BOLTED JOINTS – STILL A KEY PART OF EFFICIENT POWERTRAINS AND A CHALLENGE FOR SIMULATION

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PREPARED FOR

10TH INTERNATIONAL SYMPOSIUM ON ENGINE RELIABILITY TECHNOLOGY

VIRTUAL PRESENTATION

AGENDA

INTRODUCTION

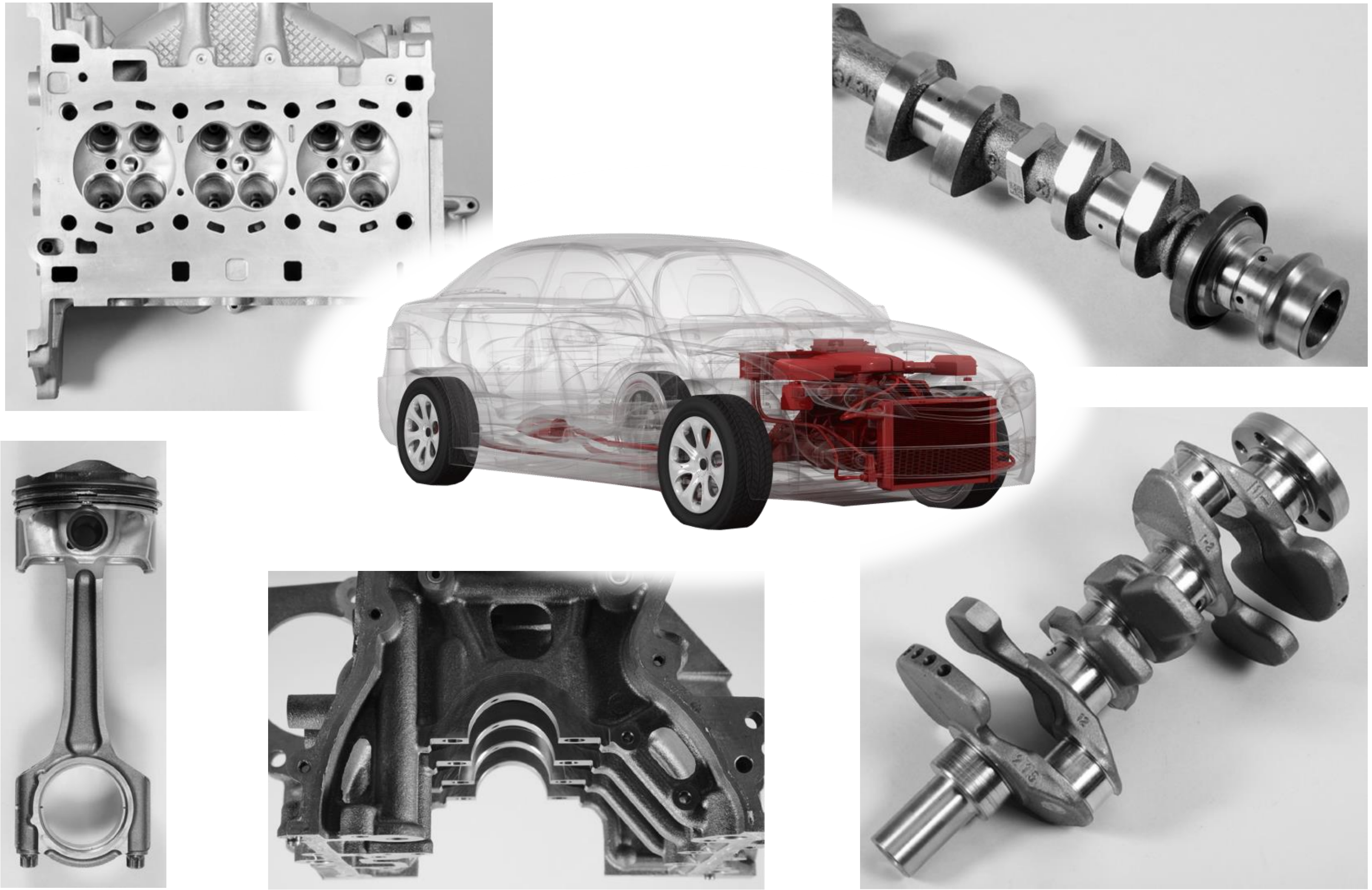
MODELING OF THE BOLTED JOINT BY FEA

POST-PROCESSING OF BOLT DYNAMIC STRESSES DERIVED BY FEA

EVALUATION OF BOLT AMPLITUDE STRESSES – EXAMPLES

SUMMARY

Bolted joints have influence on engine design and are decisive for reliability of entire powertrain



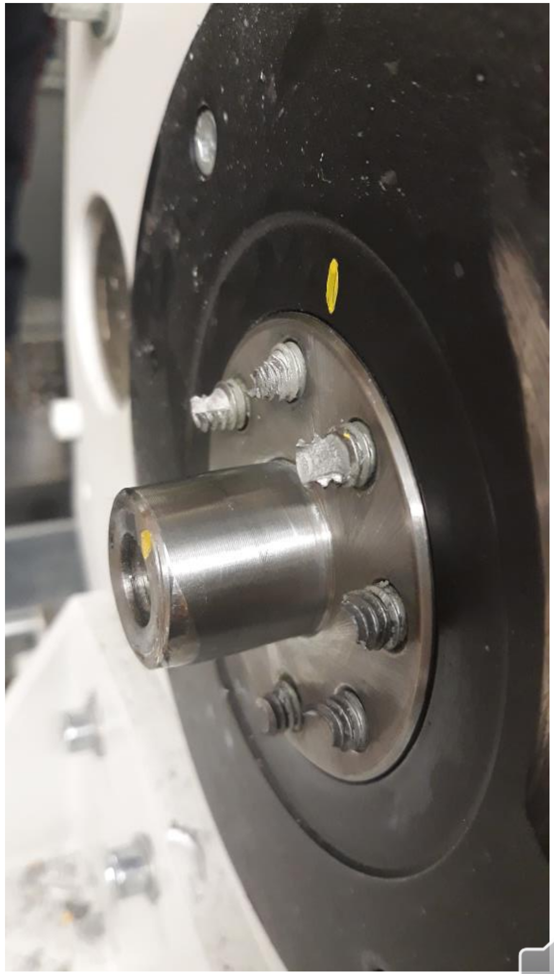
BOLT SIZE INFLUENCE

- Local
  - bore pitch
  - crankpin diameter
  - crankcase design and material
  - crankshaft seal dimensions
  - VVT variator connection details
  - ... others
- Global
  - weight
  - size
  - performance
  - efficiency
  - NVH
  - cost

Source: FEV Engine Analysis of Ford 1.0l Ecoboost MY. 2012

Safety margins of modern bolted joints are low which require higher quality in manufacturing and maintenance

EXAMPLE OF DOWNSIZED FLANGE BOLTED JOINT FAILURE IN A DRIVELINE



Analytical calculation of bolted joints has a strong historical background but rules for application of FEA for bolted joints are initially released in 2014

SYSTEMATIC CALCULATION OF HIGHLY STRESSED BOLTED JOINTS

1)

VDI 2230 Part 1 – analytical calculations

1977 | 1986 | 2003 | 2014 | 2015

Initial releases and further revisions

2014

VDI 2230 Part 2 – application of FEA

1) www.datamath.org

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Including thread details in the FEA is a big modeling, computational and evaluation effort which creates the need for simplification

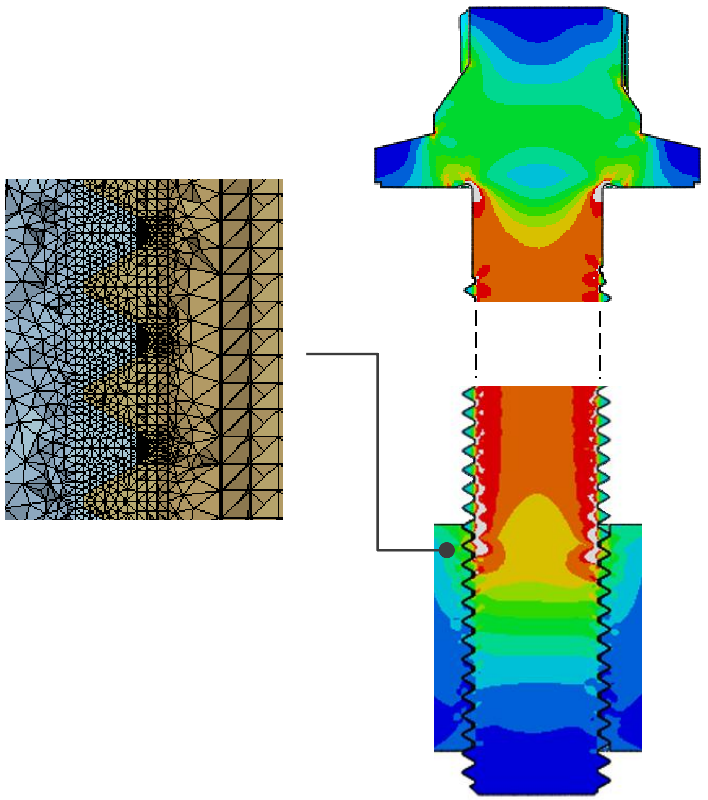
EVALUATION OF BOLT FATIGUE SAFETY

- plastic stress / strain
- material assignment
- heat treatment
- thread rolling
- tightening into yield
- local stress concentrations
- thread tolerances
- assembly introduced torsional stress

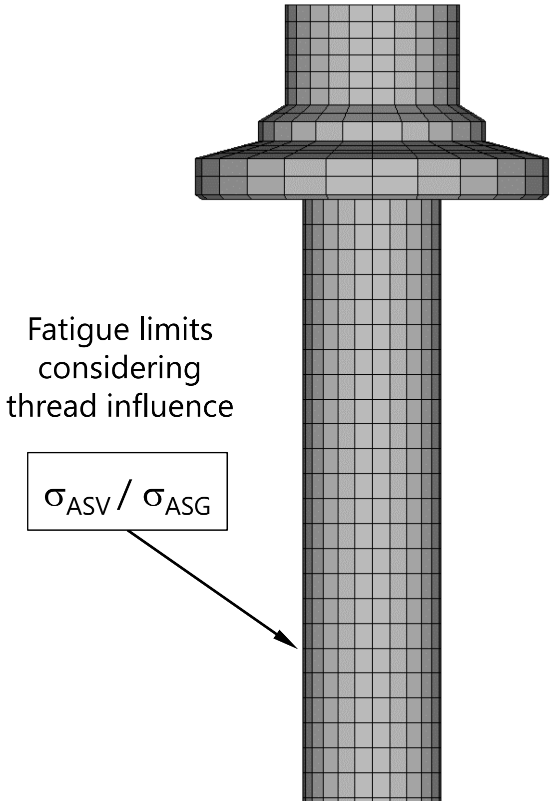
SIMULATION EFFORT

- model preparation
- computational time

Bolt FE model with thread details



Simplified bolt FE model



Application of the FEA gives a simulation engineer considerable possibilities in modeling of the bolted joint

BOLT FE MODEL CLASSES ACCORDING TO VDI 2230 PART 2 (2014)

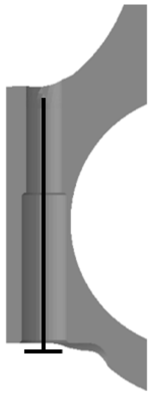
I CLASS I

- Neither bolt nor interface modeled

- Results:
  - Global deformations as an input for bolt analytical calculation

II CLASS II

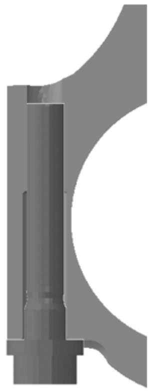
- Bolt modelled as beam



- Results:
  - Bolt internal forces

III CLASS III

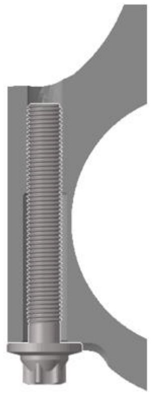
- Bolt modelled as equivalent volume



- Results:
  - Bolt internal forces
  - Local stresses of equivalent bolt volume

IV CLASS IV

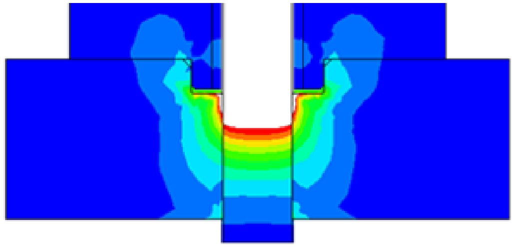
- Bolt fully modelled



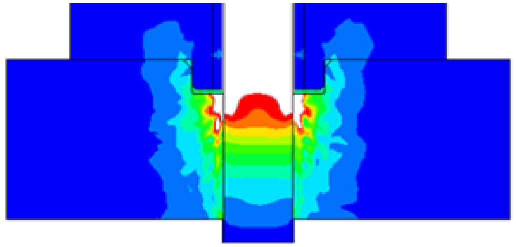
- Results:
  - Thread local stresses

There are certain aspects that need particular attention during simplification of bolt FE model

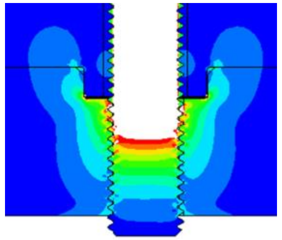
SELECTED ASPECTS FOR CLASS III BOLT FE MODEL



Clearance (op. bolt)

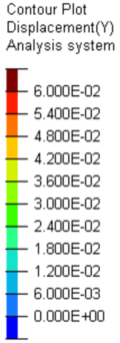


Equivalence

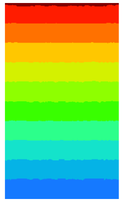


Class IV (ref.)

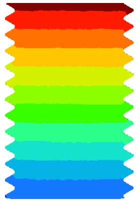
Interaction between internal and external thread



A_{d_3}

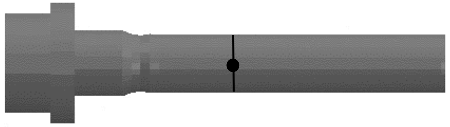


A_S

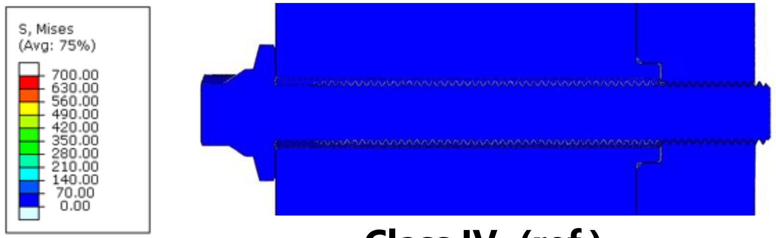


Class IV (ref.)

Bolt stiffness – equivalent cross-section area of unengaged thread region



Mechanical / thermal

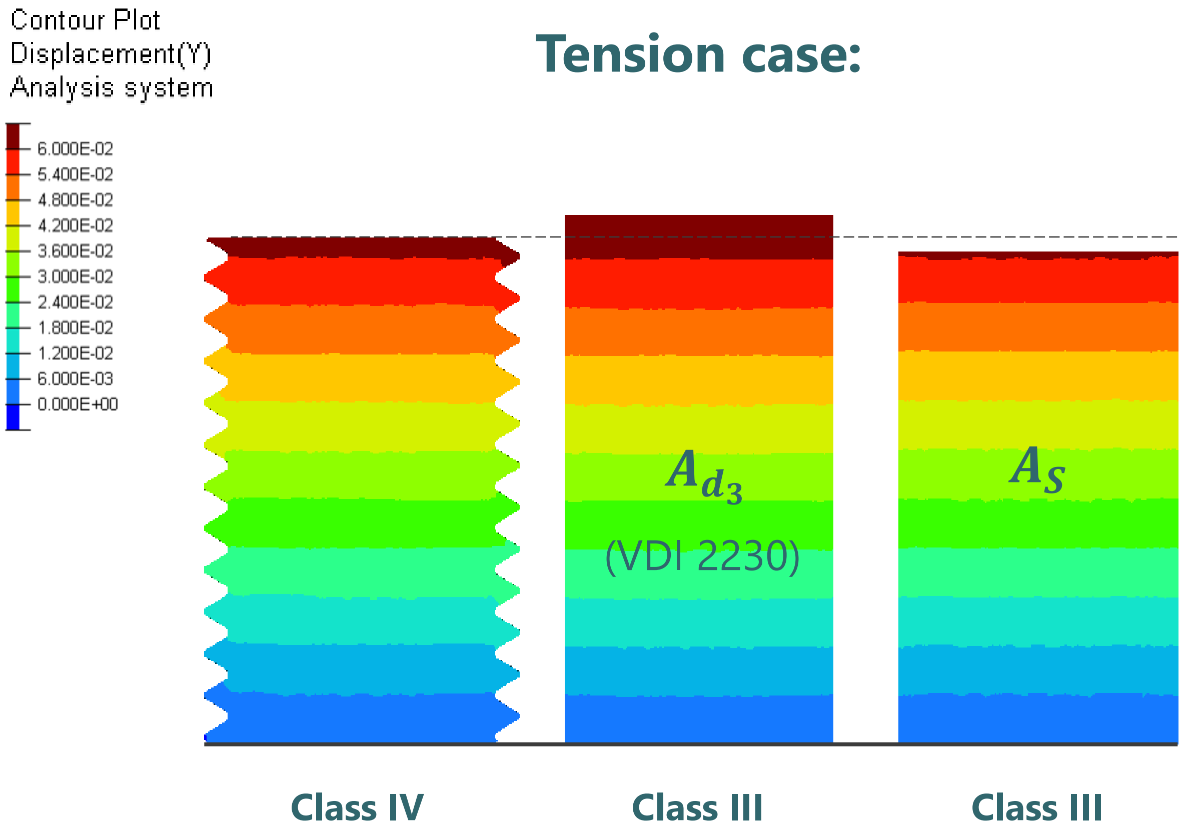


Class IV (ref.)

Bolt preload

Exact modeling of the resilience of unengaged thread is decisive for precise reproduction of bolted joint mechanical behavior in FE simulation

EQUIVALENT CROSS-SECTION AREA OF UNENGAGED THREAD REGION



Simulation / calculation type	Bolt model	Reference cross section area	Deviation in resilience in %	
	Class	-	Tension	Bending
FE	**IV**	**Real geom.**	**0.0**	**0.0**
FE	III	A_{d_3}	+ 5.1	+10.4
FE	III	A_S	- 3.3	- 6.4
Analytical	-	A_{d_3}	+ 5.5	-

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SUMMARY

Bolt dynamic load can be evaluated by use of different post-processing methods

OVERVIEW

METHOD I

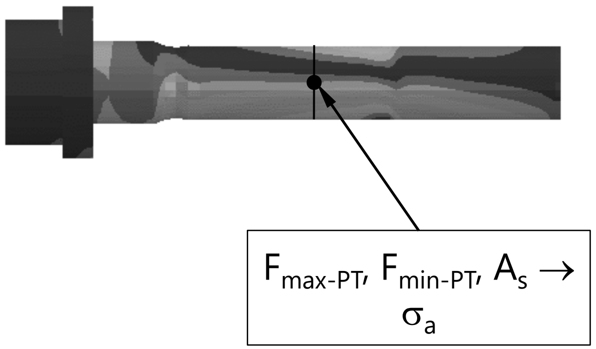
- Bolt tensile forces evaluated by reaction force in pretension node

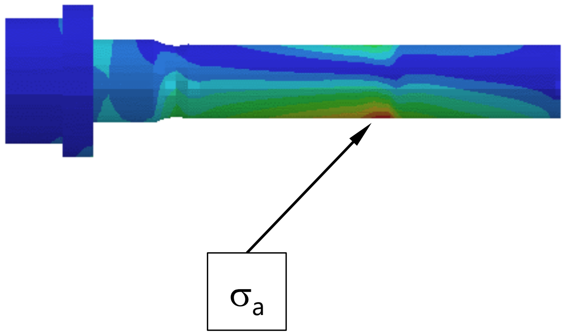
METHOD II

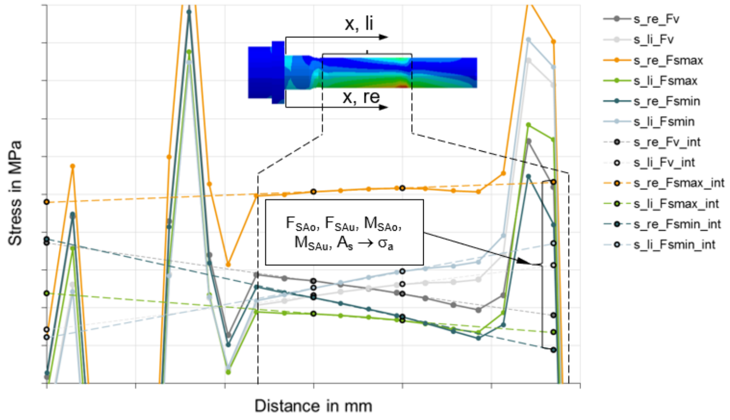
- Stresses evaluated on surface of equivalent bolt volume

METHOD III

- Bolt internal forces determined by extrapolation of stresses evaluated on surface of equivalent bolt volume (VDI 2230 part 2)





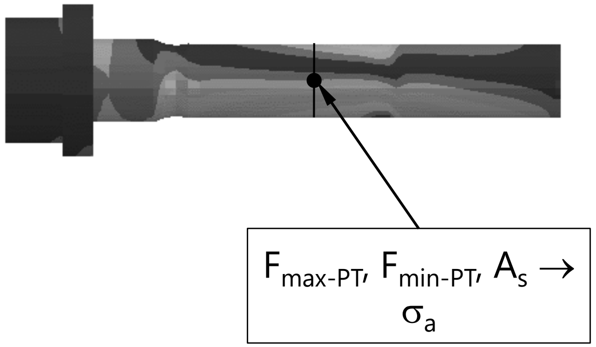


Each method provides advantages …

BENEFITS

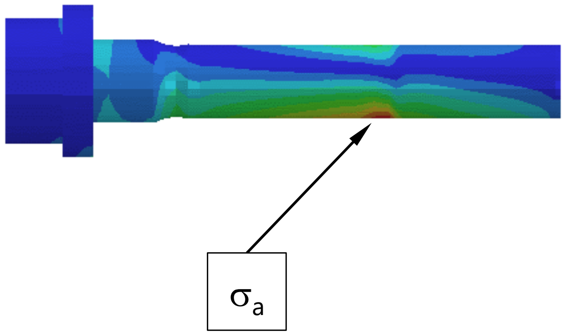
METHOD I

- Very simple approach



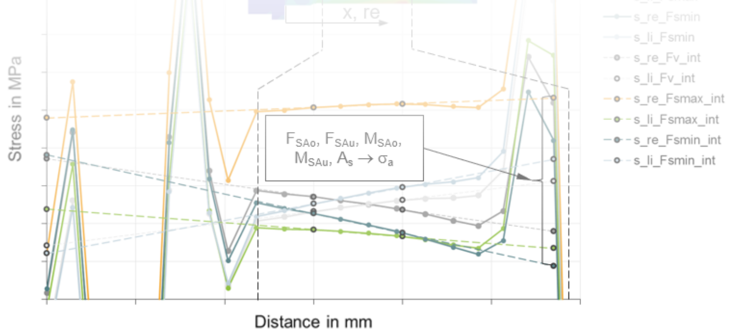
METHOD II

- Straightforward approach
- Bending stresses considered



METHOD III

- Bending stresses considered
- Part of stress concentration (already considered in bolt fatigue limits) filtered-out from stress results
- Precise modeling of bolt resilience

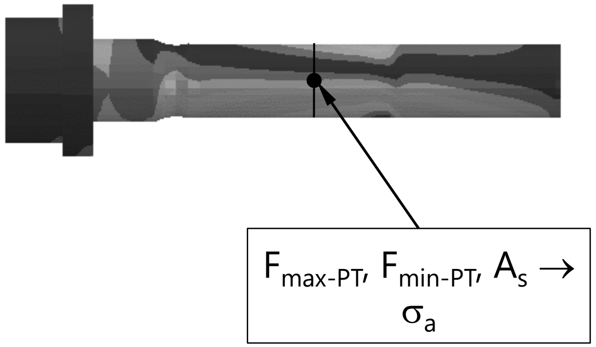


Each method provides advantages but also has certain limitations

LIMITATIONS

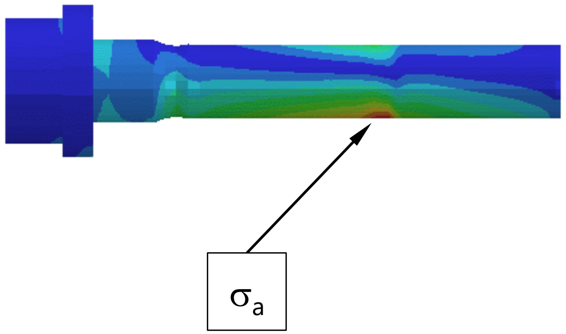
METHOD I

- No bending stresses considered



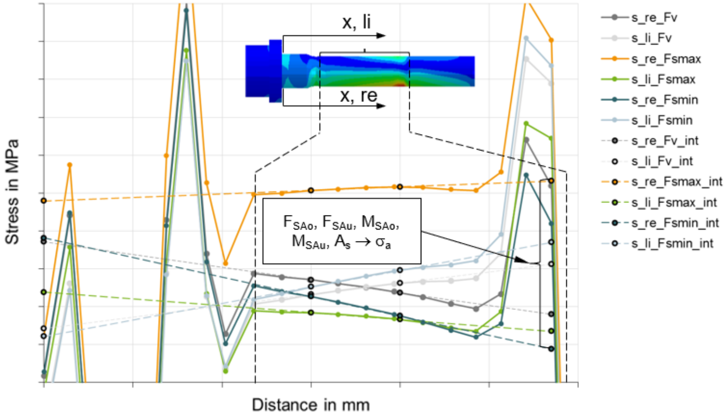
METHOD II

- Part of stress concentration (already considered in available bolt fatigue limits) included in stress results
- Influence on bolt resilience due to adaptation of bolt cross-section area to A_S



METHOD III

- High post-processing effort



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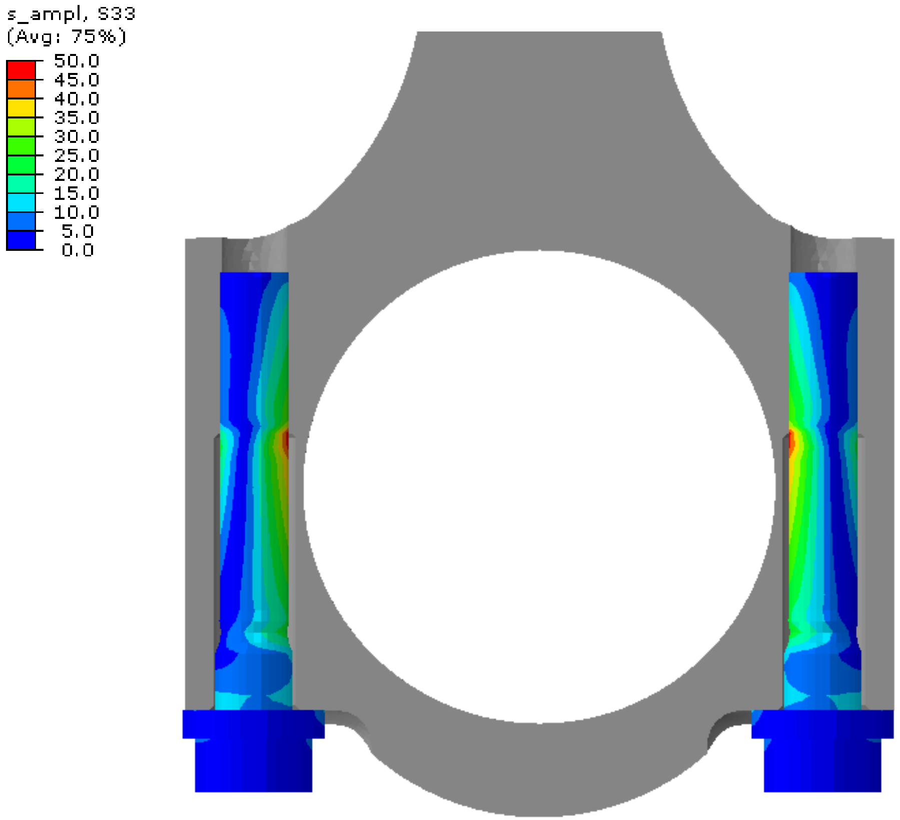
Differences in resultant bolt dynamic stress due to chosen evaluation method and cross-section area used in bolt class III FE model can be significant

STRAIGHT-SPLIT CONNECTING ROD



BOTH CAP BOLTS

- A combination of dynamic tension and bending (without shearing force) is observed
- The bending load is dominant
- The stress concentration included by Method II overestimates bolt dynamic stress by 9%
- The effect of bolt cross-section applied in FE model is on the level of 13%

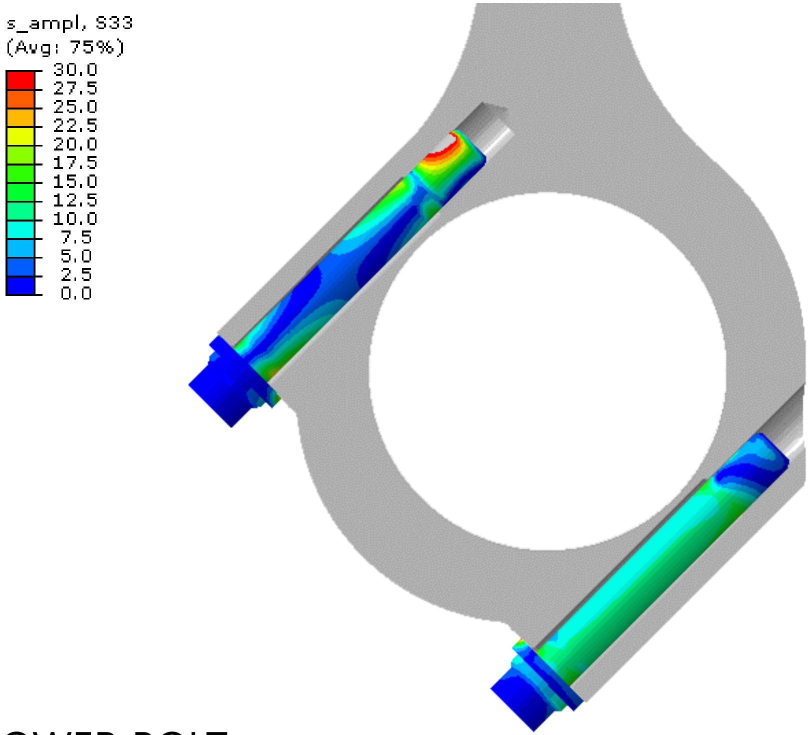
	Method I	Method II	Method III	
Bolt cross-section in FE model	A_S			A_{d3}
Resultant max. amplitude stress of the bolt	10.6 MPa	48.4 MPa	44.4 MPa	39.3 MPa

VDI 2230 part 2

Differences in resultant bolt dynamic stress due to chosen evaluation method and cross-section area used in bolt class III FE model can be significant

FEV

INCLINED-SPLIT CONNECTING ROD



UPPER BOLT

- The dynamic bending load (by shearing force) is dominant
- Effects of Method II and III as well as applied bolt cross-section in FE model are similar as in the straight-split connecting rod

	Method I	Method II	Method III	
Bolt cross-section in FE model	A_S			A_{d3}
Resultant max. amplitude stress of the upper bolt	3.4 MPa	23.5 MPa	21.7 MPa	19.6 MPa
Resultant max. amplitude stress of the lower bolt	10.4 MPa	18.4 MPa	12.8 MPa	11.8 MPa

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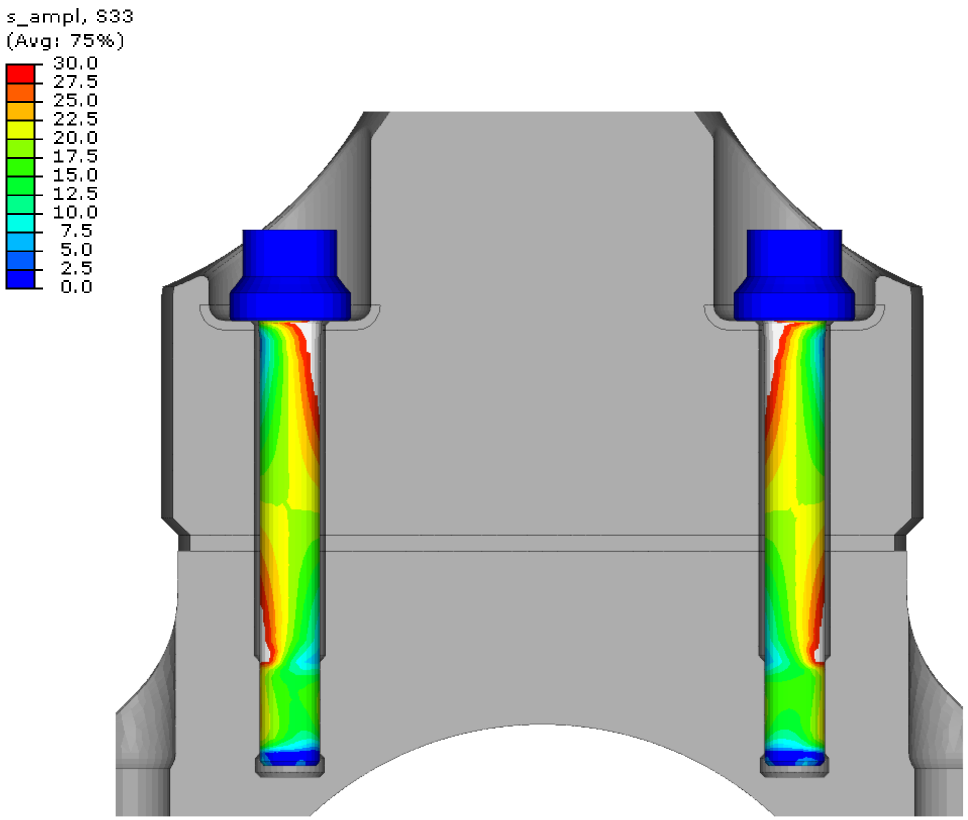
LOWER BOLT

- The dynamic tensile load is dominant, weak influence of bending is visible
- The stress concentration included by Method II overestimates bolt dynamic stress by 44%
- Effect of bolt cross-section applied in FE model is on the level of 8.5%.

Differences in resultant bolt dynamic stress due to chosen evaluation method and cross-section area used in bolt class III FE model can be significant

MARINE TYPE CONNECTING ROD



BOTH SHANK-BIG EYE BOLTS

- A combination of dynamic tension, compression and bending (by bending moment and shearing force) is observed
- The evaluation according to Method II is not performed, since only bolt cross-section of A_{d3} is considered
- Nearly equal share of tensile and bending load occurs

	Method I	Method II	Method III
Bolt cross-section in FE model	A_{d3}		
Resultant max. amplitude stress of the bolt	20.8 MPa	-	38.3 MPa

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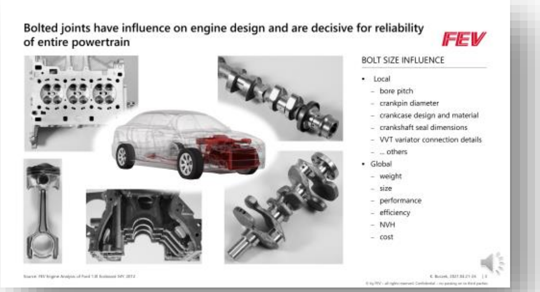
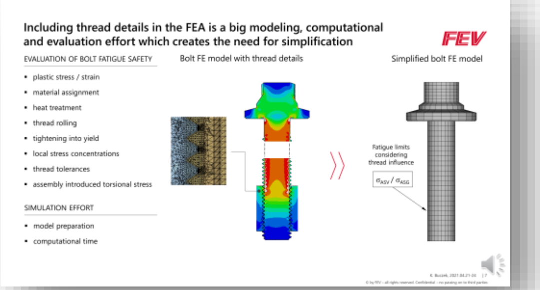
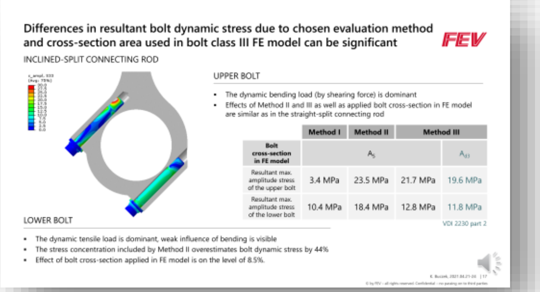
SUMMARY

Bolted joints are critical for engine reliability







- Bolted joint is a one of main fasteners used in the powertrain industry
- Bolt size influence weight, size, performance, efficiency, NVH and cost of the powertrain
- Downsizing of bolted joints requires precise evaluation with application of FEA
- Effective application of FEA in simulation of bolted joint requires simplification of bolt geometry (no thread details)
- FE modeling and post-processing of the simplified bolt have significant influence on the assessment of bolt fatigue safety

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THANKS FOR YOUR INTEREST!

谢谢

Buczek, K., Bartosik, M., Sułkowski, P.,
"Bolted Joints - Still a Key Part of Efficient Powertrains and a Challenge for Simulation“,
SAE Technical Paper 2020-01-2221, 2020,
https://doi.org/10.4271/2020-01-2221.