BOLLFILTER
Protection Systems

Analysis of the stress and load distribution of a bolt with threaded contact modeled in 3D

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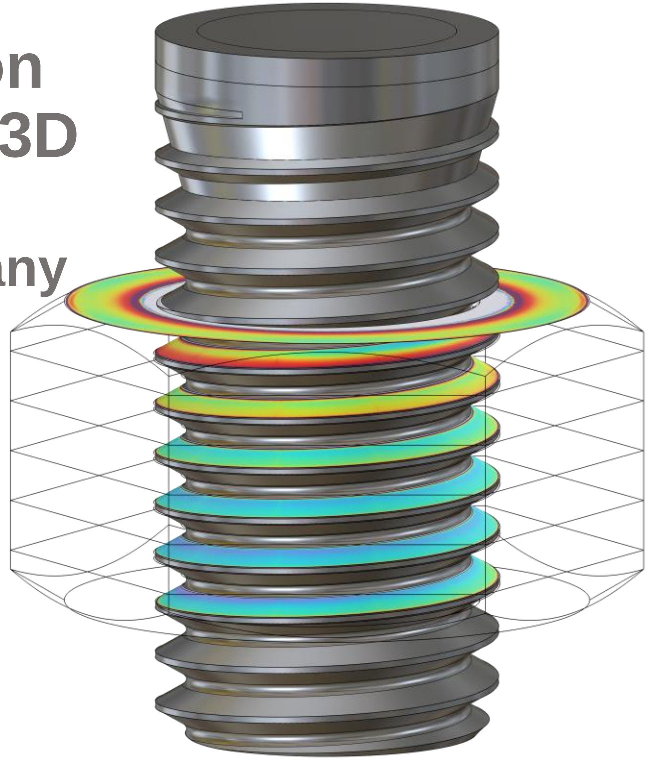

22. Oct. 2024

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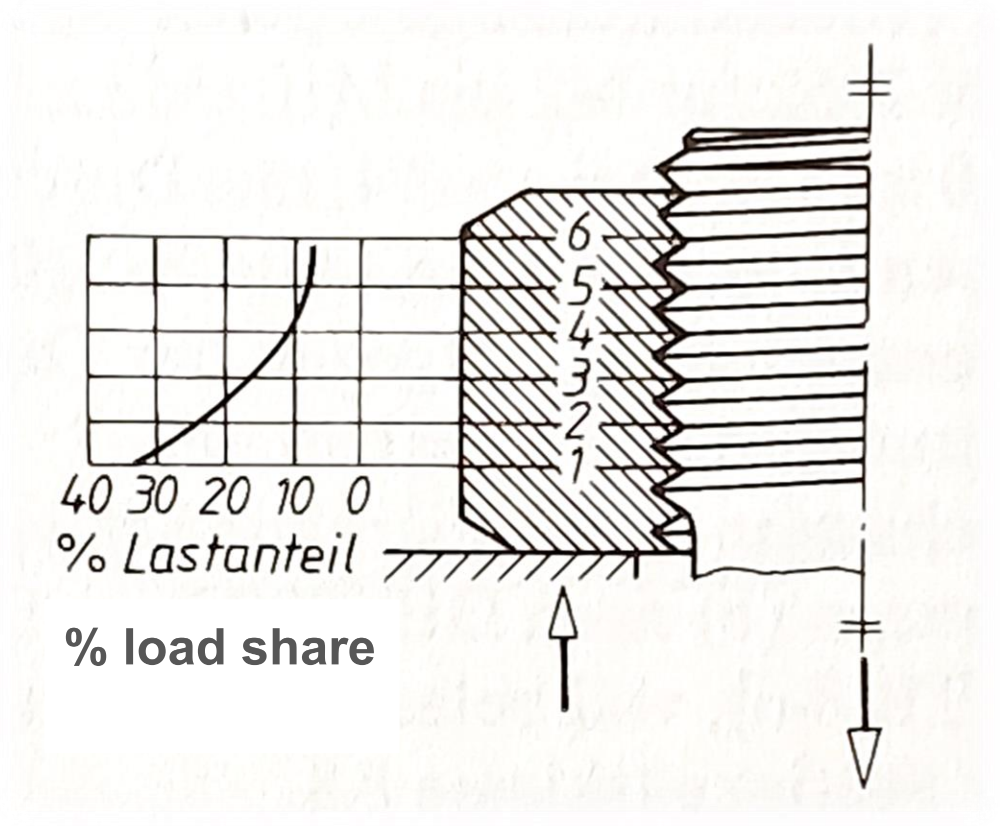
Motivation for this work



Load distribution with load share (in German: „Lastanteil") of a conventional screw [1]

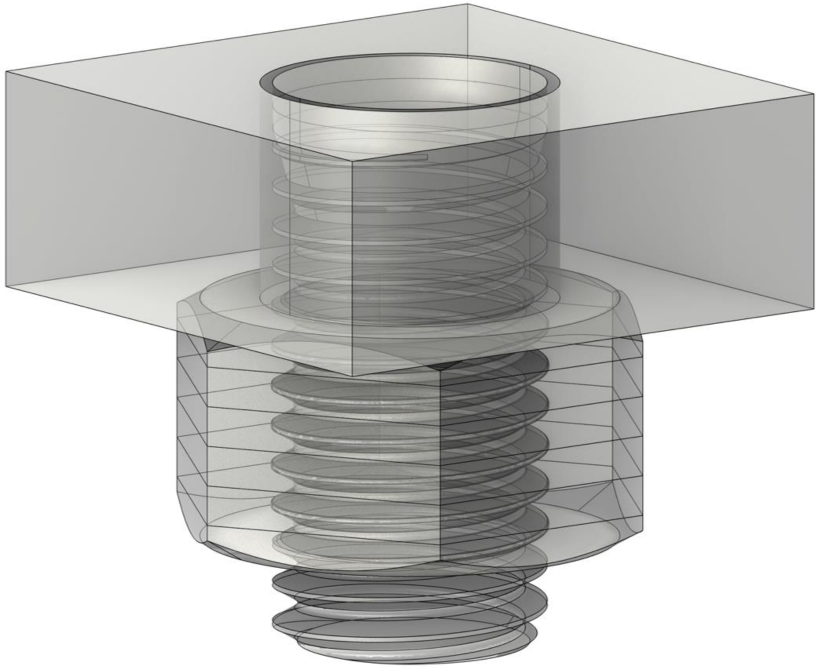
- Related to Roloff/Matek [1] it can be read, that the load share of the first thread is around one third (with in total six engaged threads):

  $\boldsymbol{\varphi \approx 1/3 \approx 0.333 \triangleq 33.3\ \%}$ (see illustration left)

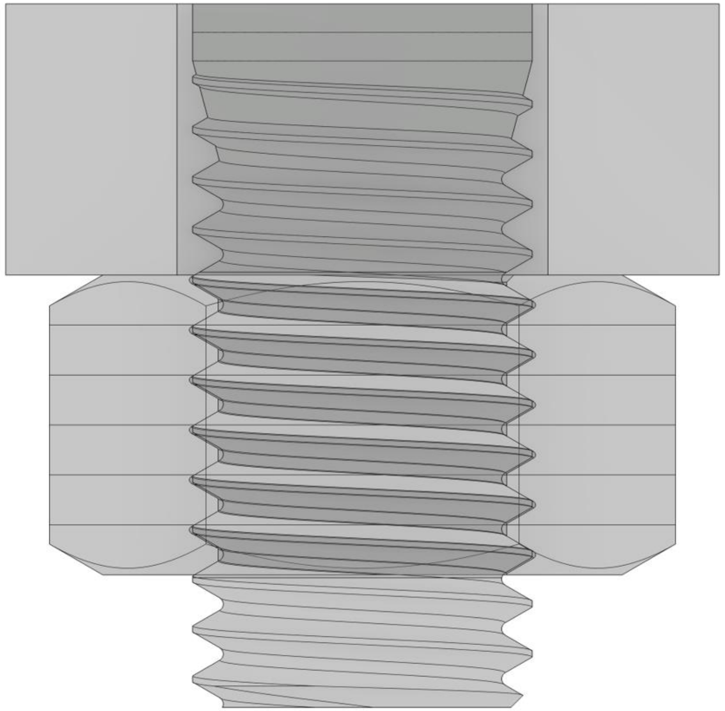
- The averaged load share is $\varphi_{average} = 1/6 \approx 0.167 \triangleq 16.7\ \% \approx 0.5 \cdot 33.3\ \%$
- That means, that the load share of the first thread is about two times larger than the average load share.
- The motivation of this work is to determine the load distribution of the threads in a study that is as accurate as possible using the finite element method (FEM) with the goal of possibly being able to determine a more precise load profile.
- Contact modeling in 3D can be a quite challenging task because of the geometric nonlinearity.

source of [1]: H. Wittel, D. Muhs, D. Jannasch and J. Voßiek, Roloff/Matek Maschinenelemente, 19th ed., Vieweg+Teubner, 2009 (page 228).

CAD / geometry for simulation



System in 3D
in transparent display



System in 3D
in transparent display
(partially in halved view)

- The modeled assembly contains of three bodies and these are:

  - bolt with external thread

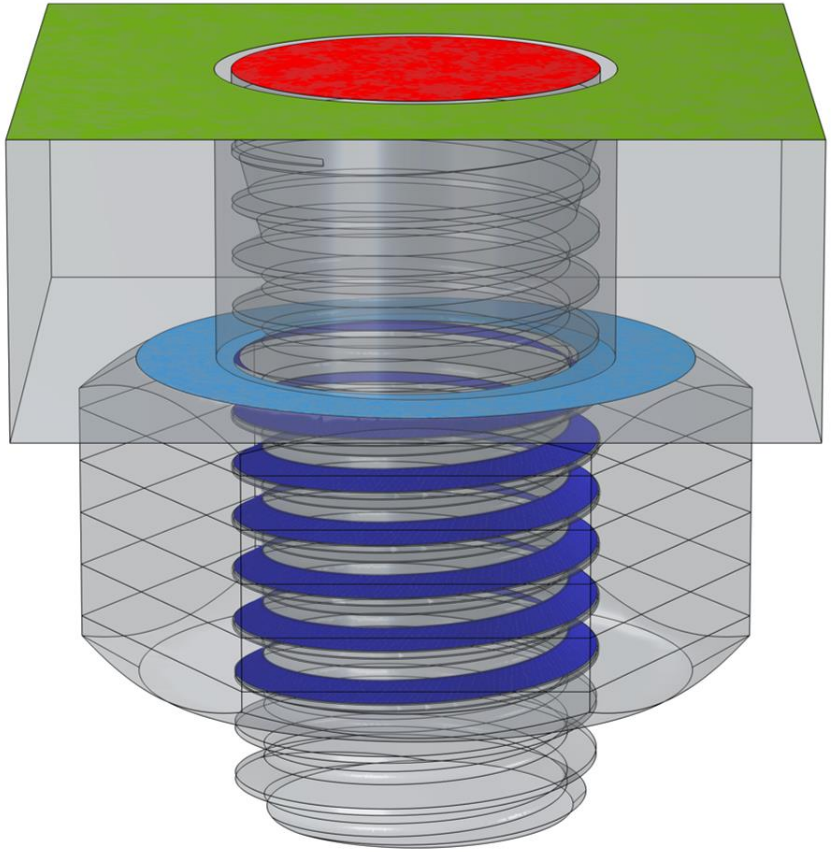
  - screw nut with internal thread
  $\varnothing_{bolt}$ = 11.9 mm (tolerance '6h')

  - Supporting block with through hole
  $\varnothing_{hole}$ = 13 mm

- Precise construction of the thread with core fillets resp. root radii

- Material of all components:
  Steel with
  Young's modulus E = 200 GPa
  density ϱ = 7850 kg/m^3
  Poisson's ratio v = 0.3

Contact pairs and boundary conditions

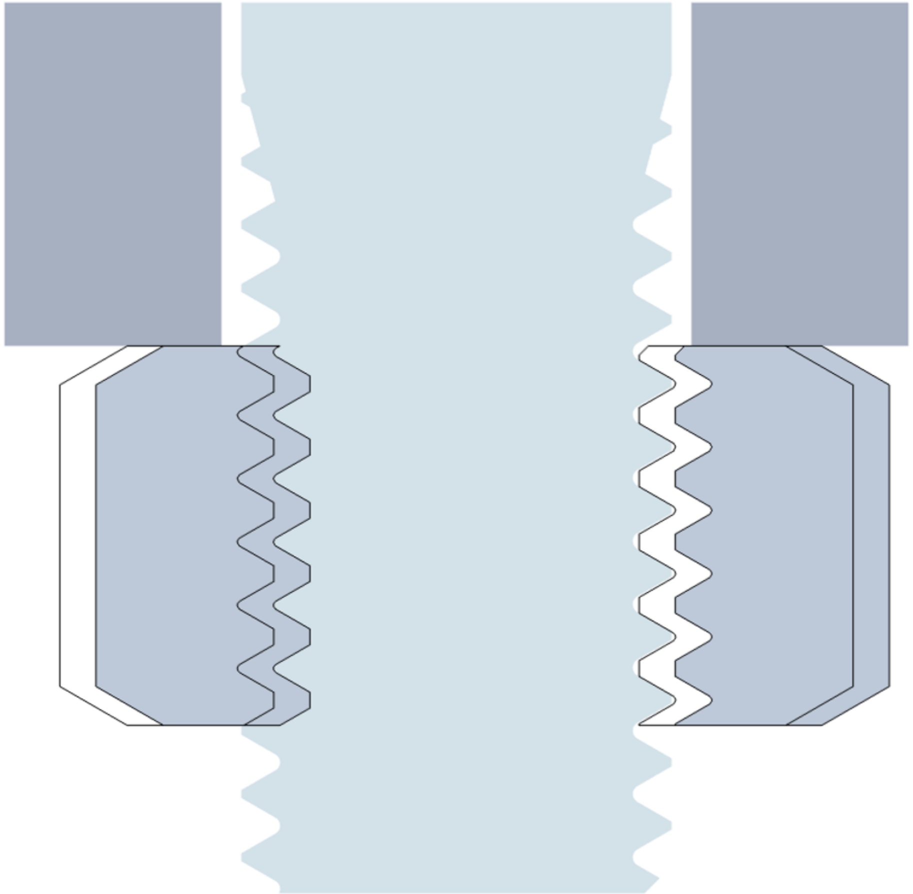


System with coloring of the
mechanical contact pairs
and the boundary conditions

- **Fixation** at the top surface of the support block
- **Force** of $F = 10$ kN
  as load upwards in vertical direction along the axis
- There are two contact pairs:

  - **contact of the nut support**
  - **thread contact**
- Modeling of the contact with the
  Contact Method
  "Augmented Lagrangian"
  as the most precise method

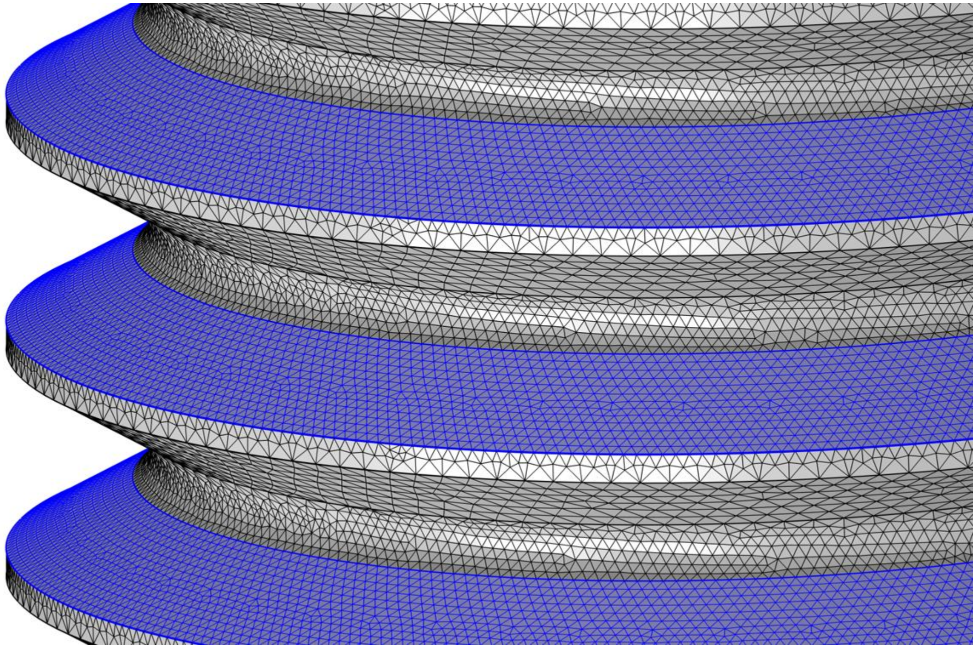
Numerical Stabilization with spring foundation

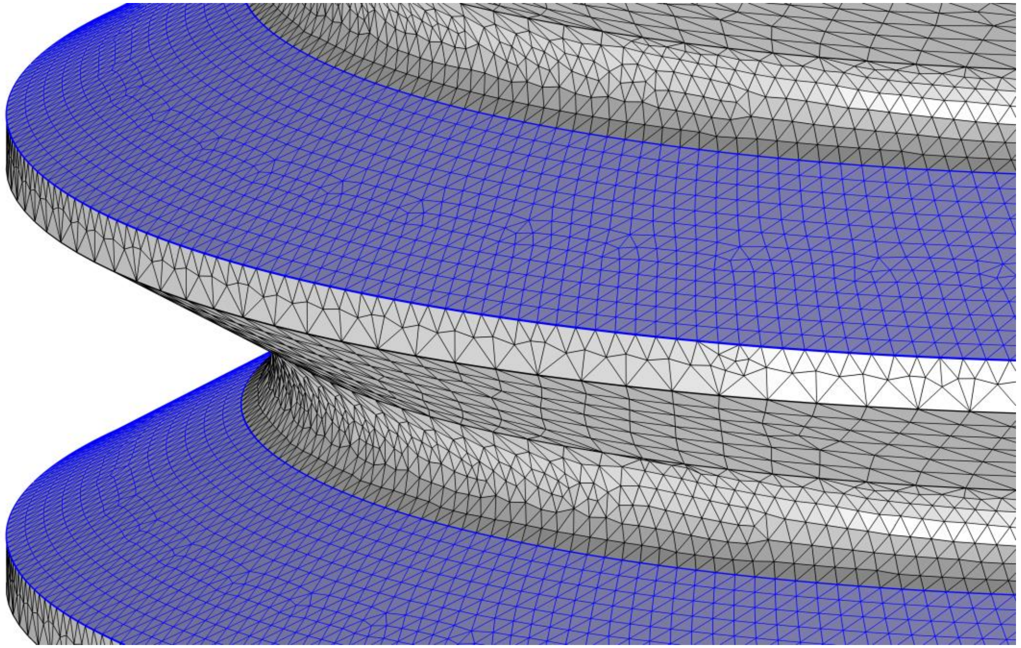


Symbolic image for a possible rigid body motion

- The support block is fixed at one surface (see last slide).
- Bolt & nut are not fully constrained
  unless additional measures are taken.
- A special modeling technique to avoid so called
  Rigid Body Motion
  [in German: „Starrkörperbewegung(en)“]
  has been applied.
- Otherwise bolt and nut can move or rotate,
  although that actually makes no sense.
- A volumetric **spring foundation** has been applied
  to the bolt & nut.
- Using a ramping factor the force is slowly increased while the initially high spring stiffness is reduced.
- A variable spring stiffness using the following formula has been applied:
  k_spring × (1-ramp_fact) × 2^(-ramp_fact × 5)

FE-Meshing at the thread

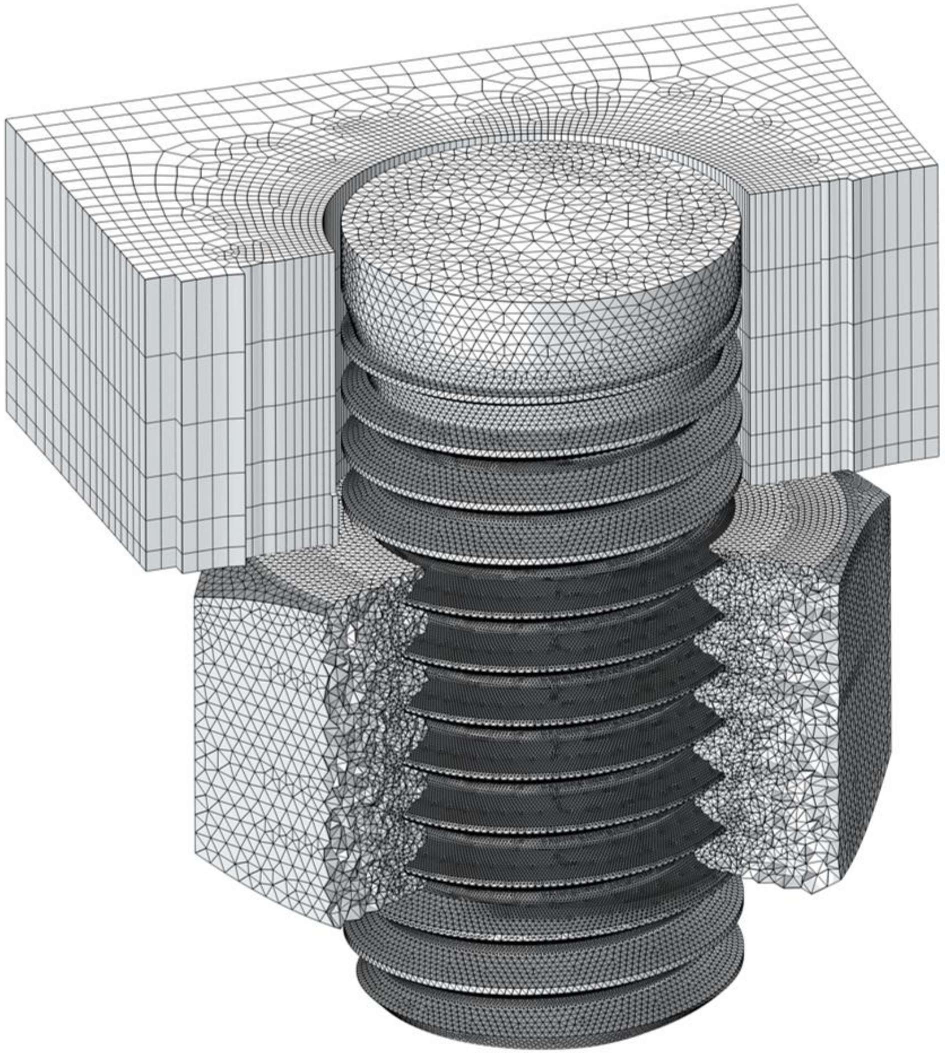


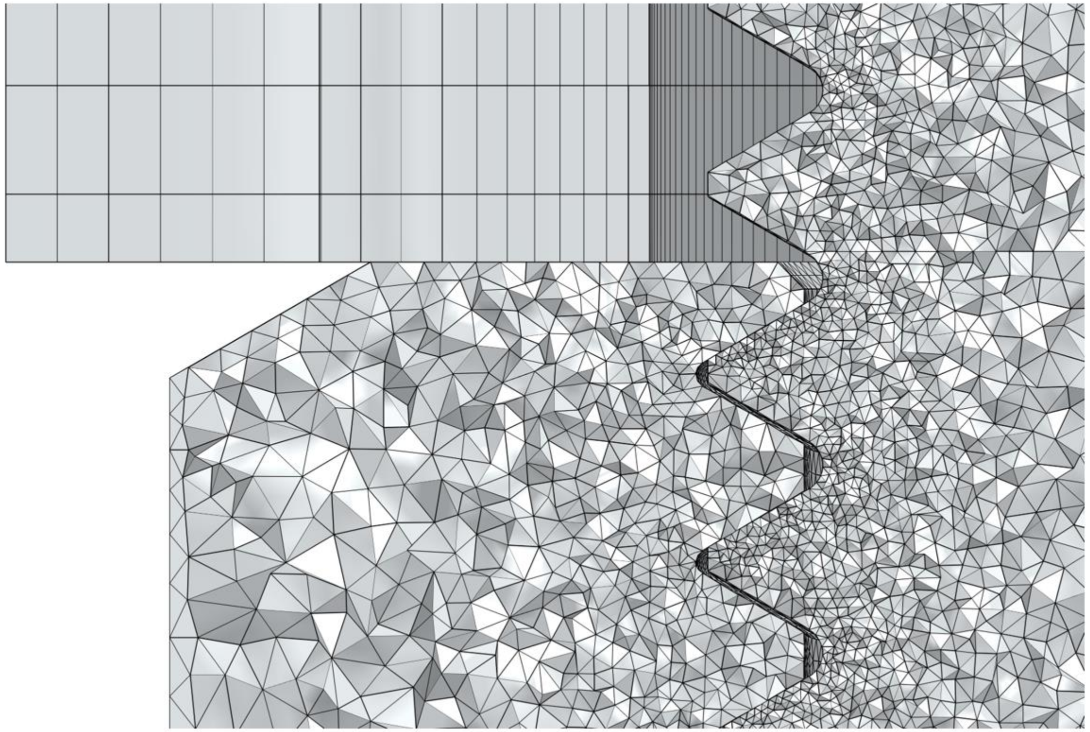


13 elements along the radial width of the thread

- Finite Element Mesh (FE-Mesh) with a number of elements of $n_{\mathrm{FE}} \approx 5.8$ Mio. Elements

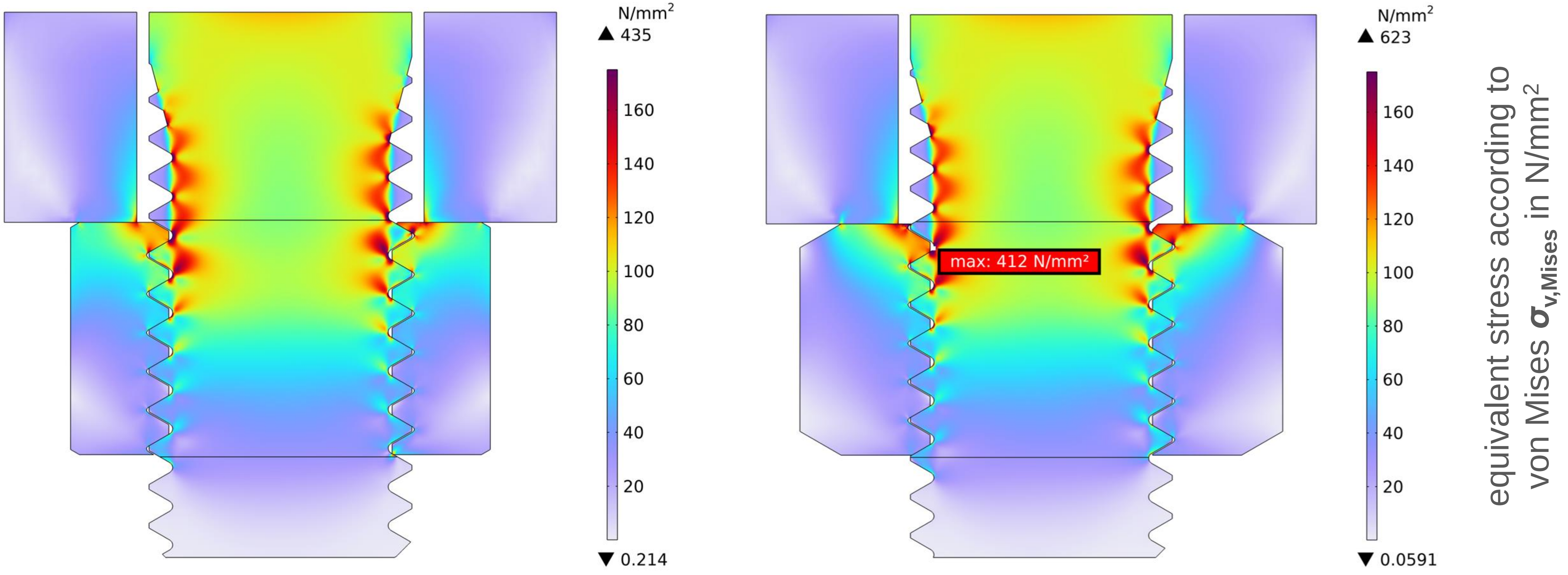
FE-Meshing in total





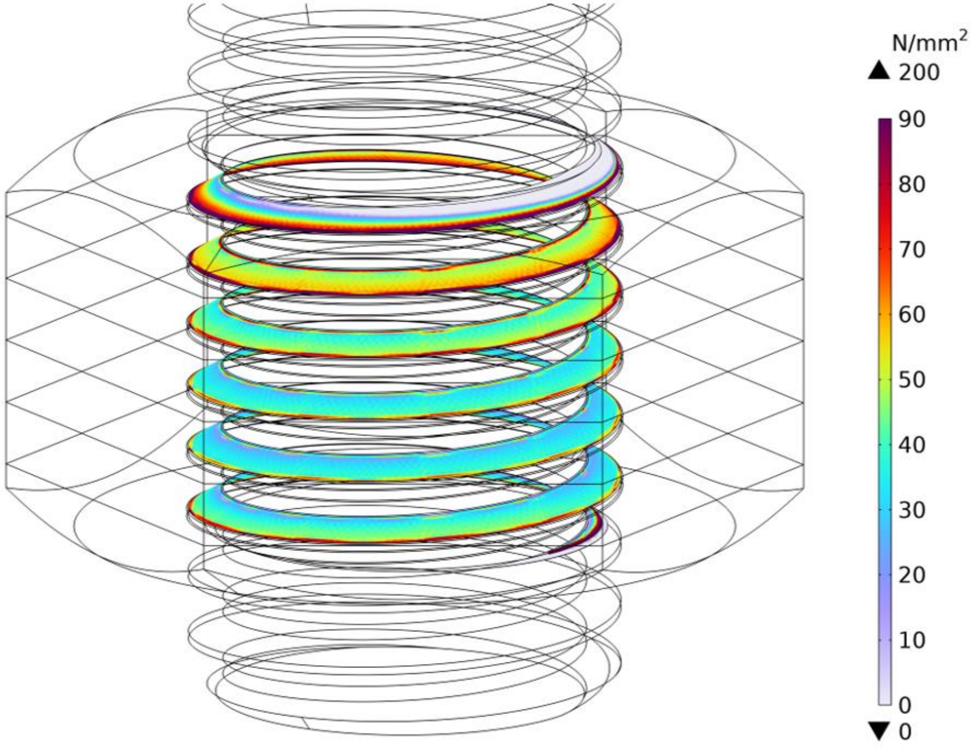
- Finite Element Mesh (FE-Mesh) with a number of elements of $n_{FE} \approx 5.8$ Mio. Elements

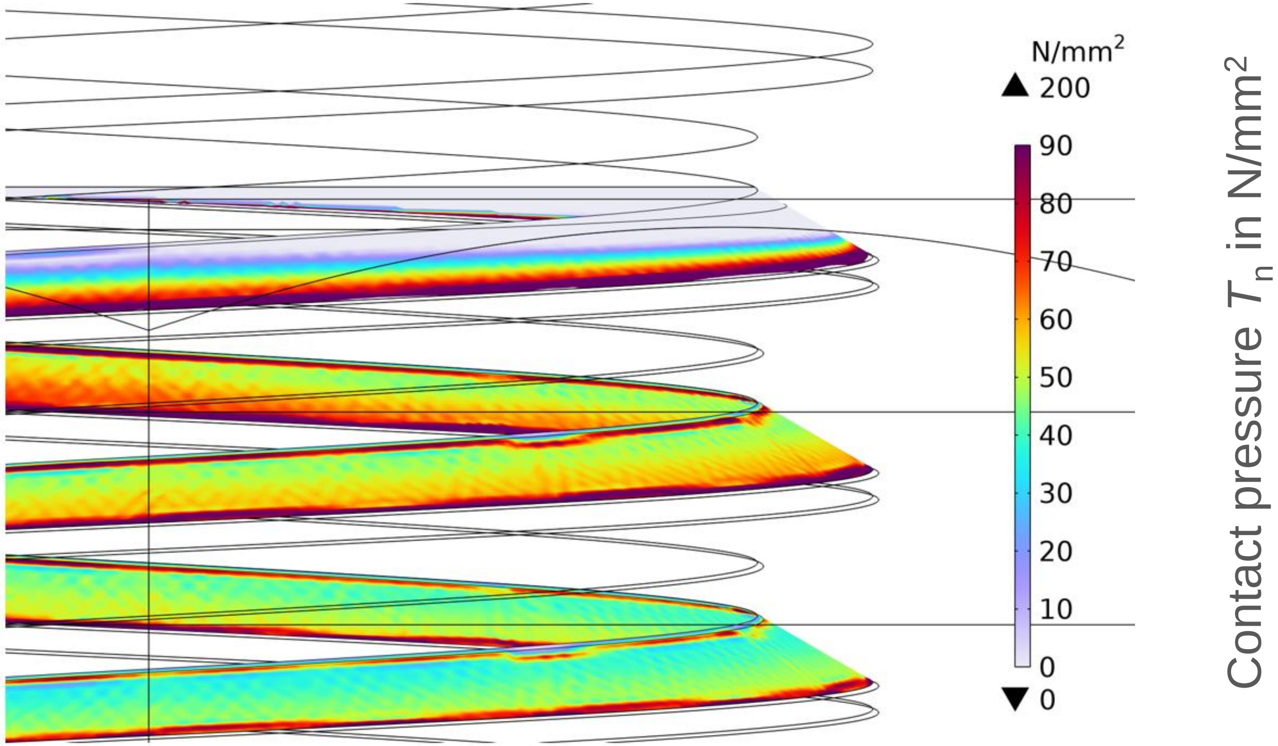
von Mises stress in vertical section views



- As expected, the maximum equivalent stress occurs in the core fillet of the first thread.

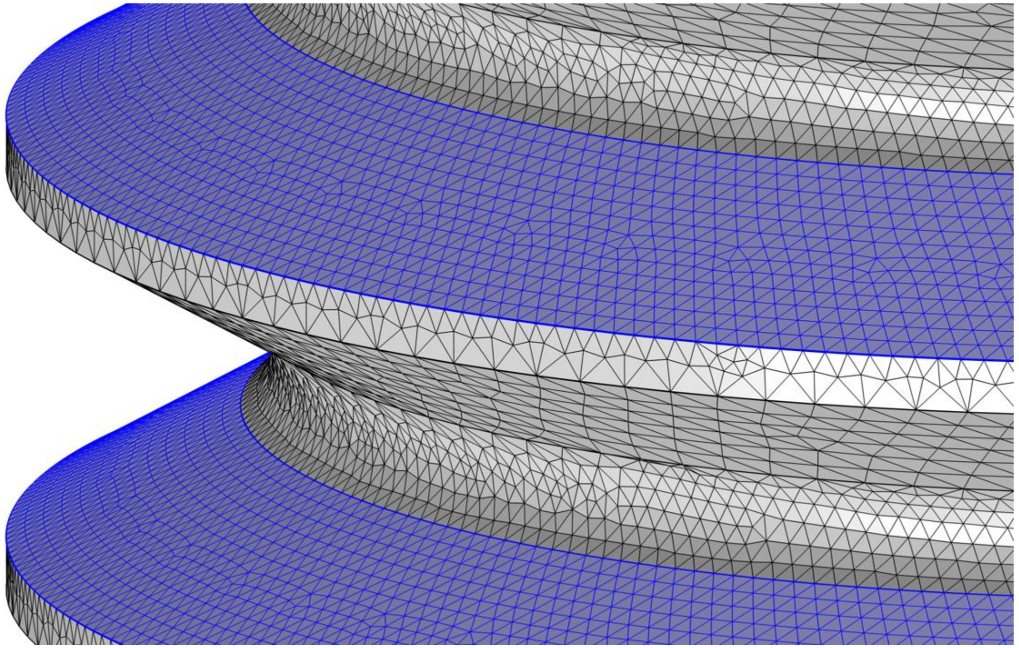
Contact pressure



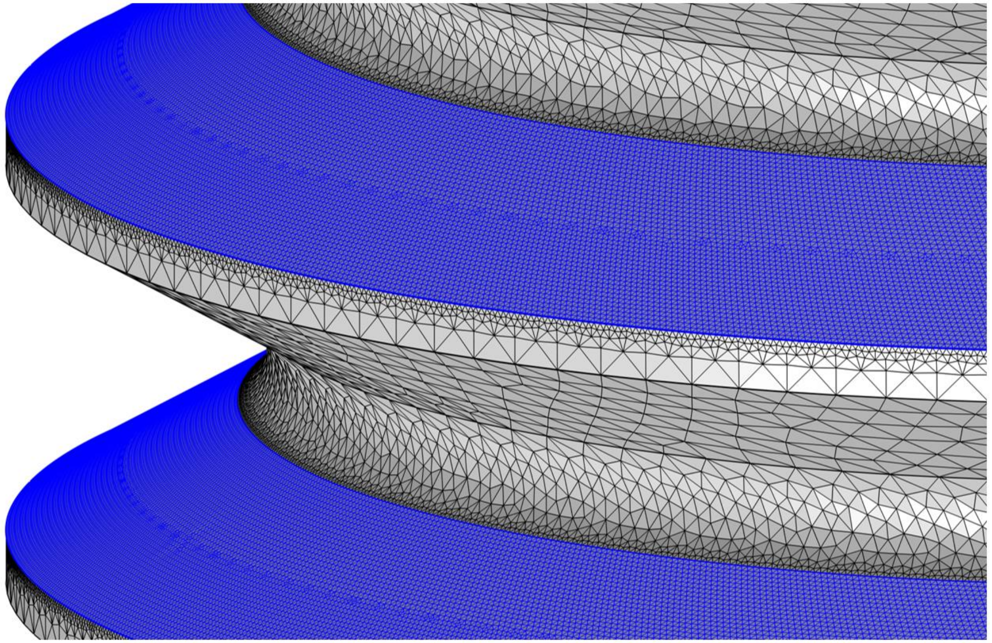


- The resolution of the contact pressure might be finer.

Mesh refinement study



13 elements along the radial width of the thread

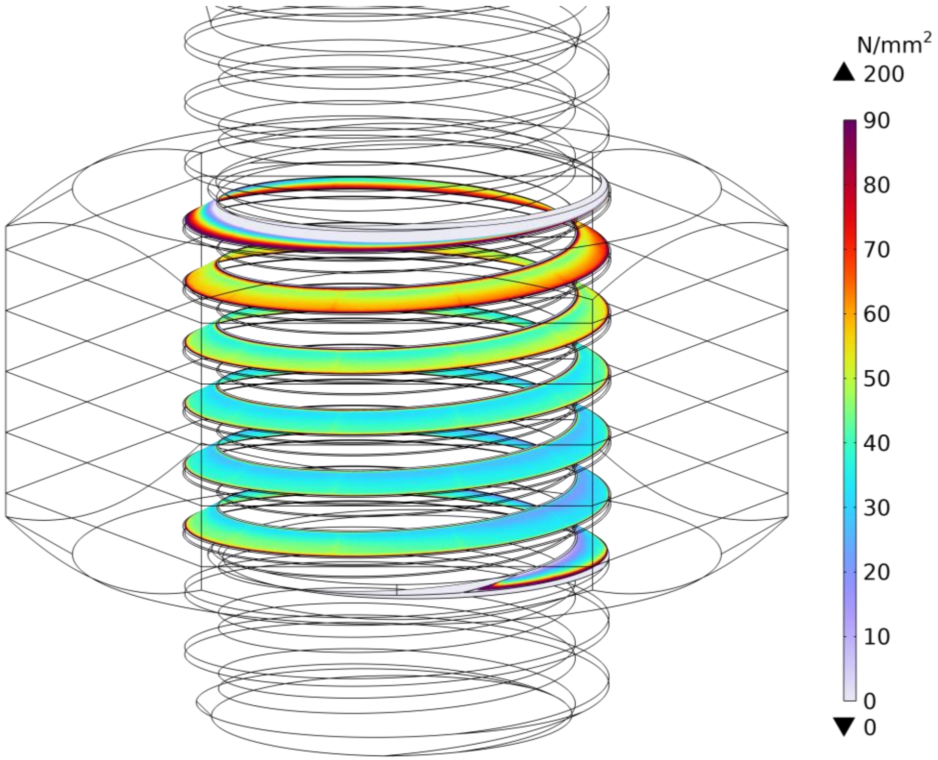


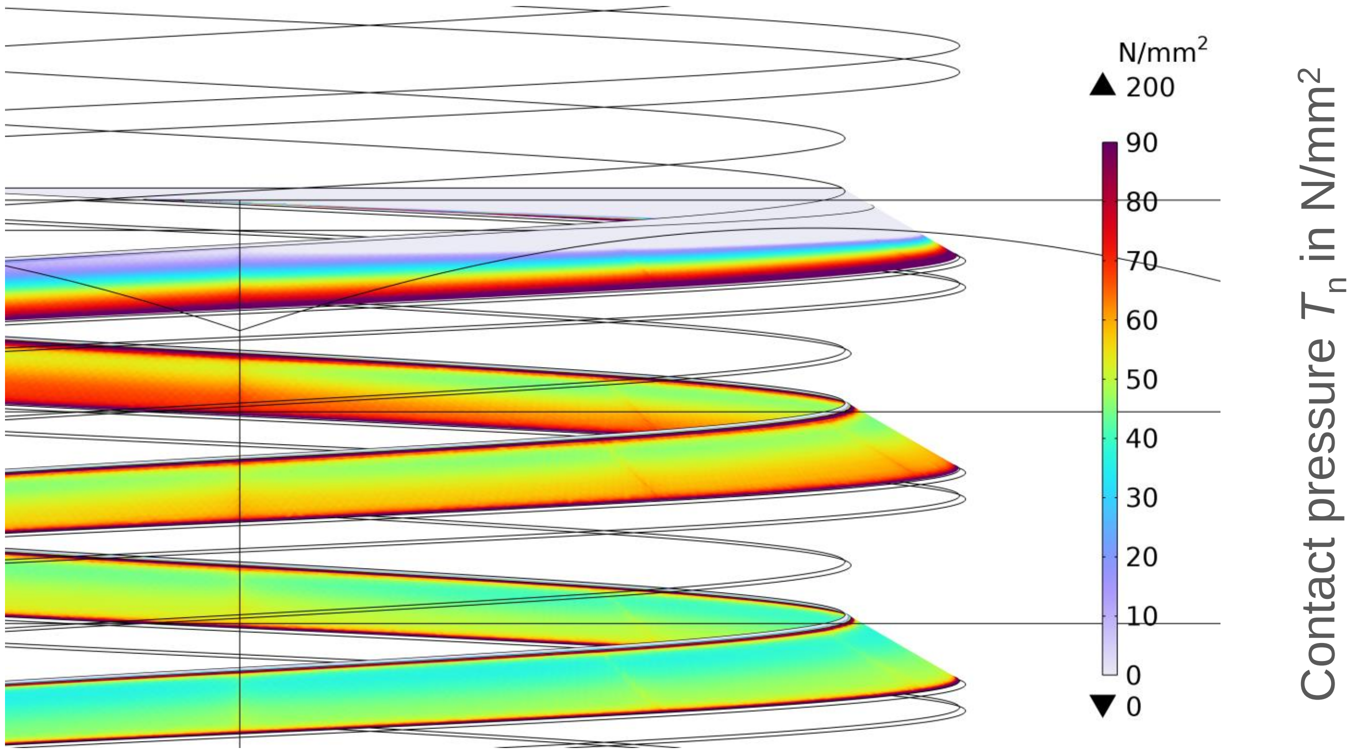
42 elements along the radial width of the thread

- **13 elements** along the thread
- Finite Element Mesh (FE-Mesh) with a total number of elements of n_{FE} ≈ **5.8 Mio.** Elements
- Memory requirement: **125 GB RAM**

- **42 elements** along the thread
- Finite Element Mesh (FE-Mesh) with a total number of elements of n_{FE} ≈ **3.2 Mio. Elements** (< 5.8 Mio.) due to a coarser meshing of the ambience and a larger max. element growth rate (**112 GB RAM**)

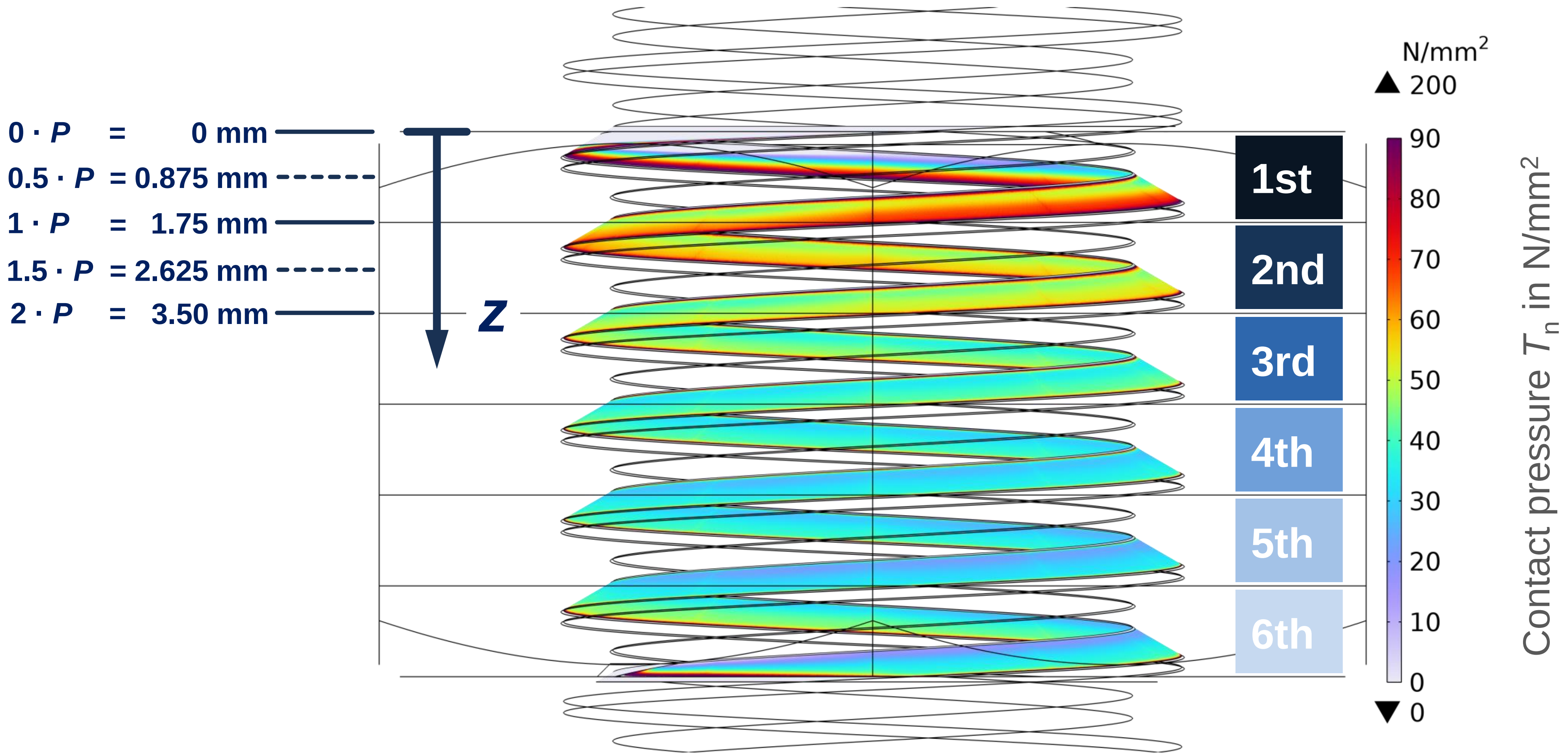
Contact pressure refined mesh





- Fine resolution of the contact pressure with this very fine FE-mesh

Contact pressure refined mesh (side view YZ)



- The averaged position of the 1st thread is at a position of half of the pitch *P* (see markings with distances left to the picture).
- This makes it even more obvious that the first thread is very close to the edge.

Contact pressure refined mesh (side view XZ)

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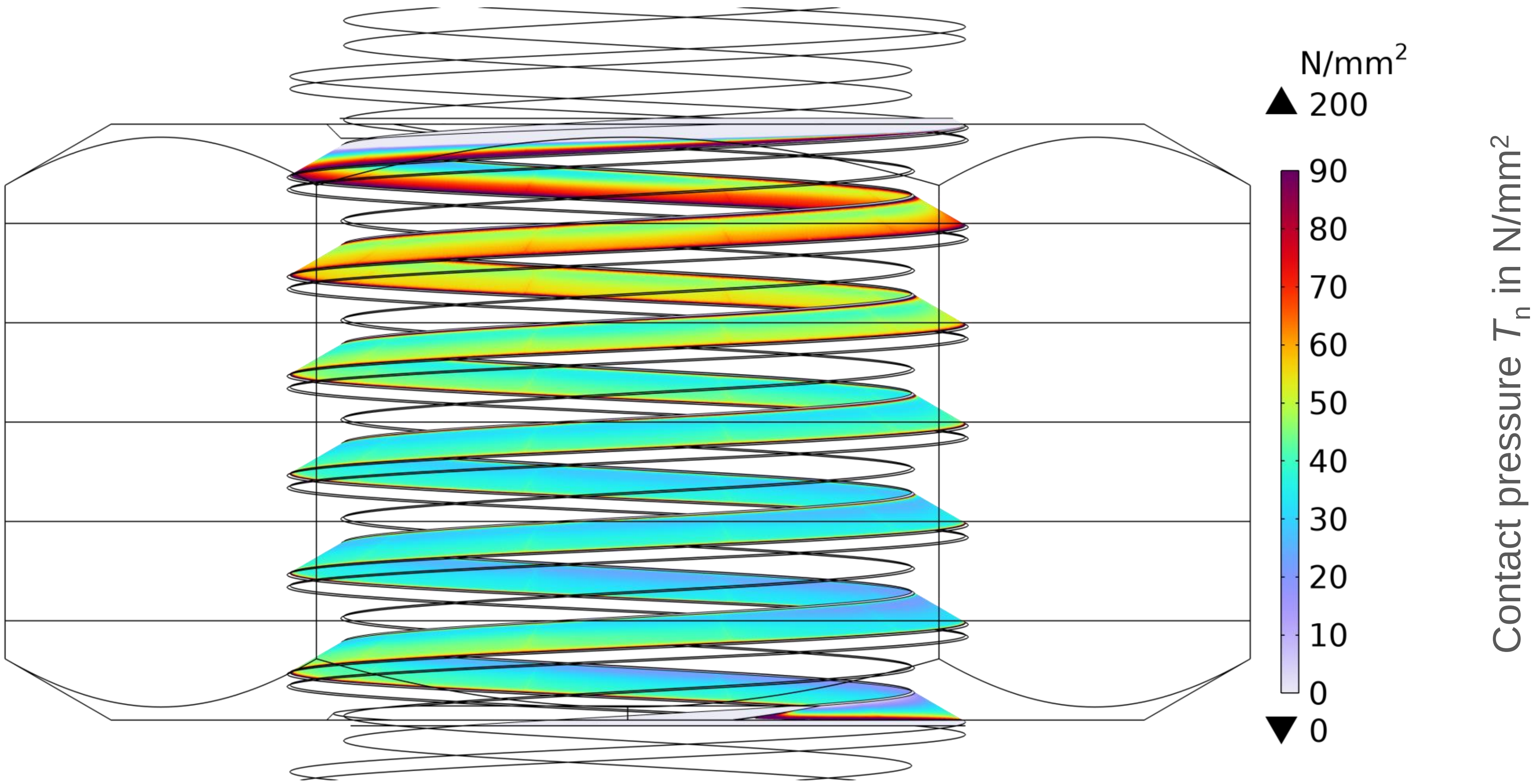

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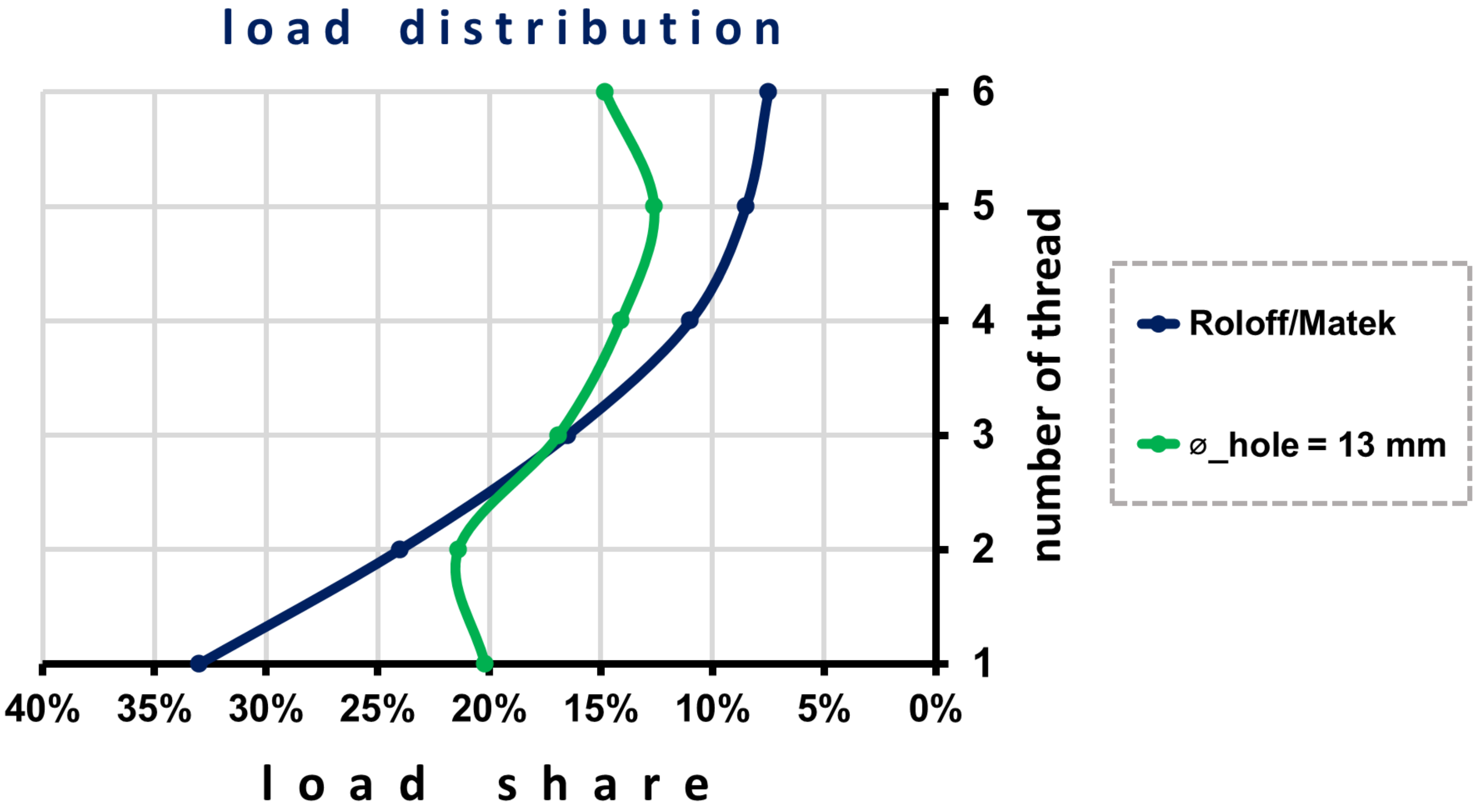
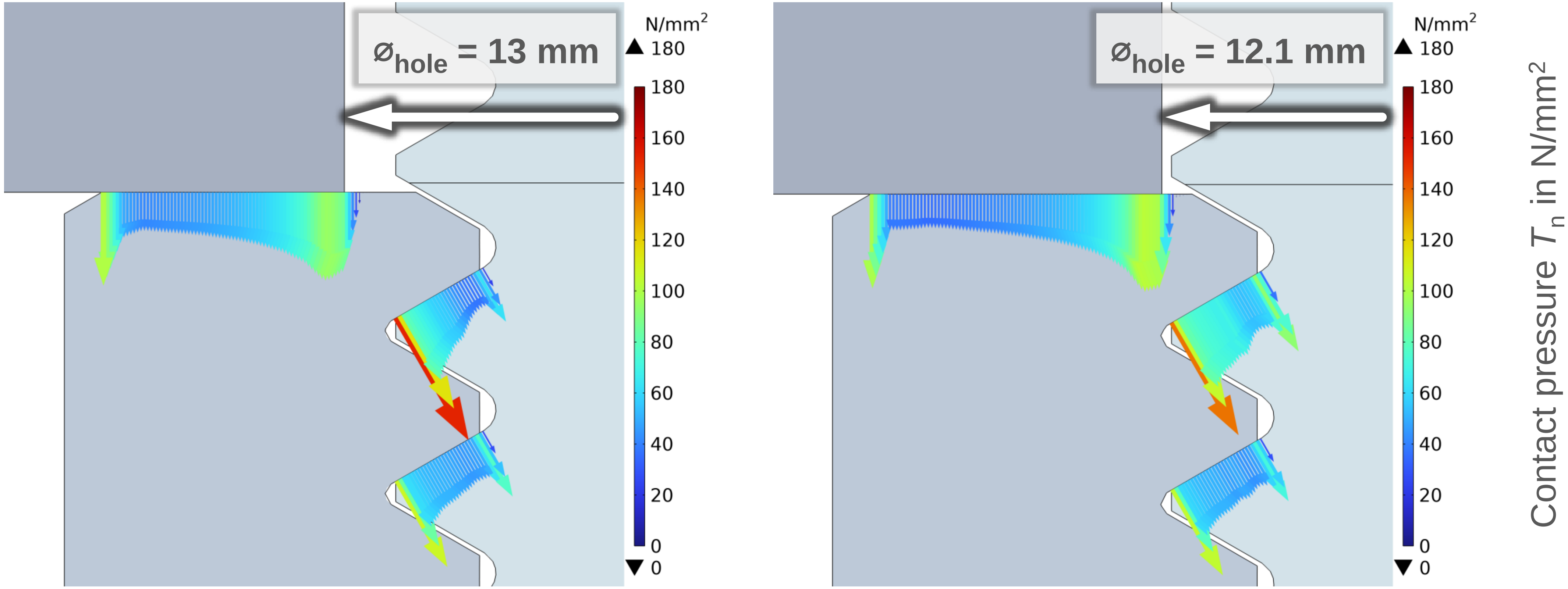
Load distribution



6th	14.8 %
5th	12.6 %
4th	14.1 %
3rd	16.9 %
2nd	21.4 %
1st	20.2 %

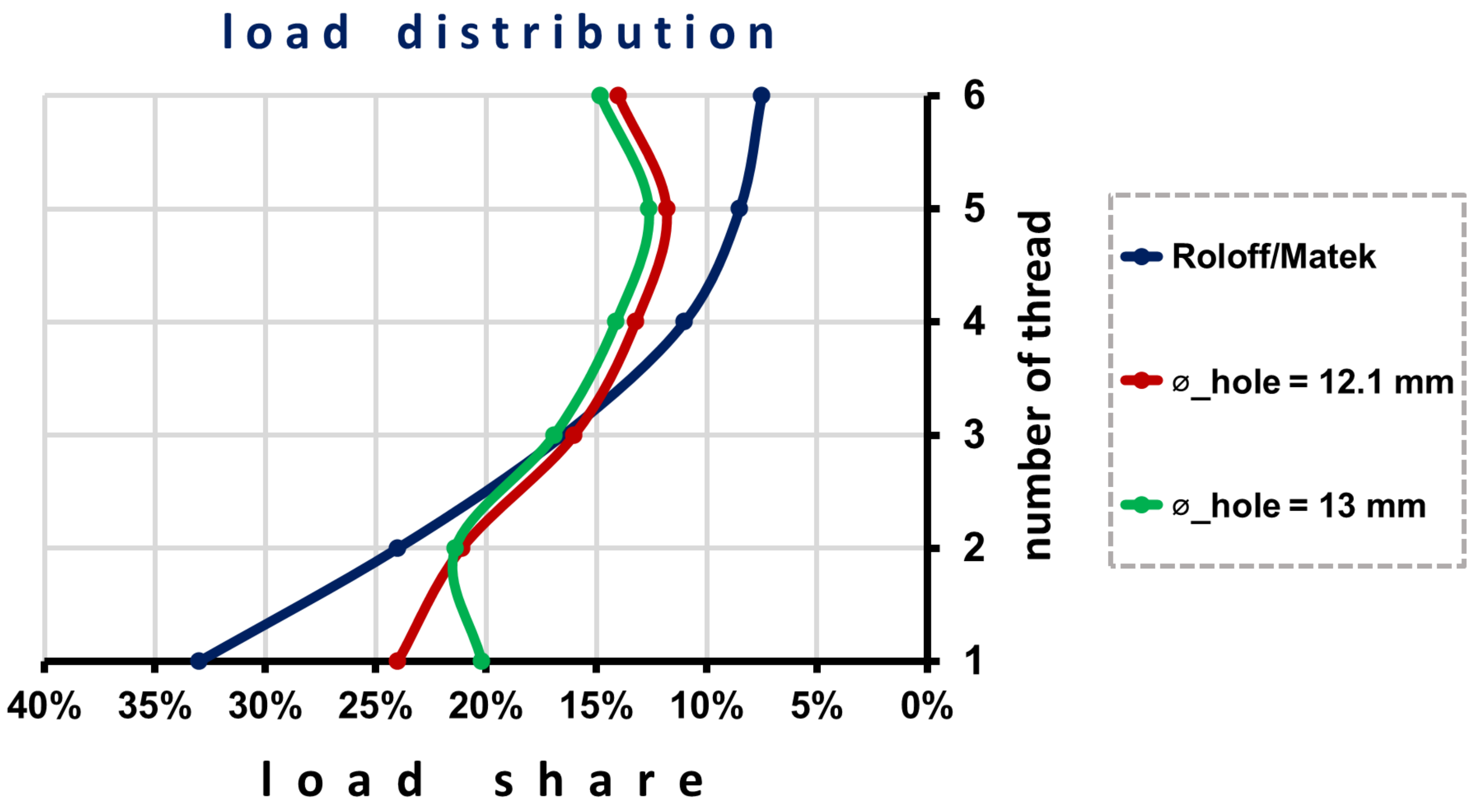
- 1st thread: load share of $\varphi_1 = 20.2\ \% \ll 33\ \%$

Contact pressure comparison 13 mm to 12.1 mm



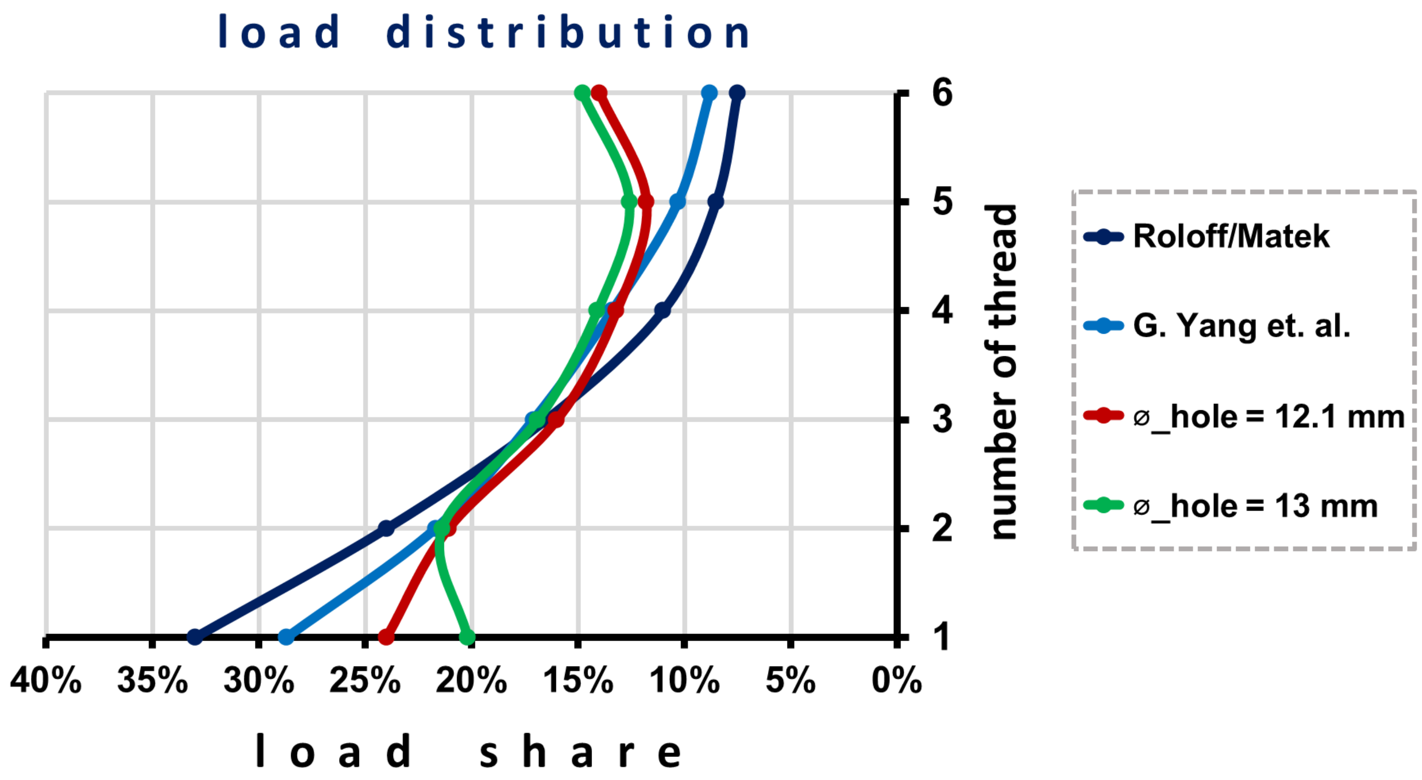
- An additional, in principle the same simulation only with a differing, smaller though hole diameter has been performed for comparison.
- Looking at the pressure profile of the first thread represented here with vectors it is to see, that the resulting force of the contact pressure is larger for the smaller through hole diameter. This is caused by a shorter path for the flow of force resp. stress flow.

Load distribution



- 1st thread: load share of φ_1 ($\varnothing_{hole}$ = 12.1 mm) = 24.0 % > φ_1 ($\varnothing_{hole}$ = 13 mm) = 20.2 %

Conclusions, Key results



- If a realistic value is used for the diameter of the through hole, the studies have shown that the first thread has a lower load share compared to the data of others.
- The reason for this is, that there are unfavorable conditions for the force flow resp. stress flow.
- The last thread has a higher load share than the penultimate thread related to the studies carried out here. This seems to be realistic because the nut ends at the last thread and the bolt continues, i. e. the material ends abruptly on one side of this contact pair. Accordingly, the force flow lines concentrate at the end of the nut.

additional source: G. Yang et. al., "Three-dimensional Finite Element Analysis of the Mechanical Properties of Helical Thread Connection", 2013.