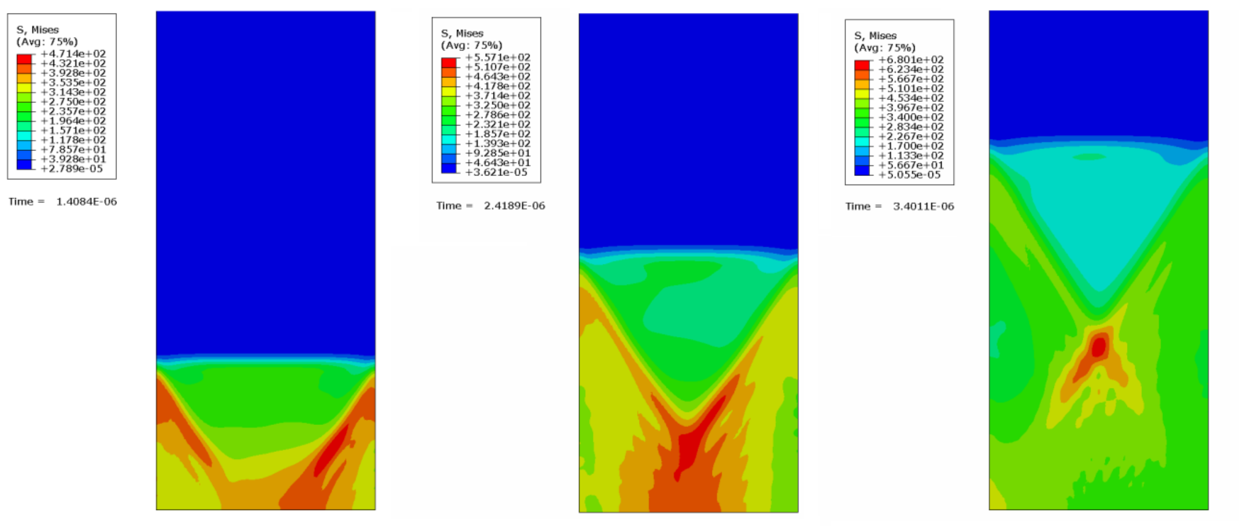
Impact stress estimation in a rock drilling machine piston*

SEES meeting

Vibration and shocks

RISE, Borås

2021-11-18



Anton Tkachuk, Mohamed Sadek, Reza Bakhshandi, Mikael Grehk, Jens Bergström

* A part of the paper on failure analysis is under preparation

Plan

Motivation

Axisymmetric analysis of normal impact

Full 3D analysis for different misalignment angles

Discussion of stress fields

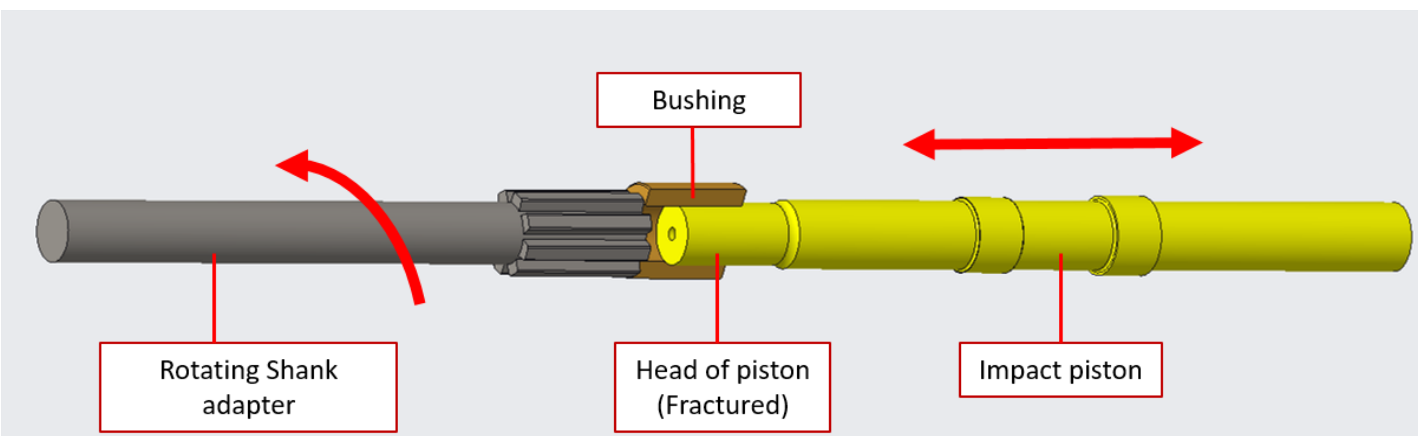
Take-away facts

MOTIVATION

Increasing lifetime of the impact piston is a crucial task

- Other parts are easier to replace
- Difficulty in inspection
- Expensive part due to complex geometry and heat treatment together with expensive material

Failure analysis requires accurate estimation of tensile stress!



Atlas Copco ECM-720 top hammer hydraulic crawler drill

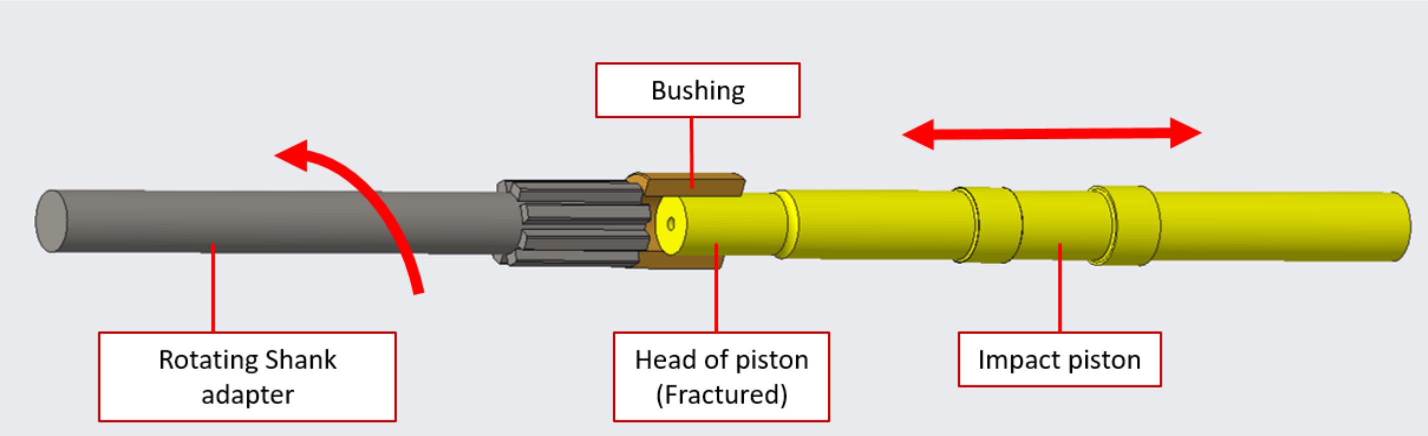
MOTIVATION

Typical conditions

- Impact frequency 10-50 Hz
- Impact velocity 10-11 m/s
- Flat on flat impact with estimated maximum misalignment angle 0.22˚
- Uncontrolled amount of lubrication
- Uncontrolled temperature
- No possibility to measure stress

Much more uncertainty than in one of my previous applications

[Mercedes Safety Center - E-Class (2017) CRASH TEST - YouTube]



Therefore, only estimation of the stress is possible!

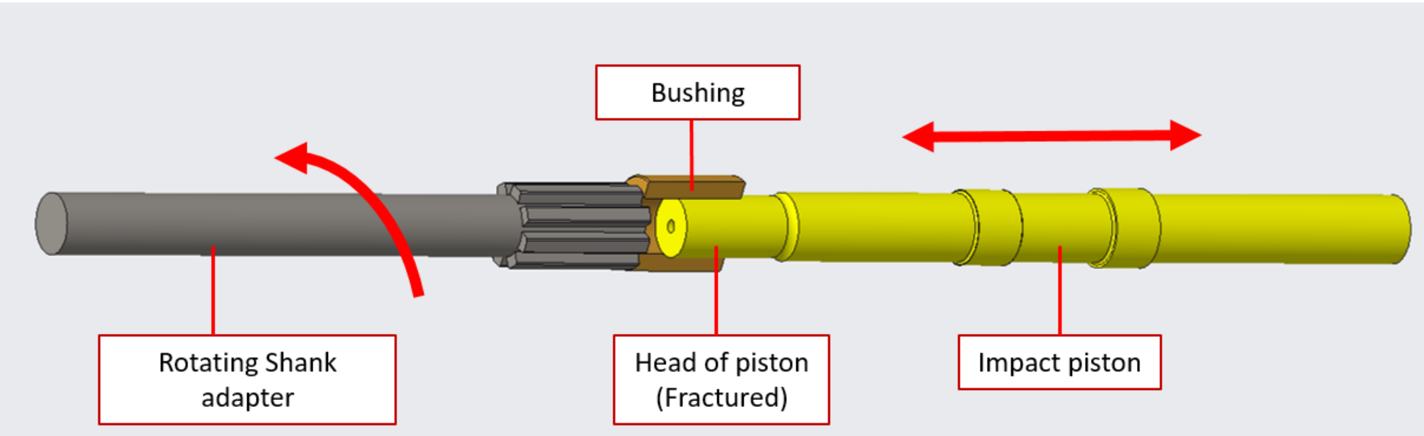
MOTIVATION

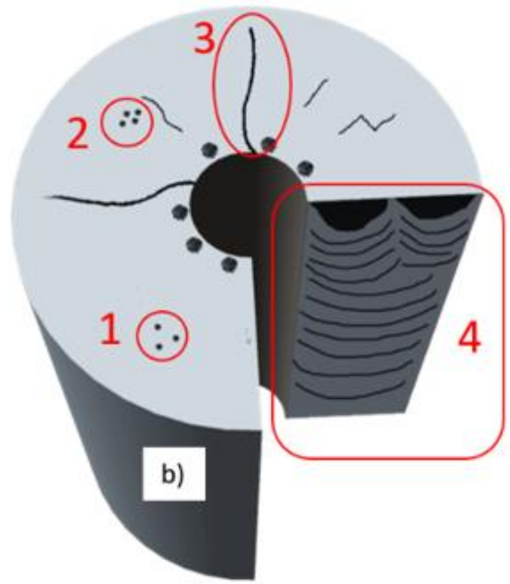
Goals for current study

- Estimate stress during impact at surface
- Explain various crack growth patterns
- Find the most dangerous load case
- Develop understanding of the process

Approach

- Use explicit dynamics simulation (with Abaqus)
- Simplify geometrical features and boundary conditions
- Neglect mechanism of pitting formation on surface
- Differentiate between crack initiation and growth

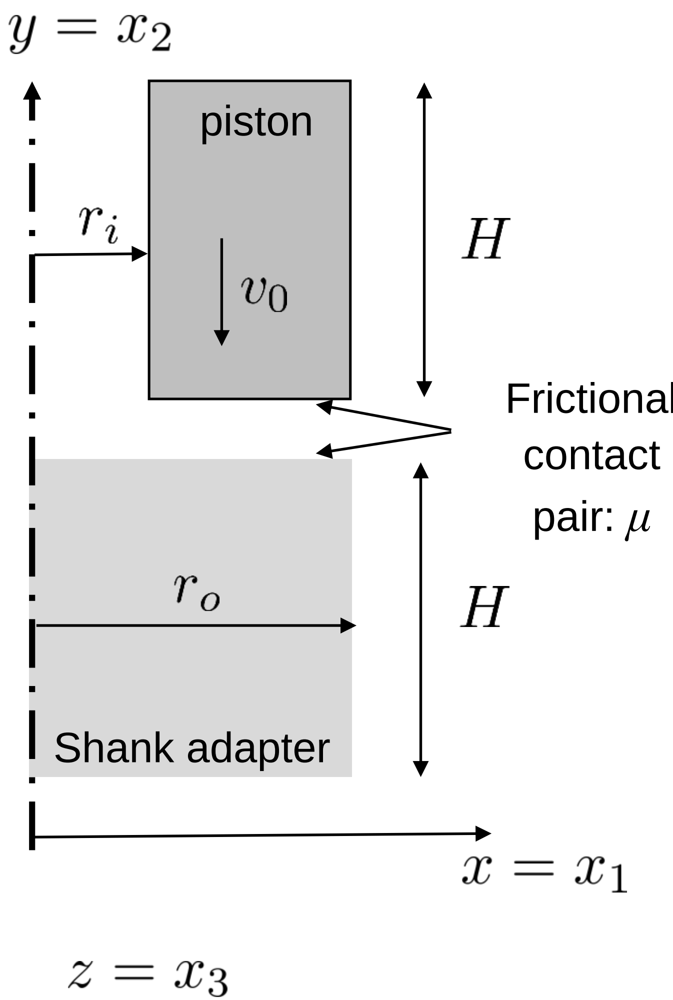




Therefore, only estimation of the stress is possible!

Axisymmetric analysis of normal impact

Setup for simulations



Units: mm-kg-s

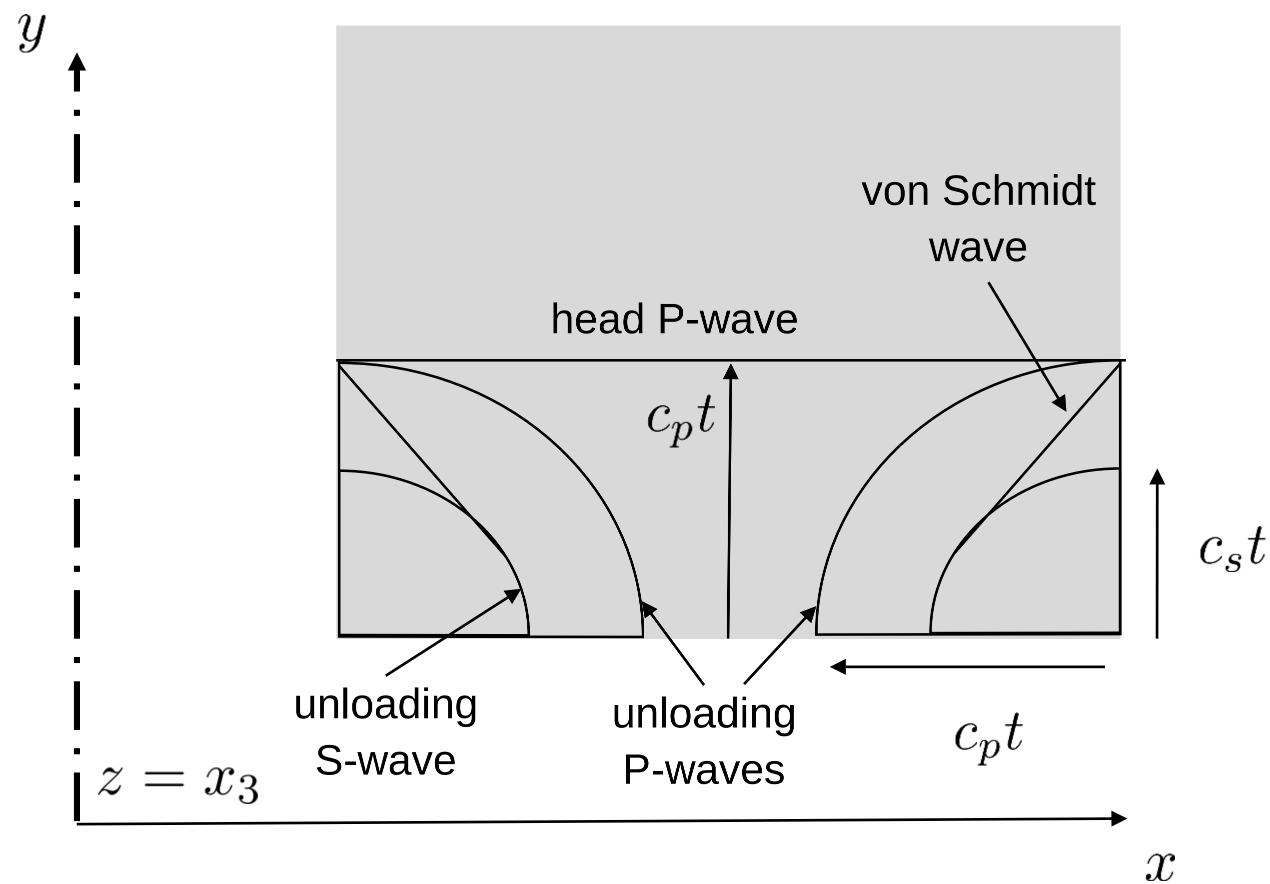
$$r_i = 6\,\mathrm{mm}$$
$$r_o = 18\,\mathrm{mm}$$
$$H = 45\,\mathrm{mm}$$
$$E = 210 \cdot 10^3\,\mathrm{MPa}$$
$$\nu = 0.3$$
$$\rho = 7.85 \cdot 10^{-6}\,\mathrm{kg/mm^3}$$
$$\mu = 0.1$$
$$v_0 = 10 \cdot 10^3\,\mathrm{mm/s}$$
$$t_{end} = 44 \cdot 10^{-6}\,\mathrm{s}$$

Mesh size 0.2 mm (5400 FE)

Simulation CPU time ca. 5 s

Axisymmetric analysis of normal impact

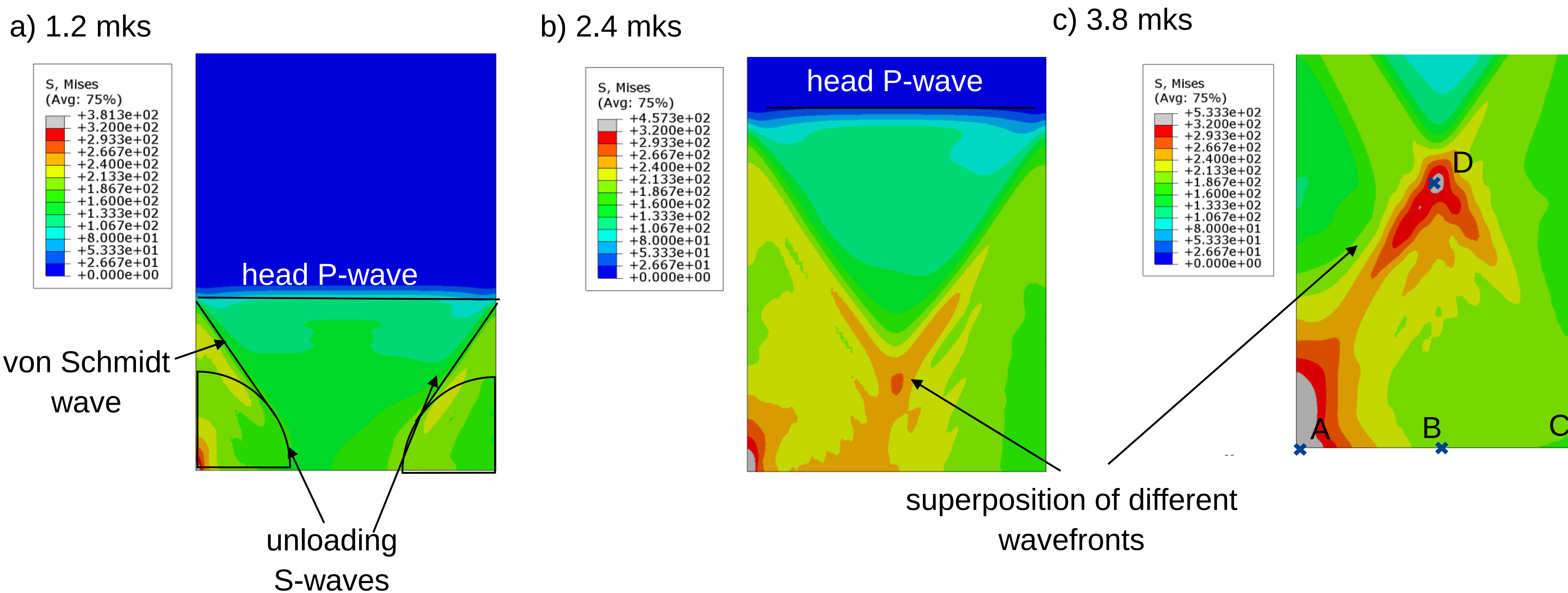
Expected solution



Cerv, J., Adamek, V., Vales, F., Gabriel, D., & Plesek, J. (2016). Wave motion in a thick cylindrical rod undergoing longitudinal impact. *Wave Motion*, *66*, 88-105.

Axisymmetric analysis of normal impact

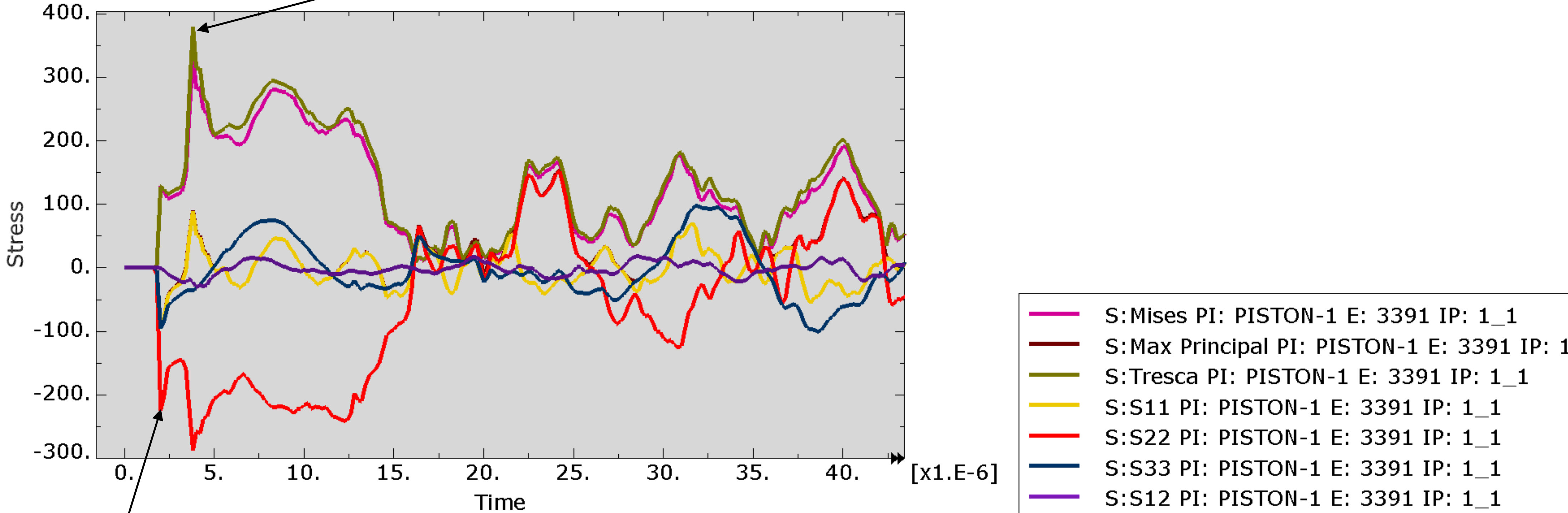
Obtained solution



Axisymmetric analysis of normal impact

Obtained solution for point D

superposition of different wavefronts



Arrival of the head P-wave

Axisymmetric analysis of normal impact

Summary of obtained solution for axisymmetric impact

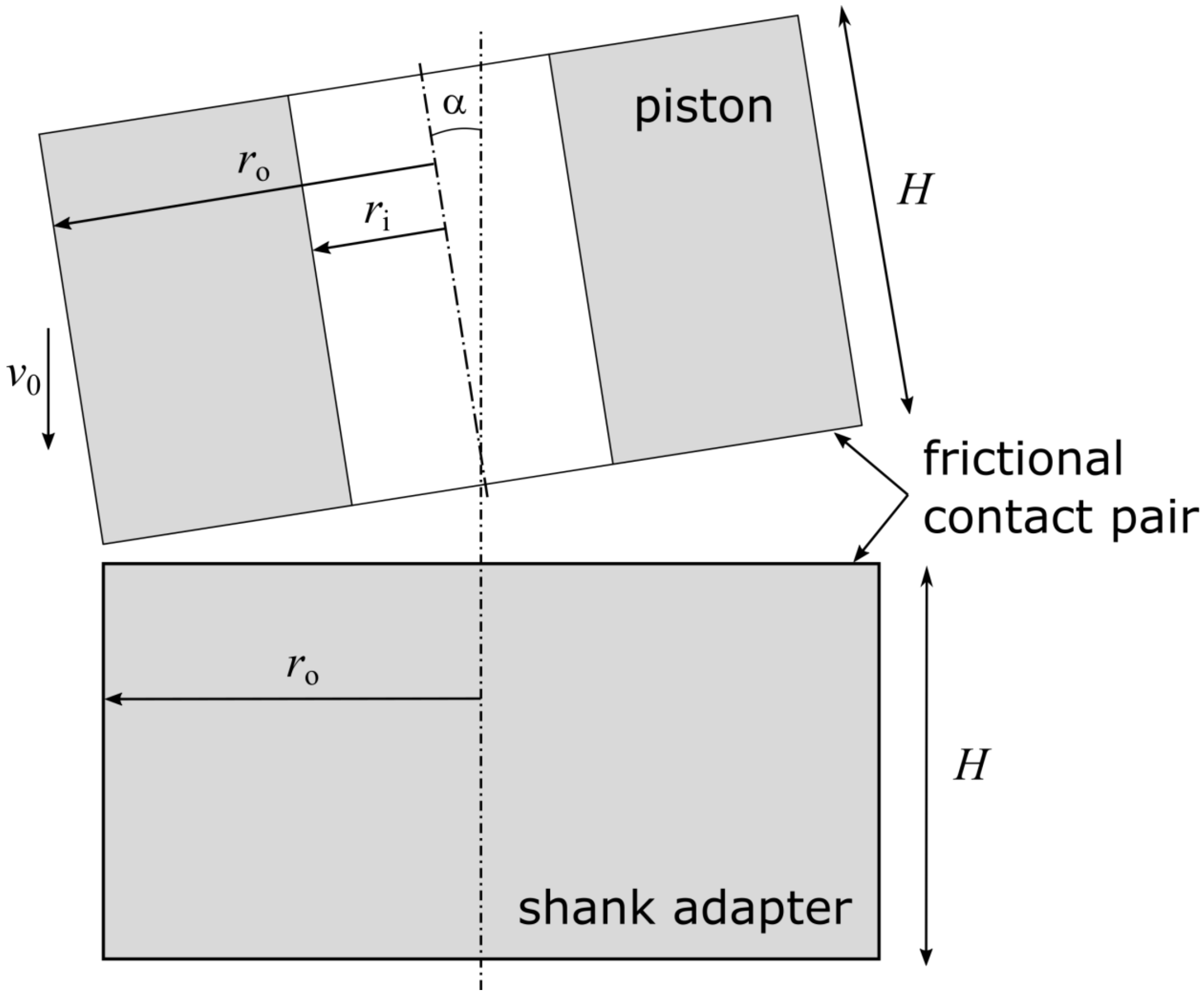
Point	A	B	C	D
Max von Mises stress, MPa	533	279	476	334
Max Tresca stress, MPa	591	285	510	379
Tensile hoop stress, MPa	**231**	166	98	98
Tensile radial stress, MPa	45	**169**	127	89

Stress are not high enough to open cracks in the used low alloyed steel
It is not the most dangerous load case
A more dangerous load case from literature*

*Wang, J., Han, B., Wang, C., Gong, Y., Li, Y., Neville, A., & Morina, A. (2021). Failure analysis of the piston used in a pneumatic down the hole impactor. *Engineering Failure Analysis*, *127*, 105561.

Full 3D analysis for different misalignment angles

Setup of simulation



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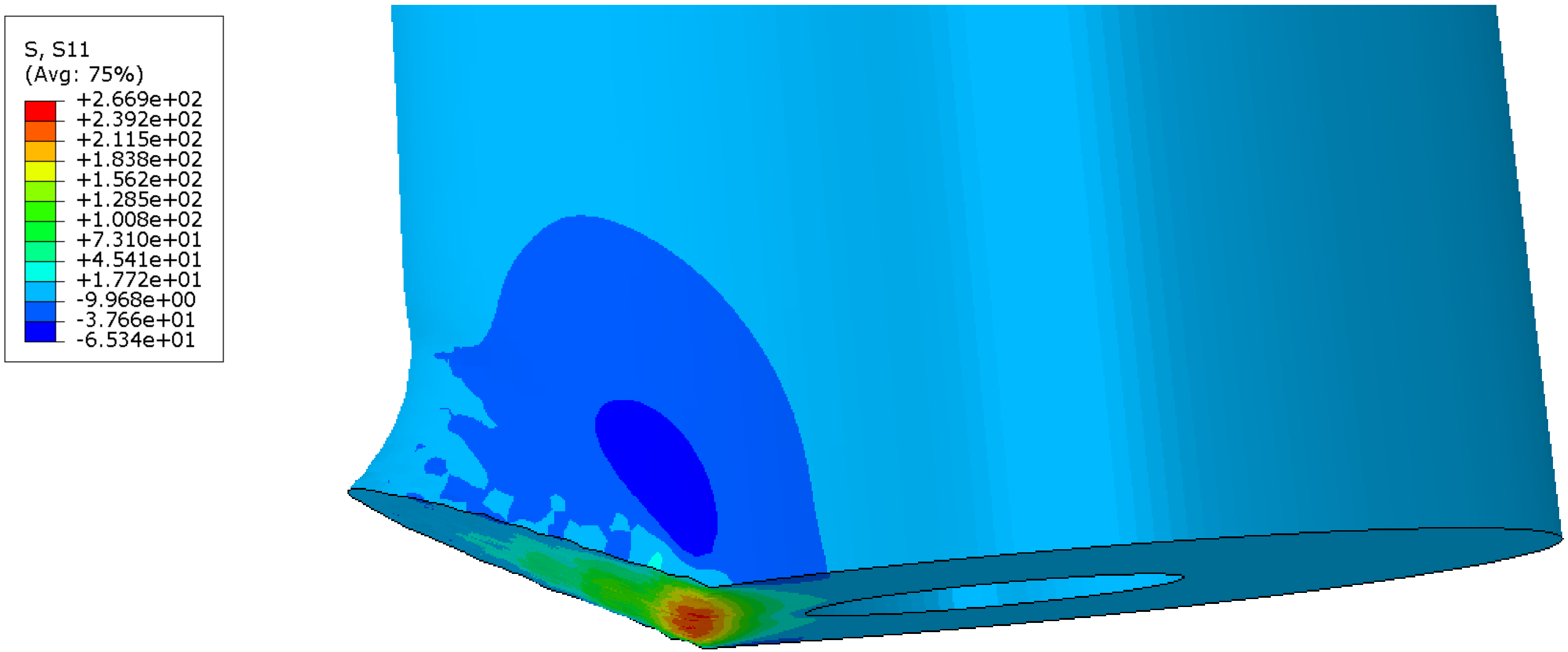
$$E = 210 \cdot 10^3\,\mathrm{MPa}$$
$$\nu = 0.3$$
$$\rho = 7.85 \cdot 10^{-6}\,\mathrm{kg/mm^3}$$
$$\mu = 0.1$$
$$v_0 = 10 \cdot 10^3\,\mathrm{mm/s}$$
$$t_{end} = 44 \cdot 10^{-6}\,\mathrm{s}$$
$$\alpha = 0.11^\circ, 0.22^\circ$$

Mesh size 0.2 mm (ca. 6.8M FE)
Simulation CPU time ca. 6h on 12 cores

Full 3D analysis for different misalignment angles

Deformation due to misalignment angle α=0.22˚



Full 3D analysis for different misalignment angles

Results for α=0.11˚

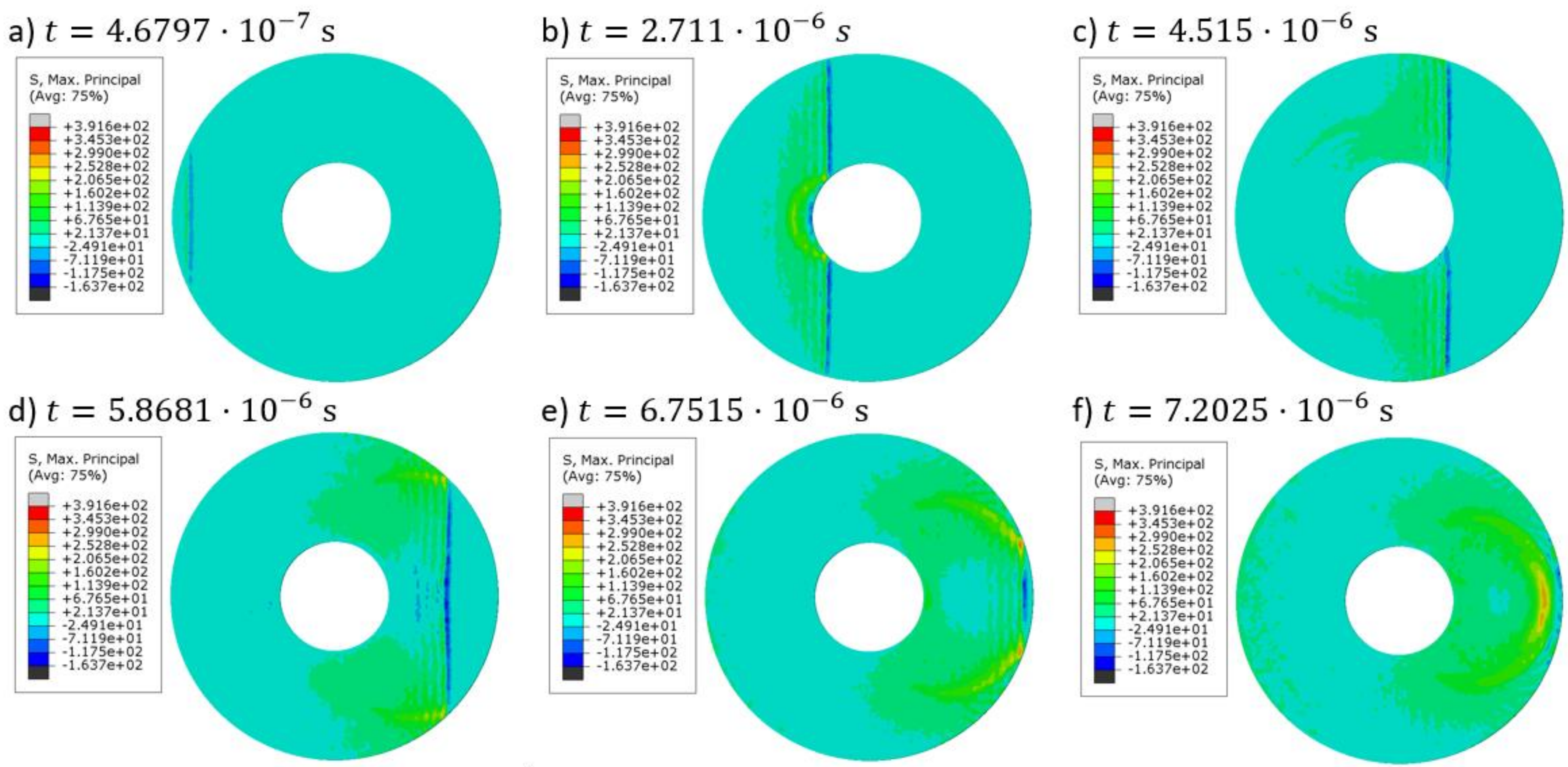
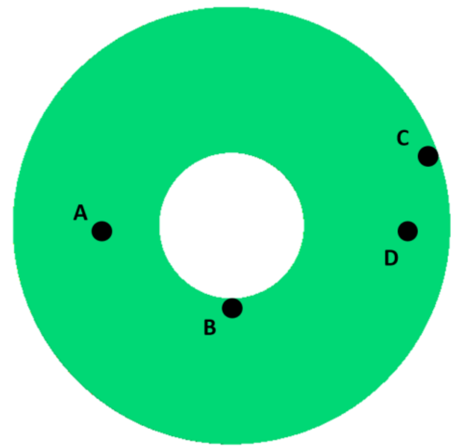


Fig. 12 Maximum principal stress in MPa on impact surface of the piston for misalignment angle α=0.11˚

Full 3D analysis for different misalignment angles

Summary of results for α=0.11°

	A	B	C	D
v. Mises, MPa	297	414	433	359
Max Principal, MPa	192	134	372	285
Tensile hoop stress, MPa	188	60	**338**	285
Tensile radial stress, MPa	129	111	65	74



Higher values!

Full 3D analysis for different misalignment angles

Results for α=0.22˚

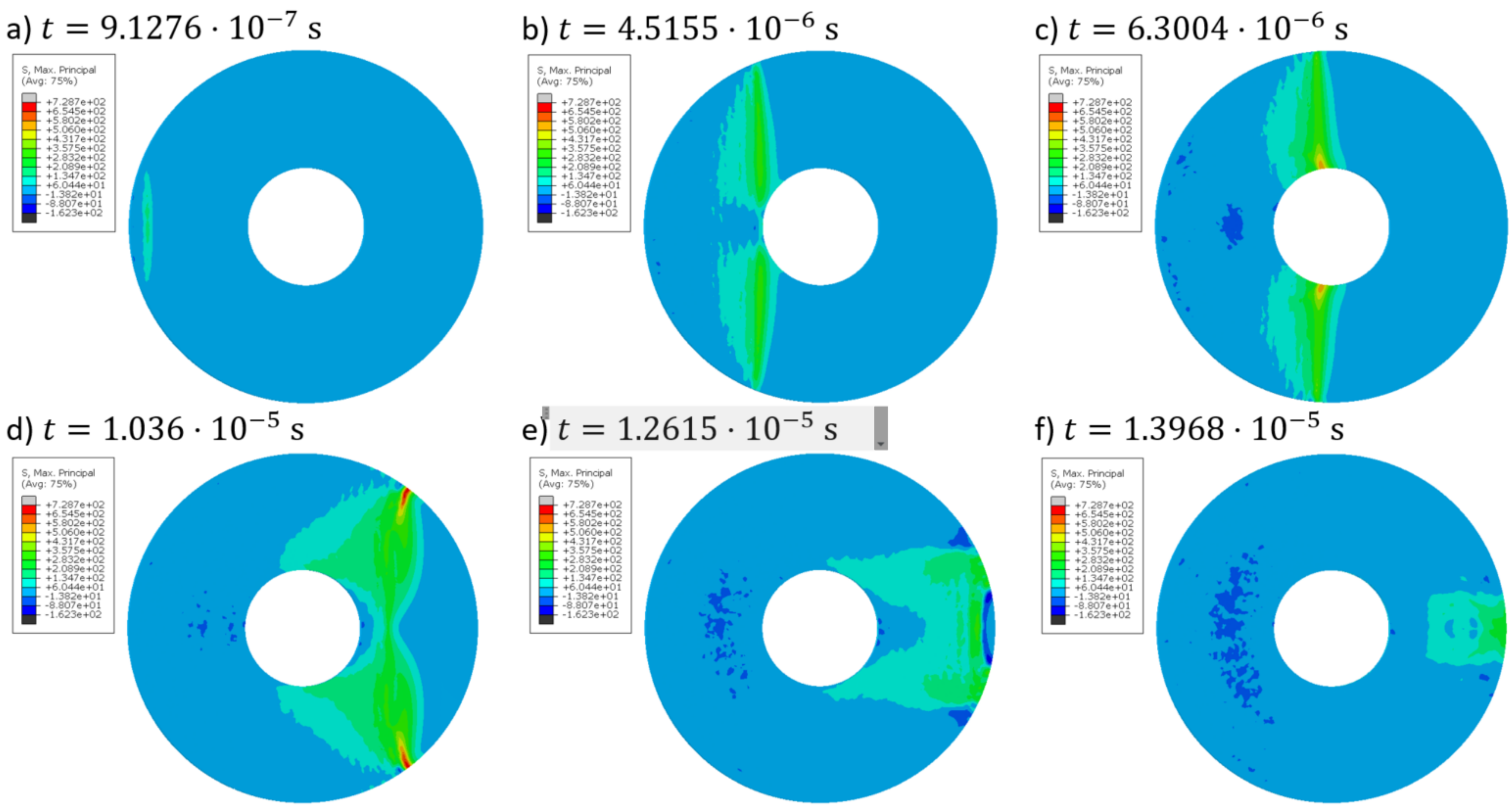
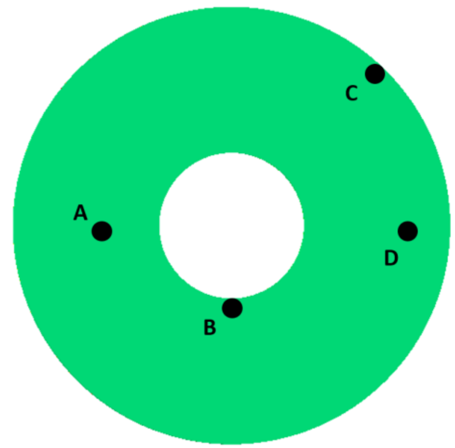


Fig. 13 Maximum principal stress in MPa on impact surface of the piston for misalignment angle α=0.22˚

Full 3D analysis for different misalignment angles

Summary of results for α=0.22˚

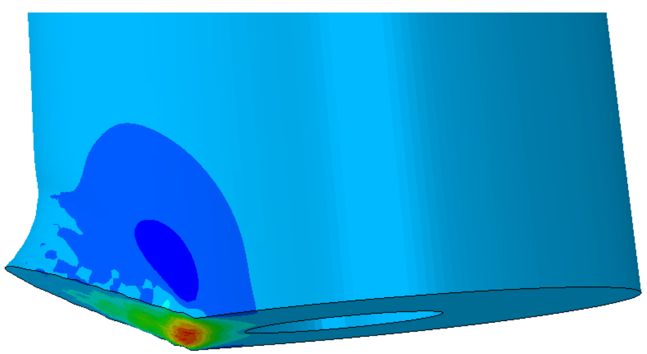
	A	B	C	D
v. Mises, MPa	278	546	1174	402
Max Principal, MPa	201	549	773	235
Tensile hoop stress, MPa	66	549	**761**	235
Tensile radial stress, MPa	200	34	52	132

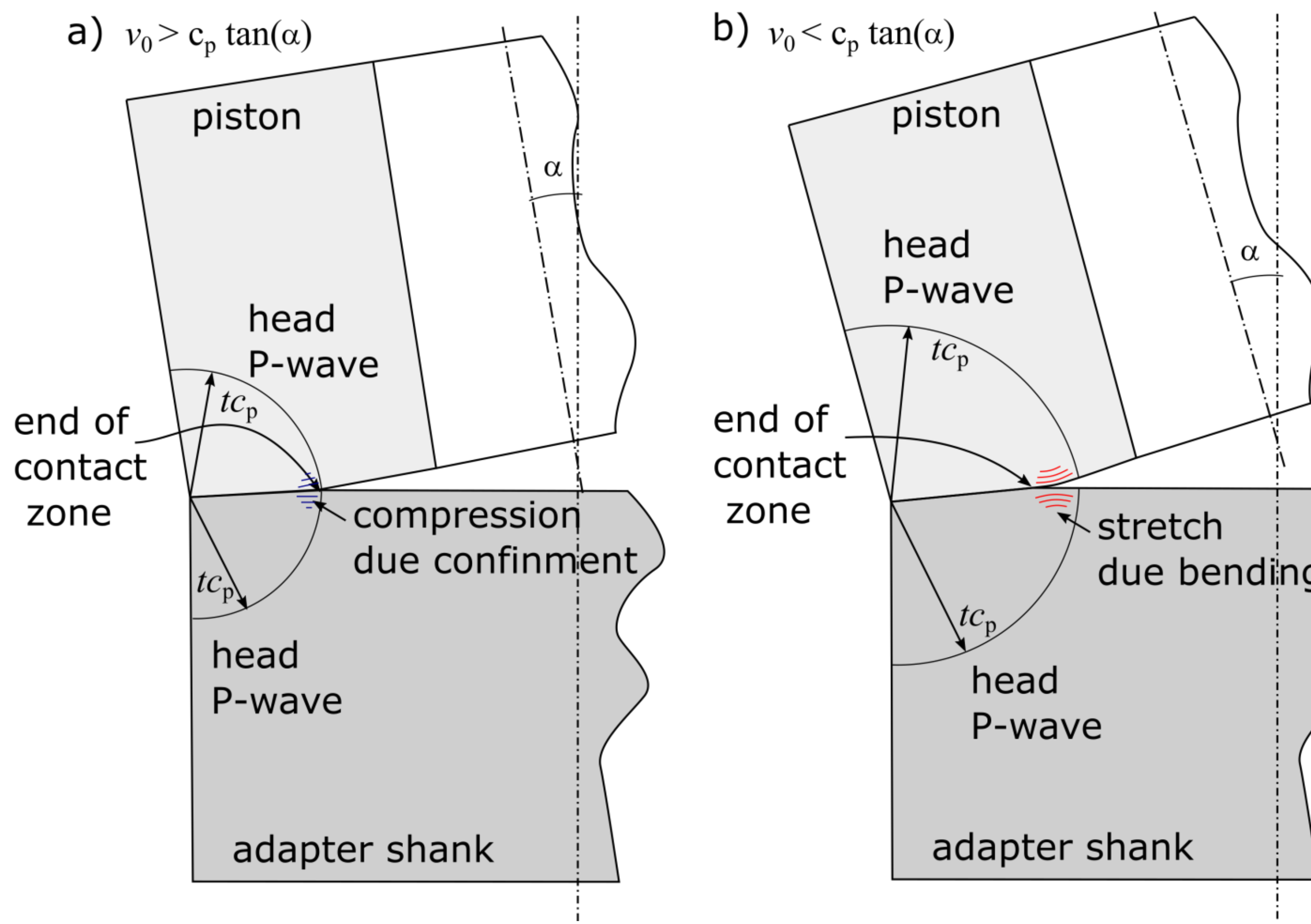


Quite high values!

Full 3D analysis for different misalignment angles

Interpretation





Take-away facts

Estimation of stress in rock drilling piston is difficult:

- **due to uncertainties and missing data**
- **most dangerous load case is not known in advance**

Series of numerical simulation on simplified geometries give insights on:

- **Impact with misalignment is more dangerous than normal impact**
- **Strong dependence on misalignment angle**
- **Misalignment angle α=0.22° yields hoop stress up to 761 MPa**
- **Impact stress wave changes the sign with condition** $v_0 > c_p \tan(\alpha)$