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Review on swelling pressure measurement techniques for intact rock samples: a discussion based on recent NTNU research under FME HydroCen

Dr. Krishna Kanta Panthi

Professor
Department of Geoscience and Petroleum
krishna.panthi@ntnu.no

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NTNU

Introduction

Rock mass => Intact rock + discontinuities + weakness zones + groundwater

Rock mass characteristics:

- **Discontinuities / inhomogeneity**
- **Weakness / shear zones**
- **Clay infilling**
- **Groundwater**

Intact rock **Rock mass**

1. Challenges associated to swelling of clay in weakness zones
2. Challenges associated to swelling of weak and sensitive rocks

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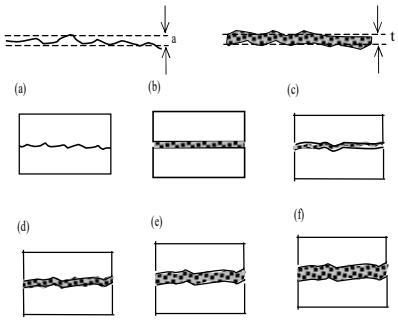
Discontinuous rock mass



Weakness and fault zones exposed to topography

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Challenges associated to swelling of clay

Concrete lining to support collapsed section of Brattsett headrace tunnel at a weakness zone containing swelling clay (Photo: Trønder Energi, 2009)

Headrace tunnel collapse at Marte tunnel in 2018

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Challenges associated to swelling of rocks

Collapse at the headrace tunnel of La-Higuera HPP (N. Trinh, 2017)

Collapse at the headrace tunnel of Kargi HPP (Statkraft, 2016)

Moglicë HPP
(Core collected in Oct 2017)

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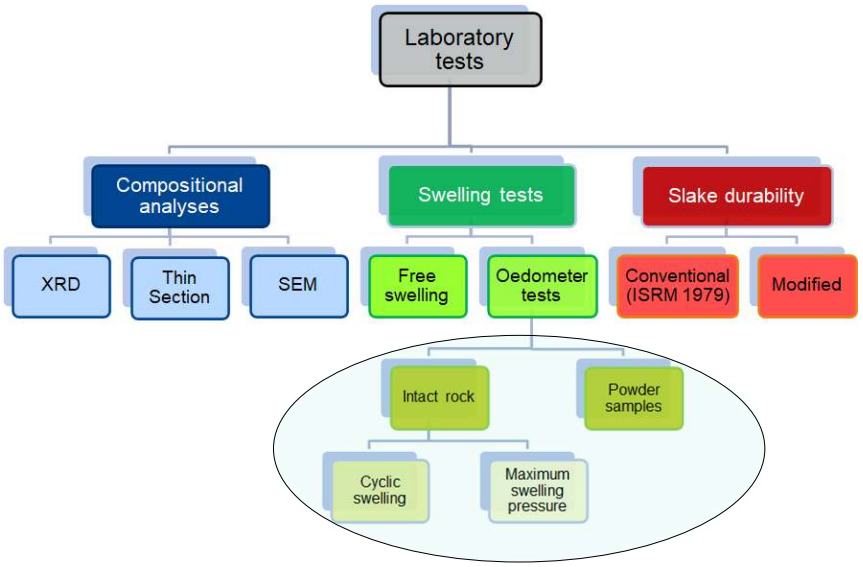
2. Laboratory testing of sensitive rocks



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3. Identification of swelling minerals

Existing (standard) preparation method

1. Fly Press Rock Crusher
2. Retch Vibratory Disc Mill RS 200
3. Splitting for XRD/XRF, thin slip and swelling tests


Fly press rock crusher


Retch Vibratory Disc mill RS 200


Splitter

- High milling energy
- Drying samples at 105 Degree C

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Example results of XRD with standard preparation

	Standard (STD) [Wt%]						
Mineral	1	2	3	4	5	6	7
Quartz	27	9	3	16	2	35	10
Plagioclase	11	-	25	19	43	18	29
Chlorite	6	34	25	8	11	7	4
K Feldspar	-	-	-	-	-	-	-
Amphibole	-	-	-	-	1	-	-
CPX	-	3	16	4	14	-	5
Calcite	10	2	7	29	5	1	29
Datolite	-	-	-	-	-	-	12
Talc	22	13	2	-	-	-	-
Serpentine	3	38	12	0	5	0	0
Smectite	1	0	1	1	0	-	-
Zeolite	5	-	-	-	-	-	-
Titanite	-	-	9	-	8	5	3
Pyrite	-	-	-	0	0	0	0
Pyrrhotite	-	-	0	0	1	1	-
Muscovite	13	-	-	18	7	33	8
Kaolinite	3	-	-	4	-	-	-
Magnetite	-	1	1	-	-	-	-
Spessartine	-	-	-	1	3	1	-

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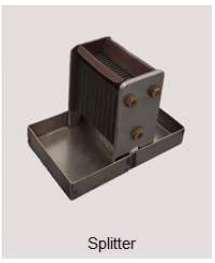
Modified preparation method

1. Fly Press Rock Crusher
2. Mortar og pestle
3. Sieving (<100µm and 100-300µm)
4. Splitting for XRD/XRF, thin slip and swelling tests


Fly press rock crusher


Mortar and pestle


Sieves


Splitter

- Low milling energy
- Reduced drying temperature (at 40 degrees)

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Example results of XRD with modified preparation

	Modified (MOD) [Wt%]						
Mineral	1	2	3	4	5	6	7
Quartz	22	10	3	15	2	34	9
Plagioclase	8	-	22	16	37	17	26
Chlorite	5	29	26	9	12	8	4
K Feldspar	4	-	-	-	-	-	-
Amphibole	-	-	-	-	1	-	-
CPX	-	5	15	3	15	-	4
Calcite	15	2	7	27	7	1	33
Datolite	-	-	-	-	-	-	11
Talc	15	12	2	-	-	-	-
Serpentine	4	40	13	2	6	0	2
Smectite	1	2	3	4	3	1	1
Zeolite	8	-	-	-	-	-	-
Titanite	-	-	8	-	7	5	2
Pyrite	-	-	-	0	0	0	0
Pyrrhotite	-	-	0	0	0	1	-
Muscovite	12	-	-	22	6	33	7
Kaolinite	6	-	-	1	-	-	-
Magnetite	-	1	1	-	-	-	-
Spessartine	-	-	-	1	2	0	-

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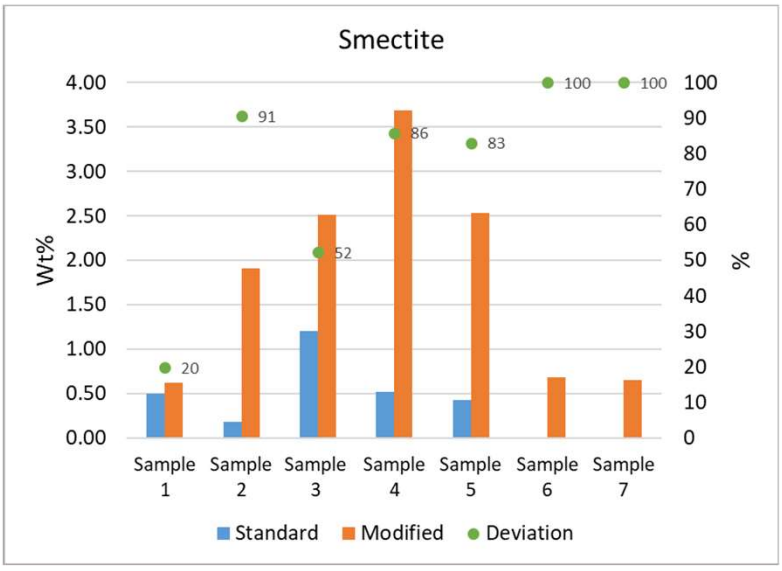
Comparison of XRD results in detecting smectite



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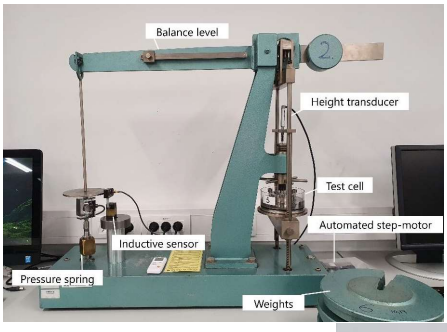
4. Oedometer testing apparatus



Standard ISRM (1979) suggested method of oedometer apparatus in use at NTNU

Details of test cell

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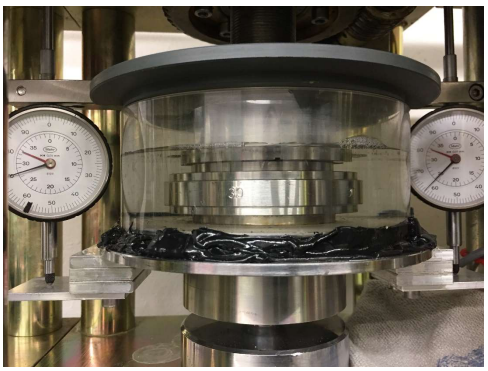
4. Oedometer testing apparatus



Modified versions of the ISRM (1989/1999) suggested method of oedometer apparatus in use at KIT.

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Testing procedure of powder sample

At NTNU	At KIT
✓ Mainly follows ISRM (1979) suggested method of oedometer maximum swelling pressure test.	✓ Modified versions of the ISRM (1989/1999) suggested method for maximum swelling pressure test.
✓ Crushing, milling until clay fraction size of 20 µm and drying at 105 degrees C.	✓ Crushing, hand milling to clay fraction of 250 µm and air dried at < 40 degrees C.
✓ 20 grams sample into test cell of 20 cm2 which is placed in the oedometer, and the sample is compressed at 2 MPa for at least 24 hours.	✓ 100–120 grams sample is compacted into a brass ring with a diameter of 60 mm until the density of sample is achieved to 2.6 g/cm2.
✓ The container surrounding the test cell is filled with distilled water and the volume of the sample is maintained constant.	✓ The container surrounding the test cell is filled with distilled water and the volume of the sample is maintained constant.
✓ The swelling pressure is registered.	✓ The swelling pressure is registered.

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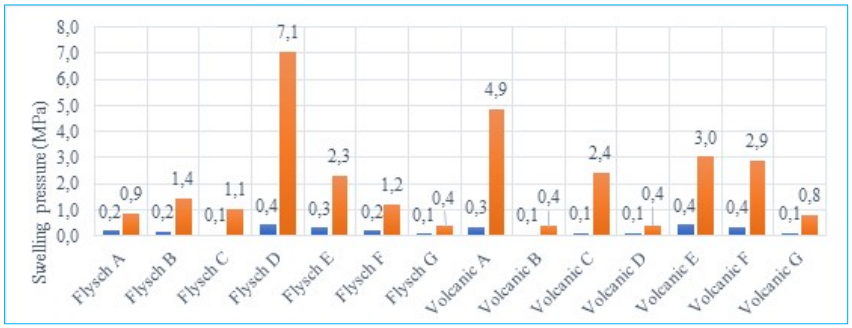
5. Comparison of the test results



Blue bars represent test results at NTNU, and orange bars represent test results at KIT

- The difference in the results are considerable. Some results from KIT seems unbelievably high.
- However, it is important to note that the chances of loosing the inherent mineralogical properties of sample material at NTNU is quite high due to the use of considerable drying temperature.

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6. Cyclic tests on intact rock samples

- Water tunnels of hydropower projects are subject to many draining and re-filling cycles over the operational life of the project.
- The water tunnels are dried during construction due to temperature increase caused by construction equipment.
- Therefore, load caused by swelling pressure also may vary over the time.
- In view of this, it is important to carry out cyclic test of the intact rock samples under controlled deformation to find out the swelling pressure trend.

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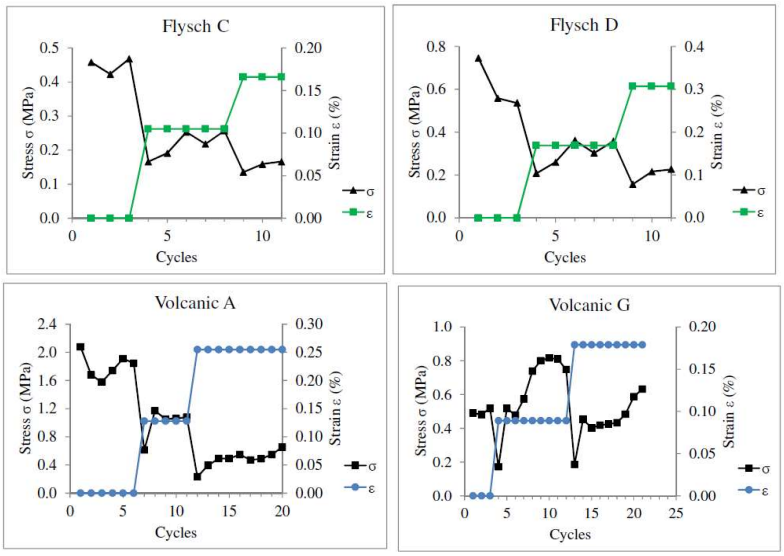
Some results of cyclic tests on intact rock samples



Top: Flysch rock samples from Moglicë HPP, Albania
Bottom: Volcanic rock (andesite) samples from Alimit HPP, Philippine

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7. Discussion on sample preparation

- Use of “Vibratory Disc Mill” in general increases the temperature during milling of samples which may destroy the inherent mineralogical character of sensitive clay minerals.
- Use of high temperature during drying of samples may also change original character of sensitive clay minerals.
- This makes it difficult to identify the actual percentage of swelling minerals there by swelling pressure.
- Therefore, the modified method of crushing and milling is recommended.
- In addition, other methods such as “thin section” and “SEM” analysis are also recommended to be carried out.

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7. Discussions on swelling test

- The research carried out clearly indicates that swelling test should be carried out for both powder and intact rock samples.
- ISRM (1979) suggested method oedometer test at NTNU has huge data base of the past.
- Therefore, both old oedometer test apparatus and newly built apparatus at NTNU laboratory should be used to find out the adjustment coefficient (ratio of old to new apparatus).
- In addition, a cyclic test is recommended to be carried out on the intact rock samples.
- This is especially the case for water tunnels passing through sensitive swelling rocks where optimization of rock support is crucial for sustainable investment and operation safety.

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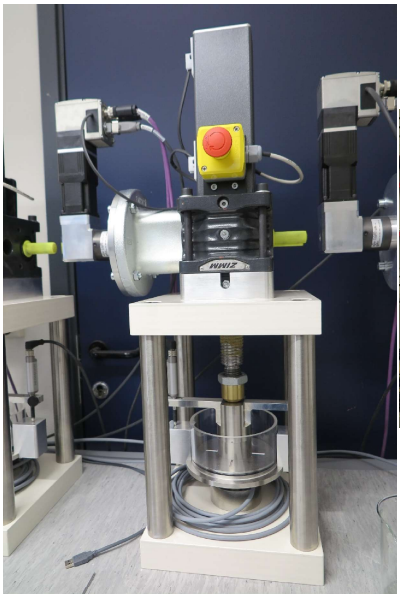
Newly built oedometer at NTNU



Fully automated oedometers for both powder and intact rock samples.

NFR support under HydroCen Lab

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