Design of multiple anchor fastenings with elastic base plate

Background and Design Proposal

in the software Anchor Profi 2.4.9

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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:

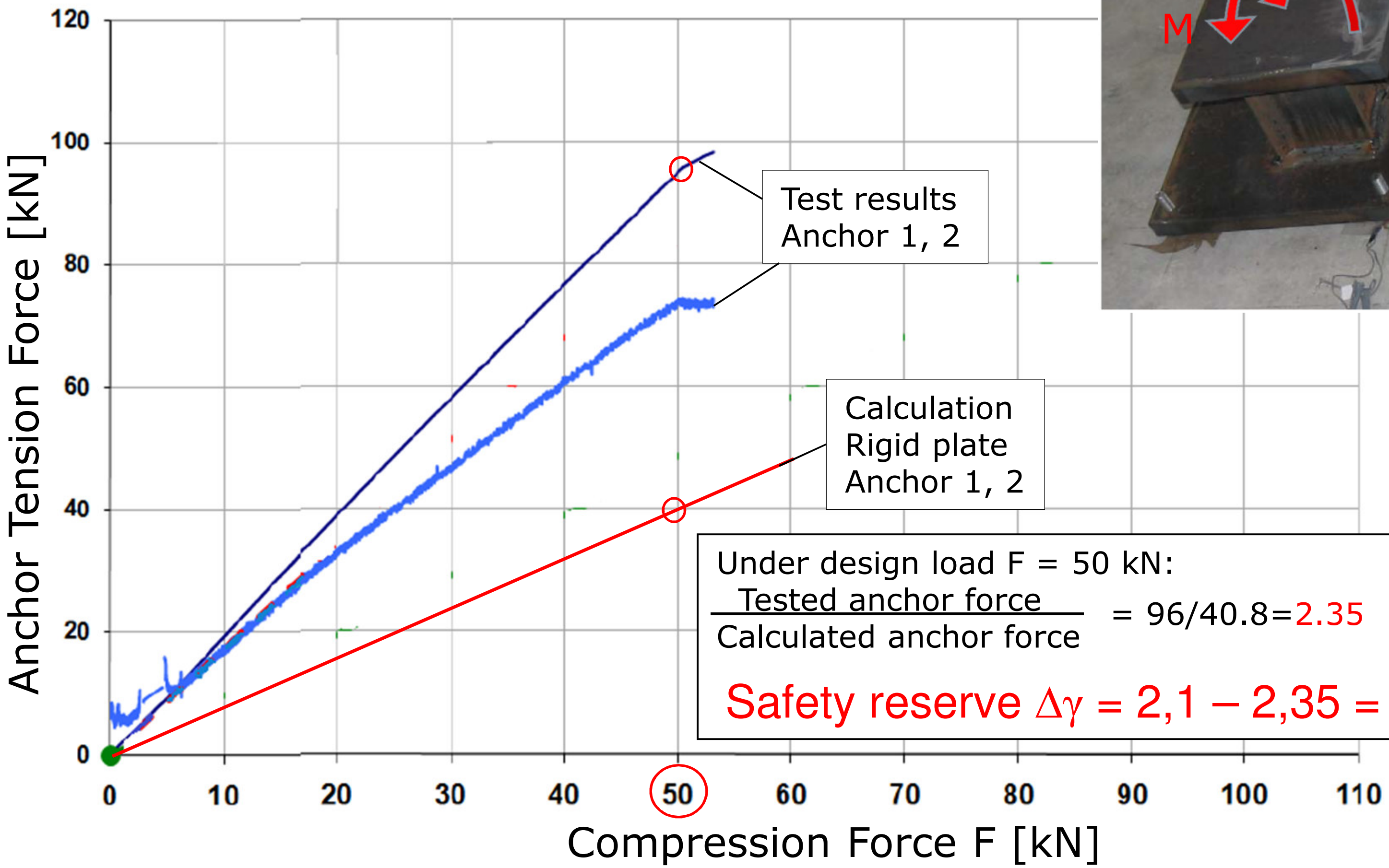
1. The pull-out failure of the highest loaded anchor is decisive for the design.
2. The utilization of anchor resistance in ULS of the highest loaded anchor is equal to 100%.
3. The global safety factor for ULS amounts

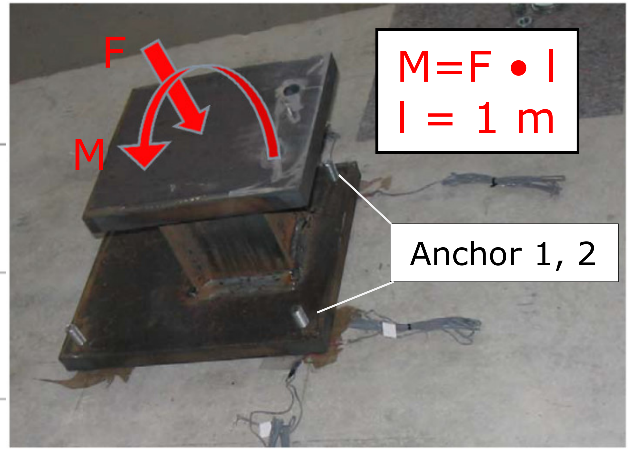
$$\gamma = 1{,}4 \cdot 1{,}5 = 2{,}1$$

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 mm, bonded anchors





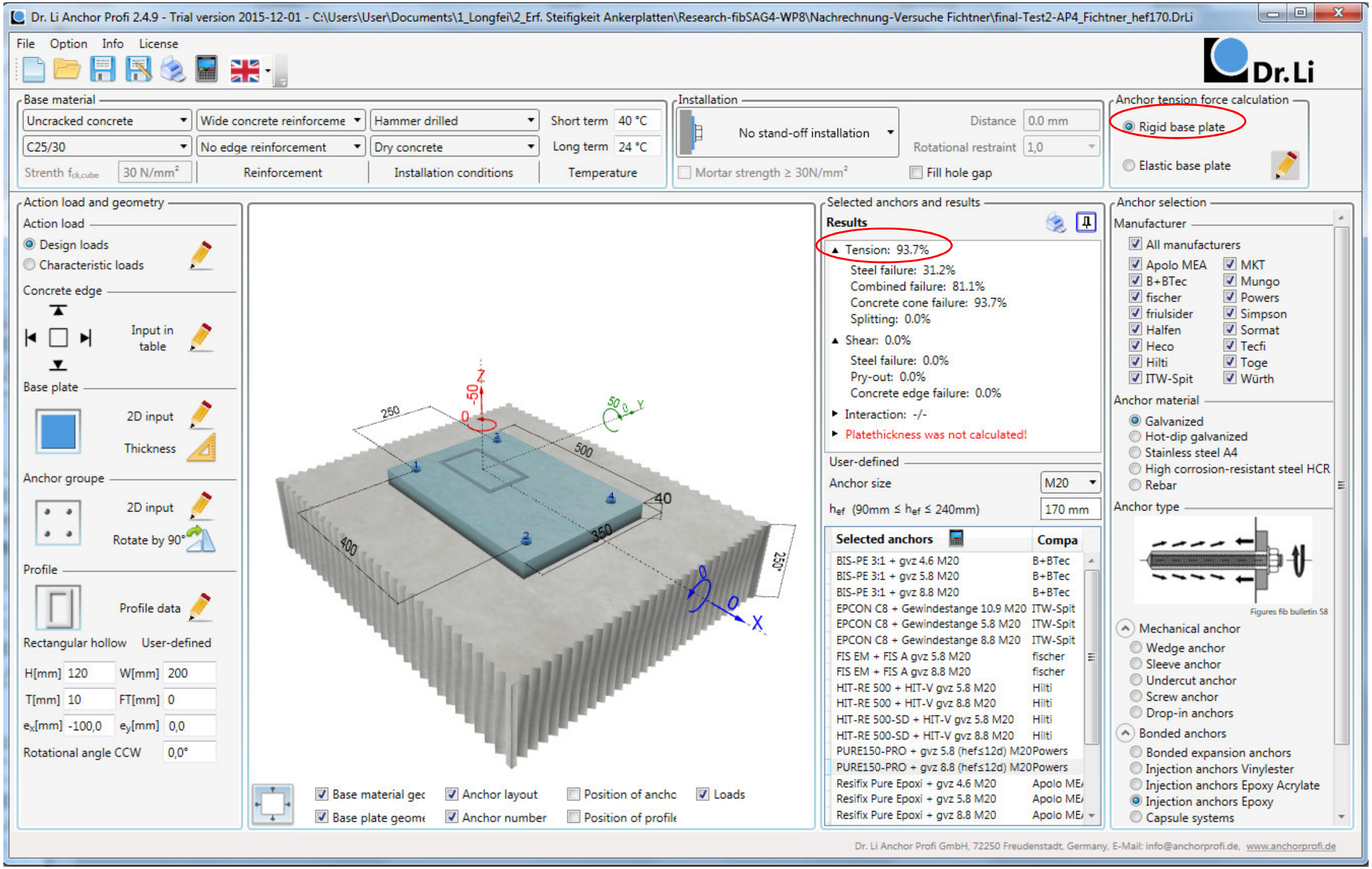
Under design load F = 50 kN:

$$\frac{\text{Tested anchor force}}{\text{Calculated anchor force}} = 96/40.8 = 2.35$$

Safety reserve $\Delta\gamma$ = 2,1 – 2,35 = -0,25

Test results and photo from the dissertation of Fichtner 2011

Design example of tested anchorage 2, rigid base plate

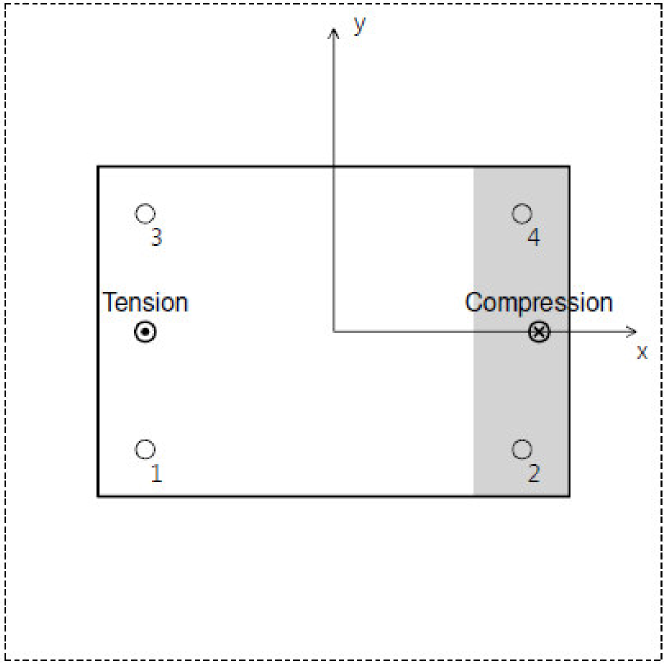


Design results of tested anchorage 2, rigid base plate

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/mm^2]
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.

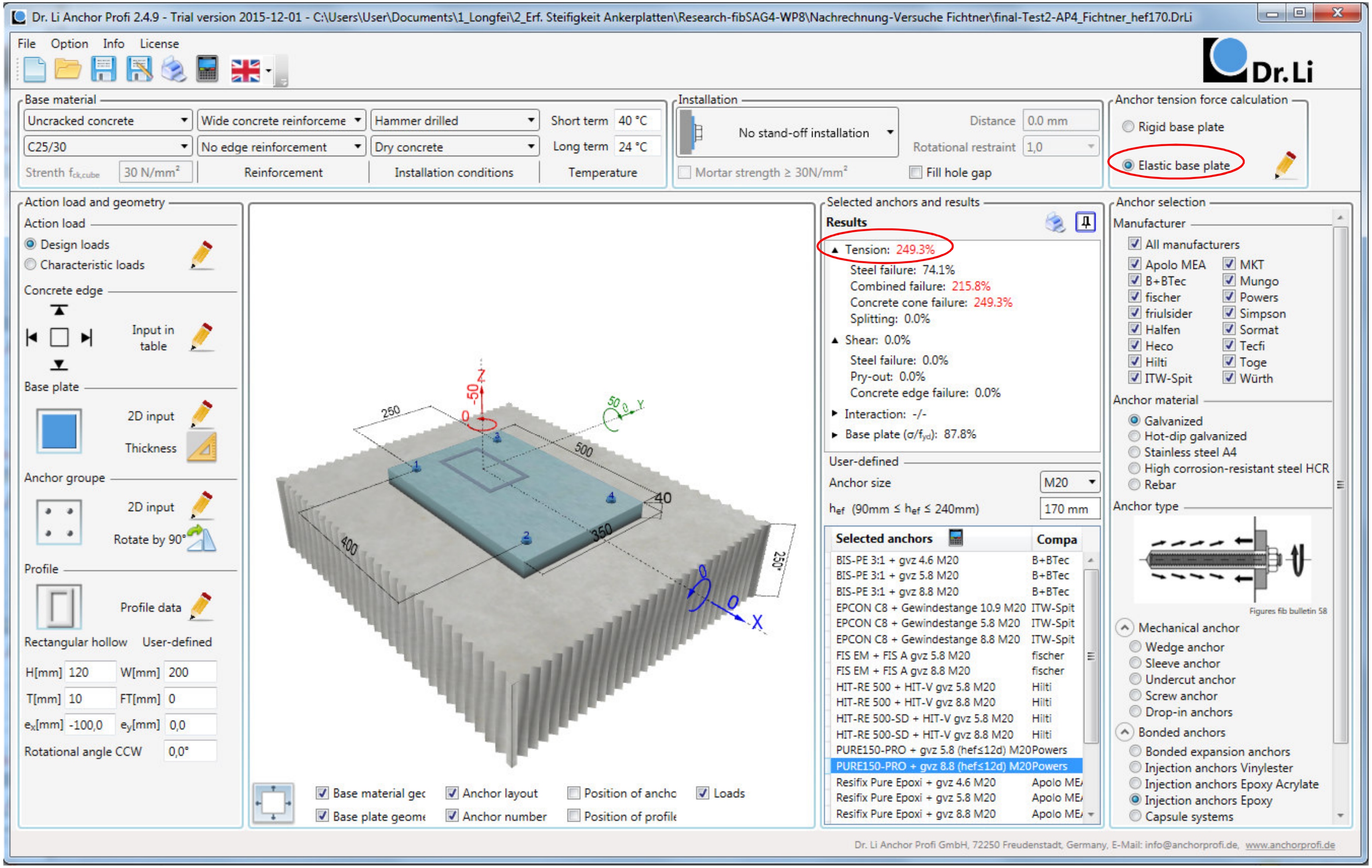


3. Verification at ultimate limit state based on EOTA TR029

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



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

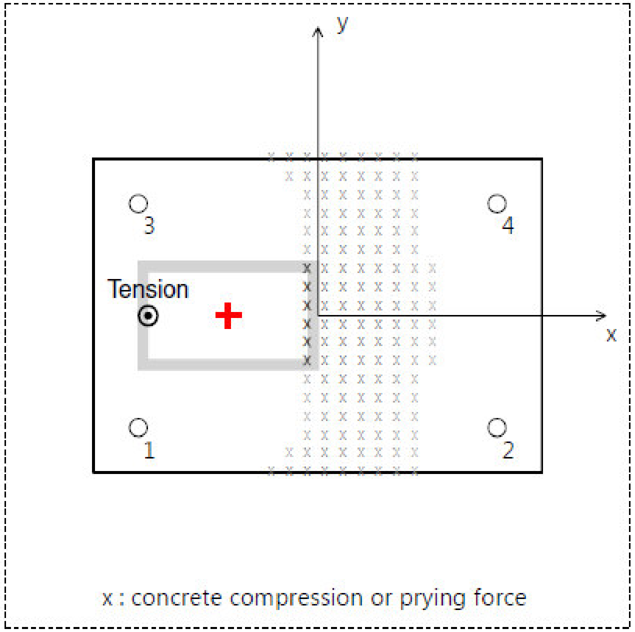
Maximum plate displacement into concrete (x/y=30.0/-10.3): 0.025 [mm]

Maximum concrete compressive stress: 11.46 [N/mm^2]

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.



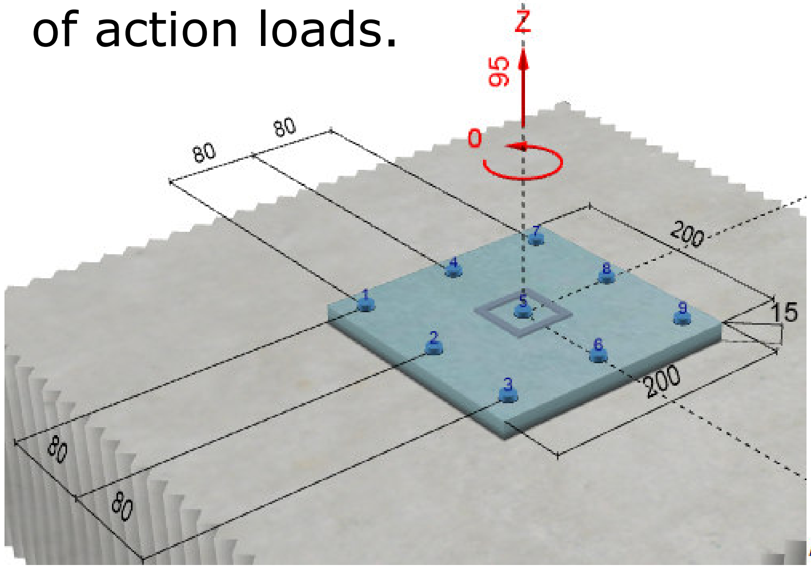
3. Verification at ultimate limit state based on EOTA TR029

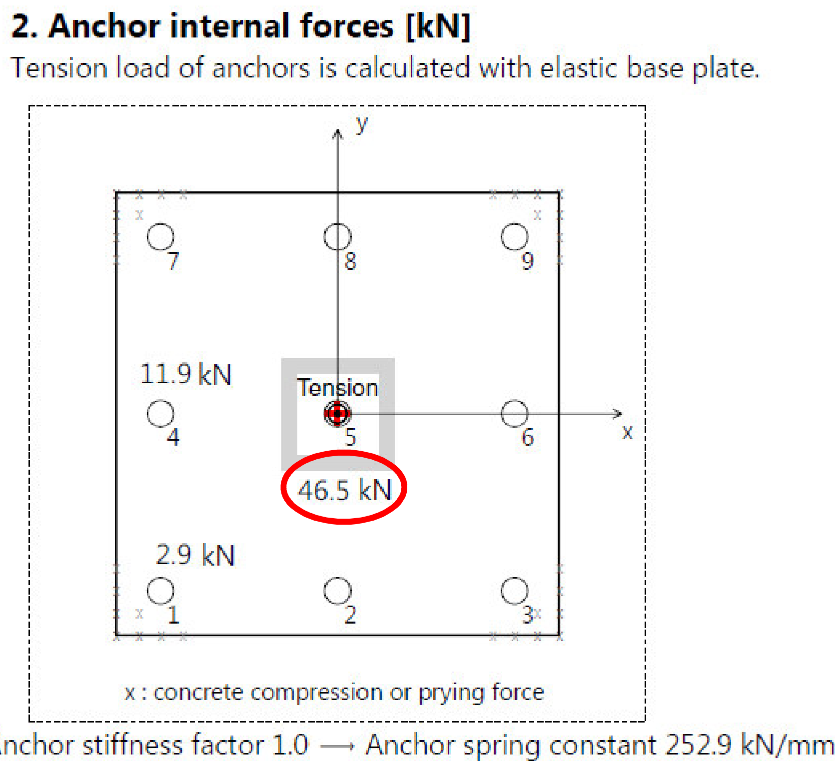
3.1 Tension load

	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

Example of special cases, anchor group similar to test of FMPA 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.





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:

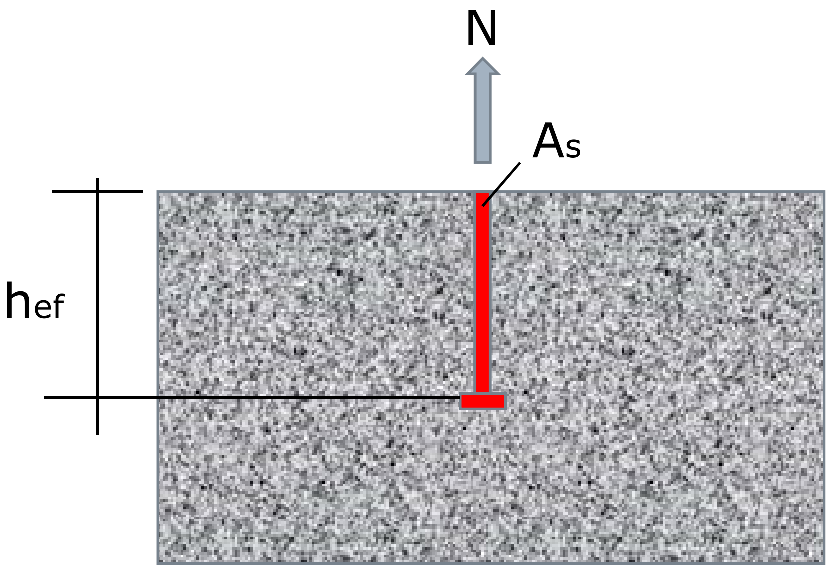
Annex C: Control of max loaded anchor according to (5.2f)

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

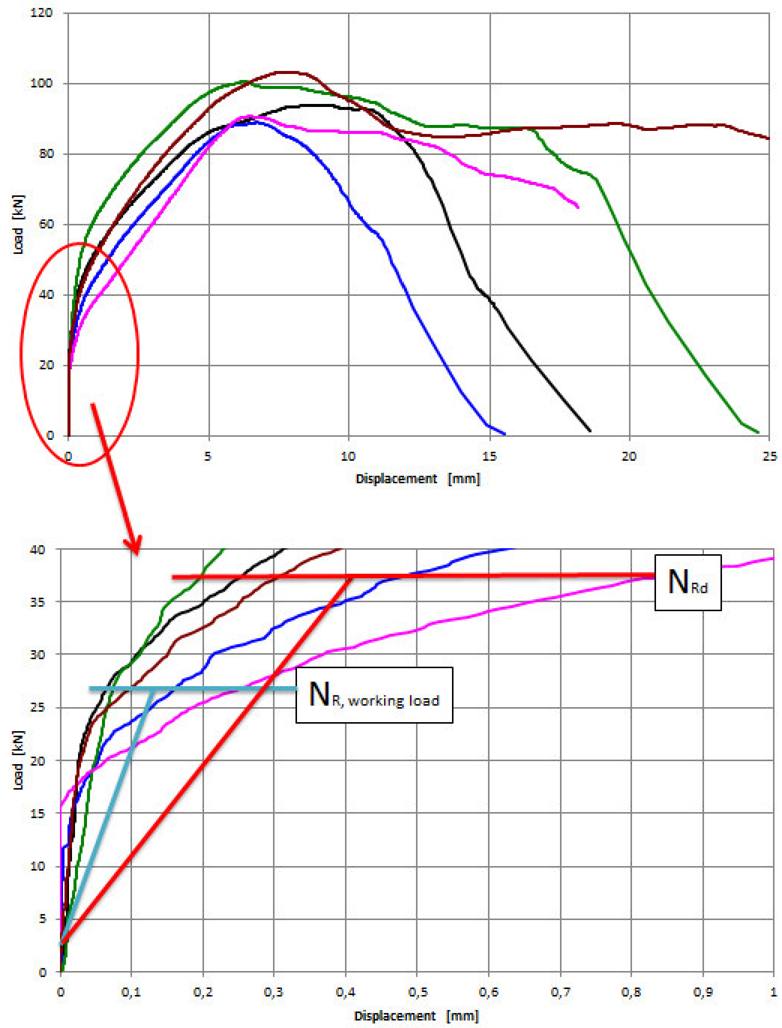
Test example,
Mechanical anchor M20,
h_{ef} =100 mm, ucr C50/60
$N_{Rd,cr}$ =37.2 kN

Mean value: **φ =0.18**

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

Mean value: **φ =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.
  φ = 1.0 for bonded anchors (TR029)
  φ = 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

  $\boldsymbol{\gamma_M = 1.1 \cdot 1.35 \approx 1.5}$ (with γ_s =1.1 acc. to EC3)