Trondheim, 9th December 2021

NoRSTRESS Seminar 2021

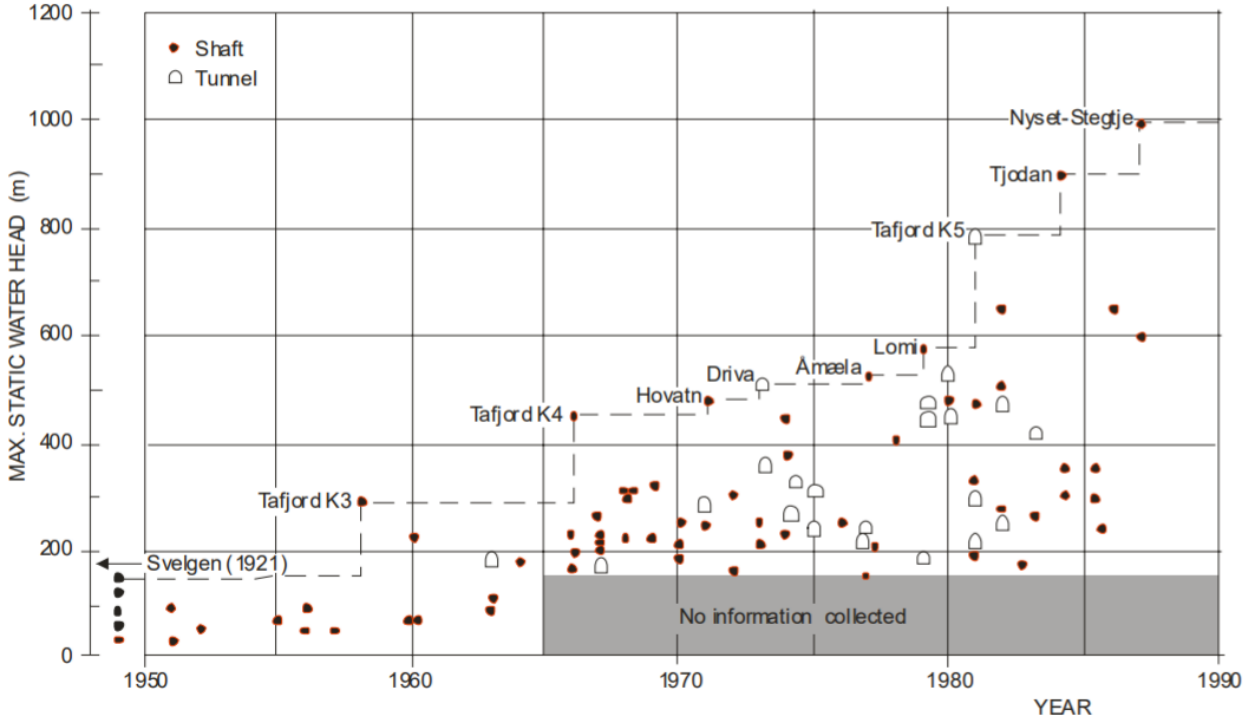
"Knowledge sharing in rock stress measurements"

Introduction of NoRSTRESS Project

NoRSTRESS project

Motivation and Background

- The Norwegian HEP industry has developed several innovative solutions (Broch, 2013):
  - Underground air-cushion surge chambers
  - Lake taps
  - Unlined high-pressure tunnels and shafts, up to more than 1000 m.
  - Underground powerhouses. Almost one third of the underground powerhouses in the world are in Norway
  - Around 5.000km of tunnels have been excavated for HEP. The Norwegian Hydro Electric Power production is truly an underground industry.
- Norwegian HEP has a worldwide reputation for cost efficiency, environmental sustainability and a proven design and construction concept.
- One of the key factors for such achievement is the understanding and utilization of in situ rock stress.

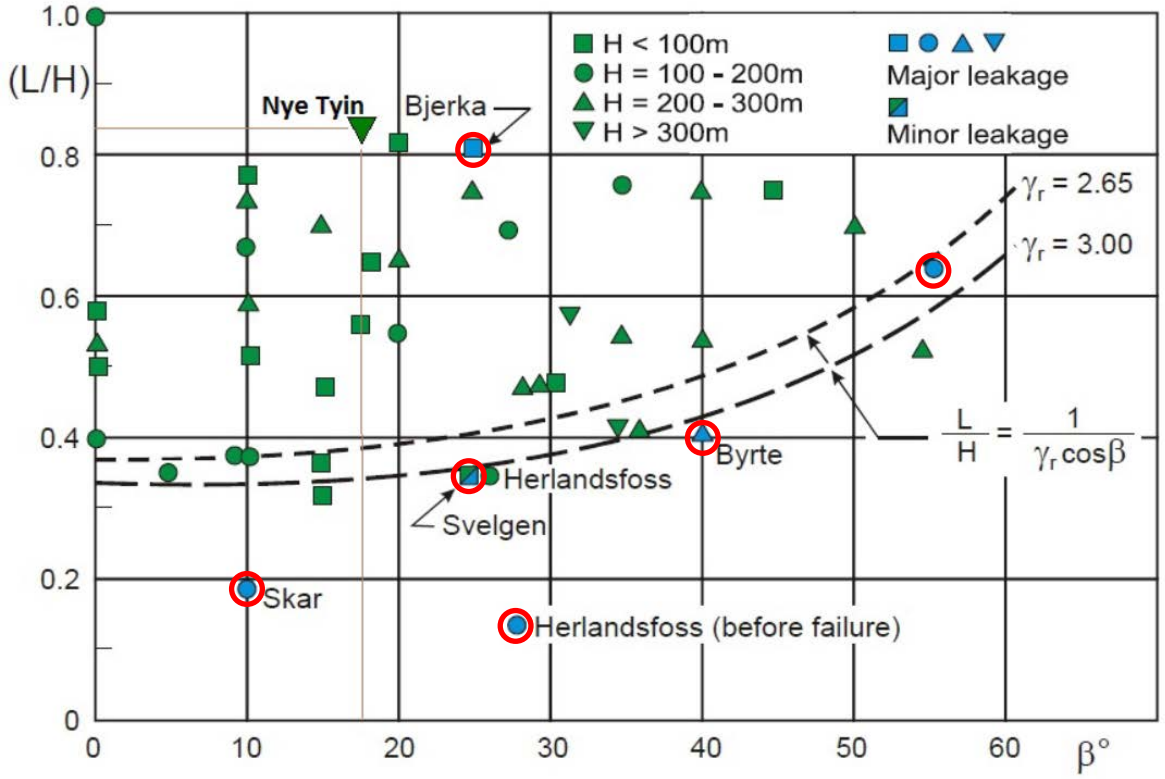


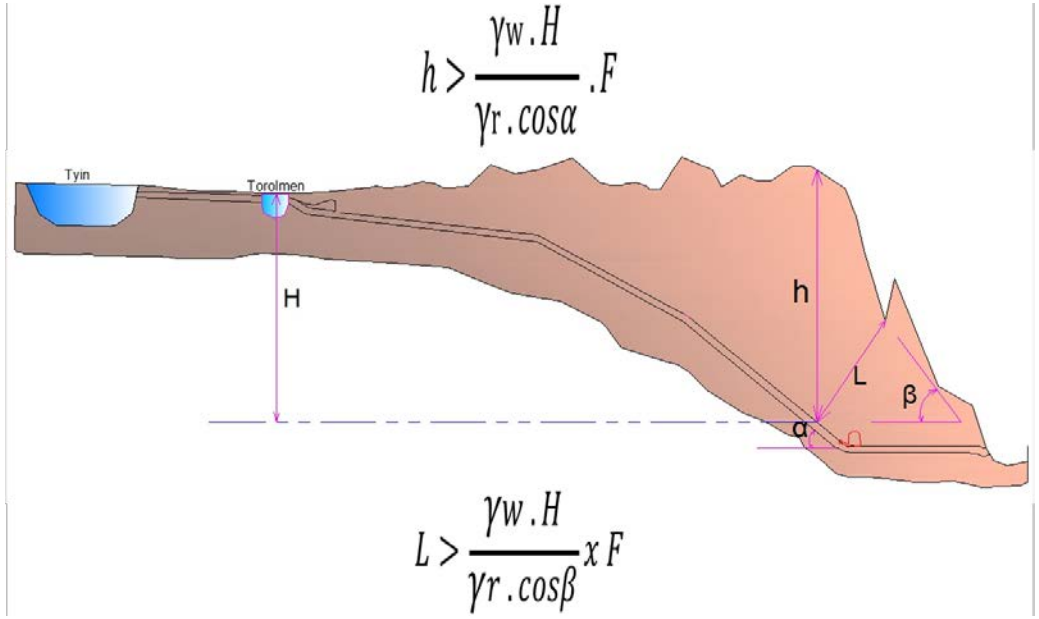
Palstrom: http://rockmass.net/ap/27_Palmstrom_on_Unlined_pressure_shafts_Norway.pdf

NoRSTRESS project

Motivation and Background

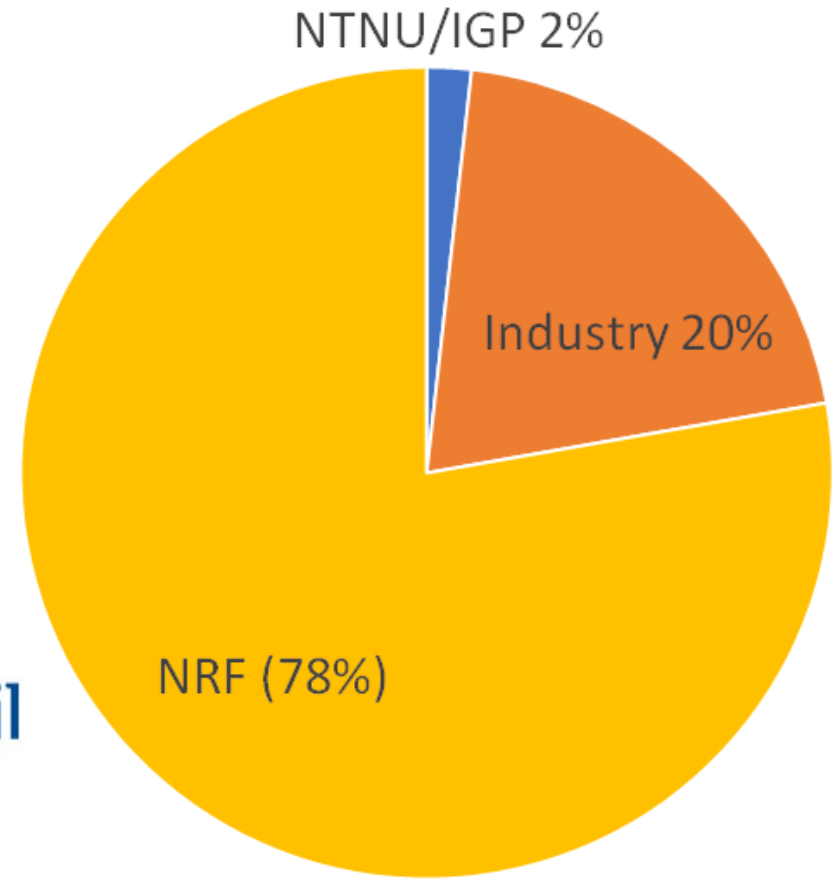
- Hydraulics failure incidents where rock overburden is relatively high (factor of safety is large than 2 according to the rule of thump);
- Successful projects with low overburden (factor of safety is about 1 and less than 1, according to the rule of thump).





Partners & Budget

Total budget: 17.59 million NOK



SINTEF

NTNU
Norwegian University of Science and Technology

Hafslund

ECO

Hydro
Industries that matter

Sira·Kvina
KRAFTSELSKAP

Skagerak Energi

Statkraft

The Research Council of Norway

Main objectives

1. Improve the knowledge front on in-situ rock stress as a large picture of **regional stress (deep stress)**, as well as **local stress variations (shallow stress)** due to local geological, topographical, and geo-tectonic features.

2. Identify the **behaviour of the rock mass** on stress related instability along the waterway system **under the condition of frequent cycles of load/unload** scenarios that is being emerged and will be the operation scenario in the days to come due to different renewable sources of energy in the grid and its relationship with the in-situ stress. Through research, the Norwegian unlined tunnel solution for developing HEP projects is strengthening in Norway as well as internationally.

3. **Establish rock stress database** for the successful evaluation of in-situ rock stress in HEP as well as other rock engineering projects during planning, construction and operation. Machine learning process can be included to form an "intelligent database" that can be extended and improved with future data.

Promised deliveries

1. World Stress Map database update:
   - A large scale/regional numerical model will be carried out. The model will include the Mid Atlantic Ridge in the Norwegian sea in order to study the origin and background of the generally high horizontal stress in Norway (deep stress).
   - With this model, data from other sources such as World Stress Map, earthquake focal mechanism, and oil industry can be utilised.
   - Qualified data of the orientation of the maximum horizontal stress will be delivered and updated to the World Stress Map (WSM) database at GFZ (Deutsche GeoForschungs Zentrum) for the Scandinavian region, a data base that has not been updated since 1986.
   - NoRSTRESS will have a close communication with the GFZ to exchange stress data and research results bilaterally, including also the latest work at GFZ, the Quantitative WSM (Q-WSM) database. The Q-WSN is of special interest to the rock engineering community and local stresses (or shallow stress) studied in NoRSTRESS can contribute to enrich the Q-WSM, and vice versa NoRSTRESS will benefit from the supplementary findings of Q-WSM.

Promised deliveries

2. Stress Database for Norwegian rock engineering projects: From the analyses and collected data, a database will be established for Norwegian ground conditions (shallow stress), including a procedure with templates to properly add future rock stress measurements to the database. Detailed guidelines of how to use (and not to use) the database will be suggested.

3. A "Best practice manual": A manual on best practice on rock stress investigation for planning and execution of the HEP projects will be produced. This delivery will complement research results from FME HydroCEN to provide useful tools for hydropower industry.

4. A design approach on rock stress applications and study: Based on gained new knowledge and competence a new design approach for developing unlined pressure tunnels and caverns using the acquired rock stress competence. Newly acquired rock stress conditions can be used to study different rock engineering issues related to rock stress, such as stress induced instability or rock mass behaviour under frequent cycles of load/unload scenario that cause high peak (water hammer) and longer waves (oscillation). A close cooperation with FME HydroCEN is required to make sure that this delivery will have mutual impact with research activities that are being carried out in FME HydroCEN.

Work packages

NoRSTRESS

https://www.sintef.no/projectweb/norstress/

WP1
Management
Leader: Dr. Nghia Trinh
Steering Committee

WP2
Review current in-situ rock stress data
Leader: Trond Larsen

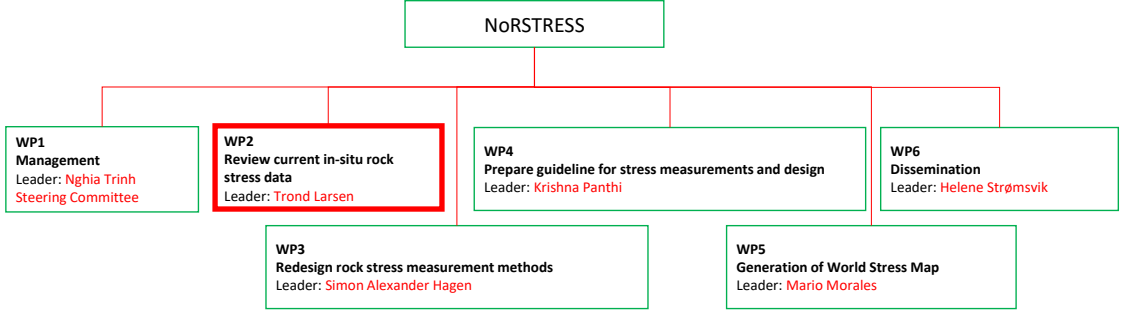
WP4
Prepare guideline for stress measurements and design
Leader: Prof. Krishna Panthi

WP6
Dissemination
Leader: Dr. Helene Strømsvik

WP3
Redesign rock stress measurement methods
Leader: Simon Alexander Hagen

WP5
Generation of World Stress Map
Leader: Dr. Mario Morales

Work package 2



WP2: Review current in-situ rock stress data (NTNU) – 1 postdoctoral fellow

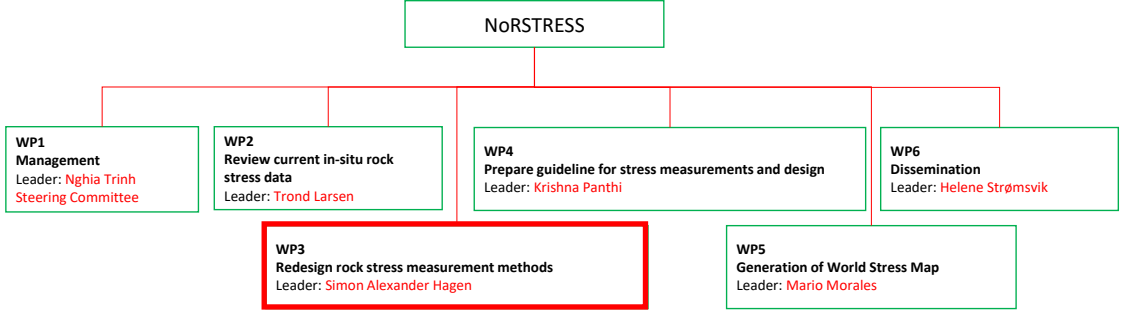
OBJECTIVE: To provide a better understanding and interpretation of in-situ rock stress data and improve the knowledge base regarding in-situ rock stress data.

Analysis and collection of in-situ rock stress data and associated geological, topographical information are done in this WP. All members of the project will have direct link with the hydropower industry through HydroCen. A joint effort the researchers and the industry partners will identifying project cases to be studied. Documentation of relevant information and data associated with stress measurement will be done taking in account periods of preconstruction, construction and operational phases of a project. WP2 comprises the following tasks:

Task 2.1 Collect information on in-situ stress data from existing sources in Norway and gather relevant information on such as geology, topography and relevant aspects at the measurement locations. Information will need to be collected from surrounding projects to enable a larger view on the data.

Task 2.2. Analyse the gathered in-situ rock stress data band identify correlations with relevant factors. Study the impact of each factor to the stress magnitude and orientation and consider local and regional factors and circumstances.

Work package 3



WP3: Redesign rock stress measurement methods (SINTEF)

OBJECTIVE: To establish the best practice methodologies and methods for rock stress investigation during different planning phases for developing a HEP. This is not limited to hydraulic fracturing method, but will also include strain relief methods. A key objective is to identify how the different methods can be combined and supplemented to improve the investigation quality. This work package will bring a significant extension and added value to the WP1.1 in the HydroCen.

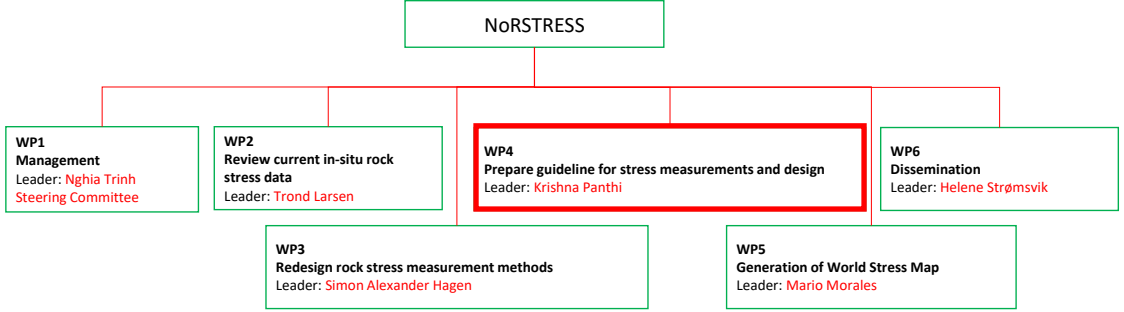
Review of in-situ rock stress measurement methods currently in use. A comprehensive evaluation of the methods for rock stress measurement will be carried out, which will include: (i) methodologies and their applicability and sources of error, (ii) evaluation of needs at various planning stages (pre-construction or construction), and (iii) evaluation of the need and utilization of geological and topographical information in connection to rock stress investigations and assessments. WP3 comprises the following tasks:

Task 3.1 The review of current rock stress measurement methods: will include a qualification of advantages, disadvantages and applicability for various purposes, with focus on HEP development. The task will include hydraulics fracturing and will cover different strain relief methods currently in use in the industry world-wide.

Task 3.2 Perform practical method test: evaluation of different in-situ rock stress methods at selected HEP project sites. At least four test sites will be performed during the project, where the projects shall test various methods/methodologies in variety og geology and topography.

Task 3.3 Recommendation for improvements: the WP will result in a scientific report with the main findings and recommendations for further methodology development.

Work package 4



WP4: Prepare guideline for stress measurements and design – Ph.D.

OBJECTIVE: To improve the knowledge and documentation of the performances of underground structures under various rock stress, geological, geo-tectonic, topographic, hydraulic and rock mechanical circumstances, the research will focus on the integrity of water-pressurised tunnels. The research will specifically focus on understanding and explaining the following cases:

- Hydraulic failure incidents where rock overburden is relatively high (factor of safety is large than 2 according to the rule of thumb); and
- Successful projects with low overburden (factor of safety is about 1 and less than 1, according to the rule of thumb).

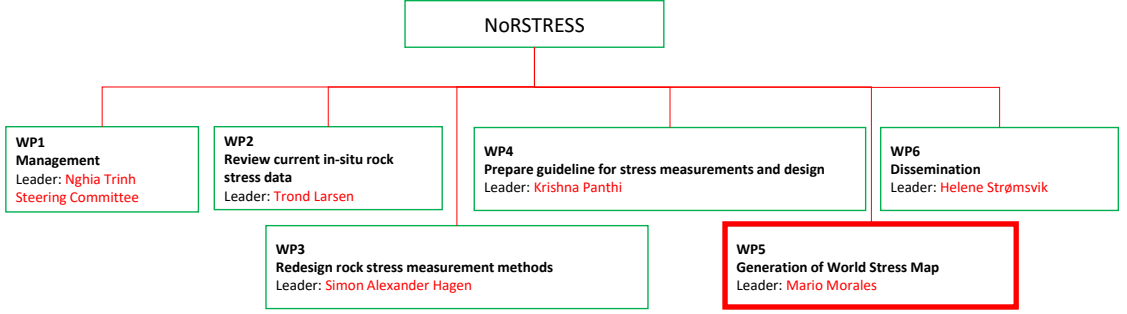
Task 4.1 Case selection and mapping: A minimum of 6 failure cases related to both high and low stress scenario will be selected and analysed. In depth information associated with geological, geo-tectonic and topographic conditions will be gathered.

Task 4.2 Identify and conduct supplementary investigations: detailed engineering geological mapping, collection of rock samples for laboratory investigations, and in-situ stress measurement(s) in-case this was not properly done during project implementation.

Task 4.3 Compile all analyses and findings in the project to prepare a recommendation of design guidelines and include in this compilation such parameters that expose a coherence with respect to in-situ stress. Formulation of stepwise analysis method. Detailed analysis and causes of the selected failure and successful cases using different approaches such as analytical, empirical, and numerical methods.

Task 4.4 Guidelines and recommendation: The task will extract findings from all WPs and transform this into open access publications and guidelines in cooperation with the participating partners. The guidelines provide advices for proper use of the database in investigation and planning of the HEP projects.

Work package 5



WP5: Generation of World Stress Map

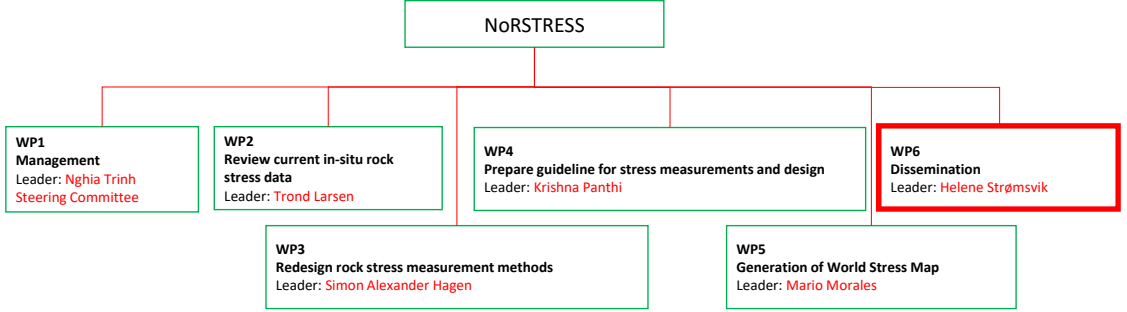
OBJECTIVE: To cooperate and contribute to the international academic and engineering society -on understanding and mapping in-situ rock stress. Bilateral exchange of information for near surface rock engineering using the underground to develop sectors such as hydropower, infrastructure, oil- and gas and civil service facilities.

A database for in-situ rock stress conditions in Norway will be built based on findings of the other WPs in NoRSTRESS. The study will follow guidance from GFZ to enable compliance with the World Stress Map (WSM) and Qualitative World Stress Map (Q-WSM), which again contribute to the project "Fennoscandian Rock Stress Data Base". WP5 comprises the following tasks:

Task 5.1: Database development and application framework: A database for the in-situ rock stress in Norway will be established based on SINTEFs experience and stress measurement data, NTNU Master Thesis Work by Simonsen (2018) will be included in the task. The database will include in-situ rock stress data as well as the geological, topographical, and other relevant information. The postdoctoral fellow working with WP2 is involved in Task 5.1.

Task 5.2 Updating the WSM and Q-WSM: NoRSTRESS will provide qualified data of the deep stress/maximum horizontal stress to be included in the WSM database at GFZ for the Scandinavian region. Findings of the local/shallow stresses will contribute to the development of the Q-WSM. The task will enable international exchange and bilateral research cooperation.

Work package 6

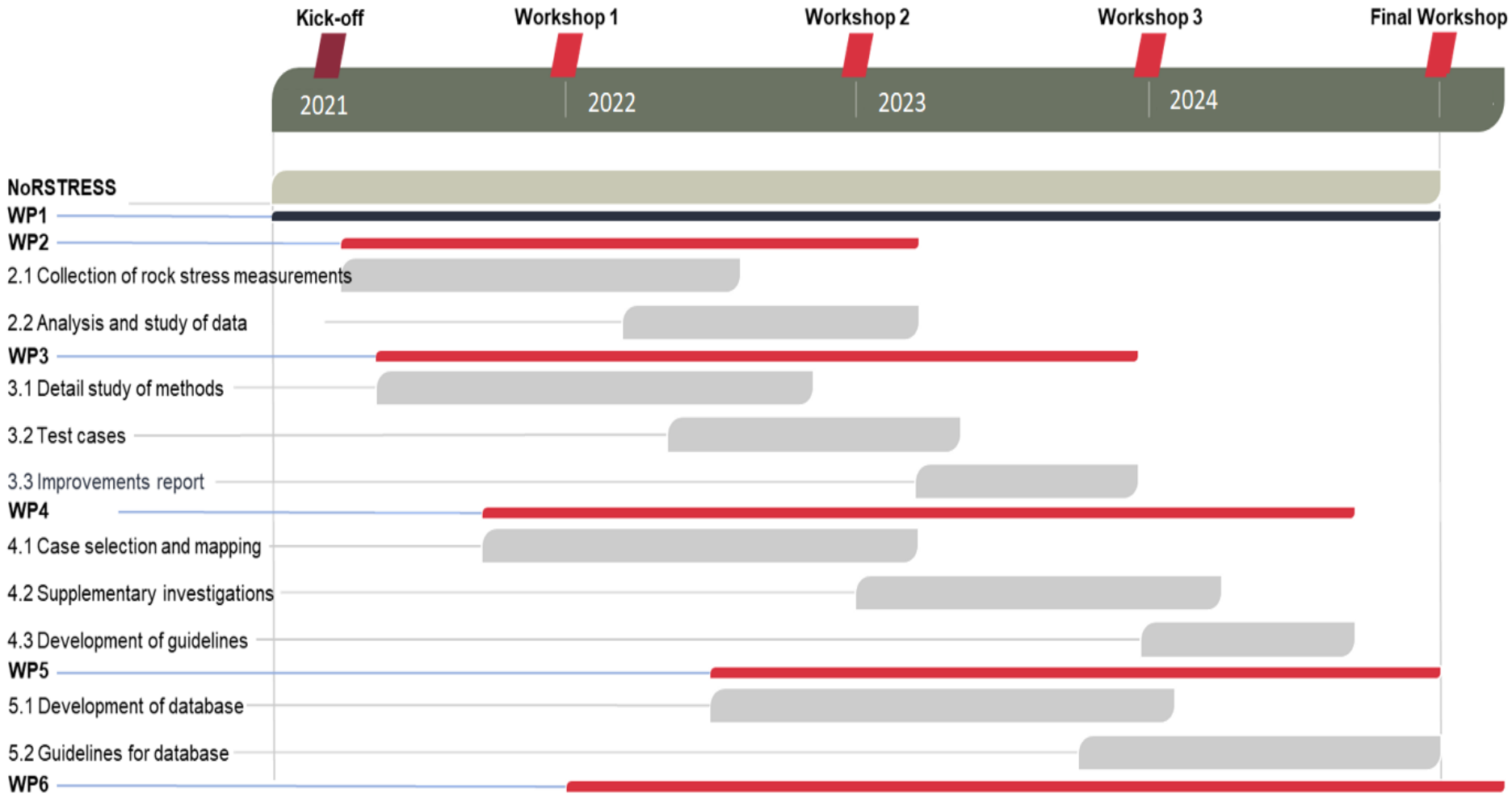


WP6: Dissemination

The research results will be disseminated mainly in three ways:

- One PhD thesis and one post-doc work, which will include a summary of the scientific research, peer-review journal papers and conference contributions.
- Final reports based on the PhDs findings and other research activities, with in-situ rock stress database, guidelines and recommendations. It is the intention to publish at least 4 papers in international peer reviewed journals and 6 papers in proceedings of national and international conferences. The main findings and recommendations will be accommodated into applicable formats for relevant implementation towards the industry partners and consultancy.
- Within the Hydropower industry in Norway, mainly through the existing FME HydroCen, but also at various national courses and conferences. The results will also be presented in the international arena, especially in countries that have applied the Norwegian underground technologies. An open workshop is planned at the completion of the project to present all the findings to the Hydropower Industry.

Project schedule



NoRSTRESS project

Kvilesteinsdammane hydropower plant/Statkraft

SINTEF

NTNU
Norwegian University of Science and Technology

Hafslund ECO

Hydro
Industries that matter

Skagerak Energi

Sira·Kvina KRAFTSELSKAP

Statkraft

The Research Council of Norway