Update on "Task 2" progress

Ground model and 3D cavern layout

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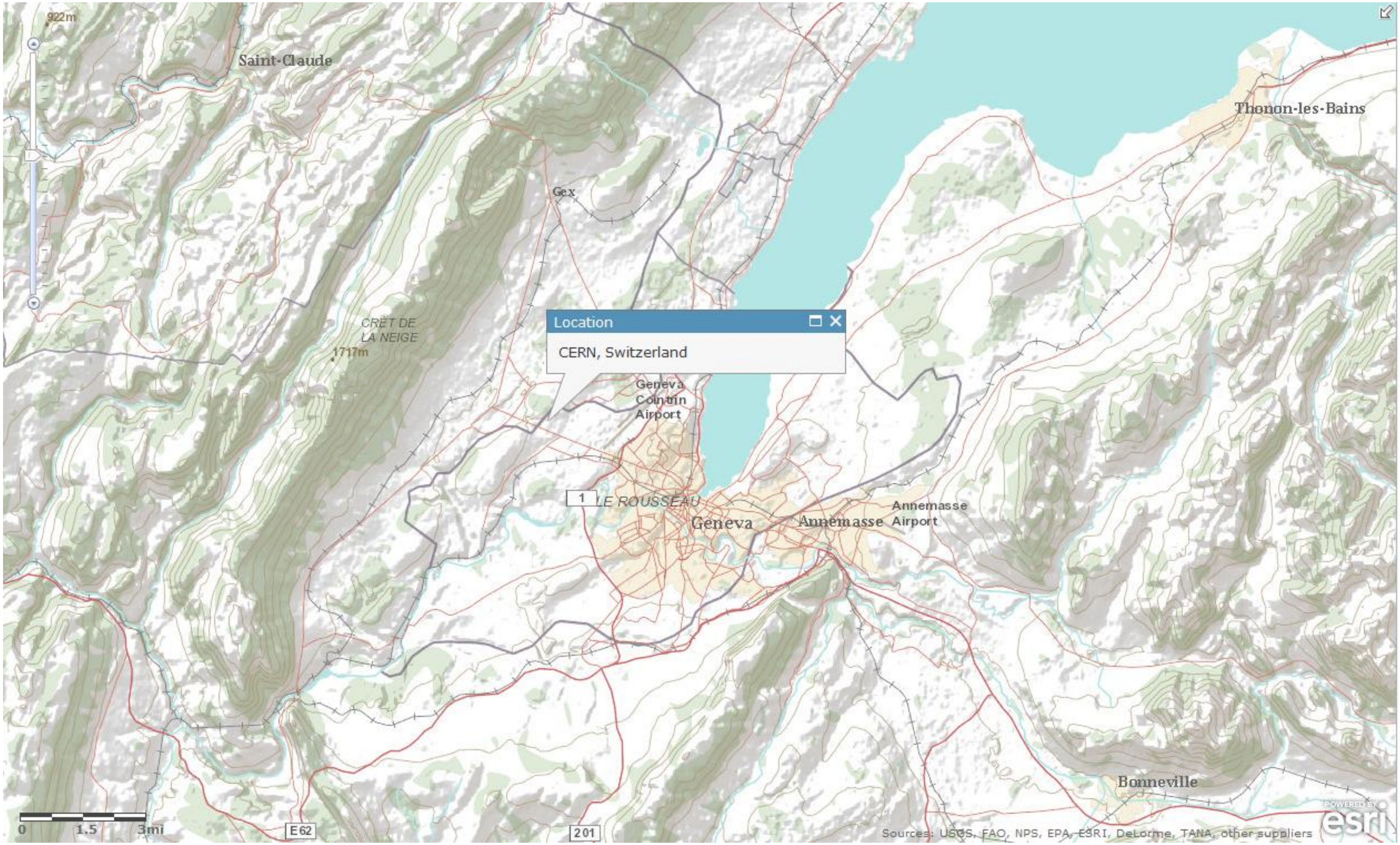
Our task….

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)


922m
Saint-Claude
Thonon-les-Bains
Gex
CRÊT DE
LA NEIGE
1717m
Location
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Geneva
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LE ROUSSEAU
Geneva
Annemasse
Annemasse
Airport
Bonneville
0
1.5
3mi
E62
201
Sources: USGS, FAO, NPS, EPA, ESRI, DeLorme, TANA, other suppliers
POWERED BY
esri

Location

This presentation…

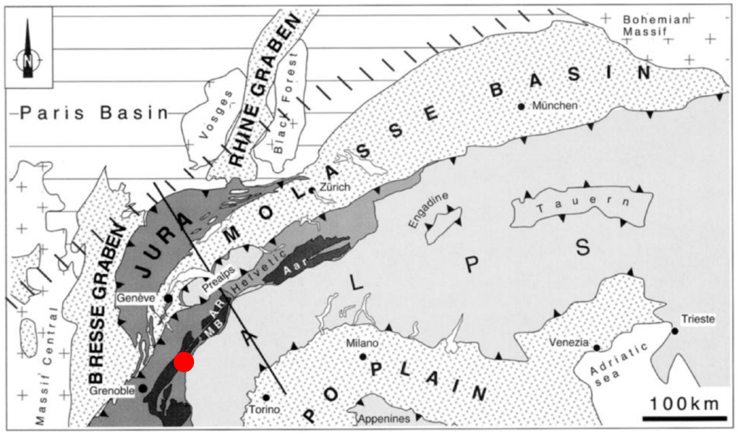
1. Data used
2. CERN Molasse Geological model
3. Molasse rock types and properties
4. Geotechnical behaviour – stress, strength & stiffness
5. Engineering behaviour – EDZ, HDZ (URL analogies)
6. Cavern design – initial studies
7. Further analysis for presentation in September (Granada)

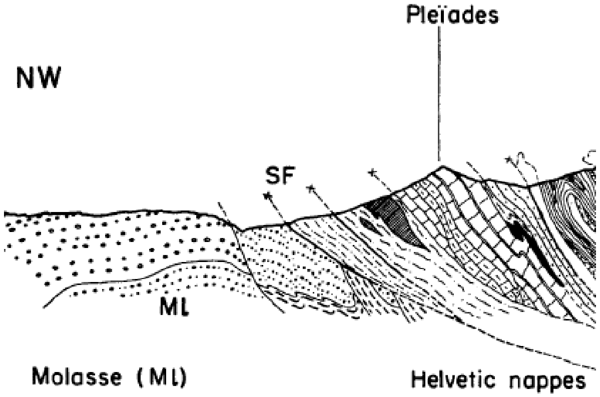
1. Data used

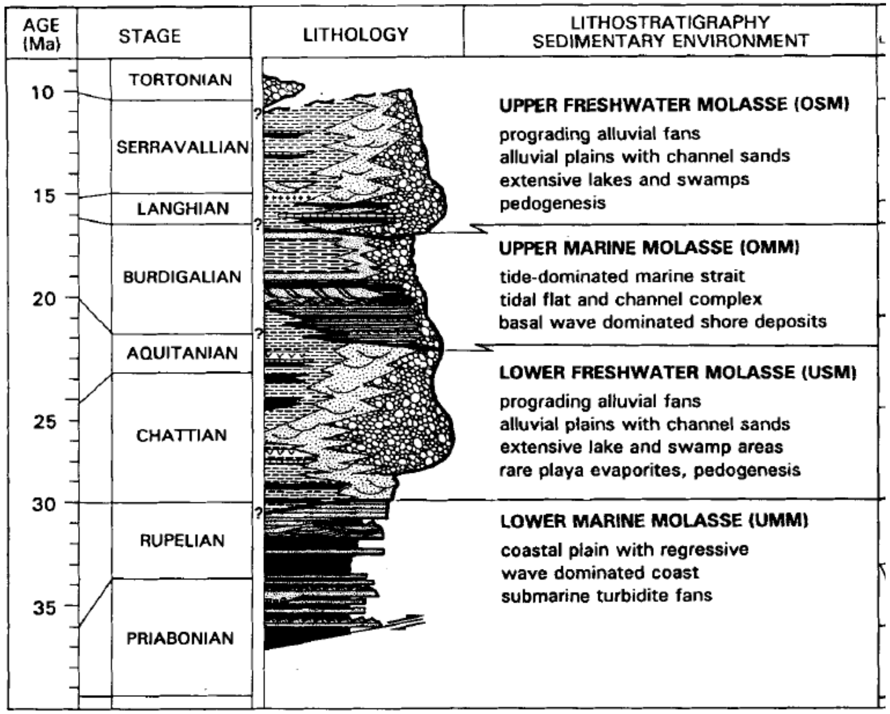
- Published geotechnical literature on Mudrocks
- Published geological/geotechnical literature on the CERN and NW Greece Molasse
- CERN reports for Point 1 and 5 (LEP) including borehole logs, in situ and laboratory testing
- Published geotechnical literature for the Underground Research laboratories (URLs) at Bure, Mol and Mont Terri in analogous mudrocks

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”







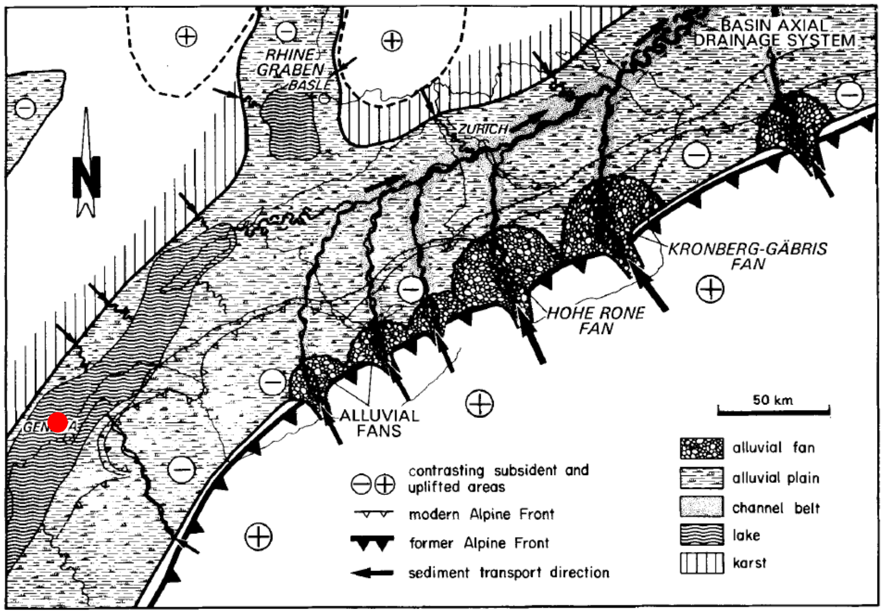


Fig. 4. Palaeogeography of the Swiss Molasse Basin at the Chattian–Aquitanian boundary. Modified and redrawn after maps by Heim (1919), Büchi & Schlanke (1977); new data based on field observations by the authors and oral communications by J.-P. Berger (Fribourg) and M. Weidmann (Jongny).

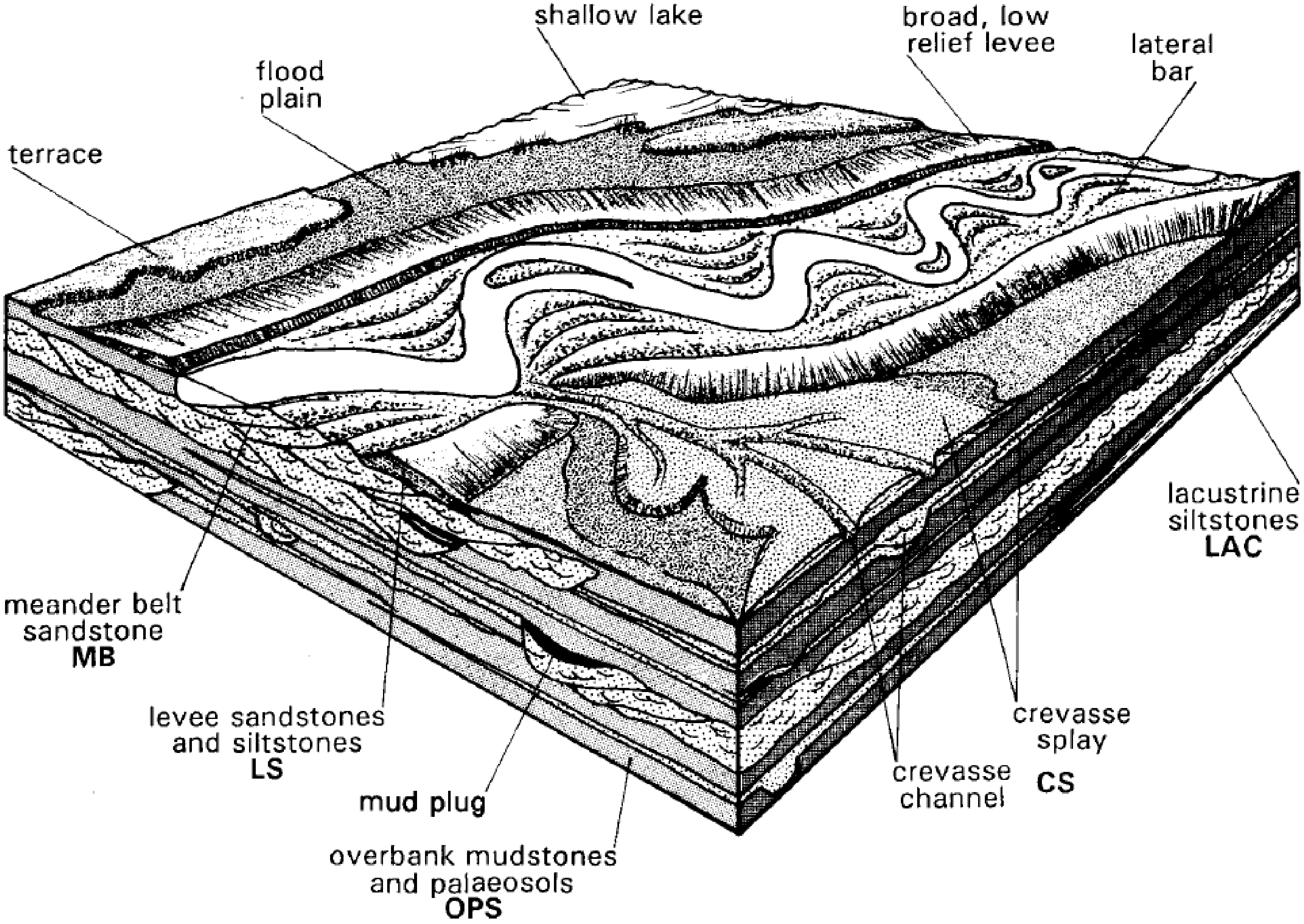
Key (facies associations and predominant lithologies):

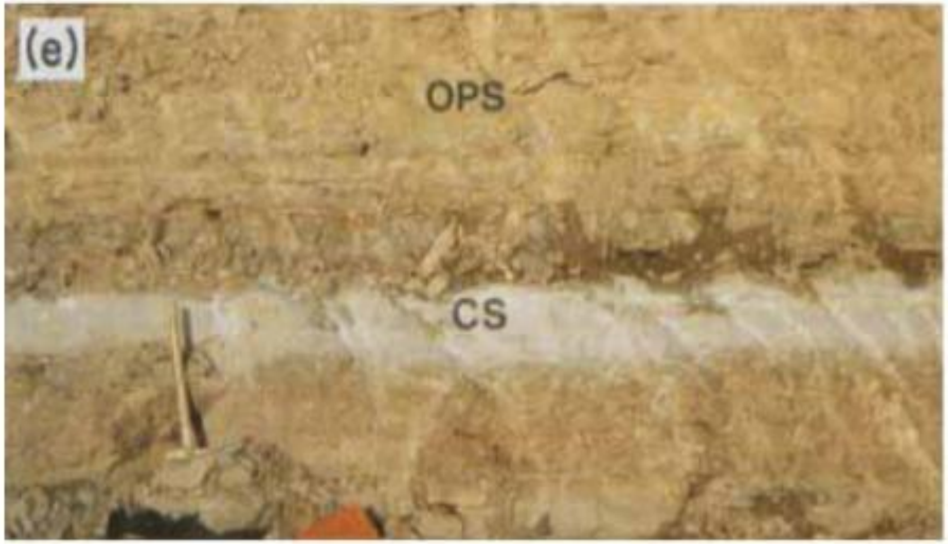
FRESHWATER MOLASSE (USM,OSM)

- alluvial fans and deltas/fan deltas (mainly conglomerates)
- distal fans with channel belts (sandstones predominant)
- alluvial plain-overbank (mainly siltstones, mudstones & marls)
- alluvial plain-channel belts (sandstones predominant)
- alluvial plain-lacustrine (mudstones, carbonates & siltstones)
- +++ bentonite
- vvv evaporite

MARINE MOLASSE (UMM,OSM)

- tidal seaway (sandstones-ripples, sandwaves, wavy bedding etc.)
- wave-dominated shoreline (sandstones)
- storm deposits (sandstones with HCS and wave ripples; UMM)
- turbidites (mostly sandstones; UMM)
- open marine (mudstone & marls; UMM)
- interdeltaic & interdistributary bays (siltstones; OMM)
- tidal flat (heterolithic mudstones, siltstones & rare sandstones; OMM)


shallow lake
broad, low relief levee
lateral bar
flood plain
terrace
lacustrine siltstones LAC
meander belt sandstone MB
levee sandstones and siltstones LS
mud plug
crevasse splay
crevasse channel
CS
overbank mudstones and palaeosols OPS



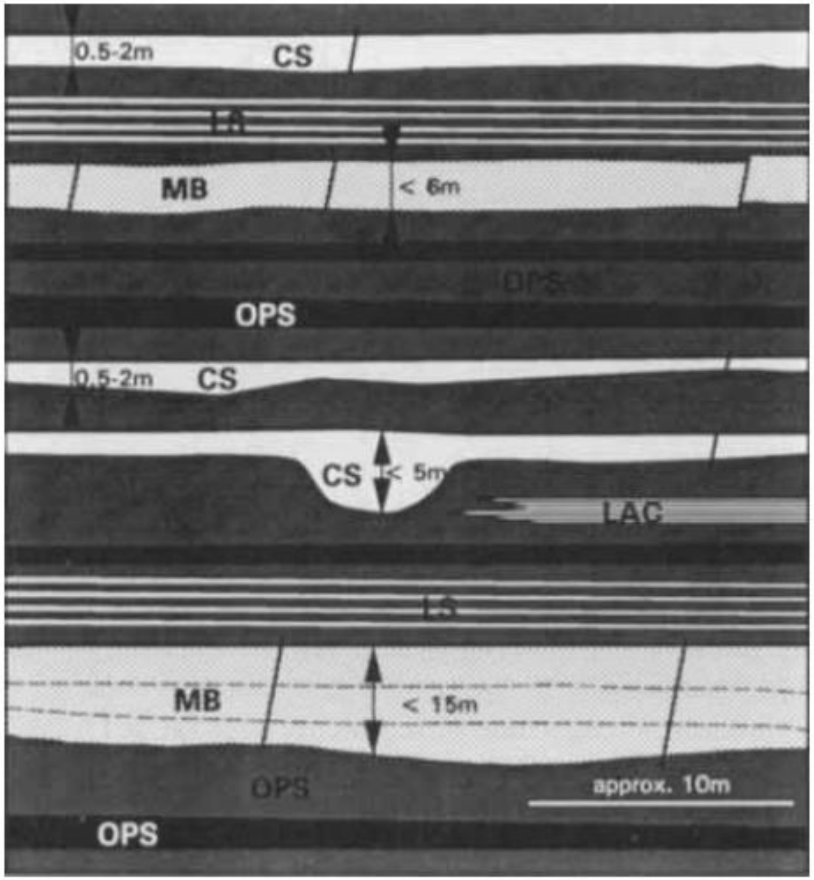


Fig. 6. Block diagram of architectural elements within the distal Aquitanian showing thicknesses of major sandstone units. MB = meander belts; CS = crevasse channels and splays; LS = levees and distal splays; OPS = overbank fines, palaeosols and swamps; LAC = lacustrine. Oblique lines are faults.

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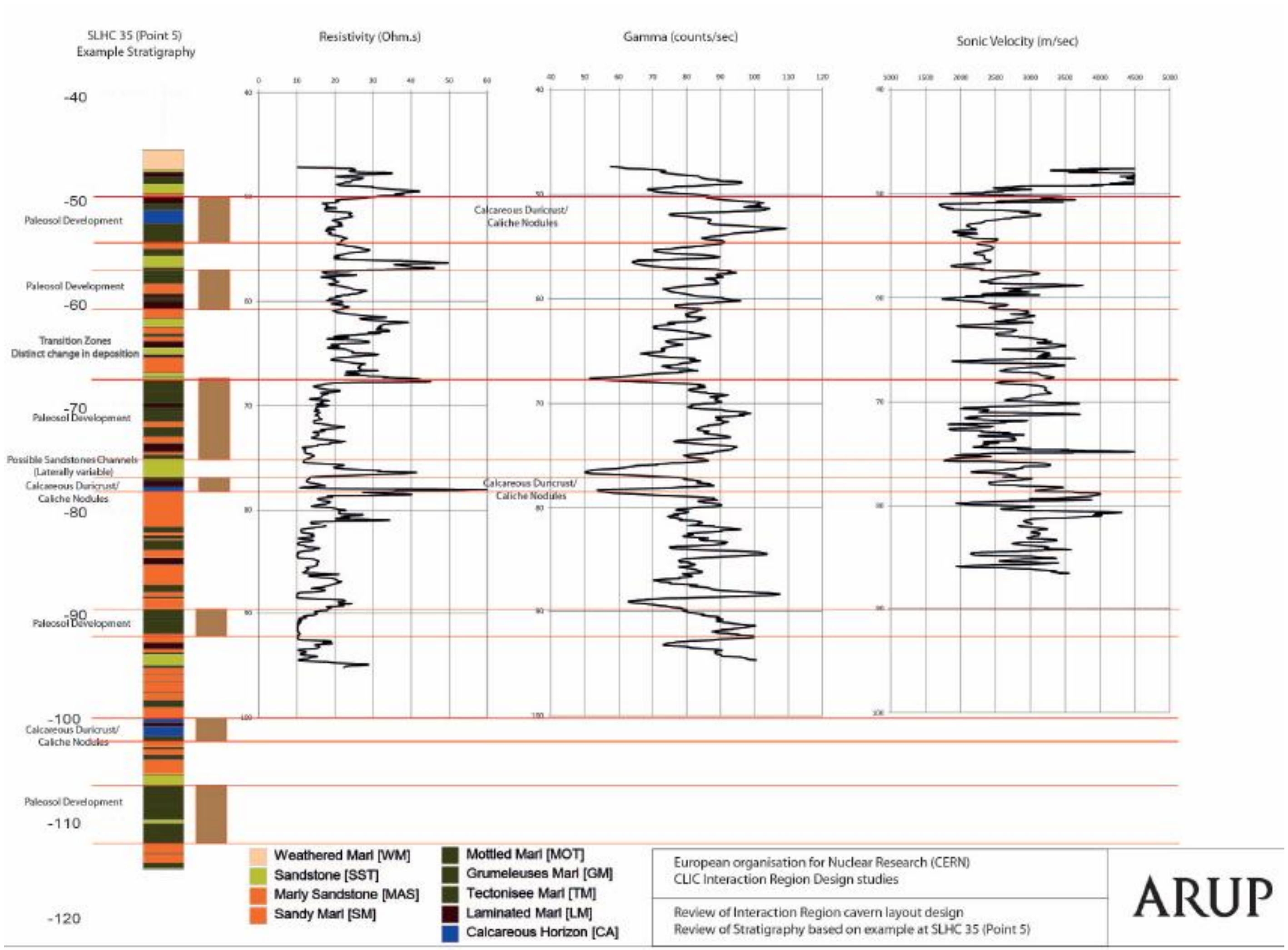
Arup interpretation of the borehole logs in this context…..



3. The molasse rocks

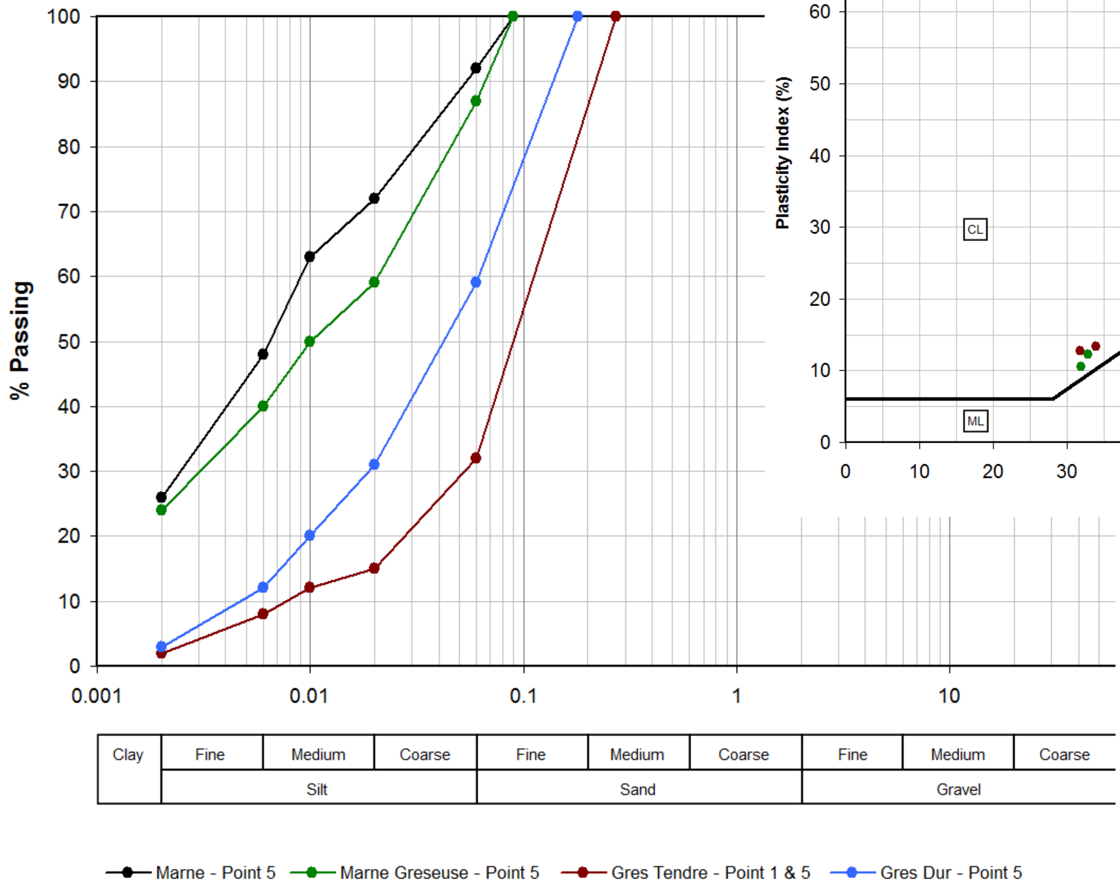
Marls: The fine grained rocks described in the CERN archive reports range from sandy Marls to marly Sandstones and *Grumeleuse* and *Tectonisee* Marls. Up to 40 -55% of the marl samples were said to be composed of clay minerals, with the remainder comprising iron oxides, feldspar, quartz and calcite/dolomite.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

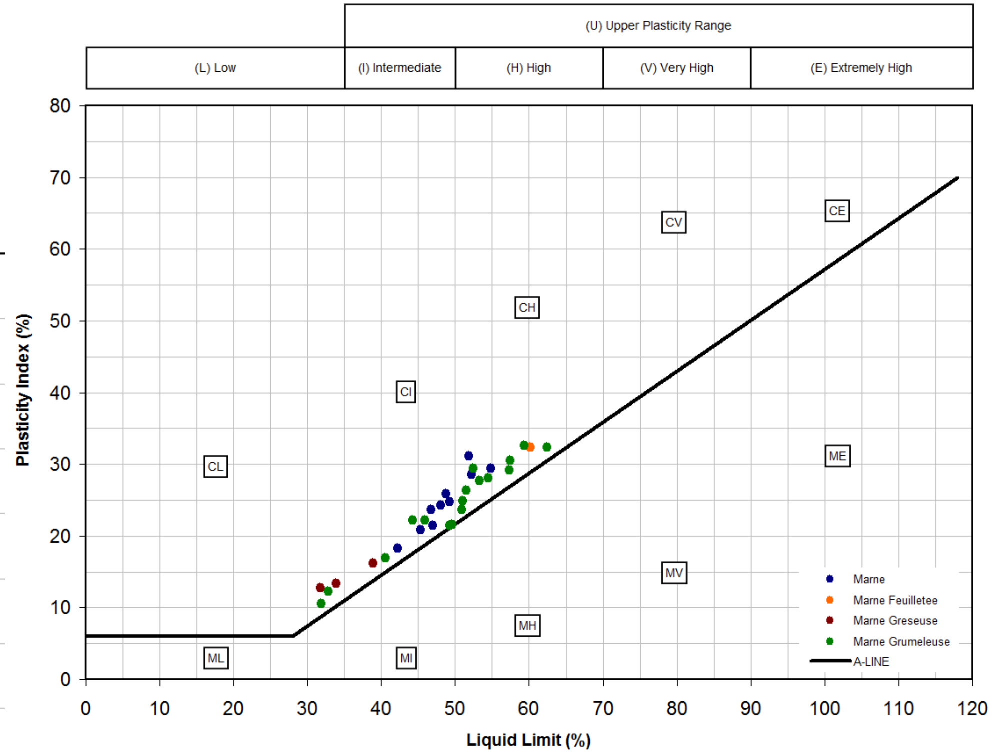
Sandstones: quartz-feldspar sands with mica (chlorite or muscovite), and calcareous cement. The grain size is fine, occasionally medium. Locally, the grain size approaches that of silt (0.002 - 0.06 mm).

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%

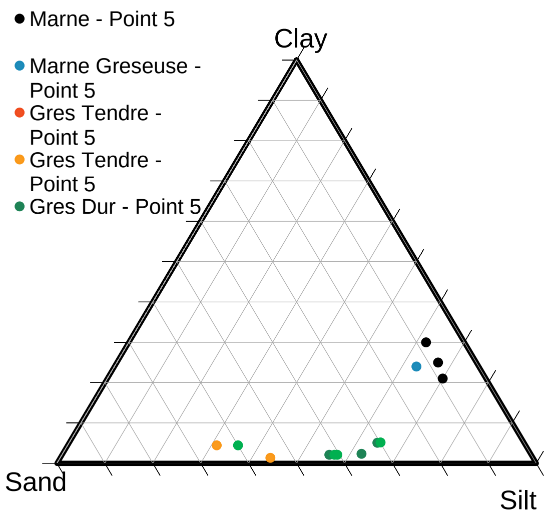




Void ratio typically 0.11 to 0.29

Porosity between 9 to 22%

Permeability <1E-12m/sec (“zero” Lugeon)

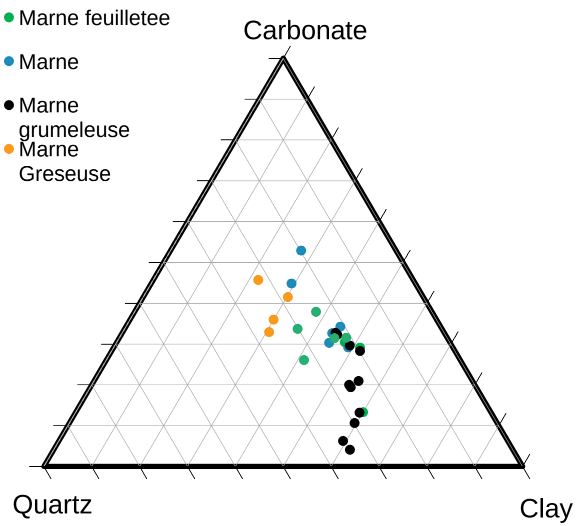


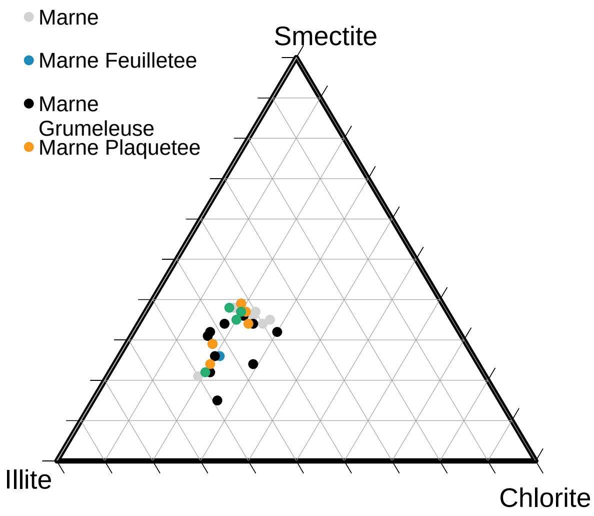
Ternary diagrams (few data)

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





4. Geotechnical

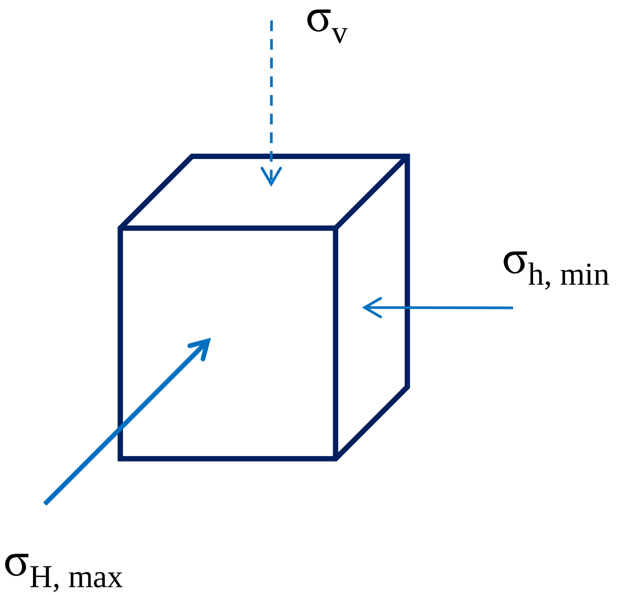
In situ stresses at LHC at 92 to 123m depth have been determined as:

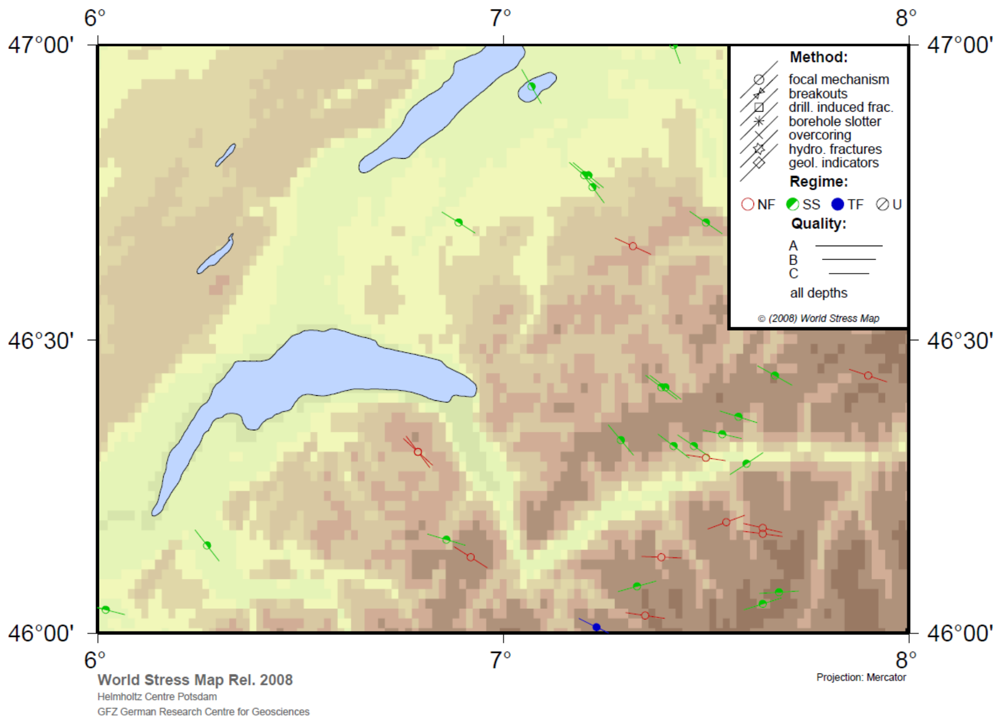
$\sigma_{H,\,max}$ = 4.7±0.7MPa to 5.3±0.7MPa (NNE-SSW to ENE-WSW);

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

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

But contradictory evidence!





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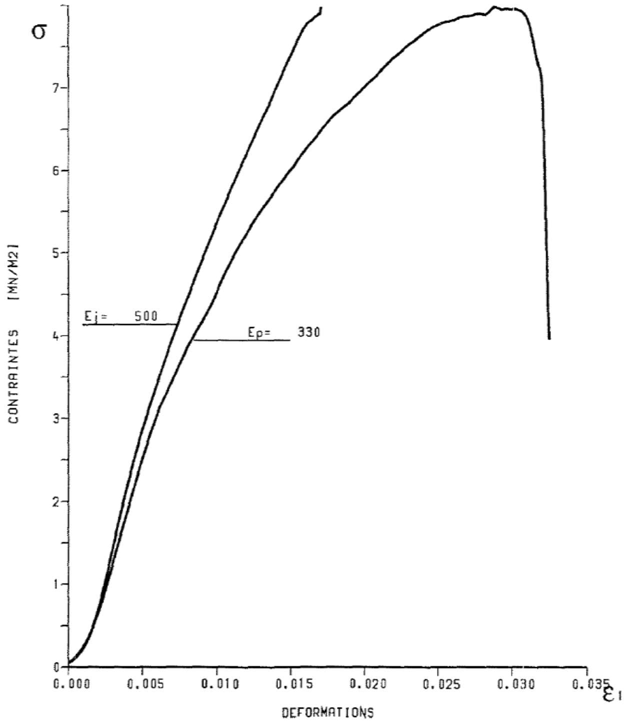
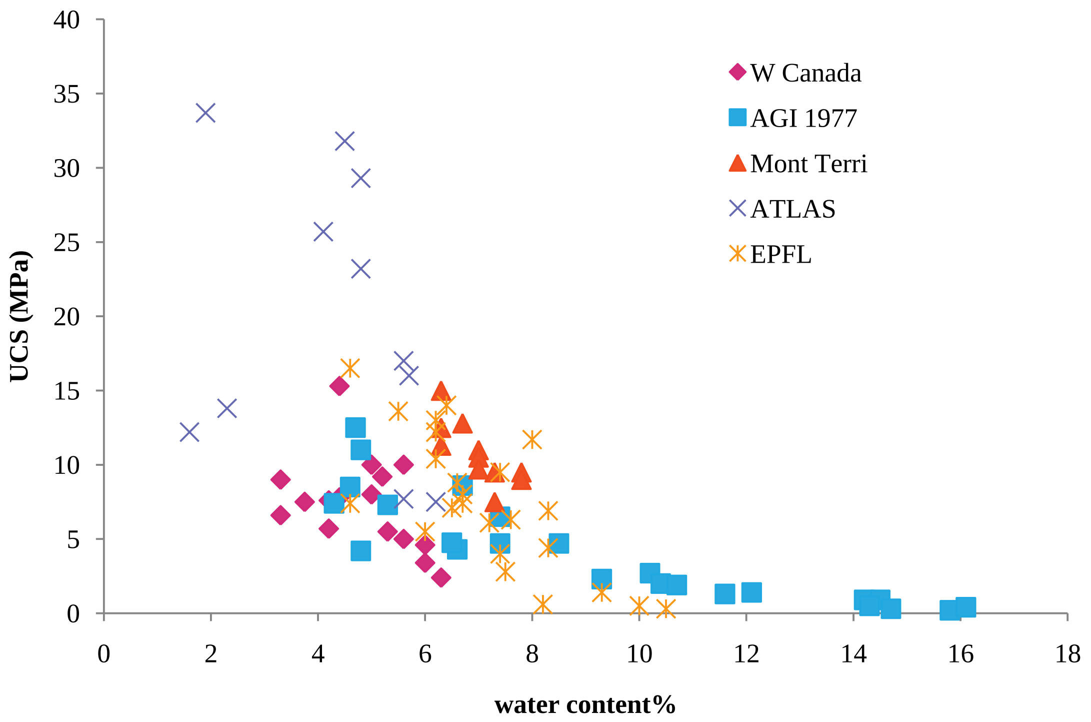
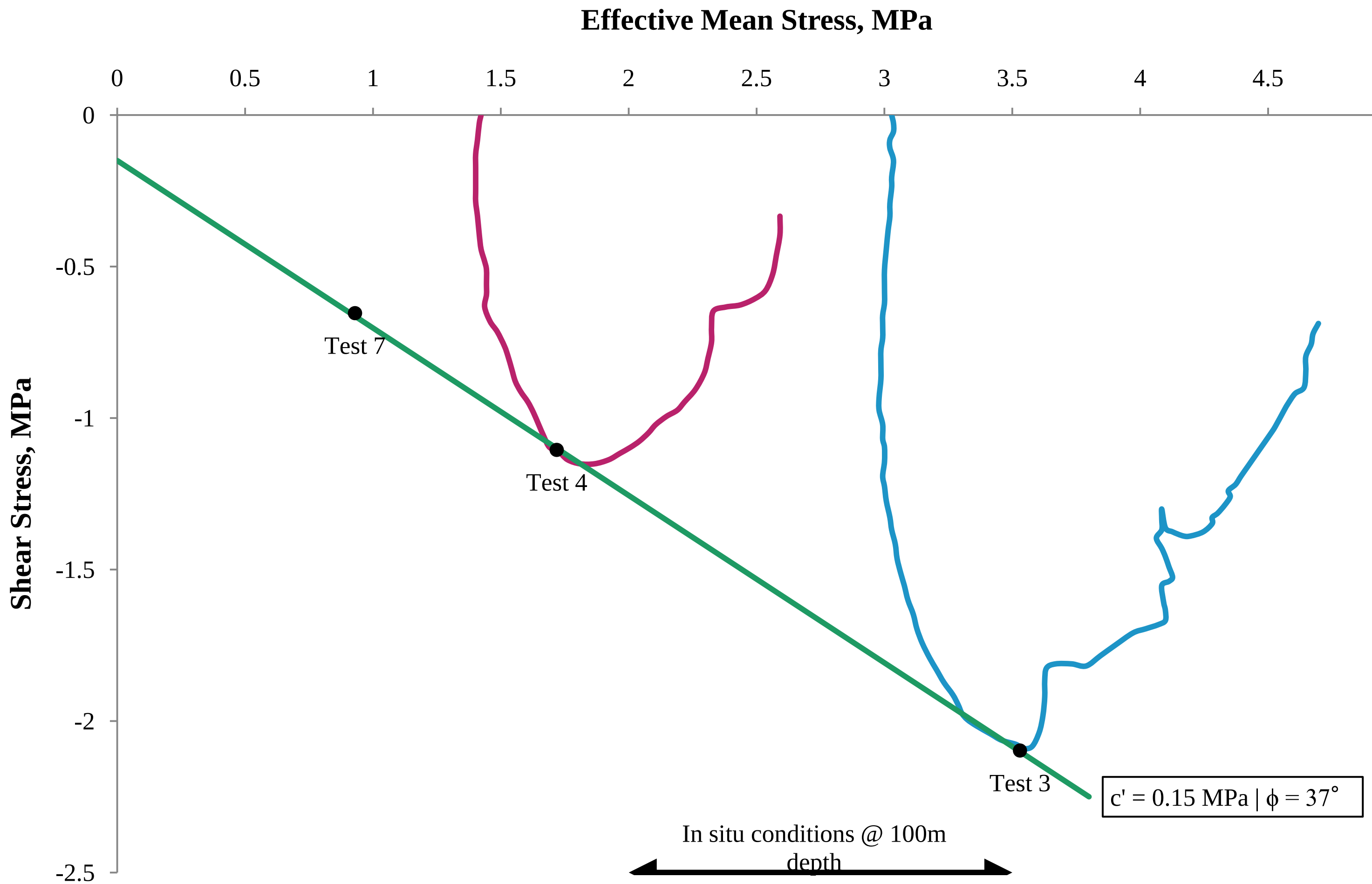


UCS test on "Marne" (at 82.3m depth) by the *EPFL*. UCS = 8MPa, w = 6.7%. Globally Youngs' Modulus (E_P) = 330MPa and local modulus(E_J) =500MPa. Modulus ratios (E/UCS) of around 100 can be estimated for the "*marne*" and 160 for the "*marnogres*" (marly sandstone) from the global strain measurement

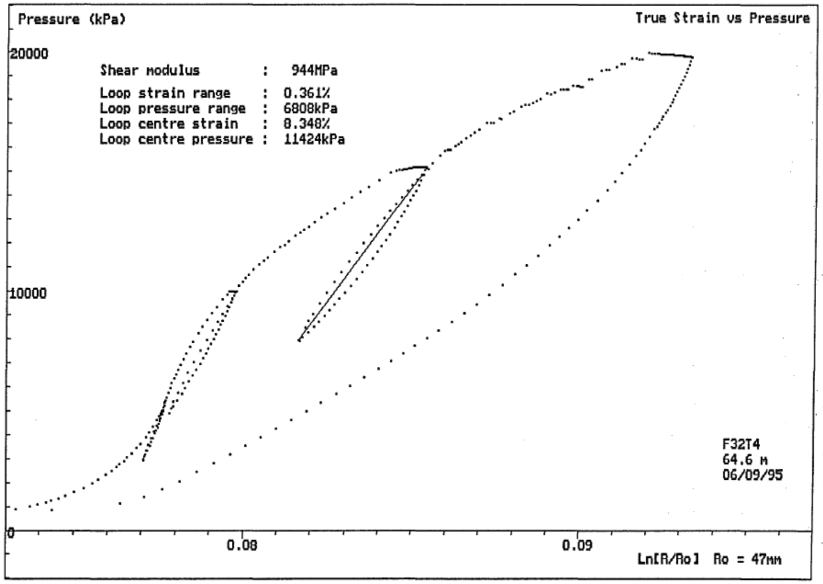


Uncertainties:

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

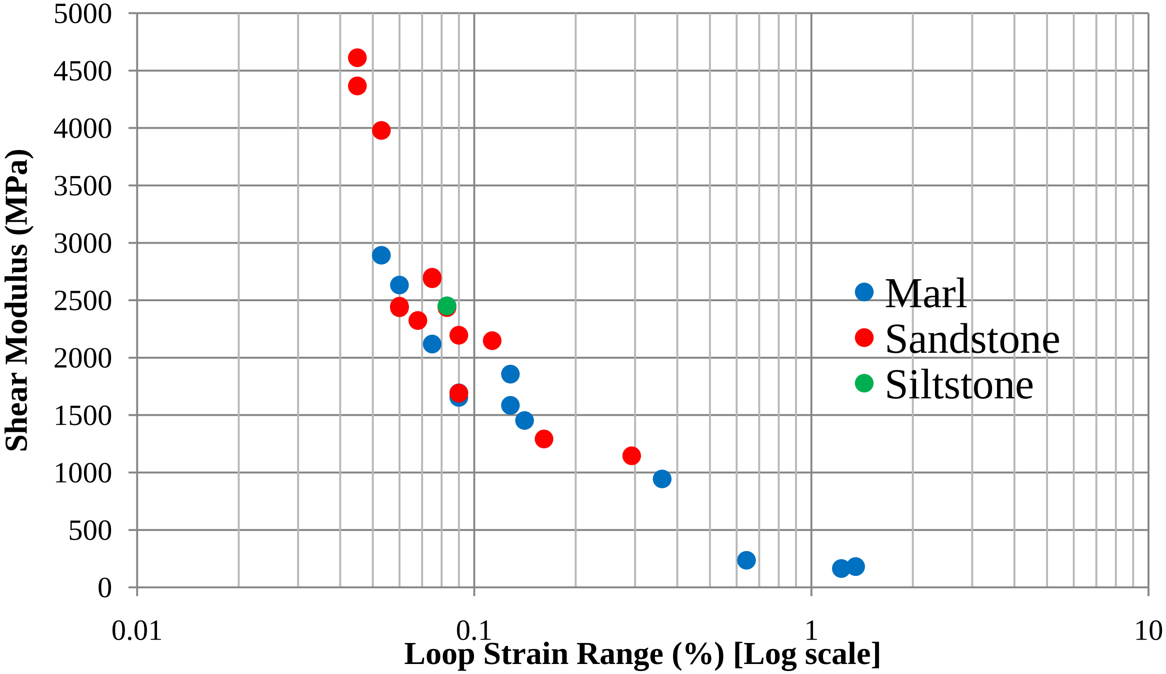


$CIU_{extension}$ and CK_oD_{ext} triaxial tests with pore pressure measurement – short term undrained strength, long term effective stress strength can be obtained. UCS test limitations reduced.



Stiffness:

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



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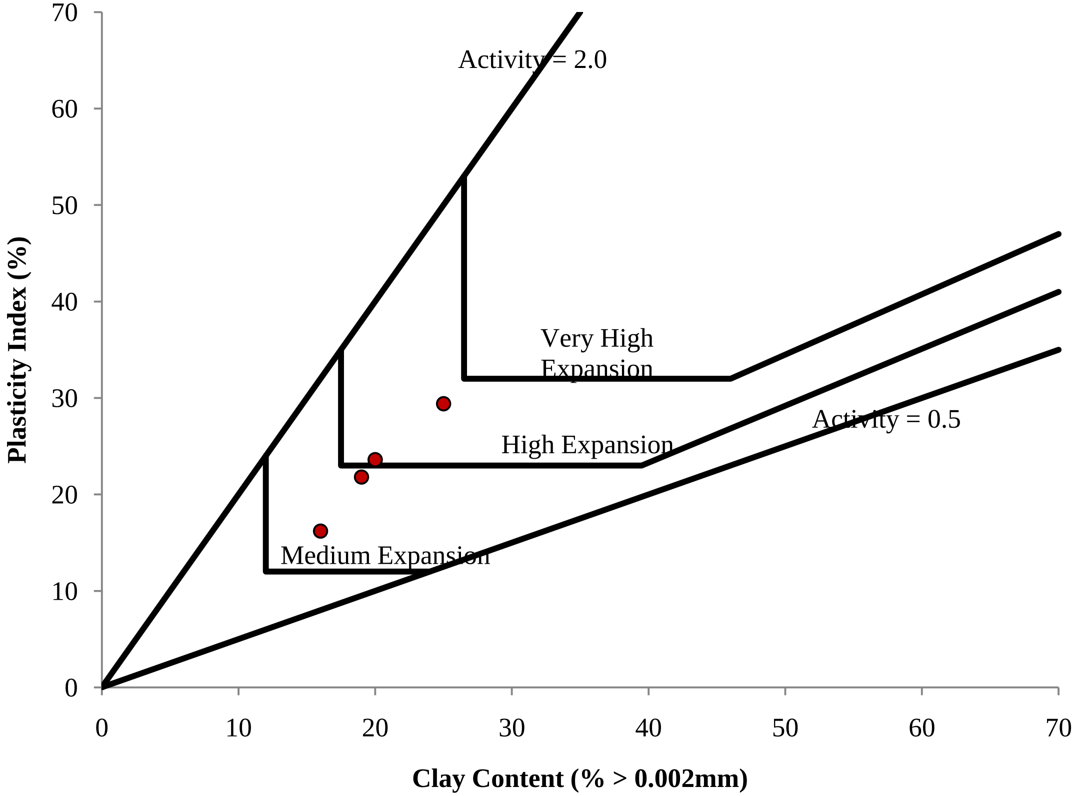
Time dependent behaviour:

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.

5. Engineering behaviour

Analogous URL's: **Mol**, Belgium in Boom Clay at 223m depth; **Bure**, France, in Callovo-Oxfordian (COX) mudstone at 500m depth; and, **Mon Terri**, in the Opalinus "Clay" at 270m depth. These have a similar range of index properties to the CERN molasse mudrocks although the Boom Clay is not "cemented"

These URL's have investigated the behaviour of mudrocks during and after tunnel construction.

For CERN, the ratio of the maximum tangential stress to the strength of the rock indicates that yield of the molasse around the excavations is likely

Similar issues of slaking, time dependent swelling and development of a yield zone around the excavations have been investigated at the URL's.

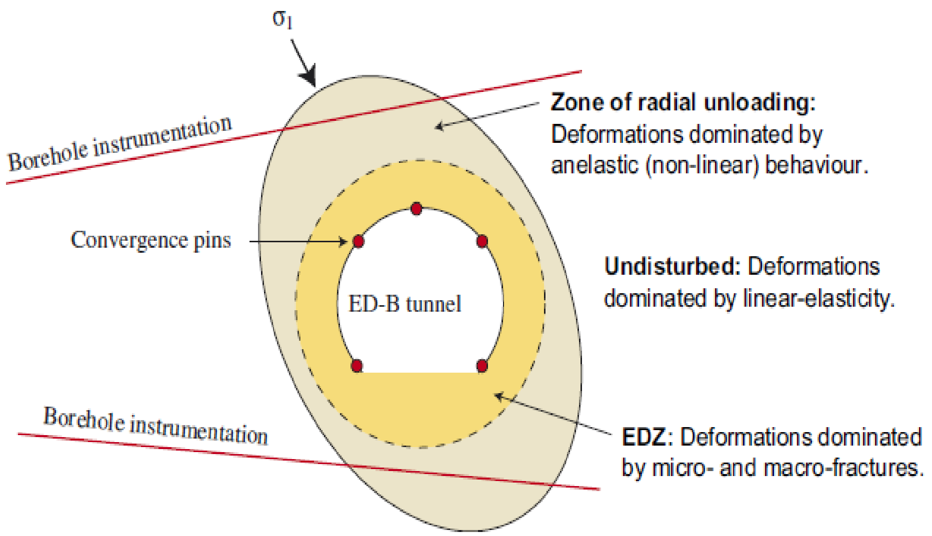
Findings….

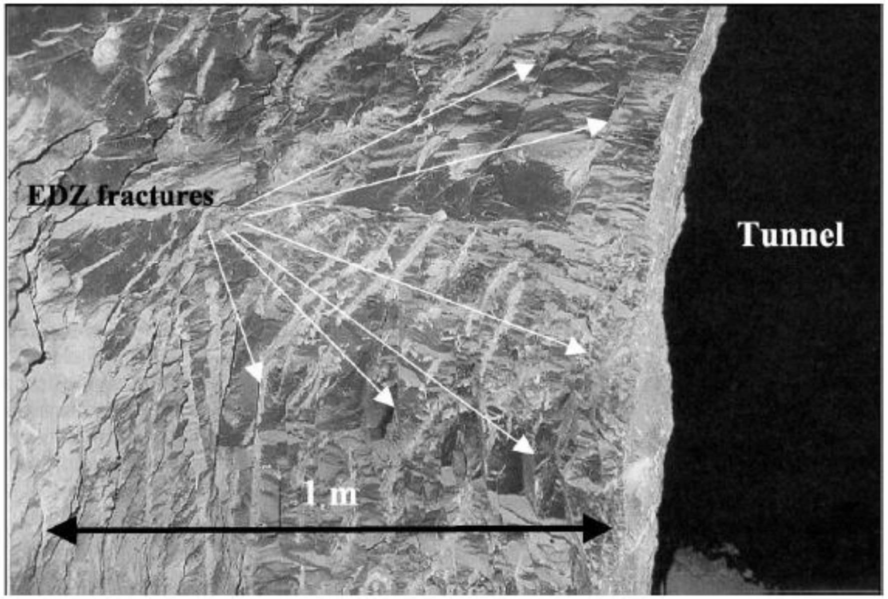
The Excavation *Damaged* Zone (EDZ): a very localised zone of fracturing where significant changes in mass permeability, pore pressures and in situ stress occur.

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:

$$R_f/a = 0.49(\pm 0.1) + 1.25^* (\sigma_{max} / UCS)$$





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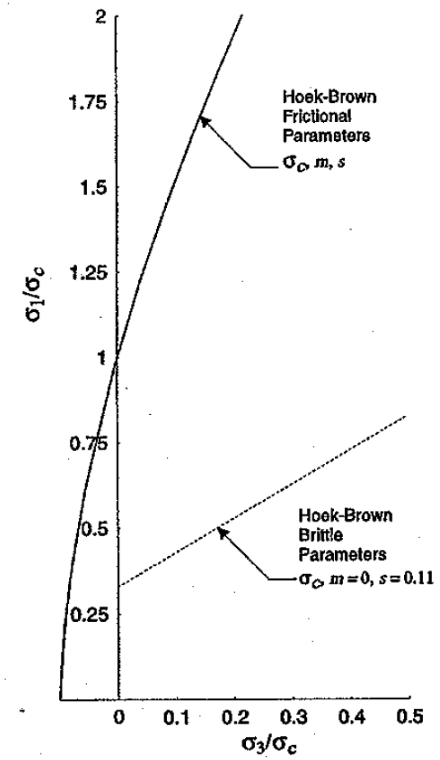
Different yield criteria approaches available for modelling mudrocks:

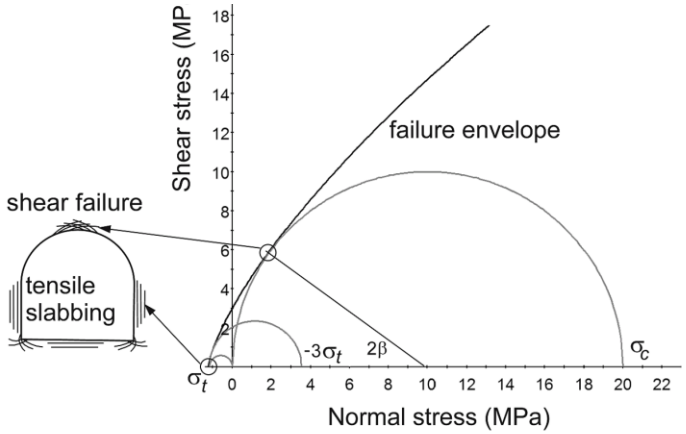
Standard Hoek-Brown or Mohr-Coulomb shear strength criterion

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

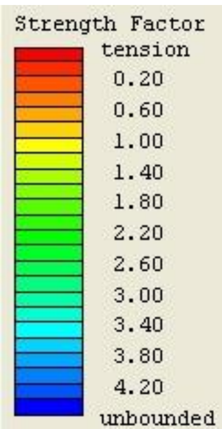
“Brittle” Hoek-Brown criterion (Martin et al, 1999)

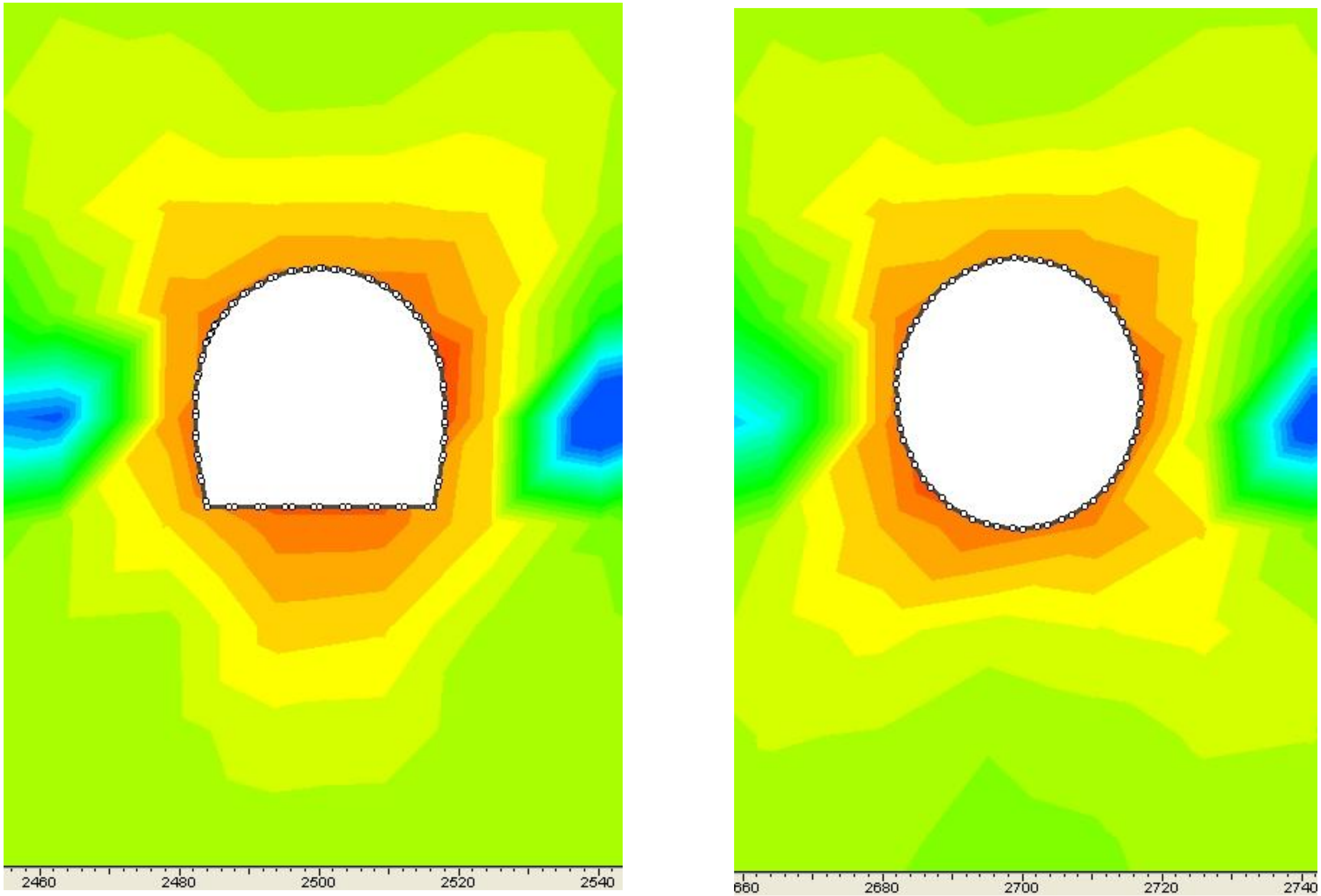
Tensile failure mechanism using Mohr-Coulomb or Hoek-Brown criterion (Hoek et al, 2005)



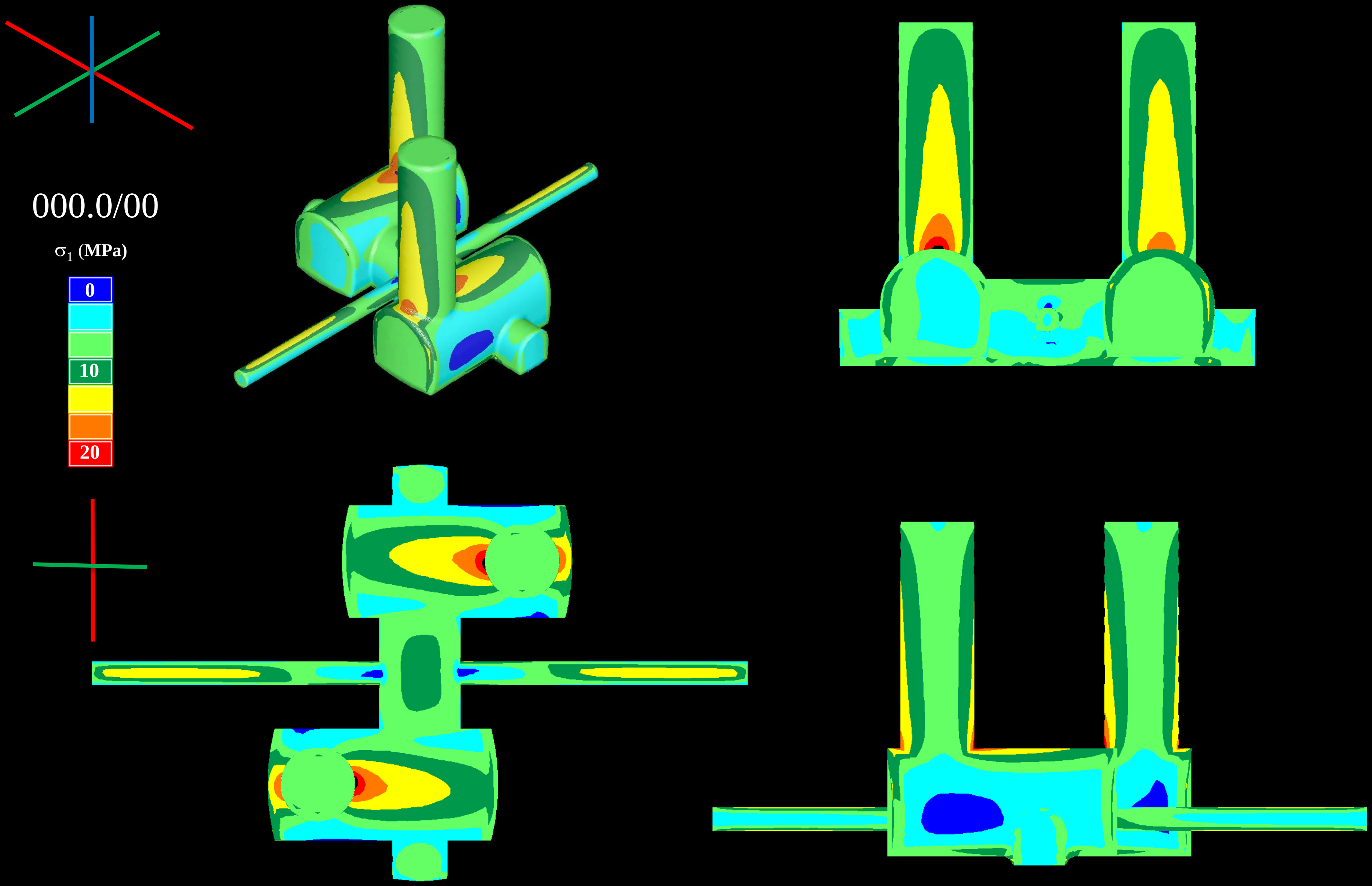


6. Initial Cavern layout studies





2D shape effects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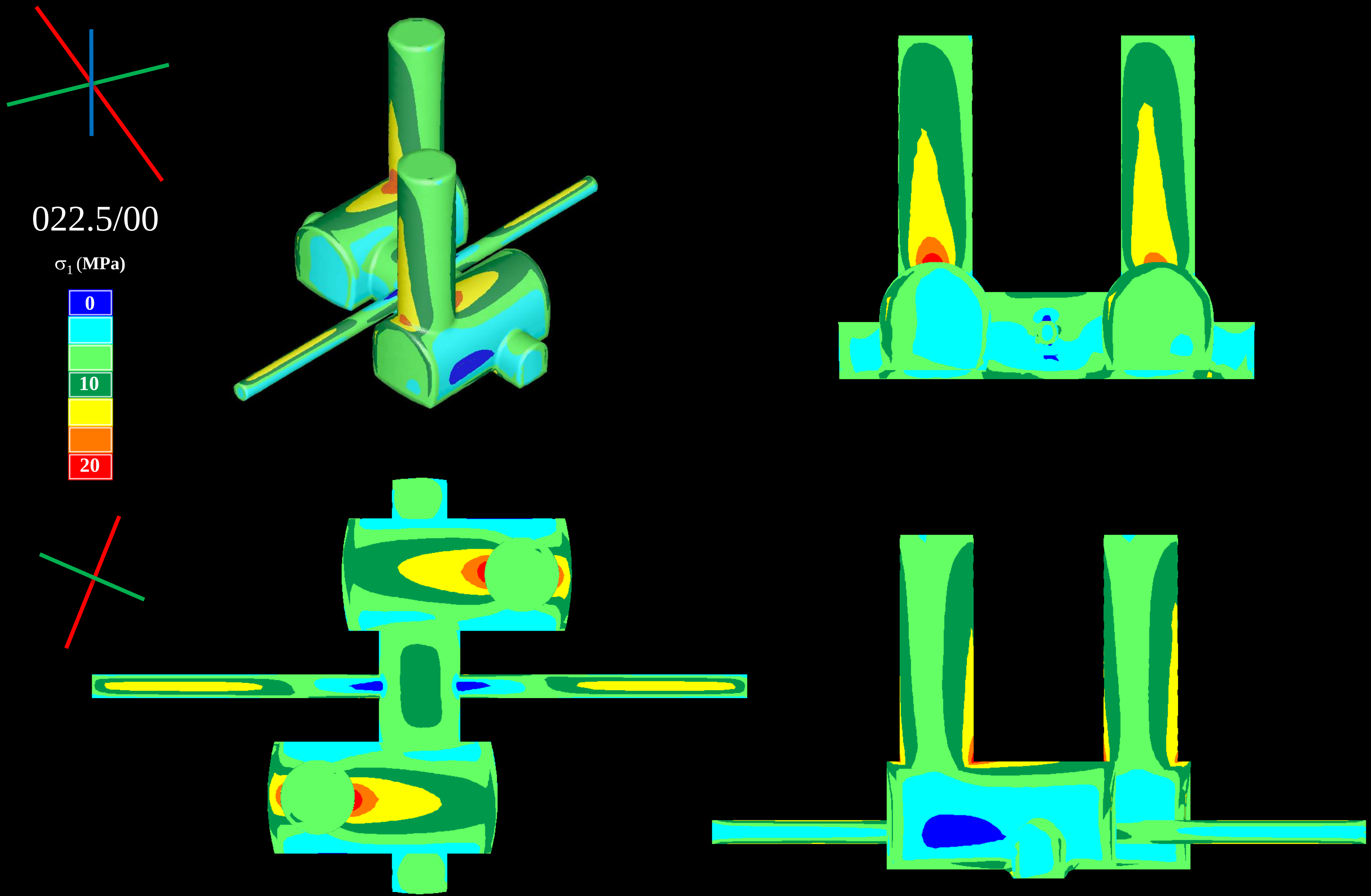
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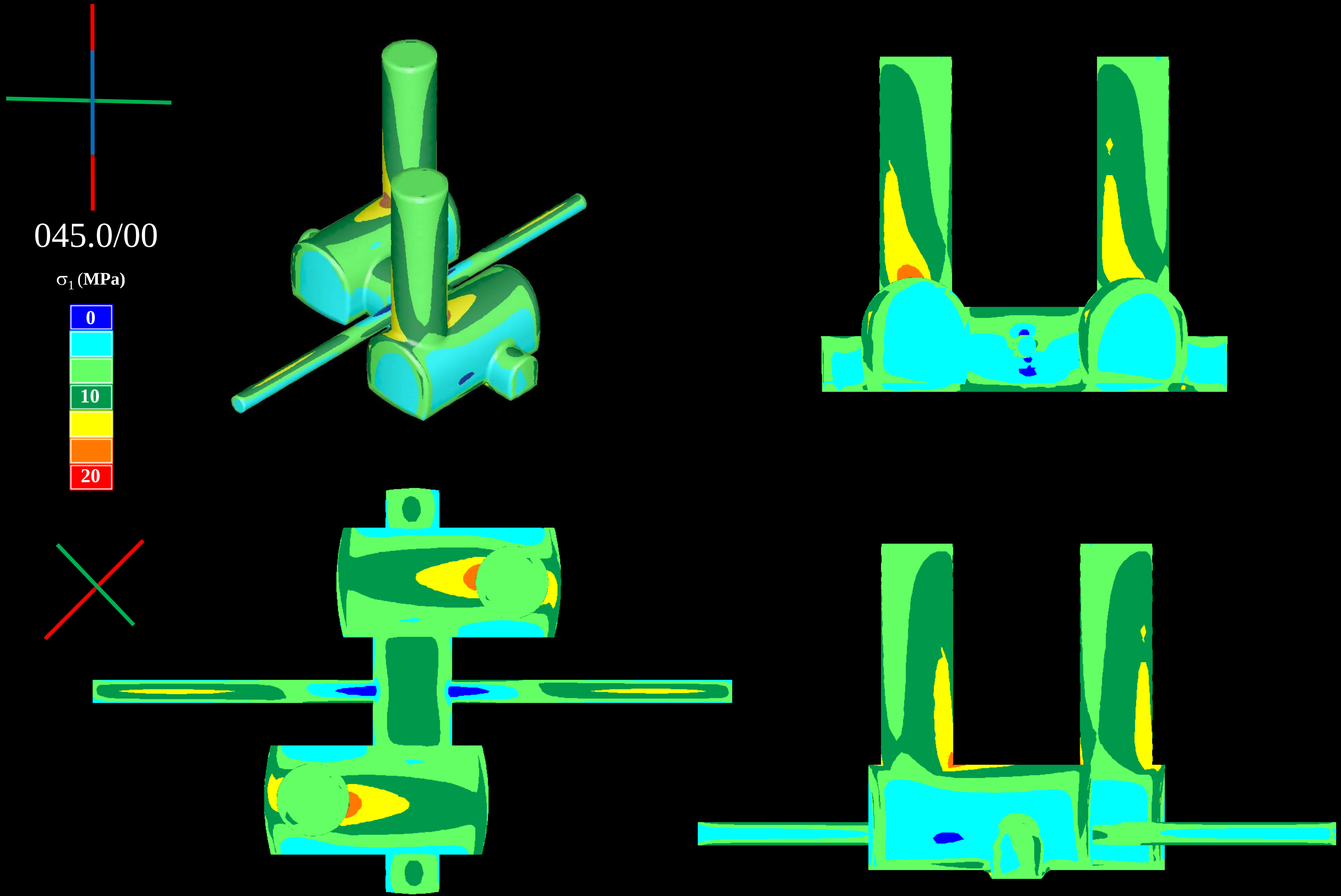
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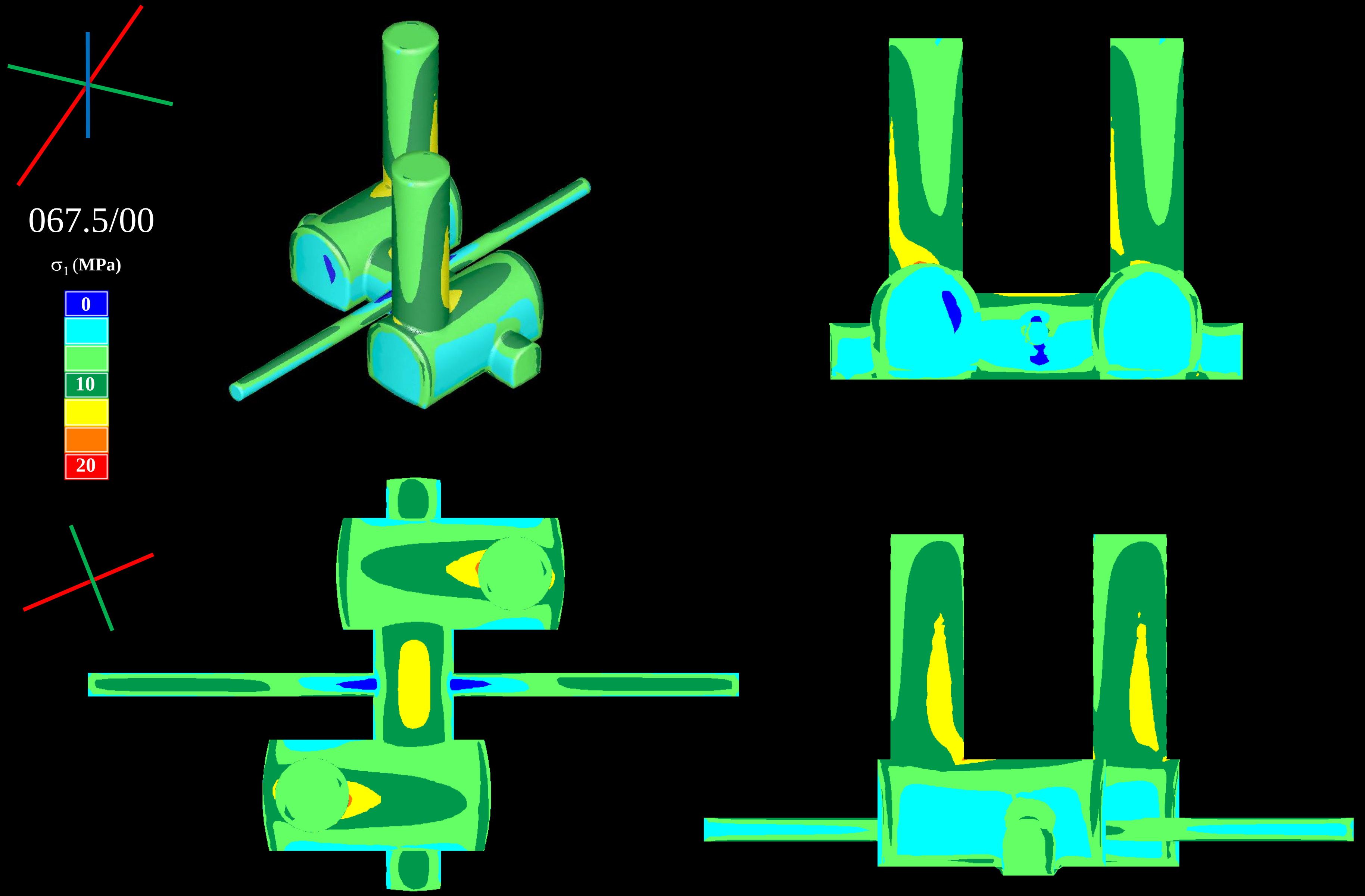
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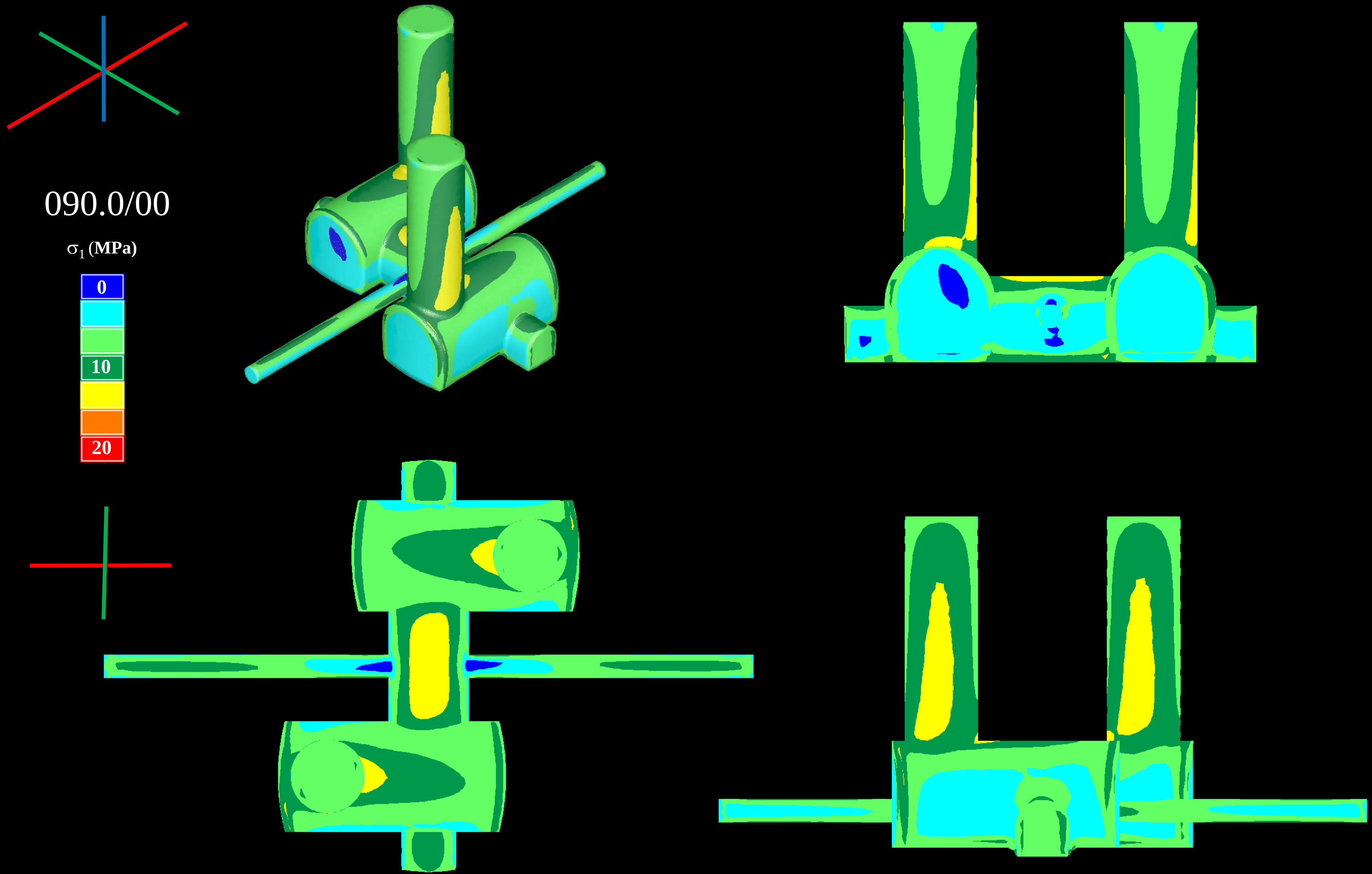
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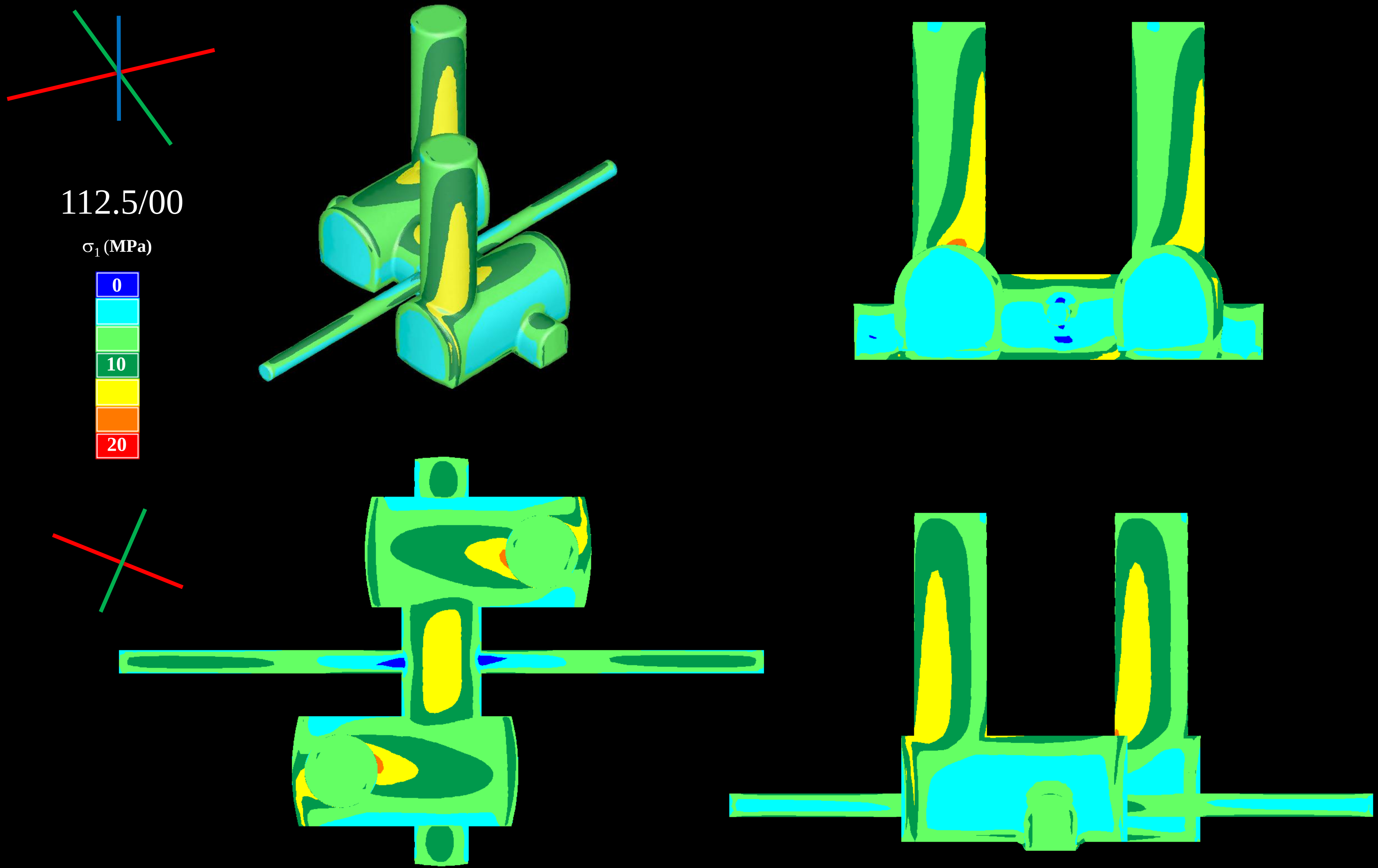

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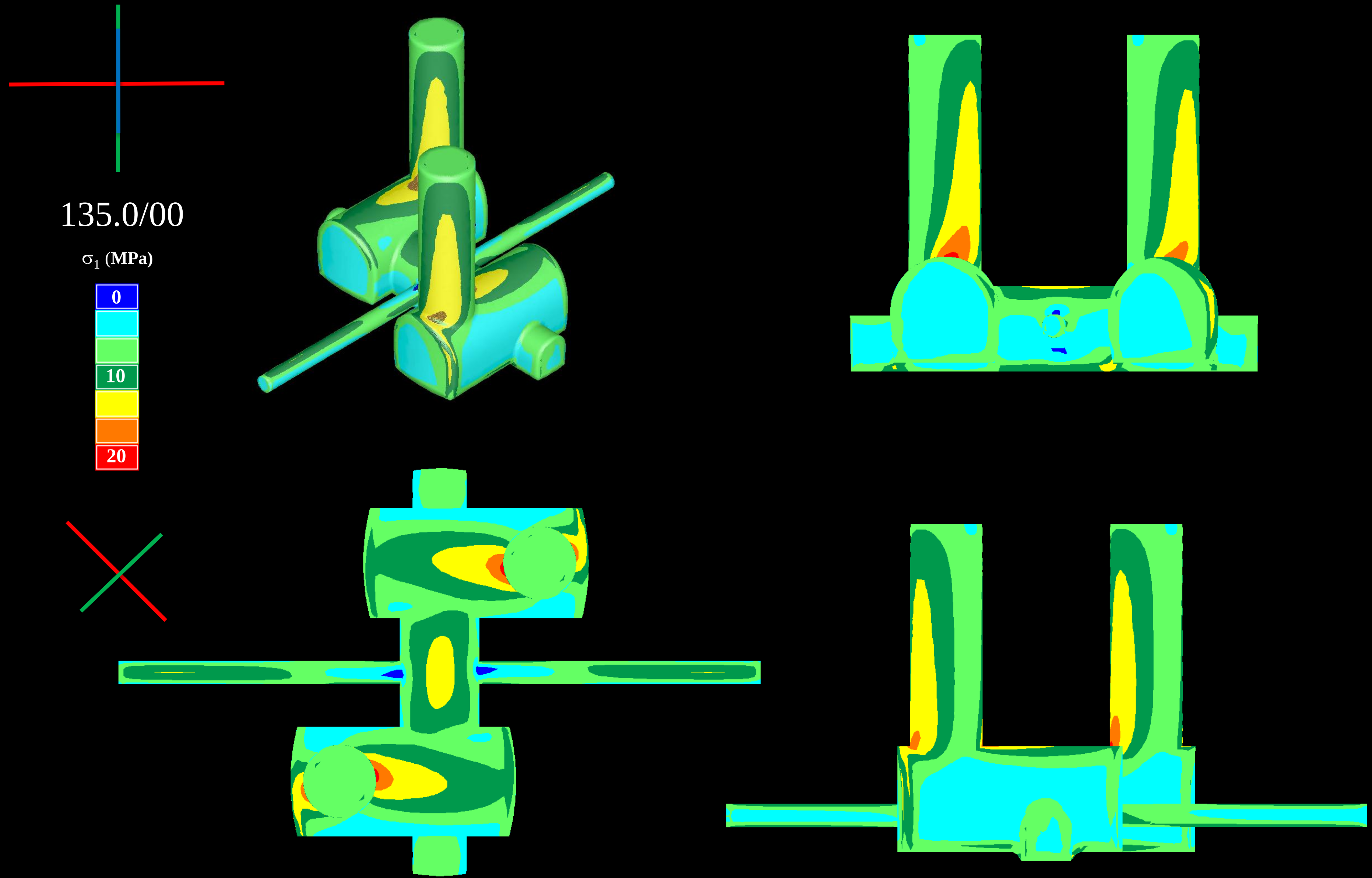

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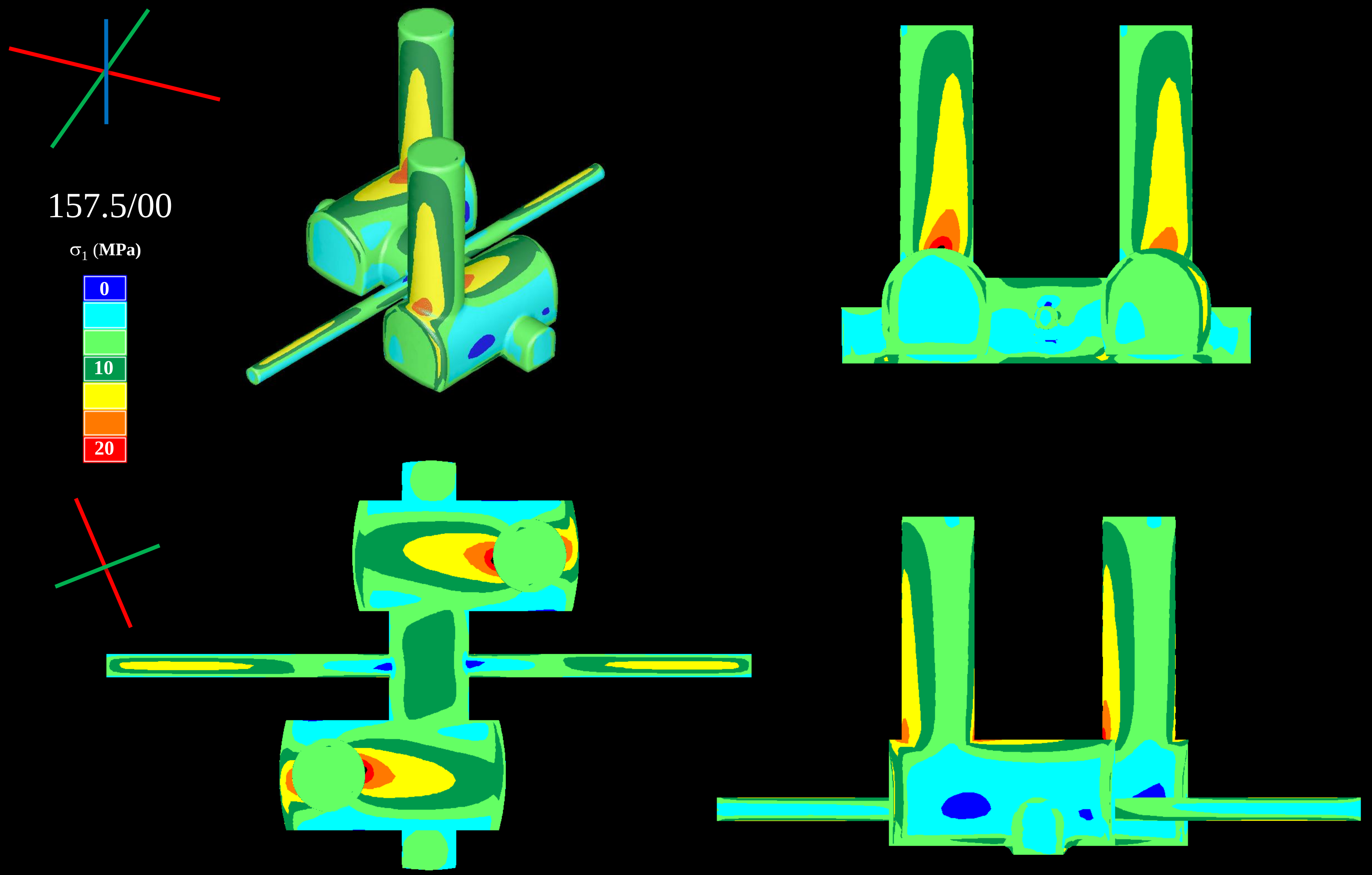
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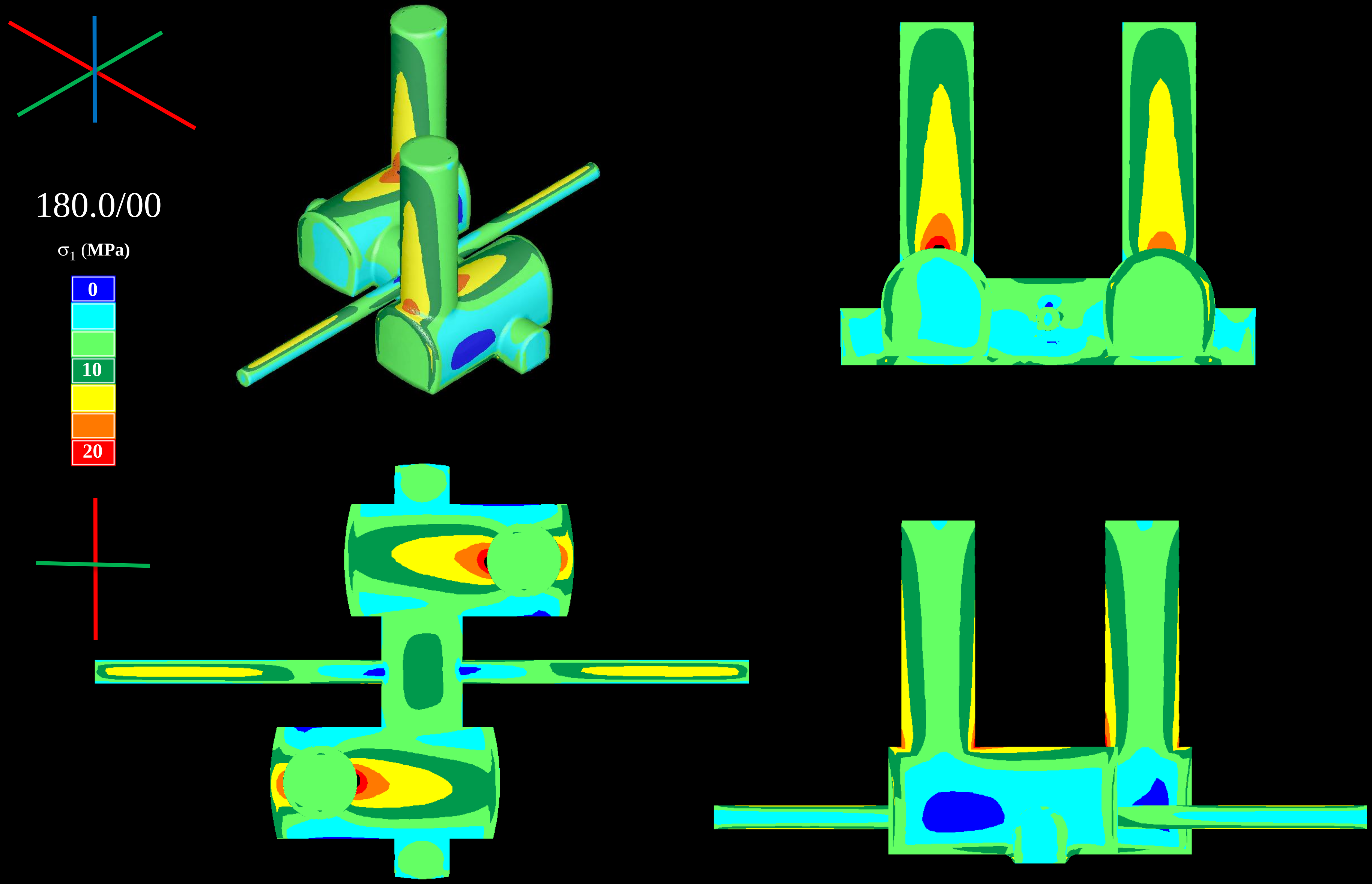
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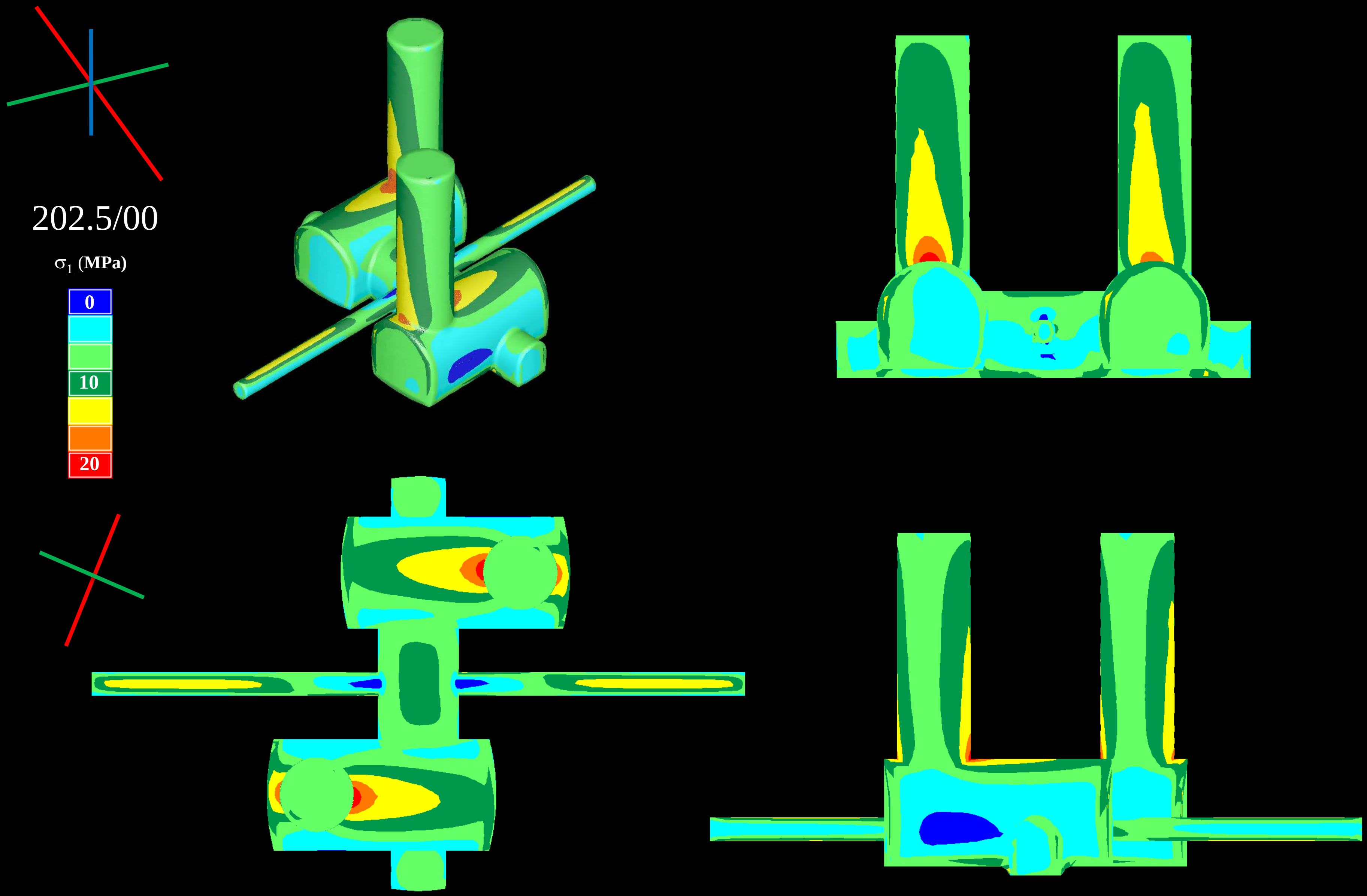

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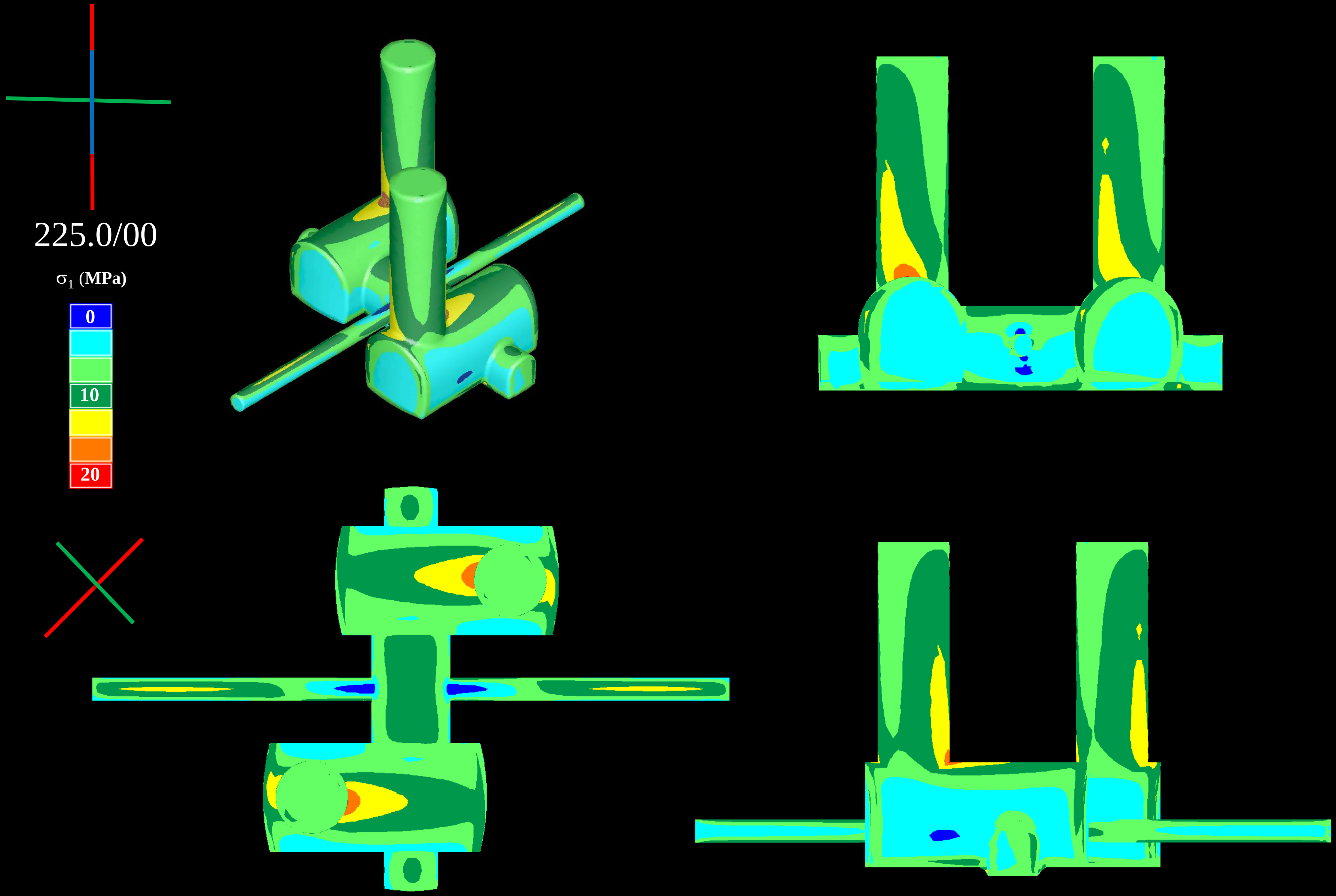
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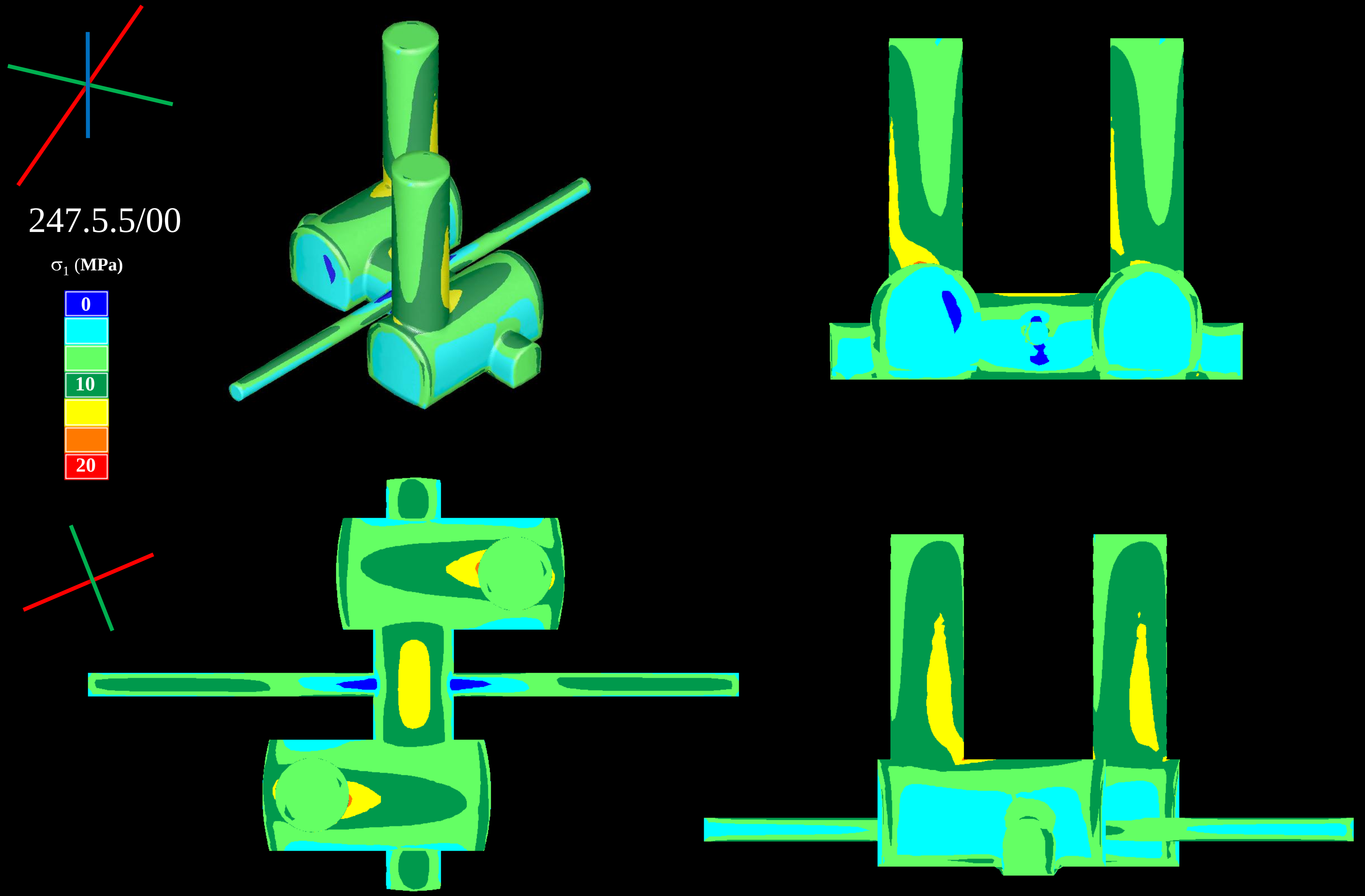

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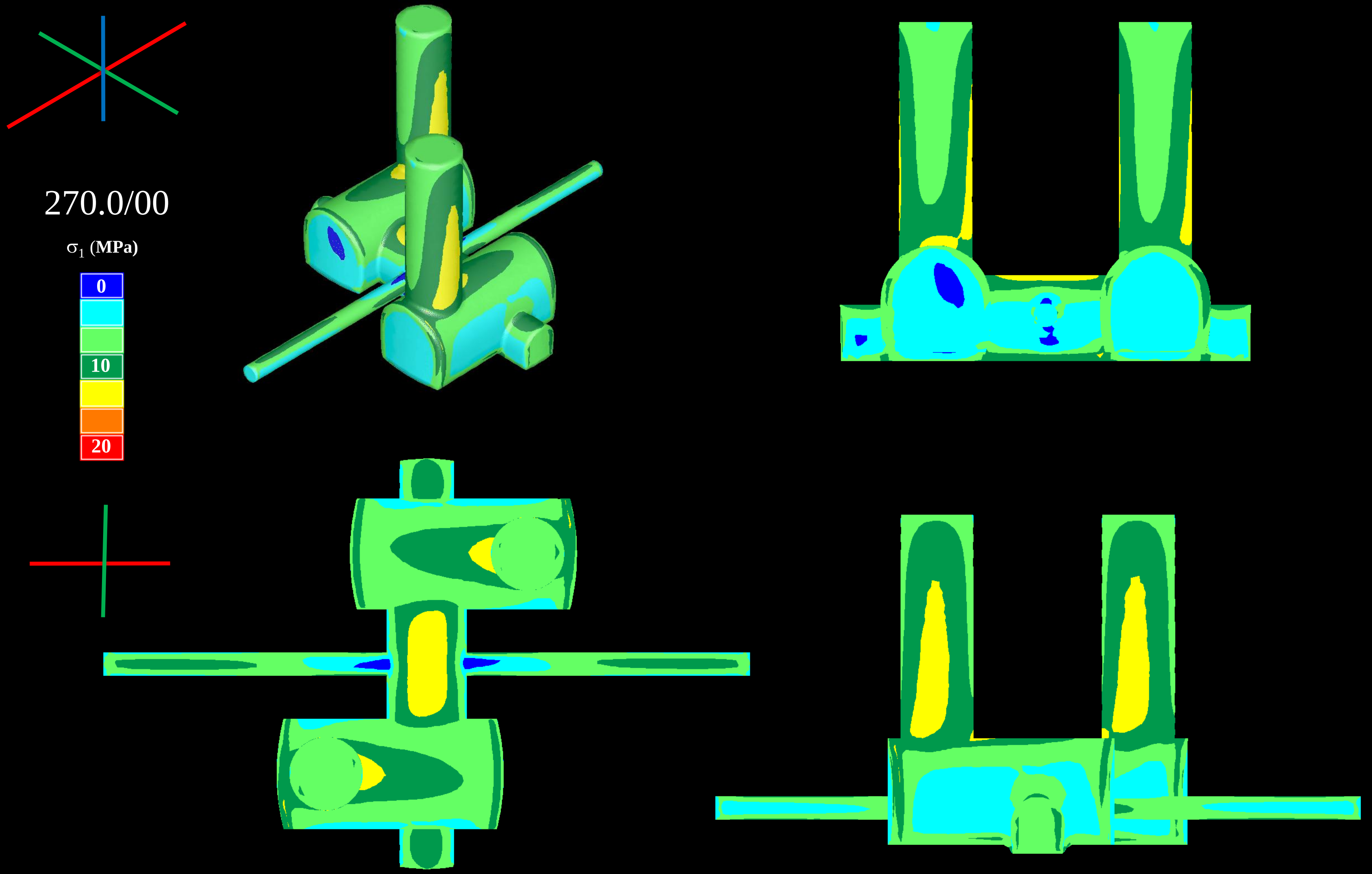

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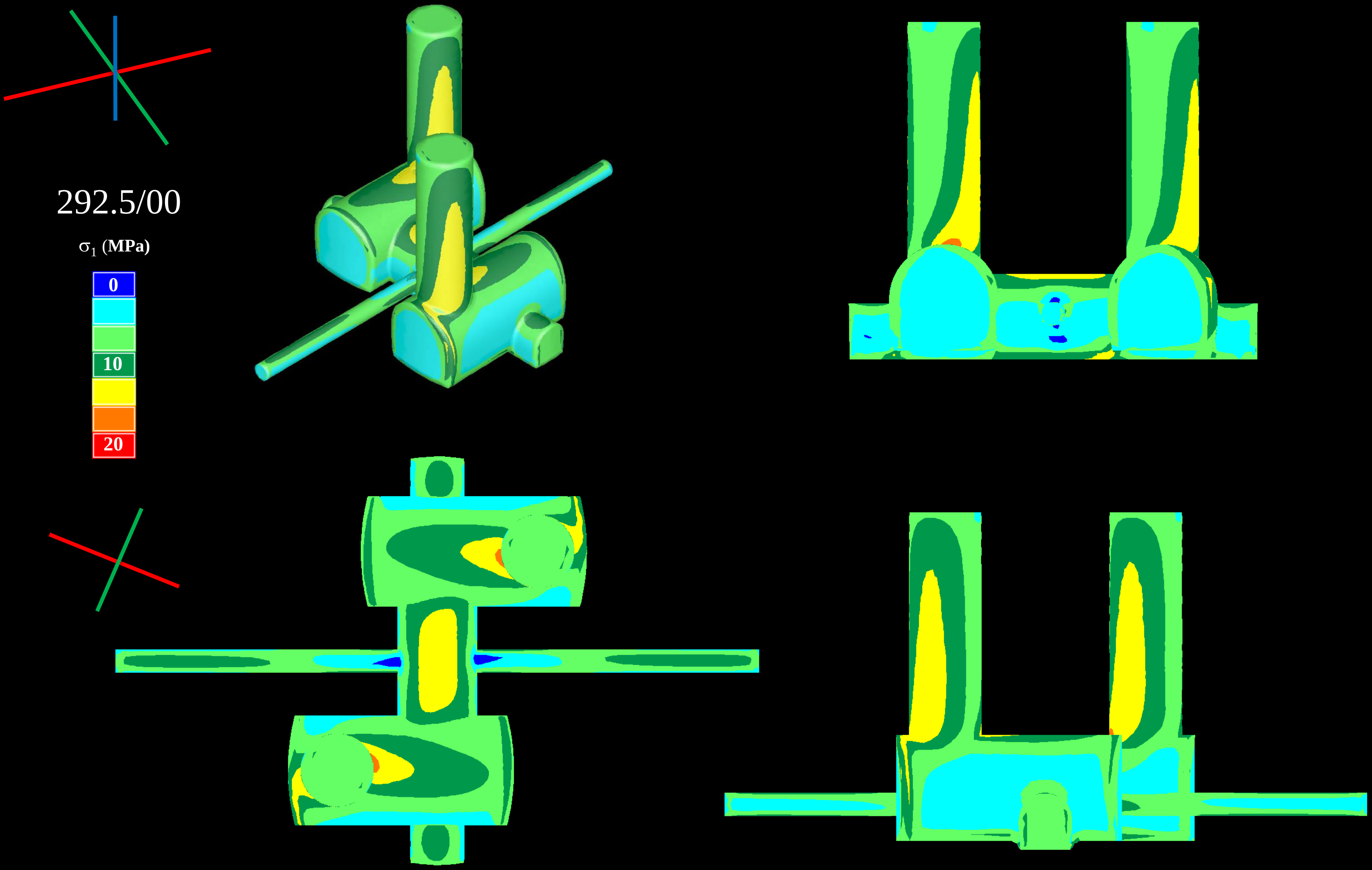

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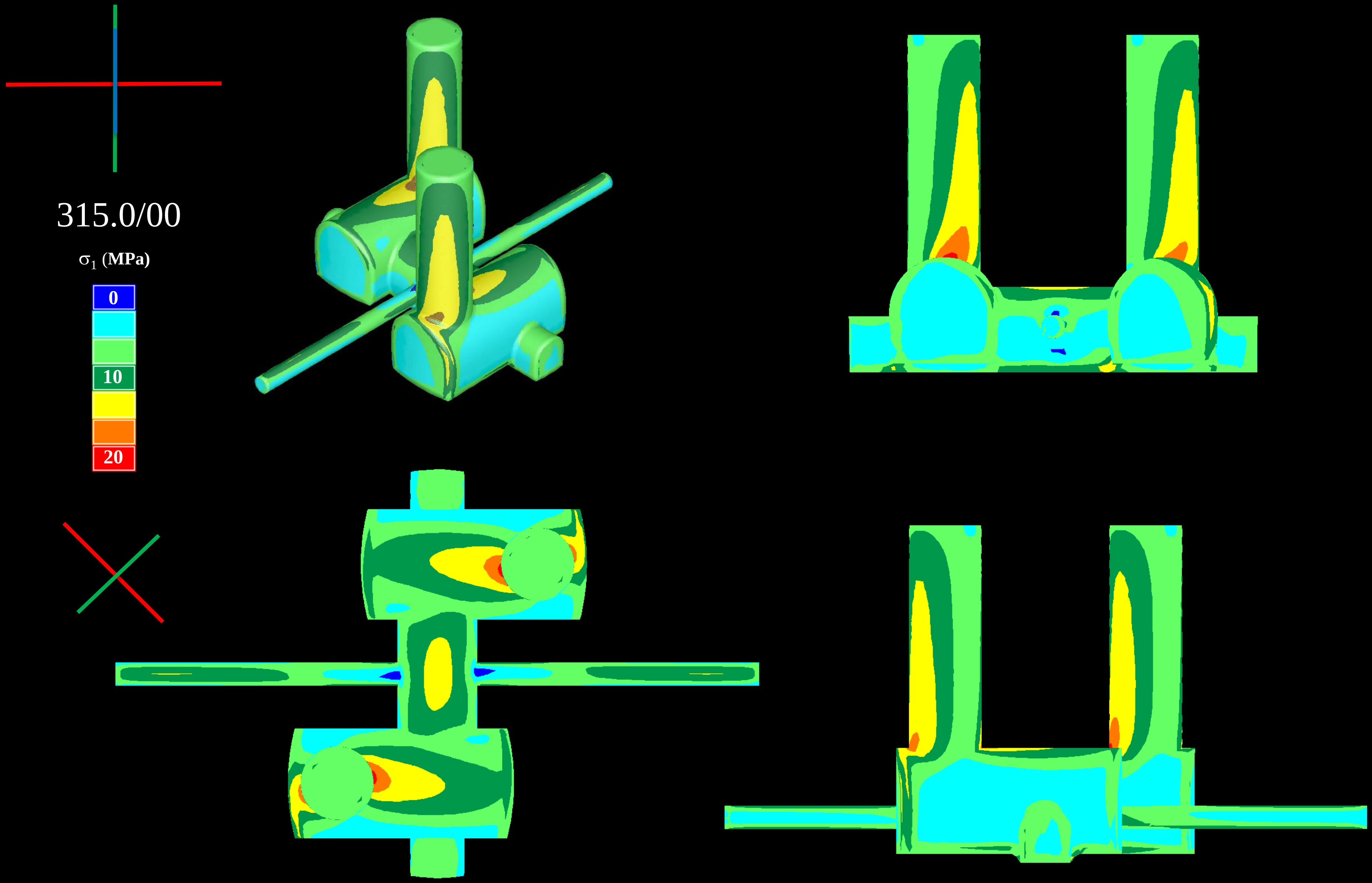

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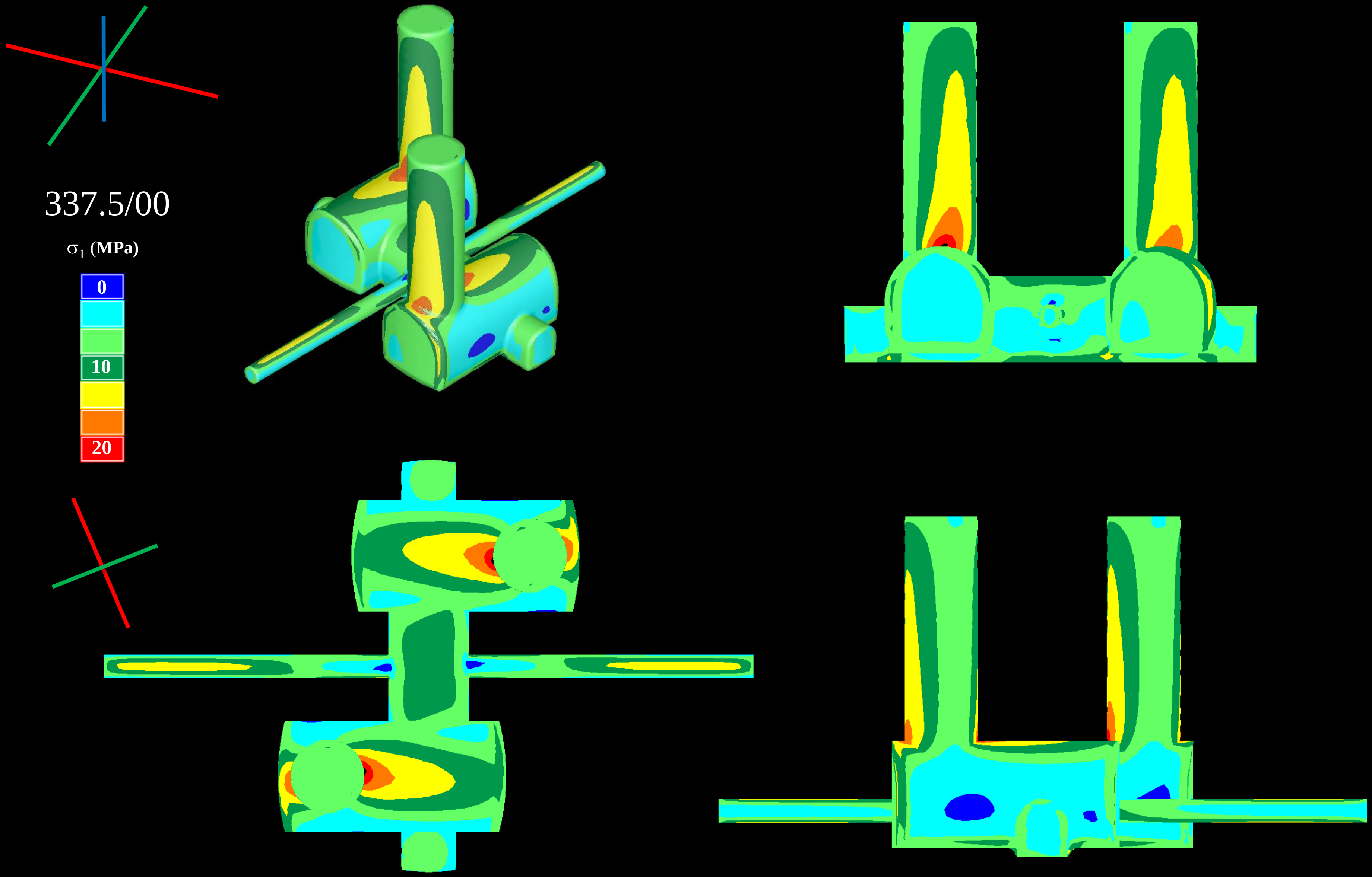

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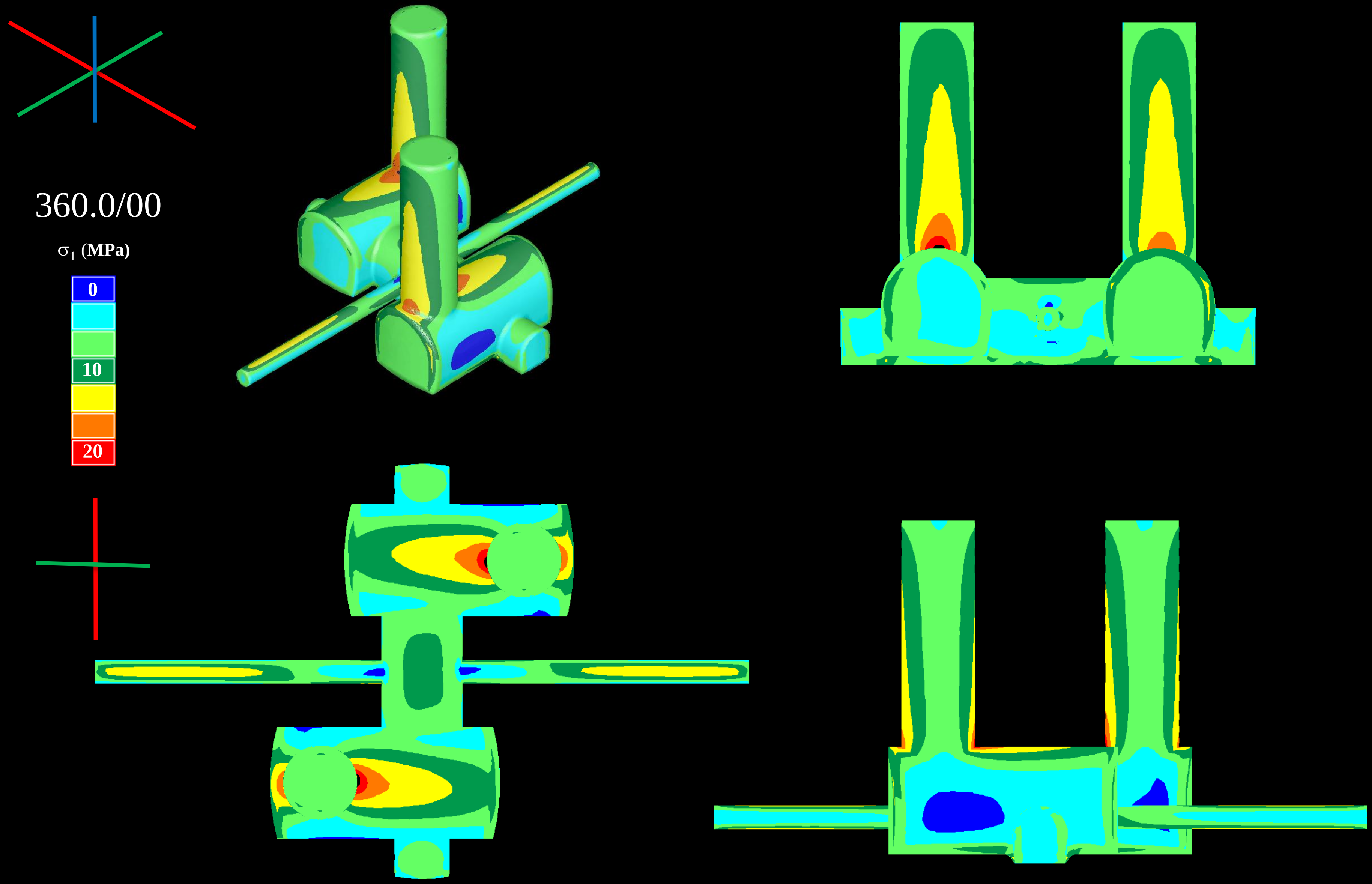

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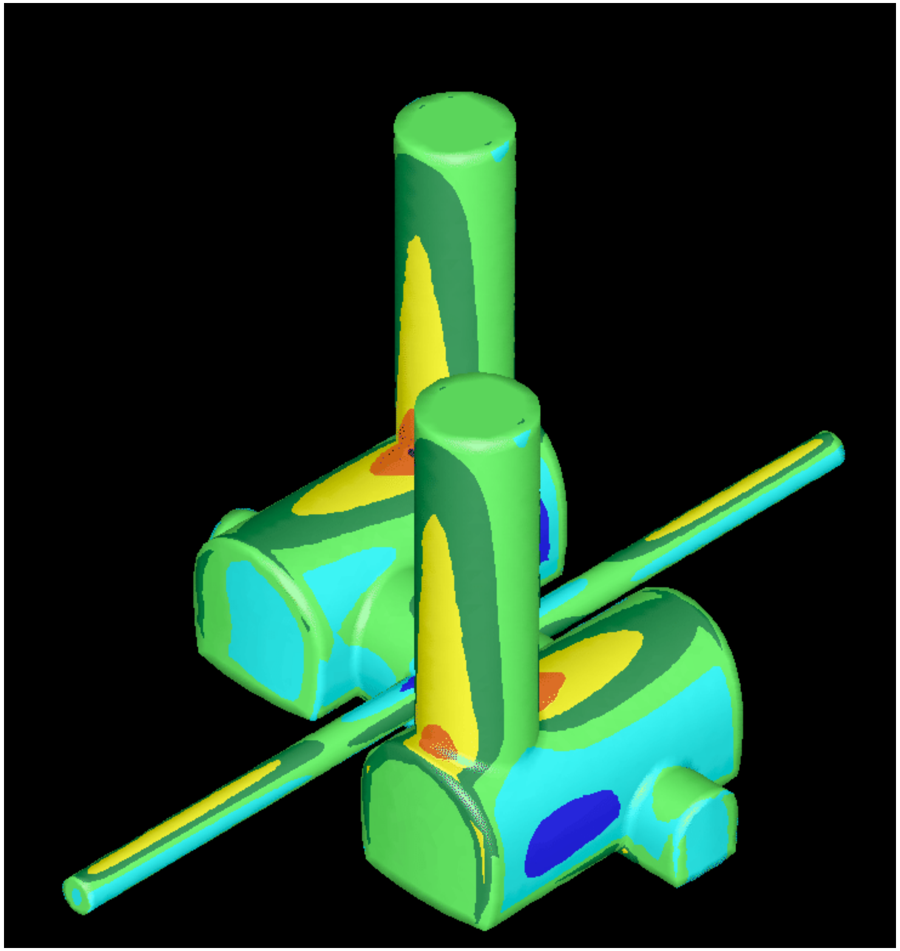
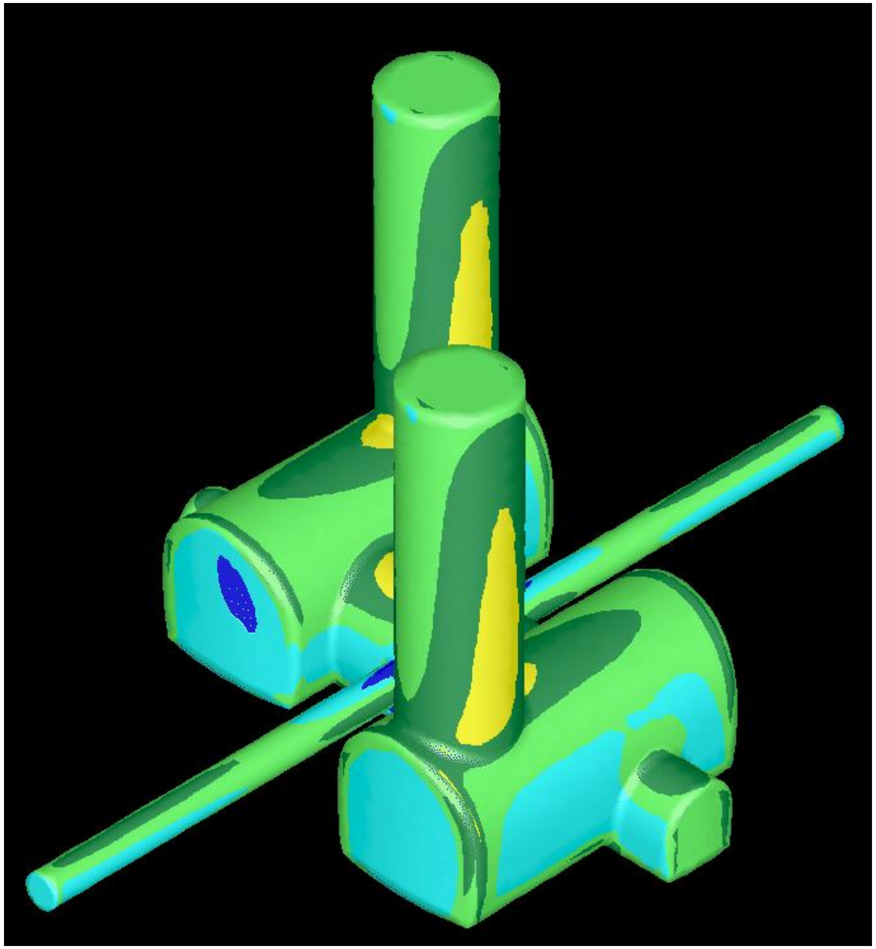
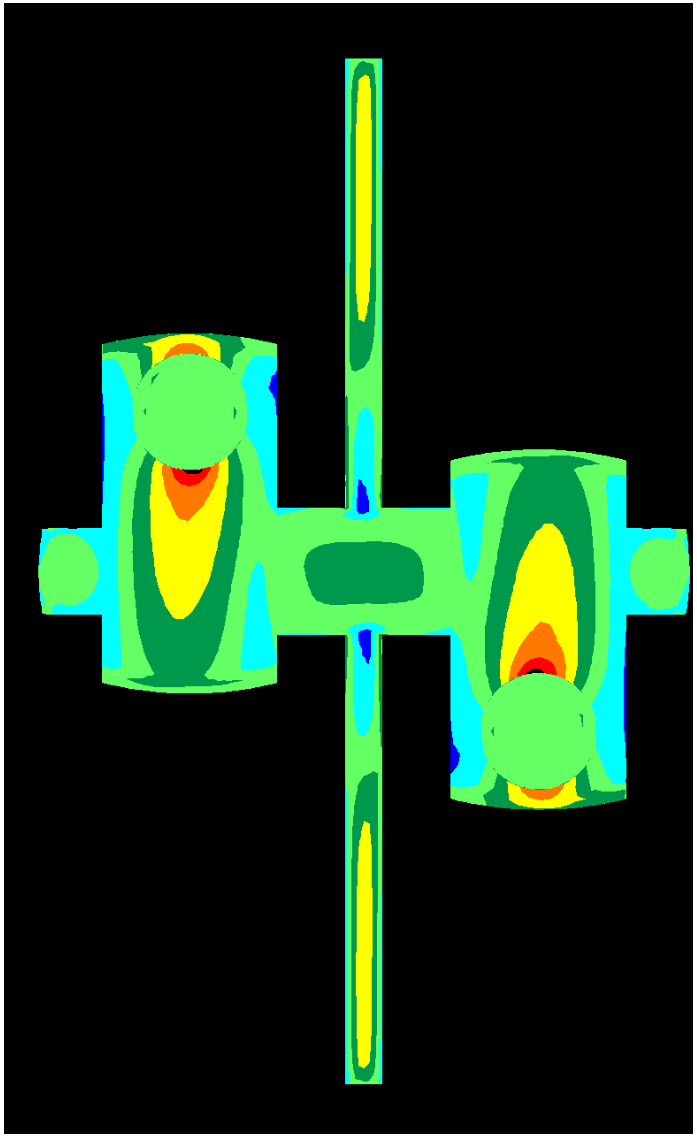


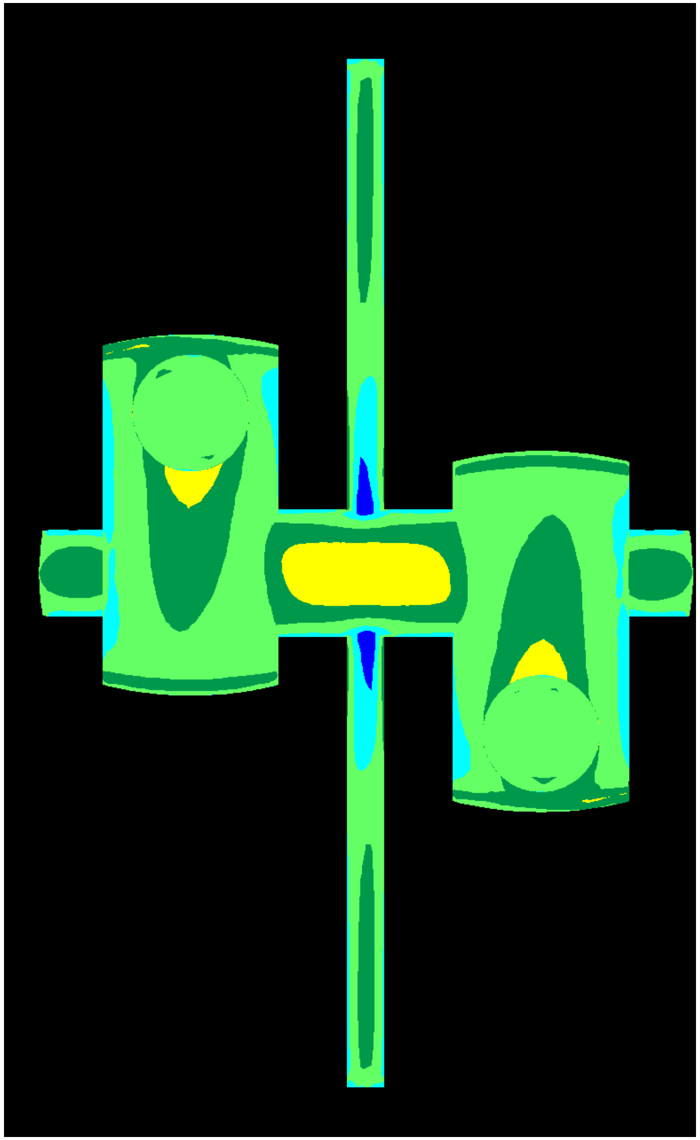
σ_H normal to beam tunnel



σ_H parallel to beam tunnel

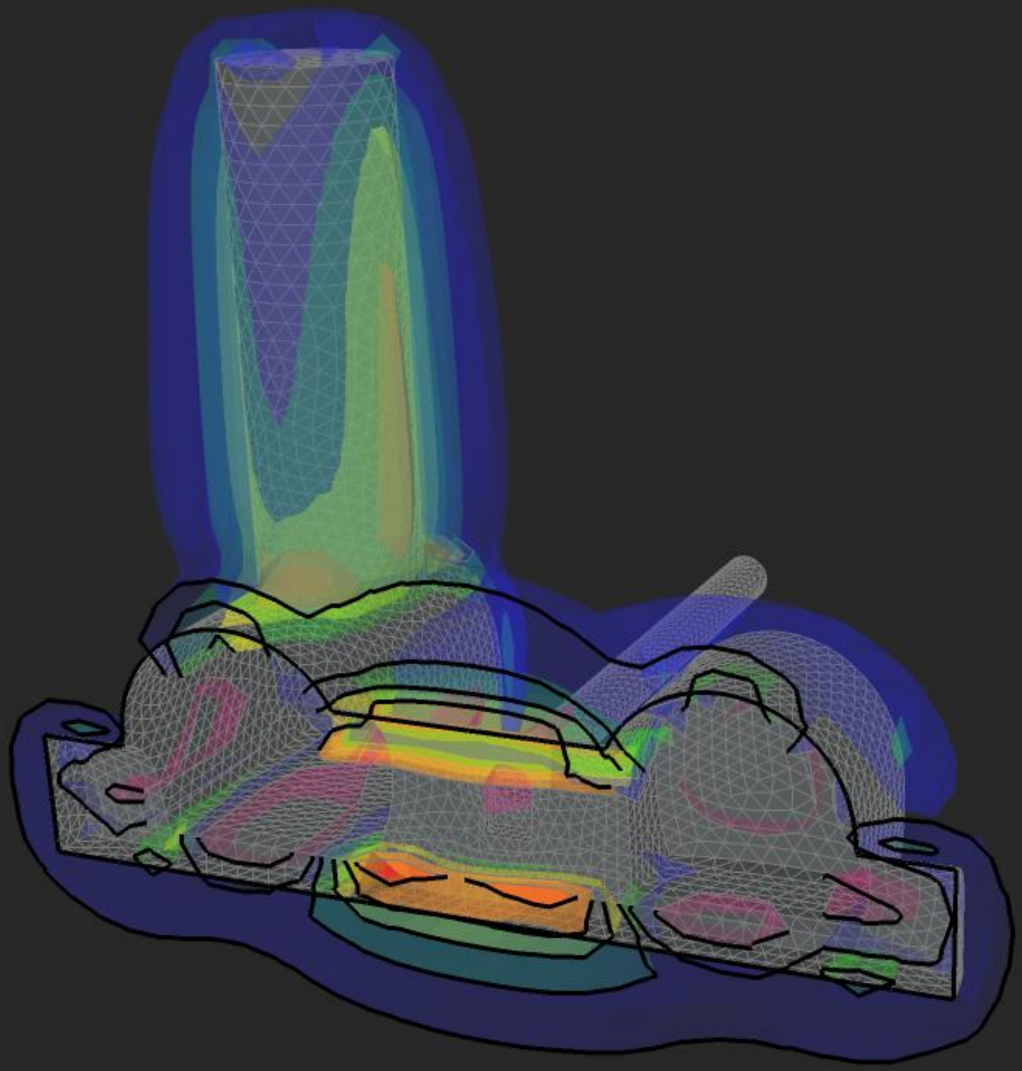


σ_H normal to beam tunnel

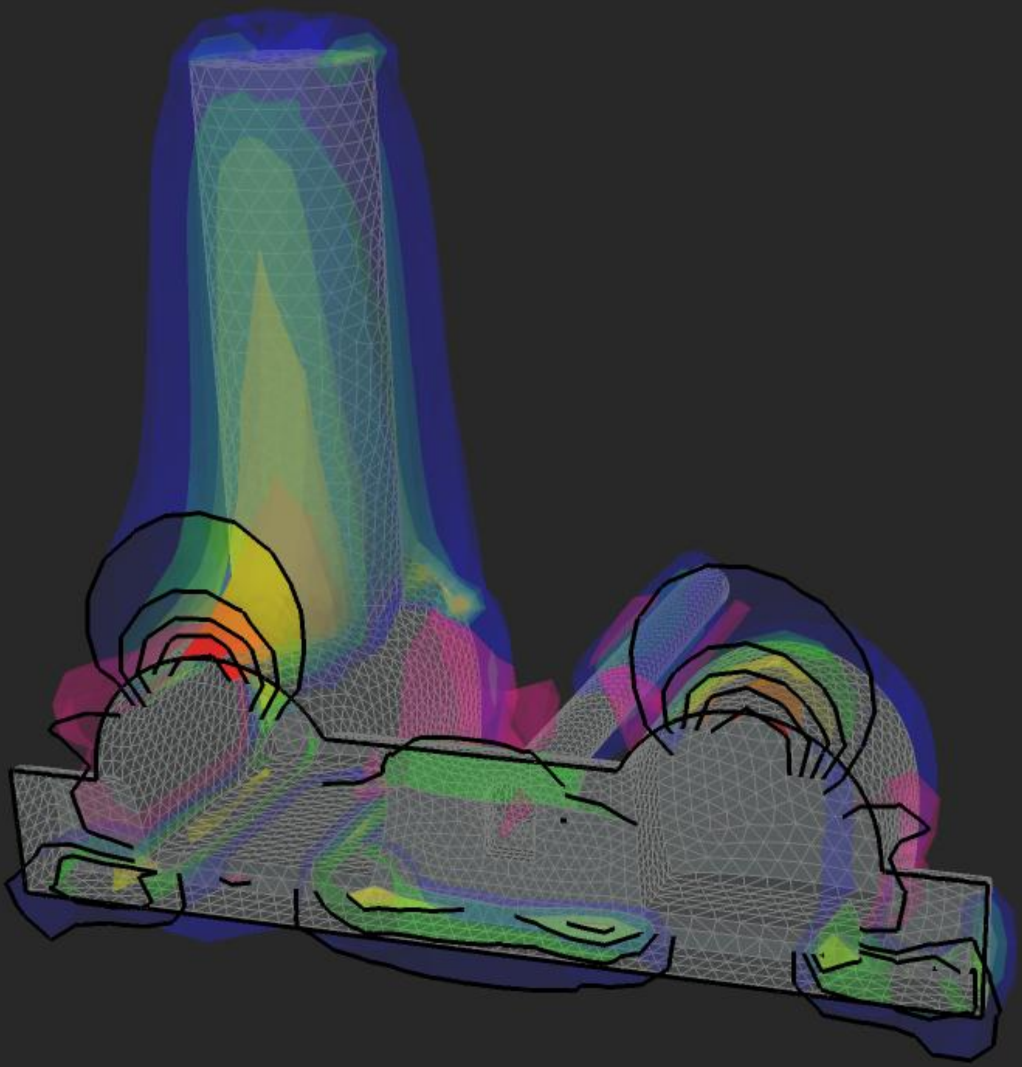


σ_H parallel to beam tunnel

σ_H parallel to beam tunnel



σ_H normal to beam tunnel



7. Further work

Complete review and collation of geotechnical index properties

Complete geophysical profiling and stratigraphic interpretation

Further consideration of yield criteria for layout cavern design

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

Detailed interpretation of HPD & Triaxial tests and Downhole P-wave data for stiffness vs strain

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