

Design of multiple anchor fastenings with elastic base plate

Background and Design Proposal
in the software Anchor Profi 2.4.9

Dr. Li Anchor Profi GmbH

Background

The test results of university Stuttgart show that the assumption of rigid base plate for design of multiple anchor fastenings may lead to huge safety deficit in some cases.

In the following slides this safety deficit is estimated in one case of the tested examples. It will be shown how this safety deficit can be avoided by elastic base plate.

Assumptions for estimating the safety deficit in the tested example:

1. The pull-out failure of the highest loaded anchor is decisive for the design.
2. The utilization of anchor resistance in ULS of the highest loaded anchor is equal to 100%.
3. The global safety factor for ULS amounts

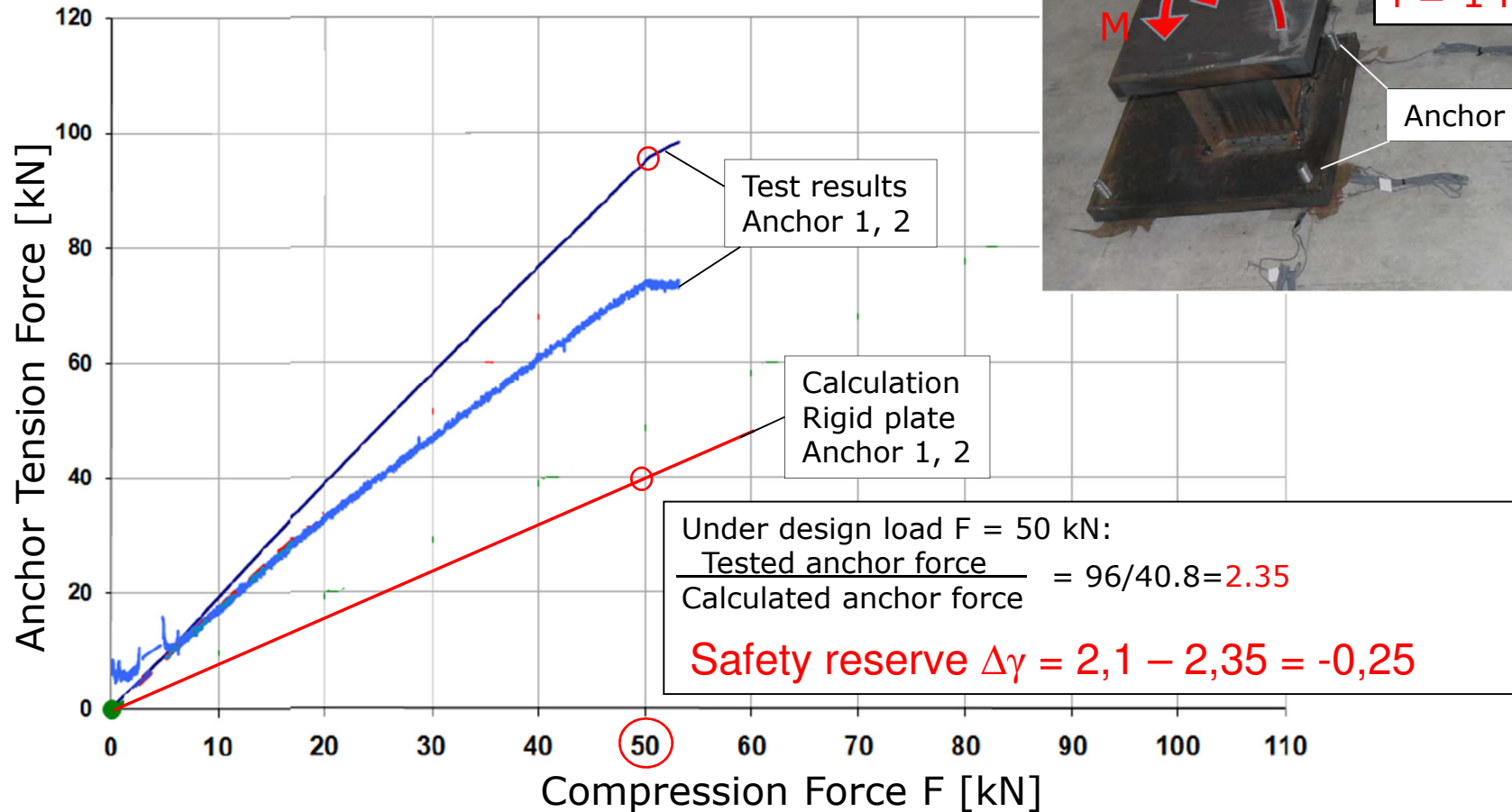
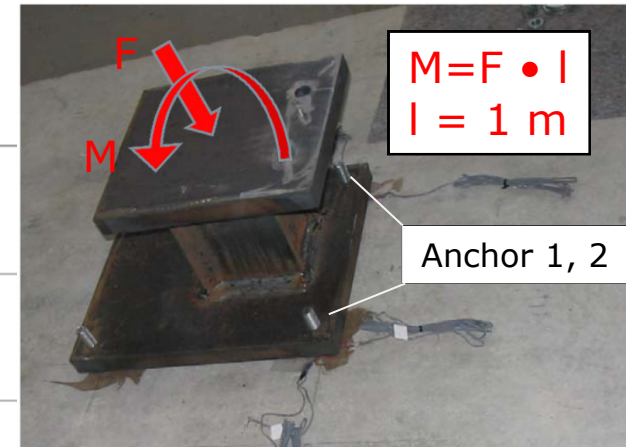
$$\gamma = 1,4 \cdot 1,5 = 2,1$$

1,4: Partial safety factor for action loads

1,5: Partial safety factor anchor material

Estimate for tested anchorage 2

Test 2 , investigated by Fichtner/Eligehausen
 Base plate thickness $t = 40 \text{ mm}$, bonded anchors



Test results and photo from the dissertation of Fichtner 2011

Design example of tested anchorage 2, rigid base plate

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Base material
 Uncracked concrete | Wide concrete reinforcement | Hammer drilled | Short term 40 °C
 C25/30 | No edge reinforcement | Dry concrete | Long term 24 °C
 Strength $f_{ck,cube}$ 30 N/mm² | Reinforcement | Installation conditions | Temperature

Installation
 No stand-off installation | Distance 0.0 mm | Rotational restraint 1,0
 Mortar strength $\geq 30\text{N/mm}^2$ | Fill hole gap

Anchor tension force calculation
 Rigid base plate
 Elastic base plate

Action load and geometry
 Action load: Design loads, Characteristic loads
 Concrete edge: Input in table
 Base plate: 2D input, Thickness
 Anchor groups: 2D input, Rotate by 90°
 Profile: Profile data
 Rectangular hollow: H[mm] 120, W[mm] 200, T[mm] 10, FT[mm] 0, e_x [mm] -100,0, e_y [mm] 0,0, Rotational angle CCW 0,0°
 Base material geom, Anchor layout, Position of anchr, Loads
 Base plate geom, Anchor number, Position of profil

Selected anchors and results
Results
 Tension: 93,7%
 Steel failure: 31.2%
 Combined failure: 81.1%
 Concrete cone failure: 93.7%
 Splitting: 0.0%
 Shear: 0.0%
 Steel failure: 0.0%
 Pry-out: 0.0%
 Concrete edge failure: 0.0%
 Interaction: -/-
 ▶ **Platethickness was not calculated!**
 User-defined
 Anchor size: M20
 h_{ef} (90mm $\leq h_{ef} \leq 240$ mm): 170 mm

Anchor selection
 Manufacturer:
 All manufacturers
 Apolo MEA, MKT
 B+BTec, Mungo
 fischer, Powers
 friulsider, Simpson
 Halfen, Sormat
 Heco, Tecfi
 Hilti, Toge
 ITW-Spit, Würth
 Anchor material:
 Galvanized
 Hot-dip galvanized
 Stainless steel A4
 High corrosion-resistant steel HCR
 Rebar
 Anchor type:
 Mechanical anchor
 Wedge anchor
 Sleeve anchor
 Undercut anchor
 Screw anchor
 Drop-in anchors
 Bonded anchors
 Bonded expansion anchors
 Injection anchors Vinylester
 Injection anchors Epoxy Acrylate
 Injection anchors Epoxy
 Capsule systems

Selected anchors

Selected anchors	Compa
BIS-PE 3:1 + gvz 4.6 M20	B+BTec
BIS-PE 3:1 + gvz 5.8 M20	B+BTec
BIS-PE 3:1 + gvz 8.8 M20	B+BTec
EPCON C8 + Gewindestange 10.9 M20	ITW-Spit
EPCON C8 + Gewindestange 5.8 M20	ITW-Spit
EPCON C8 + Gewindestange 8.8 M20	ITW-Spit
FIS EM + FIS A gvz 5.8 M20	fischer
FIS EM + FIS A gvz 8.8 M20	fischer
HIT-RE 500 + HIT-V gvz 5.8 M20	Hilti
HIT-RE 500 + HIT-V gvz 8.8 M20	Hilti
HIT-RE 500-SD + HIT-V gvz 5.8 M20	Hilti
HIT-RE 500-SD + HIT-V gvz 8.8 M20	Hilti
PURE150-PRO + gvz 5.8 (hef \leq 12d) M20	Powers
PURE150-PRO + gvz 8.8 (hef \leq 12d) M20	Powers
Resifix Pure Epoxi + gvz 4.6 M20	Apolo ME
Resifix Pure Epoxi + gvz 5.8 M20	Apolo ME
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Design results of tested anchorage 2, rigid base plate

2. Anchor internal forces [kN]

Anchor No.	Tension force	Shear force	Shear force x	Shear force y
1	40.760	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000
3	40.760	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000

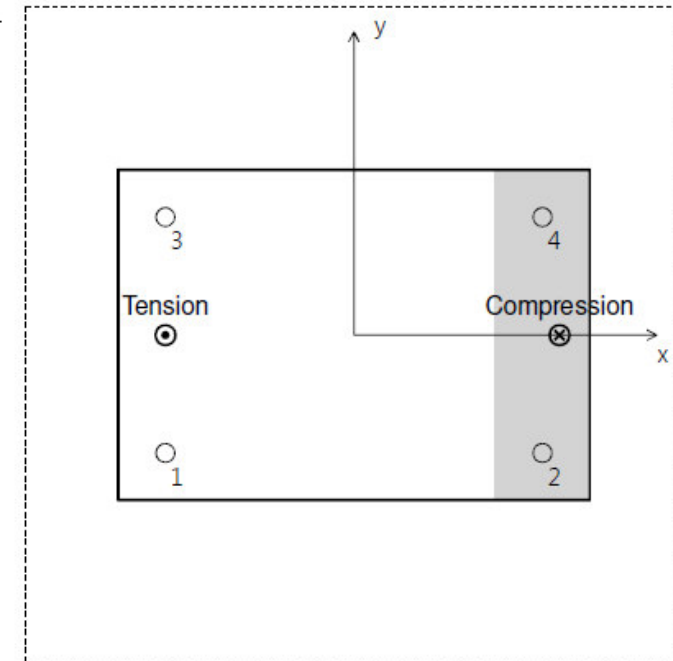
Maximum concrete compressive strain [‰]: 0.2277

Maximum concrete compressive stress: 7.06 [N/mm²]

Resultant tension force in (x/y=-200.0/0.0): 81.520 [kN]

Resultant compression force in (x/y=218.2/0.0): 131.520 [kN]

Remark: The edge distance is not to scale.



3. Verification at ultimate limit state based on EOTA TR029

3.1 Tension load

	Related anchor	Action [kN]	Resistance [kN]	Utilization [%]	Status
Steel failure	1,3	40.760	82.000	49.7	√
Combined failure	1,3	81.520	100.532	81.1	√
Concrete cone failure	1,3	81.520	87.012	93.7	√
Splitting failure	-	-	-	-	No calculation

Design example of tested anchorage 2, elastic base plate



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File Option Info License

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 C25/30 | No edge reinforcement | Dry concrete | Long term 24 °C
 Strength $f_{tk,cube}$ 30 N/mm² | Reinforcement | Installation conditions | Temperature

Installation
 No stand-off installation | Distance 0,0 mm | Rotational restraint 1,0
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Anchor tension force calculation
 Rigid base plate
 Elastic base plate

Action load and geometry
 Action load: Design loads | Characteristic loads
 Concrete edge: Input in table
 Base plate: 2D input | Thickness
 Anchor groups: 2D input | Rotate by 90°
 Profile: Profile data
 Rectangular hollow | User-defined
 H[mm] 120 | W[mm] 200
 T[mm] 10 | FT[mm] 0
 e_x [mm] -100,0 | e_y [mm] 0,0
 Rotational angle CCW 0,0°

Selected anchors and results
Results
 Tension: 249.3%
 Steel failure: 74.1%
 Combined failure: 215.8%
 Concrete cone failure: 249.3%
 Splitting: 0.0%
 Shear: 0.0%
 Steel failure: 0.0%
 Pry-out: 0.0%
 Concrete edge failure: 0.0%
 Interaction: -/
 Base plate (σ/f_{td}): 87.8%
 User-defined
 Anchor size M20
 h_{ef} (90mm $\leq h_{ef} \leq 240$ mm) 170 mm

Selected anchors	Compa
BIS-PE 3:1 + gvz 4.6 M20	B+BTec
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3D Model: A 3D perspective view of a concrete slab with a rectangular base plate. The slab has a thickness of 250 mm. The base plate has a width of 400 mm and a length of 500 mm. Four anchors are shown protruding from the base plate. Dimensions for the anchors are 250 mm (width), 350 mm (length), and 40 mm (height). A coordinate system (X, Y, Z) is shown with the origin at the center of the base plate.

Legend:
 Base material geo | Anchor layout | Position of ancho | Loads
 Base plate geom | Anchor number | Position of profile

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Design results of tested anchorage 2, elastic base plate

2. Anchor internal forces [kN]

Tension load of anchors is calculated with elastic base plate.

Assumed: Anchor stiffness factor 1.00 → Anchor spring constant 302.4 kN/mm.

Anchor No.	Tension force	Shear force	Shear force x	Shear force y
1	96.761	0.000	0.000	0.000
2	2.665	0.000	0.000	0.000
3	96.761	0.000	0.000	0.000
4	2.665	0.000	0.000	0.000

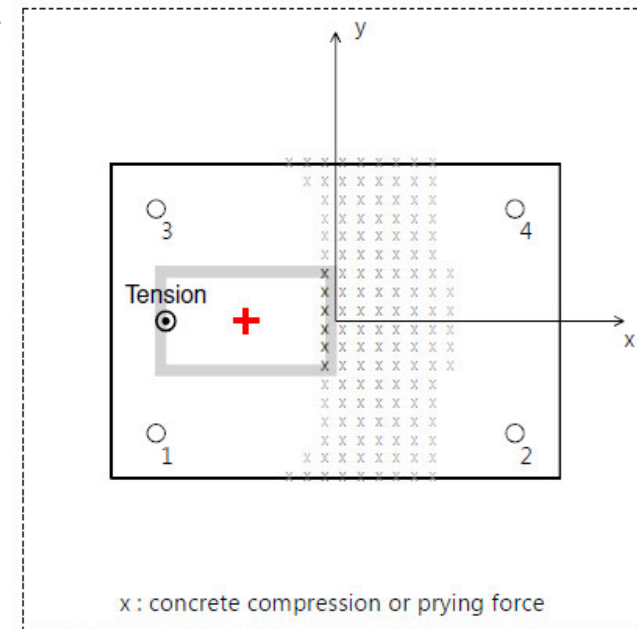
Maximum plate displacement into concrete (x/y=30.0/-10.3): 0.025 [mm]

Maximum concrete compressive stress: 11.46 [N/mm²]

Resultant tension force in (x/y=-189.3/0.0): 198.853 [kN]

Resultant compression force in (x/y=36.9/0.0): 248.853 [kN]

Remark: The edge distance is not to scale.



3. Verification at ultimate limit state based on EOTA TR029

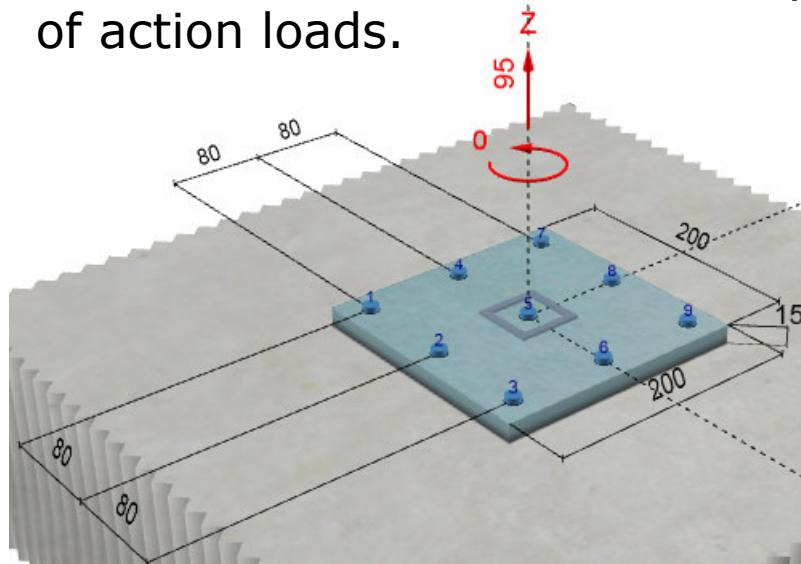
3.1 Tension load

	Related anchor	Action [kN]	Resistance [kN]	Utilization [%]	Status
Steel failure	1,3	96.761	130.667	74.1	√
Combined failure	1,2,3,4	198.853	102.933	193.2	X
Combined failure e	1,3	96.761	44.834	215.8	X
Concrete cone failure	1,2,3,4	198.853	89.112	223.1	X
Concrete cone failure e	1,3	96.761	38.814	249.3	X
Splitting failure	-	-	-	-	No calculation

Special cases

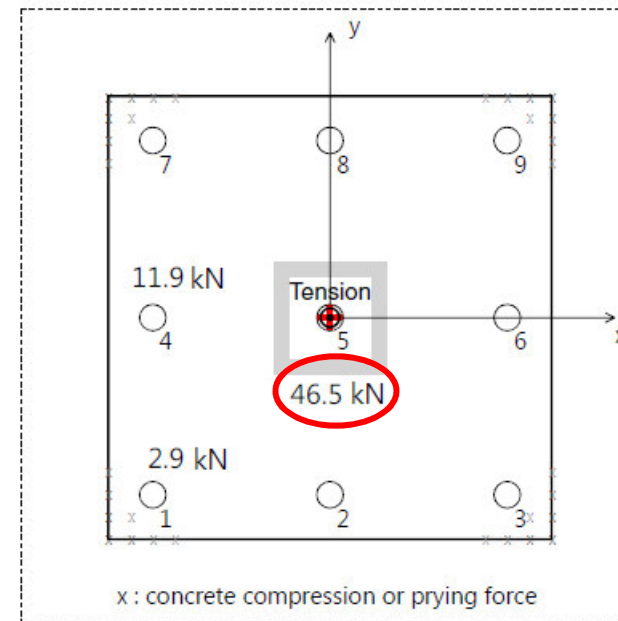
Example of special cases, anchor group similar to test of FMFA Stuttgart, 1983

- $N_{\max} = 46.5$ kN with real elastic base plate
- $N_{\max} = 95/9 = 10.5$ kN with rigid base plate
- But the concrete cone capacity $N_{Rd,c}$ acc. to current CC method is almost the same for both cases because of no eccentricity of action loads.



2. Anchor internal forces [kN]

Tension load of anchors is calculated with elastic base plate.



Anchor stiffness factor 1.0 → Anchor spring constant 252.9 kN/mm

Are the current design methods suitable for the elastic base plates?

ETAG 001 Annex C	Suitability Check	TR029	Suitability Check
Steel failure	√	Steel failure	√
Pull-out	√	Combined failure	√X
Concrete cone	√X	Concrete cone	√X
Splitting	√X	Splitting	√X

√: Suitable; √X: may be suitable with additional conditions

Additional proof for elastic base plates in Anchor Profi 2.4.9:

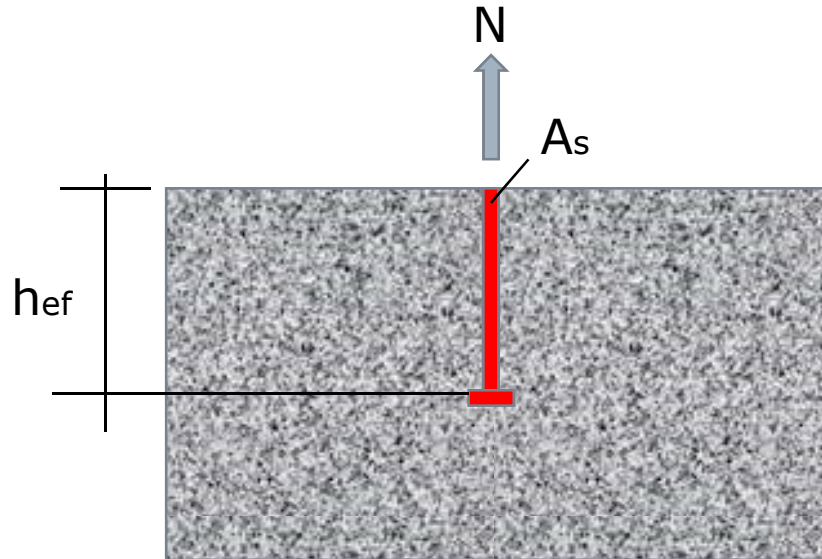
Annex C: Control of max loaded anchor according to (5.2f)

TR029: Control of max loaded anchor analogous to (5.2f) of
ETAG 001 Annex C

Anchor spring constant C_A , determined by tests, could be expressed by

$$C_A = \varphi \cdot E \cdot A_s / h_{ef}$$

with φ : anchor stiffness factor



A_s : Anchor stressed cross section

E : Elasticity module

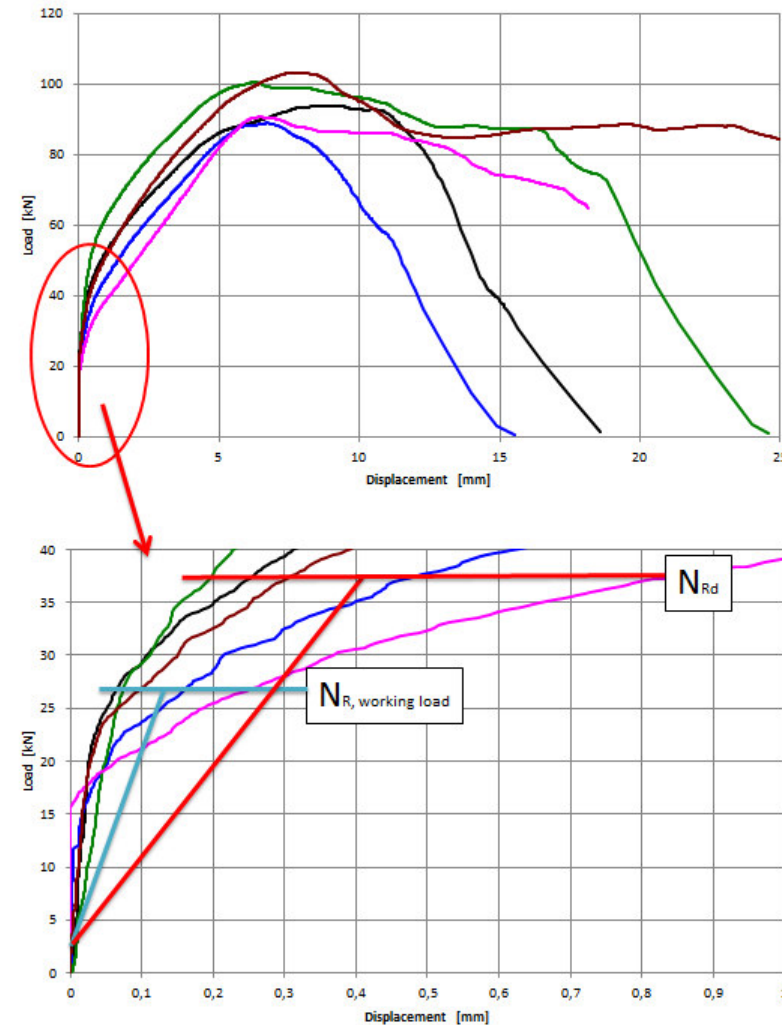
Test example,
Mechanical anchor M20,
 $h_{ef} = 100$ mm, ucr C50/60
 $N_{Rd,cr} = 37.2$ kN

Mean value: $\varphi = 0.18$

$N_{R,cr}$ (safe working resist.)
 $= 26.6$ kN

Mean value: $\varphi = 0.41$

**Anchor stiffness:
Nonlinear, large scatter**



Anchor stiffness factor φ determined by tests

- Mean value in uncracked concrete should be used, because the most application cases are in uncracked concrete.

Without test results the factors may be proposed.

$\varphi = 1.0$ for bonded anchors (TR029)

$\varphi = 0.5$ for mechanical anchors (Annex C)

- Additional factor 1.35 to consider the scatter of anchor stiffness for determining the design yield stress of base plate

$\gamma_M = 1.1 \cdot 1.35 \approx 1.5$ (with $\gamma_s = 1.1$ acc. to EC3)