SINTEF

Technology for a better society

Research based technologies for tunneling

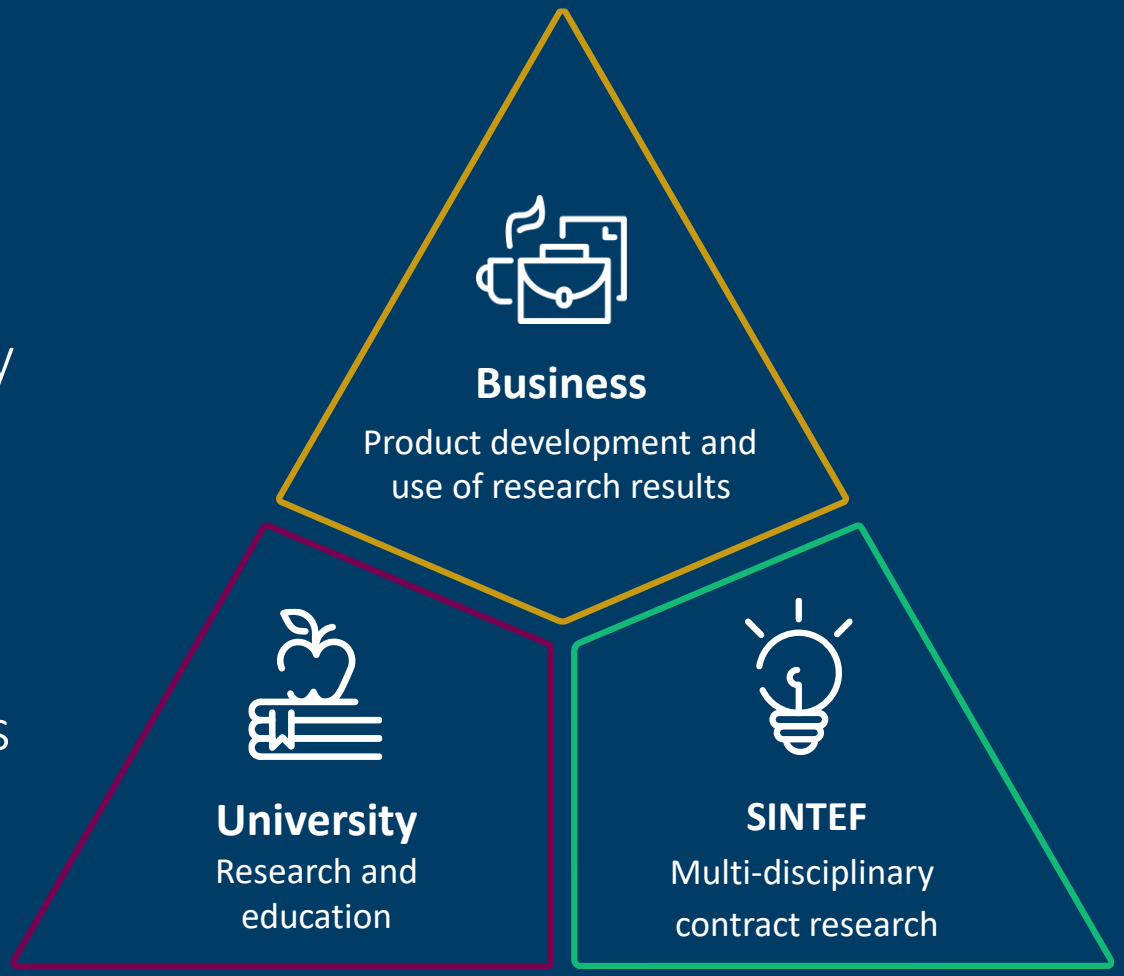
Technology for a better society

Innovation through co-operation and expertise
University and research together

SINTEF was created by the professors at NTNU in 1950 to commercialise their research results and innovations.

SINTEF is one of Europe's largest independent research organisations. Every year we carry out several thousand projects for customers large and small.

SINTEF is an independent, not-for-profit organisation. None of its owners receive any form of dividend. Any financial surplus is invested in scientific equipment, skills and expertise.



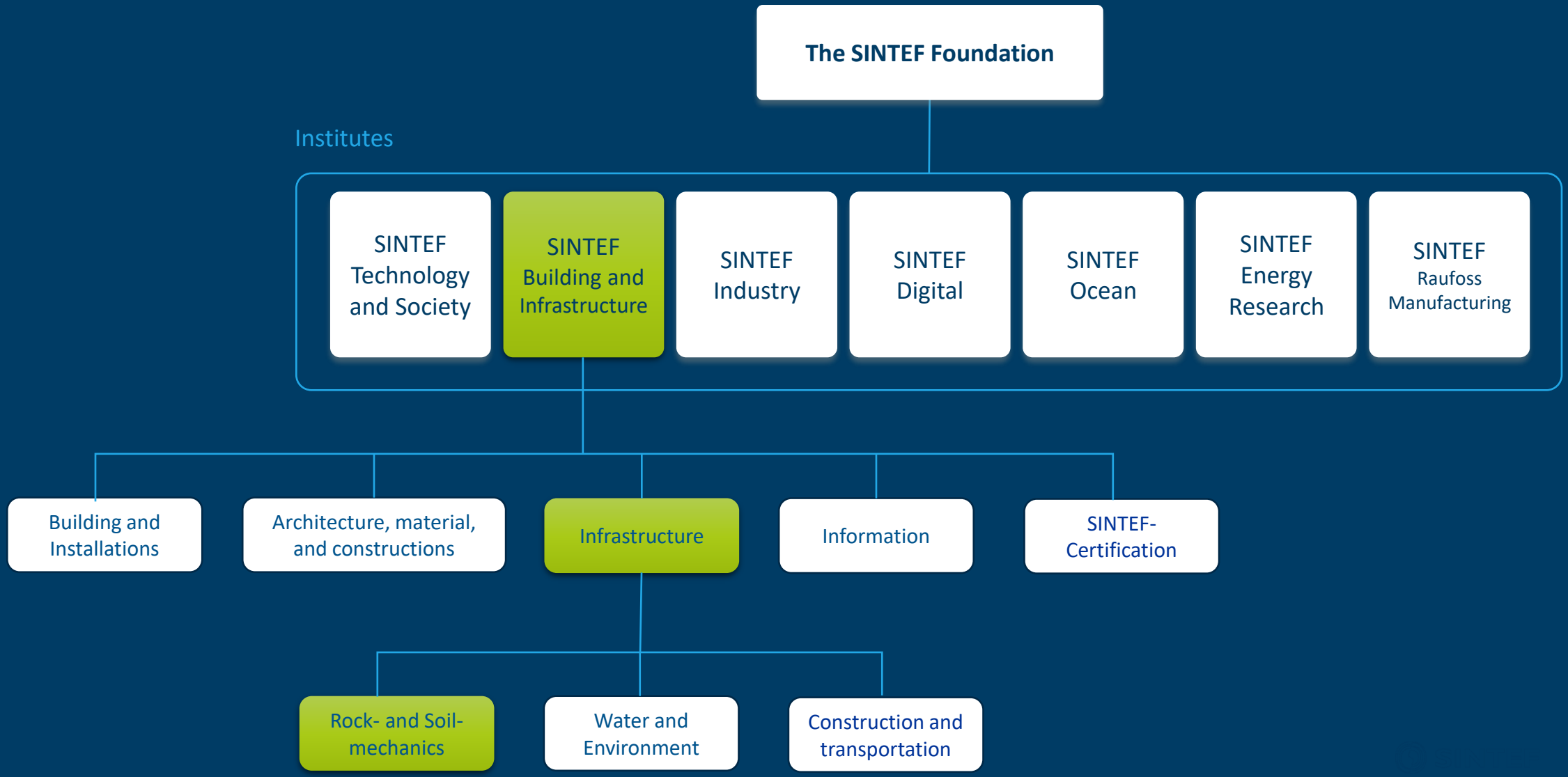
One of Europe’s largest independent research organisations

NOK 3.2 billion
Revenues

NOK 450 MILL
International sales

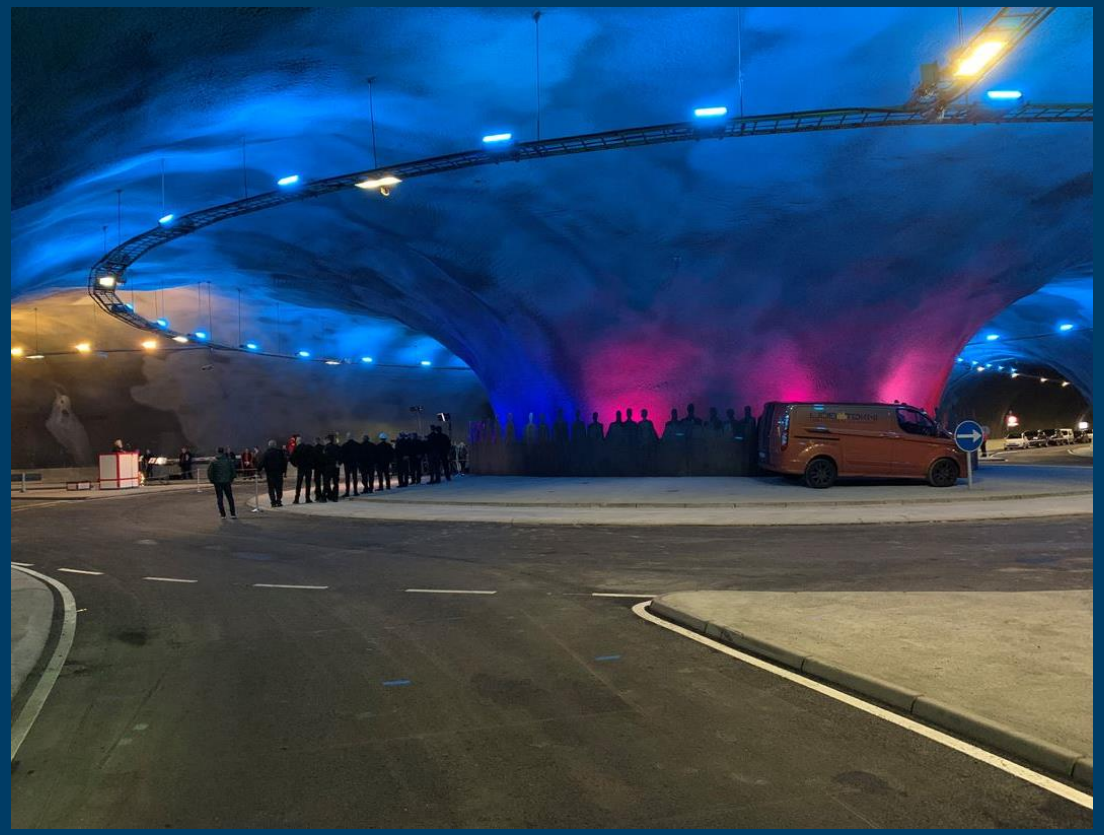
SINTEF

SINTEF - organisation



Rock and Soil Mechanics

Fields of expertise

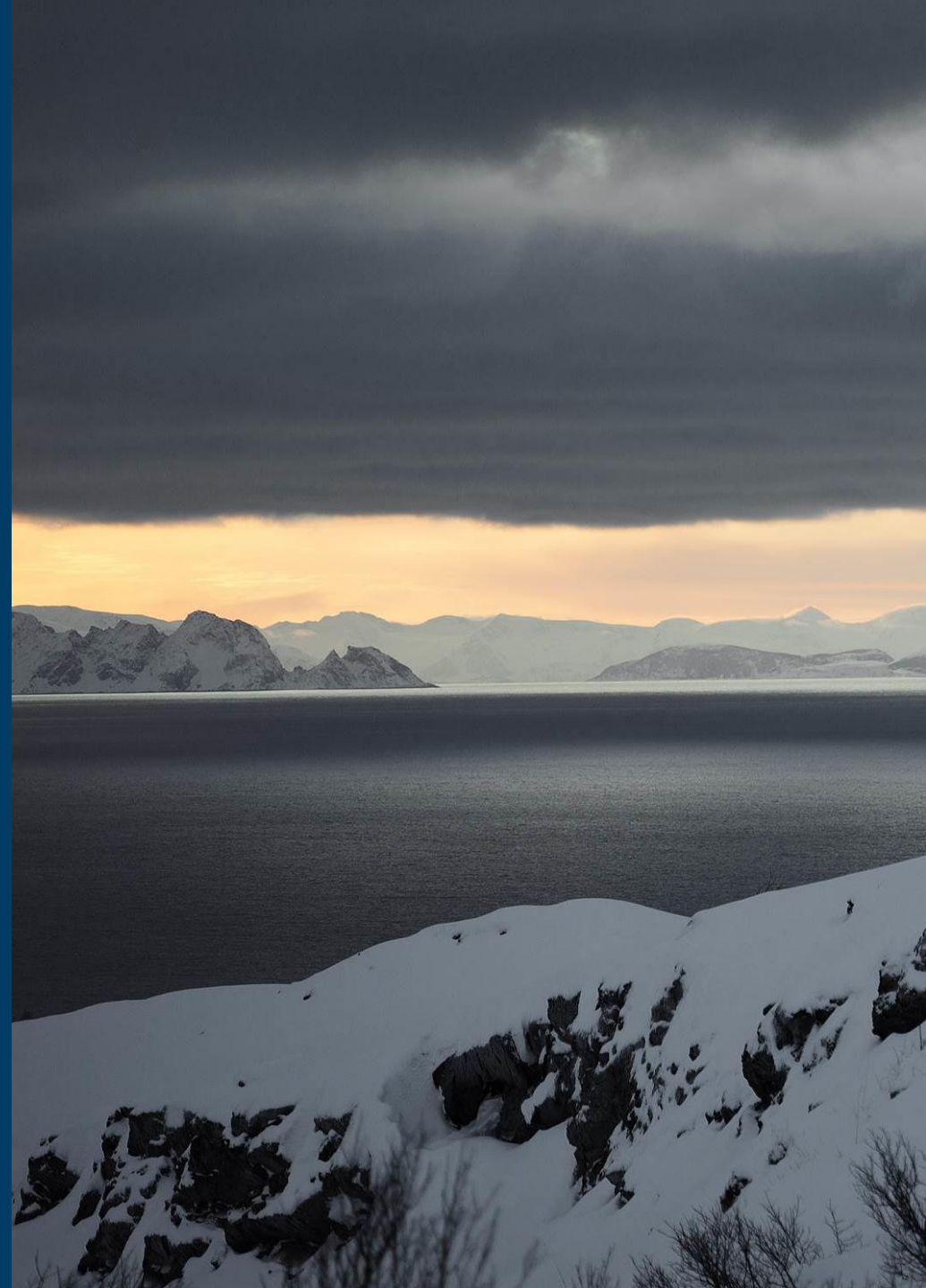


- The Norwegian Way of Tunnelling
- Rock support, bolting, sprayed concrete
- Ground water control and grouting design
- TBM Considerations
- Geology, hydrogeology & environment
- Planning and execution of ground investigations
- Engineering geological planning and conceptual design for both infrastructure and mines/quarries
- Rock stability analyses (slopes and UG)
- Sustainability in tunnelling

The Norwegian way of Tunnelling

Expertise on all aspects of Norwegian tunnelling method including

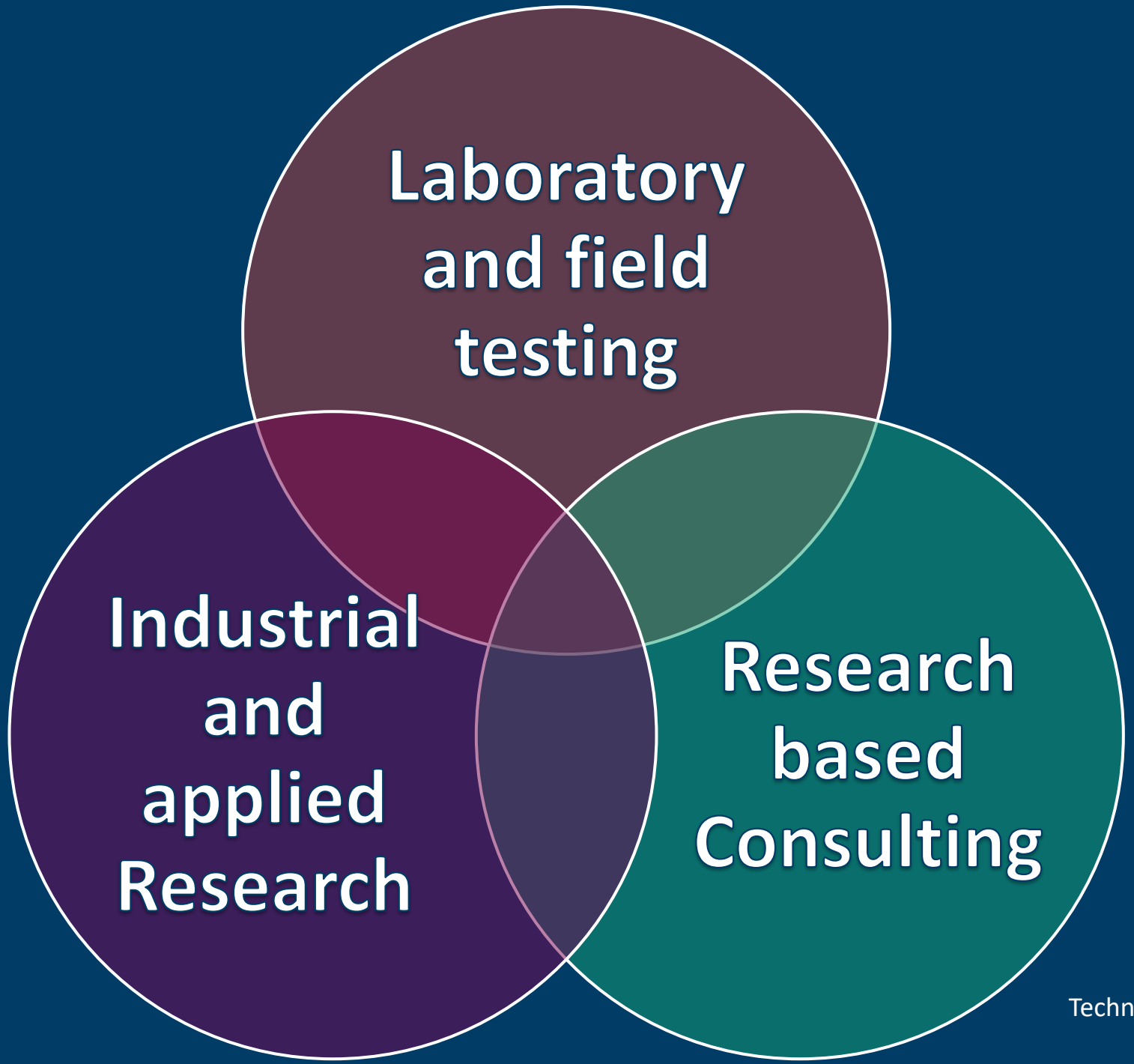
- Engineering geological planning and conceptual design Planning and execution of ground investigations
- Early project cost estimations
- Project implantation
- Contract strategy
- Site organisation
- Rock support methodology
- Ground water control
- Engineering geological considerations
- LCA analysis
- Environmental considerations



Our contribution to the tunnelling industry

- Tunnel and underground technology, including mines
- Geotechnics, including foundation solutions, securing and stability
- Buildings, infrastructure and other facilities in cold areas
- Extraction and utilization of geo resources, including local use of surplus materials
- LCA Analysis and environmental impacts
- Slope stability on portals

SINTEF



Technology for a better society

Laboratory and Field testing

Expertise

- Engineering geology testing; drillability and abrasiveness
- Rock mechanical testing
- Rock Mechanical field measurements and monitoring
- Geotechnical field measurements

Available Tests

- Full scale testing of rock bolts
- Having specific laboratory test equipment and test methodology to evaluate TBM performance:
  - Drilling Rate Index ™ (DRI ™)
  - Bit Wear Index ™ (BWI ™)
  - Cutter Life Index ™ (CLI ™) (TBM cutter life)
  - Soil Abrasion Test ™ (SAT ™).
  - RIAT
- TM-registered indices (TradeMark) developed by SINTEF and NTNU constitute indirect measures of the geological material's drillability and represent important factors for estimating the time and cost of building tunnels and underground spaces.

Figure 1: Outline of the Rolling Indentation Abrasion Test (RIAT) method (left) and photo during testing (right).

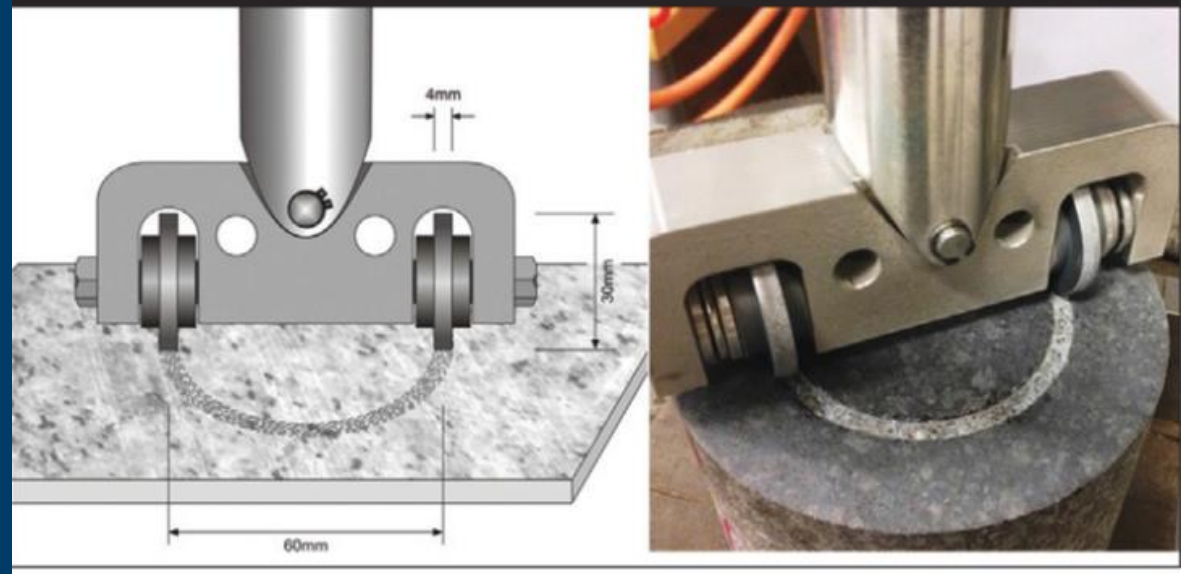
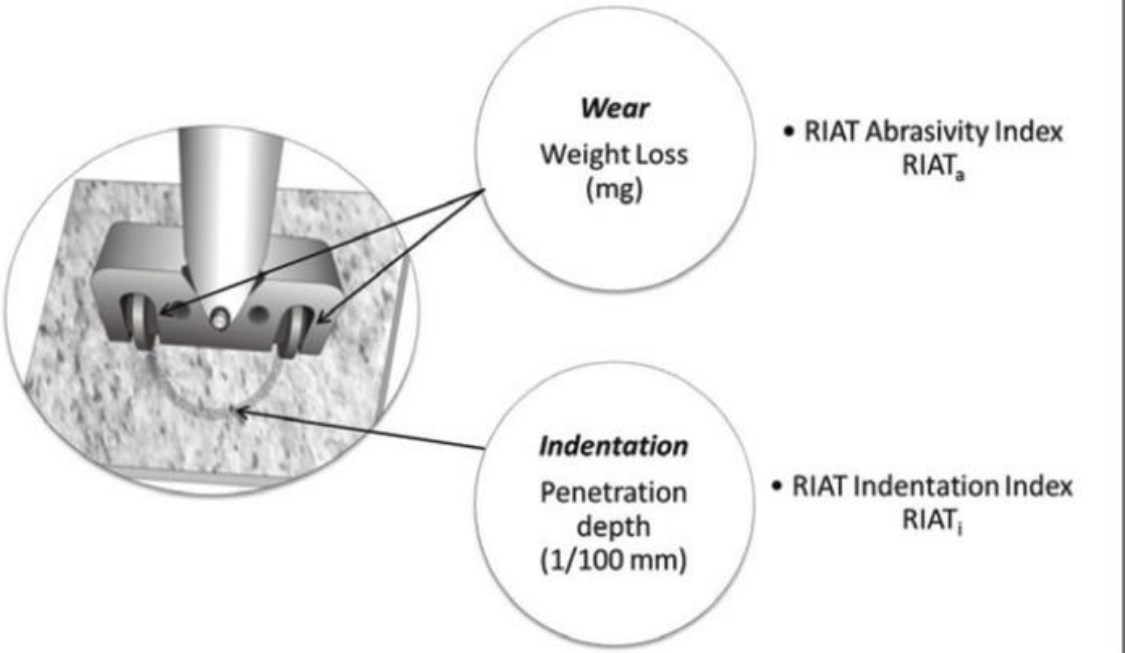


Figure 2: Description of the outputs resulting of the RIAT method.



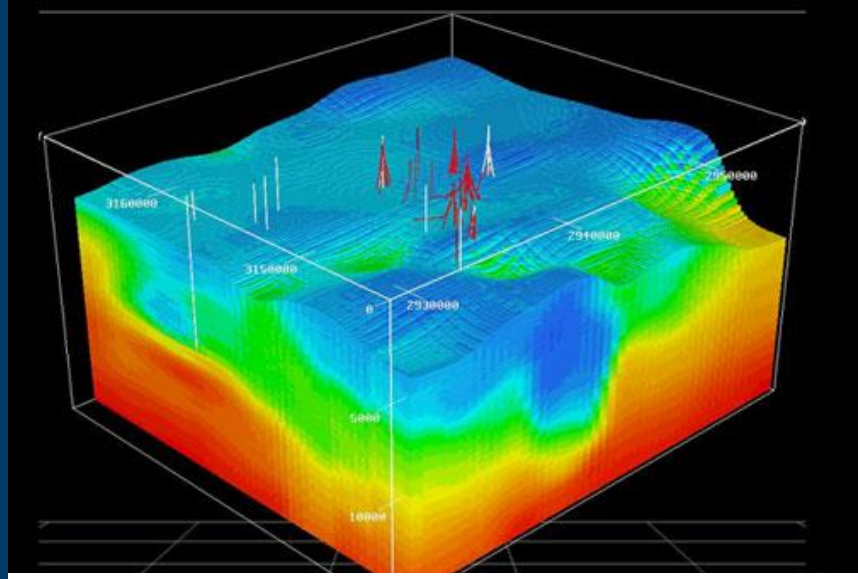
Research based consulting

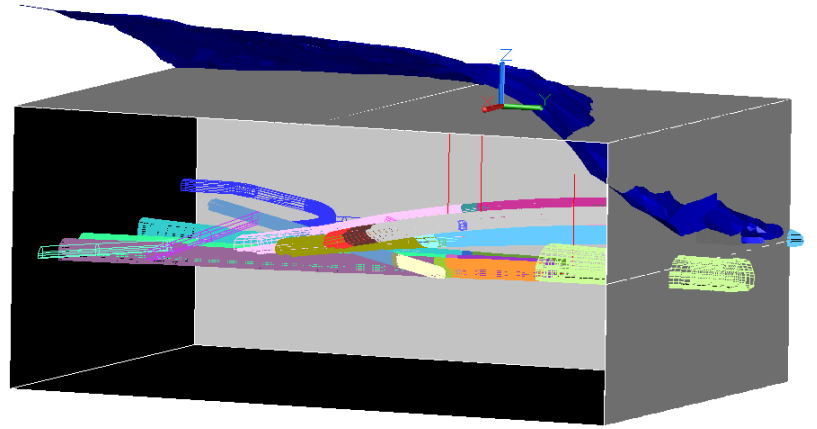
SINTEF has a unique competence and ability due to several factors

- A world leading rock laboratory
- Capability to do in-situ testing
- Close proximity and close cooperation with NTNU
- Unique competence built through leading large industry wide research programs in tunnelling and underground works
- A long history of special assignments

Advanced geomechanical simulations

- SINTEF perform advance numerical modelling for foundation work, rock support behaviour, rock stability analysis and frost estimations among others
- In situ testing is imperial as an input to the models
- Tripod; a concept combining 1) numerical modelling with 2) real behaviour monitored by stress measurements and extensometers 3) model calibration





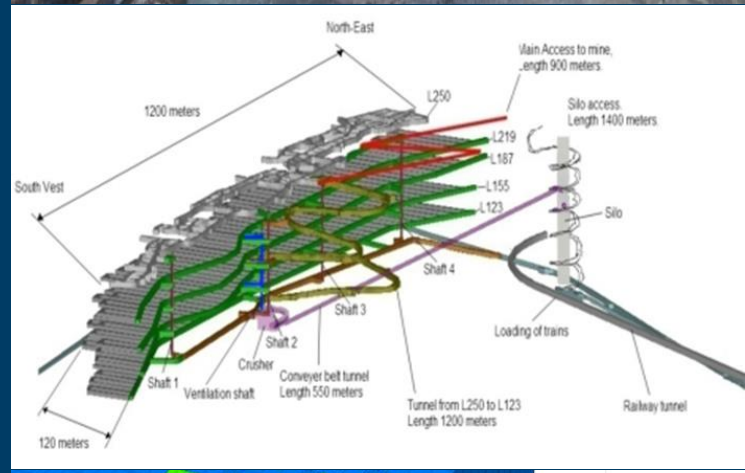
New technologies for tunnel construction and increased utilization of the underground

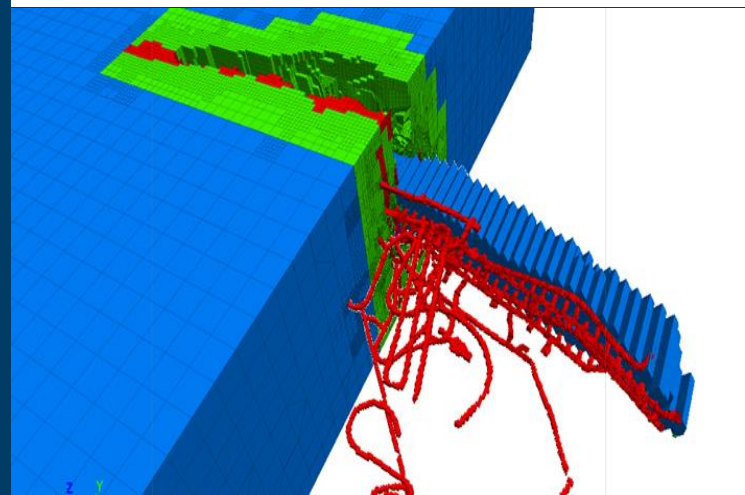
TRIPOD – Developed from SINTEF mining experience

A rock engineering tool, combined of 3 components:

- Investigations: Stress measurement, mapping, laboratory tests;
- Numerical model: 2D or 3D;
- Monitoring: displacement and stress.

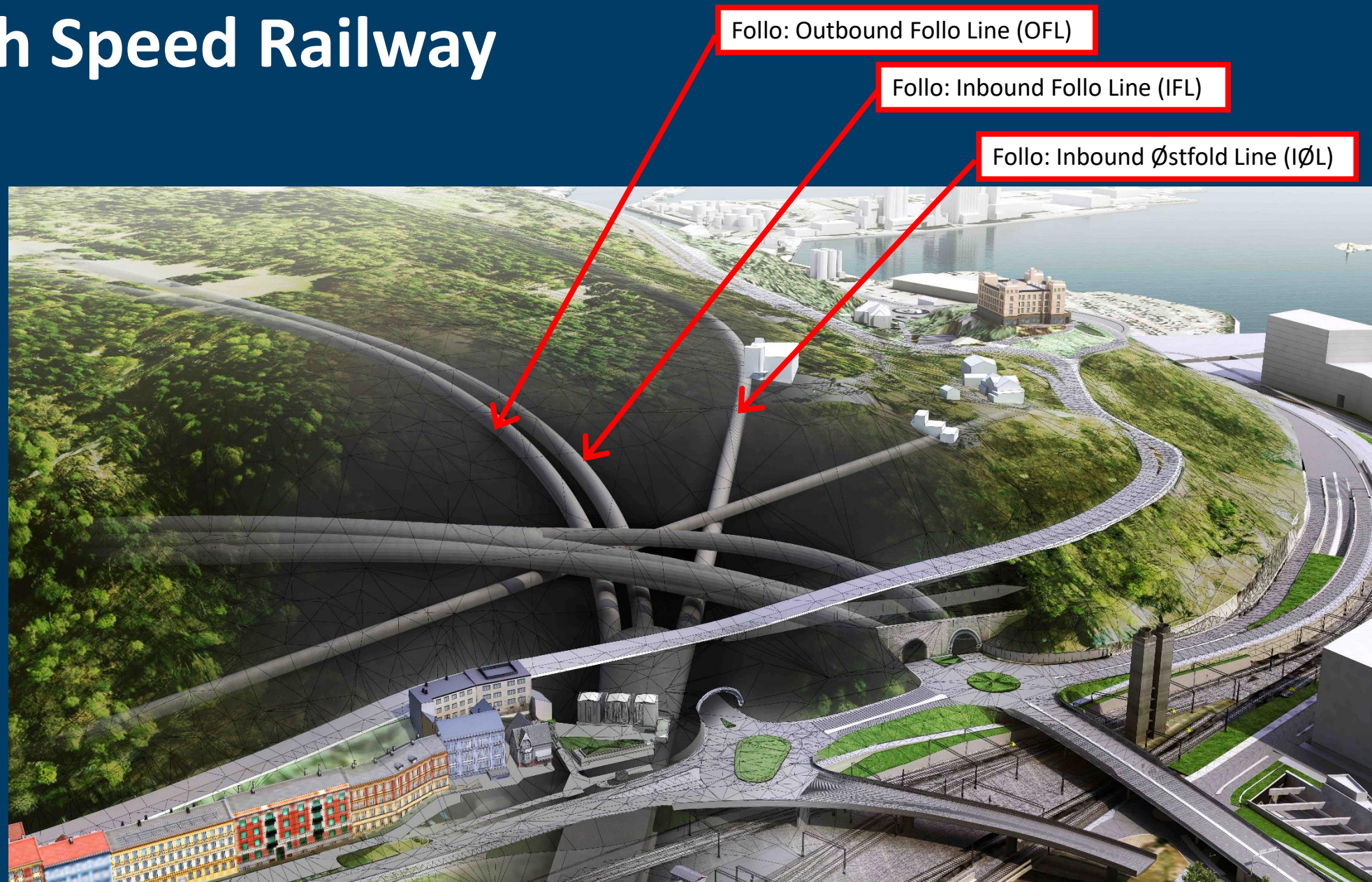
Investigations provide high quality inputs to the numerical model. Model is further calibrated/verified/controlled by monitoring so that it become a reliable tool for planning.





Follobanen project – High Speed Railway

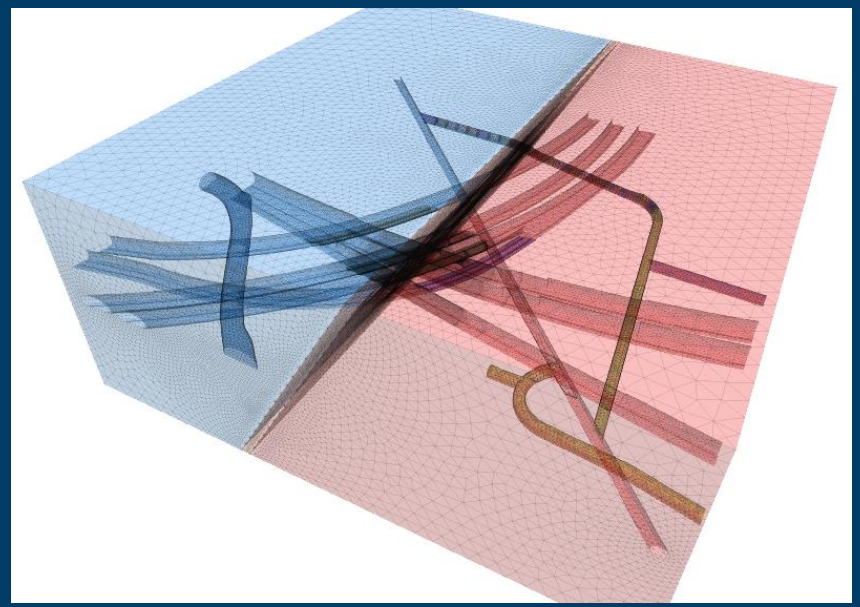
- Vertical distance to the existing tunnels is less than 4 m;
- Existing tunnels are busy traffic tunnels;

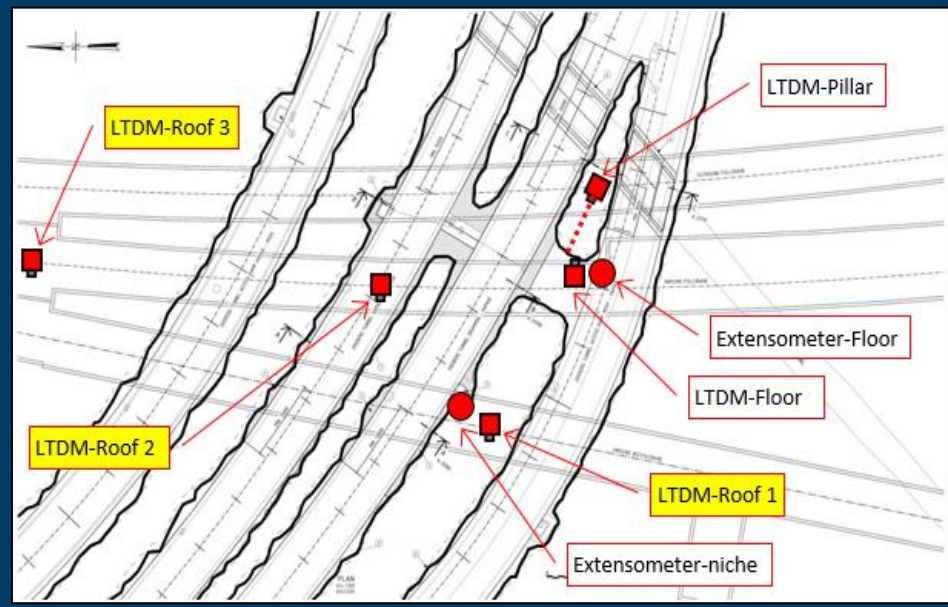


Follobanen project – A HSR and project requirements

1. No negative effect on the stability of the Ekeberg tunnels;
2. No disturbance of traffic in the Ekeberg tunnels during the construction of the Follobanen tunnels;
3. Thus, the stability of the existing tunnels must be ensured at all time;
4. Any risk of instability in the existing tunnel must be detected beforehand to make necessary precaution actions;

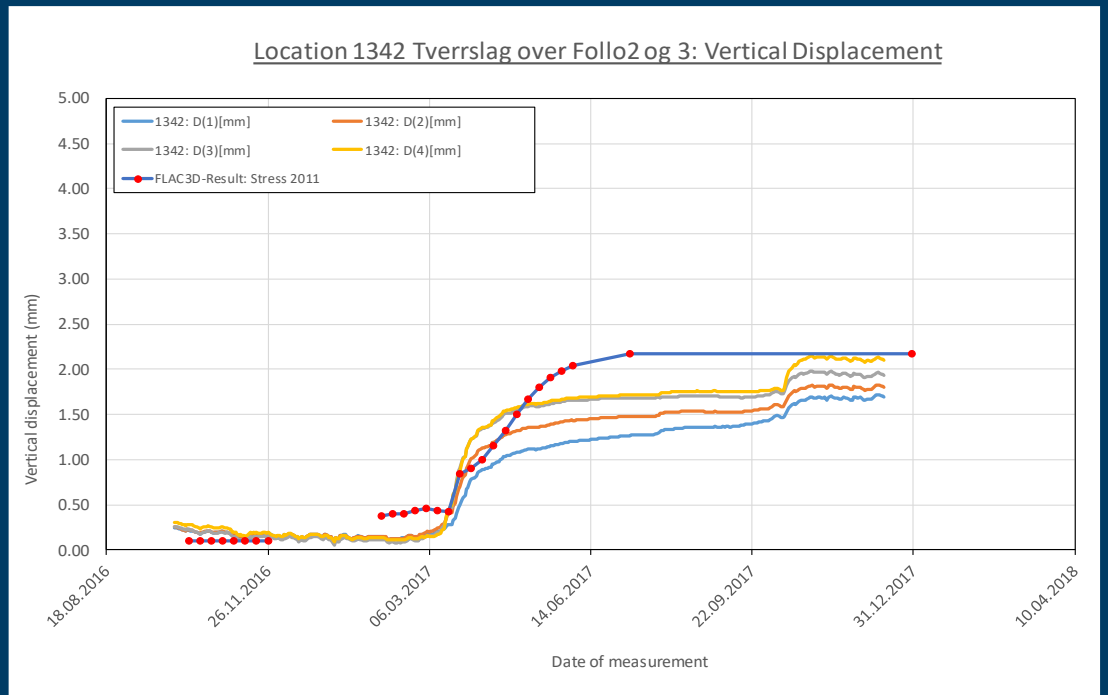
Follobanen project – A metro system: SINTEF's "Tripod" philosophy





Follobanen project – A metro system: SINTEF's "Tripod" philosophy

- The whole "Investigation – Model – Monitoring" system is working smoothly to predict the critical construction steps;
- The project is almost completed now and no risk of instability is observed.



SUPERCON (shotcrete)

- Find solutions that make it possible to strengthen the "Norwegian way" of supporting tunnels as a time- and cost-effective tunnel concept, tailored to fit most rock conditions and variations in traffic density. Moreover, reduced materials consumption, sustainable raw materials and production methods will be key aspects to be considered.
- Areas where increased knowledge is needed are:
  - Utilising new, eco-friendly materials in sprayed concrete – improved material properties
  - Robotized application methods
  - Improved durability to ensure a common service life requirement of 100 years - Sustainability
  - New approach for structural analysis and design

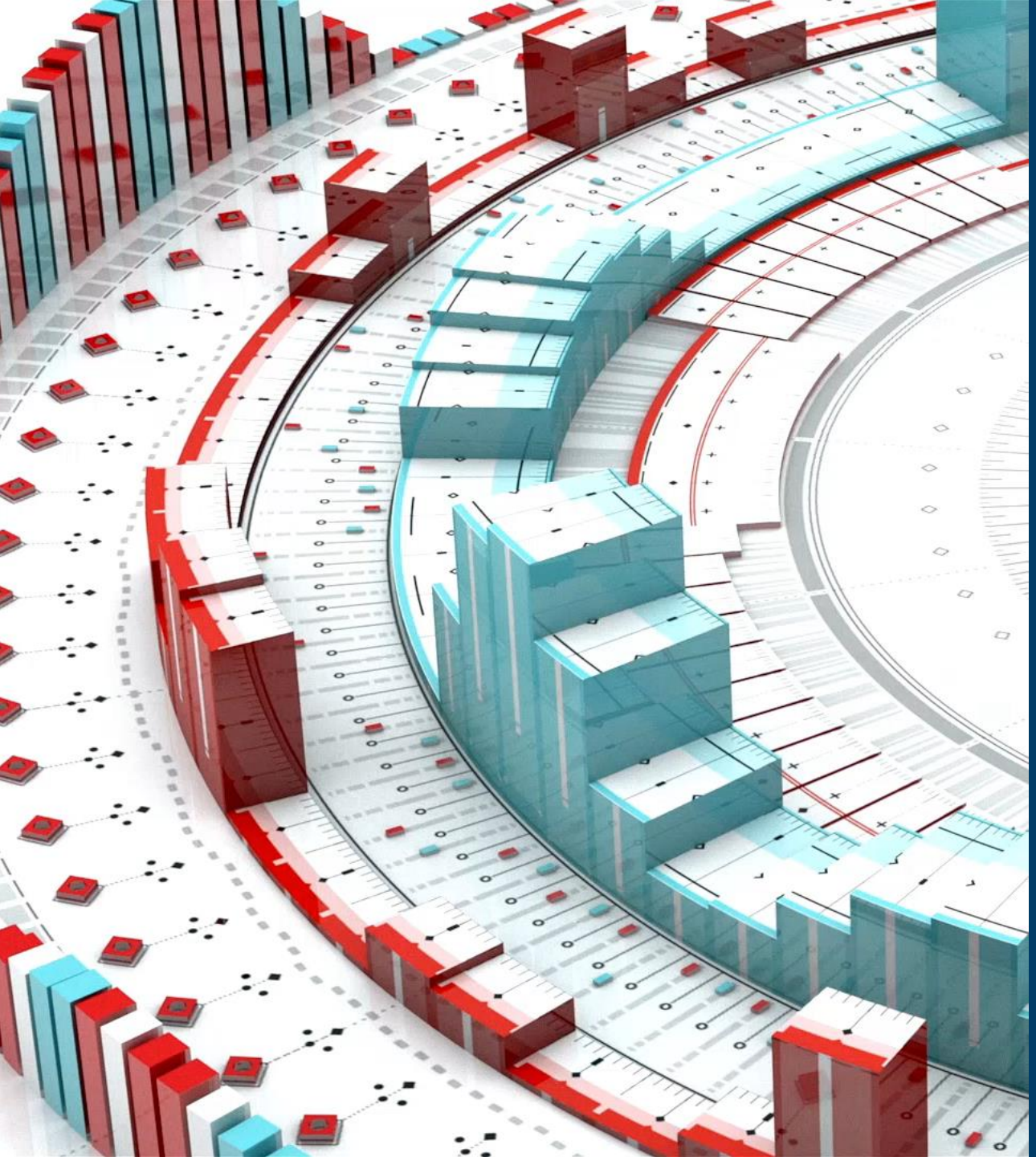
NORSTRESS (rock stress)

- NoRSTRESS is aiming to increase the level of competence amongst owners, designers, contractors, research institutions and academia involved in hydropower on: (i) in-situ rock stress, (ii) rock stress measurement methodologies, and (iii) holistic failure-success interpretations.

- Partners: NTNU/IGP, Hafslund E-CO Energi AS, Hydro Energi AS, Sira-Kvina kraftselskap DA, Skagerak Kraft AS, Statkraft AS.
- Type: Knowledge-Building Projects for Industry (KPN)
- Public funding: 13,68 mill. kroner

LOGIC GROUTING / TIGHT (grouting)

- A new grouting procedure combined with improved logging and interpretation of data during grouting has the potential of significant reduction in the consumption of cement and time, which gives environmental and economic gain. Logic Grouting will develop, test and provide the tools the partners need to implement the grouting strategy in real life
  - Partners: SINTEF and Bever Control
  - Cooperating Partners: Bane NOR, AMV, Skanska, Veidekke and Implenia
- TIGHT will contribute to further developing the Norwegian injection tradition that has been in use for many decades already, and at the same time build up greater real competence related to what physically happens in the rock mass when it is subjected to high-pressure injection.
  - SINTEF, NGI, NTNU
  - Normet Norge AS, GMA, BASF Norge AS, Rescon Mapei AS, Andersen Mek. Verksted AS, Bever Control, LNS AS, Veidekke ASA, GeoVita AS.



PROMOTUN (tunnelling)

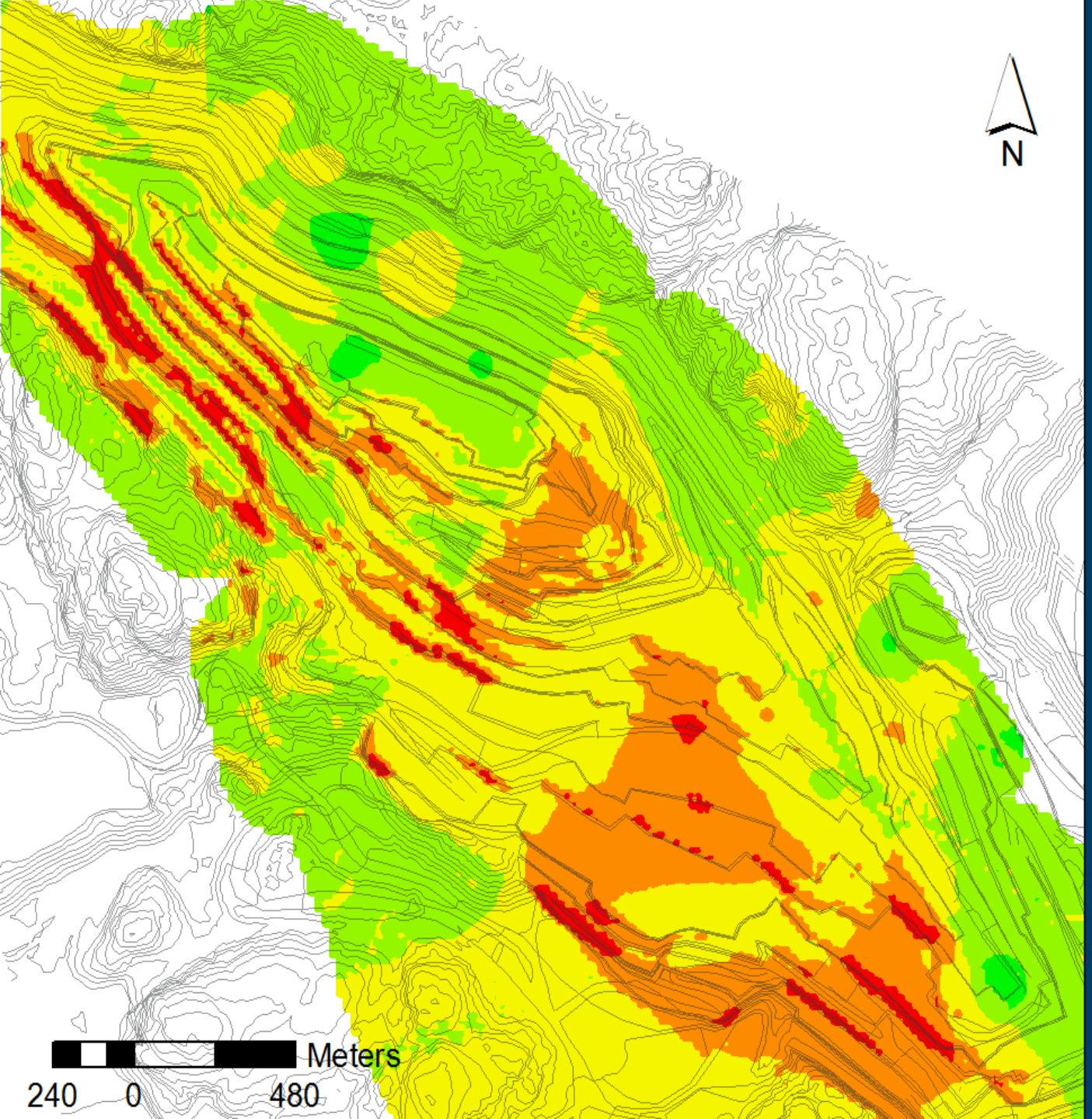
- ProMoTun aims to develop a data driven application for collecting and analysing productivity data from tunnel construction.
- ProMoTun will also give builders and contractors a better basis for discussing the tunnel construction process and thus lead to a reduced number of disputes.

DePOPS (slope stability)

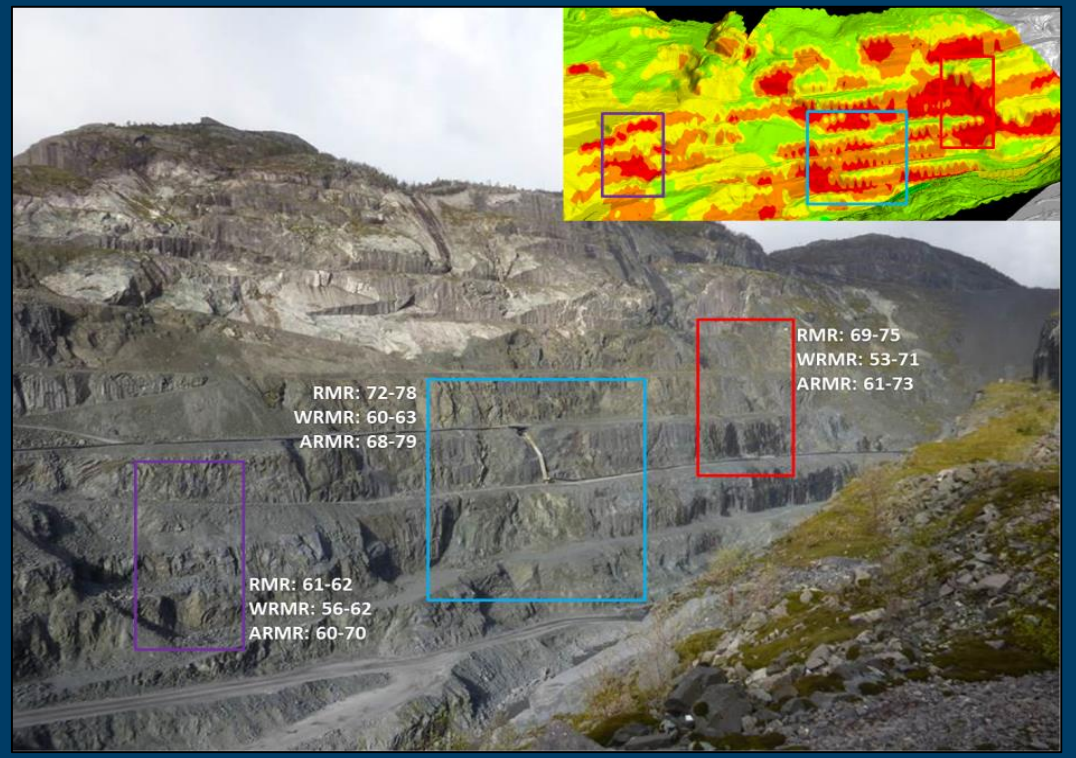
Prepare a danger zone map for stability in an open pit, which is important for optimizing production in relation to stability challenges and a safe workplace.

Parameter	Weight (P_i^{AHP})	Rank
UCS	3.2 %	9
RQD	5.3 %	8
Joint spacing	5.6 %	7
Joint persistence	13.2 %	3
Joint aperture	7.1 %	6
Joint roughness	19.1 %	2
Joint infilling	10.3 %	4
Joint weathering	9.1 %	5
Groundwater	27.1 %	1
TOTAL	100.0%	-

	Original RMR		WRMR	
	min	max	min	max
UCS	0	15	5.9	9.1
RQD	3	20	10.4	12.6
Joint spacing	5	20	12.2	12.8
Joint persistence	0	6	-3.6	9.6
Joint aperture	0	6	-0.6	6.6
Joint roughness	0	6	-6.5	12.5
Joint infilling	0	6	-2.2	8.2
Joint weathering	0	6	-1.6	7.6
Groundwater	0	15	-6.1	21.1
TOTAL	8	100	8.0	100.0

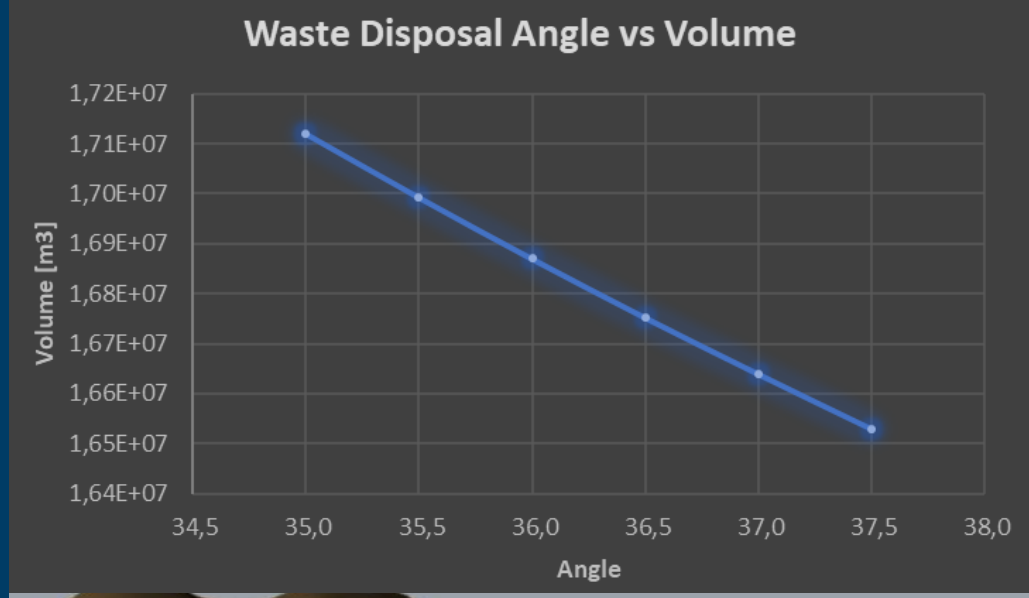


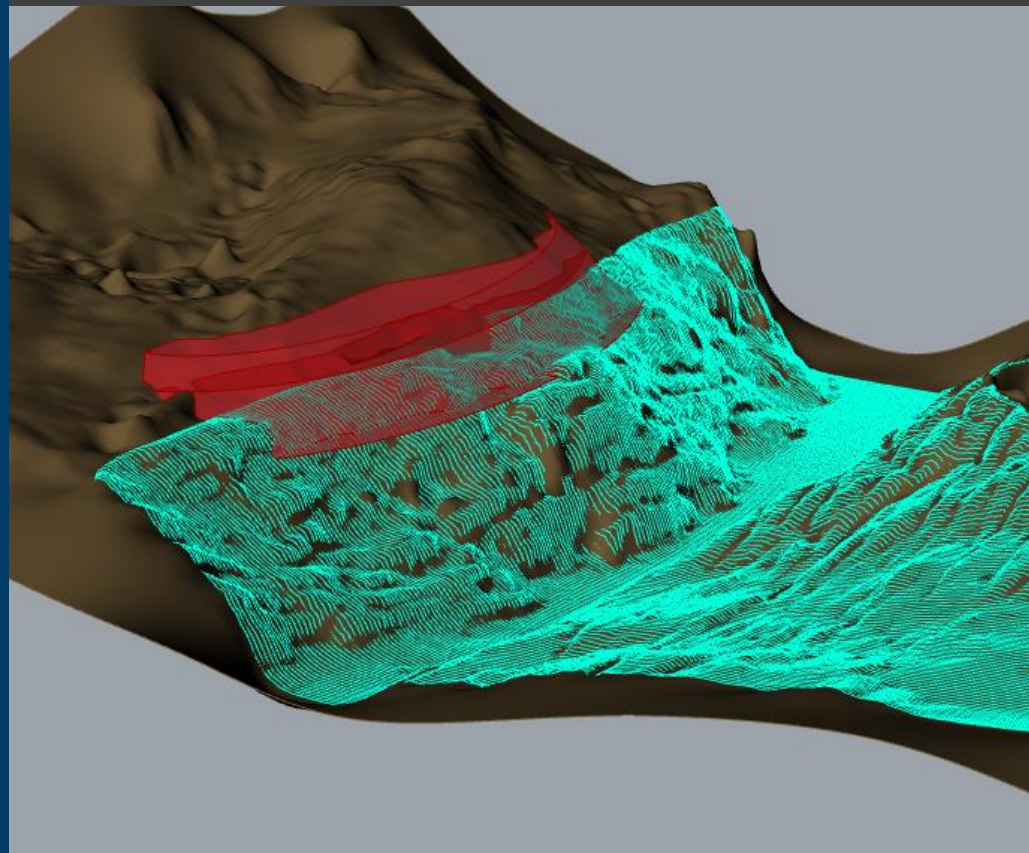
Range of SMR	RMR		ARMR		WRMR	
	Count	%	Count	%	Count	%
80 to 100	-	0 %	-	0 %	-	0 %
60 to 80	5	8 %	6	10 %	1	2 %
40 to 60	37	61 %	41	67 %	9	15 %
20 to 40	14	23 %	12	20 %	40	66 %
0 to 20	5	8 %	2	3 %	11	18 %



GeoBIM

- A complete review and state of the art of the current status of Building Information Models (BIM) applied to rock and soil mechanics.
  - BIM is/has been extensively applied to buildings and recently at tunnels. No evidence of BIM applied to geological problems and surface rock/soil problems has been found.
  - The acquired knowledge was applied to a real-life problem with data supplied from a client to help testing the capabilities of the methodology.
  - Conference article to promote BIM in geology related problems (planned 2022).
- How the project has contributed / will contribute to business development
  - The project as resulted in increased knowledge of parametric modelling and its field of applicability.
  - As part of the project 2 licenses of Rhino 7 and 1 for Griddle were acquired as part of the project.
  - The Griddle license is a strategic asset, since it will help internalizing the meshing process required for 3D numerical models in FLAC. This part of any numerical model has been usually externalized to a third-party supplier.





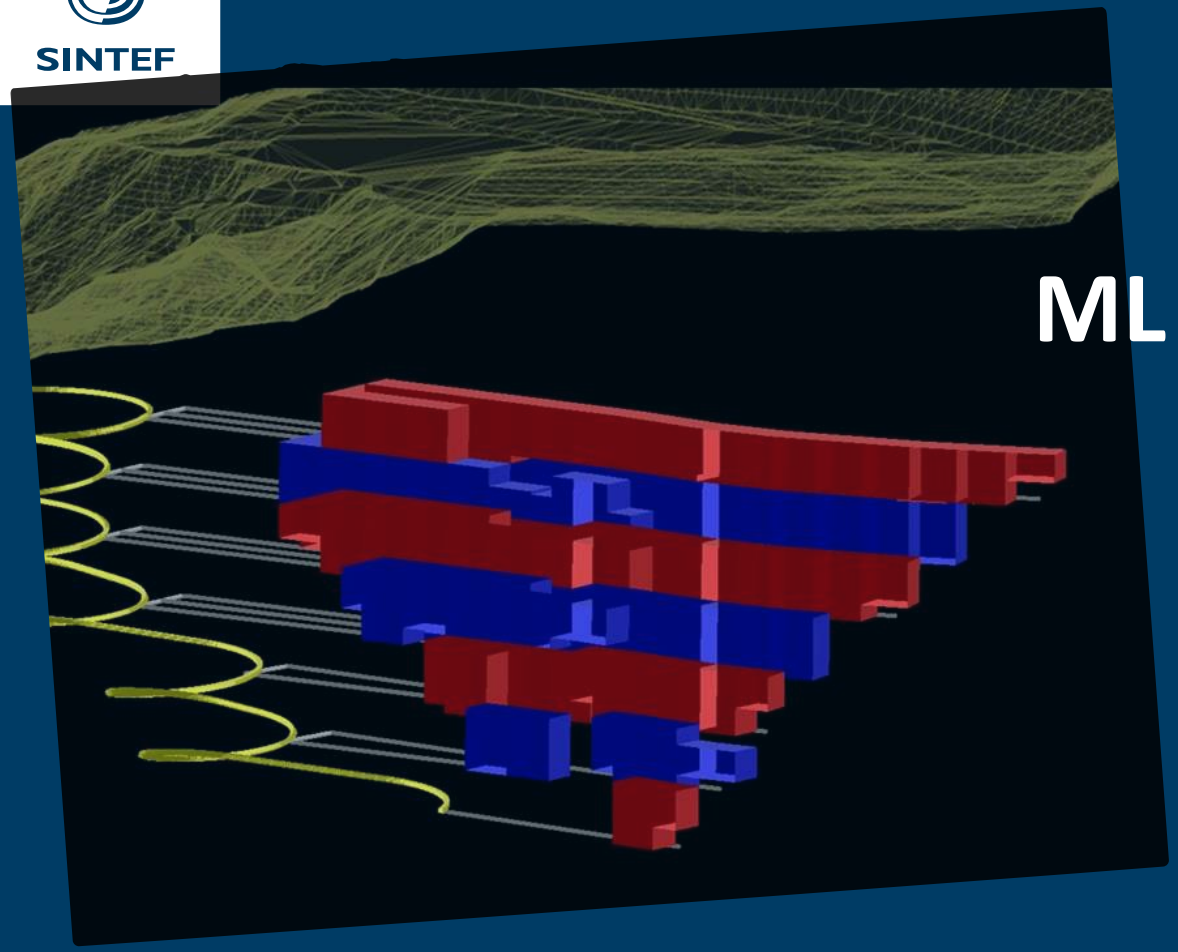
Research ideas

Mario Morales

September 2022

OptiTUN

- Generate an algorithm (and a methodology) to identify and prioritize road tunnelling projects.
  - A road map of Norway with topography
  - Revenue factors (savings on trip time and CO2, LCA, societal impact, winter, etc)
  - Cost factors (financial, emissions during construction, maintenance, etc)
  - Possible to extrapolate for finding hydropower hidden gems?



ML for TriPOD Rockburst

- Use an arrange of (cheap) sensors to gather data in many parts of a mine to prognose rockbursts based on explainable Machine Learning (ML).
  - Build up on TriPOD knowledge
  - Use back analysis and numerical modelling to calibrate
  - Can help us to develop meshing skills for 3D modelling and "gain back" some clients

echnologies for tunnel construction and increased tion of the underground

Norwegian "trolls" have for centuries lived in beautiful mountain halls

Thank you for your kind attention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