Required Thickness of Flexurally Rigid Baseplate for Anchor Fastenings

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2. Elastic analysis of anchor fastenings with baseplate
3. Stiffness condition for flexurally rigid baseplate
4. Required additional proof for anchor fastenings with elastic baseplate
5. Conclusions

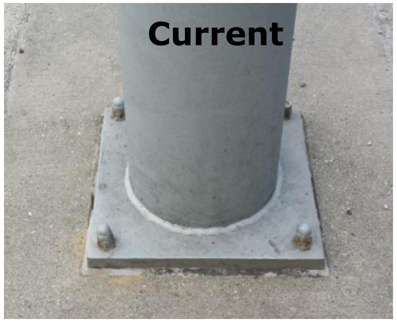
Design flow-chart of Anchor Fastening:

Current: **Rigid baseplate**

- Design of anchorages with assumption of rigid baseplate
may be unsafe in many case.

Future: **Elastic baseplate**

- Design of anchorages with real behavior of elastic baseplate
will be sample and safe in all cases.



Eurocode 2 (prEN 1992-4) specifies:

The anchor tension forces on a baseplate may be calculated assuming a linear distribution of strains **as a beam section**, if the baseplate is sufficiently rigid.

But How to define

the "sufficiently rigid" for baseplate ?

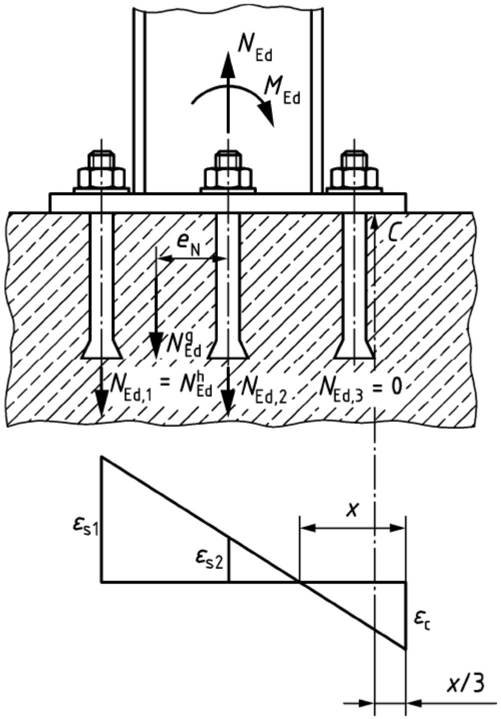


Figure 6.2

of prEN 1992-4 (Eurocode 2: Design of concrete structures — Part 4: Design of Fastenings for Use in Concrete, 2016-03-17)

Eurocode 2 defines the "sufficiently rigid" of baseplate as follows:

a) The base plate remains elastic under design actions $\sigma_{Ed} \leq \sigma_{Rd}$ and

b) Its deformation remains negligible in comparison with the axial displacement of the fasteners.

But now this stiffness condition does not work because

1. The deformation of baseplate and anchors can not be calculated by the assumed beam section method "plane sections remain plane".

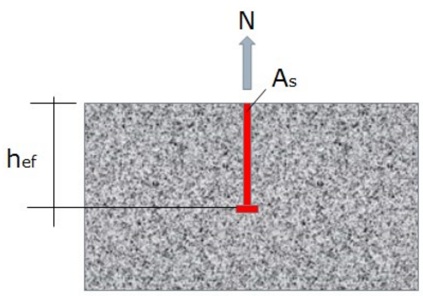
2. With elastic analysis of anchorage systems it is not defined which deformations are to be compared, because the deformations are considered with their compatibility.

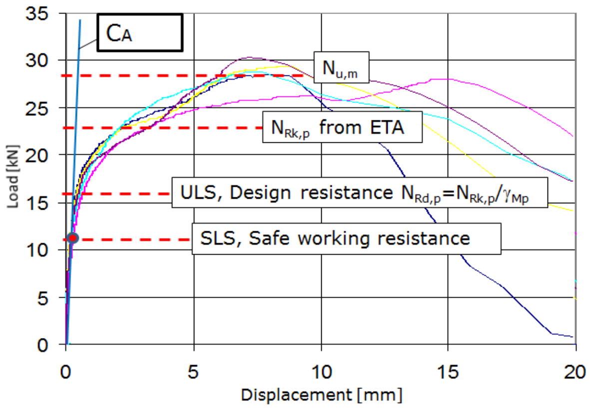
3. With elastic analysis the anchor stiffness at SLS is required. This stiffness is not available in current ETAs.

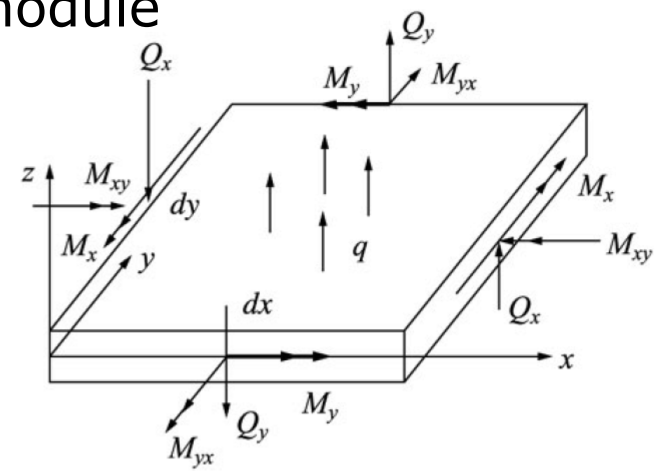
=>We need applicable stiffness condition!

For the elastic analysis the Kirchhoff plate theory is used with the baseplate being elastically bedded on concrete base. Bolts and concrete areas are represented by elastic springs. The following parameters are taken for the calculation.

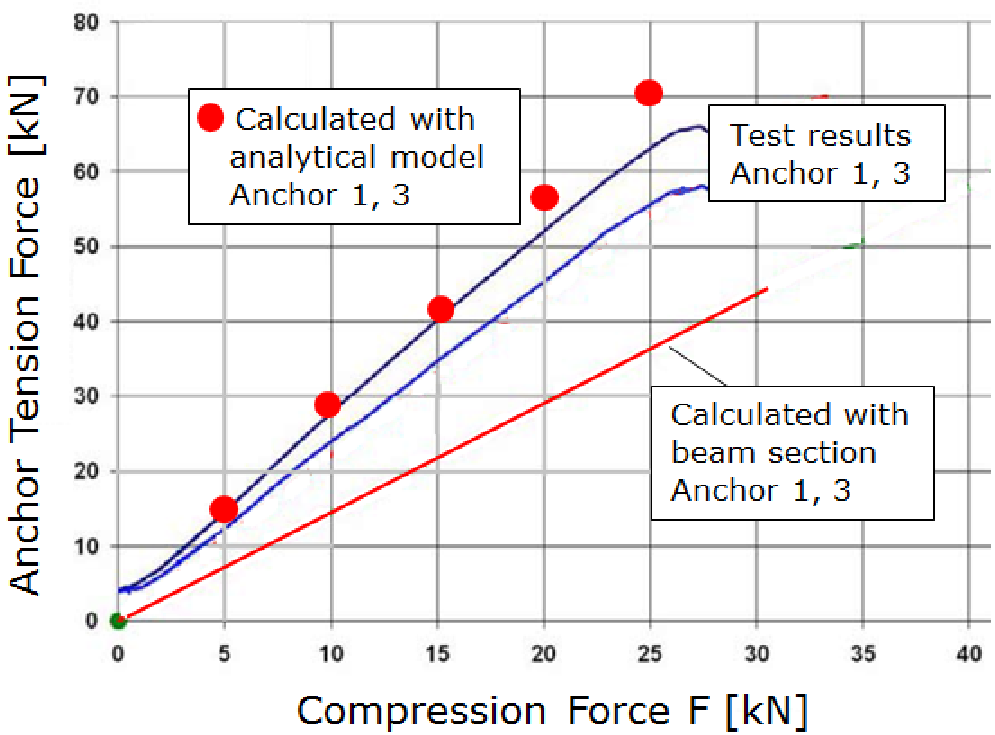
1. Anchor Stiffness C_A under SLS of single anchor
2. Concrete bedding factor C_C
3. Connect profile on the base plate
4. Baseplate thickness t_{fix}, and its E-module

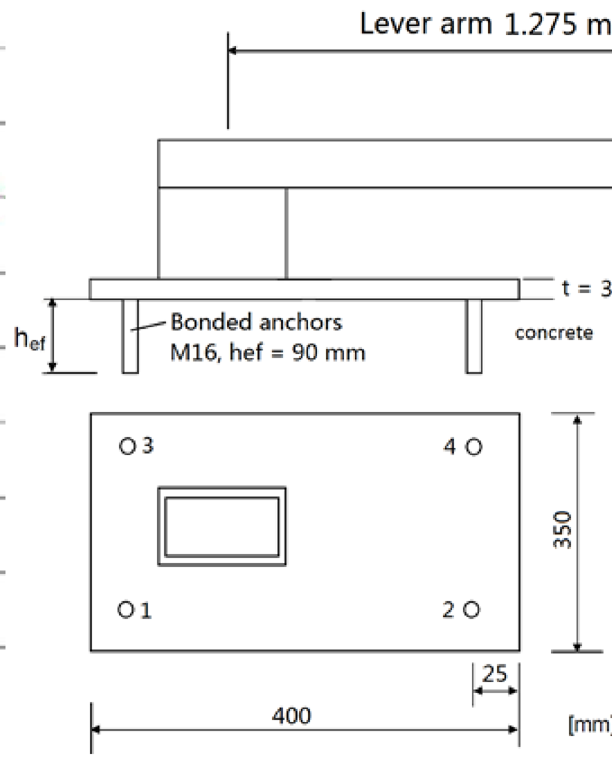






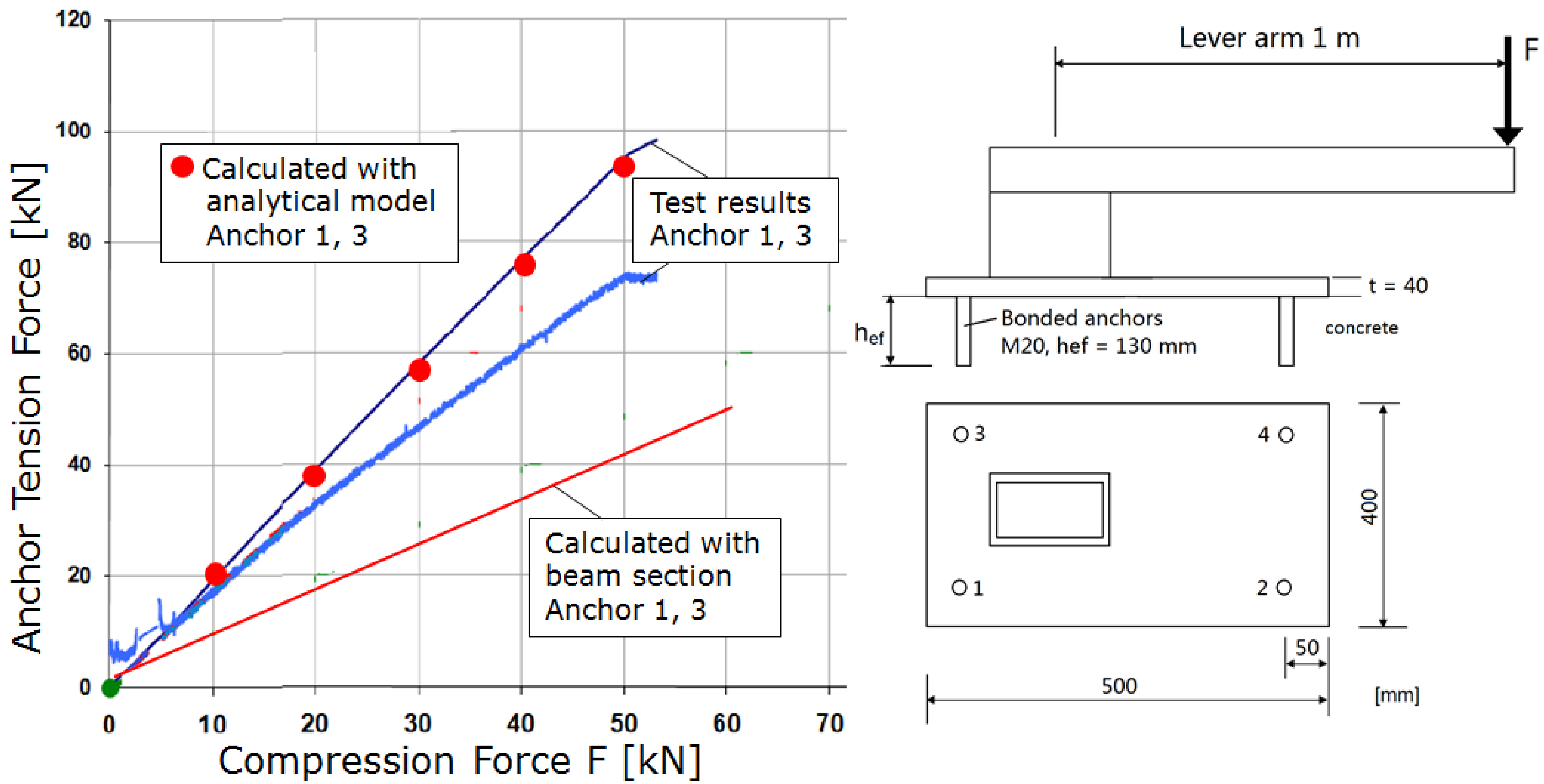
Comparison between calculated and tested results, No 1





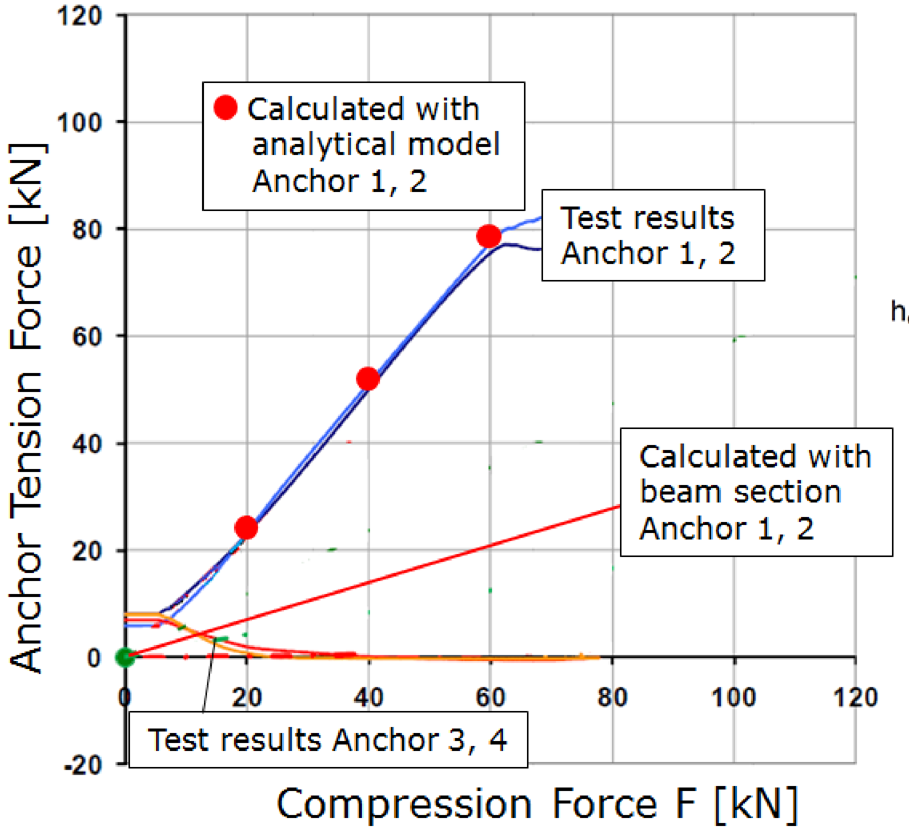
Test 1 from dissertation Fichtner, university Stuttgart 2011

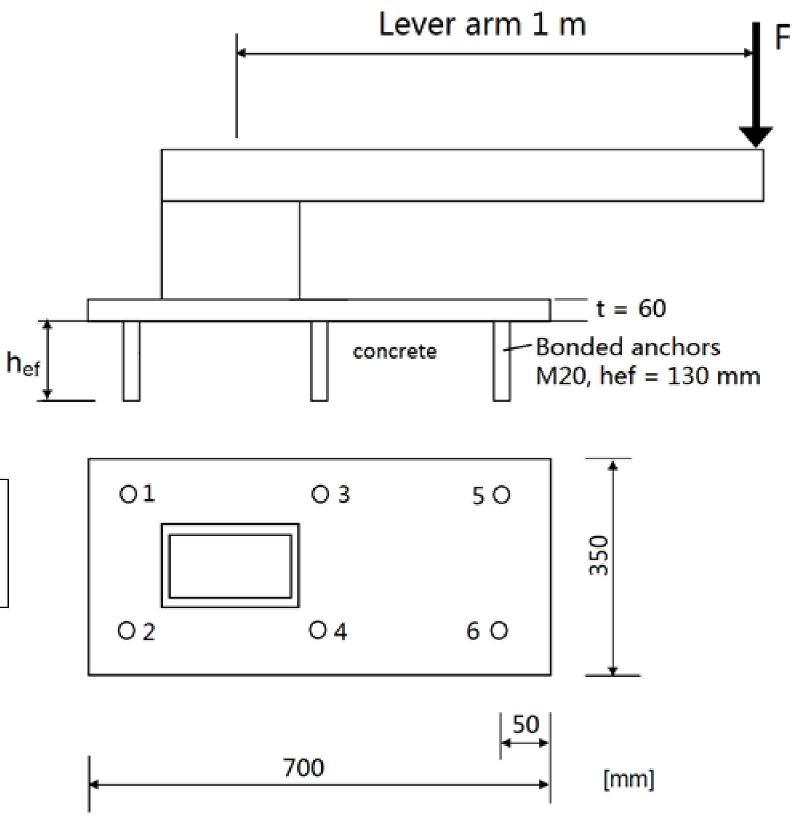
Comparison between calculated and tested results, No 2



Test 2 from dissertation Fichtner, university Stuttgart 2011

Comparison between calculated and tested results, No 3





Test 3 from dissertation Fichtner, university Stuttgart 2011

Stiffness condition for flexurally rigid baseplate

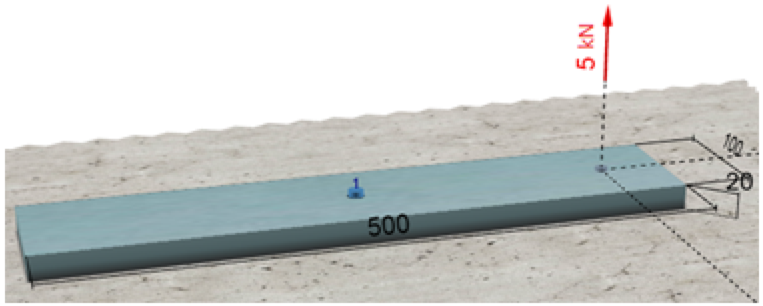
As shown the elastic baseplate model can accurately predict anchor tension force distributions on baseplate. With this in mind, the following stiffness condition for flexurally rigid baseplate is proposed:

- The baseplate is treated as elastic under design actions $\sigma_{Ed} \leq \sigma_{Rd} = f_{yk} / \gamma_M$ and

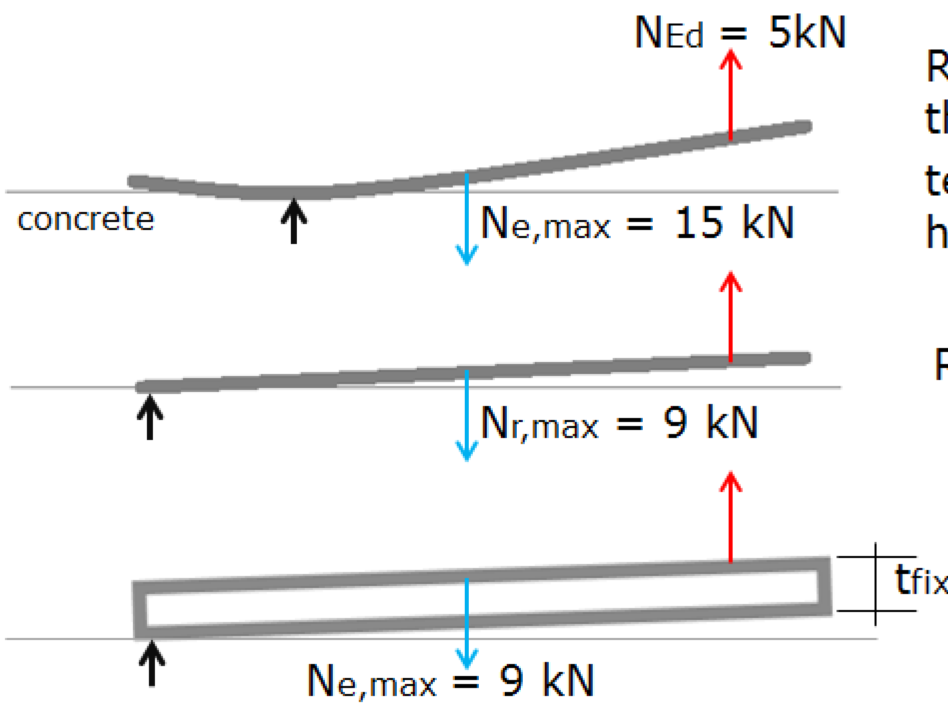
- The highest anchor tension forces, $N_{r,\,max}$ of flexurally rigid baseplate, calculated by beam section method and $N_{e,\,max}$ of elastic baseplate, calculated by the elastic baseplate method are equivalent:

$$N_{e,\,max} \approx N_{r,\,max}$$

Stiffness condition for flexurally rigid baseplate



Example 1,
Bonded anchor M12, hef = 120 mm, C20/25, assumed C_A =126.5 kN/mm

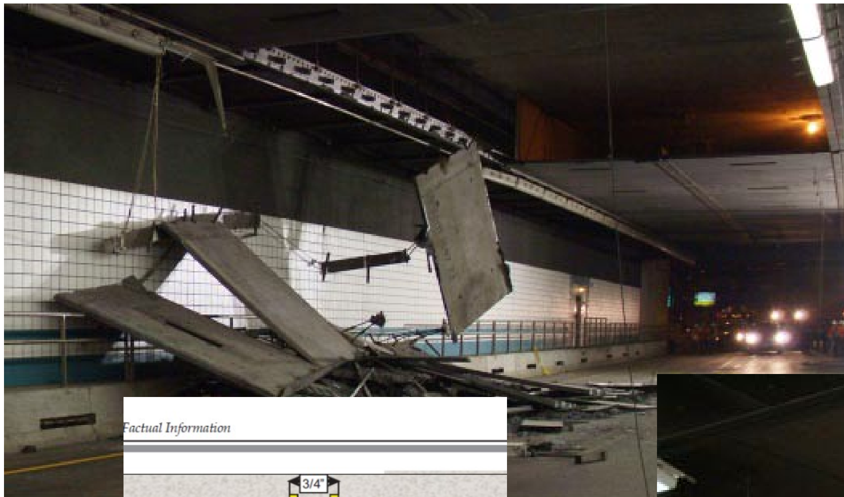


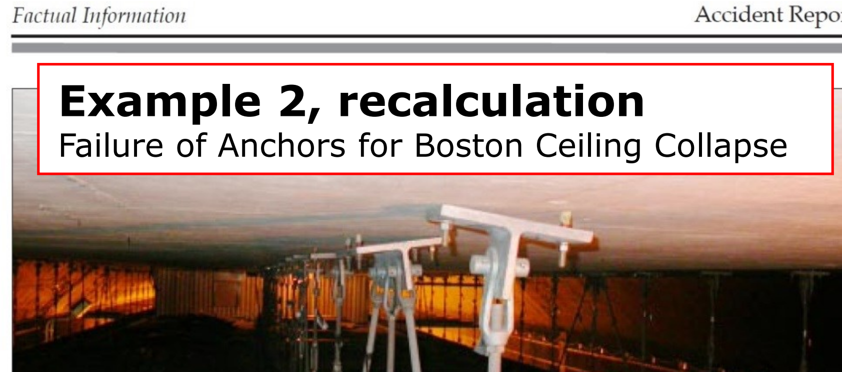
Results of FEA with t_{fix} = 20 mm fulfill the condition $\sigma_{Ed} < \sigma_{Rd}$, but the anchor tension force $N_{e,max}$=15 kN is much higher than $N_{r,max}$=9 kN.

Results of assumed rigid base plate

FEA with the condition of $N_{e,max}$ = 9 kN results in the required thickness of t_{fix} =41 mm for flexurally rigid base plate.

Stiffness condition for flexurally rigid baseplate





Example 2, recalculation
Failure of Anchors for Boston Ceiling Collapse

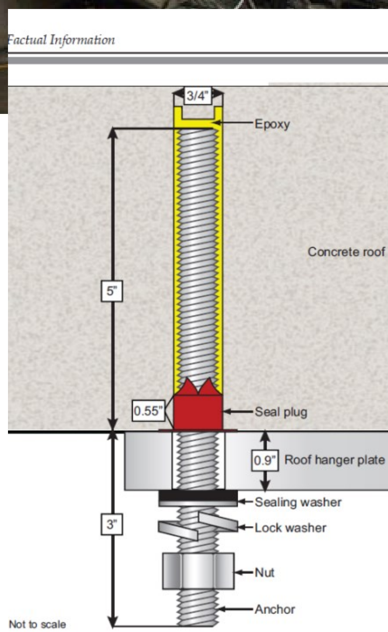
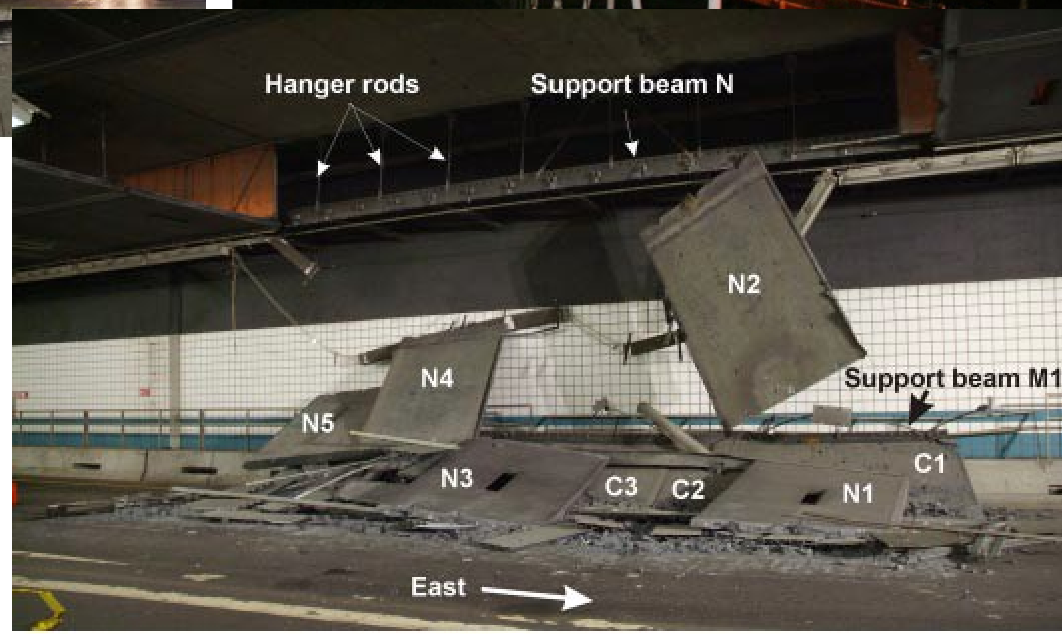
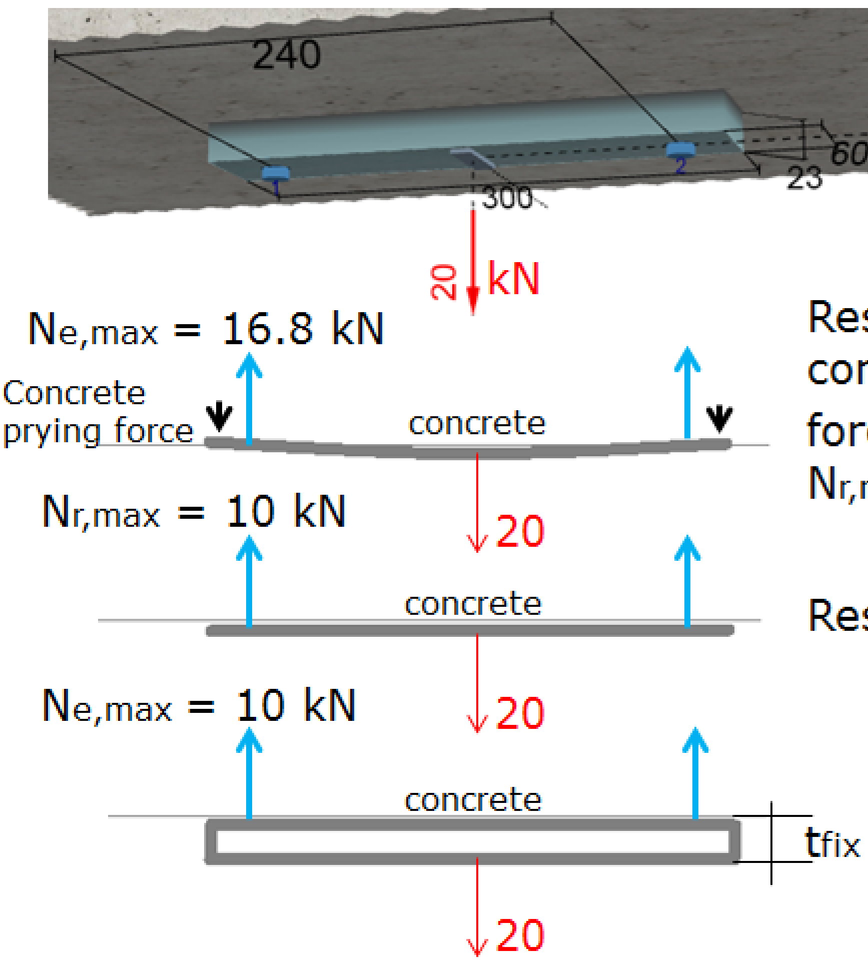


Figure 7. Typical adhesive anchor and roof hanger plate assembly.



Stiffness condition for flexurally rigid baseplate

Dr.Li



Example 2
Bonded anchor M16, hef = 127 mm, C20/25, assumed C_A = 203.9 kN/mm

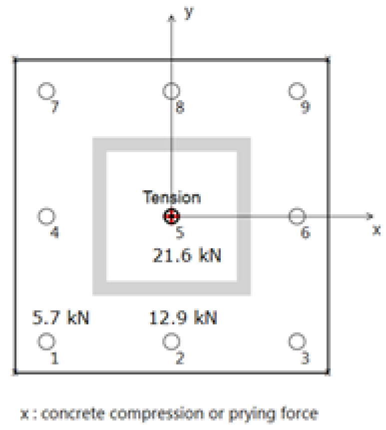
Results of FEA with t_{fix} = 23 mm fulfill the condition $\sigma_{Ed} < \sigma_{Rd}$, but the anchor tension force $N_{e,max}$ = 16.8 kN is much higher than $N_{r,max}$ = 10 kN due to concrete prying force.

Results of assumed rigid base plate

FEA with the condition of Ne,max = 10 kN results in the required thickness of t_{fix} = 35 mm for flexurally rigid base plate.

Required additional proof for elastic baseplate

As shown, this stiffness condition may lead to unrealistic plate thicknesses. That means, elastic baseplate model has to be used in the practice. But the current design method in EC2 lacks any provision for the elastic baseplate model. E.g., the resistance of the tested 9-anchor group at concrete cone failure cannot be calculated by EC2 because the reduction factor for non-uniformly distributed anchor tension loads cannot be considered by load eccentricity on anchors.



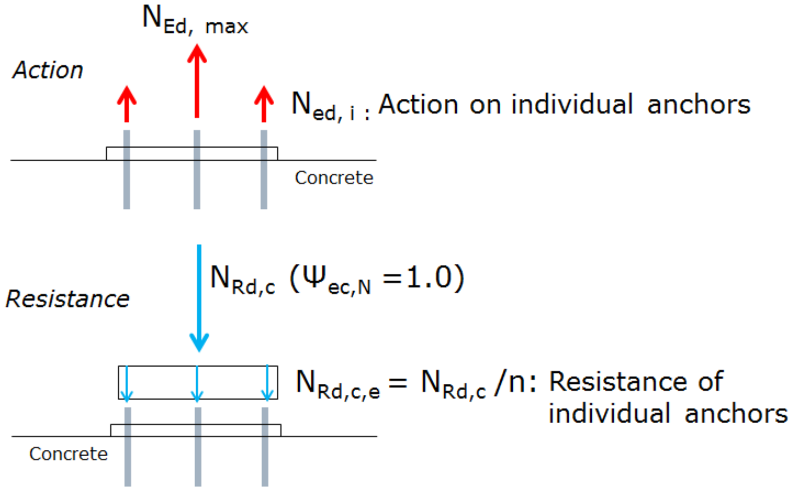
Therefore additional proof to EC2 is necessary for anchor groups with elastic baseplate. For this additional proof, the use of

$\Psi_{ec,N} = 1,0$ and

$N_{Ed,\ max} \leq N_{Rd,c}/n$

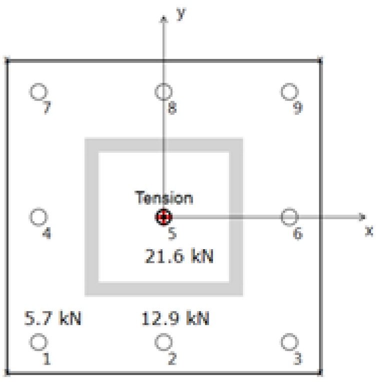
may be proposed conservatively.

n: number of tensioned anchors



Proof condition: $N_{Ed,\ max} \leq N_{Rd,c,e}$

Verification of the additional proof for elastic baseplate



x : concrete compression or prying force

Baseplate stiffness	Concrete cone resistance [kN]		Safety factor	
t_{fix} [mm]	N_{Rd}, calculated	N_{Ru}, tested	N_{Ru}/N_{Rd} tested/calculated	N_{Ru}/N_{Rd} required
10	33.1	93	2.8	
15	43.9	94	2.1	≥ 1.5
20	56.3	92	1.6	
Rigid	90.7	-	-	

Comparison of design resistances N_{Rd} with tested failure loads N_{Ru}

Conclusions

According to EC2 the anchor tension forces on baseplate are assumed to have a plane distribution. Therefore the baseplate has to be sufficiently stiff (rigid). But there is no workable provision available to check the required stiffness of baseplate.

The elastic baseplate model can very accurately calculate the anchor tension force distribution. With this model a stiffness condition is proposed to control the equivalent highest anchor tension forces between rigid and elastic baseplate. Results indicate that the required thickness for the rigid baseplate to be valid is unrealistic in many cases. That means, the elastic baseplates have to be used in the practice.

An additional proof to EC2 for concrete cone failure is necessary in order to use the elastic baseplate model, because the anchor tension forces do not have plane distribution on elastic baseplate. The procedure for this additional proof has been proposed and verified with test results. With this additional proof, elastic baseplates could be generally used in the design of multiple anchor fastenings.