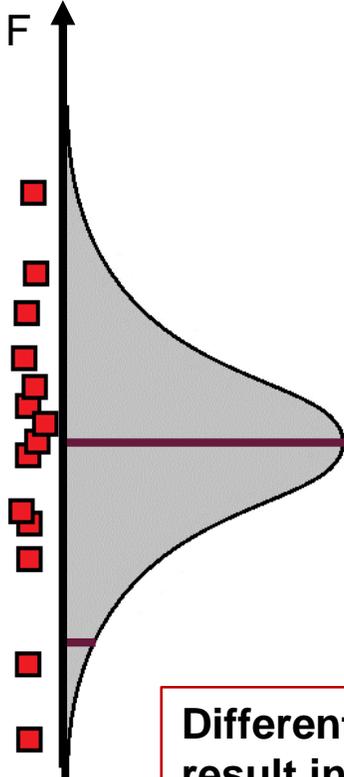
Mean value

$F_{5\%}$
Characteristic
resistance

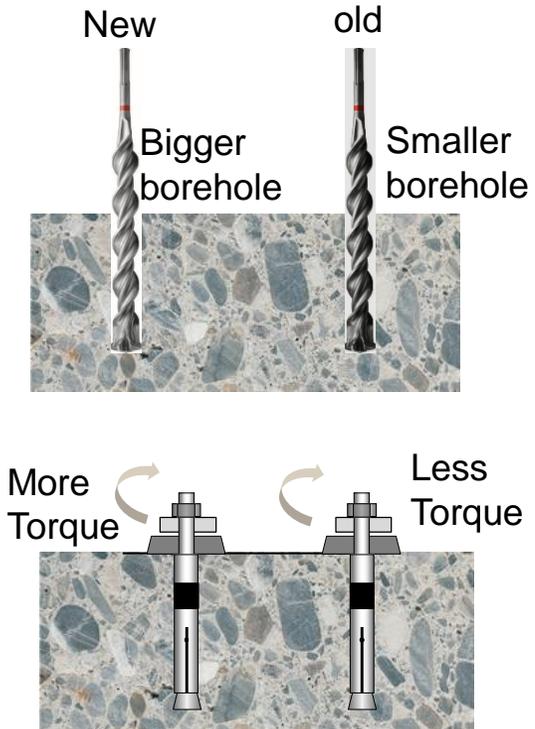**Different scatter will result in different resistance!**

THE CHARACTERISTIC RESISTANCE IS OBTAINED FROM A NUMBER OF DIFFERENT TEST SERIES

Installation conditions

Variable effect

Crack influence

New

old

Bigger borehole

Smaller borehole

More Torque

Less Torque
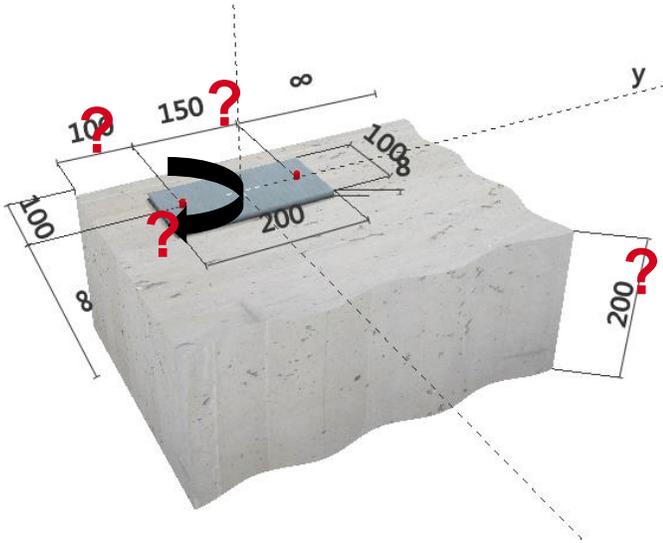
Installation methods, boundaries, requirements (installation torque/curing time, etc)

CHARACTERISTIC RESISTANCE IS PROVIDED IN THE ETA, BASED ON EVALUATION OF DIFFERENT TEST SERIES

WHICH ONE IS BETTER?

Product A		Product B	
New drill bit	10kN	New drill bit	12kN
Old drill bit (heavily worn out)	9kN	Old drill bit (heavily worn out)	8kN

May be concluded as unqualified anchor due to sensitivity!

(6) This document relies on characteristic resistances and distances which are stated in a European Technical Product Specification (see Annex E). At least the characteristics of Annex E are given in a European Technical Product Specification for the corresponding loading conditions providing a basis for the design methods of this EN.

NOTE   The numerical values for certain parameters given in Notes can be used for pre-dimensioning. The values for verification are given in the European Technical Product Specifications and may be different.

The EN1992-4 clearly states that the design of anchor fastenings shall rely on ETA (European Technical Product Specification)
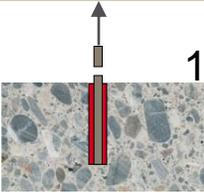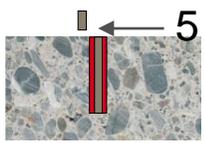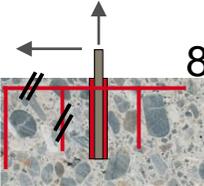
PARTIAL SAFETY FACTOR CONCEPT

DESIGN VALUE IS BASED ON THE FAILURE MODE AS WELL AS ANCHOR FASTENER'S PERFORMANCE
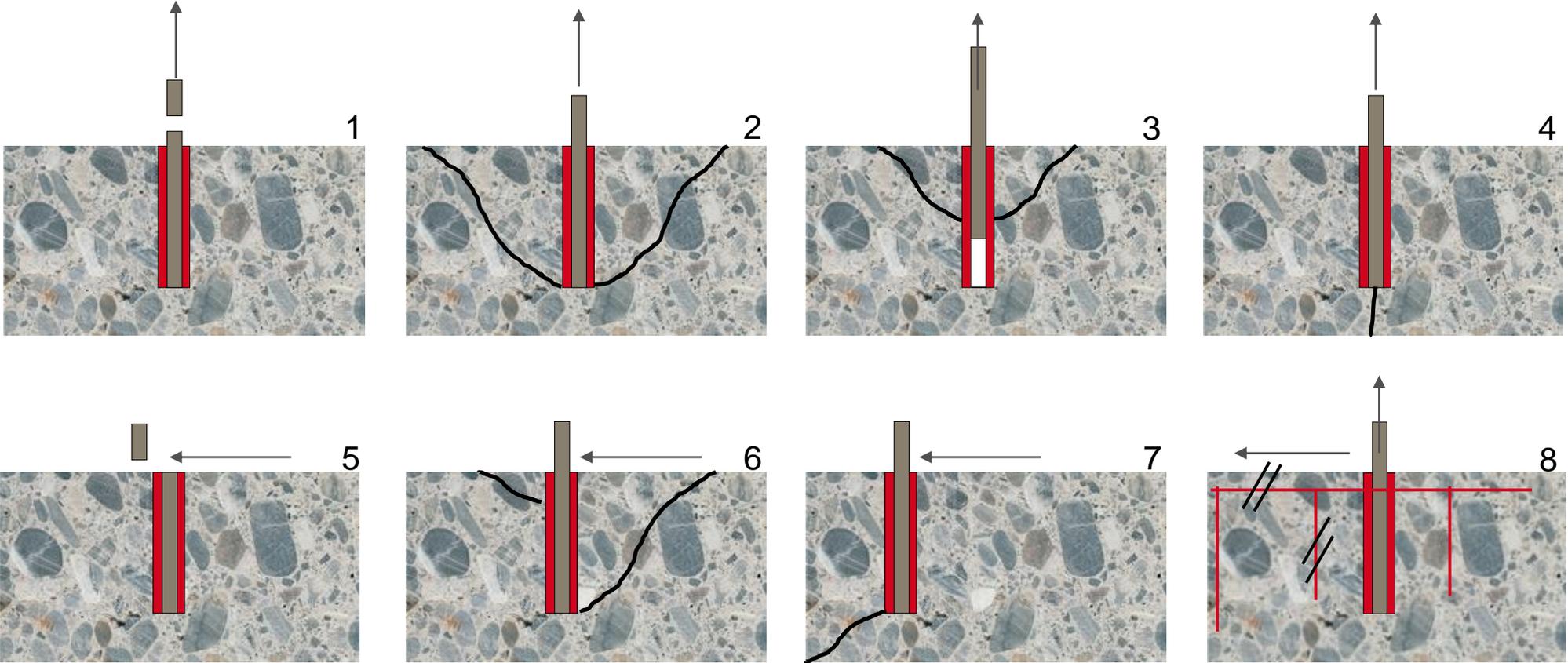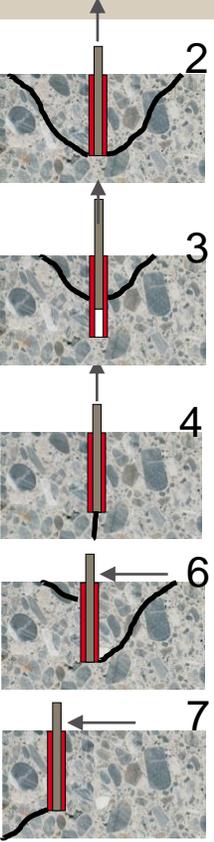
IN TERMS OF SAFETY FACTORS, FAILURE MODES CAN BE CLUSTERED IN TWO GROUPS: #1 STEEL

Steel failure	Permanent and transient design situations (ULS)	Accidental design situations (ULS)
1	$= 1,2 \cdot f_{uk} / f_{yk} \geq 1,4$	$= 1,05 \cdot f_{uk} / f_{yk} \geq 1,25$
5	$= 1,0 \cdot f_{uk} / f_{yk} \geq 1,25$ when $f_{uk} \leq 800\,\text{N/mm}^2$ and $f_{yk} / f_{uk} \leq 0,8$ $= 1,5$ when $f_{uk} > 800\,\text{N/mm}^2$ or $f_{yk} / f_{uk} > 0,8$	$= 1,0 \cdot f_{uk} / f_{yk} \geq 1,25$ when $f_{uk} \leq 800\,\text{N/mm}^2$ and $f_{yk} / f_{uk} \leq 0,8$ $= 1,3$ when $f_{uk} > 800\,\text{N/mm}^2$ or $f_{yk} / f_{uk} > 0,8$
8	1,15	1,0

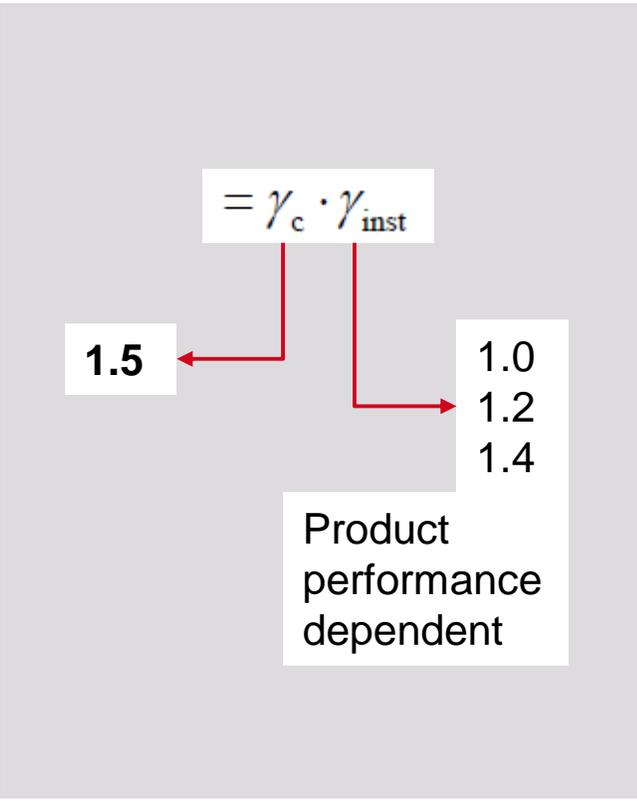*SLS, $\gamma_M = 1,0$ is recommended

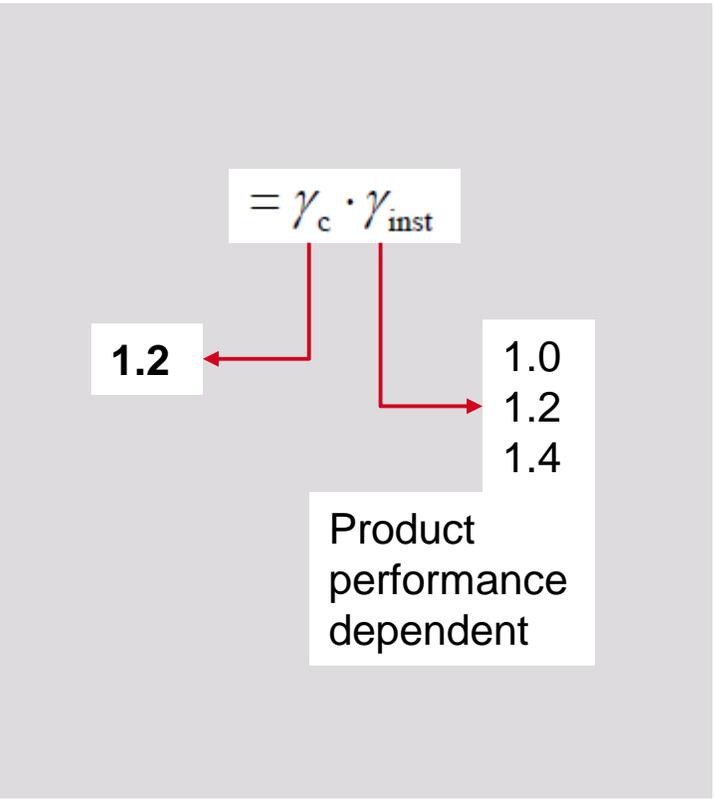# IN TERMS OF SAFETY FACTORS, FAILURE MODES CAN BE CLUSTERED IN TWO GROUPS: #2 CONCRETE

Concrete failure

2

3

4

6

7

Permanent and transient design situations (ULS)

$$= \gamma_c \cdot \gamma_{inst}$$

1.5

1.0
1.2
1.4

Product performance dependent

Accidental design situations (ULS)

$$= \gamma_c \cdot \gamma_{inst}$$

1.2

1.0
1.2
1.4

Product performance dependent

*SLS, $\gamma_M = 1,0$ is recommended.

SERVICE LIMIT STATE

Displacement caused by action ≤ Displace requirement

$$E_d \leq C_d$$

Defined by designer per
application needs

DISPLACEMENT OF ANCHOR FASTENERS IS GIVEN BY ETA

Always corresponding with load level

			M8	M10	M12	M16	M20	M24
Displacements under tension loading								
HST3								
Effective embedment depth	$h_{ef.2}$	[mm]	47	60	70	85	101	125
Tension load in cracked concrete	N	[kN]	3,6	5,7	9,5	13,4	17,4	19,0
Corresponding displacement — Short term	δ_{N0}	[mm]	0,6	0,6	0,8	1,8	1,3	2,2
Corresponding displacement — Long term	$\delta_{N\infty}$	[mm]	1,1	1,3	1,6	1,7	1,8	2,5
Tension load in non-cracked concrete	N	[kN]	5,7	9,5	11,9	18,9	24,4	28,6
Corresponding displacement	δ_{N0}	[mm]	0,2	0,3	0,2	0,8	0,5	0,5
Corresponding displacement	$\delta_{N\infty}$	[mm]	0,4	0,5	0,4	1,5	0,9	1,4

DISPLACEMENT CALCULATION

Linear relationship	Vectorially accumulation

Example:
M10, HST3, under tension load 19 kN

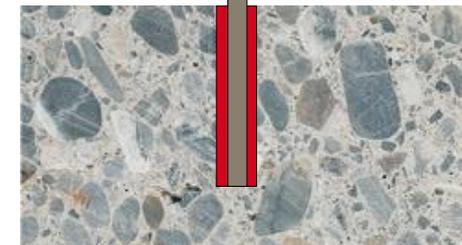From ETA, under 9.5kN, the δ_{N0} =0.8mm $\delta_{N\infty}$ =1.6mm.
Calculation: Under 19kN, the δ_{N0} =1.6mm $\delta_{N\infty}$ =3.2mm.

- $\dfrac{P_t}{K_t} = \dfrac{P_r}{K_r} + \dfrac{P_c}{K_c}$

- $E = \dfrac{\sigma}{\varepsilon} = \left(\dfrac{P}{\delta}\right)\left(\dfrac{L}{A}\right)$

- t = Total
- r = Anchor
- c = Concrete
- K = Stiffness

- E = Young's Modulus
- L = Stressed Length
- A = Stressed Area

Tension 2 mm

2.8 mm

Shear 2 mm

KEY SUMMARY

1. **EN1992-4 is based on fastening design theory and corresponding test results, therefore some scope limitation applies.**

2. **Design fastening for use in concrete as per EN1992-4 fully relies on an ETA.**

3. **A proper design includes ULS, SLS, and durability consideration.**

4. **Partial safety concept = different failure modes may have different safety factor.**

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