FINITE ELEMENT ANALYSIS OF AN ANCHOR BASE PLATE

FINITE-ELEMENTE-ANALYSE EINER ANKERPLATTE

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SUMMARY

Finite Element (FE) analysis are being increasingly used to compute the realistic response of an anchor base plate or to estimate the load distribution an anchor group configuration. The anchors are modelled as springs for such a FE analysis. But the modelling approach for anchor base plate and the profile may vary depending on the aim of the analysis, designer's preferences, and the FE analysis tool (software). Hence, depending on the choice of modelling approach different designers can make different sets of assumptions and thus, will end up modelling the same problem using different types of elements. It is here where the question arises do all models deliver the same result? What is the expected scatter just because of modelling approaches? The presented study provides an answer to these questions with the help of an example comparing four different modelling approaches.

ZUSAMMENFASSUNG

Finite-Elemente-Analysen (FE) werden zunehmend eingesetzt, um das realistische Verhalten einer Ankerplatte zu berechnen oder die Lastverteilung in einer Gruppenkonfiguration zu ermitteln. Die Anker werden bei einer solchen FE-Analyse als Federn modelliert. Der Modellierungsansatz für die Ankerplatte und das Profil kann jedoch je nach Ziel der Analyse, den Präferenzen des Ingenieurs und dem FE-Analyseprogramm variieren. Je nach Wahl des Modellierungsansatzes treffen verschiedene Ingenieure unterschiedliche Annahmen und dadurch werden dieselben Probleme mit unterschiedlichen Elementtypen modelliert. An dieser Stelle stellt sich die Frage, ob alle Modelle das gleiche Ergebnis liefern? Wie groß ist die erwartete Streuung aufgrund der Modellierungsansätze? Anhand eines Beispiels liefert die vorliegende Studie eine Antwort auf diese Fragen, in dem vier verschiedene Modellierungsansätze verglichen werden.

1. INTRODUCTION

In the last decade(s) a lot of advances have been made in the field of computations and simulations. Its not only the hardware which has become significantly faster over the years but it's also the numerical techniques which have significantly advanced. These advancements have led to a significant increase in the use of simulations in various fields of structural engineering. This increased used of simulation / numerical techniques has in turn increased the confidence and general acceptance of numerical techniques within the research and design communities. Keeping up with the general trend in civil and structural engineering, the use of simulations has also increased in the fastening technology.

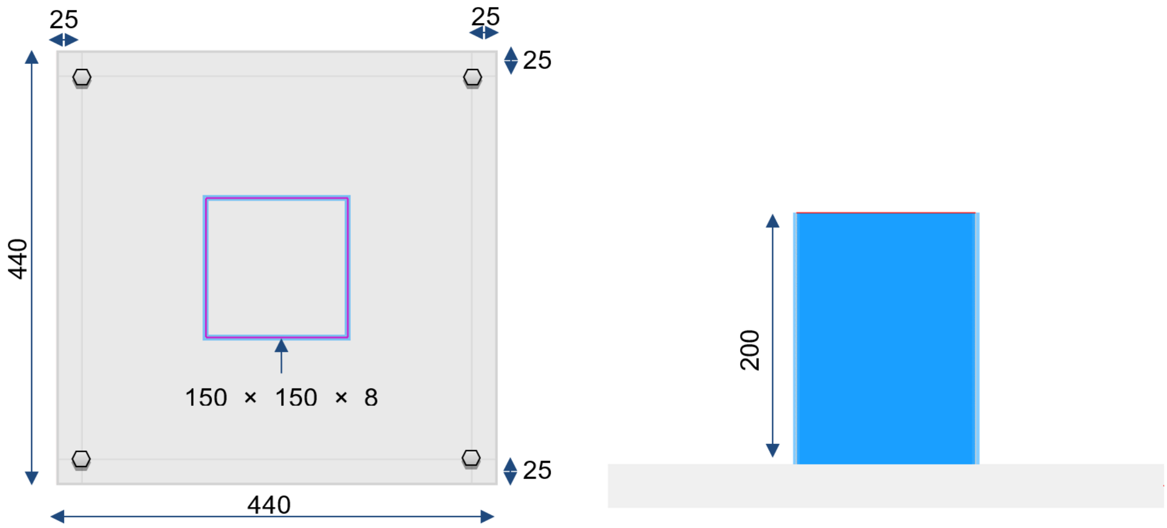
There is no doubt that the computational power has increased over the years, the computers have become faster and can now handle bigger problems, but this does not necessarily mean that we should not make efforts to optimise our numerical models. It would be logical to consider models with different levels of complexity and computational demands for different requirements. For instance, when the global response of a structural is to be evaluated beam & shell elements would be more efficient as compared to solid elements and when a local phenomenon like bond in end anchorage zone is to be investigated solid elements (or may be combination of solid elements with other element types) would be a preferred choice.

Furthermore, there are more tools available to the designers as were in the past. This on one-hand increases the modelling possibilities but on the other-hand may also confuse the designer who might not always have an expertise in Finite Element (FE) analysis. Moreover, in absence of recommendations or guidelines on what a model should consider (minimum requirements) or on the modelling procedure to be followed for a particular problem. The situation might become more complicated, raising questions on the influence of various assumptions or simplifications made to develop a FE model on the predicted results.

The paper presents a numerical investigation conducted using general purpose Finite Element program Ansys®[1], with an aim to compare different modelling approaches which may be used to model the realistic response of a base plate using linear springs for anchors. Furthermore, the presented results help to draw general conclusion with respect to the modelling procedure for base plates using different element types (Solids, Shells, Solid + Beams, Shell + Beams).

2. NUMERICAL INVESTIGATION

To investigate the effect of different modelling approach on the calculated anchor forces and stresses in the base plate, an anchor connection consists of a square Base Plate (BP) with side 440 mm and thickness of 35 mm is selected. A steel profile centrally connected to the base plate is a box profile with dimensions of 150 × 150 × 8 mm. The geometric details and the position of anchors, as shown in Fig. 1 are kept same for all simulations.



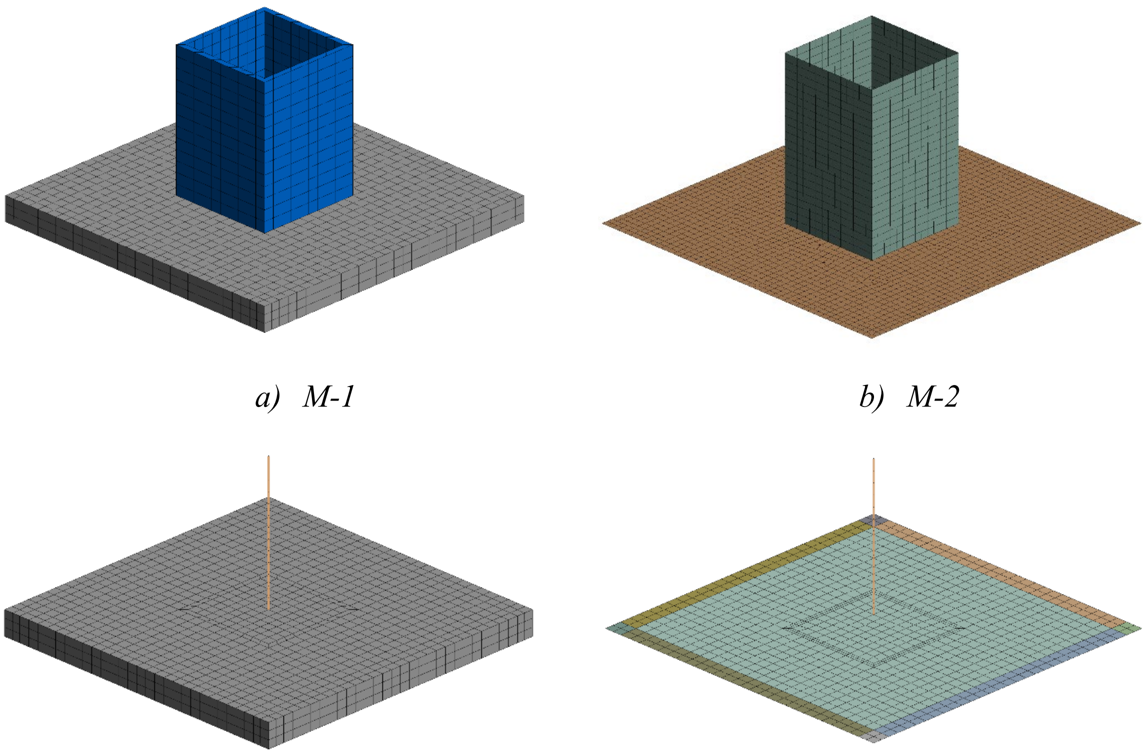
a) Top View *b) Side View*

Fig. 1: Geometric details of the base plate (All dimensions in mm)

The most used Finite Elements, i.e., solid element, shell elements and beam elements are grouped to yield four different modelling approaches, shown in Fig. 2, which may be chosen by the user (of a FE program) or designer. In this paper these modelling approaches are referred as:

1. M-1: Base plate and the profile both are modelled using solid elements
2. M-2: The base plate and the profile both are modelled using shell elements
3. M-3: The base is modelled using solid elements and the profile is modelled using beam elements
4. M-4: The base is modelled using solid elements and the profile is modelled using beam elements.

The above-mentioned modelling approaches are all foreseeable to be used by different designers depending on one's experience/expertise with different element types. Its common that the designers performing FE analysis as part of their daily design tend to use one type of element more often depending on their design problems, for example beam & shell elements are commonly used for global analysis and solid elements are used to investigate a local problem in detail. Furthermore, there are also situations where the most optimised way to analyse a problem would be modelling different components with different element types. For example, with respect to fastening connections, to analyse the connection – structure interaction the base plate can be modelled using solid or shell elements and the structure members (beams or columns) with beam elements.



a) M-1 *b) M-2*

c) M-3 *d) M-4*

Fig. 2: Discretized view of different modelling approach

2.1 General modelling aspects for all approaches

Certain general aspects of the model which are same for all the models are described in this section.

2.1.1 Applied loads

The connection is subjected to axial tension and biaxial moments as shown in Fig. 3. In the FE models (for all modelling approaches) the load is applied on the top of the box profile.

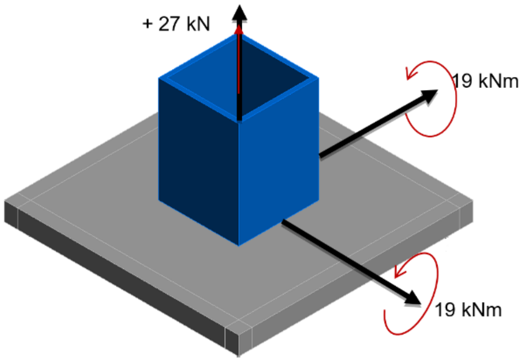


Fig. 3: Loads on the connection

2.1.2 Anchor springs

Each individual anchor in the connection is modelled using 3 individual springs, one along each orthogonal axis, as shown in Fig. 4. The springs represent the axial (under tension) stiffness and shear stiffnesses (in two directions) of the anchor. All springs are linear for this study with an axial stiffness of 100 kN/mm and shear stiffness(es) of 300 kN/mm. The axial spring is modelled as a compression only spring since the anchors are assumed to take tension only and the compression forces are transferred by the base plate to the base material.

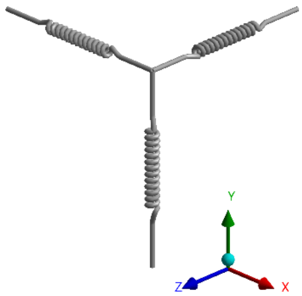


Fig. 4: Anchor springs

It should be noted that even though there are no shear forces acting on the anchor connection, shear springs are needed to prevent rigid body motion and make the model numerically stable.

2.1.3 Bearing action of base plate

The base plate transfers the compressive forces to the base material via bearing action. To model this bearing the complete connection is placed on a rigid body as shown in Fig. 5 and a frictionless contact is defined between the base plate and the rigid body. The contact is modelled using Pure-Penalty formulation in order to have a control over the contact stiffness. This contact stiffness is needed to correctly model the bearing offered by different grades of concrete. Different empirical equations based on different assumptions can be found in literature. These equations vary from extended versions of equations used for calculating the soil springs used for modelling soil-structure interaction [2]to simply equation defining contact stiffness as a factor of concrete strength [3]. In the presented study the base concrete is assumed to be of grade C20/25 and the contact stiffness is taken as 375 N/mm/mm^2 (i.e., $15 \cdot f_{ck,cube}$ as used by Lie, 2018 [3]).

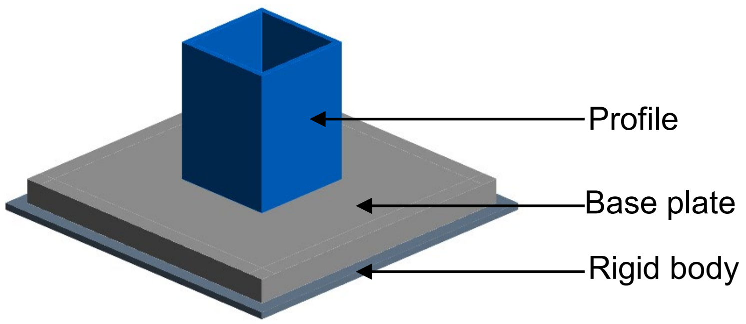


Fig. 5: Geometric components in the FE model

2.1.4 Connection between the profile and the base plate

The connection between anchor plate and box profile was not given any special consideration, for instance, the weld is not modelled. The method / modelling assumption / procedure in which this connection is realised depends on the adopted modelling procedure. For example, for model with solid elements only (M-1) or shell elements only (M-1) a classical direct node to node connectivity can be considered. In other words, the topology between different geometries is shared which implicitly leads to common nodes at shared geometric boundaries. But for modelling approaches where the profile in modelled using beam element (e.g., M-3 & M-4) certain assumptions must be made to correctly model this connection. These assumptions are part of the investigated parameters discussed in next section.

2.1.5 Material model for steel

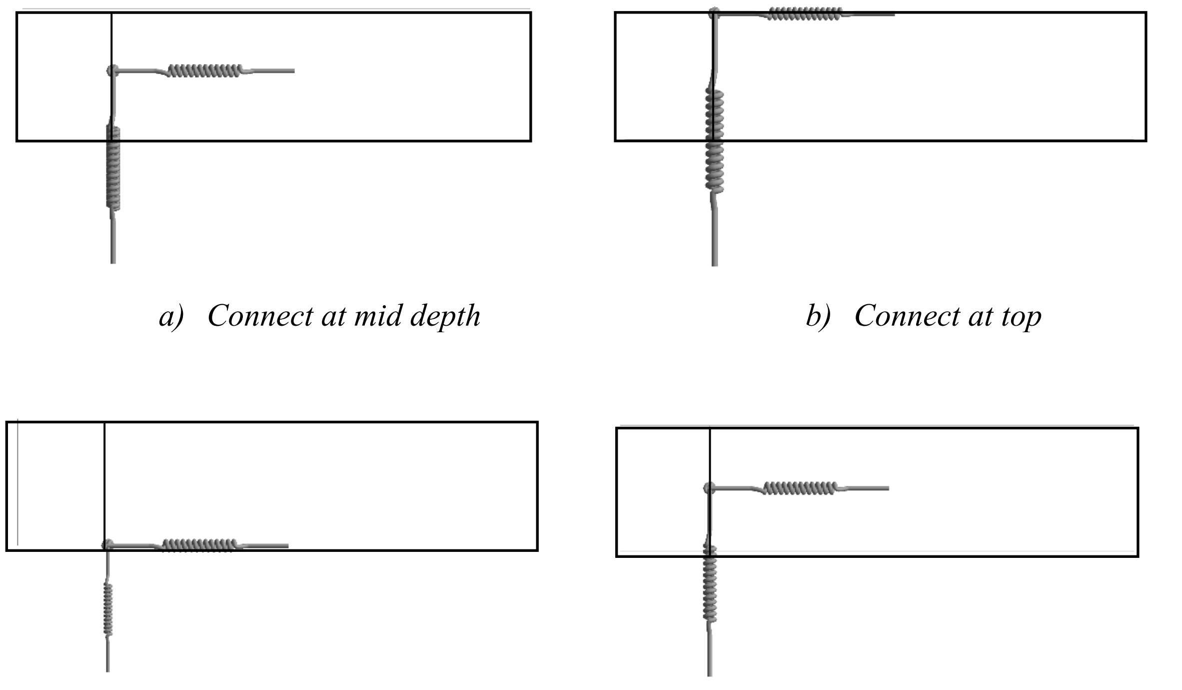
In general, the analysis could also be performed assuming the steel to be linear elastic, if the design criteria is based on the limiting stresses in the base plate. But in certain cases, designer might be interested in non-linear response or ultimate response of the connection. Thus, in such cases steel should be modelling appropriate plasticity model. In the presented study, steel in modelled using bilinear isotropic plasticity model. The steel grade is assumed to be S235 (Yield strength f_y = 235 MPa).

2.2 Investigated aspects for different modelling approaches

Even though the model looks simple, there are number of assumptions which can be or rather have to be made while following different modelling approaches (M-1 to M-4). The assumptions whose influence has been investigated in this study are descripted below.

2.2.1 Modelling approach M-1: Point of connection between the anchor spring and the base plate.

In case of the modelling approach M-1 where the base plate is modelled using 3D solid elements. There are 4 different possibilities to connect the anchor spring to the base plate without giving special attention to the hole for the anchor in the base plate.



a) Connect at mid depth *b) Connect at top*

c) Connect at the bottom *d) Connection to both top and bottom**

Fig. 6: Possible ways of connecting spring to base plate modelling using solid elements
(-Graphically it looks the same as the case where the springs are connected to the middle node. But in this case the displacement that induces force in the anchor is computed based on both top and bottom nodes)*

2.2.2 Modelling approach M-2: Offset surface.

While modelling/idealizing a geometry with shell elements, the shell surface can be defined in 3 different ways i.e., the offset of the shell with respect to the solid geometry. These 3 offset methods, viz., mid surface, top surface and bottom surface as shown in Fig. 7. It should be noted that the box profile was always modelled using mid-surface offset.

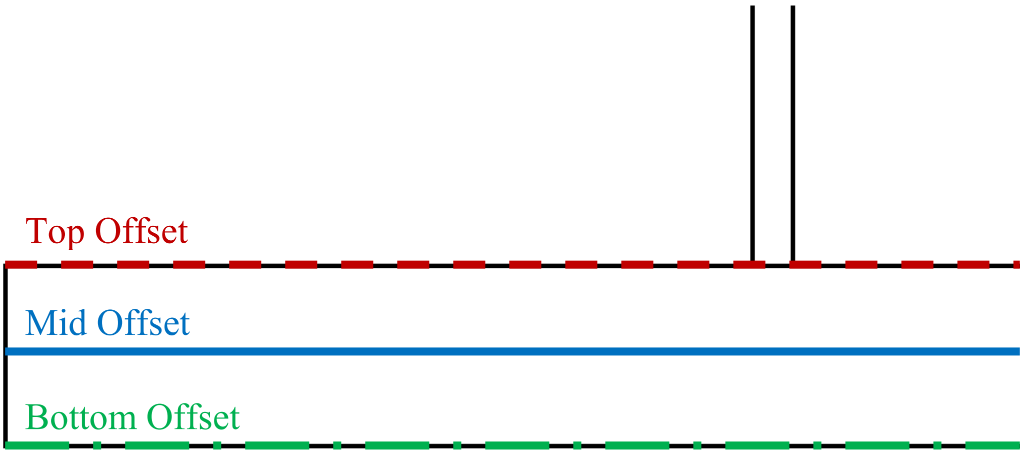


Fig. 7: Possible offset definitions for shell elements

2.2.2 Modelling approach M-3 and M-4: Geometry scoped for connecting the beam element with the base plate modelled using solid or shell elements.

When the box profile is idealised/modelled using beam elements a connection must be defined between the beam and the base plate. The beam profile cannot be connected to a point on the base plate because this would lead to localised stress concentration and incorrect load transfer from the profile to the base plate. A better approach would be to model the profile cross-section geometry on the surface of the base plate and then define a connection between the bottom node of the beam profile and this cross-section geometry (drawn on the base plate). In this study a fixed connection is defined between the beam node (bottom most node close to the base plate) and the cross-section geometry sketched on the base plate. In other words, the deformations from the connecting node of beam are transferred one-to-one to the scoped cross-section geometry. This cross-section geometry can be area or line geometry depending on the choice of modelling assumptions. Therefore, the designer must make assumption about how the profile cross-section geometry is to be idealised on the base plate. As shown in Fig. 8, there are 4 different possibilities viz., draw cross-section with area (between the inner and outer edge), idealised it as lines representing outer, middle, or inner surfaces of the cross-section.

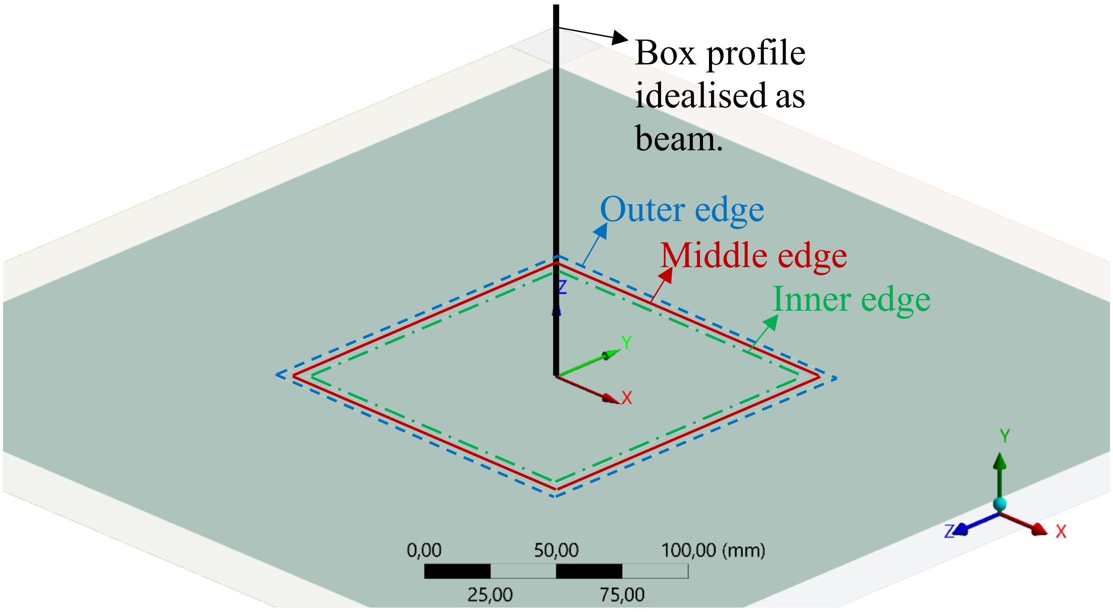


Fig. 8: Possible geometric scoping for modelling approaches M-3 & M-4*

(-Area geometric scoping is not shown in the figure to avoid congestion in the figure. For an area scoping method, the area between the inner and outer edge of the profile is used)*

It should be noted that while investigating this parameter the following other parameters, mentioned below, were kept constant:

1. In M-3 modelling approach the anchor springs are scoped to top and bottom node at respective anchor location.
2. In M-4 modelling approach the shell elements are modelled using mid surface offset.

2.3 Results and discussion

The results of the investigated modelling parameters in terms of the predicted maximum force on the anchor and maximum stresses in the base plate are summarised in Table 1 and shown in Fig. 9.

It is observed that except for the two modelled with modelling approach M-1 (solid elements only) where the anchor springs are attached to the top or bottom node. All models predicted (almost) same maximum anchor force. Hence, it can be concluded that the modelling approach has negligible influence on the computed anchor forces. But the same cannot be said about the maximum stresses in the anchor base plate. Except for the modelling approach M-3 (Solid elements for base plate and beam element for profile) the scatter due to investigated modelling parameters within each modelling group is small.

Table 1: Summary of the results of the investigation

Modelling approach		Investigated parameter	Maximum load on anchor	Maximum stress in the base plate
[-]	No.	[-]	[kN]	[MPa]
M-1	1	Spring connection-Mid node	53.05	244
	2	Spring connection-Top node	47.29	235
	3	Spring connection-Bottom node	47.60	235
	4	Spring connection-Top + Bottom node	53.06	244
M-2	5	Shell with Mid surface offset	53.10	210
	6	Shell with Top surface offset	53.05	206
	7	shell with Bottom surface offset	53.05	204
M-3	8	Scoped geometry for connection: Area	53.21	195
	9	Scoped geometry for connection: Outer edge	53.20	221
	10	Scoped geometry for connection: Middle edge	53.21	248
	11	Scoped geometry for connection: Inner edge	53.21	280
M-4	12	Scoped geometry for connection: Area	53.22	196
	13	Scoped geometry for connection: Outer edge	53.21	186
	14	Scoped geometry for connection: Middle edge	53.22	199
	15	Scoped geometry for connection: Inner edge	53.23	209

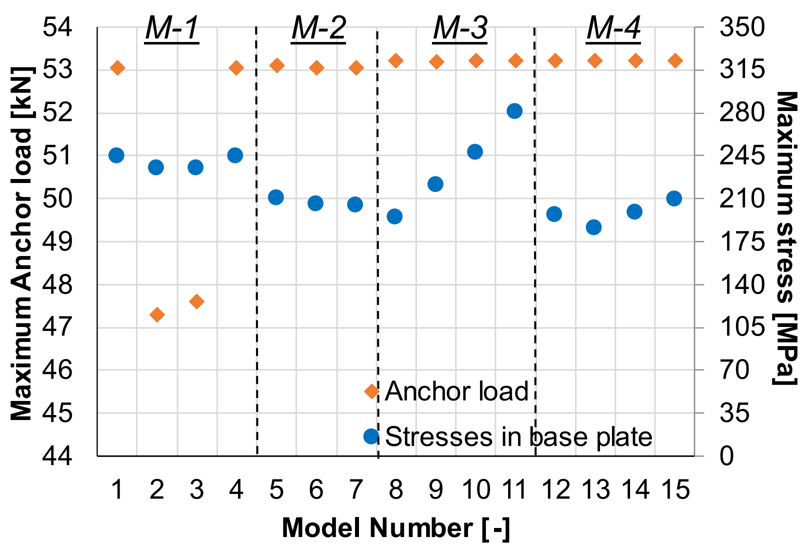
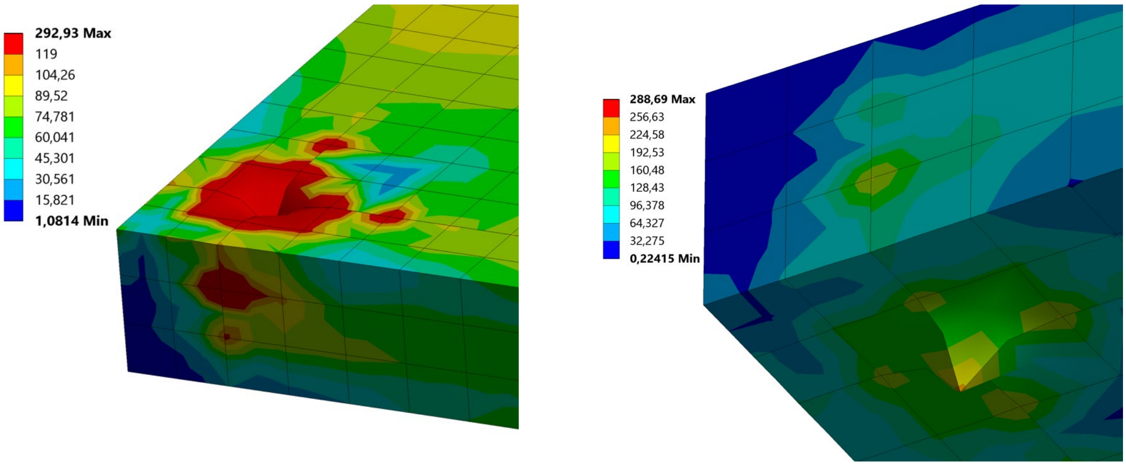


Fig. 9: Calculated maximum force on anchor and stresses in anchor base plate

The stresses in base plate predicted using modelling approach M-1 (model number 2 & 3) and M-3 (model numbers 9 to 11) are higher as compared to all other models because of the stress stresses concentration. The stress concentration at anchor location can also cause error in predicted maximum force on the anchor as is the case with model number 2 & 3. The excessive local deformation due to stress concentration in these models is shown in Fig. 10. In such case extra care should be taken while evaluating the maximum stresses in the base plate and the elements connected to node where the spring is connected should be excluded as shown in Fig. 11.



a) Model number - 2 *b) Model number - 3*

Fig. 10: Excessive deformation at anchor connection due to stress concentration

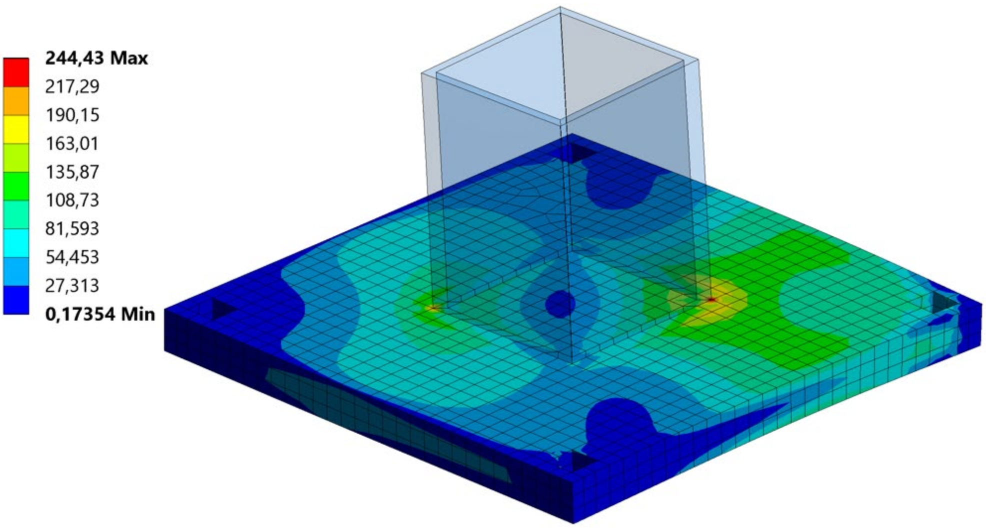


Fig. 11: Stress distribution in base plate (Modelling approach M-1; Model No: 4)

2.4 CONCLUDING REMARKS

The paper presented a comparison of various modelling approached which can be used for modelling the anchor connections including base plate and profile. Based on the presented results, it is found that the computed anchor forces are less sensitive to modelling approaches as compared to the stresses in the base plate. In principle, a designer may opt for any of the modelling approaches and get comparable results, provided appropriate assumptions are made. Some modelling recommendations which can be drawn from the presented results are given below:

1. The stress results of the models with solid elements only (M-1) should be evaluated with caution as they are prone to stress concentration at various connection locations.
2. If the solid elements are required for detailed analysis of certain connection system, the anchor spring connection should be defined using top and bottom nodes of the base plate at the anchor location.
3. In general, for shell elements, any of the three offset approaches may be used.
4. To define a connection between the profile idealised as beam to the base plate modelled using solid or shell elements. It is recommended to sketch the profile cross-section on the base plate surface and scope this sketched cross-section area as the domain which is connected to the vertex/node of the beam element.

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