

Finite Element Validation of PROFIS Engineering Results with ANSYS

Customer

Hilti – Global Application SW

Feldkircher Strasse 100

9494 Schaan, Lichtenstein

Mr. Mario Fitz

Mrs. Daphne Rocha

Documentation

Project consultant

Mayra Hoppstädter M.Sc.

Project leader

Univ.-Prof. Dr. techn. ANDREAS TARAS

Chair of Steel Structures

Institute of Structural Engineering

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1. Introduction

1.1. Task

A typical steel to concrete base plate connection designed in PROFIS Engineering was examined and compared to independent modelling in the program ANSYS.

The connection geometry is shown in Figure 1. It consists of beam HEB 220, base plate (460x460), four anchors (Hilti HY2000-A+HIT-Z M20), mortar (20 mm) and concrete foundation (420 mm). The steel components consist of S235JR and the concrete is of grade C20/25. In a first step, the connection is simply loaded with moment. In further steps, different types of loading are considered as well.

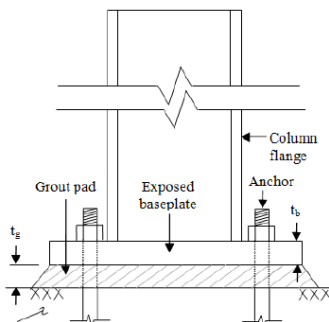


Figure 1: sketch of base plate connection

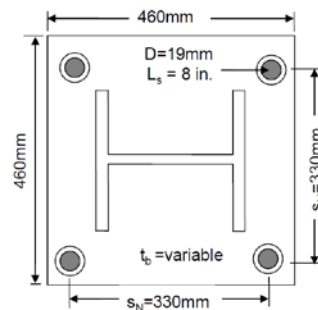


Figure 2: dimensions of the base plate

The presented example should be calculated with different programs to do a comparison.

1.2. Goal

The aim of this work is to build and compare simulation models of the base plate, using an established, high-end commercial FEM software (ANSYS) as benchmark for the validation of FEM implemented in PROFIS. The comparison thus serves to identify differences in modelling and to evaluate the approaches.

The following versions of the two softwares were used:

- PROFIS version 3.0.34.199
- ANSYS Workbench version 19.0

2. Model with PROFIS

In the first step the base plate design is modelled in PROFIS Engineering with the advanced base plate (ADBP) extension. The model is shown in Figure 3.

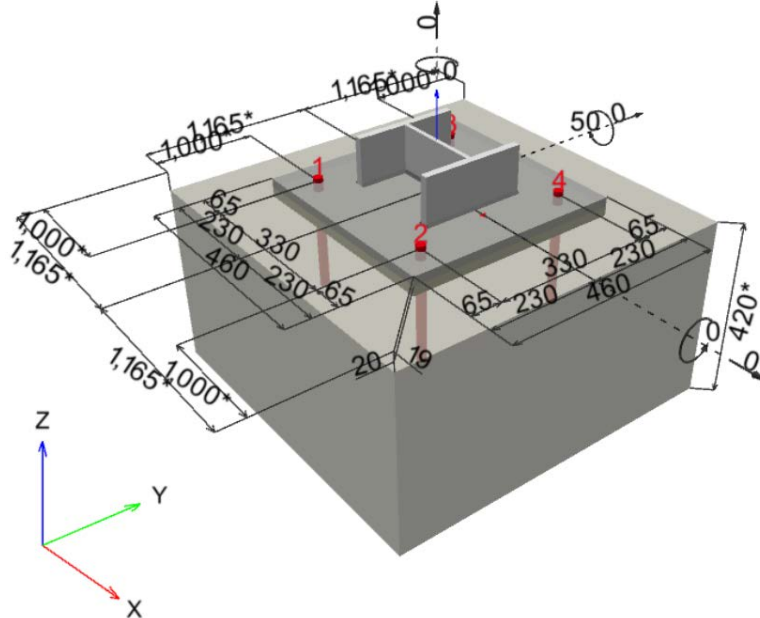


Figure 3: Model in PROFIS

A detailed view of the dimensions of the base plate is depicted in Figure 4. The dimensions are equal for all models to be modelled.

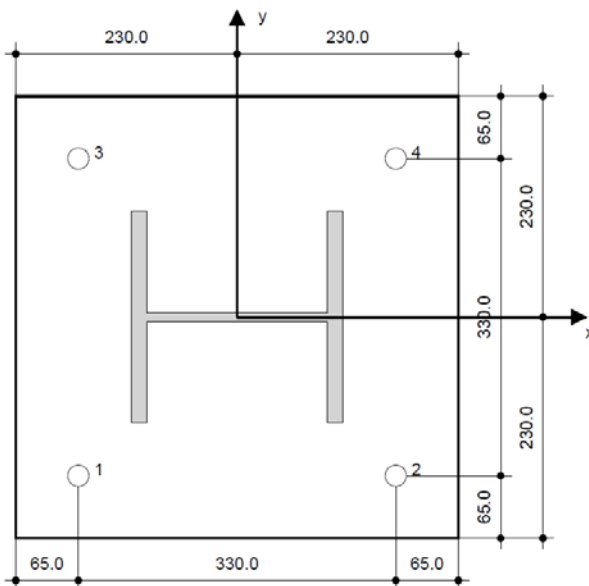


Figure 4: Dimensions of the base plate

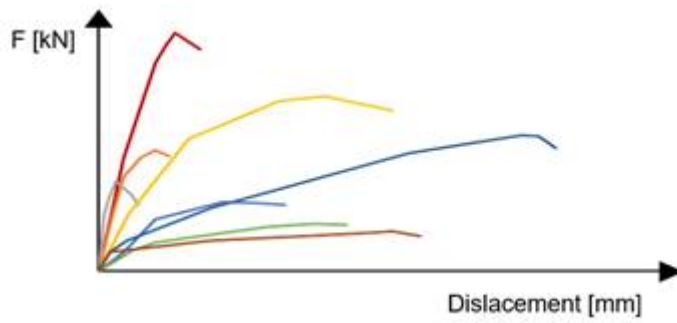


Figure 5: Load-Deformation diagram of the anchor bolt

To calculate the base plate model, the mesh properties in Table 1 are used. The properties are also consistent for all models.

Table 1: Mesh properties in PROFIS

mesh	properties
Number of elements on edge	10
Min size of element	8 mm
Max size of element	30 mm

3. Model with ANSYS

The model of the base plate is developed with ANSYS Workbench version 19.0.

The workflow consists of the following steps:

- Create geometry
- Assign material
- Define interactions (like contact, spring etc.)
- Generate mesh
- Define support & loading
- Solve
- Post processing

3.1. Individual Components

3.1.1. Steel parts

The steel parts consist of a base plate as well as the column's flanges and web.

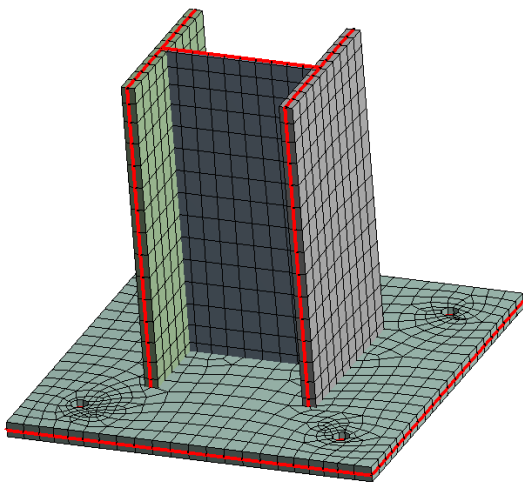


Figure 6: steel parts

Material properties were assigned to these modelled parts. For the steel S235JR, a bilinear stress-strain curve as shown in Figure 7 was considered. An elastic-plastic material with a near-horizontal yielding “plateau” is modelled, in accordance with the method in EN 1993-1-5, Par. C.6, (2). The very low tangent modulus increases the numerical stability in leading to convergence of the non-linear iterations.

The material is thus defined by the two parameters:

- yield strength $f_y=235$ MPa
- tangent modulus ($=21$ MPa = $\frac{E}{10\,000}$).

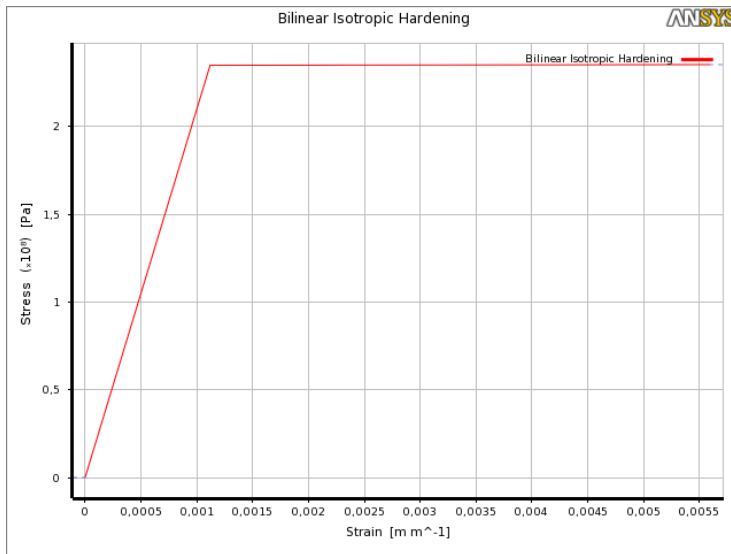


Figure 7: bilinear material model for steel

3.1.2. Anchors

The HILTI anchor bolts are modeled with spring elements presented in Figure 8.

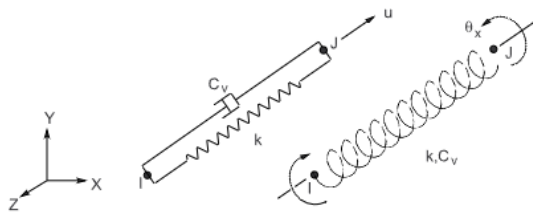


Figure 8: Spring element [1]

3.1.3. Mesh

The mesh properties are chosen so that they closely follow the standard mesh used in PROFIS (see Table 1). For the profile, the base plate and the rigid surface, isoparametric linear shell elements with the ANSYS designation SHELL181 are used, see Figure 9.

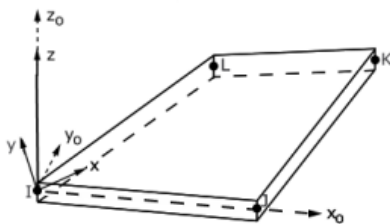


Figure 9: linear shell element SHELL181 [1]

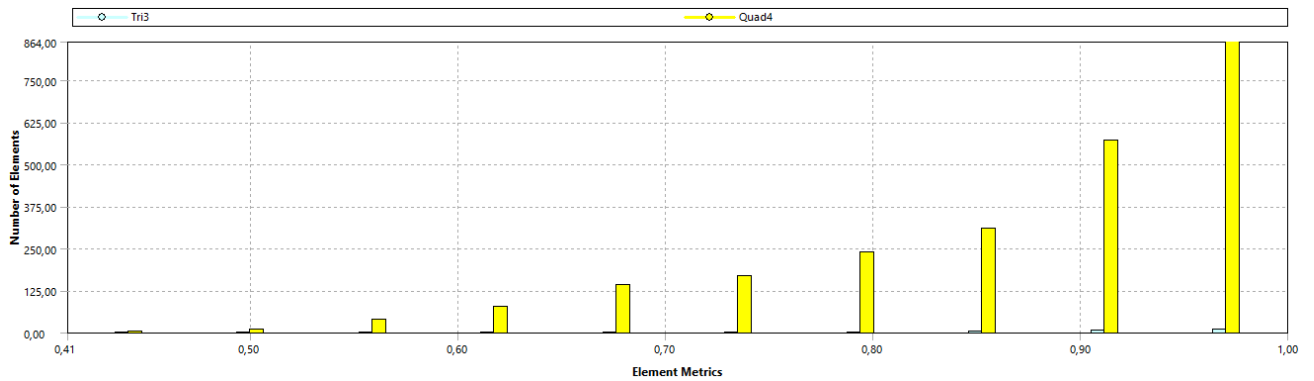


Figure 10: mesh quality

For the comparison of the results, the mesh size and quality are crucial, because (local) stresses and strains in particular are quite dependent on these factors. Figure 11 presents the mesh quality in ANSYS. A value of “1,00” is the optimum; a clear majority of the used elements are close to this benchmark value, therefore the distribution of the mesh quality can be deemed to be appropriate.

3.1.4. Interaction

In order to ensure that the components correctly interact with each other, so-called “contact pairs” and “contact properties” need to be defined. This is done to ensure that the components display the intended displacement behavior with respect to each other in response to applied loading.

First of all, the contact pair and property definition between base plate and the discrete rigid surface that represents the concrete is modelled.

Table 2: material properties concrete

property	unit	value
ρ	[kg/m ³]	2500
E	[N/mm ²]	29962
ν	[-]	0,20
f_{ck}	[N/mm ²]	28
f_{ctm}	[N/mm ²]	2,2

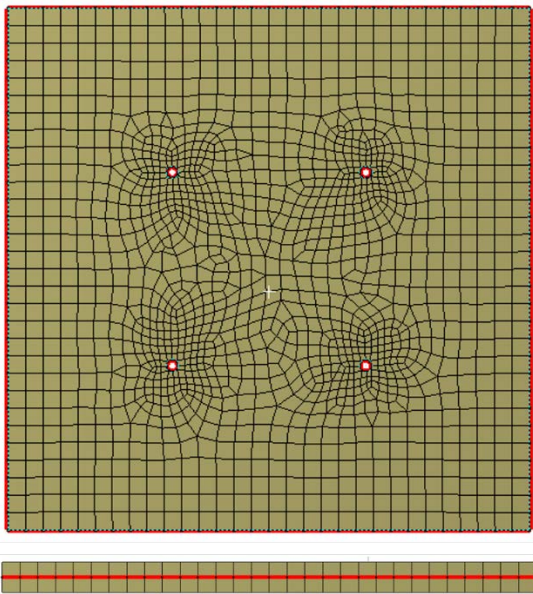


Figure 11: concrete block; top view; side view

The contact between the discrete rigid surface and the base plate allows the plate to lift but not penetrate the concrete.

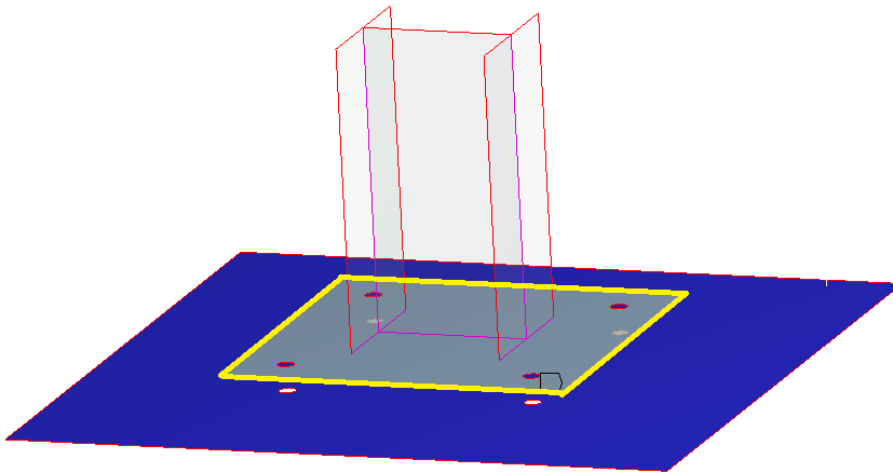


Figure 12: frictionless contact

3.1.5. Welds

To connect steel profile and steel base plate two different weld types are modelled. Butt welds are represented by calculating profile and base plate as one part whereas fillet welds refer to multi-point-constraints that introduce a geometrical gap.

3.2. Loading and Boundary conditions

The loading and boundary conditions of the model include variable acting loads acting on the column (e.g. the bending moment of 50 kNm), as well as the fixed support of the complete discrete surface.

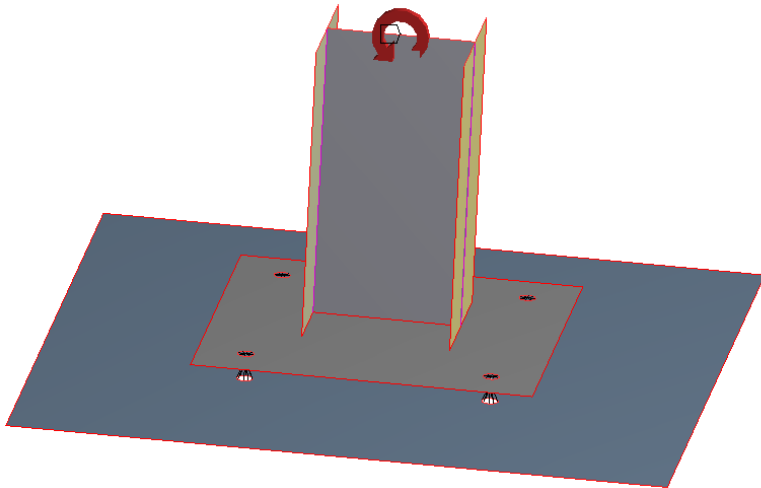


Figure 13: loading - moment

4. Comparison

The following chapter lists and compares the results of the two software used to analyze the considered example. In the first step, base plate thicknesses of $t_{bp}=19\text{ mm}$ and $t_{bp}=25\text{ mm}$ are evaluated. The results are compared both for butt and fillet welds. Table 3 shows an overview of the results for $t_{bp}=19\text{ mm}$.

Table 3: Comparison results for $t_{bp} = 19\text{ mm}$ und $M_y = 50\text{ kNm}$

result	unit	PROFIS fillet weld	PROFIS butt weld	ANSYS fillet weld	ANSYS butt weld
anchor force	[kN]	113,1	104,8	105,5	110,5
equiv. stress	[N/mm ²]	236	237	235,4	239,1
equiv. plastic strain	[%]	0,3	0,7	1,6	1,5
pressure concrete	[N/mm ²]	24	22	30	31
deformation	[mm]	3,9	2,9	1,7	1,9

Overall, the results produced by the two software packages are quite close. The anchor forces in particular only differ slightly. These differences amount to about 7% at most. The maximum equivalent von Mises stresses are naturally all quite close (and at the value of yielding), since the applied loads lead to yielding in some points. The maximum plastic strains and the observed deformations differ more markedly between ANSYS and PROFIS. The differences in deformations, while large, can be mostly attributed to the difference of the modelled length of the attached column, since this is the location of maximum deformation in ANSYS, and can thus be ignored.

As a first observation, it can be stated that the distribution of stress and strain looks quite comparable in the output plots for both software packages. In PROFIS as well as in ANSYS, the equivalent stress in the base plate has the location of its maximum stress on the tension side around the anchors. On the compression side, the stress is close to zero in both ANSYS and in PROFIS. In addition, the maximum concrete stress is locally concentrated in the tensile-side corners, where prying forces are developing. It is precisely in these areas, as well as in the bolt holes, that the maximum strains in the steel and stresses in the concrete appear. Due to the sensitivity of the results to the modelling of the concrete interaction, as well as due to the minor relevance of strain and stress peaks in these highly localized regions, the observed discrepancies can thus be said to be of very small practical significance.

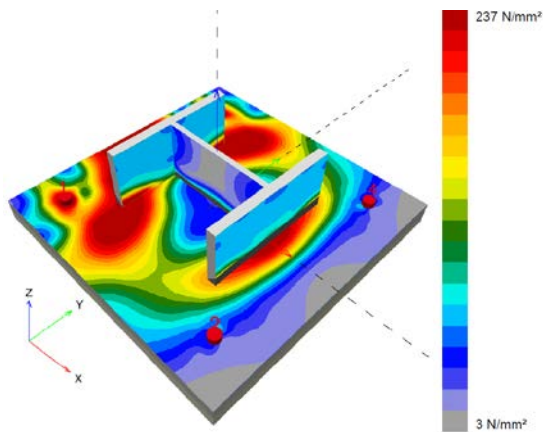


Figure 14: Equivalent stress in base plate PROFIS 19mm,butt weld

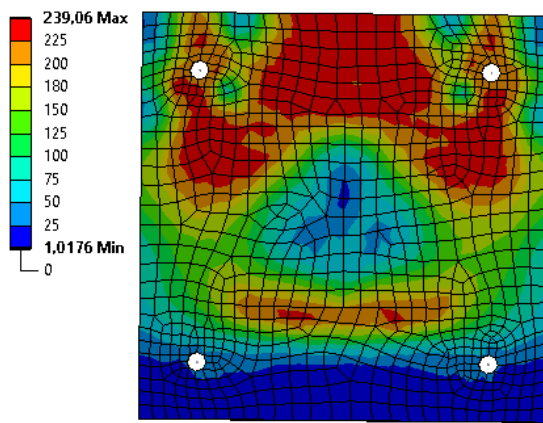


Figure 15: Equivalent stress in base plate ANSYS 19mm,butt weld

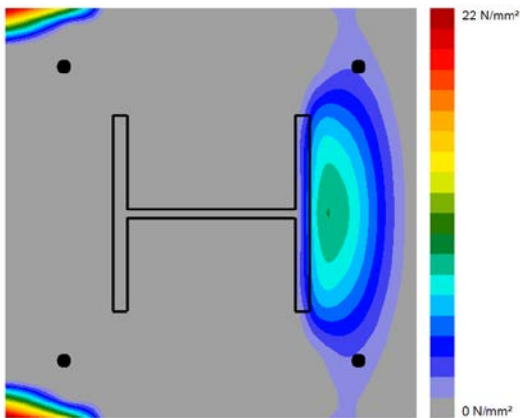


Figure 16: Stress in concrete PROFIS 19mm, butt weld

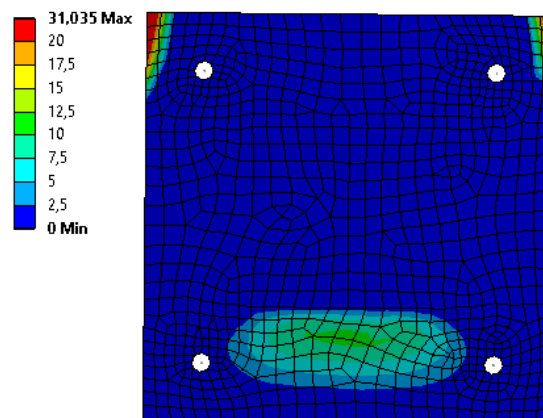


Figure 17: Stress in concrete ANSYS 19mm, butt weld

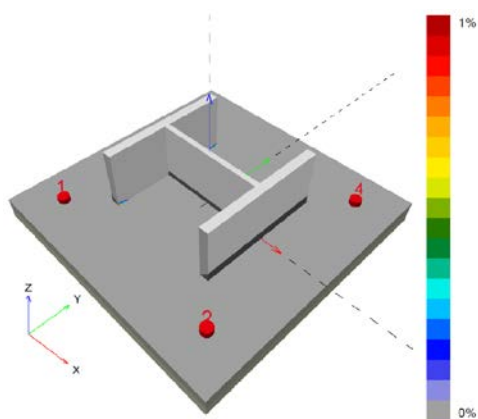


Figure 18: Equivalent strain in base plate PROFIS 19mm,butt weld

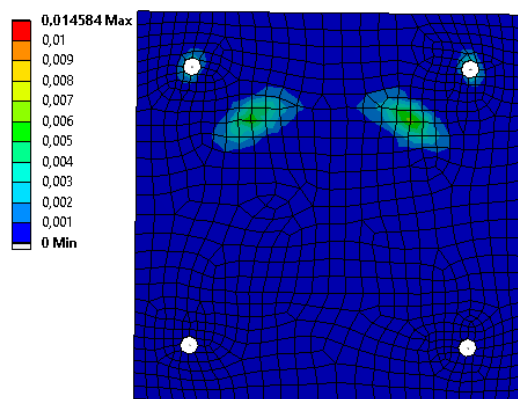


Figure 19: Equivalent strain in base plate ANSYS 19mm,butt weld

In the following, the same comparison is done for the case with $t_{bp} = 25 \text{ mm}$. Table 4 compares the results for the software with butt as well as with fillet welds.

Table 4: Comparison results for $t_{bp} = 25 \text{ mm}$ and $M_y = 50 \text{ kNm}$

result	unit	PROFIS fillet weld	PROFIS butt weld	ANSYS fillet weld	ANSYS butt weld
anchor force	[kN]	89,1	85,0	86,8	89,6
equiv. stress	[N/mm ²]	235	236	235,2	235,1
equiv. plastic strain	[%]	0,0	0,3	0,9	0,5
pressure concrete	[N/mm ²]	12	10	16,4	16,3
deformation	[mm]	2,1	1,7	0,9	1,1

Again, the results are quite close for the two software products. In this case, with a thicker base plate, the anchor force reported in ANSYS and PROFIS are closer to each other than for the thinner plate, in particular for the fillet welds. Butt weld models lead to higher anchor forces, as was observed before. Overall, the observed tendencies regarding the concrete pressure and the deformation continues.

The following pictures illustrate the above observations. The figures show the comparisons for fillet welds. The plastic strain is not shown because it is zero in PROFIS. The maximum equivalent stress in the base plate is in this case more locally spread. There is less stress directly around the anchors. The concrete stress distribution is quite comparable to the one observed in the case with the thinner base plate.

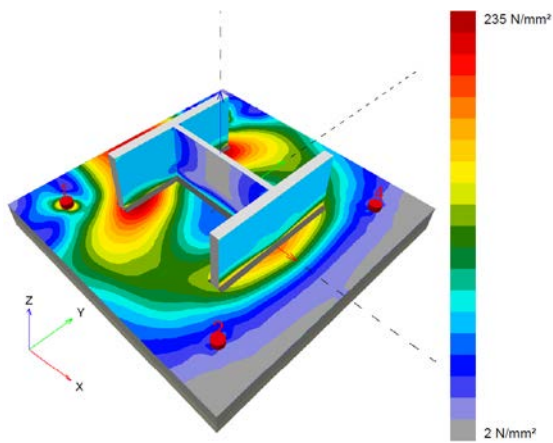


Figure 20: Equivalent stress in base plate PROFIS 25mm, fillet welds

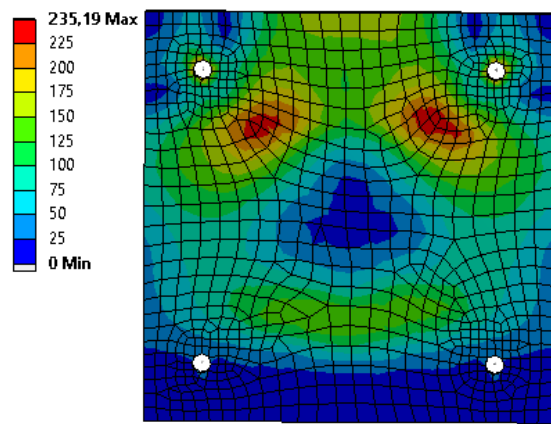


Figure 21: Equivalent stress in base plate ANSYS 25mm, fillet welds

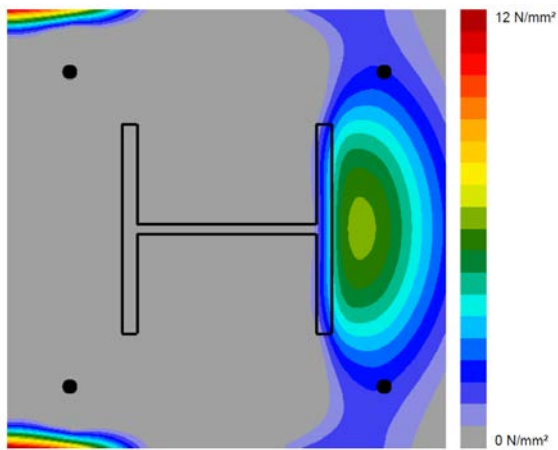


Figure 22: Stress in concrete PROFIS 25mm, fillet welds

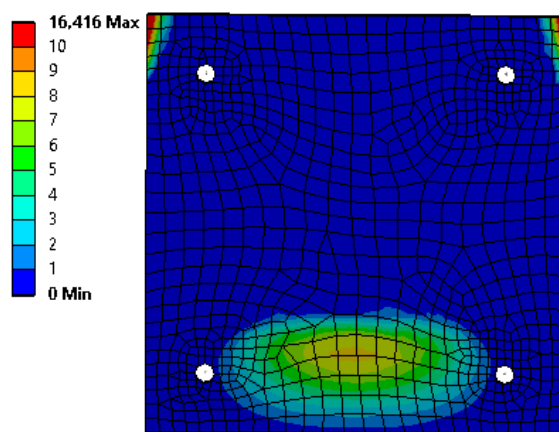


Figure 23: Stress in concrete ANSYS 25mm, fillet welds

5. Parameter variation

The previous examples illustrated the overall behavior for two different base plate thicknesses. In the following the influence of the base plate thickness and the loading should be evaluated for the two software.

In the first step, the base plate thickness is varied between 15 to 29 mm in steps of 2 mm. All other parameters are kept equal and only a bending moment of 50 kNm is applied. Figure 25 shows the change of the anchor force as a function of base plate thickness.

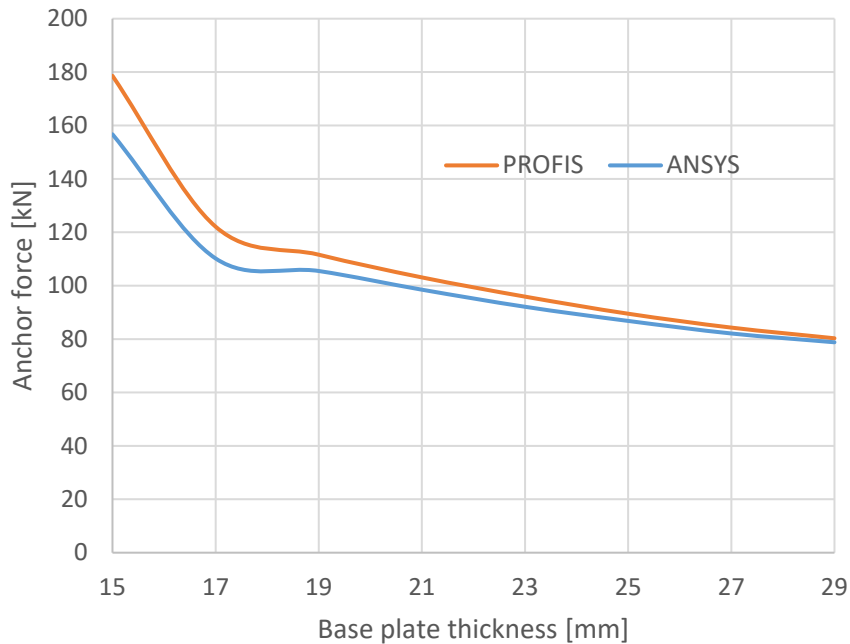


Figure 24: influence of the base plate thickness on the anchor force using fillet welds

For the two models and software packages, the results show a similar, somewhat nonlinear functionality. The nonlinearity is especially pronounced in the range of 15 till 19 mm of base plate thickness. In this range, the variation between the different software solutions is the largest. Both display nearly the same behavior beginning with a thickness of 25 mm.

The results show a slightly stiffer behavior of the base plate in the ANSYS model. The largest difference is in a range of a very thin base plate which is not the realistic design case and result of independent modelling.

In a second step, the loads are varied for both base plate thicknesses and the case of fillet welds. To evaluate the influence of these parameters, four different load scenarios are introduced: uniaxial bending, bending and compression, biaxial bending and compression as well as bending, compression and shear. In every scenario, the bending moment is varied.

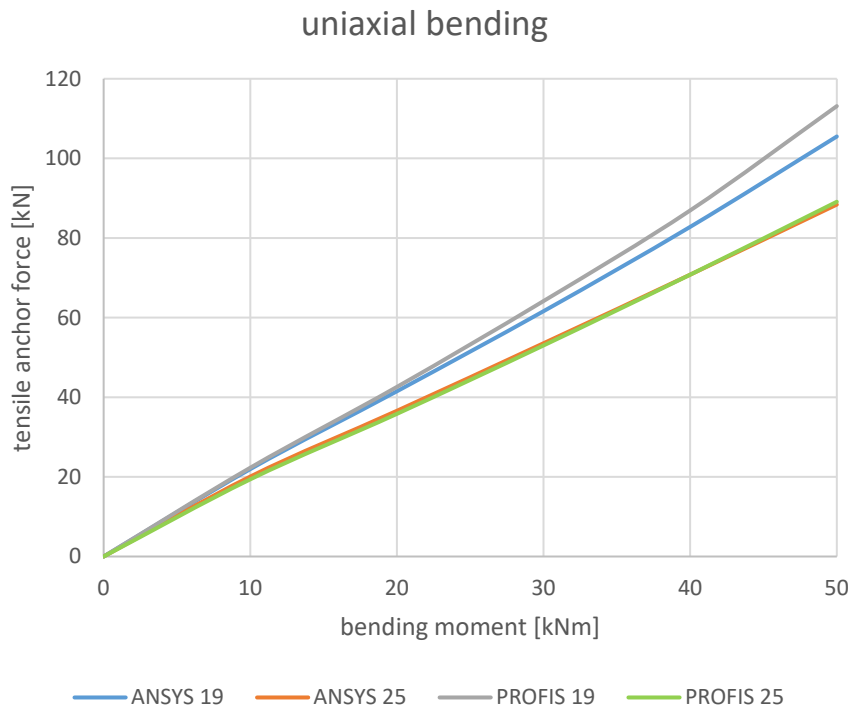


Figure 25: influence of uniaxial bending moment on the anchor force in ANSYS and PROFIS

In the case of uniaxial bending, PROFIS and ANSYS lead to nearly identical results for a base plate thickness of 25 mm. For the thinner base plate, the results start to differ from a moment of 20 kNm. The maximum difference is of about 8 kN and stays below 10%.

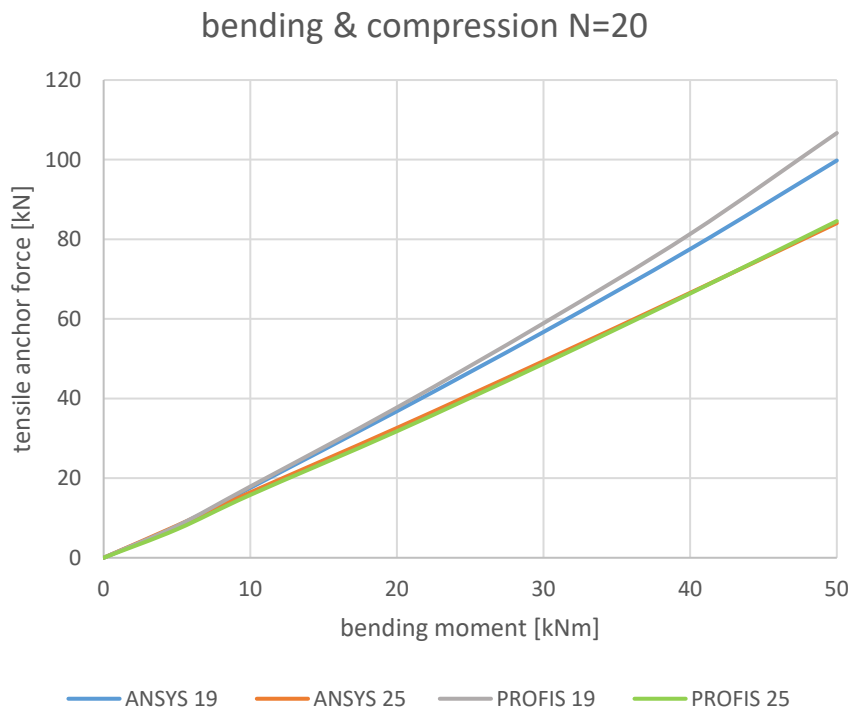


Figure 26: influence of uniaxial bending moment and compression force (20 kN) on the anchor force in ANSYS and PROFIS

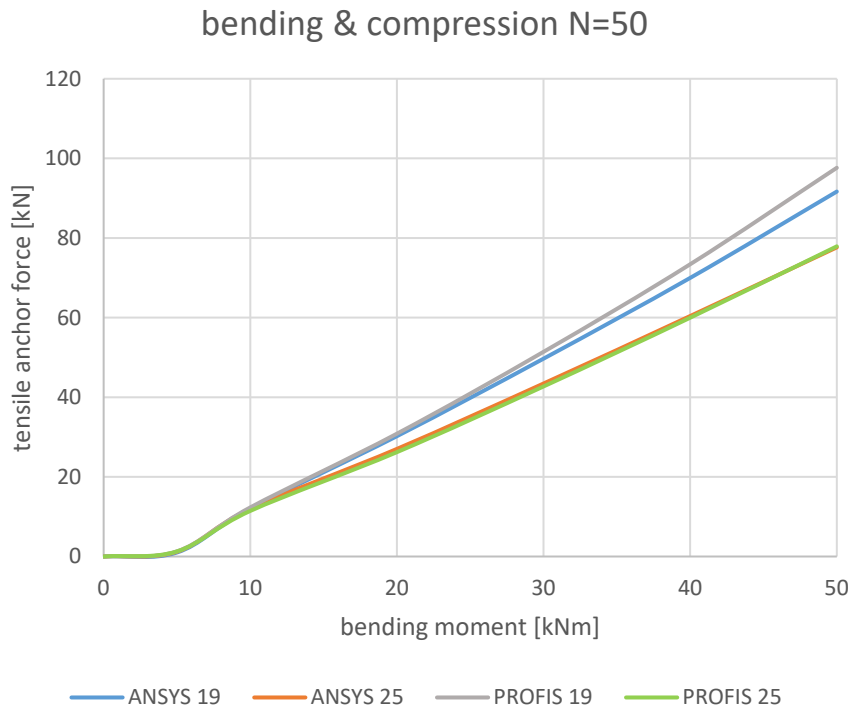


Figure 27: influence of uniaxial bending moment and compression force (50 kN) on the anchor force in ANSYS and PROFIS

The same behavior like for uniaxial and biaxial bending can be observed for bending in combination with compression. In this case the maximum difference in the anchor force lies between 6 and 7 kN.

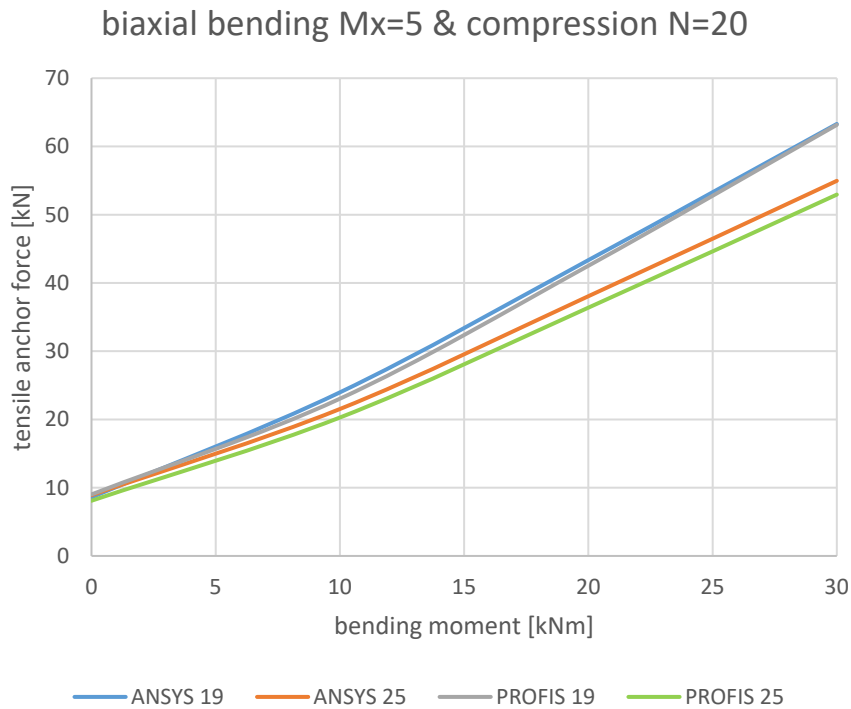


Figure 28: influence of biaxial bending moment and compression force (20 kN) on the anchor force in ANSYS and PROFIS

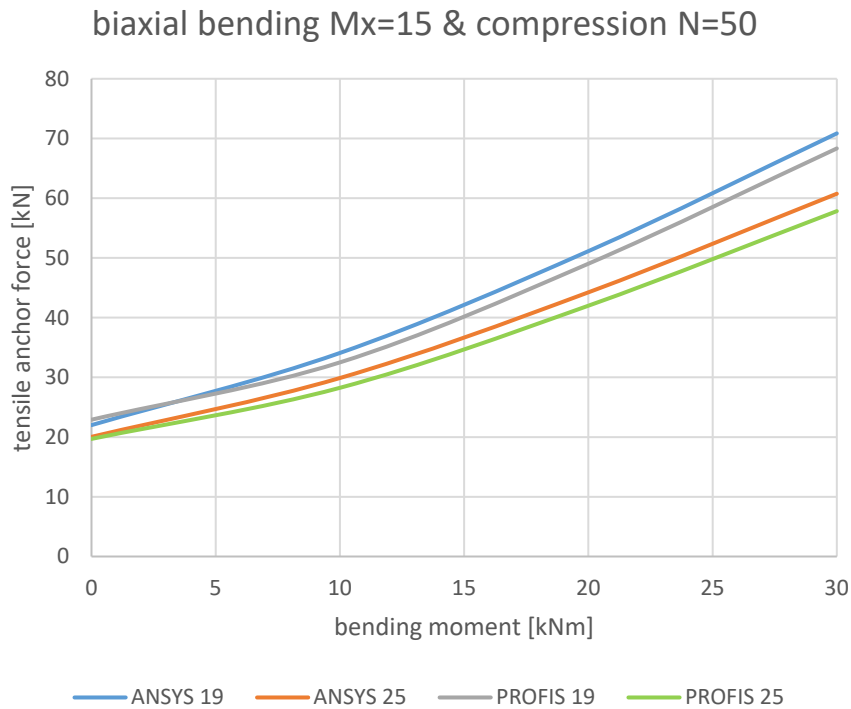


Figure 29: influence of biaxial bending moment and compression force (50 kN) on the anchor force in ANSYS and PROFIS

In the following figures and table, the stress distribution in the base plate and the concrete for the biggest bending moment are visualized.

Table 5: results for the biaxial bending scenario with $t_{bp} = 25 \text{ mm}$ and $M_y = 50 \text{ kNm}$, $M_x = 15 \text{ kNm}$, $N = -50 \text{ kN}$

result	unit	PROFIS fillet weld	ANSYS fillet weld
anchor force	[kN]	68,3	70,9
equiv. stress	[N/mm ²]	192	228
equiv. plastic strain	[%]	0	0,16
pressure concrete	[N/mm ²]	7	12
deformation	[mm]	0,5	1,9

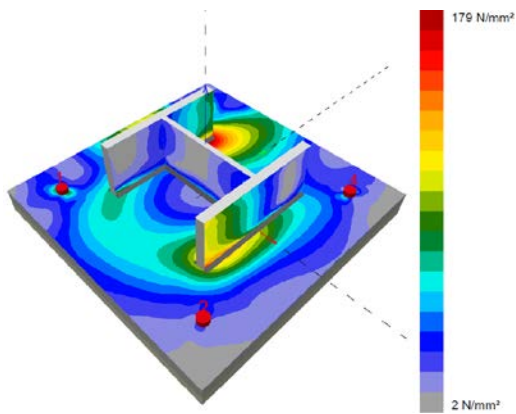


Figure 30: equivalent stress for biaxial scenario in PROFIS

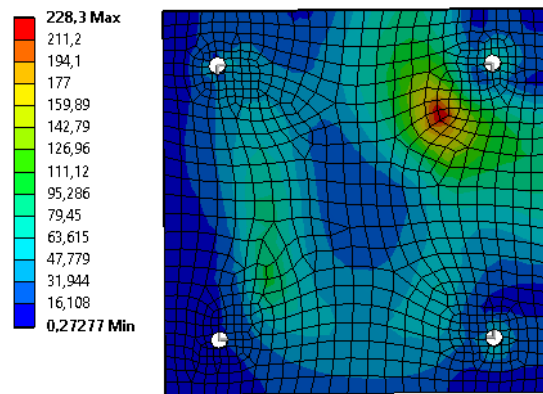


Figure 31: equivalent stress for biaxial scenario in ANSYS

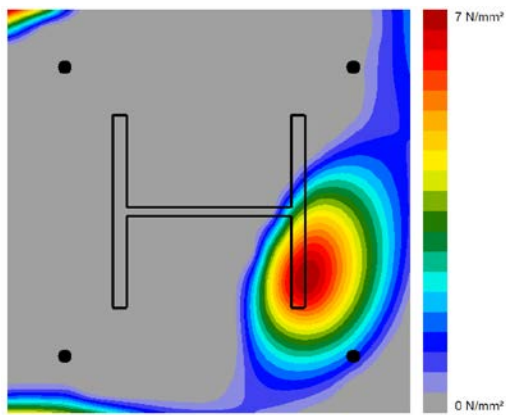


Figure 32: pressure in concrete for biaxial scenario in PROFIS

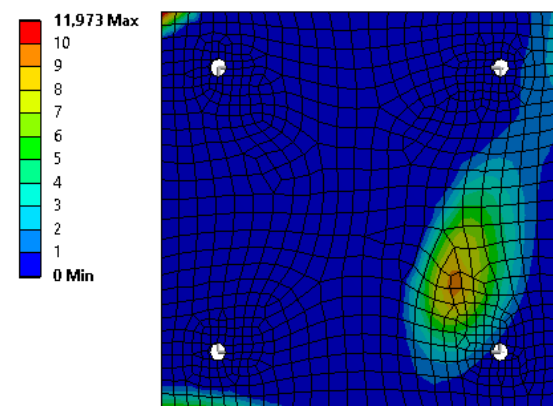


Figure 33: pressure in concrete for biaxial scenario in ANSYS

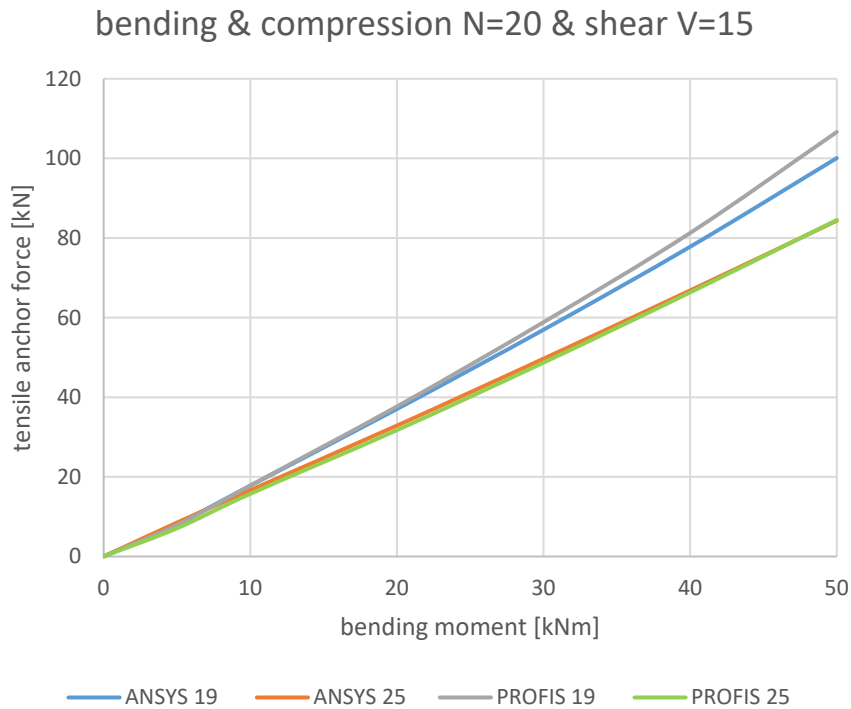


Figure 34: influence of bending moment, compression force (20 kN) and shear on the anchor force in ANSYS and PROFIS

For the scenario of bending moment, compression and shear, the observed trend is equal to the one found for uniaxial bending.

Table 6: results for the biaxial bending scenario with $t_{bp} = 19 \text{ mm}$ and $M_y = 50 \text{ kNm}$, $N = -20 \text{ kN}$, $V = 15 \text{ kN}$

result	unit	PROFIS fillet weld	ANSYS fillet weld
anchor force	[kN]	106,6	100,1
equiv. stress	[N/mm ²]	236	236,5
equiv. plastic strain	[%]	0,3	1,4
pressure concrete	[N/mm ²]	22	27,9
deformation	[mm]	3,7	1,6

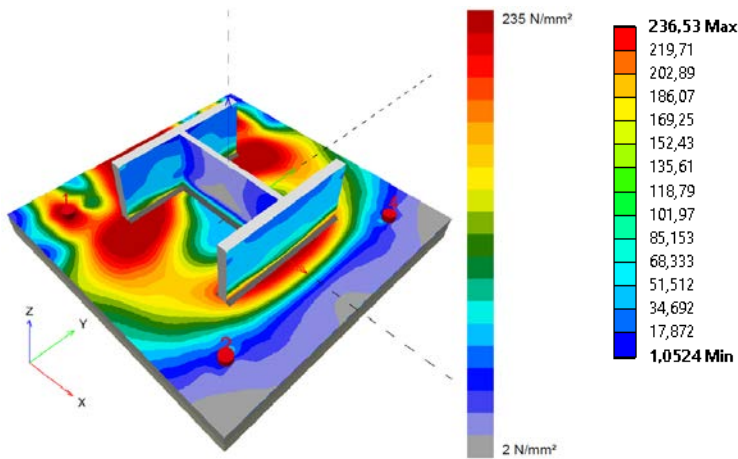


Figure 35: equivalent stress for shear scenario in PROFIS

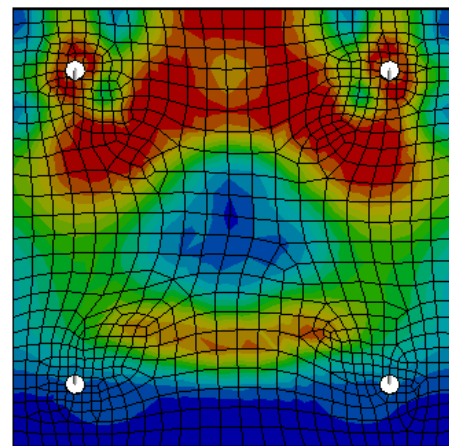


Figure 36: equivalent stress for shear scenario in ANSYS

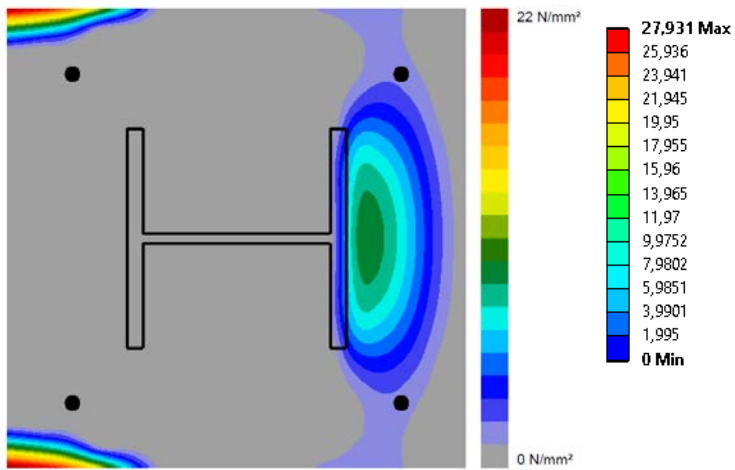


Figure 37: pressure in concrete for shear scenario in PROFIS

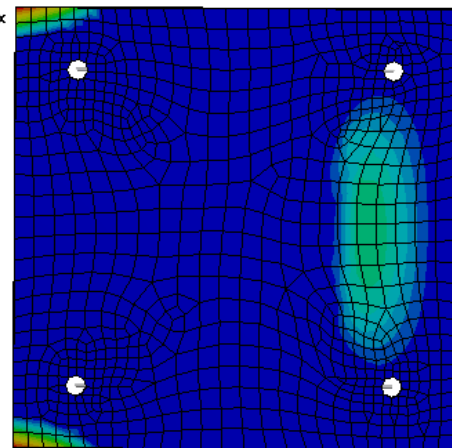


Figure 38: pressure in concrete for shear scenario in ANSYS

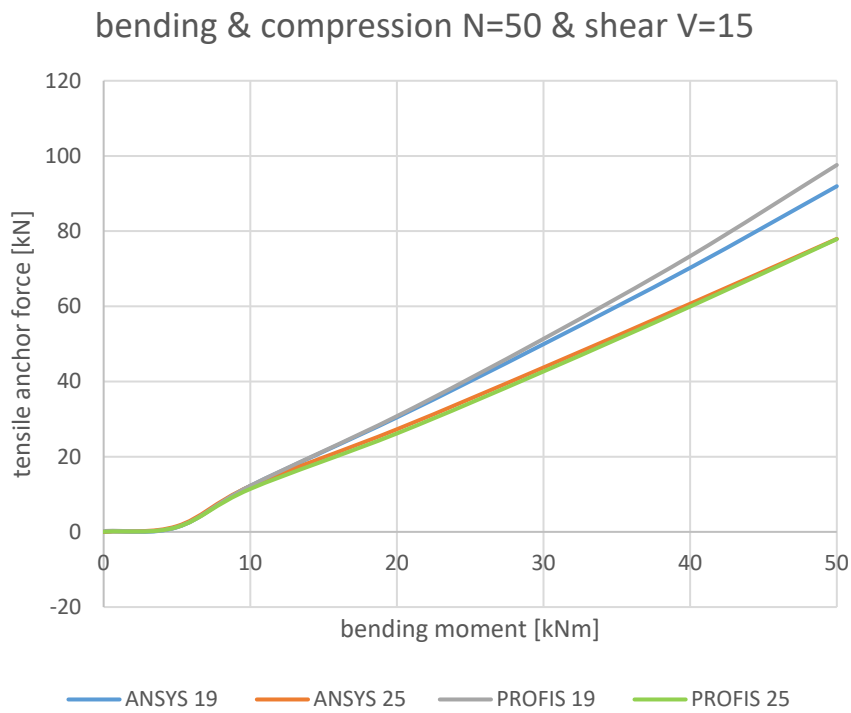


Figure 39: influence of bending moment, compression force (50 kN) and shear on the anchor force in ANSYS and PROFIS

6. Summary and Conclusions

This report documented a series of comparative finite element calculations with the software PROFIS and ANSYS, carried out with the aim of validating the FEM implementation in PROFIS against benchmark cases developed with a high-end commercial FEM software package, in order to identify any discrepancies and to qualitatively assess their significance.

The calculations lead to the following conclusions:

- When comparable modelling techniques are used, PROFIS and ANSYS lead to very similar results for the anchor forces, overall distribution of concrete compression forces and global deformations in the base plate. Differences in the anchor forces are consistently below 10%.
- Locally, higher differences may occur in the regions where prying forces are present: concrete stresses and plastic strains may differ significantly in percentage terms. However, these strain and stress values are extremely localized, extending only very partially over a single element. In ultimate limit state design, this type of discrepancy may generally be ignored.

Neubiberg, September 2018

Prof. Dr. Andreas Taras
Project leader

Mayra Hoppstädter M.Sc.
Consultant

Literature

[1] ANSYS Inc., ANSYS User's Manual, 2018.

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