# Update on "Task 2" progress

Ground model and 3D cavern layout

Our task….

Initial review of the geological, geotechnical and civil engineering aspects of the IR cavern layout and design and potential risks and opportunities for the design and construction in the Molasse (Task 2)

Separate review of the design of the experiment foundations (including cavern invert) and transportation mechanism to cater for a maximum load of 15,000tonnes ….(Task 1)
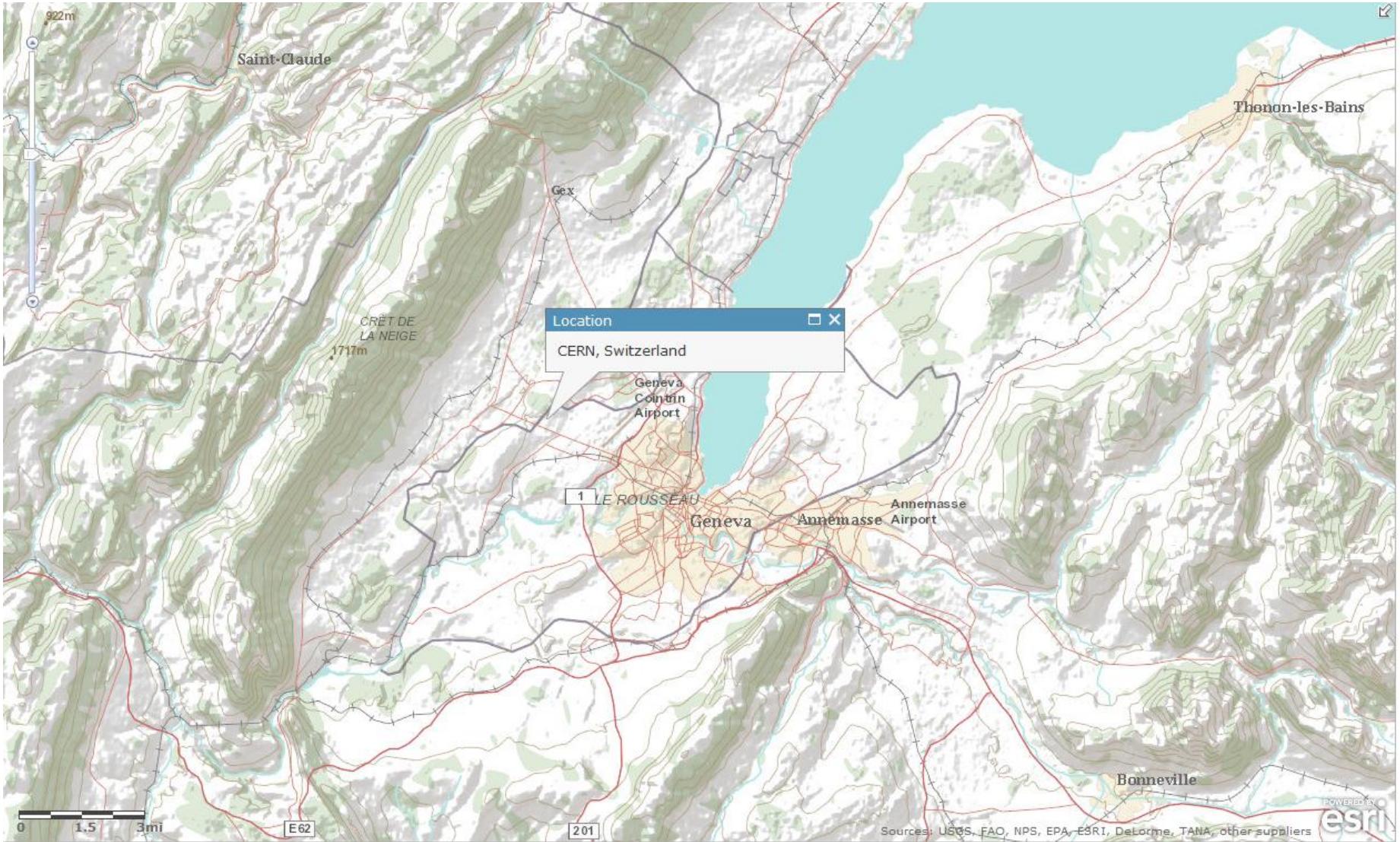
Location

This presentation…

1. Data used

2. CERN Molasse Geological model

3. Molasse rock types and properties

4. Geotechnical behaviour – stress, strength & stiffness

5. Engineering behaviour – EDZ, HDZ (URL analogies)

6. Cavern design – initial studies

7. Further analysis for presentation in September (Granada)

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1. Data used

Published geotechnical literature on Mudrocks

Published geological/geotechnical literature on the CERN and NW Greece Molasse

CERN reports for Point 1 and 5 (LEP) including borehole logs, in situ and laboratory testing

Published geotechnical literature for the Underground Research laboratories (URLs) at Bure, Mol and Mont Terri in analogous mudrocks

Input Document Register	Required data (all cases)	Requi
Uncontrolled in printed form	Required data when filed as hard copy only	Requi hard c
Document summary		

Our ref	Short name/description (including link to document)	User defined category for easier searchin
1	4410-CLIC-Workshop-Moving-Aligning[1].p	Presentation
2	CE_Talk_GERWIG_feb2011[1].pdf	Presentation
3	CES_workshop_Kurt[1].pdf	Presentation
4	DM_JCG_16Fev2011[1].pdf	Presentation
5	IR_Workshop_16_Feb_2011[1].pdf	Presentation
6	LCWorkshop-Vibrations[1].pdf	Presentation
7	17000001D CLIC-Detectors Hall Area (surf	Drawing
8	17000001E CLIC-Detectors Hall Area (surf	Drawing
9	BATIMENT_SH_18_(LEP-DZ-12999_0109)	GI Point1
10	BATIMENT_SM_18_(LEP-DZ-1_2173_000	GI Point1
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16	ANNEXE_A3_3545_81_PLANCHES_PHO	GI Point1
17	ANNEXE_A4_3545_81_LEVE_DES_DISC	GI Point1
18	ANNEXE_A5_3545_81_ESSAIS_DILATON	Tests Point 1
19	ANNEXE_A6_3545_81_HYDROFRACTUR	Tests Point 1
20	ANNEXE_A7_3545_81_MESURES_DE_S	Tests Point 1
21	ANNEXE_A8_3545_81_ESSAIS_LUGEON	Tests Point 1
22	RECONNAISSANCES_GEO_3545_81_(LI	GI Point1
23	SLHC25.pdf	GI Point1
24	Rapport_d_interpretation_(LHC-DZ-1_3999	GI Point1
25	COUPE_POINT_1_(3545.401).pdf	GI Point1
26	SONDAGES_(LHC-DZ-1_3999_1401..1404	GI Point1

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2. Geological model

- Late Oligocene to early Miocene epoch rocks (Chattian to Aquitanian Stages approx. 30 – 21Ma) sediments eroded from the Alps
- Lake and river deposits formed in a humid environment
- Mainly "marl", siltstone and sandstone
- Up to 2.6km has been eroded: heavily "over-consolidated" and cemented
- Relatively unaffected by Alpine Orogeny, but some gentle tilting and minor faults
- "bedded" cm to m scale, but largely "unfractured"
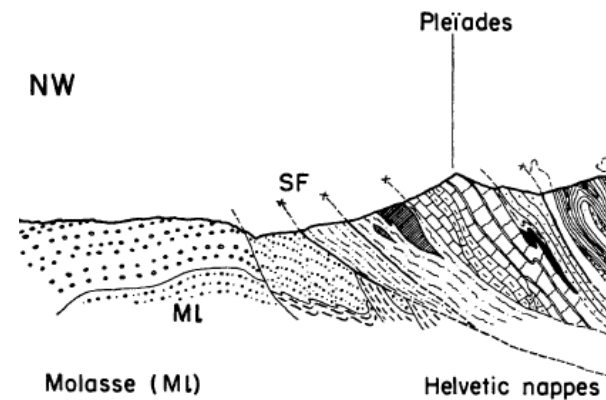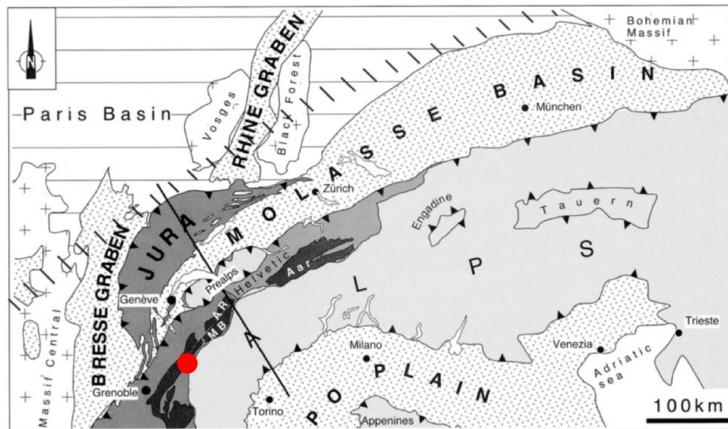
3. The molasse rocks

Marls: The fine grained rocks described in the CERN archive reports range from sandy Marls to marly Sandstones and *Grumeleuse* and *Tectonisee* Marls. Up to 40 -55% of the marl samples were said to be composed of clay minerals, with the remainder comprising iron oxides, feldspar, quartz and calcite/dolomite. The majority of the clay minerals are composed of illite, whilst the remainder consist of chlorite and mixed layer illite-smectites.

Sandstones: quartz-feldspar sands with mica (chlorite or muscovite), and calcareous cement. The grain size is fine, occasionally medium. Locally, the grain size approaches that of silt (0.002 - 0.06 mm).

Calcareous deposits (Caliche/ Duricrusts): occasionally Strong nodular limestone with marl matrix, marly limestones and marls with intercalations of limestones and gypsum.

Hawkins & Pinches (1992)

Siltstone – clay minerals <25%
Mudstone – clay between 25 and 40%
Claystone – clay >40%
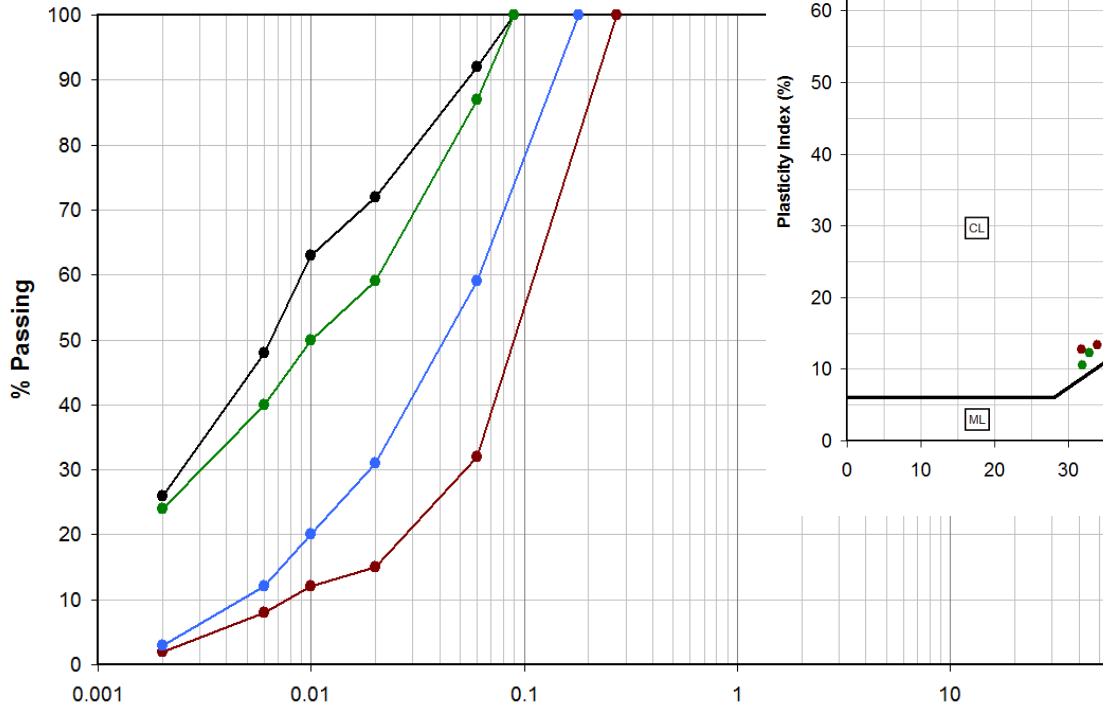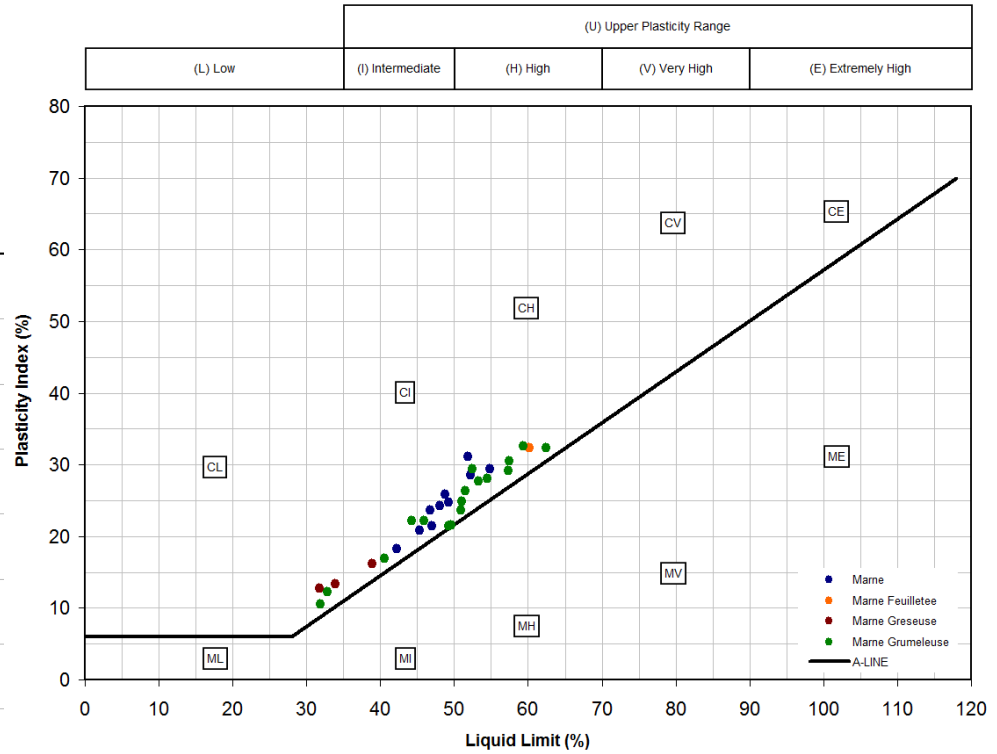
Void ratio typically 0.11 to 0.29

Porosity between 9 to 22%

Permeability very low ("zero" Lugeon)
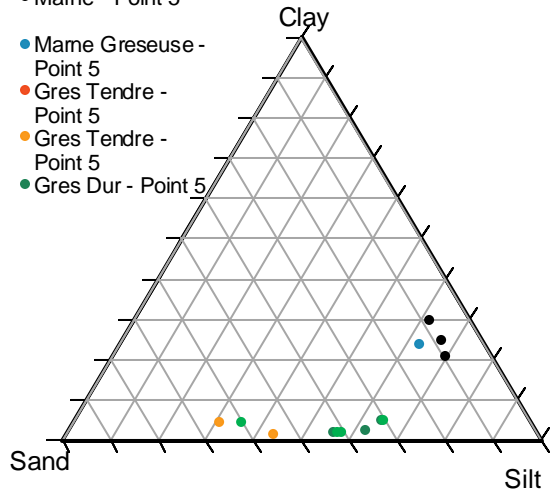
Ternary diagrams (few data)

Clay-silt-sand diagram: "marne" actually a siltstone-mudstone

Quartz-clay-carbonate: Wide carbonate range; least carbonate in fissured marls (leaching?)

Illite-smectite-chlorite: tight grouping; consistent clay mineralogy across lithologies

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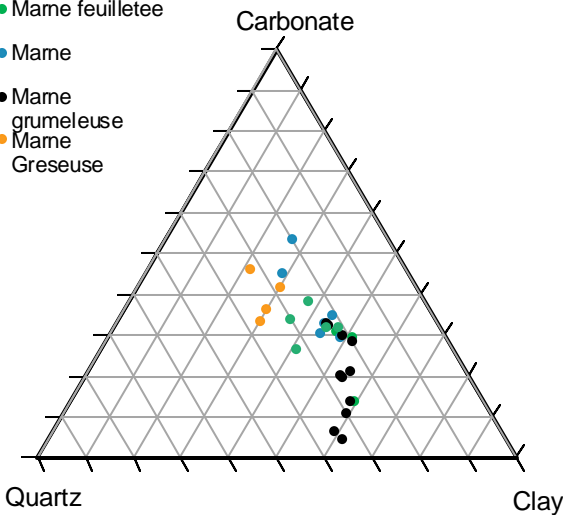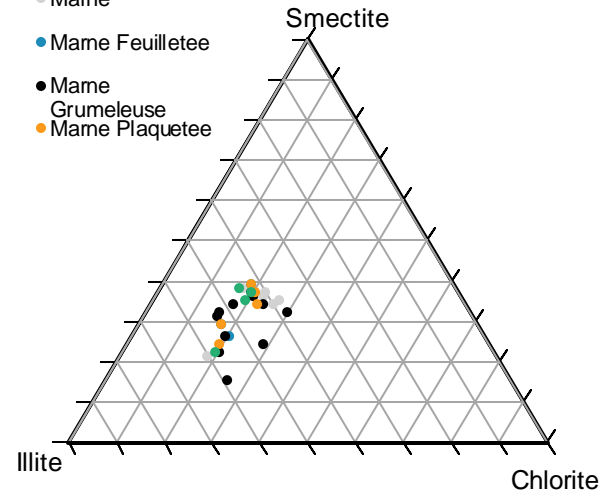
4. Geotechnical

In situ stresses at LHC at 92 to 123m depth have been determined as:

$\sigma_{H, max} = 4.7 \pm 0.7$MPa to 5.3 ± 0.7MPa (NNE-SSW to ENE-WSW);

$\sigma_{h, min} = 3.44 \pm 0.15$MPa to 3.95 ± 0.15MPa;

σ_v = overburden (mean bulk unit weight taken as 23.75 to 25.10kN/m³.

But contradictory evidence!
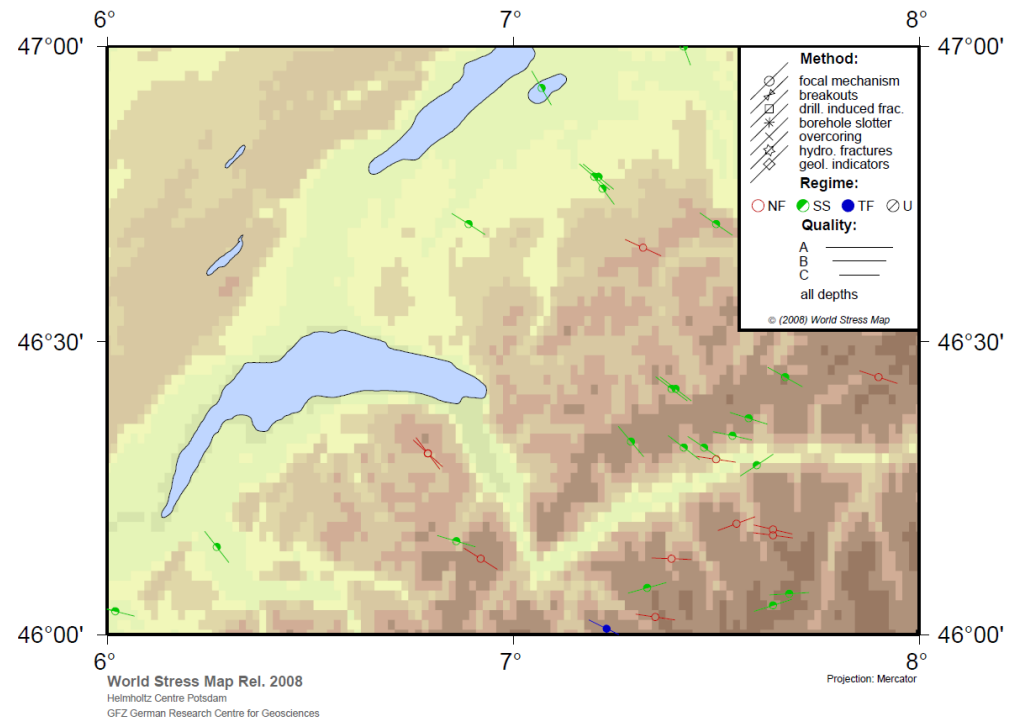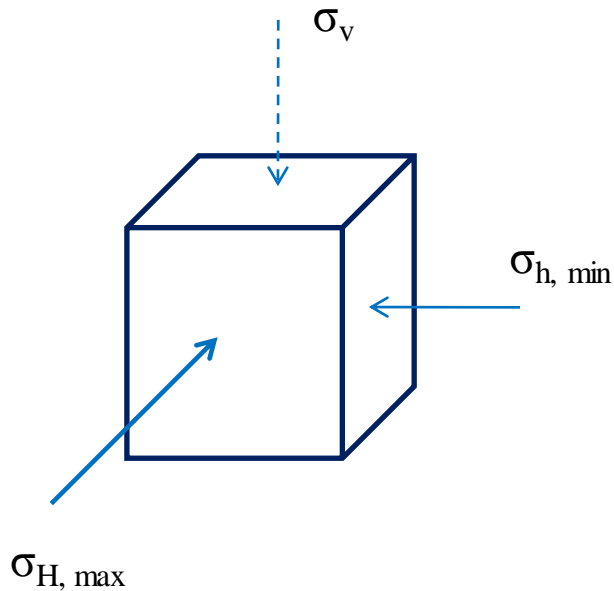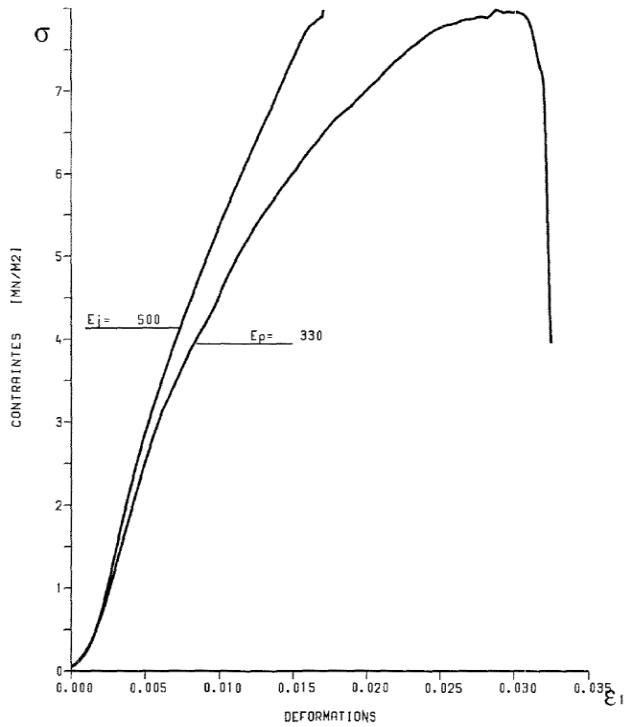
UCS test on "Marne" (at 82.3m depth) by the *EPFL*. UCS = 8MPa, w = 6.7%. Globally Youngs' Modulus (E_P) = 330MPa and local modulus(E_J) =500MPa. Modulus ratios (E/UCS) of around 100 can be estimated for the "*marne*" and 160 for the "*marnogres*" (marly sandstone) from the global strain measurement

Uncertainties:

- P' at failure?
- Pore pressures?
- Rate effects?
- Disturbance/slaking?
- Fabric?

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Effective Mean Stress, MPa

Shear Stress, MPa

Test 7

Test 4

Test 3

c' = 0.15 MPa | φ = 37°

In situ conditions @ 100m depth
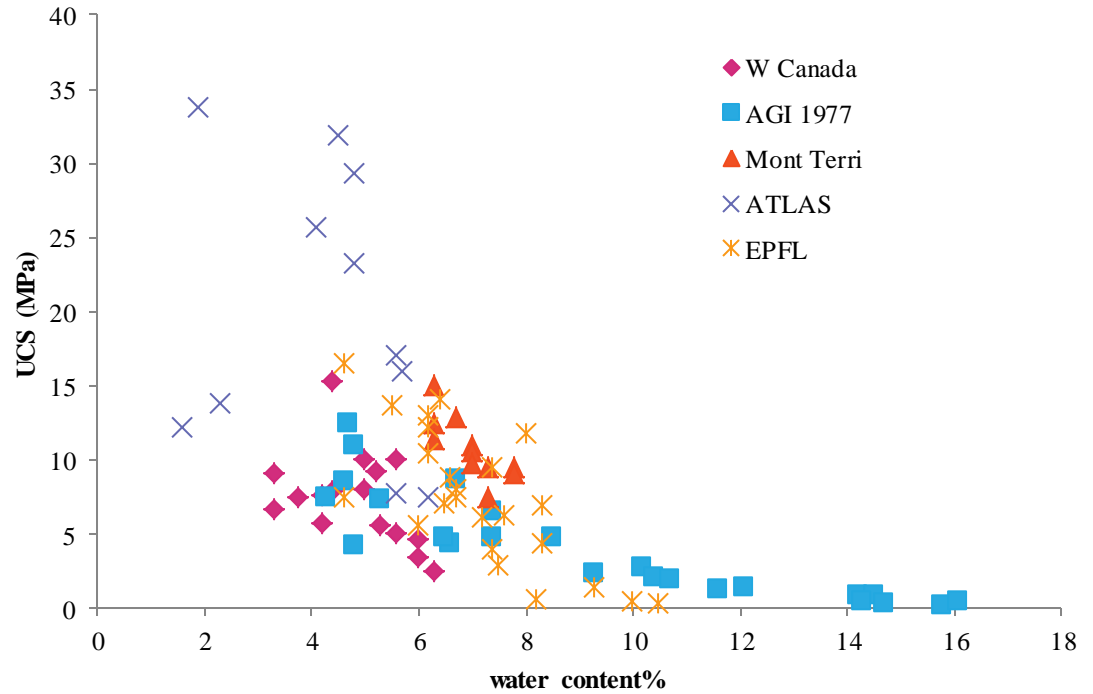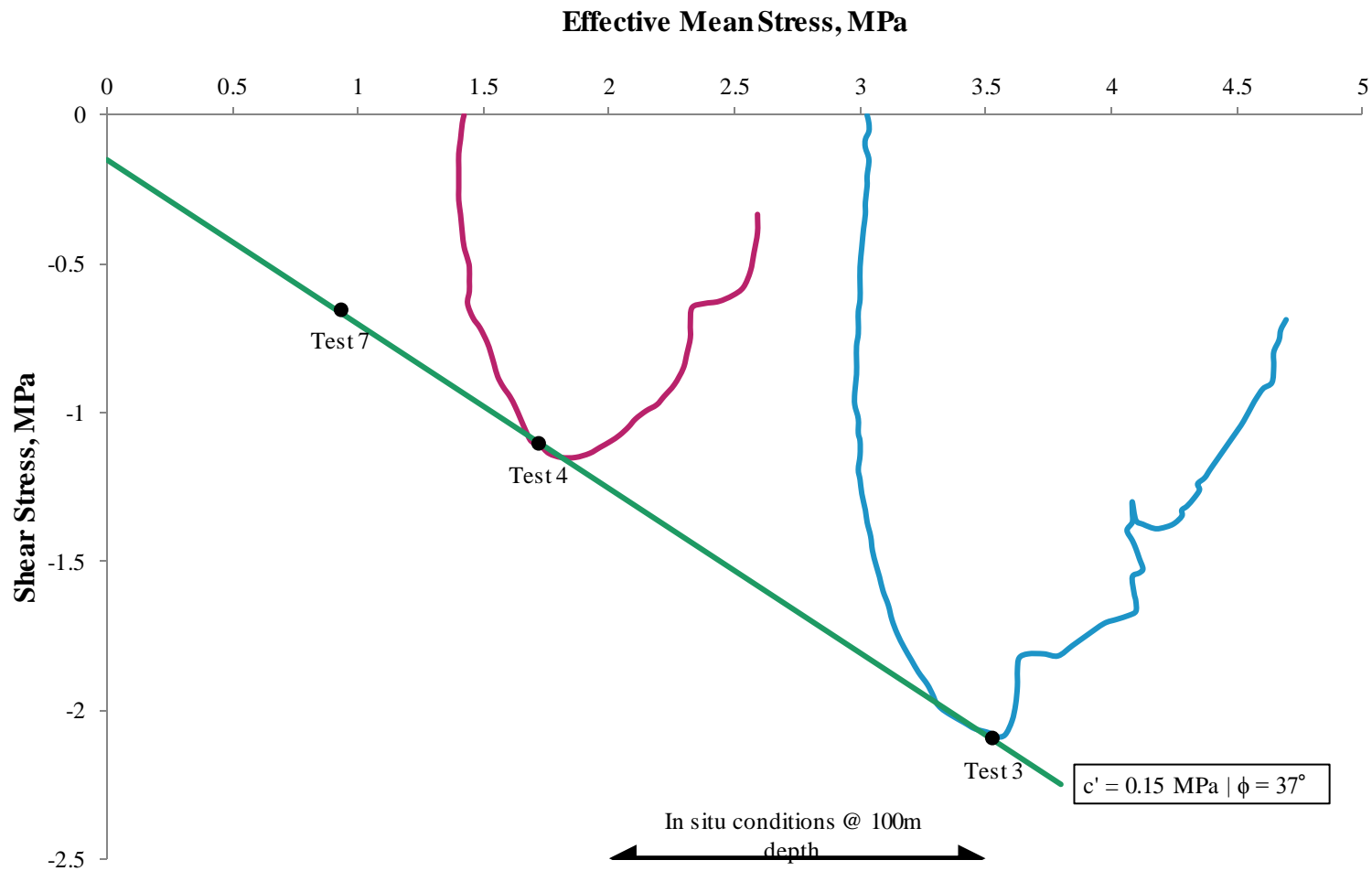
$CIU_{extension}$ and CK_oD_{ext} triaxial tests with pore pressure measurement – short term undrained strength, long term effective stress strength can be obtained. UCS test limitations reduced.

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$\sigma(MPa) = 740kPa$

$\delta = 0.5mm$

$=>$

$G_0 = 6.5GPa$

$\varepsilon(\%) = 0.017$

Stiffness:
- UCS MR = 100 to 160
- Shear modulus from HPD tests shows distinct reduction with increasing strain
- Creep & hysteric effects evident….

However!

Transient Load:
- Low stress & strain levels
- Available test stress and strain levels not relevant?
- Require information regarding tests carried out in similar loading conditions + strain levels
- Monitoring Data

Short term deformation (*PLAXIS* Linear Elastic)

Morianne
E = 50MPa
$K_0 = 2$

Molasse
E = 3000MPa
$K_0 = 2$

Detector + 15m x
15m slab = 742kPa

300mm Shotcrete
E = 20,000MPa

5000mm Mass
Concrete Invert
E = 25,000MPa

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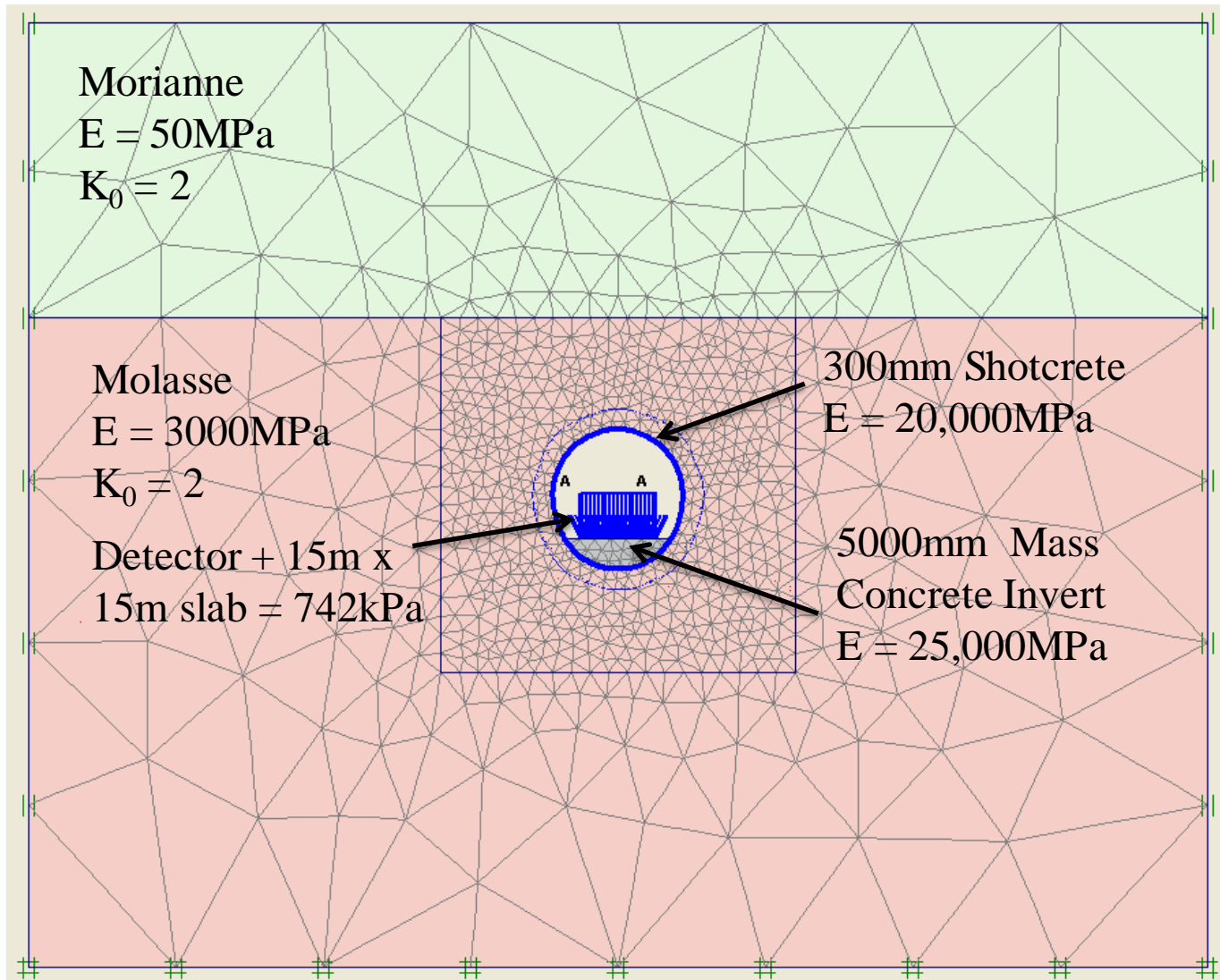
Short term Loading (*PLAXIS* Linear Elastic)

Principal Stress Trajectories
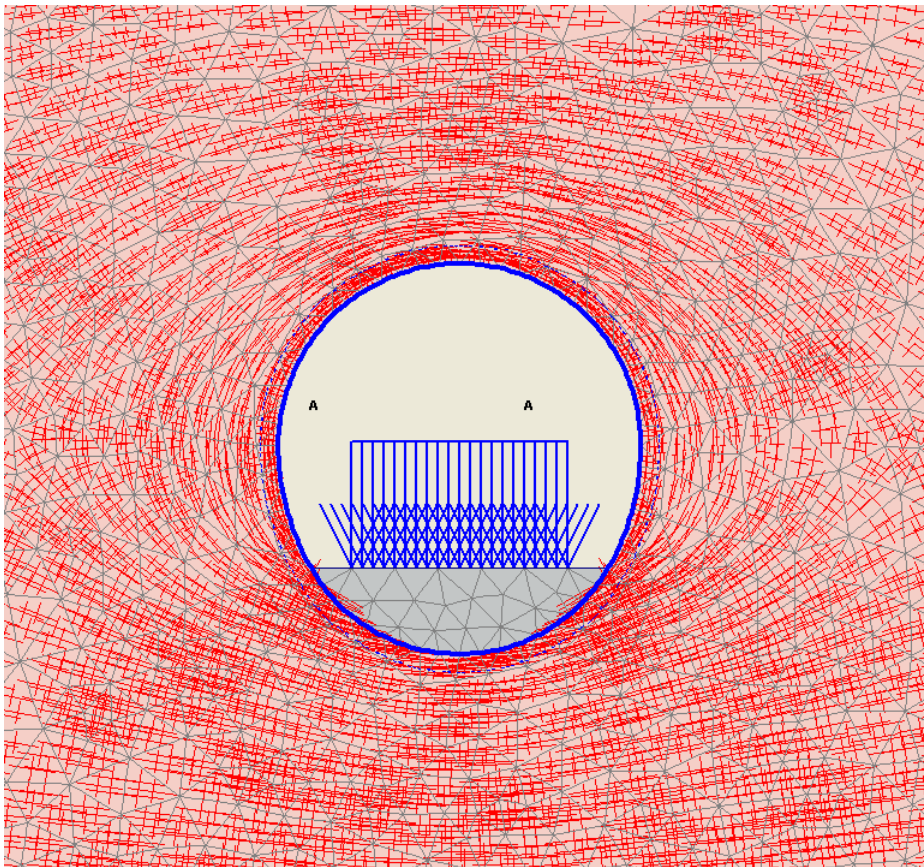
P' contours
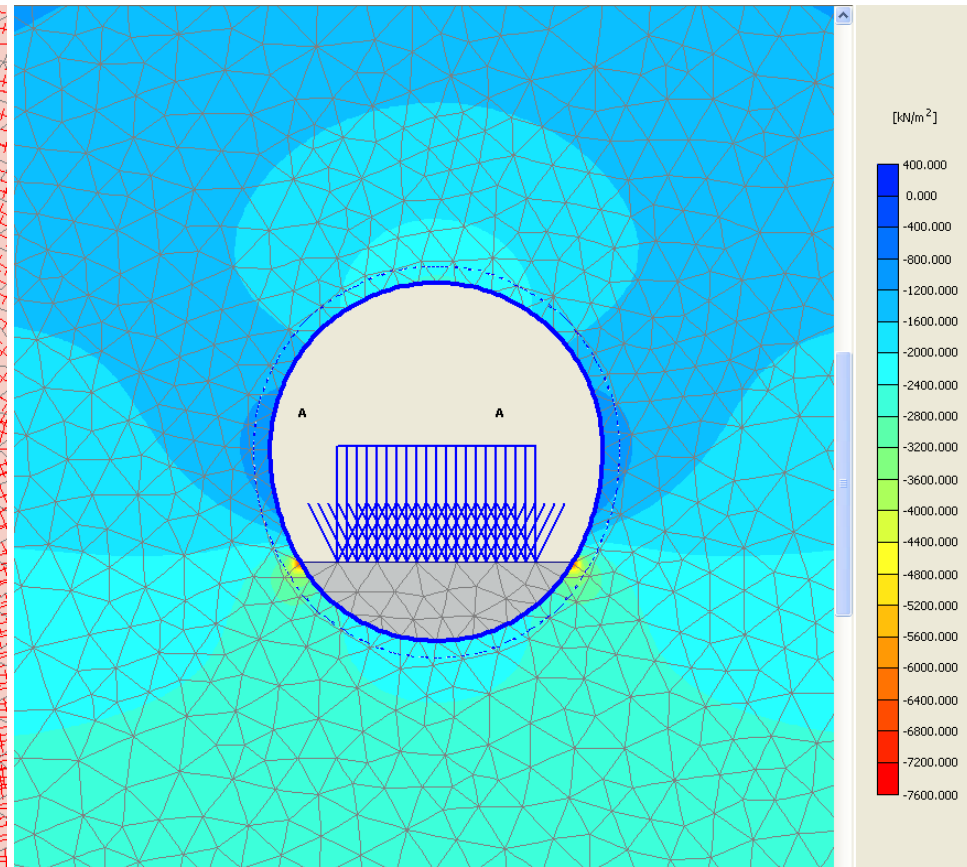
Short term Loading (*PLAXIS* Linear Elastic)

Shear Stress
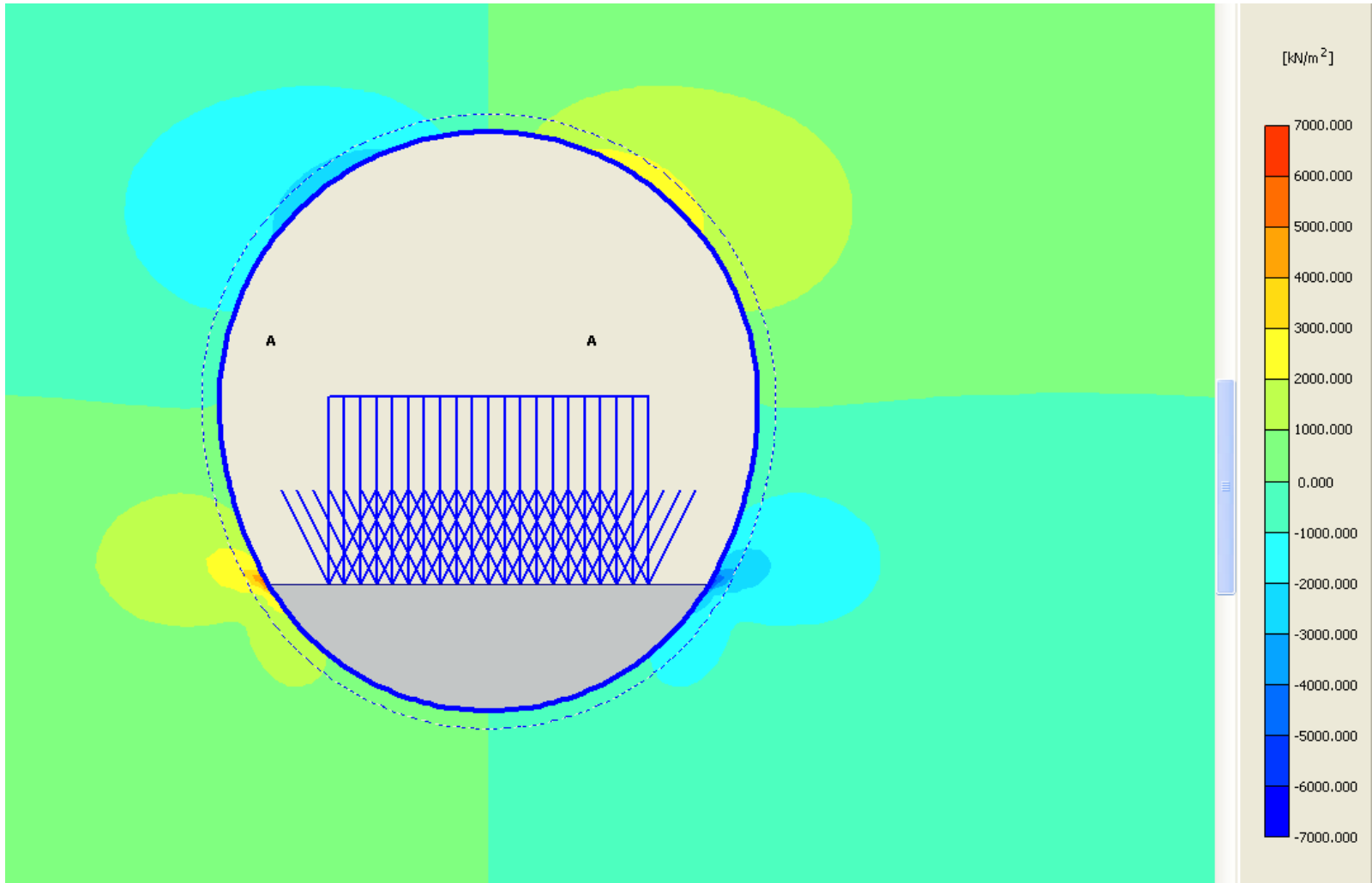
Short term Loading (*PLAXIS* Linear Elastic)

Deformations
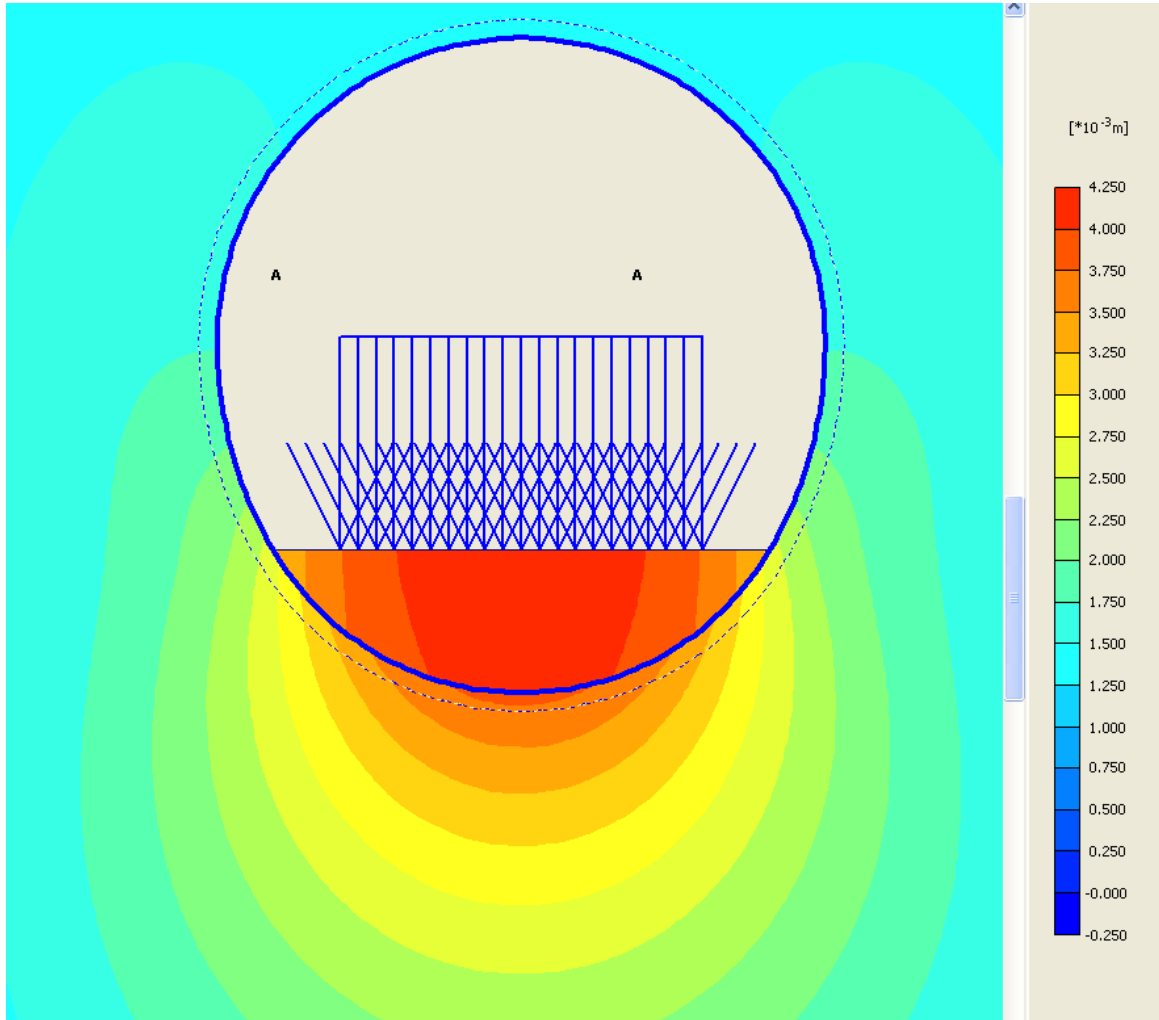
Slab differential settlement
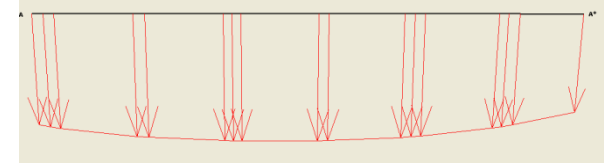
0.6mm per 15m
0.004% strain

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Short term Loading (*PLAXIS* Linear Elastic)

Total Strains

Incremental Strains

Total strains
Extreme principal strain -366.07*10^{-3} %

Incremental strains
Extreme principal strain increment -17.86*10^{-3} %

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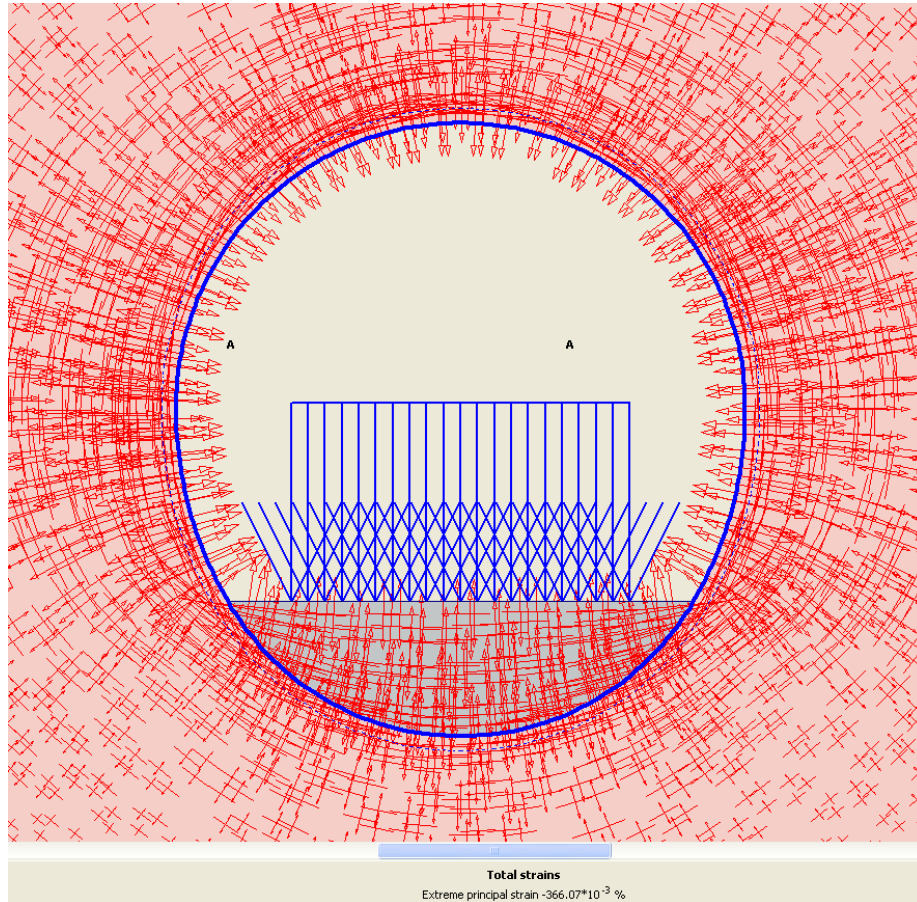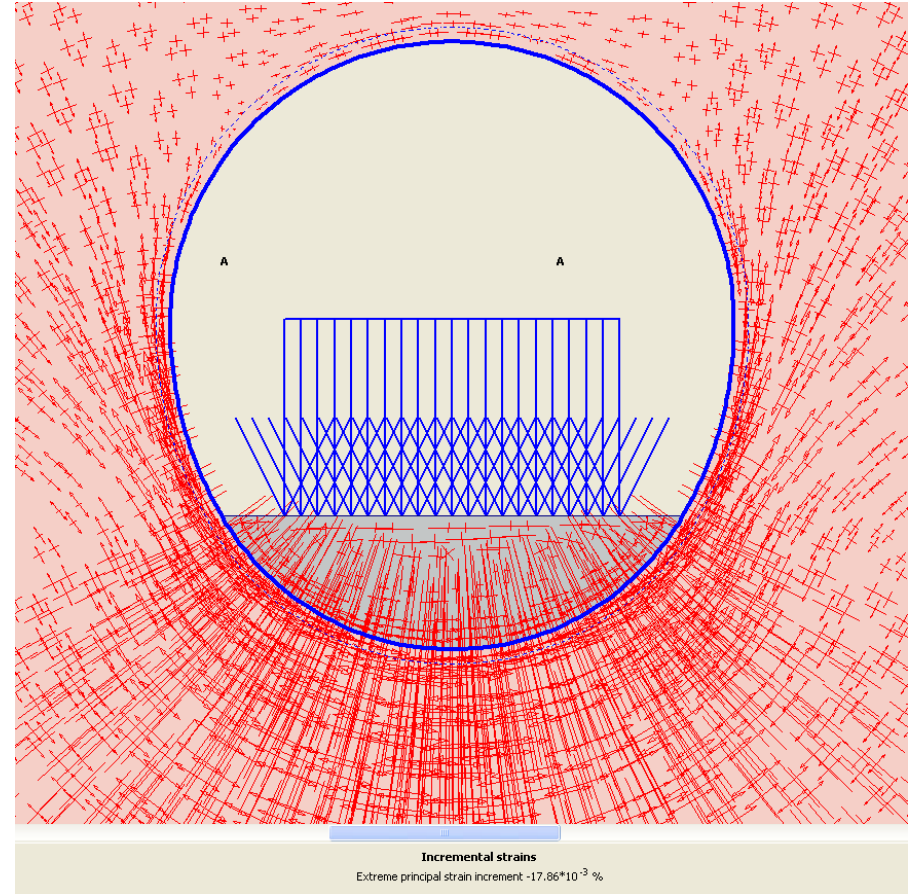
Time dependent behaviour:

1. swelling & softening due to smectite
2. Large secondary consolidation/creep behaviour (1D compression)
3. reductions in modulus of between 20 to 50% (6-months) and 40 to 70% (50-years) were estimated from Triaxial tests
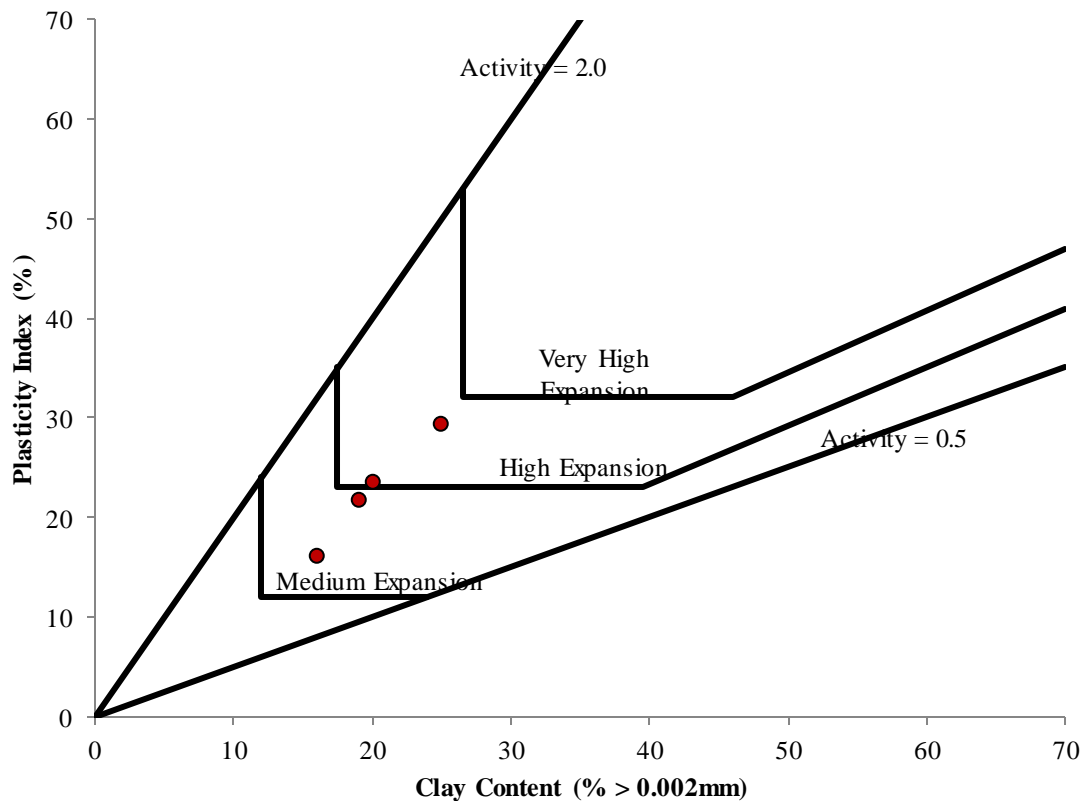
Mixed layer clay-smectite accounts for up to 8 to 15% of the rock. Swelling tests show there is a potential for significant time-dependent swelling strains of up to 25% and swelling pressures of over 2MPa - i.e. > the unconfined tensile strength of the rock.

Monitoring Data
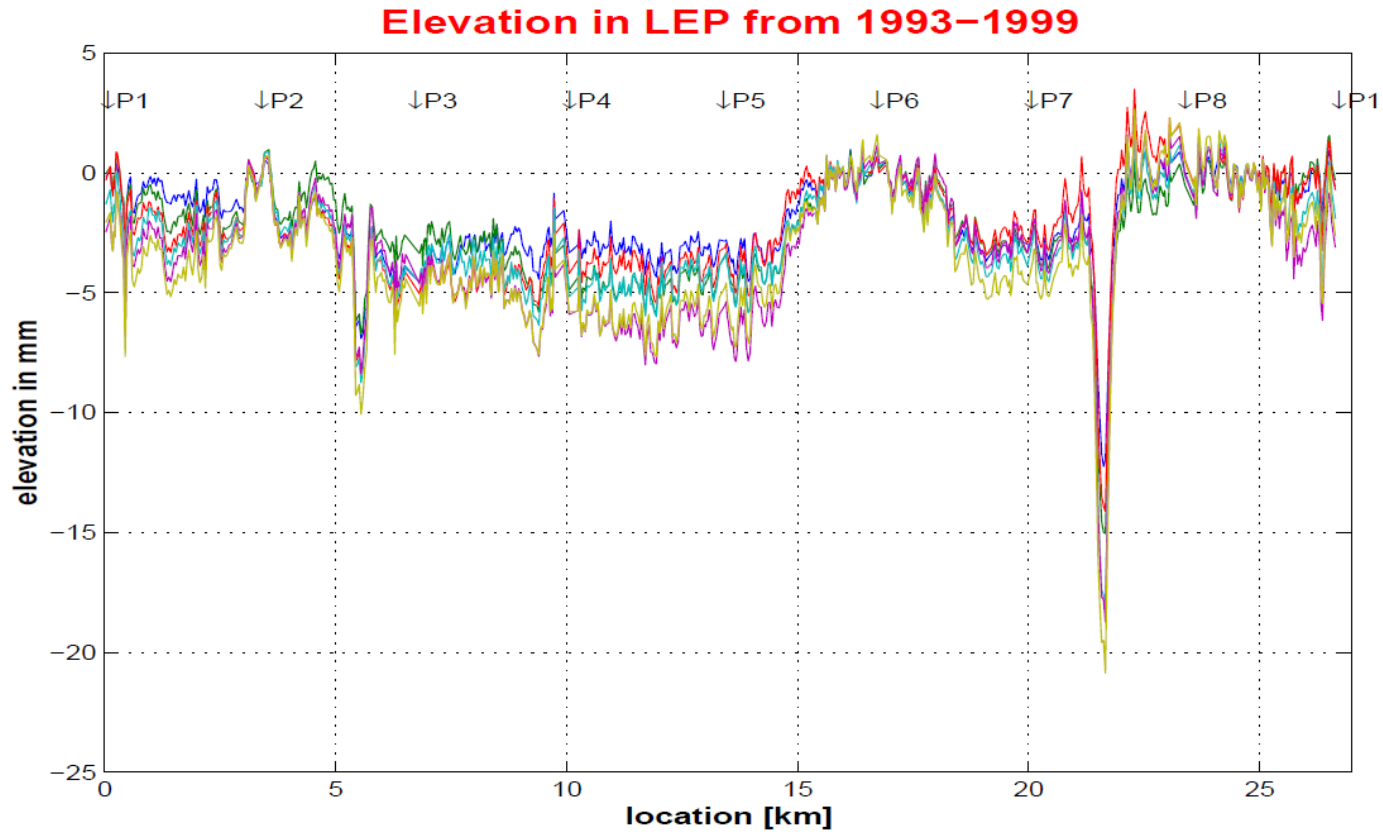
Pitthan (1999) -LEP Vertical Tunnel
Movements - Lessons for future colliders

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Findings….

The Excavation *Damaged* Zone (EDZ): a very localised zone of fracturing where significant changes in mass permeability, pore pressures and in situ stress occur.

Excavation *Disturbed* zone (EdZ), or Hydraulic disturbance zone (HDZ): the volume of rock where perturbations in the stress field induce significant changes in pore pressure. This zone extends for 10 radii or more beyond the excavations. This zone also exhibits a change to anelastic behaviour. However no change in permeability occurs in this zone.

Empirical estimates of the extent of the EDZ:

$R_f/a = 0.49(\pm 0.1) + 1.25*(\sigma_{max}/UCS)$
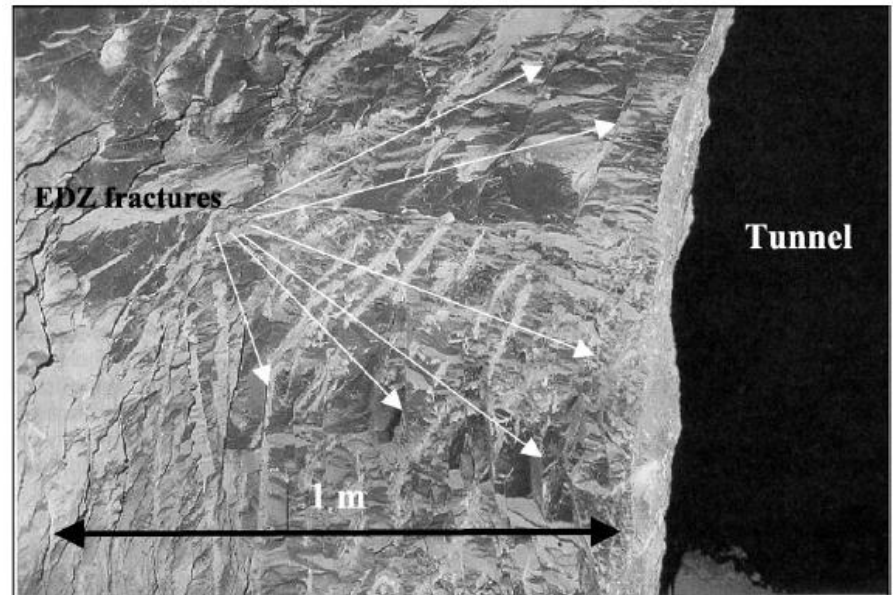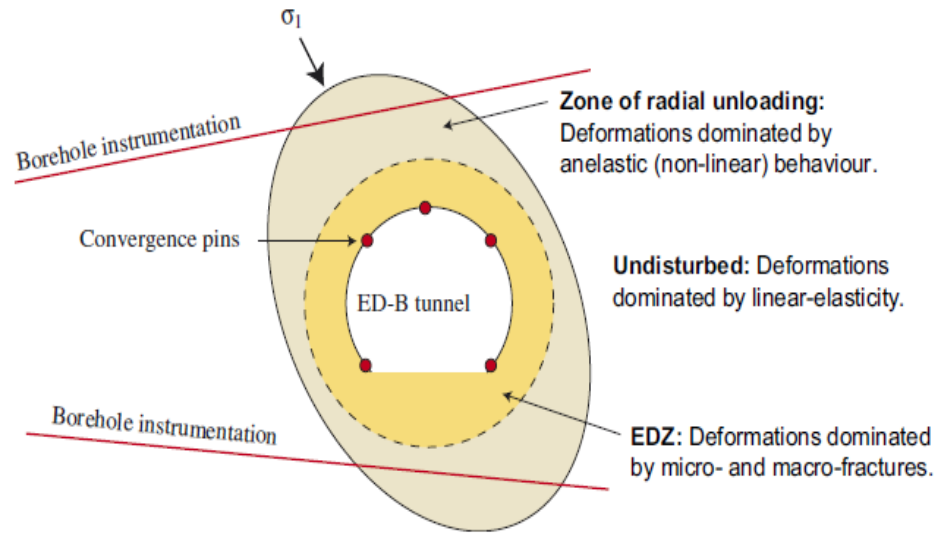
Different yield criteria approaches available for modelling mudrocks:

Standard Hoek-Brown or Mohr-Coulomb shear strength criterion

Undrained shear strength with stress dependent modulus (Corkum & Martin, 2007)

"Brittle" Hoek-Brown criterion (Martin et al, 1999)
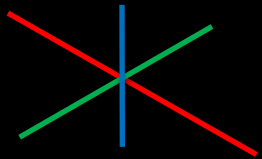
Tensile failure mechanism using Mohr-Coulomb or Hoek-Brown criterion (Hoek et al, 2005)

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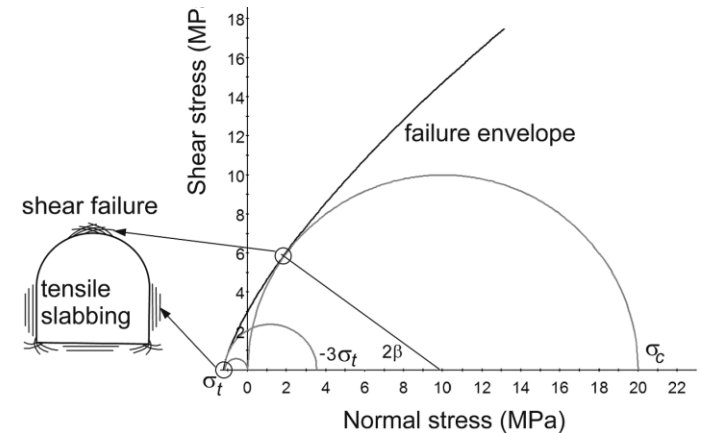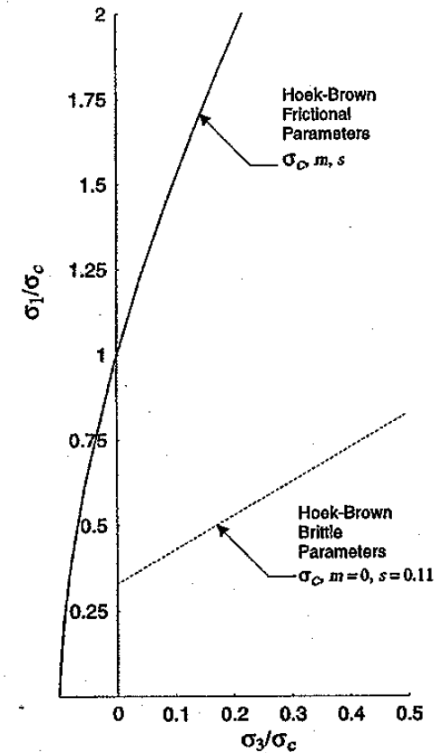
Cavern Stress State
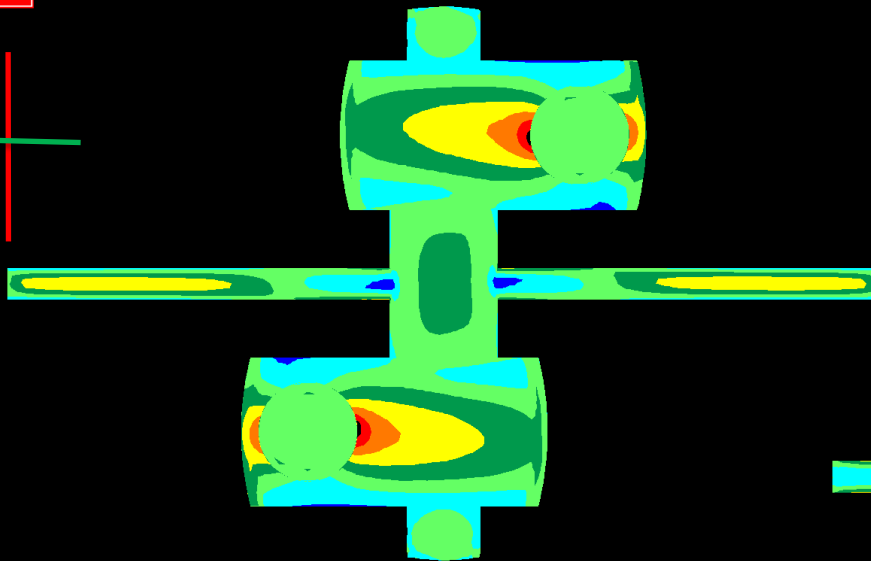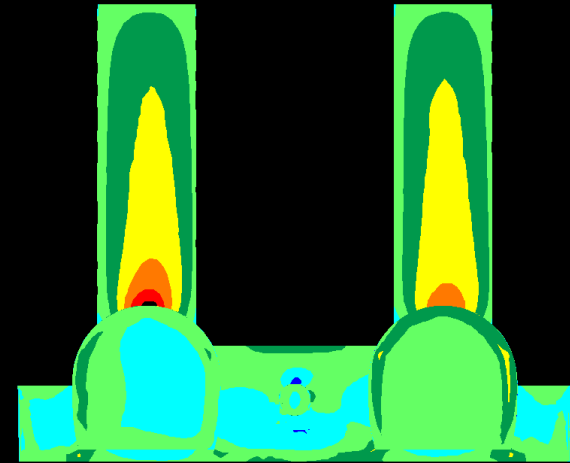
Simple modelling to examine:

1. Cavern layout and optimisation

2. Invert stress state as starting point for foundation analysis
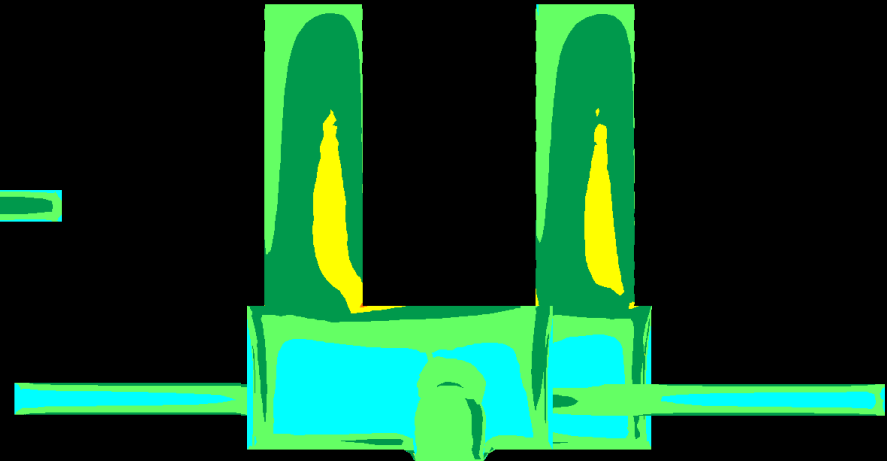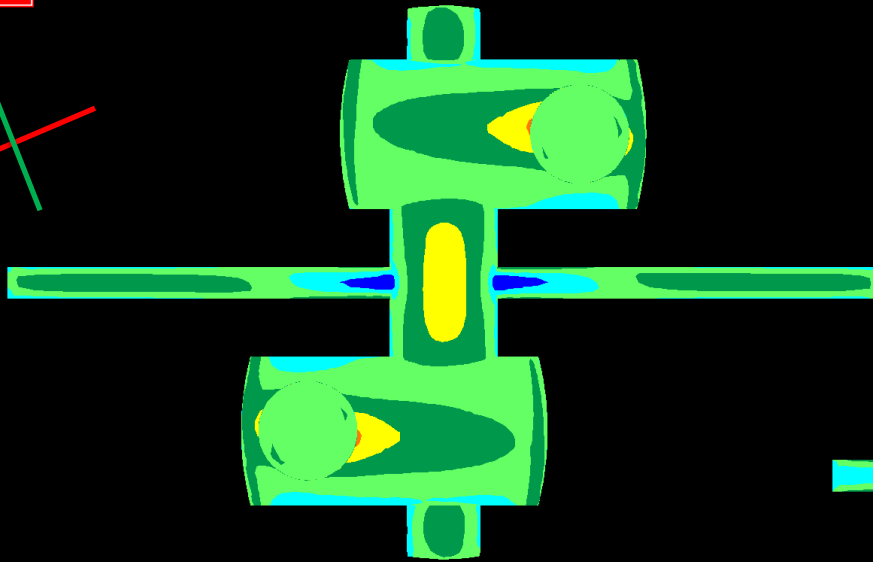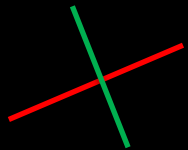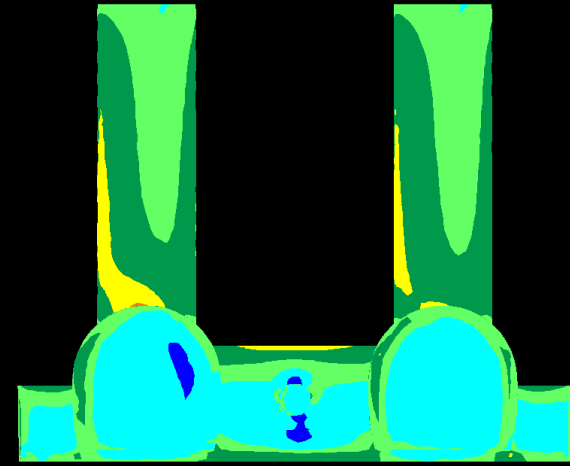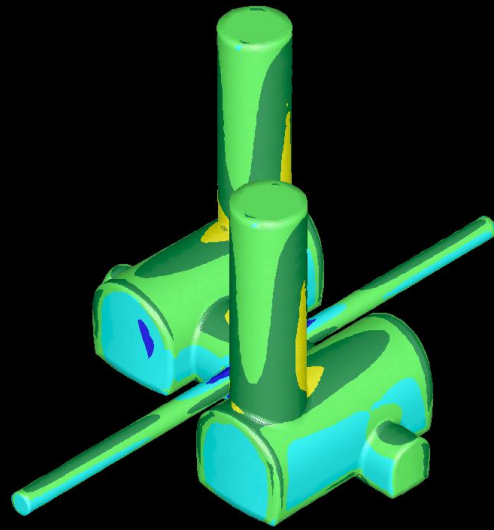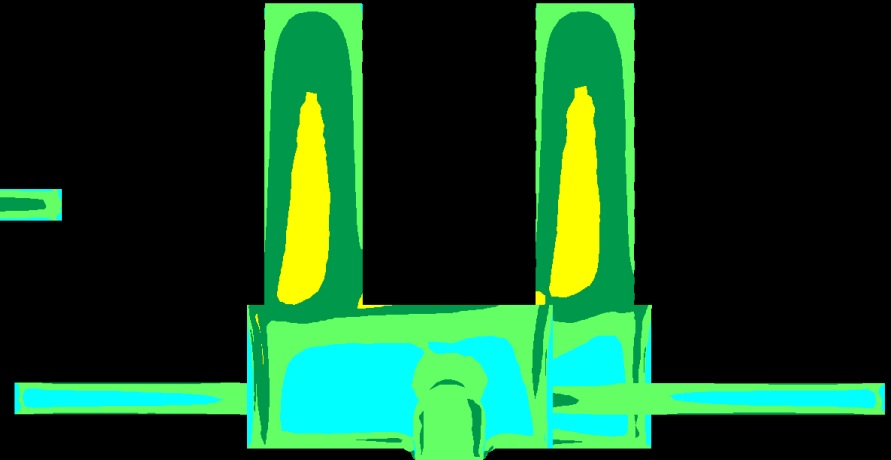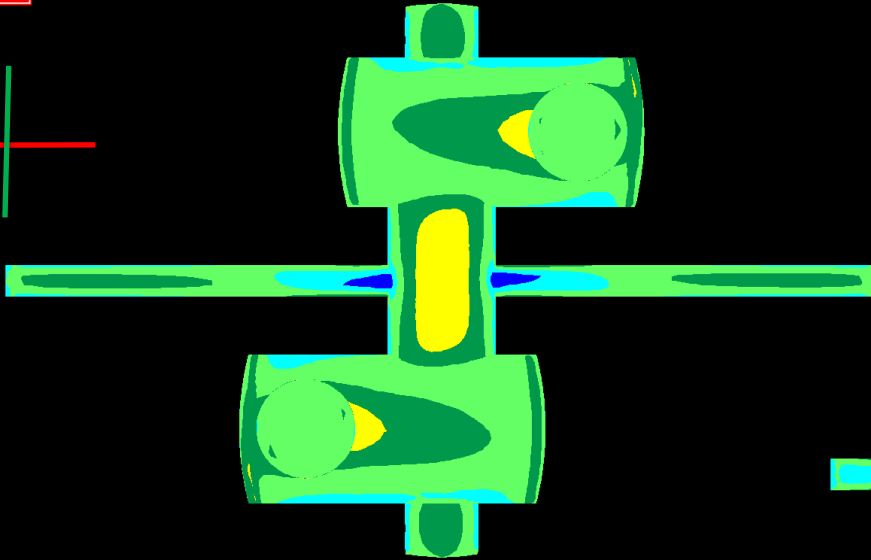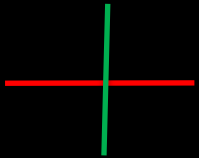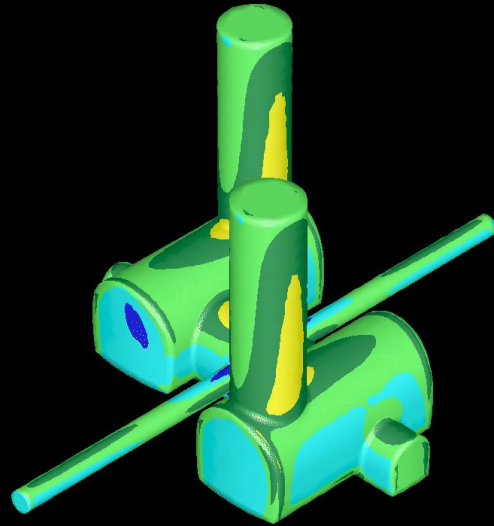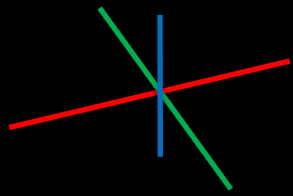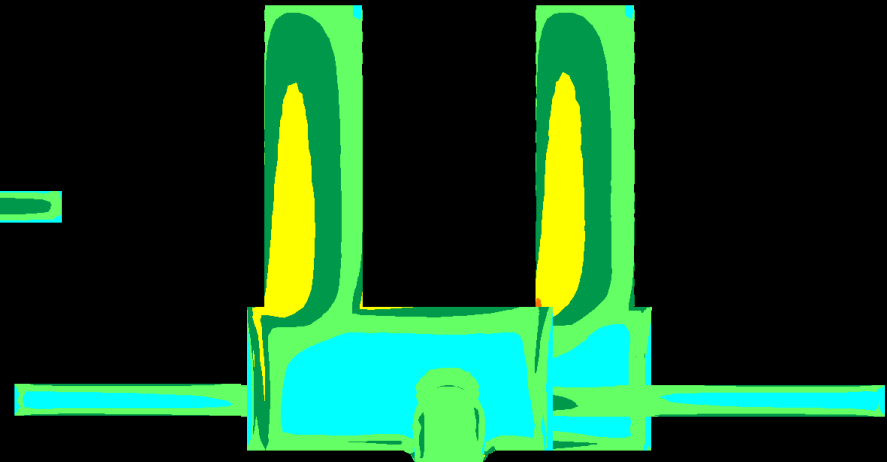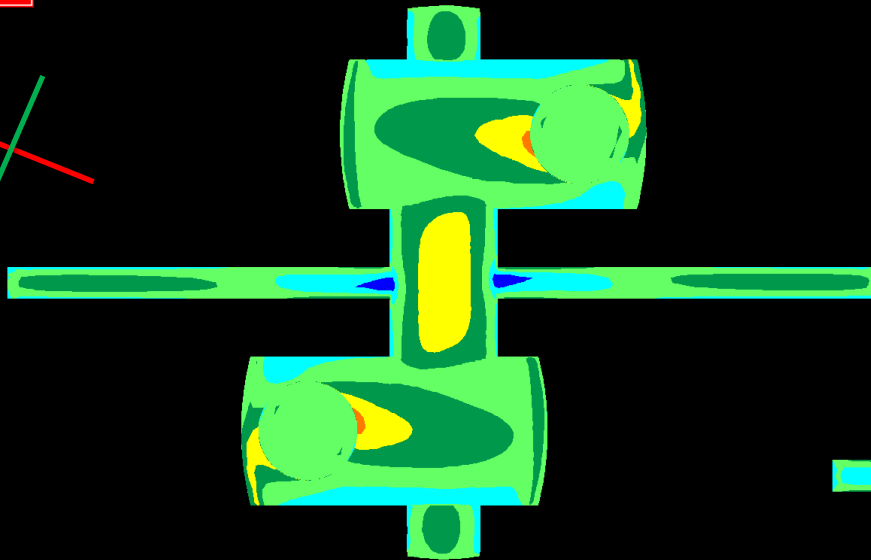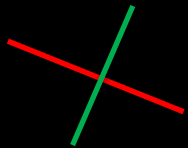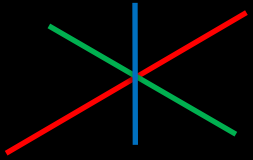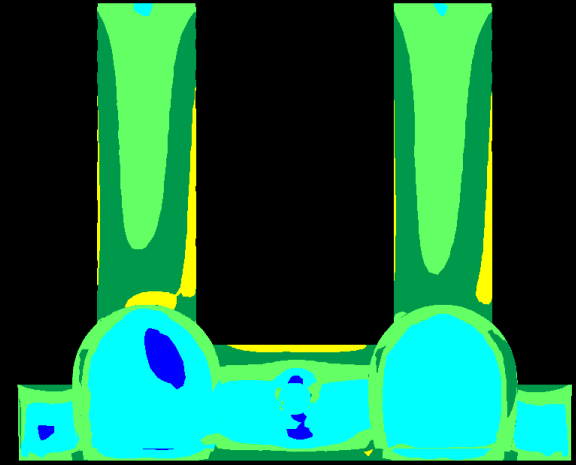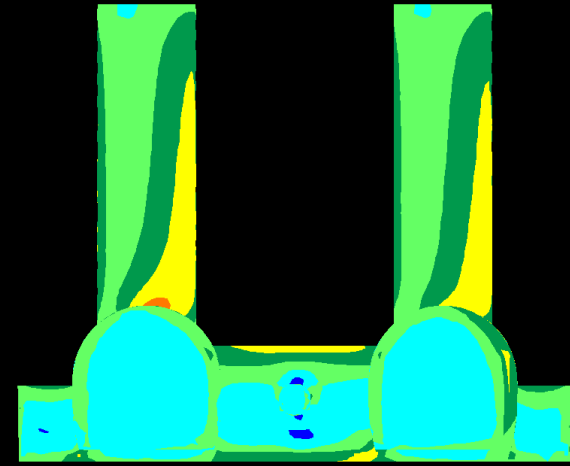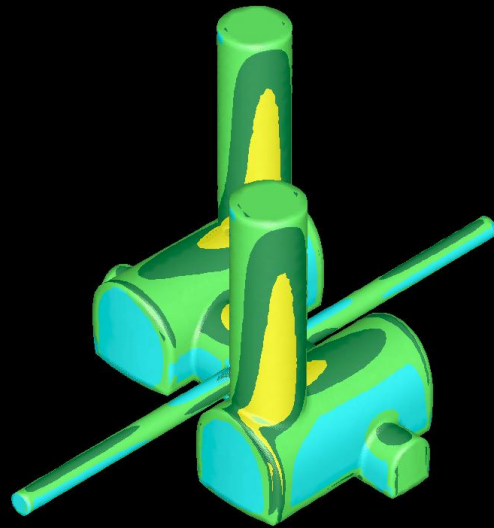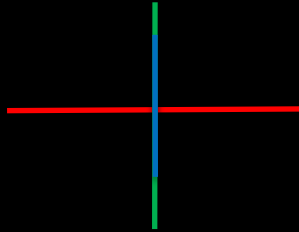
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000.0/00

σ_1 (MPa)

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σ_1 (MPa)

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σ_1 (MPa)

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225.0/00

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σ_1 (MPa)

ARUP

270.0/00

σ_1 (MPa)

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20

ARUP

292.5/00

σ₁ (MPa)

0

10

20

ARUP

315.0/00

σ_1 (MPa)

0

10

20

ARUP

337.5/00

σ_1 (MPa)

ARUP

360.0/00

σ_1 (MPa)

0

10

20

ARUP

σ_H normal to beam tunnel

σ_H parallel to beam tunnel

ARUP

σ_H normal to beam tunnel

σ_H parallel to beam tunnel

ARUP

σ$_H$ normal to beam tunnel

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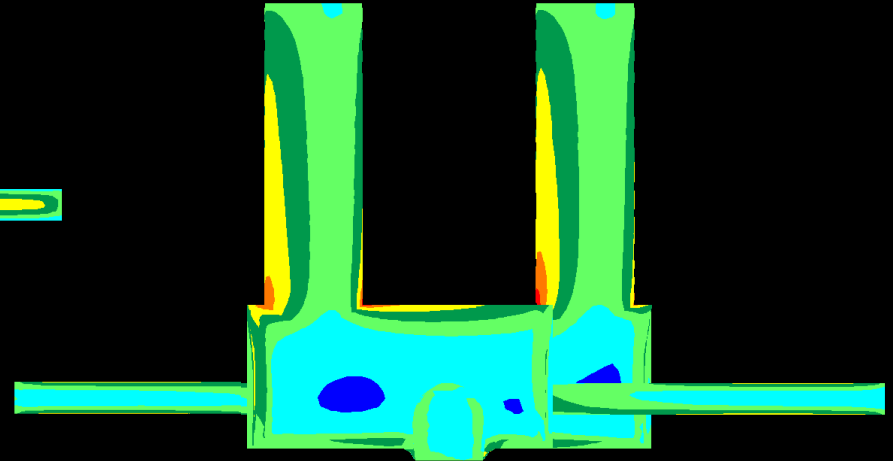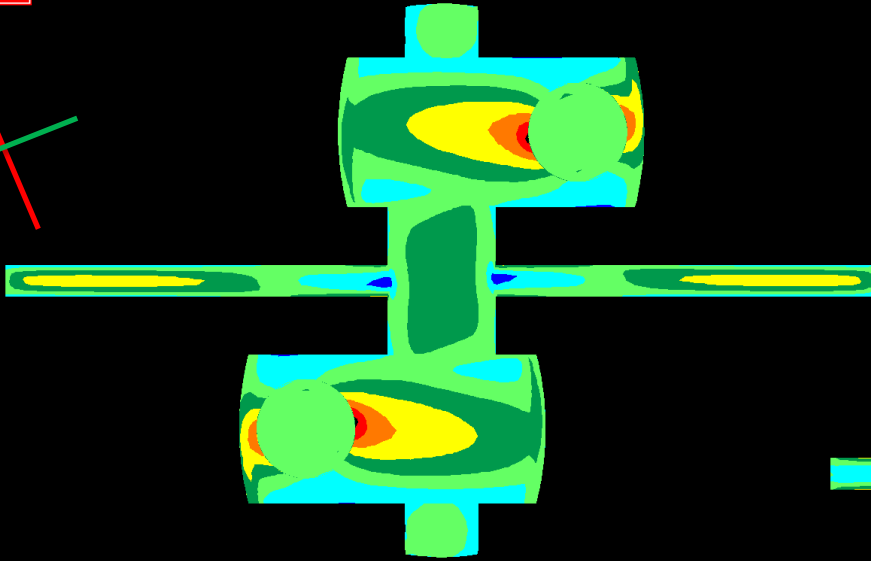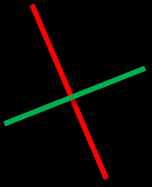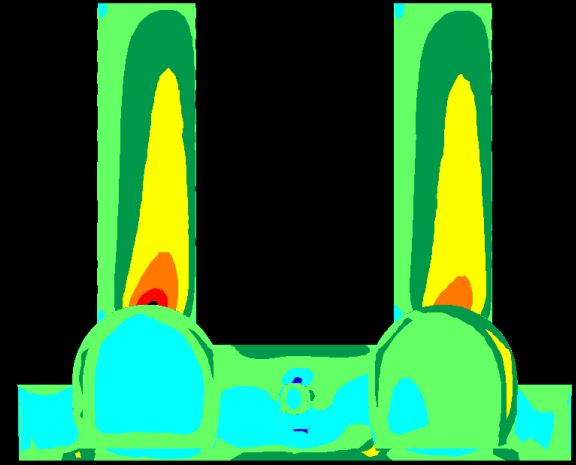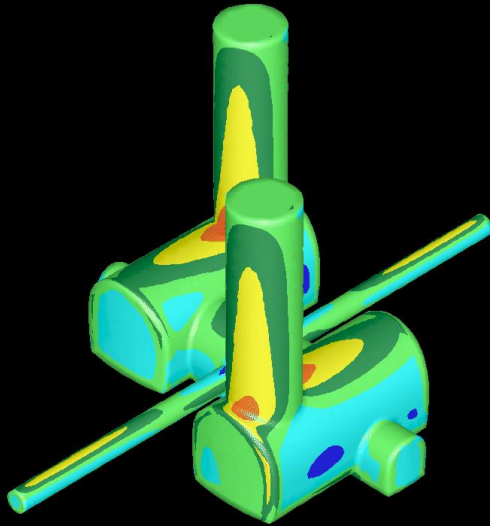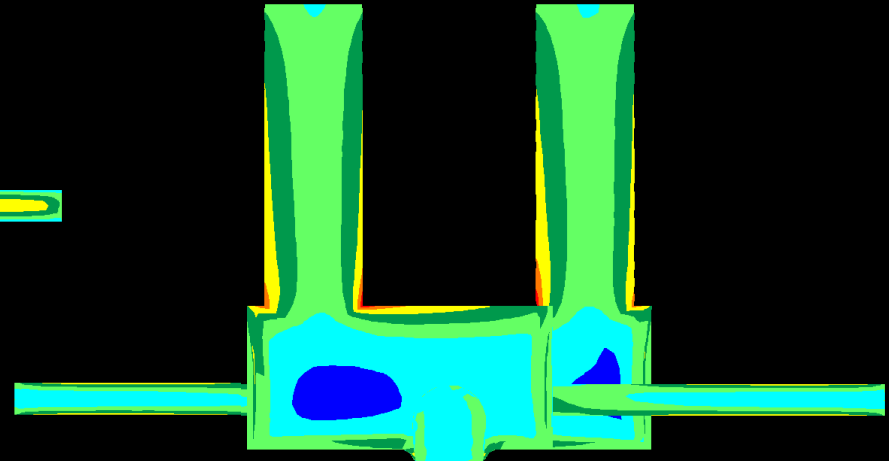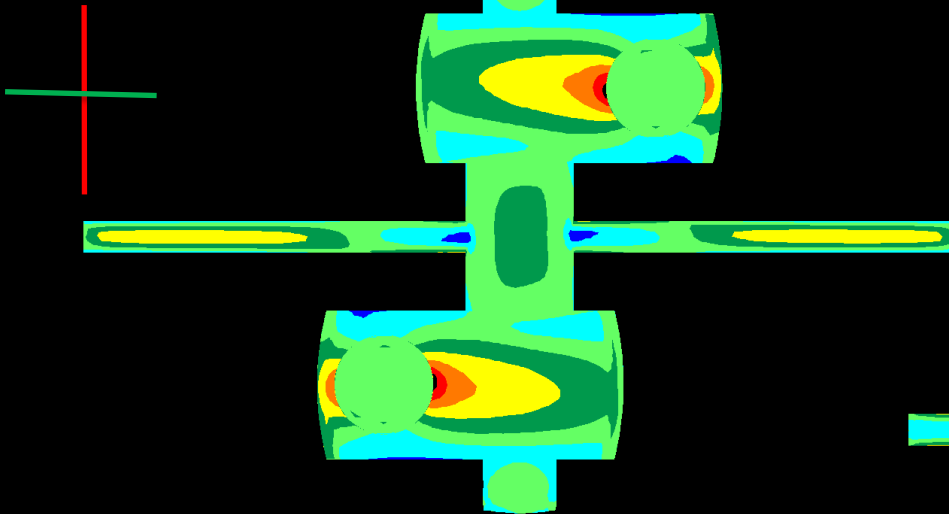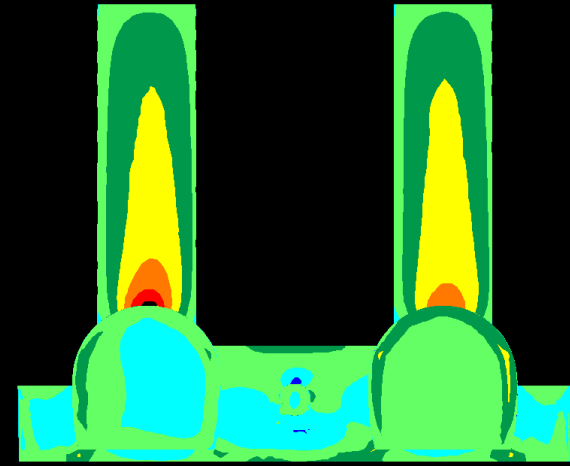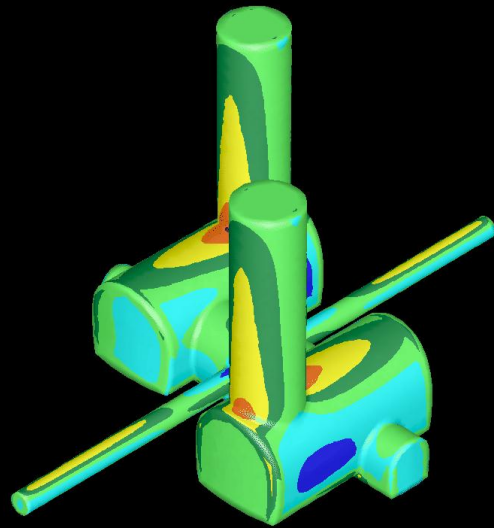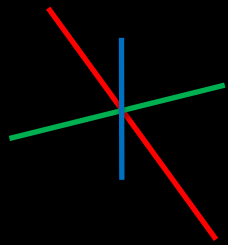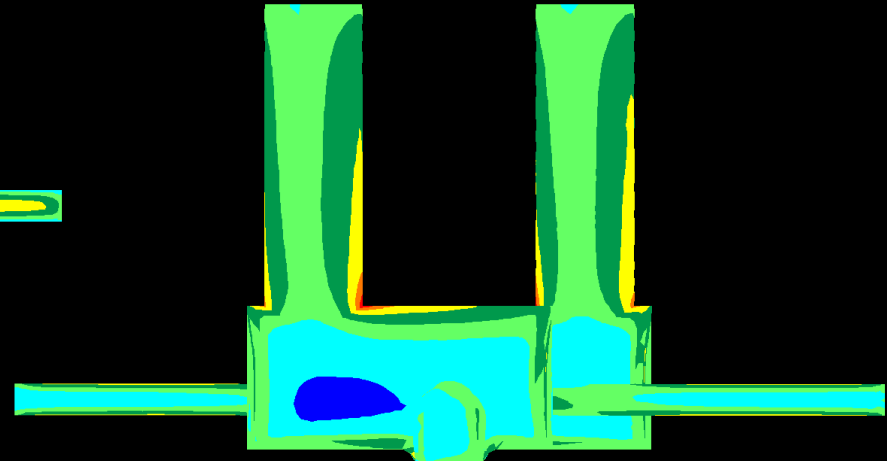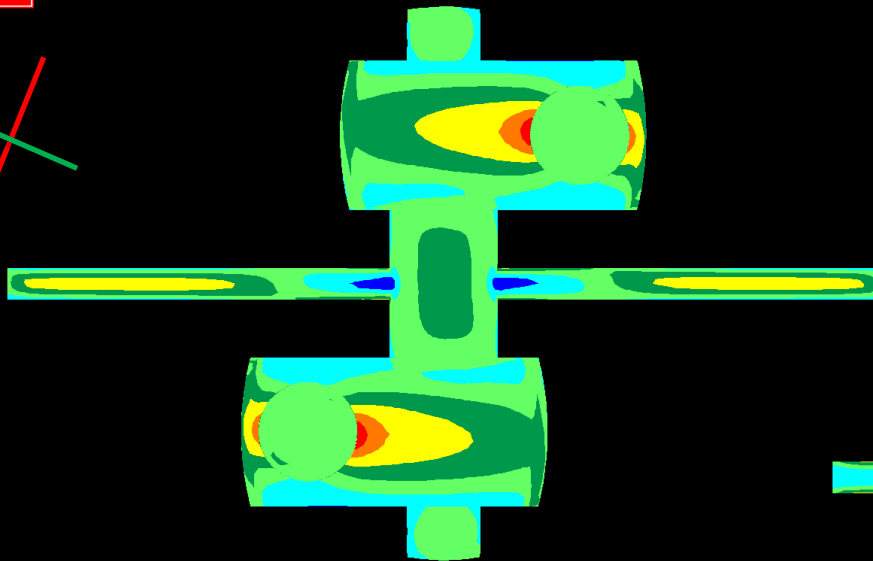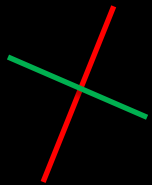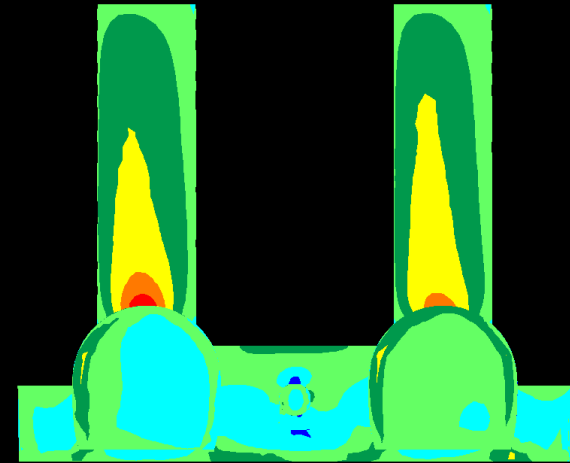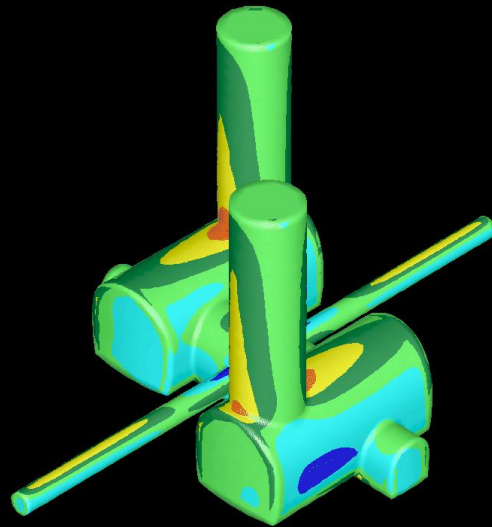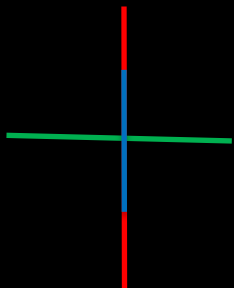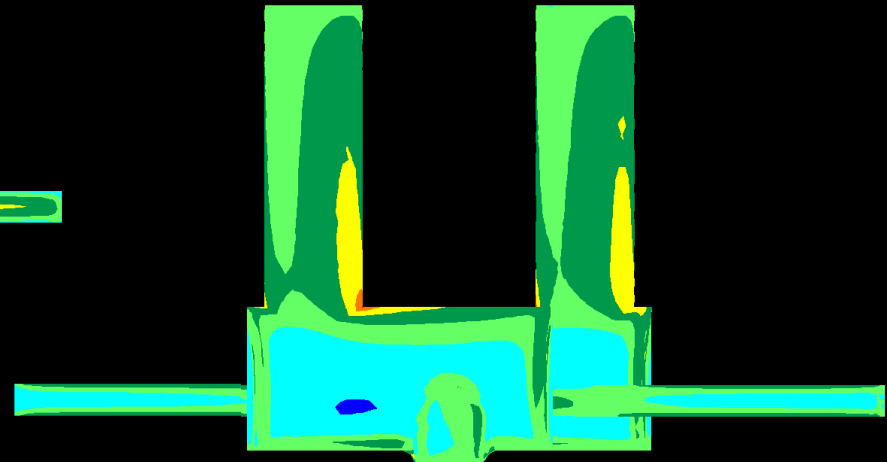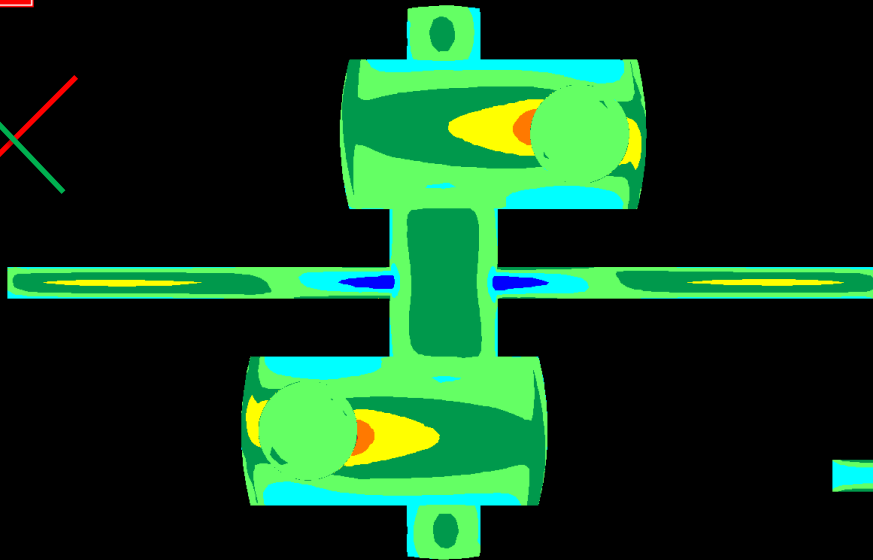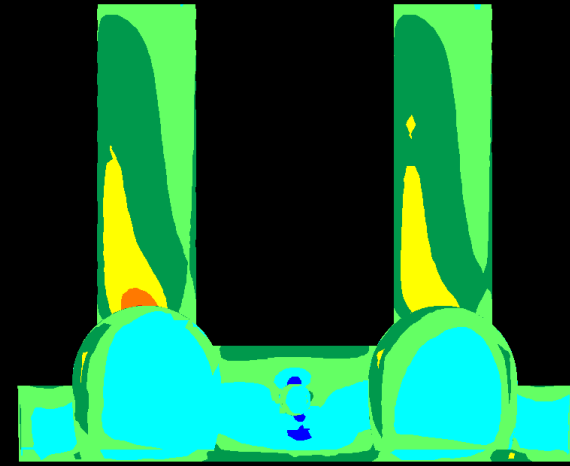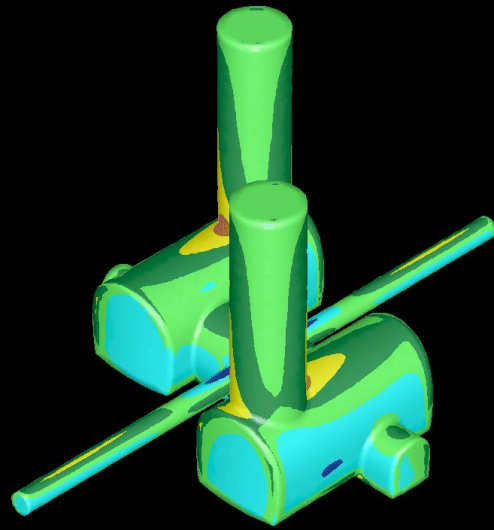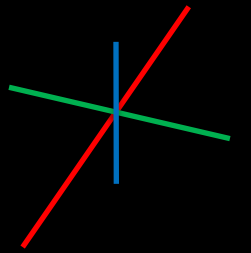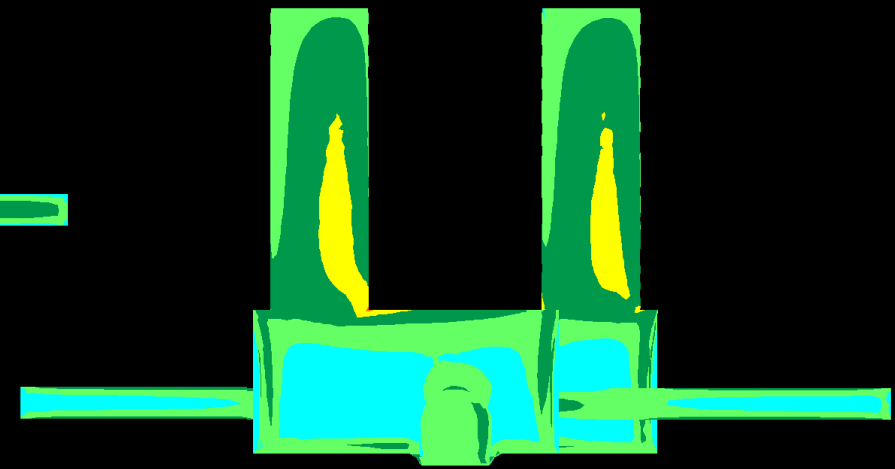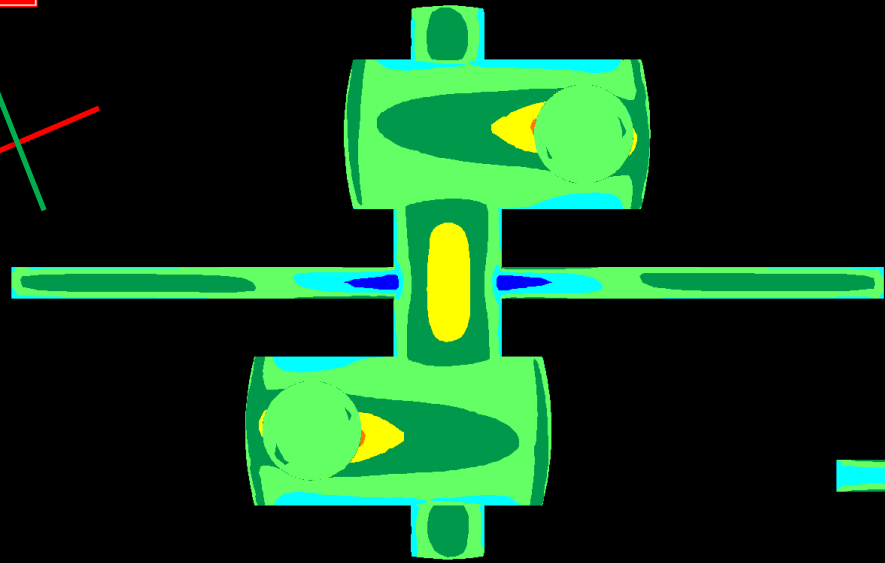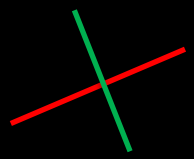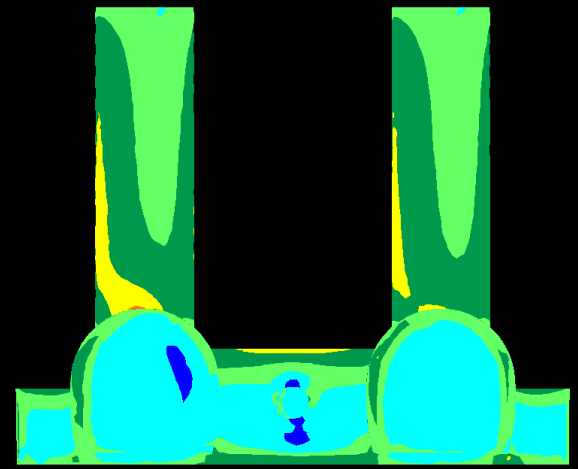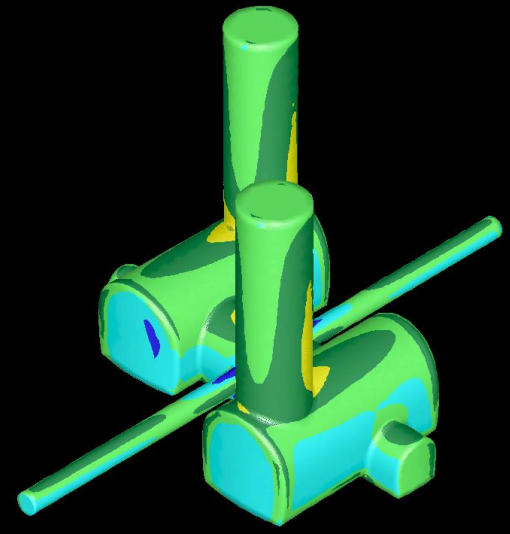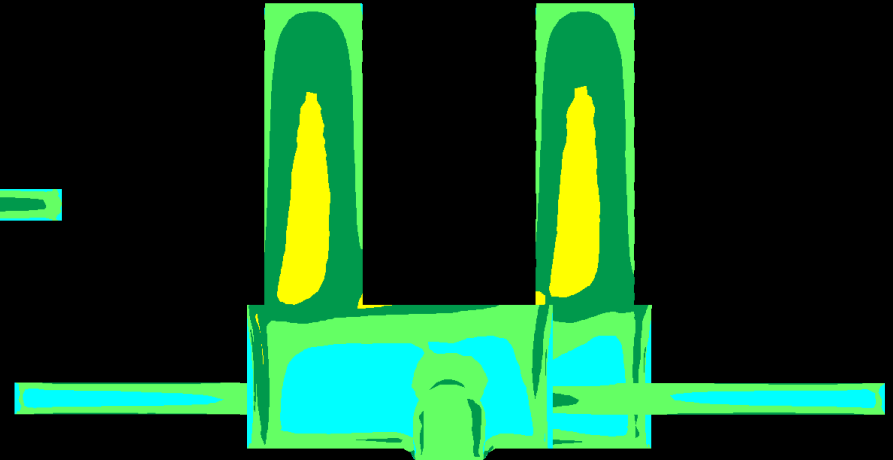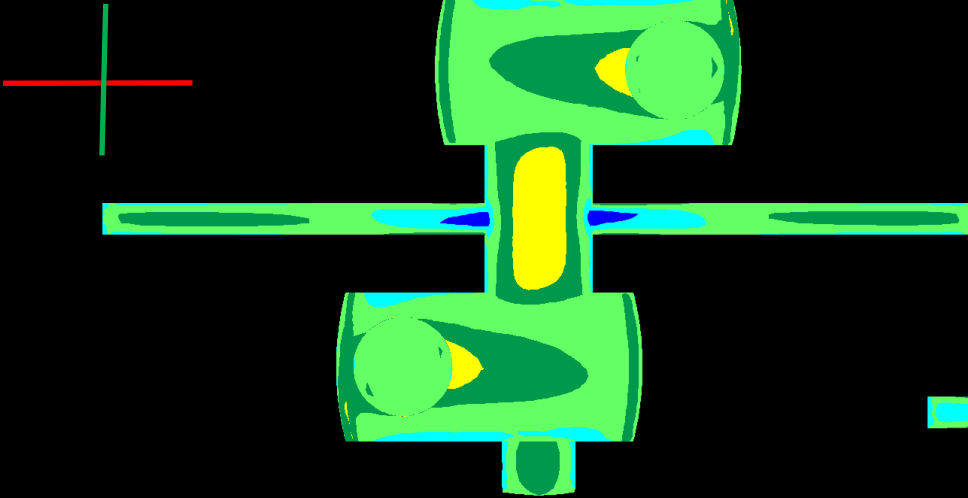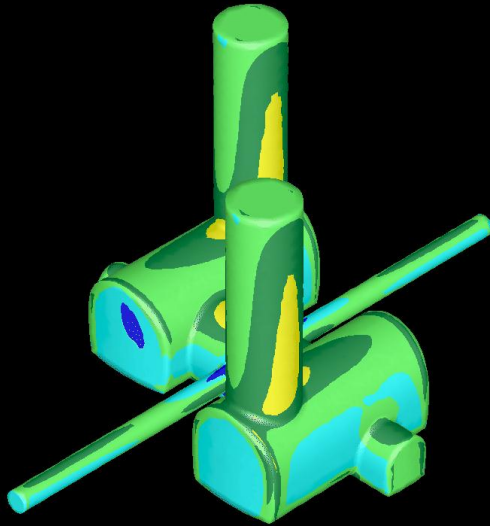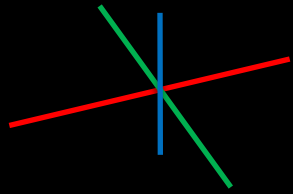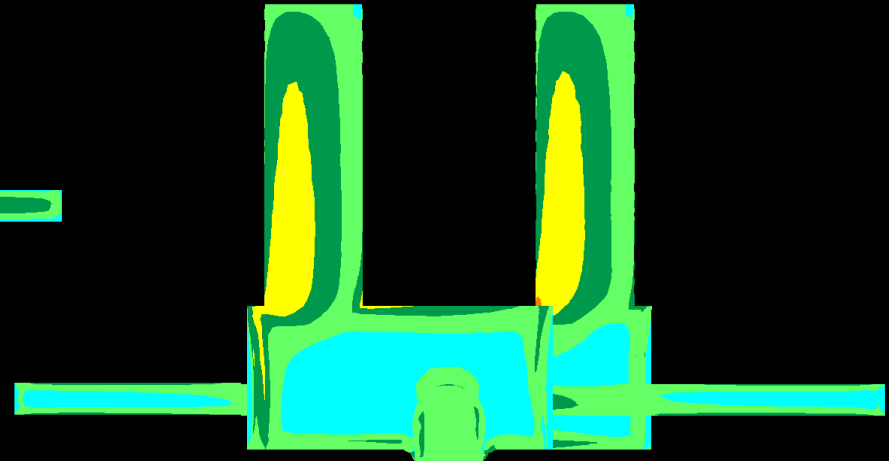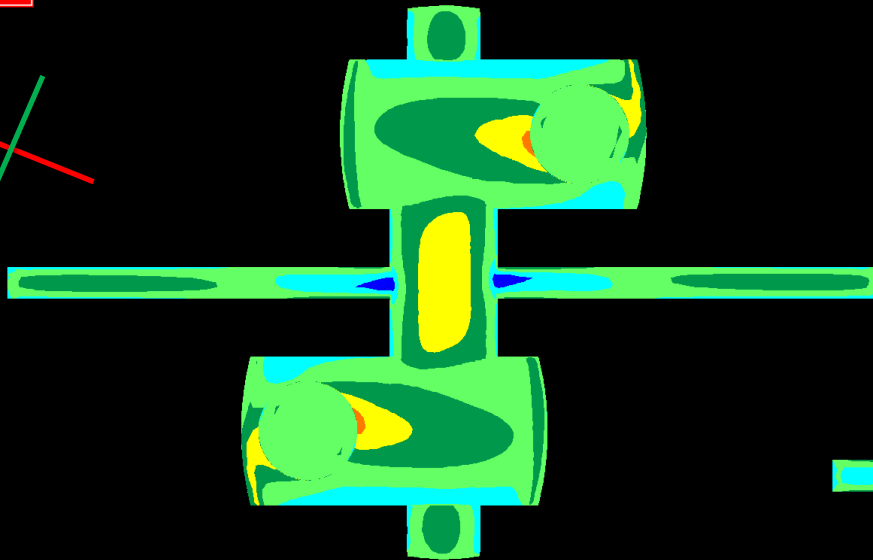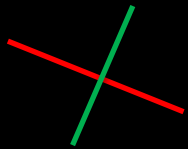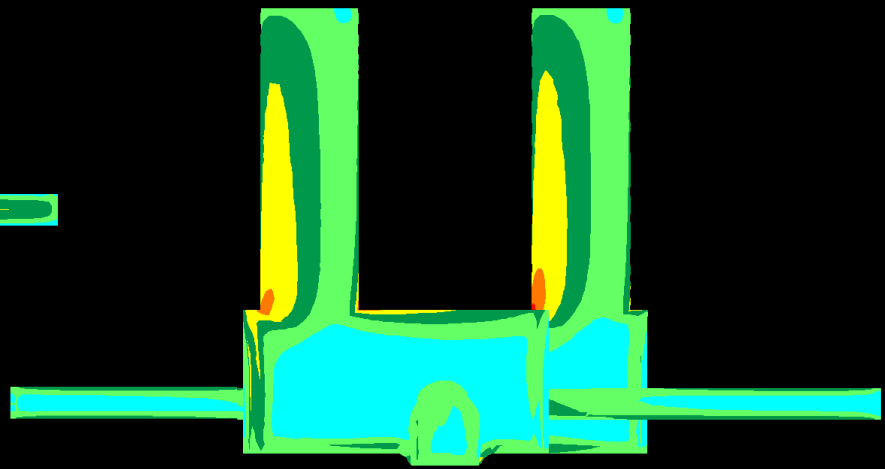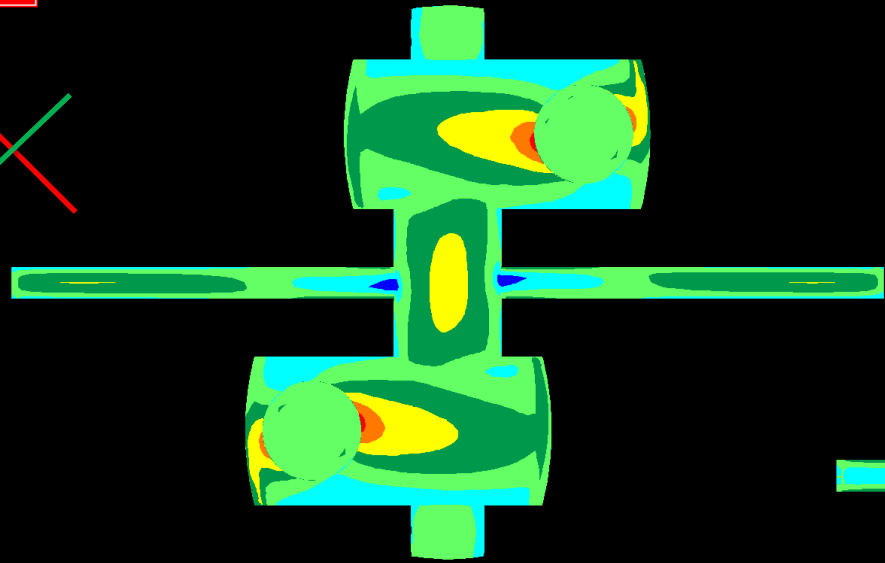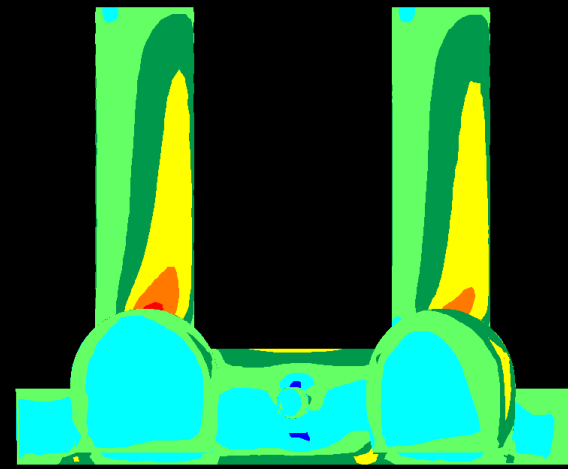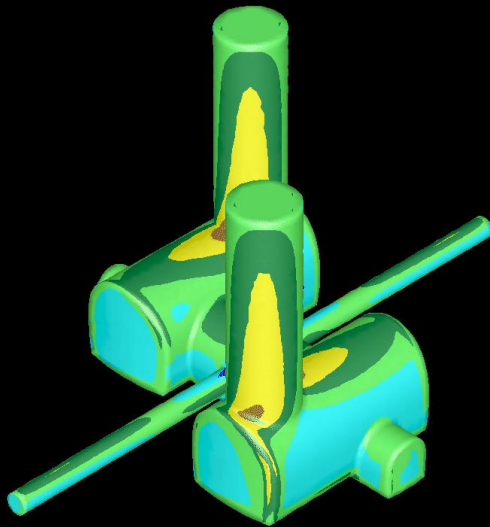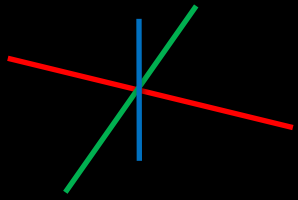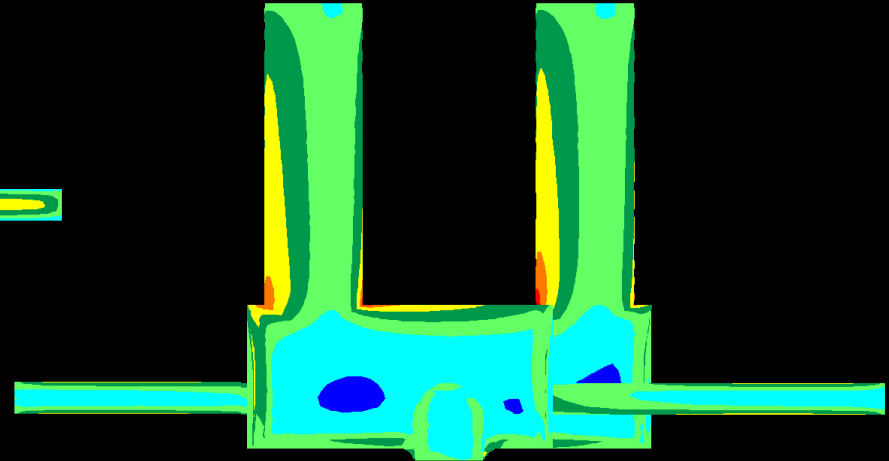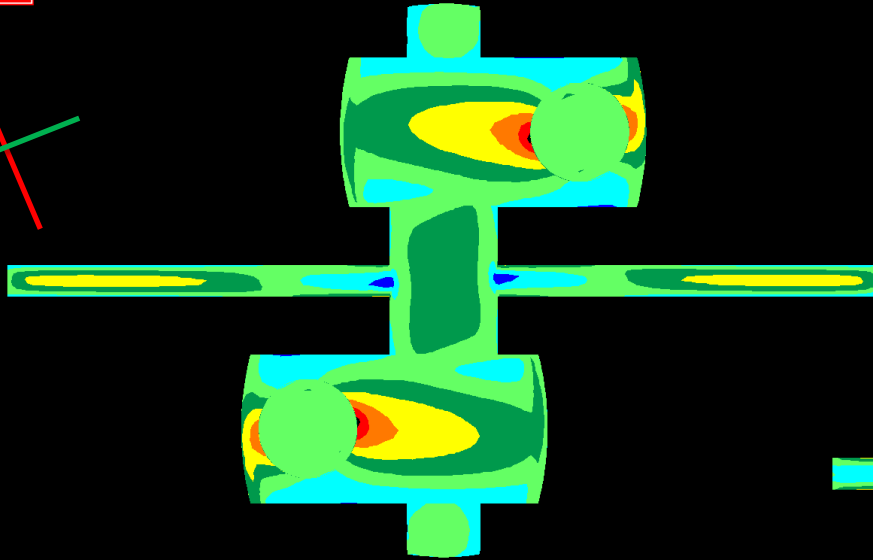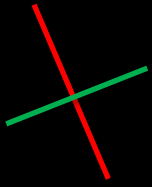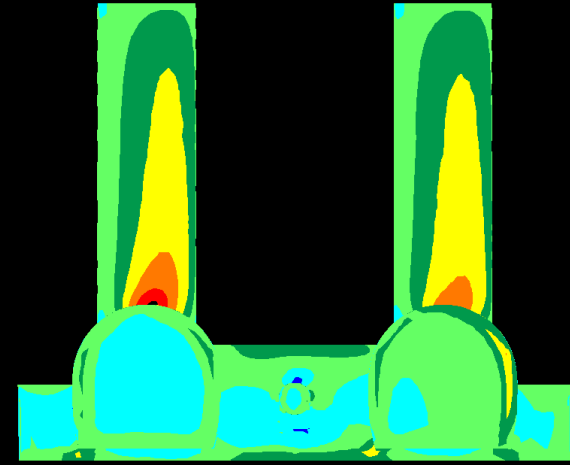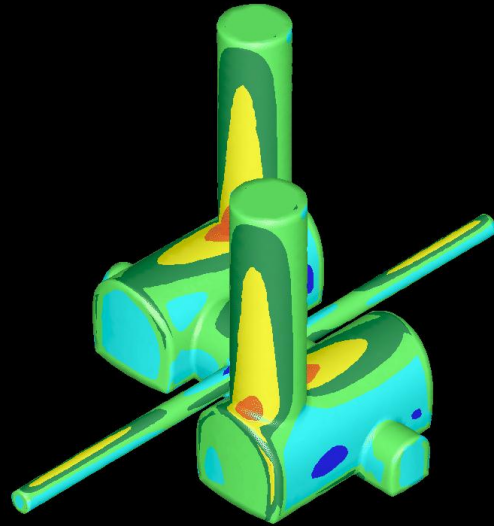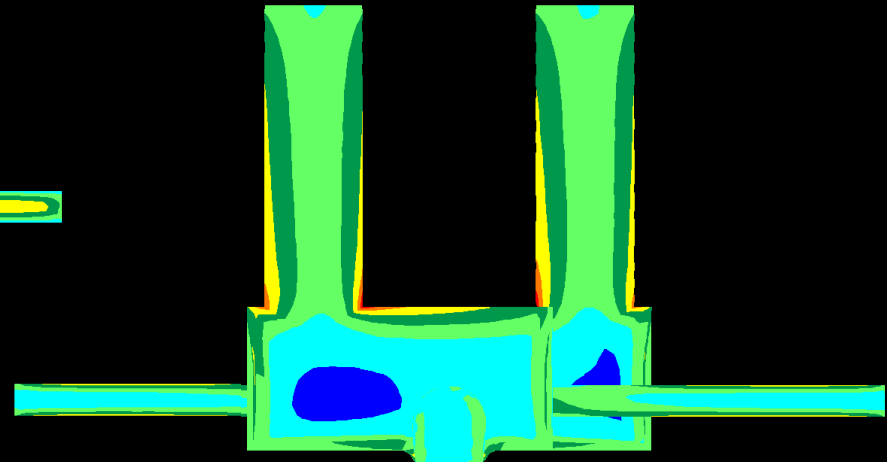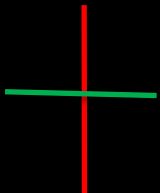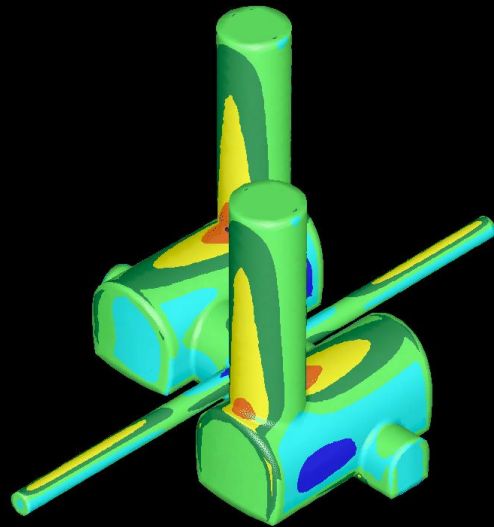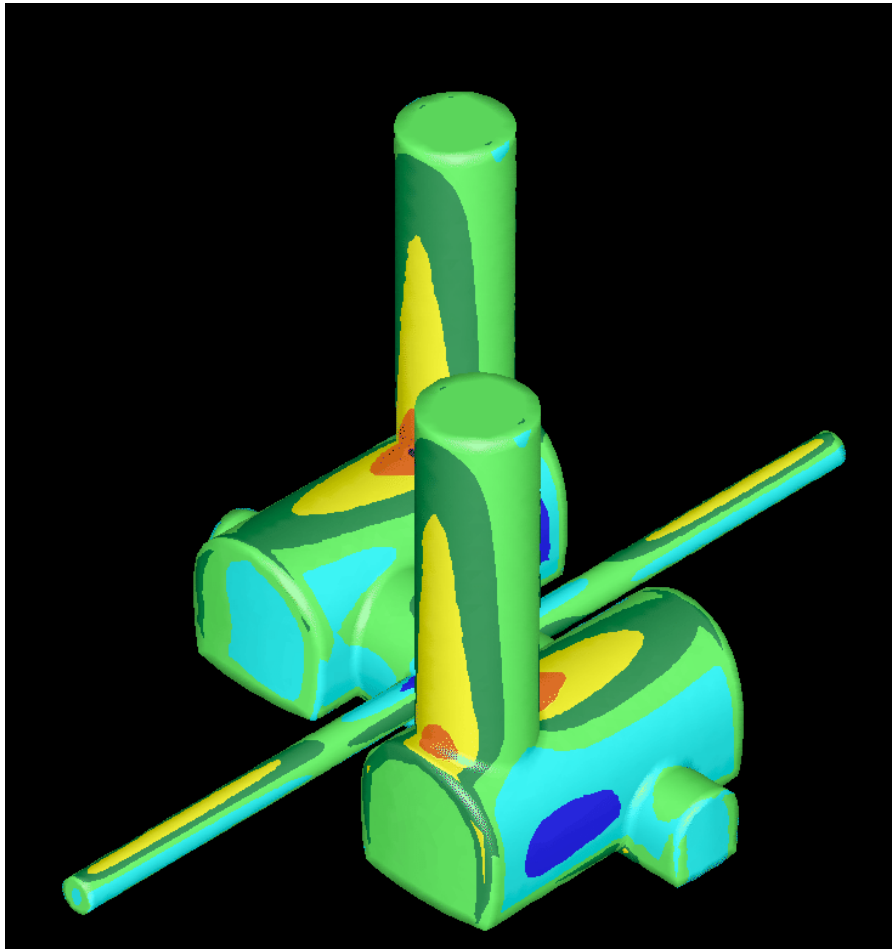
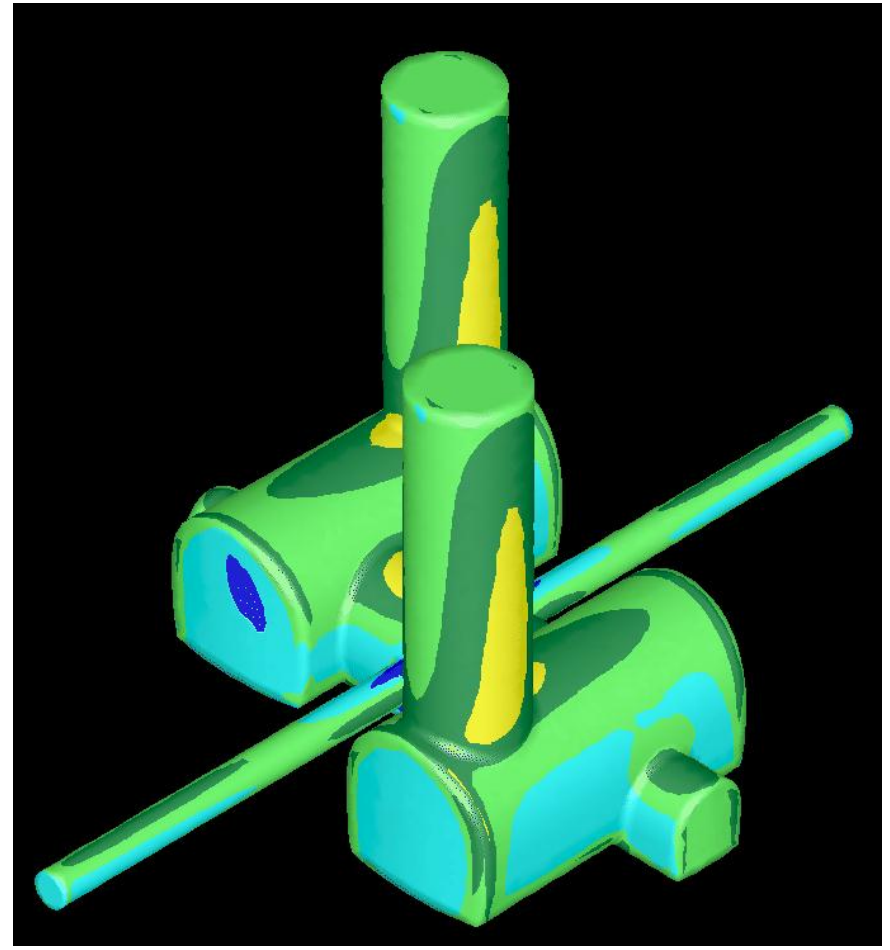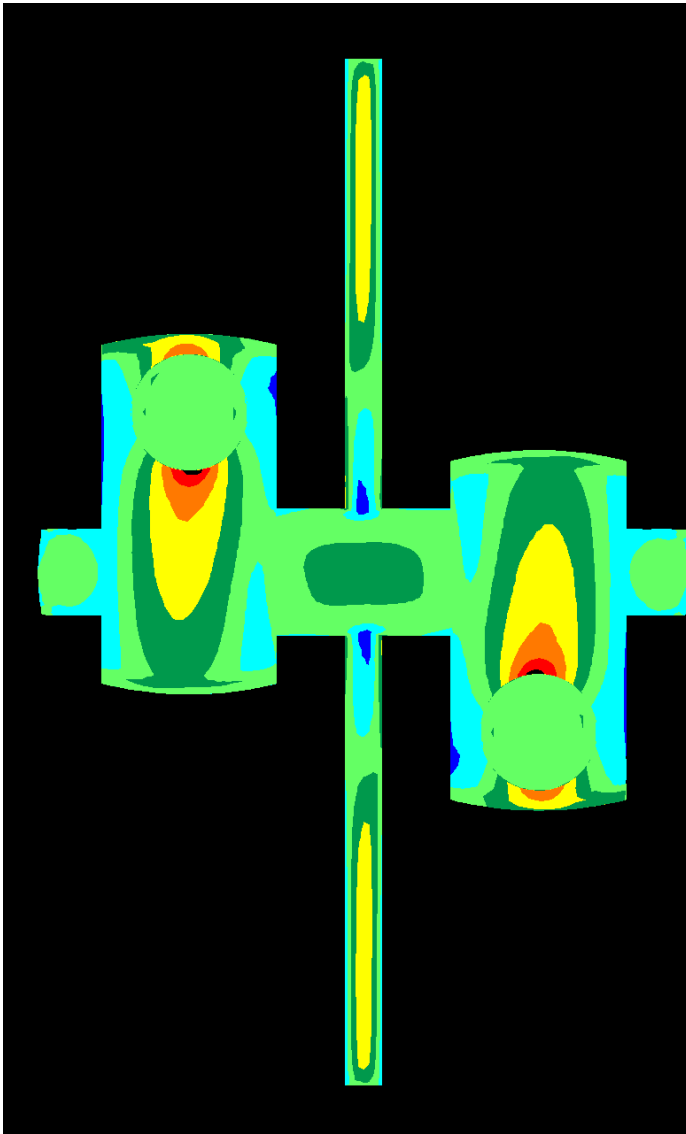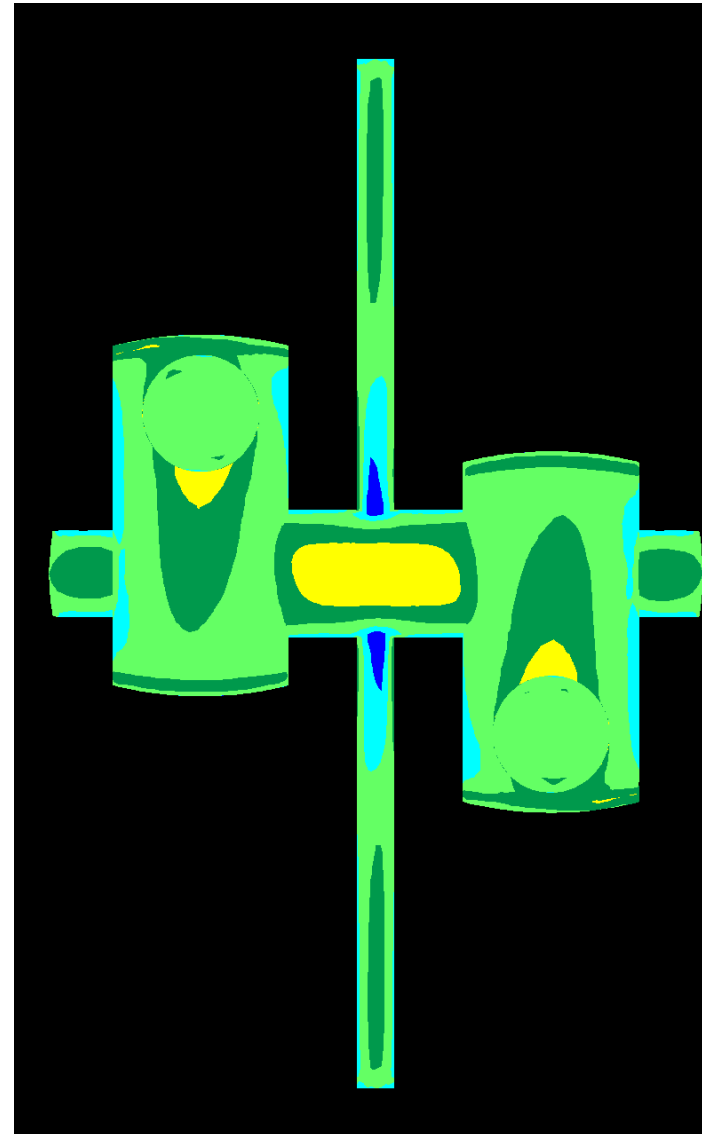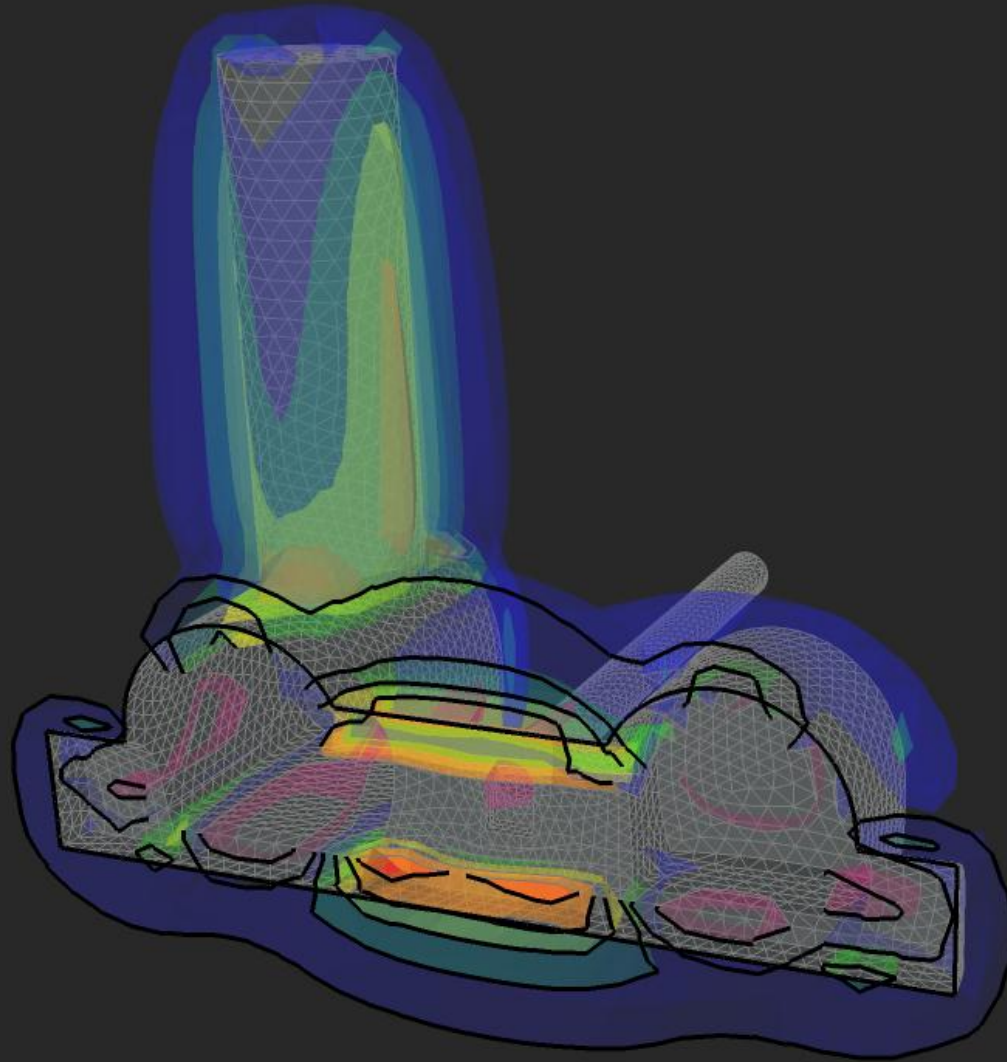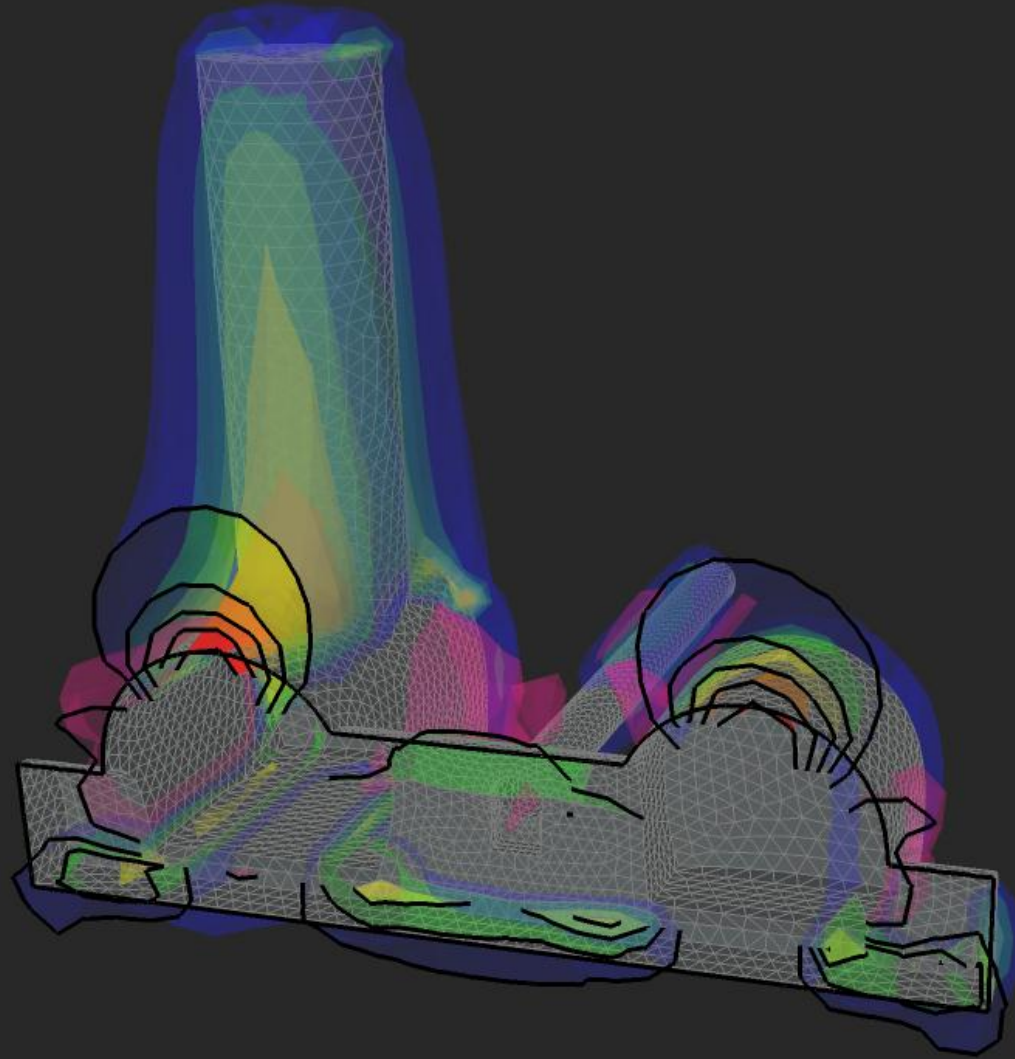# 7. Further work

Collect data regarding small strain @ low stress range

Collect data regarding ground movements in Molasse rocks for similar loading conditions

Complete review and collation of geotechnical index properties

Complete geophysical profiling and stratigraphic interpretation

Detailed interpretation of relevant geotechnical tests

Further consideration of yield criteria for layout cavern design

Complete 3D boundary element analysis of cavern orientation and revised layout and shape

Develop non-linear "BRICK" model for molasse yield – undertake ground-structure interaction analysis for detector-slab-cavern invert foundation "system".

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