Stiffness requirements for baseplates

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ABSTRACT: In Europe, the resistance of fastenings with cast-in-place and post-installed anchor systems is calculated according to the CC-Method (Concrete Capacity Method). The actions on the fasteners are calculated according to the theory of elasticity assuming a rigid baseplate. A sufficient stiffness of the baseplate has to be ensured and therefore certain criteria must be fulfilled. Because of some investigation showing that the design method for the baseplate does not lead to the estimated ultimate load, further numerical and experimental research was done and is described in this paper. It results in a new design approach, which takes the previous method into account and extends it with further parameters to get a baseplate thickness which ensures a safe and economic fastening.

1 INTRODUCTION

The CC-method is very useful for calculating the ultimate load of fastenings in concrete because of its simplicity and good predictability. Considering the concrete parameters, embedment depth and distances to other fasteners and edges, it is possible to determine the ultimate loads.

The CC-Method is also used to calculate complex arrangements of fasteners, which are connected by baseplates to a single fastening point.

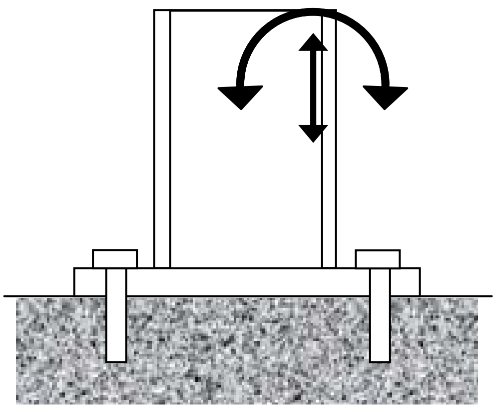

Figure 1. Example of a baseplate construction.

Usually one has different loading situations on such a fastening. While applied normal and shear forces are usually distributed equal to the fasteners, eccentrically positioned forces result in a bending moment. This moment takes loading from some anchors and puts it on others. But the quantity of this unequal loading not only depends on the relation of the normal/shear force to the bending moment. It is also influenced by the stiffnesses of all parts of the fastening – usually one would think about the baseplate thickness at first.

2 STATE-OF-THE-ART SYNTHESIS

In the past a few approaches were made to determine the distribution of forces under the baseplate to predict a reliable ultimate load. Following the method used for steel constructions (e.g. T-Stubs), one could assume the compressive force under the baseplate near or under the attachment. Several investigations stated this approach to be very conservative, because of the very different stiffnesses using steel bolts/screws on the steel construction side and anchors in the fastening technology.

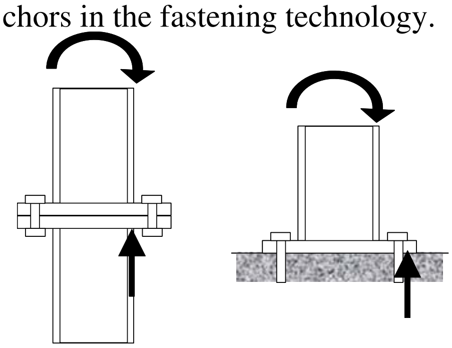

Figure 2. Approaches for the location of the compression force.

The other, more realistic, approach is to get the distribution from the concrete methods. Usually the concrete constructions do not have large deformations and so the cross-section is supposed to remain plain. The so-called Bernoulli-Hypothesis, which is applied here, allows the use of the theory of elasticity.

Using a baseplate the concrete surface would stay plain and so it is only necessary to take care of the baseplate to do the same – till it reaches the ultimate load. The method developed by Mallée (1999) is about limiting the stress in the baseplate (stress limit approach). These stresses – mean values over an area of 2*t+s (Figure 3) – have only to be lower than the uniaxial yield limit of the baseplate steel. Mallée concludes that the deformation of the baseplate then is only elastic and small enough to ensure a plane surface, too.

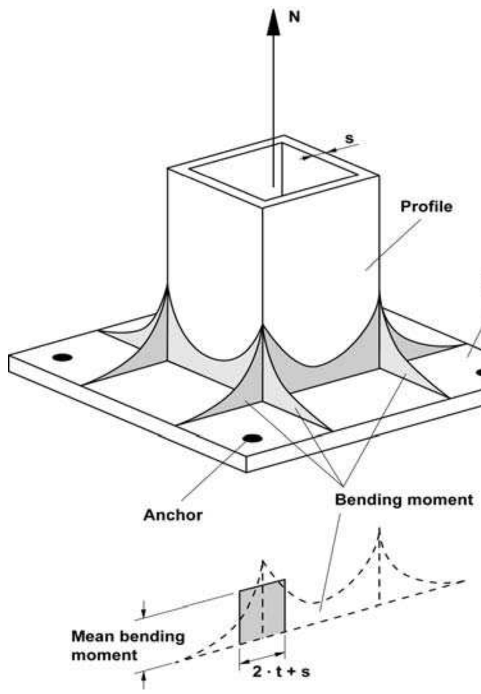

Figure 3. Stress distribution in the baseplate and calculation of mean values (Mallée, 1999).

If the baseplate is assumed to remain plane then one has only to consider the – mostly elastic - deformation that the baseplate brings to the concrete surface in the area of compression (Figure 4).

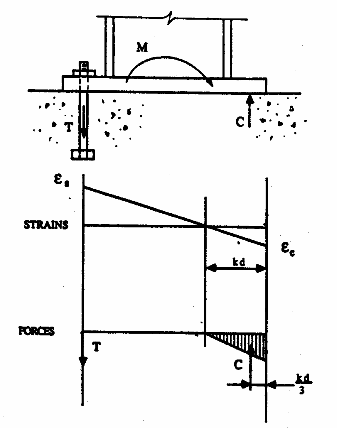

Figure 4. Static model of an elastic calculation of a baseplate.

At least it is – compared to the first assumption – a little more complex, but still a linear elastic problem. Like many of the companies of the fastening technology sector and at first the IWB (Institute of Construction Materials) have shown, it is possible to calculate this FE model in a few seconds on usual PC configurations.

3 PROBLEM AND INVESTIGATION

Of course this method is not quite suitable for all of the constructions one can think of. Mainly it never takes into account all the differences in the load-displacement curves that exist for fastening components.

This problem was first observed by the state office for structural engineering Baden-Württemberg, Schneider (1999) who carried out a few finite element studies. In this investigation 3 different assemblages were tested, which mainly differed in their loading direction and position of attachment while all baseplates had four anchors connected.

The results discovered problems especially with structures with eccentrically applied attachment.

Mallée (1999) carried out numerical and experimental tests to state his theory to be safe. Like Schneider he calculated the distribution of forces in the anchors while reaching the design load. His conclusion was quite different from Schneider's.

But for the quantification of safety it is not only necessary to look at the design load, because it mainly takes into account of the deformation. One has to observe the ultimate load of the construction, too.

The author of this paper did further numerical and experimental research to describe the most relevant parameters. The parameters are summed up in Table 1. In column 2 the varied number of each parameter is shown and in column 3 the applied values.

Table 1: Investigated parameters and values.

No.		Count	Value
1	Stiffness of fastener	3	30-160 kN/mm
2	Embedment depth of fastener (h_{ef})	3	80-240mm
3	Eccentricity of attachment	2	0-XXX mm
4	Eccentricity of loading	3	-5000, 0, 5000mm
5	Type of loading	2	normal force w&w/o bending moment
6	Number of fasteners	3	4, 6, 9
7	Size of baseplate	3	1, 2, 3 * h_{ef}

Because not all combinations make sense for describing the problems of baseplate constructions, not every possible model was created. In total over 200 simulations were carried out. The baseplate thickness was calculated using the stress limit approach by Mallée.

4 RESULTS

4.1 *Stiffness of fasteners*

The first parameter to explain is the stiffness of each fastening. Figure 5 shows the influence of the stiffness (in KN/mm) on the ultimate load of the baseplate.

All results given next are in comparison to the predicted values using the theory of elasticity.

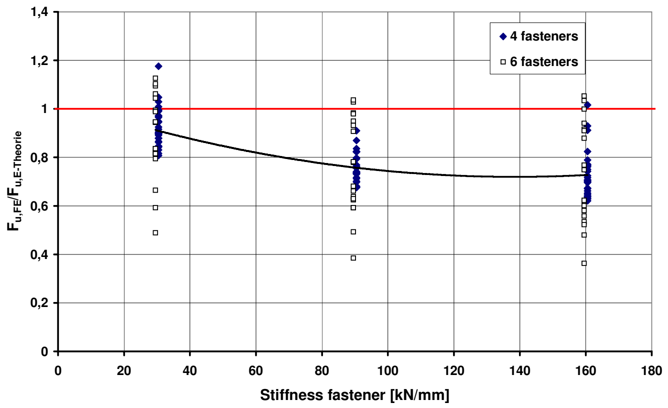

Figure 5. Influence of the fastener stiffness.

If the stiffness of the fastener increases, the ultimate load decreases up to 50% to 70% of the predicted value using the theory of elasticity. If the fastener stiffness is below 30 kN/mm, the decrease is less 20 % or even less. The spread is very large.

Of course, if one takes out a few series of simulations with absolutely comparable conditions, the diagram looks like Figure 6.

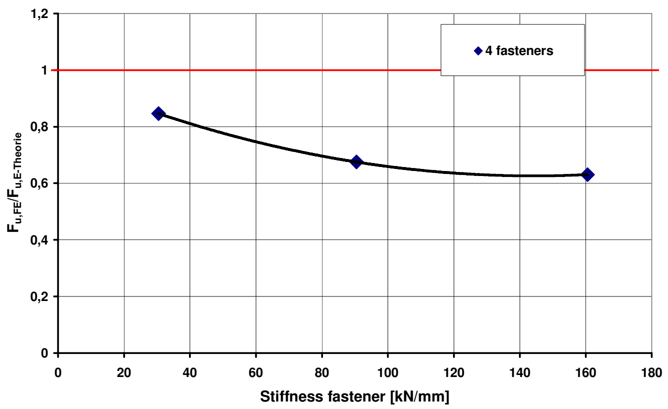

Figure 6. Influence of stiffness of fasteners.

The decrease in ultimate loading does not differ that much using the highest and lowest stiffness, so this parameter cannot be the only one, that affects the load-displacement curve of such a construction.

4.2 *Influence of type of loading*

Figure 7 shows the influence of the load type. The large values on the X-axis indicate a huge eccentricity of the tension or compression normal force and therefore a relatively high bending moment.

In the middle (that is near the Y-axis) the related normal force is much higher and produces less bending moment. The loading on the baseplate is mainly done by the high compression reaction forces under the baseplate.

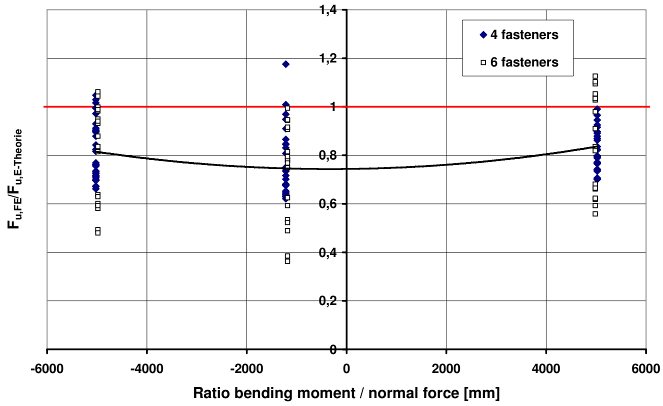

Figure 7. Influence of the type of applied loads.

The average-value curve in Figure 7 shows that a larger external lever arm yields decreasing ultimate loads of the construction.

4.3 *Influence of the profile position*

The next parameter is the eccentricity of the attached profile. The focus is on small attachments compared to the baseplate size. It's obvious to conclude in case of large attachments that the baseplate would not deform that much because of its strong bracing.

In Figure 8 shows the effects that eccentricity of the attachment has on its ultimate capacity.

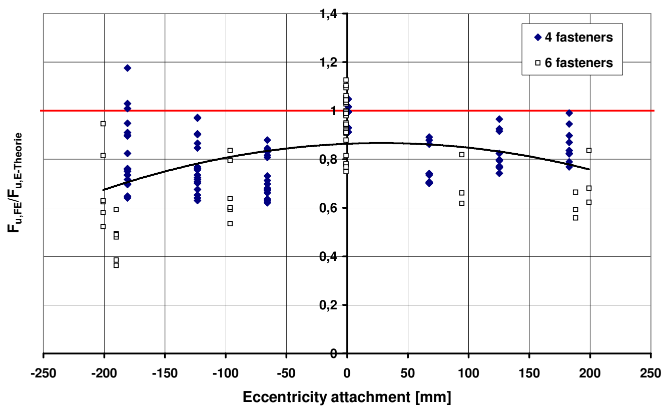

Figure 8. Influence of the position of the profile on the baseplate.

The drawing shows that with mid-positioned attachments the calculated values according to the theory of elasticity are not essentially decreasing. But if the profile is moved out of the centre of the baseplate the baseplate seems overstressed and the ultimate load falls.

4.4 *Influence of the number of fasteners*

The last view on results presented here is on the number of fasteners. In Figure 9 only the simulations with 4 and 6 fasteners are shown.

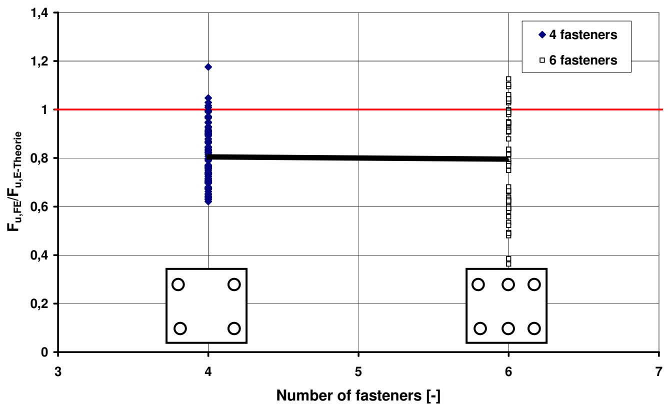

Figure 9. Influence of the number of fasteners.

As one can see, the mean value nearly stays constant, but the spread is larger while taking 6 anchors. An explanation is the generally larger dimensions of a baseplate in case of 6 anchors and the additional 2 fasteners in the middle of the plate.

5 COMPARISON OF SIMULATIONS TO EXPERIMENTAL STUDIES

The evaluation of the numerical studies was done by simulating experimental tests with the finite element model. Therefore all parameters were considered and taken as far as known. While the conditions of constraints do not affect the whole test – the edge distances and concrete body dimensions are large enough – some parameters like concrete, anchor and baseplate type were known and modeled in detail.

Like in the tests, all simulations were loaded until a concrete cone failure occurred. The ultimate load was taken at the highest point of the load-displacement curve.

In Figure 10 the values for the ultimate load are compared. On the X-axis the stiffness of the fastener is written and the dashed horizontal line describes the ultimate load, which is calculated using the theory of elasticity.

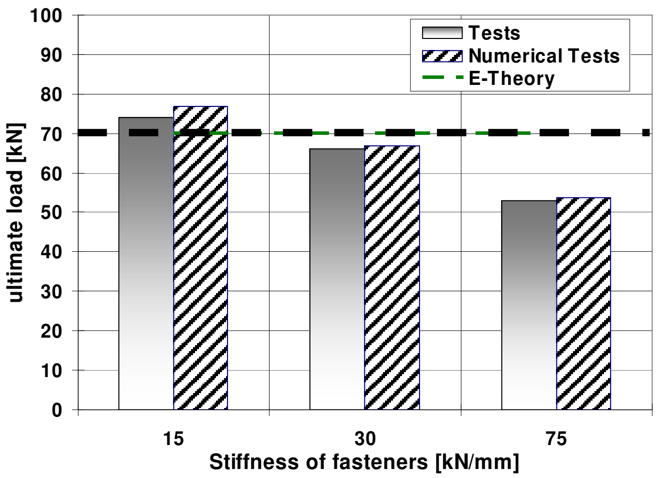

Figure 10. Parameter fastener stiffness.

In all three cases the simulations are very close to the test results. They all are in a range of 1-4% compared to the tests. In the following diagram the ultimate loads according to the plate thickness is shown. The difference between tests and simulation is as small as in the first figure.

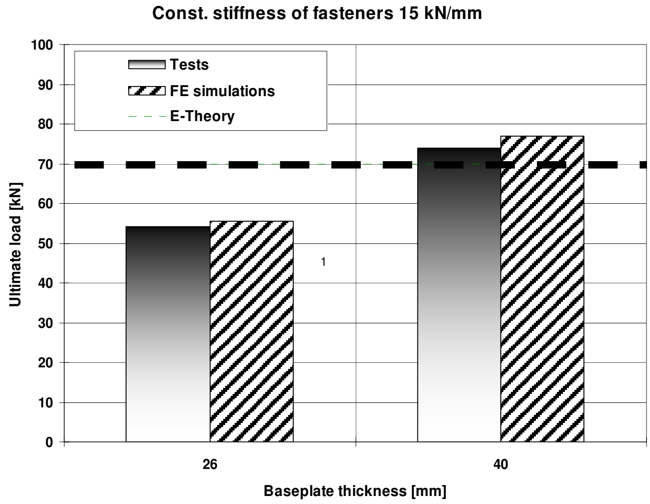

Figure 11. Parameter thickness of baseplate.

6 DESIGN APPROACH

While the results show, that some parameters have more influence on the load-displacement behavior of a construction, there are other – smaller – boundaries which are worth to be considered, too.

Since the new design approach takes into account the stiffnesses of the different substructures coming into play in the behavior of a baseplate, the proposed approach can be shortly called “stiffness criterion”. The design should first be made with the stress limit approach as suggested by Mallée. With the results of the elastic calculation the following formula is entered:

$$\alpha_S = \frac{f_C}{f_B + f_T} \le 1{,}0$$

$f_B = \frac{N_u}{k}$ deformation of anchor

$f_T = \frac{N_u * l_T^3 * 12}{E * b * t_{fix}^3}$ deformation in tension area

$f_C = \frac{C * l_C^3 * 12}{E * b * t_{fix}^3}$ deformation in compression area

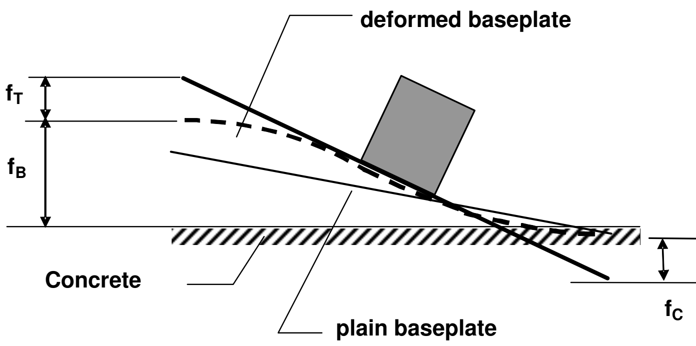

Figure 12. Schematic drawing; relation of the deformations.

The use of this approach should be done – for difficult constructions (e.g. loading in two directions) – by implementing it into the already existing finite element programs. The advantage is that the values f_C and f_T can be calculated automatically.

The following diagram shows, that the Parameter α_S is a good indicator whether the assemblage will reach the ultimate which was calculated using the theory of elastcity.

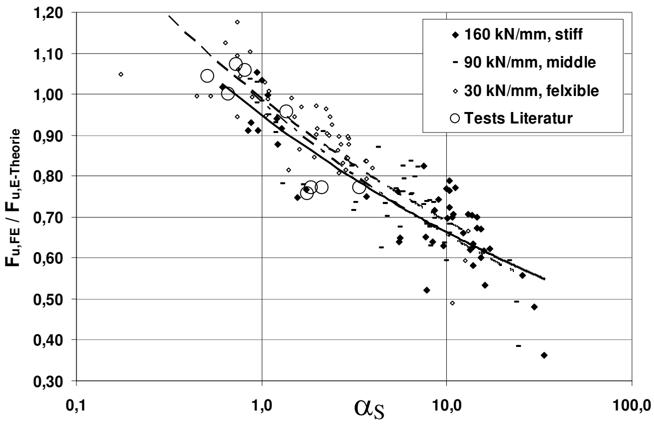

Figure 13. Correlation between the stiffness parameter and the ultimate loads of a fastening point.

7 CONCLUSION

Baseplates are very often used to connect steel constructions to concrete foundations or walls. Because of its heterogeneity those assemblies need to be designed carefully.

The approach by limiting the stresses in the baseplate below the yield strength of the steel material by choosing an appropriate thickness is in many cases a sufficient method which leads to fast, safe and economic solutions.

But not all baseplate constructions with their various parameters fit into this scheme. Sometimes the stiffnesses of all parts of the connection point are very different and have to be investigated further.

With the presented results and approach, all influences of the connection are considered and will lead – in addition to the stress limit approach – to a safe solution for a much larger application range.

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