COMSOL CONFERENCE
2017 ROTTERDAM

Multiphysics model to ensure power cables are restrained safely

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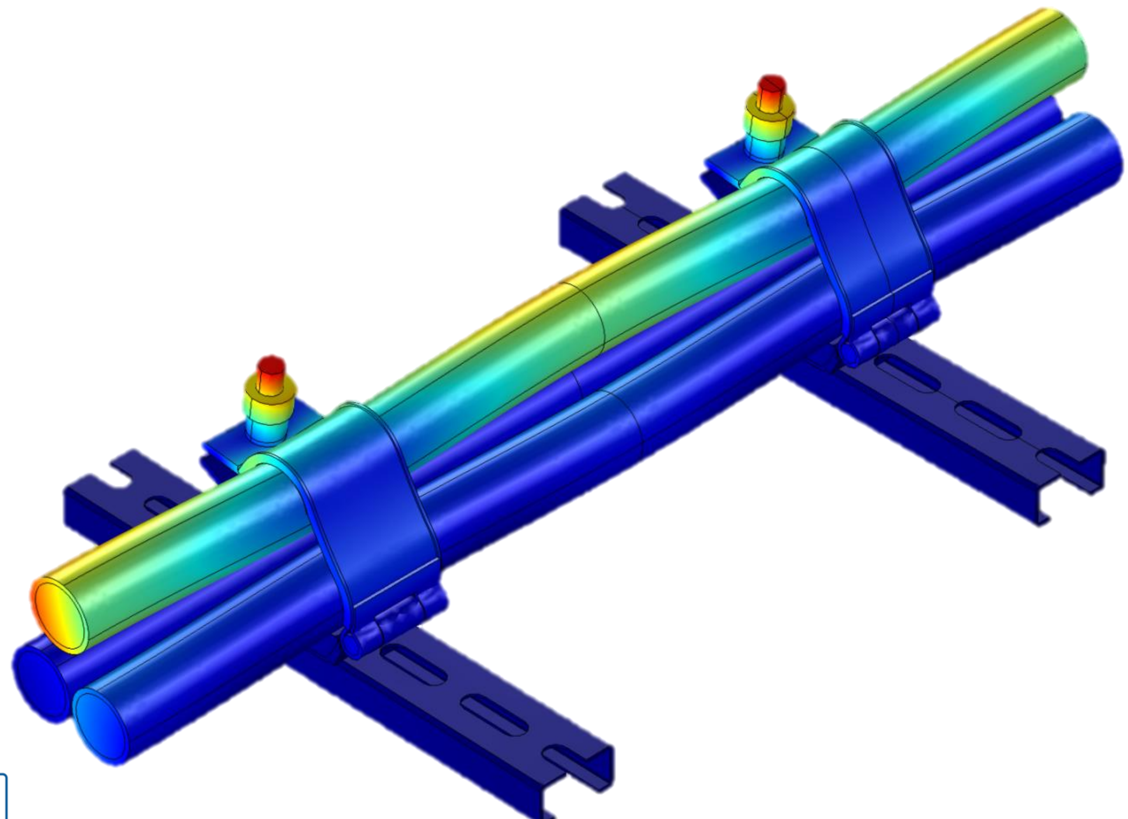

Presenter: Mark Yeoman PhD

Date: 19 October 2017

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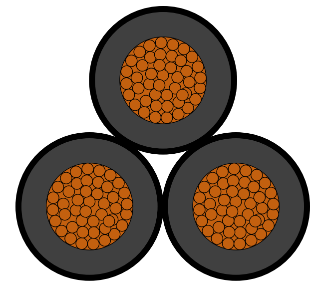
Single Phase Cables

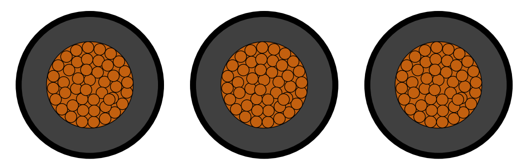
Trefoil & Flat Formation

- Three phases, single core configurations:
  - Trefoil & Flat formation
- Minimises the induction of eddy currents
  - Reduce the effect of localised heating, while maintaining the current carrying capacity of the circuit
- Ideal for medium to high voltage cables
  - Up to 400kV

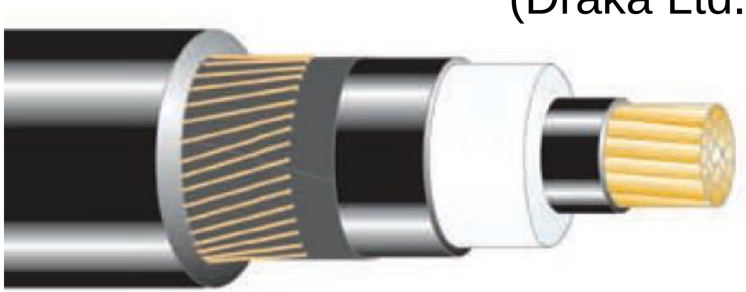
Trefoil Formation

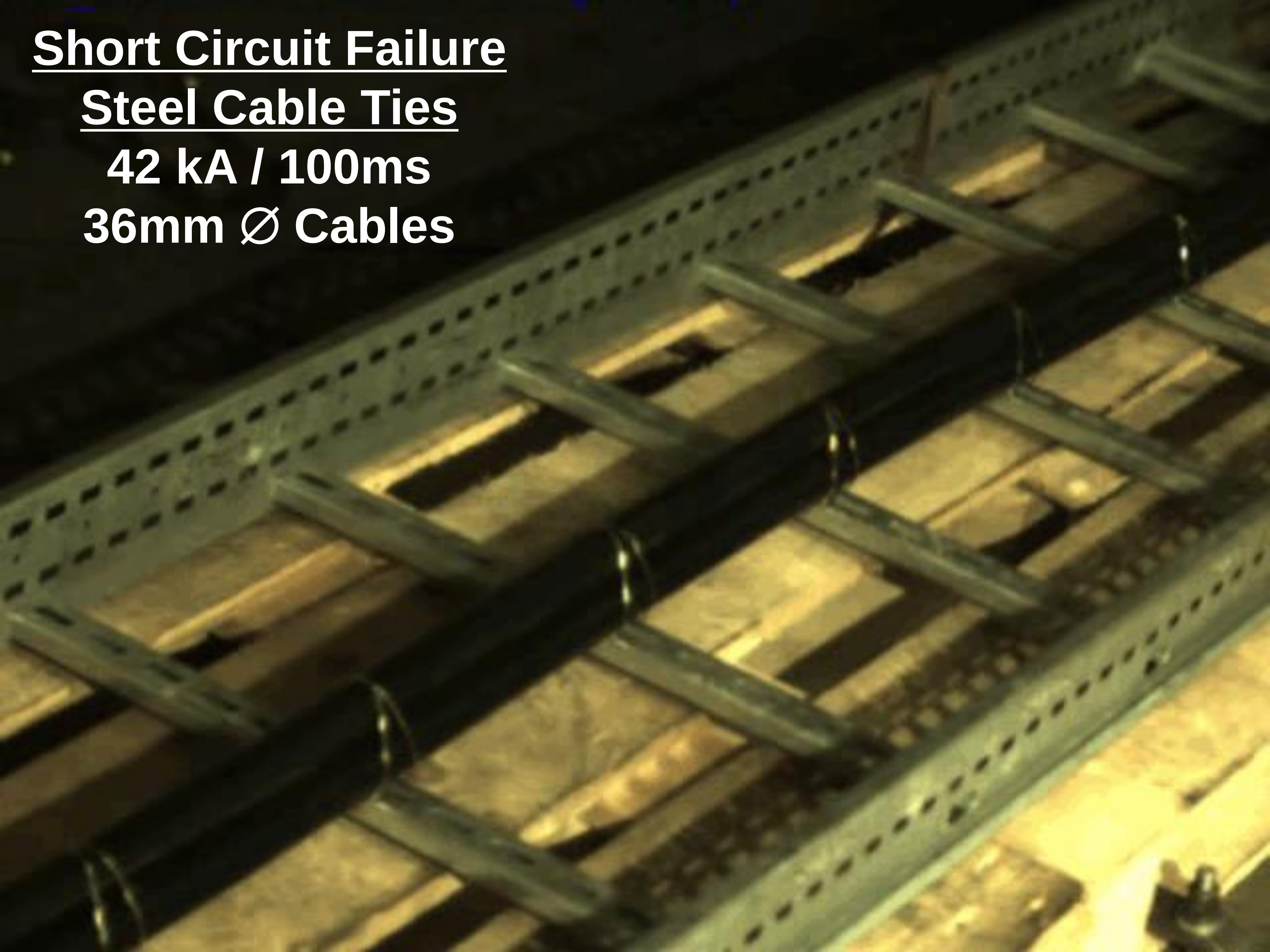


Flat Formation



Unarmoured single core medium voltage cable (Draka Ltd. UK)




Short Circuit Failure
Steel Cable Ties
42 kA / 100ms
36mm ∅ Cables

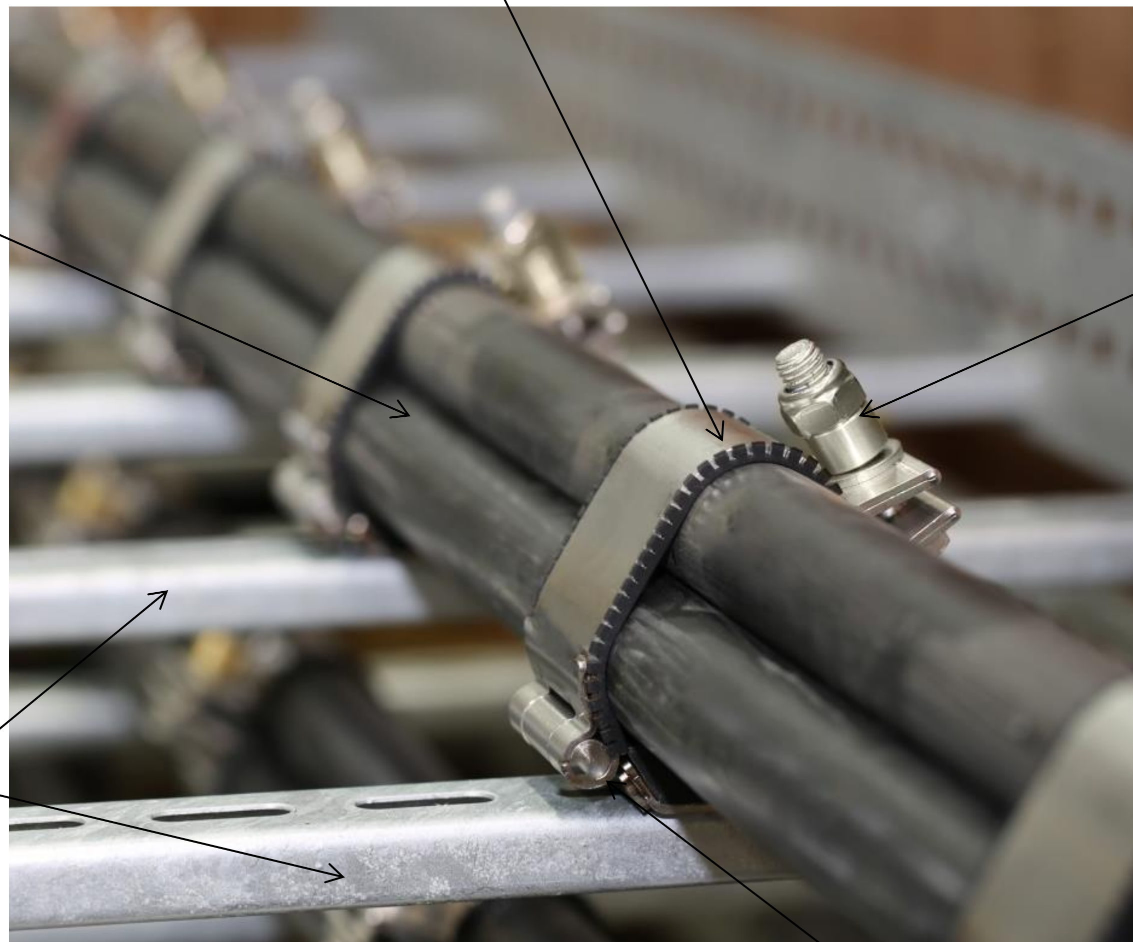
Trefoil Cleat Designs in Use

Current: up to 200kA

liner

Power cables in trefoil formation

Clamping bolt & spacer

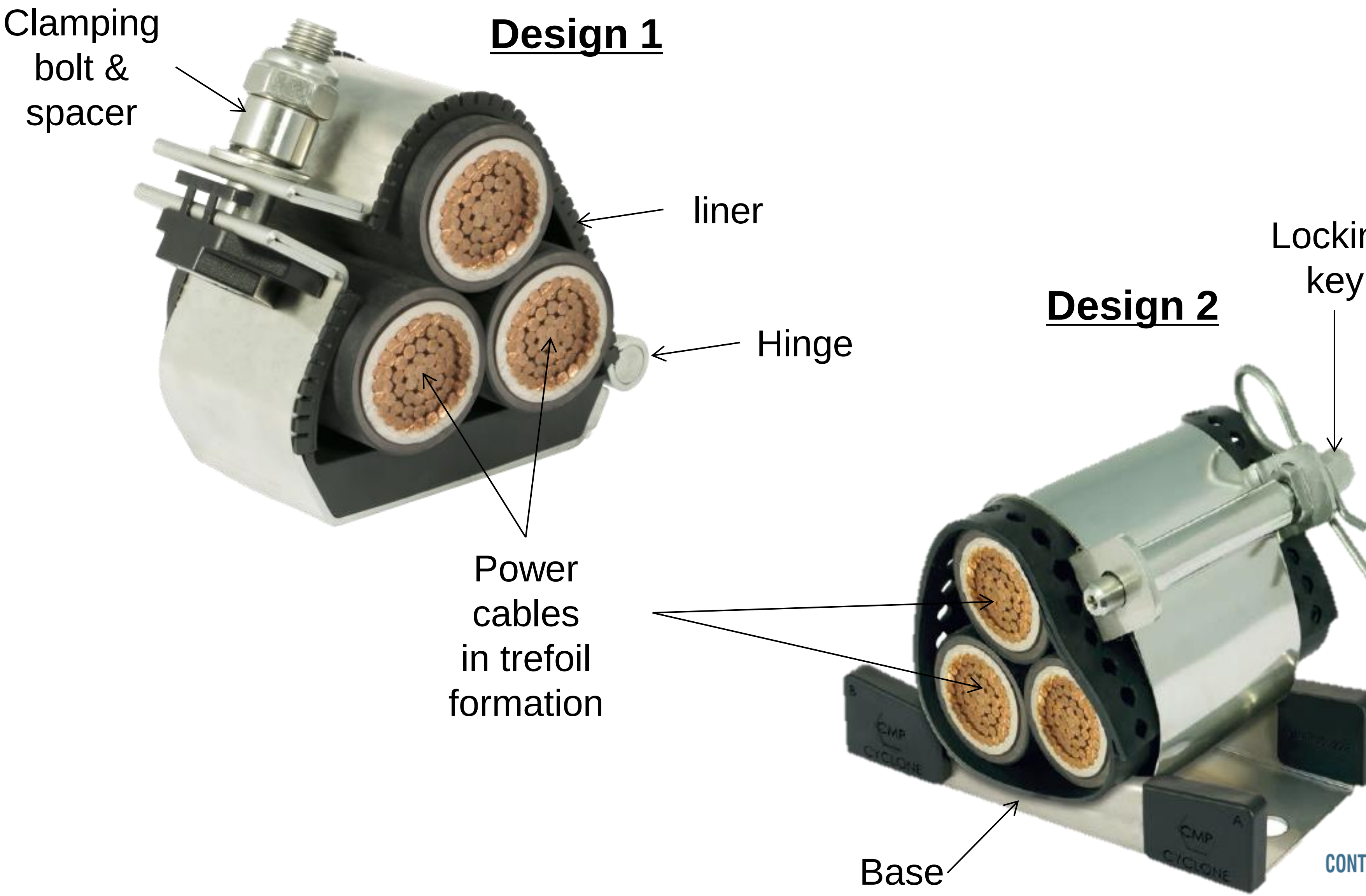


Attachment ladder fixed to wall/ceiling

Hinge

Example trefoil Cleat Designs

VARIOUS



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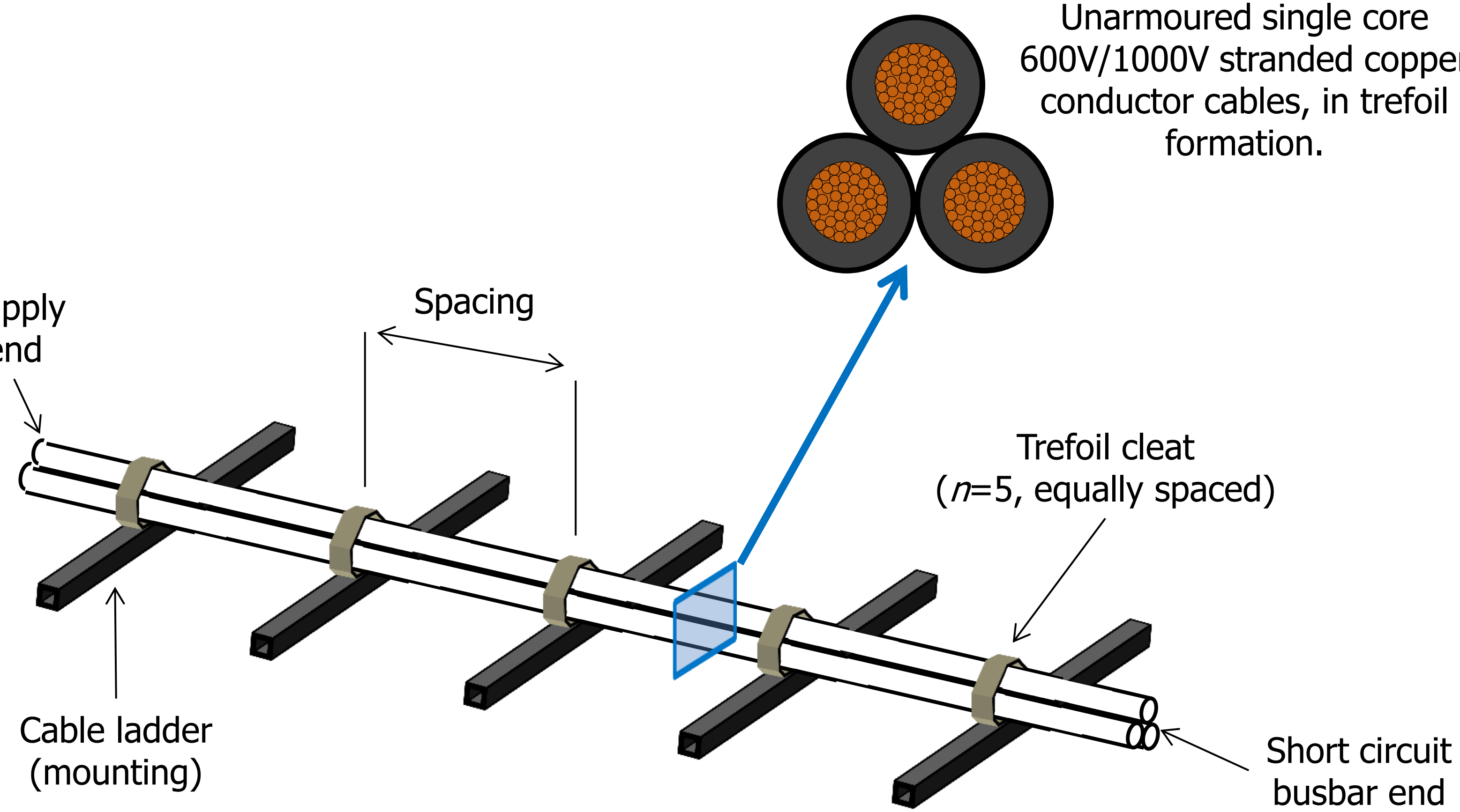
Trefoil Test Configuration

IEC 61914:2015 Standard

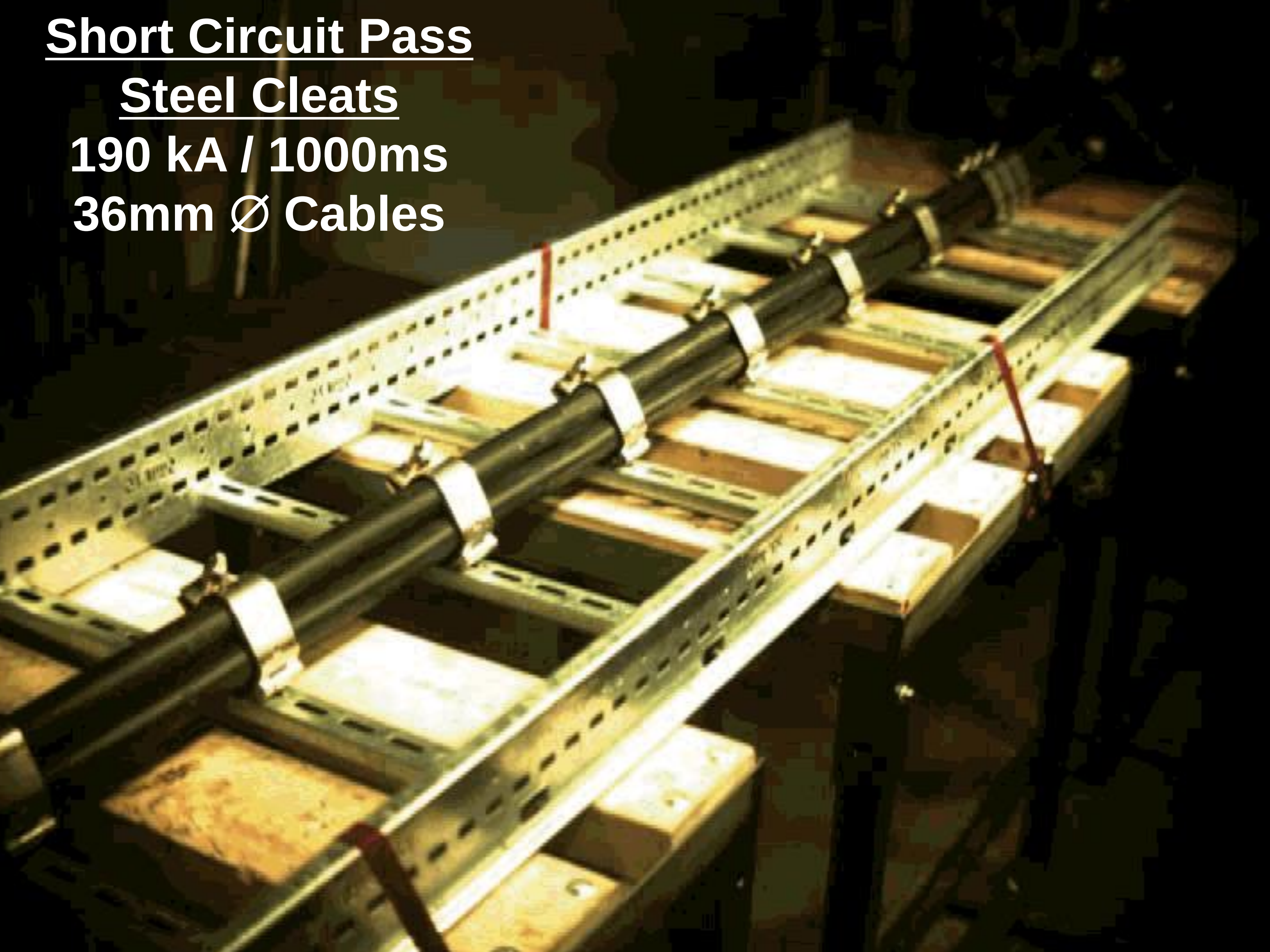


Short Circuit Pass

Steel Cleats

190 kA / 1000ms

36mm ∅ Cables



STANDARD TEST ALLOWANCES

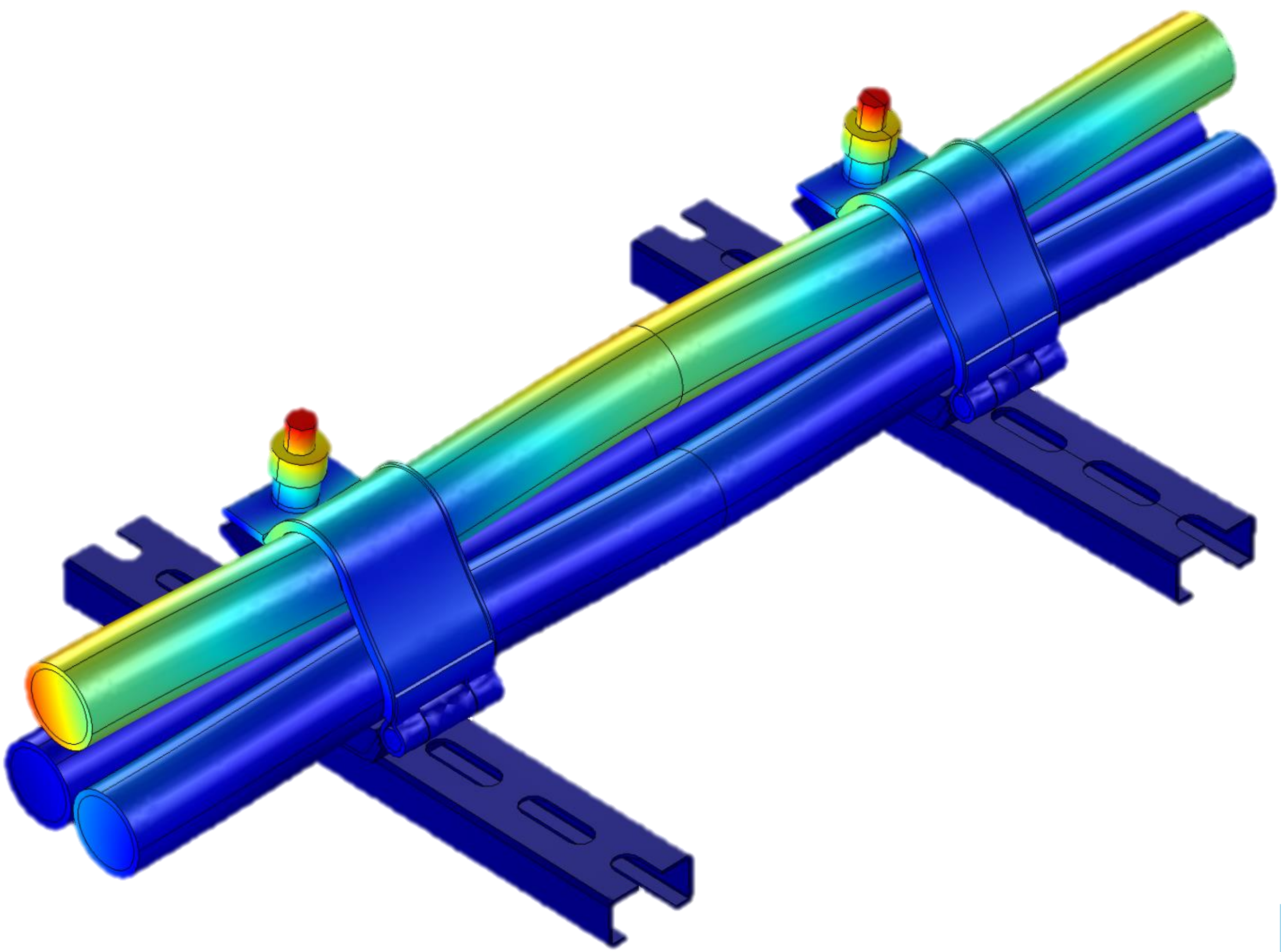
Standard
(IEC 61914:2015)

→ Not necessary for manufacturer of cleats to test product to standards

→ Test setup allows discretion of user to change/adjust ladder, ladder mountings & bolts.
- Stiffer ladder & ladder mountings can change results drastically
- Different size bolts & bolt specifications including torque loading can pass/fail cleat design

→ Orientation of cleats can be at users discretion
- For single bolt systems, bolt can be placed on either side depending on user preference

→ Certification by 3rd party
- Only requires inspection & observation of physical test
- Pass/fail for grade



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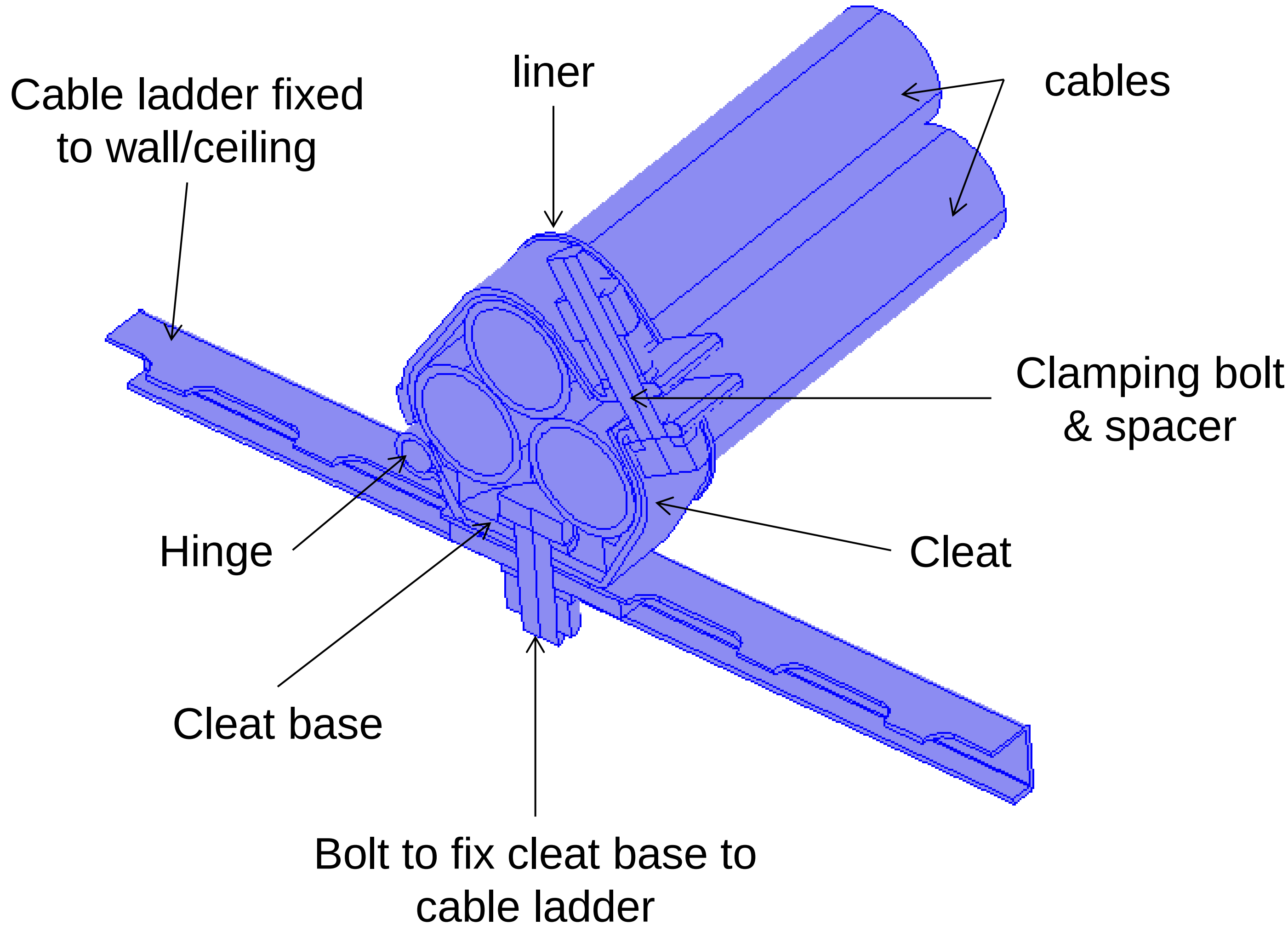
COMPONENTS MODELLED



Load Conditions & Install Configuration

Cleat type: Design 1
Cleat Configuration: 33-38
Cable diameter: 36 mm
Cable Core Area: 500 mm^2
Cleat spacing: 300 mm
Peak fault current: 190 kA
.

Coupled Physics & Boundary Conditions

Coupled Physics & Mathematics

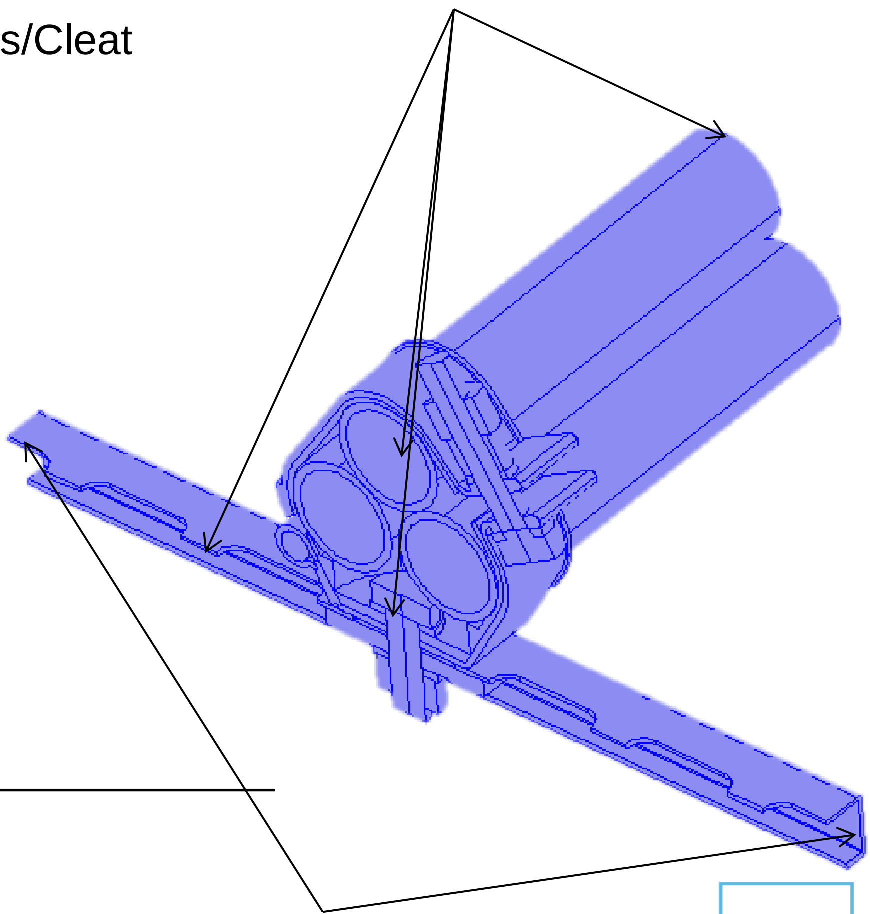
& Boundary Conditions

Structural Mechanics
- Hyperelastic Material → Sheath
- Plasticity → Copper Cores
- Contact Mechanics → Cables/Cleat

Electrical (AC)
- AC → Copper Cores
- Current density applied

Magnetic
- Magnetic field (B)
- Lorentz Forces

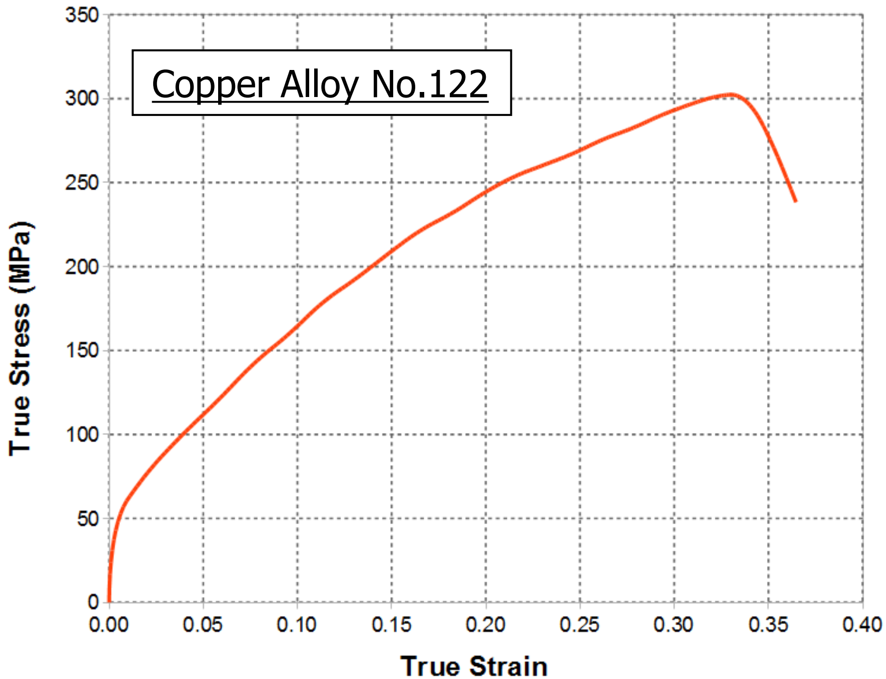
Moving mesh
- Updating cable positions



MATERIAL RELATIONS

→ Hyper-elastic Material
- Polyurethane Sheath

Material Models → Elasto-plastic Materials
- Cable Cores
- Copper Alloy No.122
- Stainless Steel Cleat

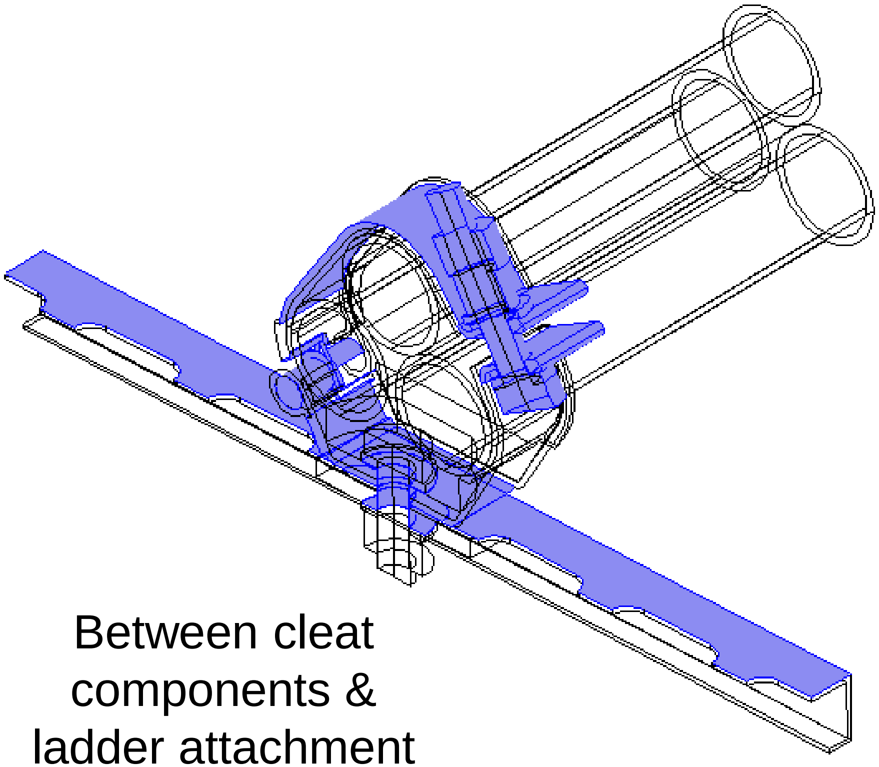


Stainless Steel
Mechanical Properties
(Utilized Minimum value in range)

Young's modulus	190	-	203	GPa
Flexural modulus	190	-	203	GPa
Shear modulus	74	-	81	GPa
Bulk modulus	134	-	151	GPa
Poisson's ratio	0.265	-	0.275	
Shape factor	62			
Yield strength (elastic limit)	205	-	310	MPa
Tensile strength	510	-	620	MPa

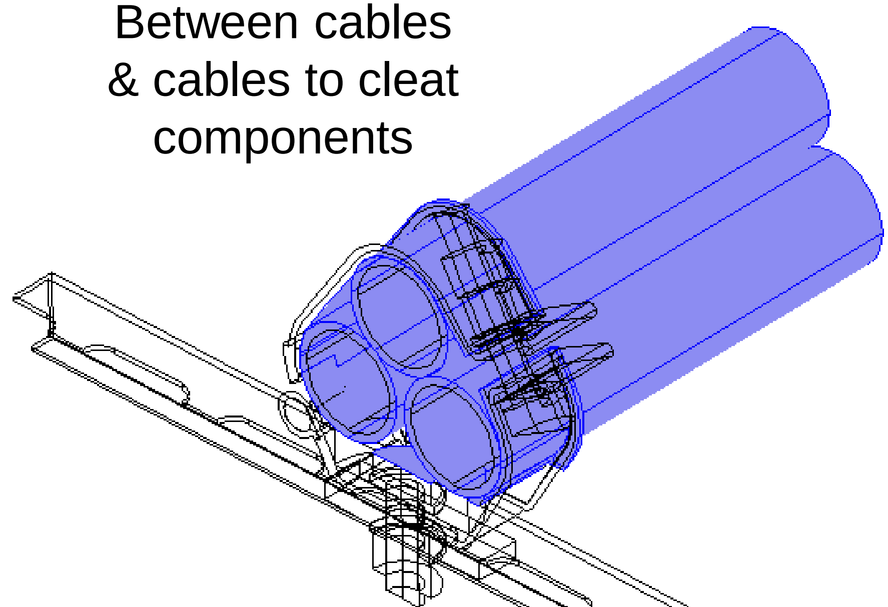
CONTACT

COULOMB FRICTION

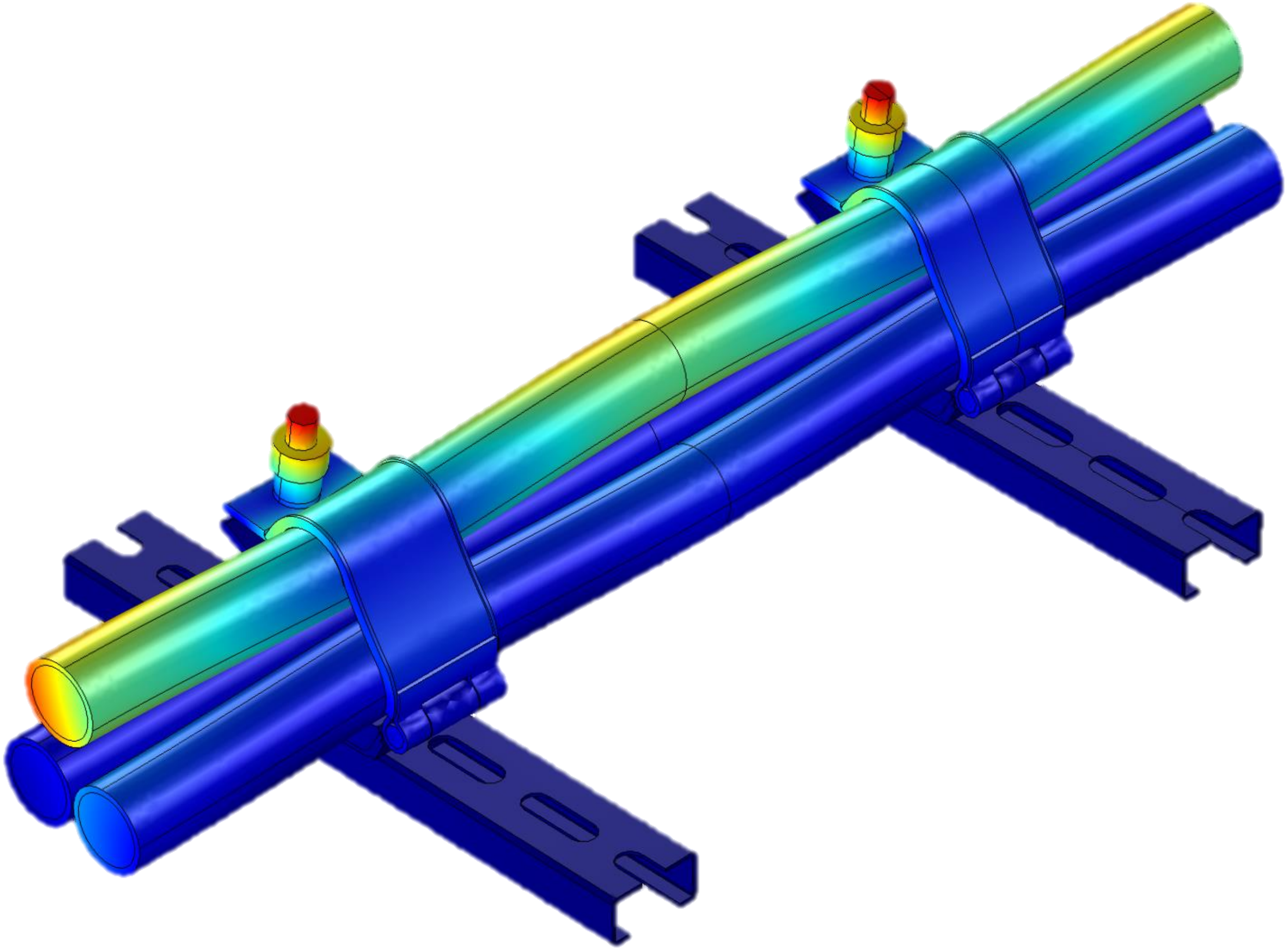


Between cleat components & ladder attachment

Between cables & cables to cleat components



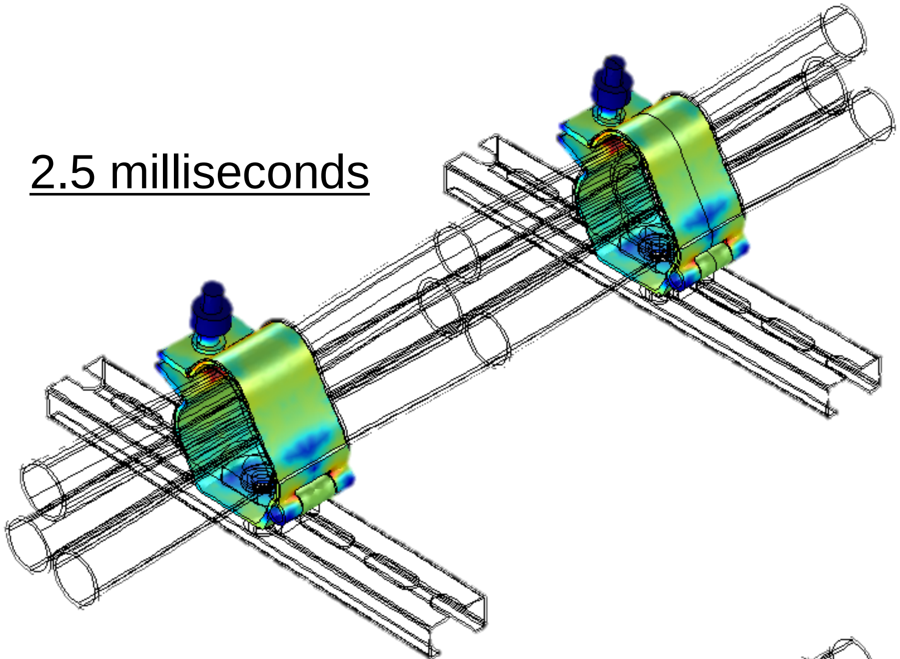
Over 15 individual contact sets



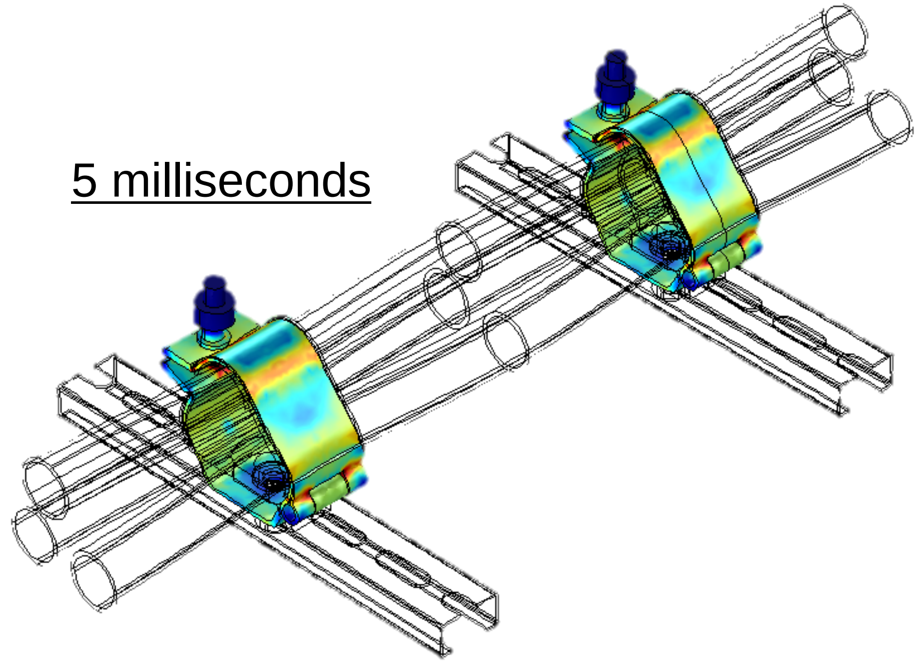
Cleat Stresses

During Short-Circuit

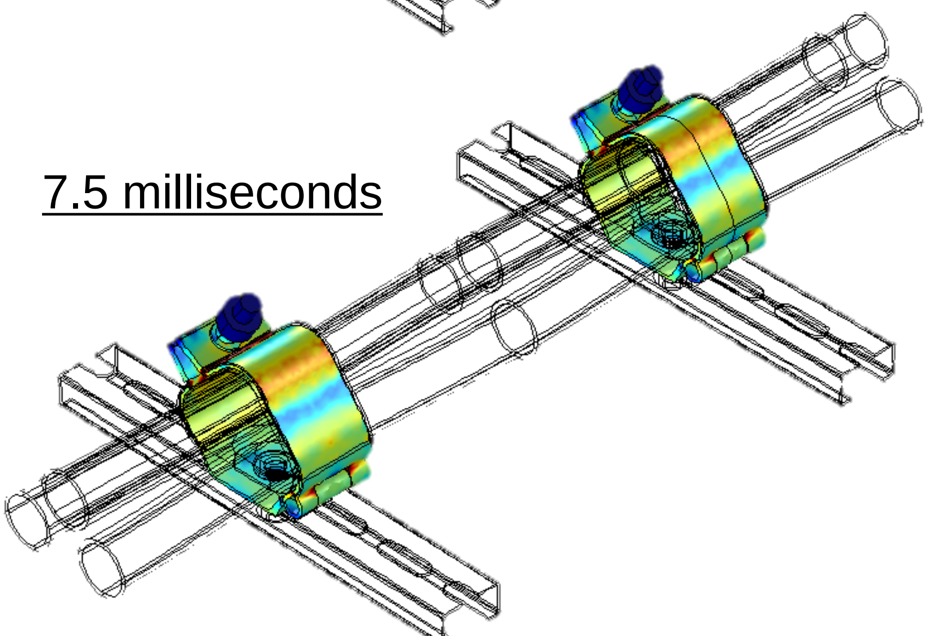
2.5 milliseconds



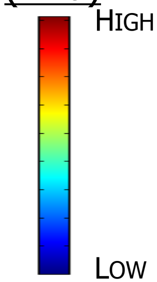
5 milliseconds



7.5 milliseconds



Stress (MPa)



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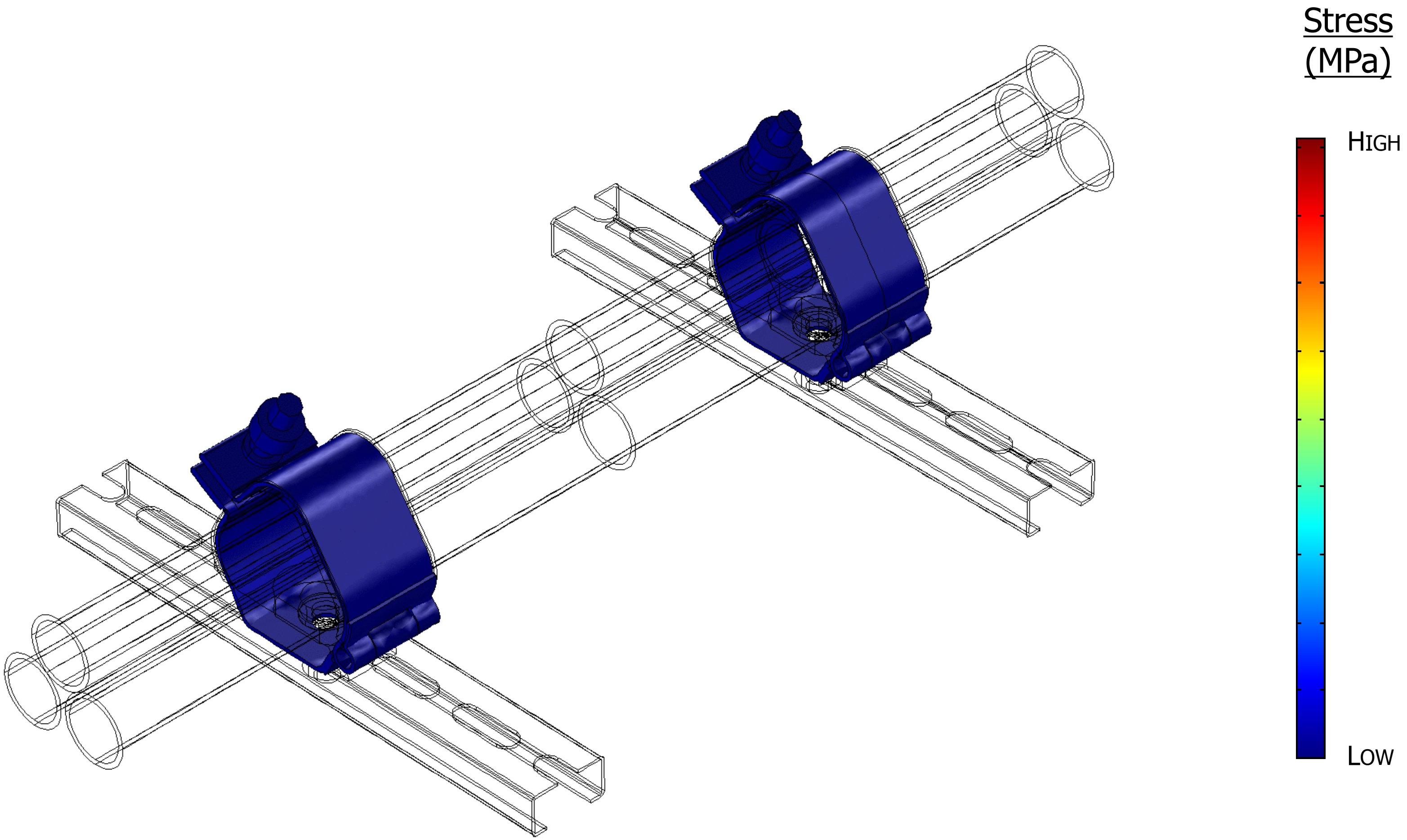
Cleat Stresses

Animation



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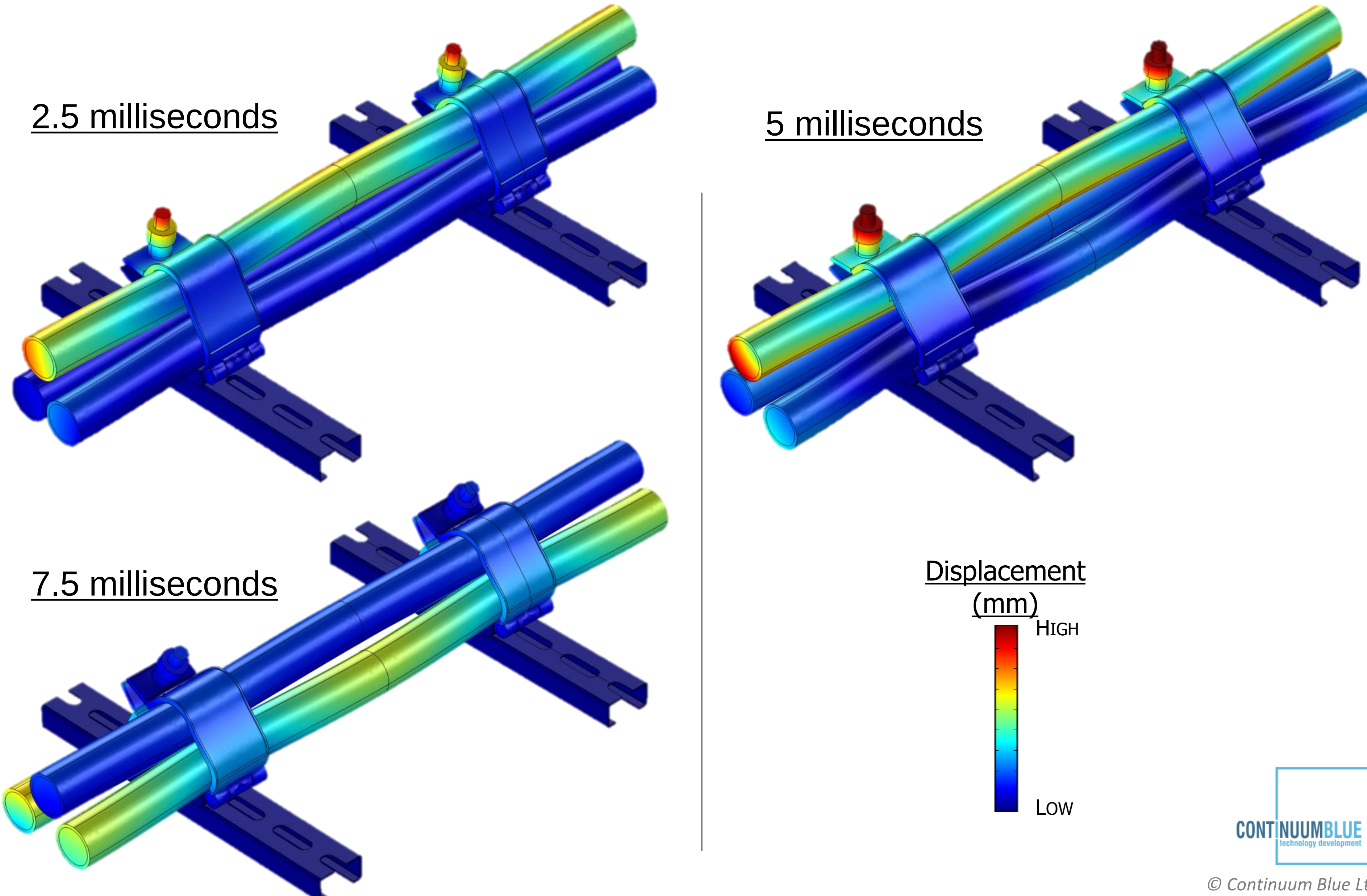
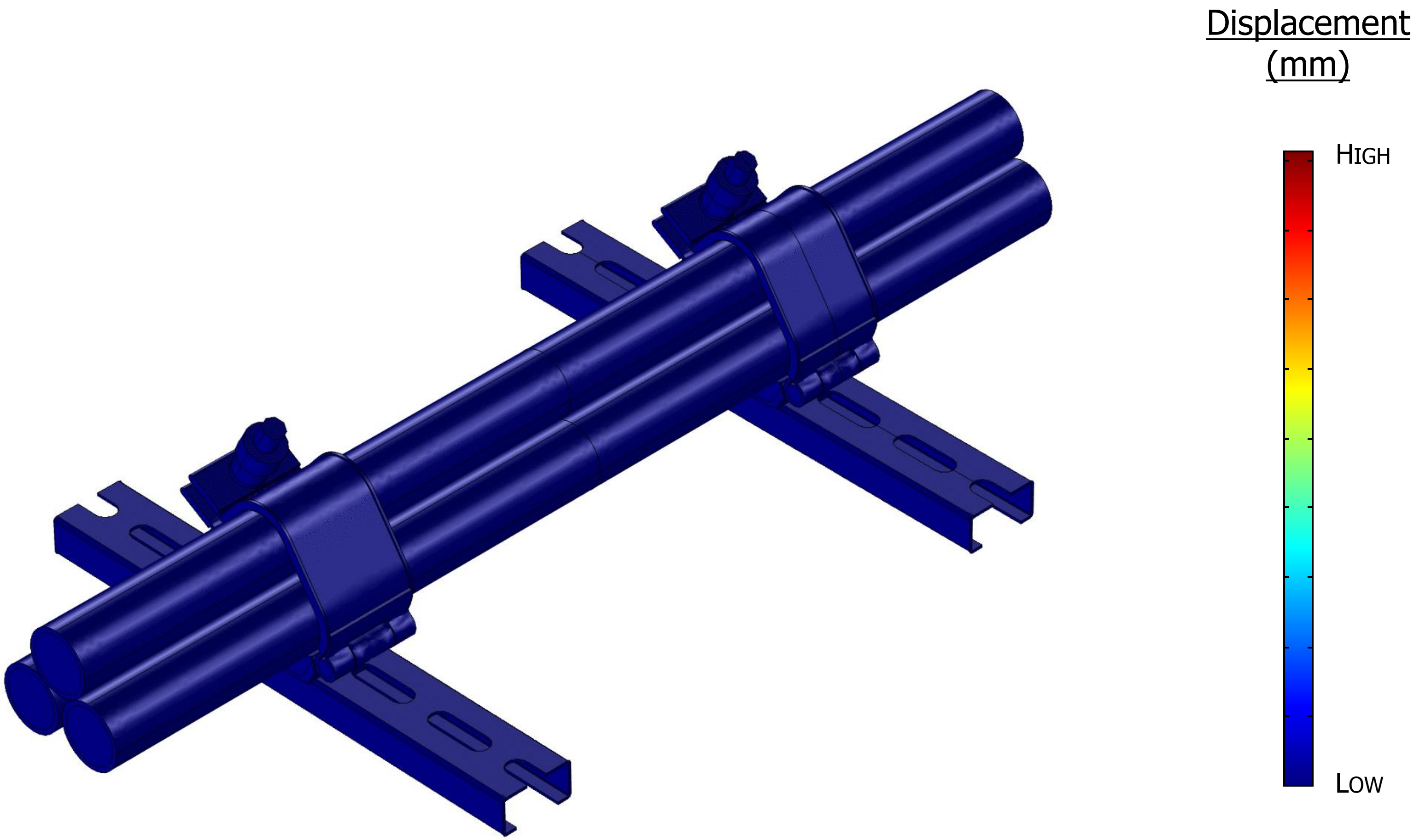
Cable & Cleat Displacements

During Short-Circuit



Cable & Cleat Displacements

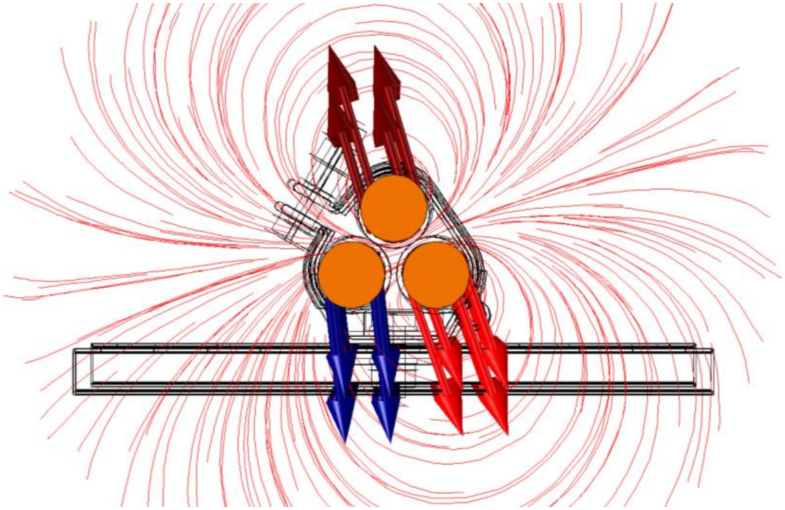
Animation



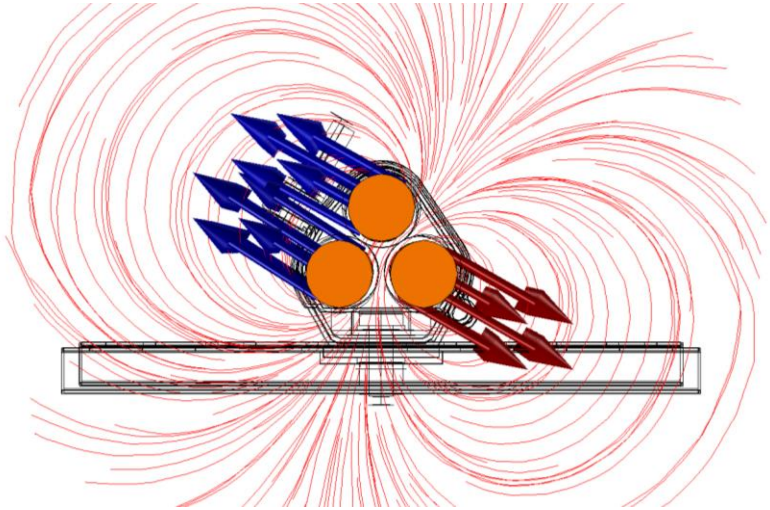
Force Vectors & Magnetic Field

During Short-Circuit

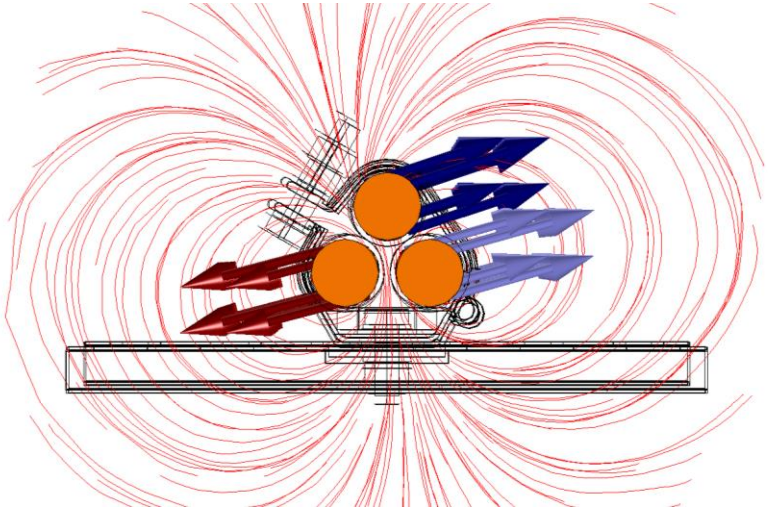
2.5 milliseconds



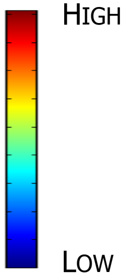
5 milliseconds



7.5 milliseconds

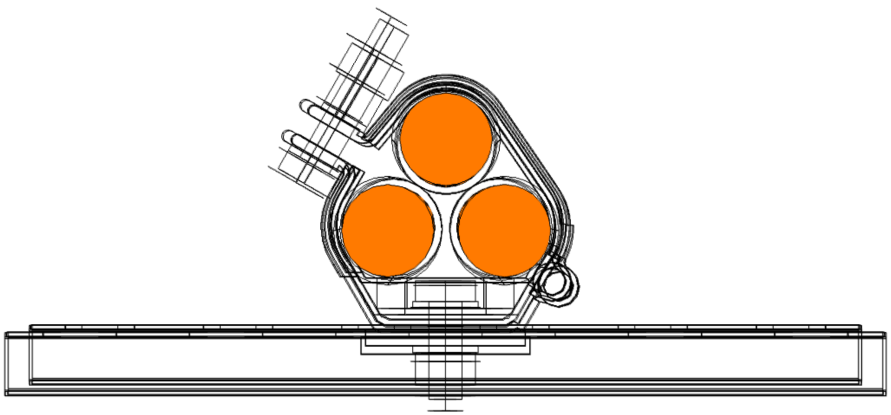


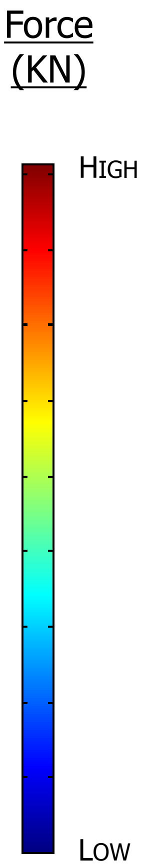
Conductor Force (kN)



FORCE VECTORS & MAGNETIC FIELD

ANIMATION





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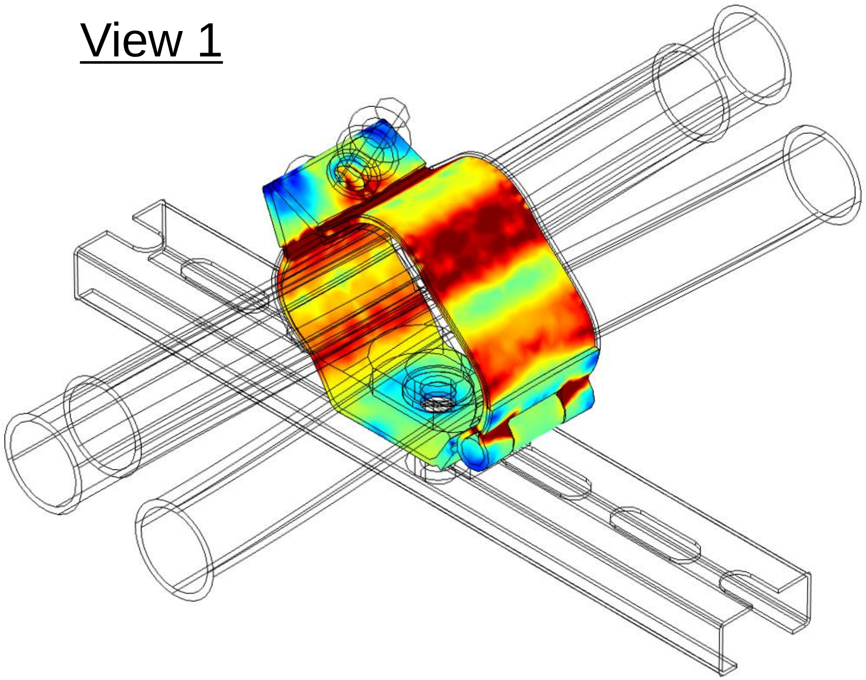
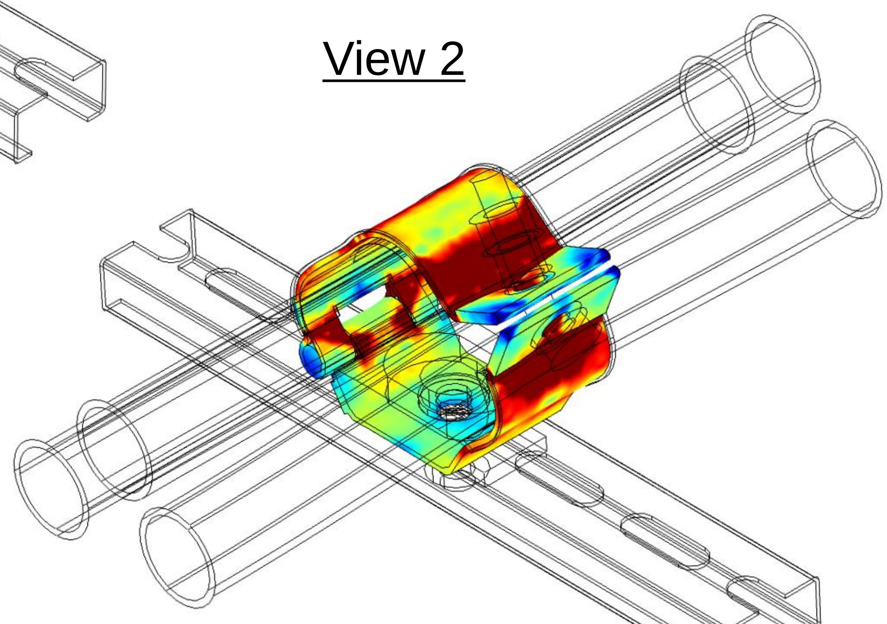
Residual Stresses in Cleat

After Short Circuit

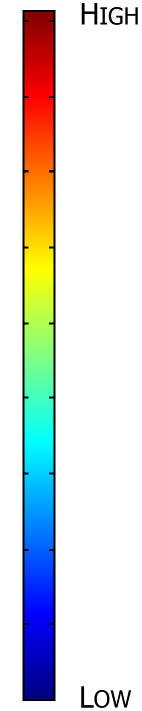
View 1



View 2



Residual Stress (MPa)



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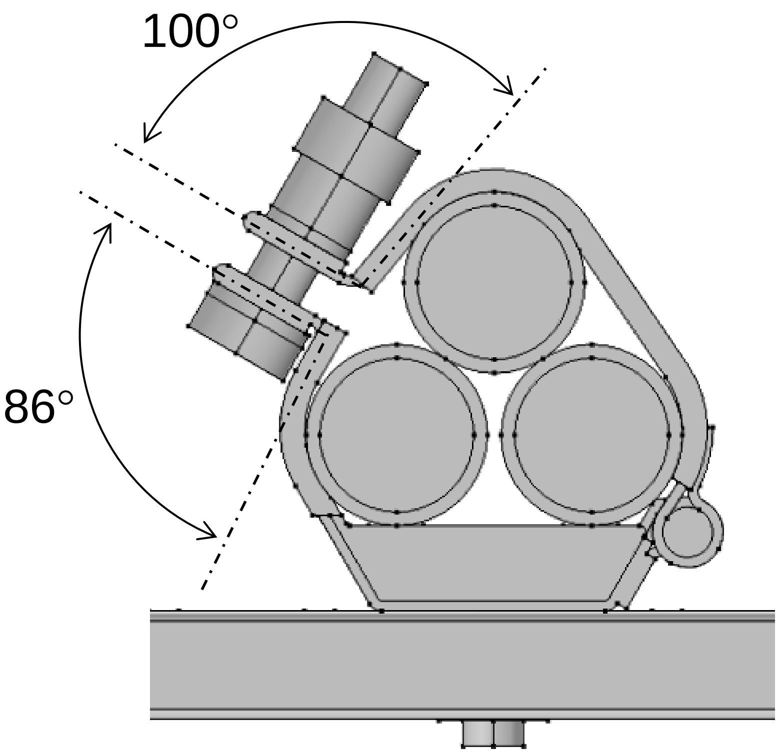
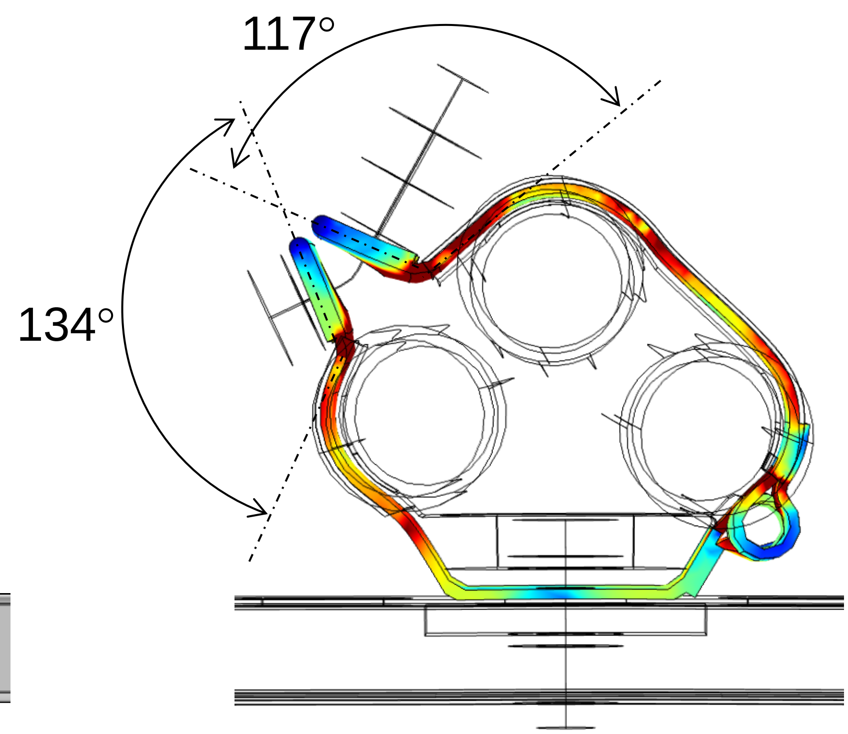
Permanent Deformation

After Short-Circuit

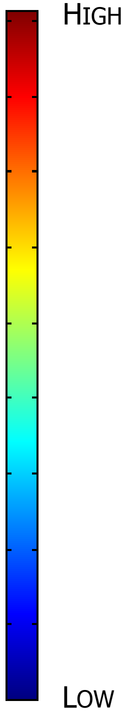
Initial Undeformed State



Final Deformed State & Residual Stress

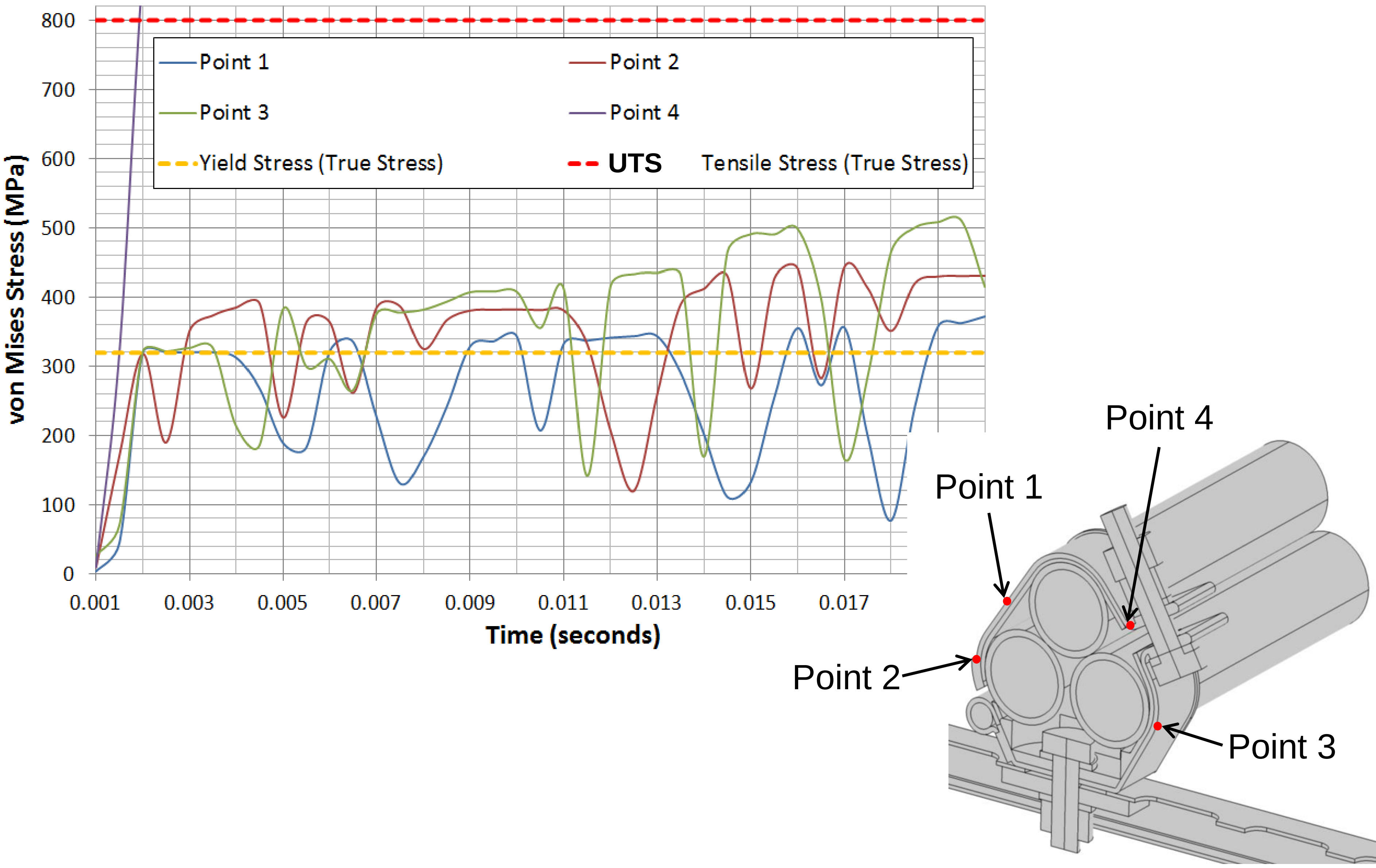


Residual Stress (MPa)



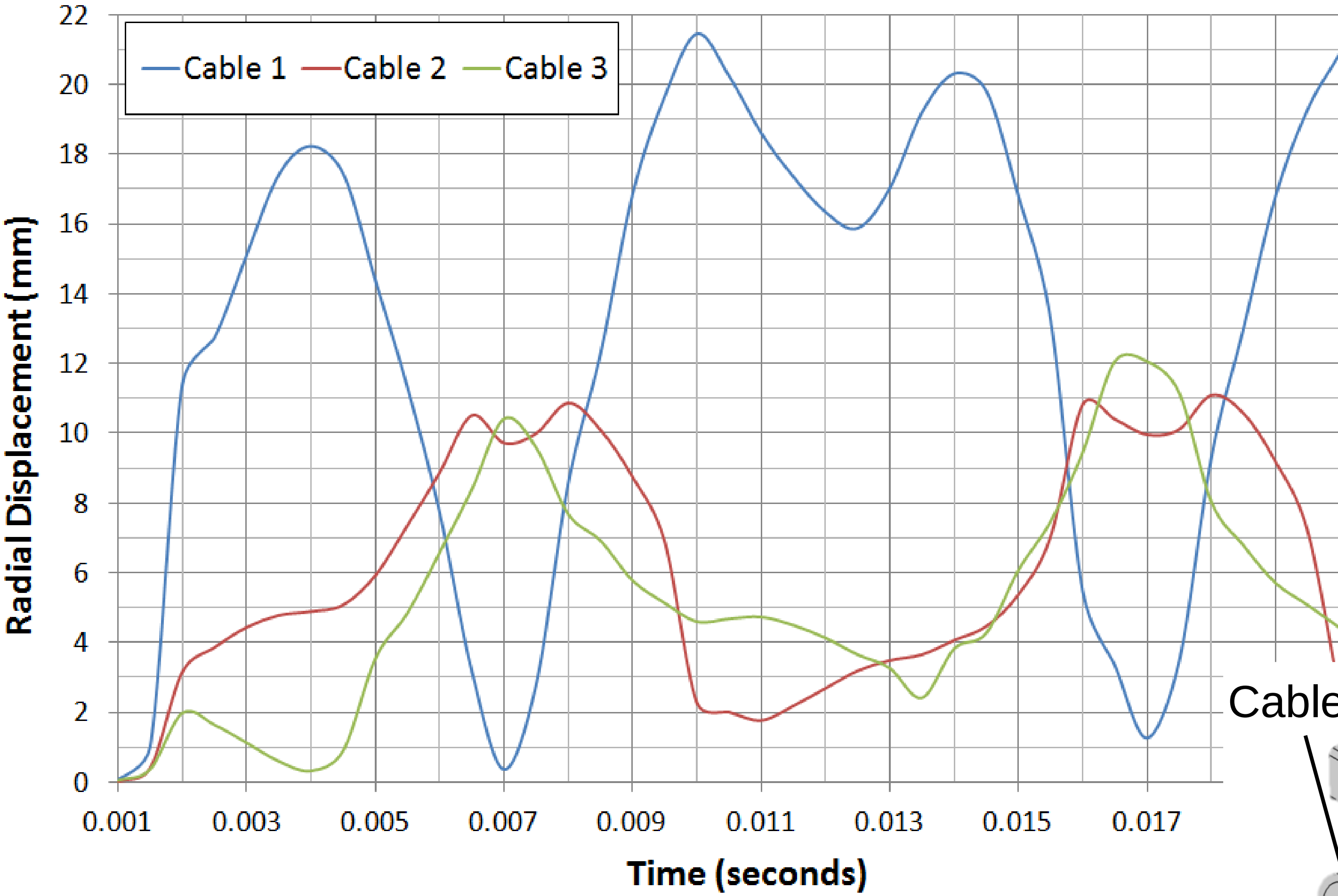
Stress Analysis at Specific Points

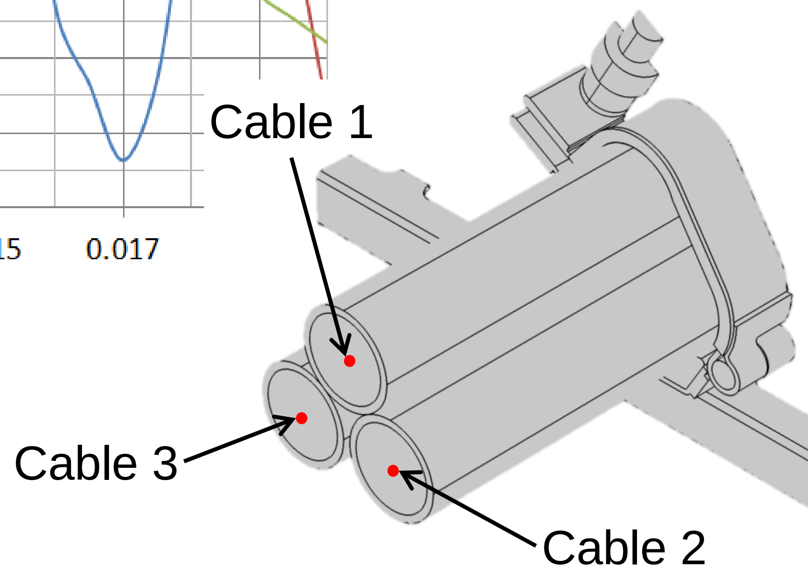
During Short-Circuit

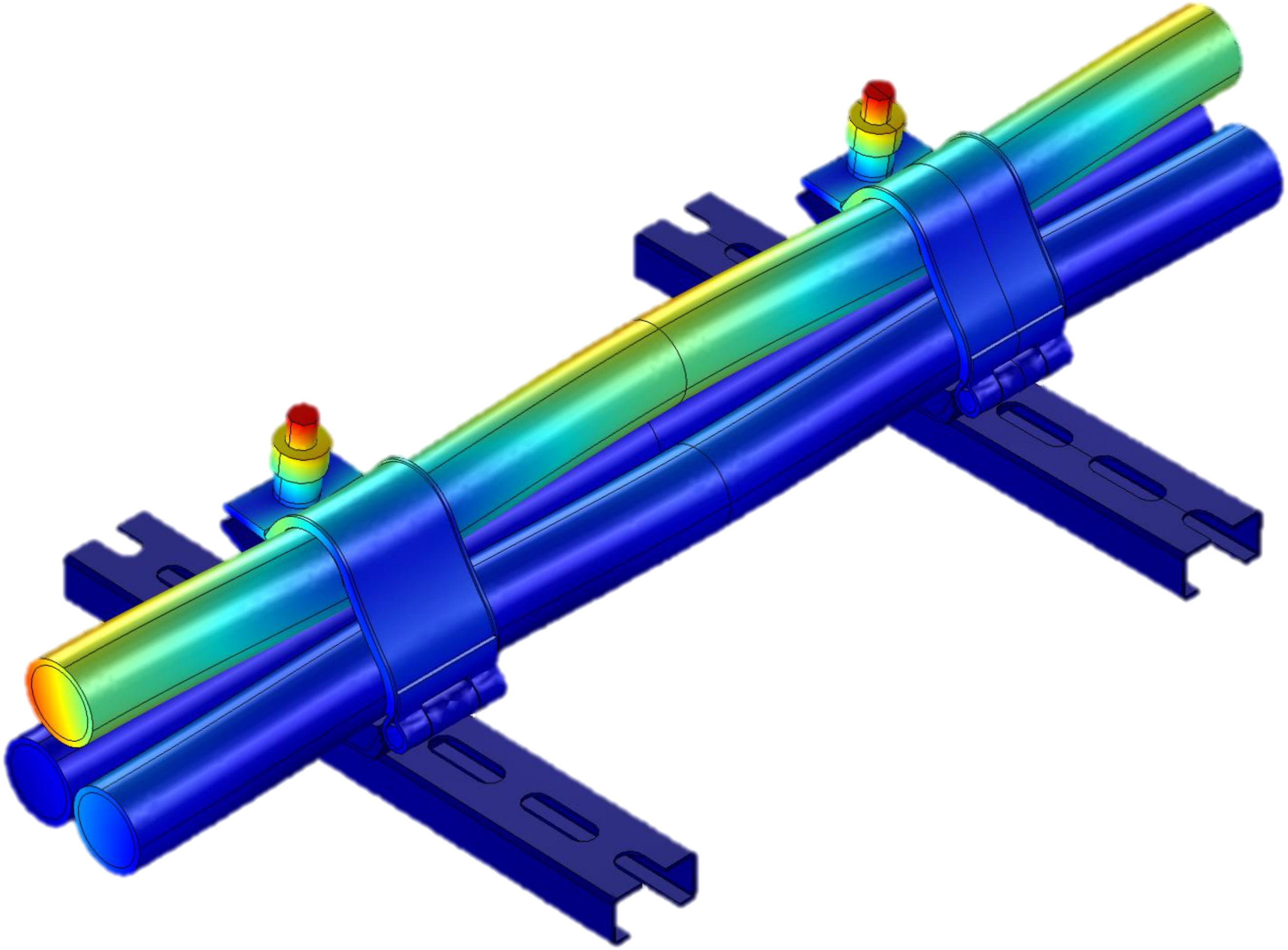


Cable Displacements

During Short-Circuit







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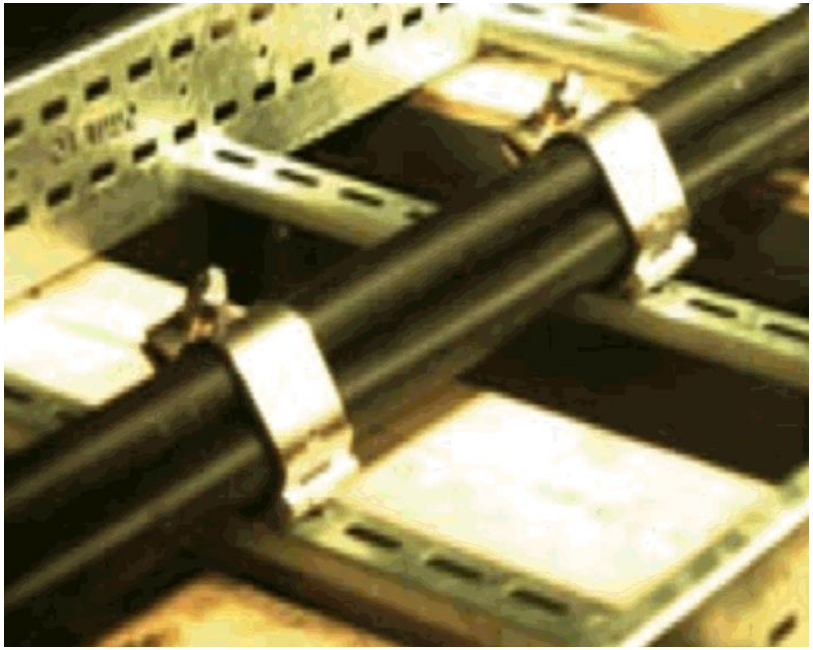
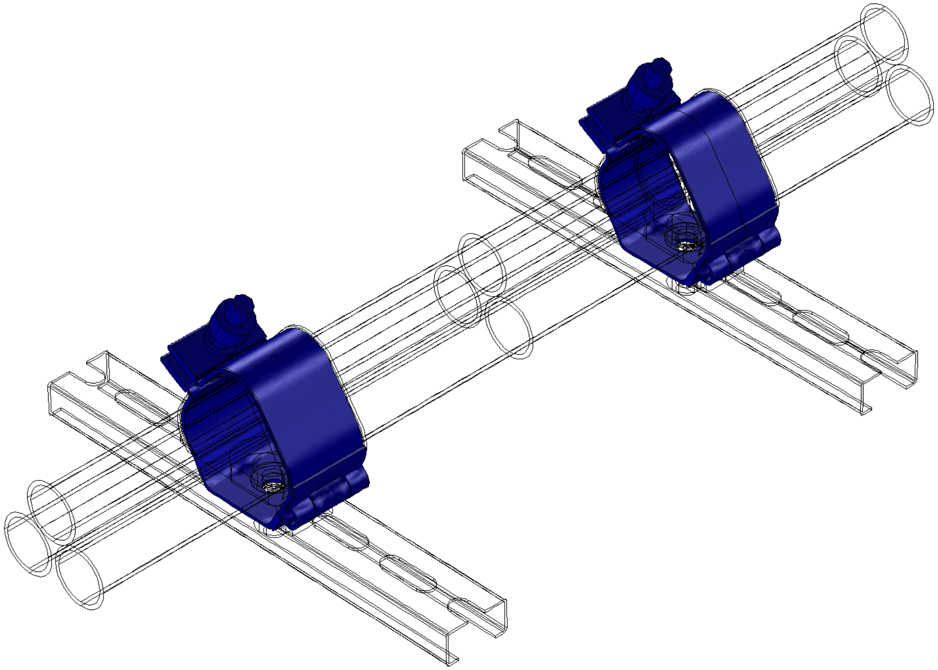
Comparison to Physical Tests

Physical Test



Model
(Cleat von Mises Stress)



VALIDATION

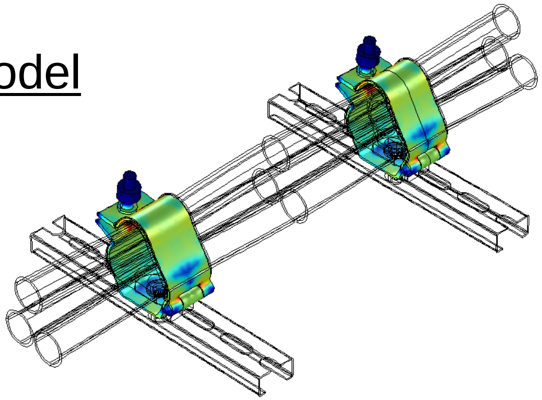
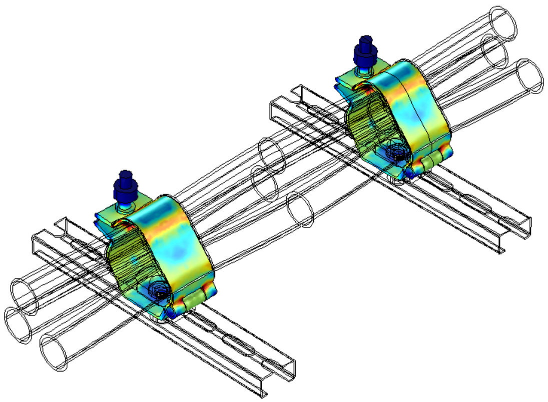
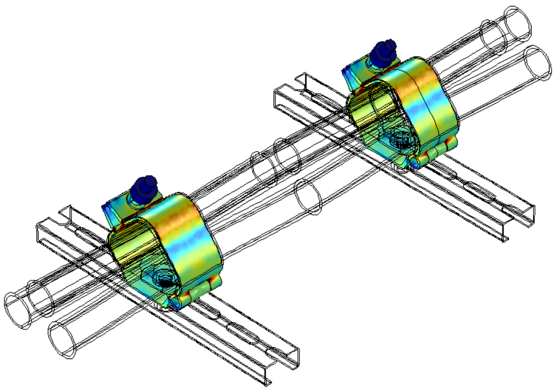
VARIOUS TIME POINTS

2.5 milliseconds	5 milliseconds	7.5 milliseconds

Physical Test



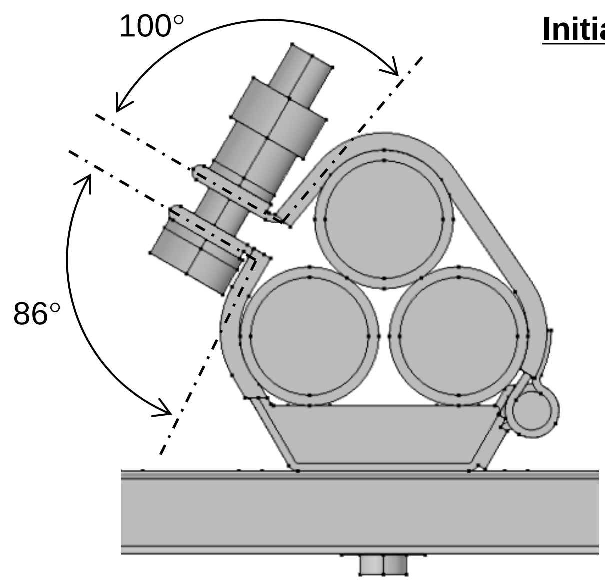
Model

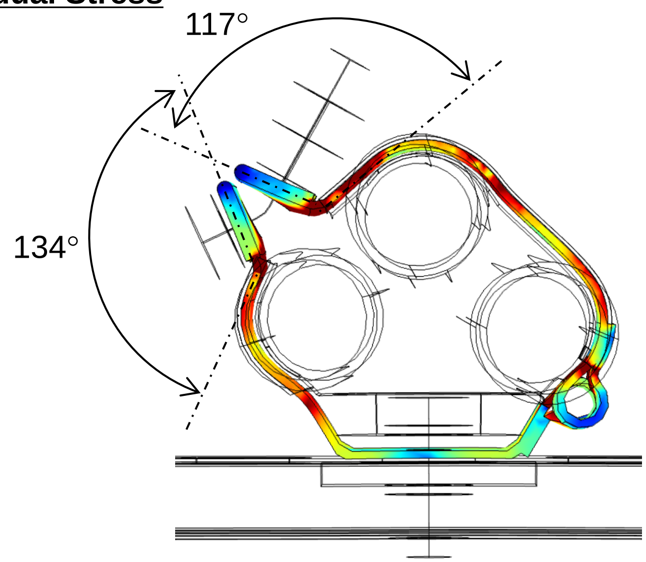
VALIDATION

PERMANENT DEFORMATION & RESIDUAL STRESS

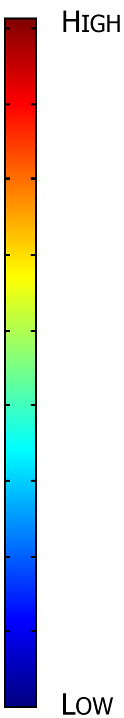
Initial Undeformed State



Final Deformed State & Residual Stress



Residual Stress (MPa)



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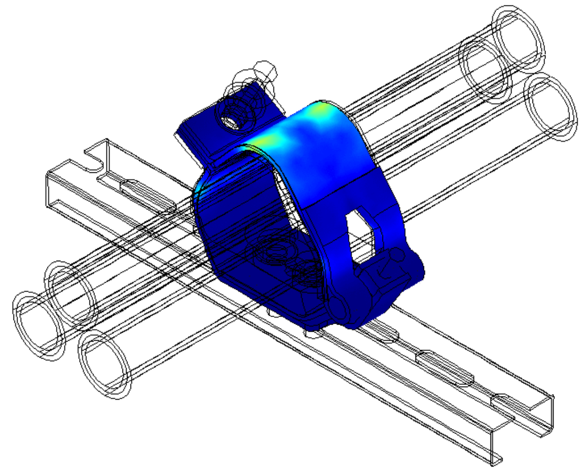
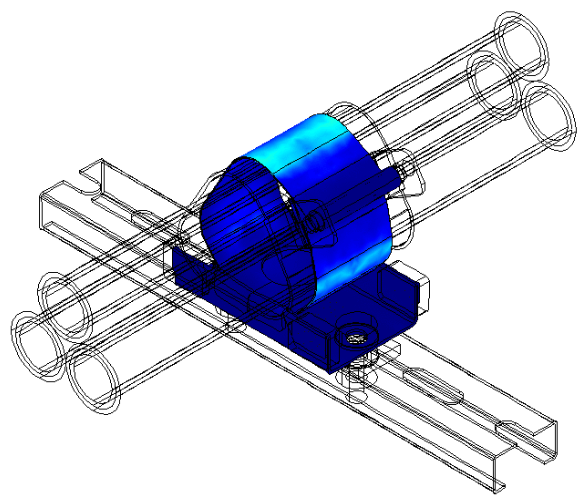
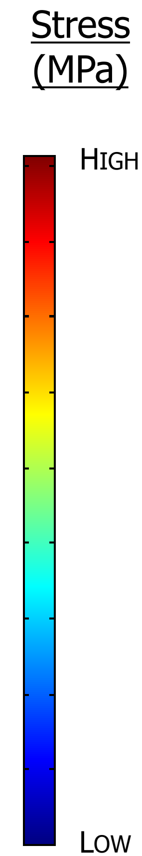
Other Cleat Designs & Physical Tests

Correlations



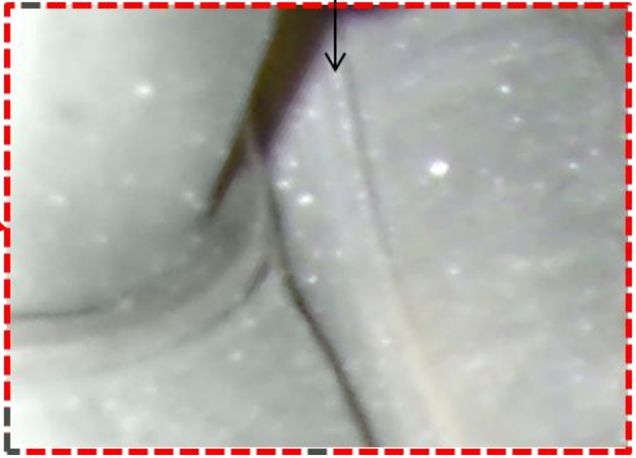


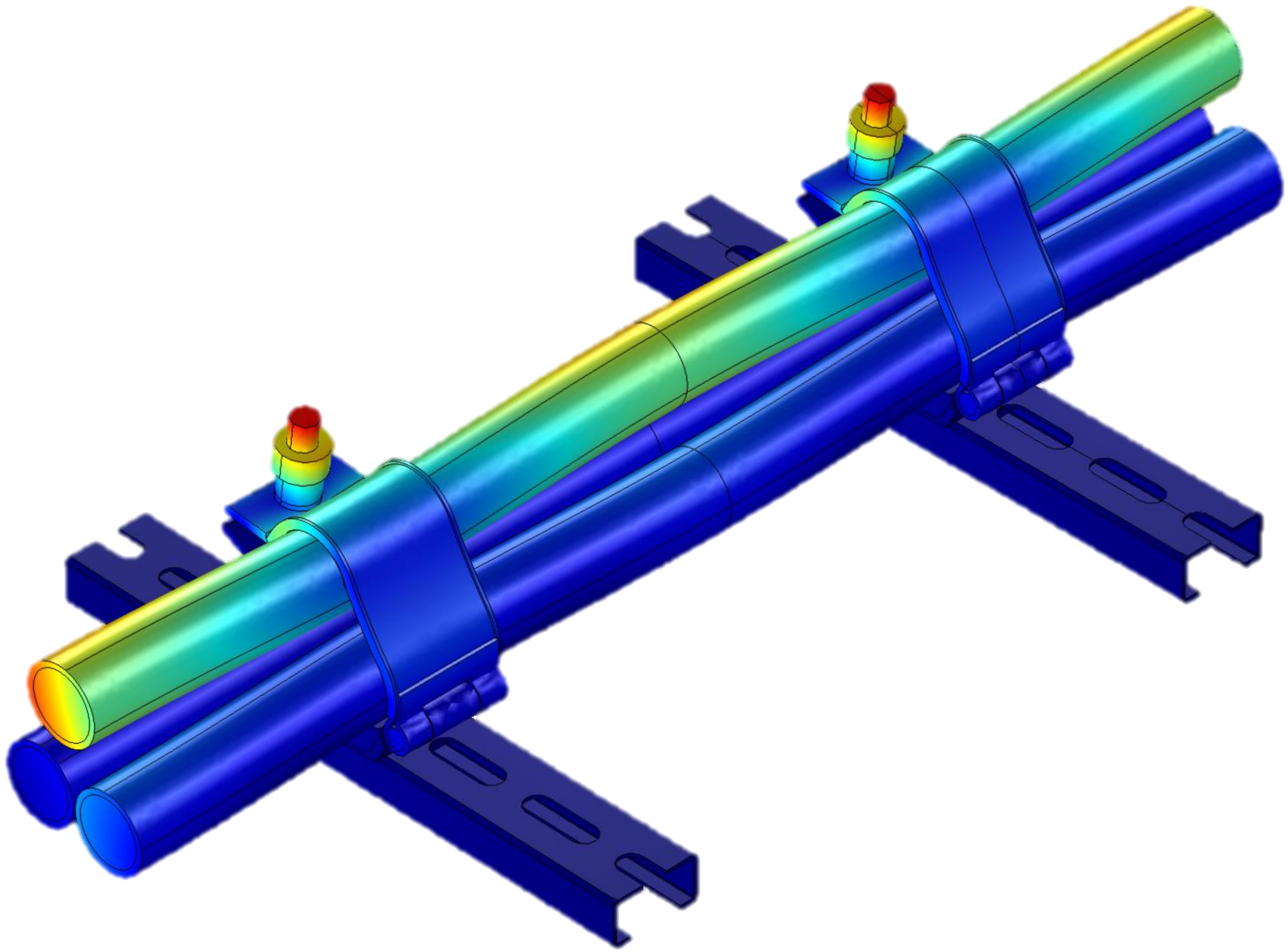


Superficial Surface Material Failure

Above UTS

Small amounts of micro-cracking on top surface of cleat wall at crease/bend





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Analytical Maximum Force

IEC 61914:2015 Standard

A three-phase short circuit in trefoil formation, the maximum force on the conductor as detailed in IEC 61914:2015 (Appendix B), is described by the following:

$$F_t = \frac{0.17 \times i_p^2}{S}$$

Where:

- F_t Maximum Force per unit length of cable (N/m)
- i_p Peak short circuit current (kA)
- S Centre-to-centre distance between neighbouring conductors (m)

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Model vs IEC 61914 Analytical Solution

Maximum force per unit cable length

IEC 61914 Standard	Model Results	
$$F_t = \frac{0.17 \times i_p^2}{S}$$ Parameters: S= 36mm i_p = 190kA	*Cable section constrained within cleat width only*	*Along whole length of cable, including cable length between adjacent cleats*
170.5 kN/m	159.3 kN/m	124.5 kN/m
Percentage Variation	-6.53%	-26.98%

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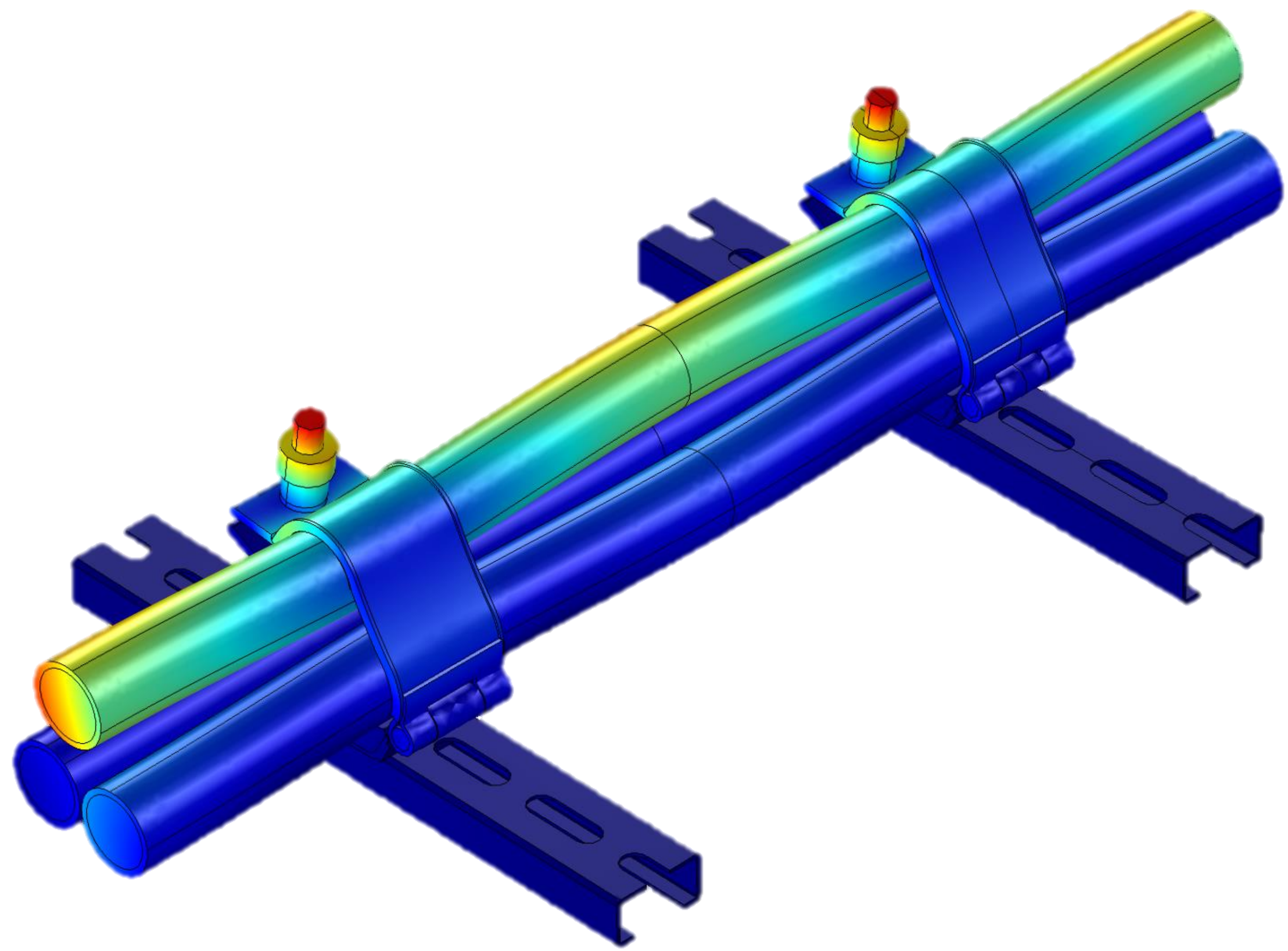

Conclusion

Design 3

- A 3D multiphysics model has been developed, which is fully parameterised and couples the electrical, magnetic and structural physics to fully describe the response of a constraining cleat under short-circuit conditions.

- The multiphysics model has been assessed & compared to physical tests for a range of cleat designs, sizes & spacing.

- The multiphysics model provides additional data for design engineers, which would not be possible to gain through physical tests. Additionally, this can provide data such as residual stresses within the cleat, which is not physically possible, without destroying the cleat in the process.

- The models maximum force per unit length observed by the short-circuiting cables has also been assessed & compared to the analytical solution from the IEC 61914:2015 standard, where the model predicts a value 6.53% lower to the analytical solution.

    - This is expected as the model takes into account movements of the cables within the cleat, & the resulting reduction in the electromagnetic forces.

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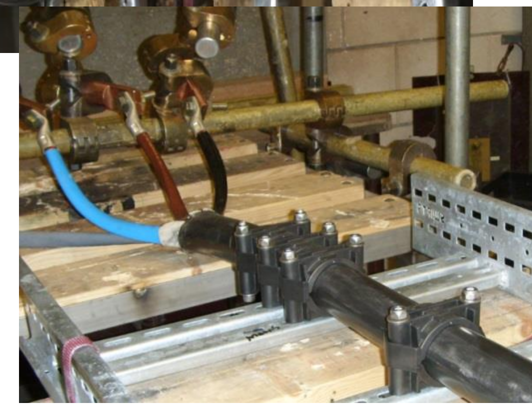
Discussion



- Much work still needs to be done on the multiphysics model, including further additions;
  - Intermediate straps,
  - Additional cable options, such as cable armour sheath material options.
  - Assessment of Category 2, or multiple short-circuit testing.
  - The possibility of two phase short-circuit faults, and how this may change the cleat performance.
- Standard requires short circuit to be done in particular phase in cycle
  - Thus, initial position of side bolt position: left vs. right will affect failure outcome
  - Standard needs to be updated to ensure test is carried out with side bolts positions alternated along length of ladder
- Test standard does not specify which cable copper alloy is to be used, only that cable must not have an armour layer
  - Copper alloys with low stiffness & yield point gives dramatically better results

THANK YOU

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Questions & Answers

Continuum Blue Ltd.

Research & Development

Multiphysics Modeling (FEA/CFD)

Motion & Load Analysis

Material Selection & Optimization

Testing & Assessment

Mechanical Testing

Material Assessment

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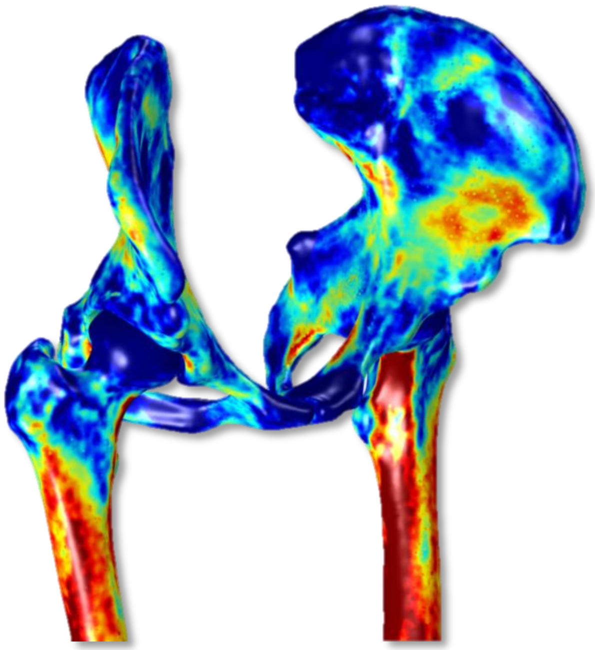
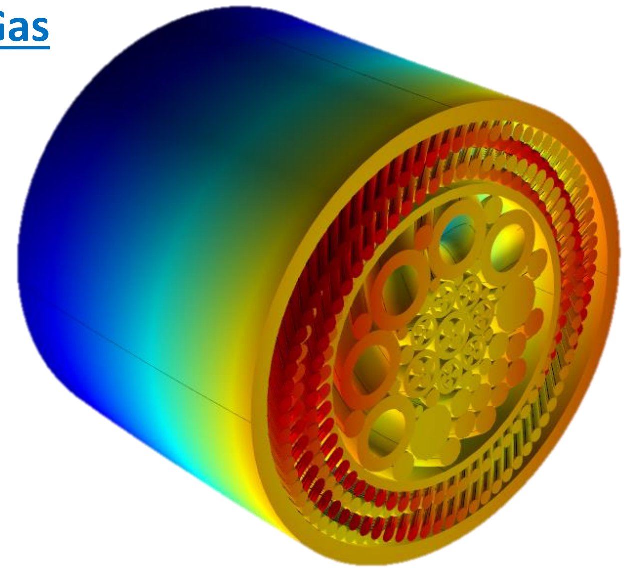
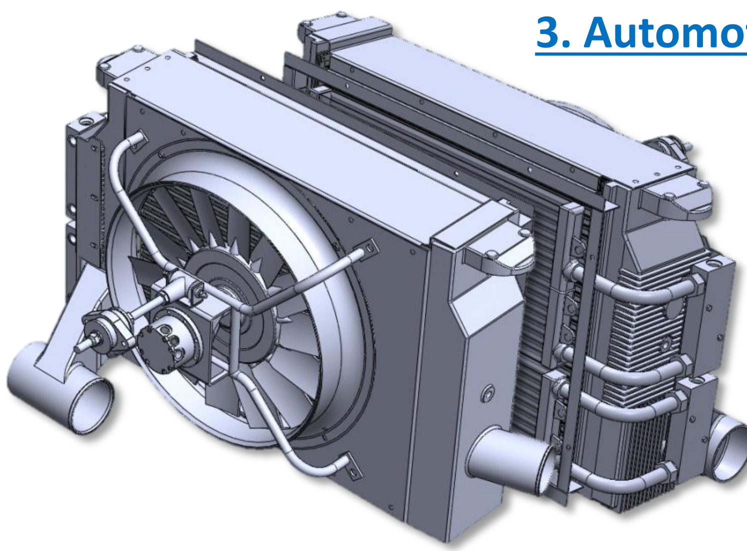


1. Medical Implants

2. Oil & Gas



3. Automotive



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CONTINUUMBLUE technology development

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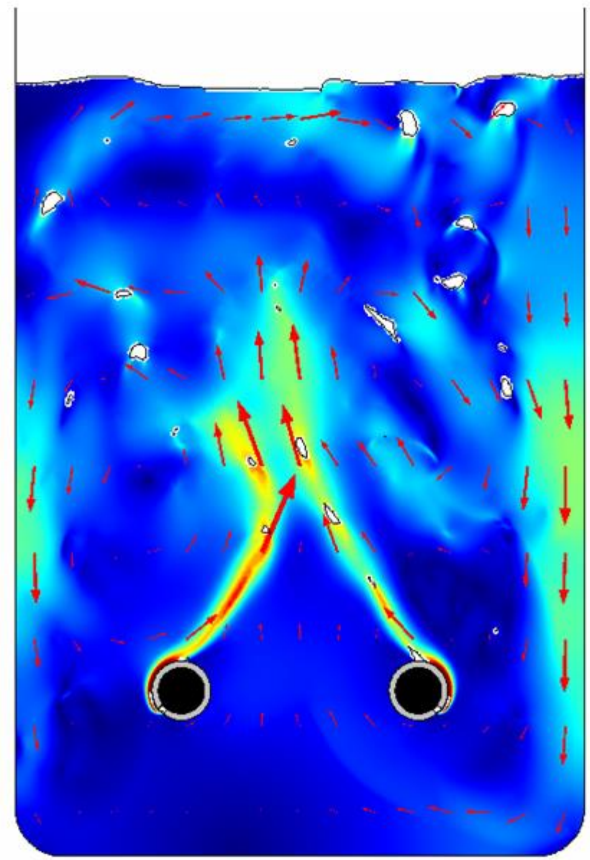
1. Drug Delivery

Image courtesy:
Alchemy Pharmatech Ltd.



2. Bioreactors

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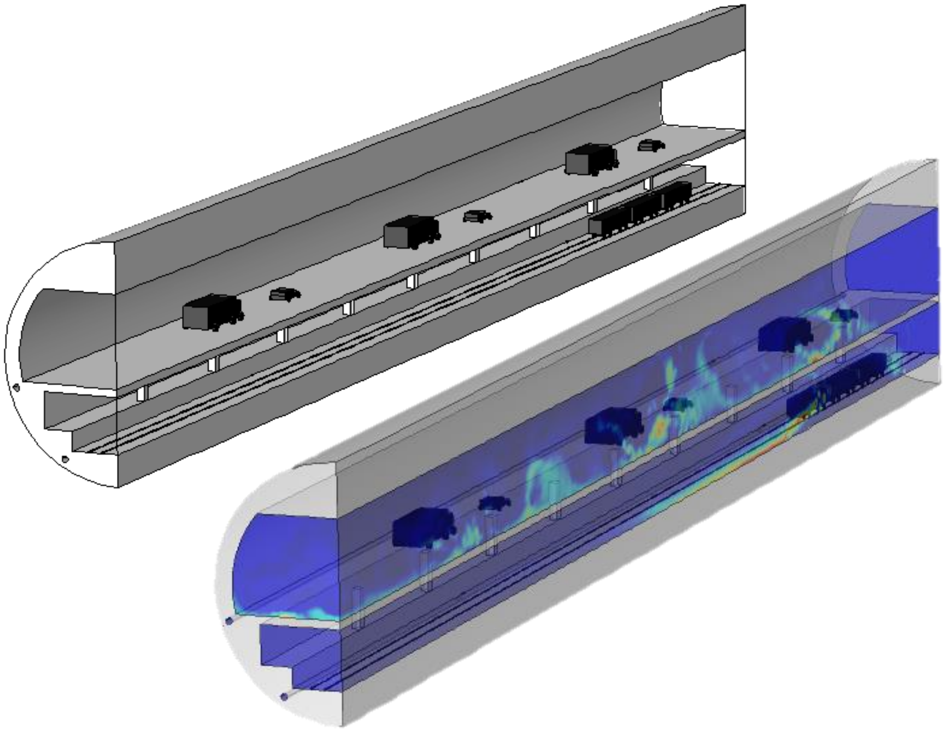
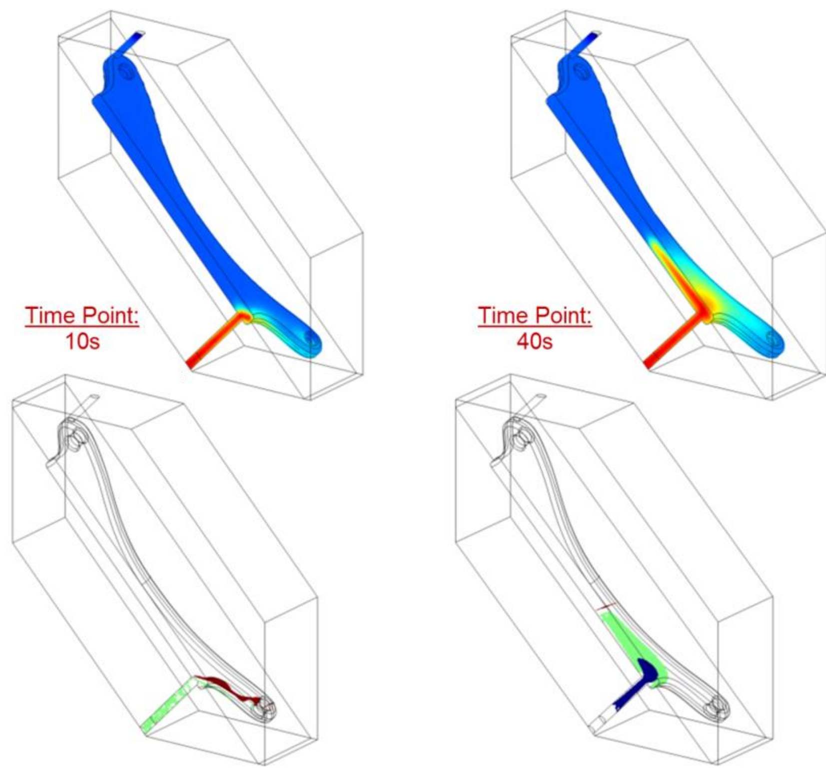
CONTINUUMBLUE technology development



4. Mould Flow Analysis

- Multiphase flow
- Mixing of Polymers
- Thermal
- Polymer curing



3. Transport

- Vehicle emissions in tunnel
- Air quality analysis

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