Rock Engineering in Difficult Ground Conditions- Soft Rocks and Karst – Vrkljan (ed)

Hydrogeological and geotechnical in-situ testing for large caverns

M. Kech, D. Naterop
Solexperts AG, Mettlenbachstrasse 25, 8617 Mönchaltorf, Switzerland

R. Senti
Nordostschweizerische Kraftwerke AG - NOK, Parkstrasse 23, 5401 Baden, Switzerland

ABSTRACT: Calculations based on assumed rock parameters alone do not provide a complete and reliable picture of the interaction between rock and underground structures. More detailed and reliable information is obtained by hydrogeological and geotechnical in-situ tests.

In-situ investigations were carried out for large power house caverns of the future pump storage power station Linth-Limmern, Canton Glarus, Switzerland. To investigate the bedrock at the cavern locations 10 horizontal to upward vertical inclined 50-130 m deep boreholes were drilled from an exploration tunnel and from two cross cuts.

Many hydraulic and geotechnical borehole tests were performed. To estimate the hydraulic permeability in upwardly inclined boreholes two custom-made four-fold groundwater multi-level test systems were designed and built. These systems allow boreholes to be saturated so that hydraulic heads of the isolated borehole sections could be monitored and tested. The systems proved to be time- and cost-effective. All in-situ tests were performed after the boreholes were completed without the use of the drill rig.

The in-situ hydrogeological and geotechnical tests provided site specific hydraulic and rock mechanical properties that were an essential element for design, tender and future construction of the caverns. The procedure and the benefits of preferred in-situ testing for the construction of large underground caverns will be discussed.

1 INTRODUCTION

The Glarner Power Plants Linth-Limmern Corporation KLL is constructing a pump storage power station between Lake Mutt and Lake Limmern in the Swiss Alpes.

The Linth-Limmern power stations will be extended by two new large power house caverns that are located 500 m below ground nearby the northern bottom side of the Lake Limmern (Fig. 1). Both caverns are extensive with lengths of 160 m, widths of up to 25 m and heights of maximum 50 m. The site is situated 1700 m above sea level.

Geological mapping of the ground surface and of the excavations faces in the exploration tunnel indicate that upper jurassic limestones, so-called Quintnerkalke, are present in the area of the future caverns. The Quintnerkalke are generally massive, hard and stable, but locally softer with a well developed schistosity. There are possible local water-bearing fault zones and karst systems.

These features are linked to the major regional joint system that strikes SE-NW, sub vertically inclined. Three other less important joint sets are present in the region.

In-situ investigations in the area of the future caverns were carried out from April to Mid of June 2008 because of the large dimensions of the planned caverns and only rudimentary knowledge of the geological, geotechnical and hydrogeological conditions.

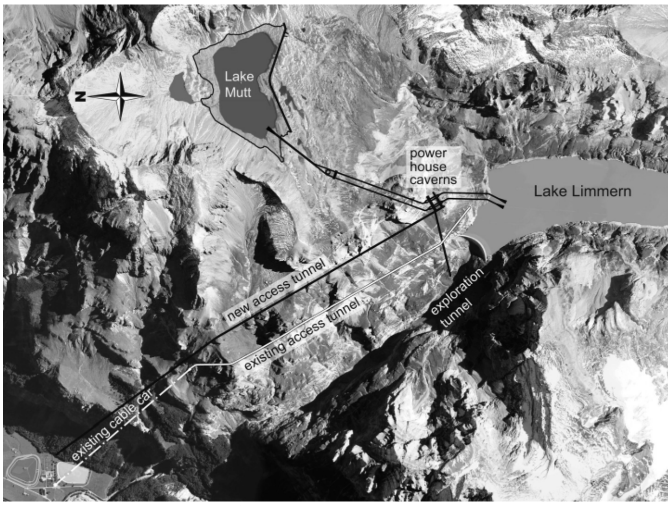

Figure 1. Overview of the planned Linth-Limmern pump storage power station construction (source NOK).

2 INVESTIGATION PROGRAM

2.1 Main objectives

The in-situ investigations of the bedrock at the future caverns should deliver detailed information of:
- structural properties of the bedrock (bedding, joints, faults, karst features)
- in-situ determination of the rock mass mechanic properties (elasticity and deformation modulus)
- in-situ rock stress characterization (minimal horizontal principal stress and its direction)
- identification and quantification of water-bearing zones (hydraulic conductivity, piezometric pressure head)

2.1 Methodology

Ten investigation boreholes were drilled from an exploration tunnel and two cross cuts in the area of the future caverns (Figs 2-3). All boreholes were cored with a diameter of 96 mm (HQ) and had inclinations from horizontal to upwards vertical with depths from 50 m to 130 m.

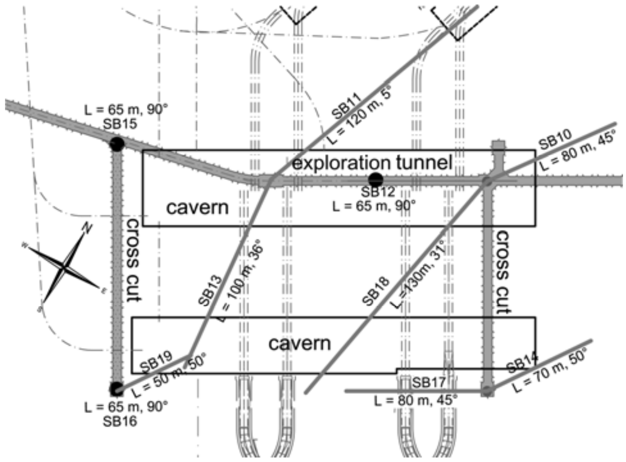

Figure 2. Location of the exploration tunnel, cross cuts, investigation boreholes and future caverns (source NOK)

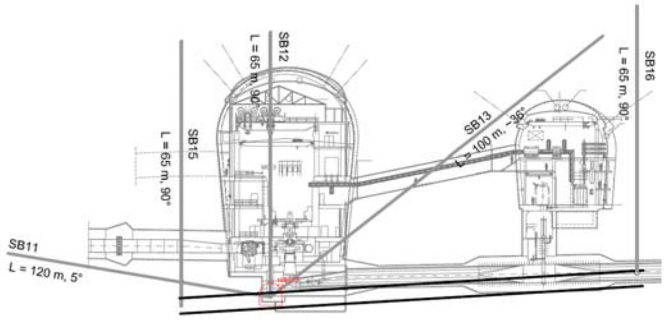

Figure 3. Cross section of the future caverns with investigation boreholes (source NOK).

After completion of the borehole(s), the following borehole tests were performed:
- Optical borehole scanning in each borehole for structural properties of the bedrock
- 5 Dilatometer tests in each borehole (total 50 tests) for E- and D-modules of the rock mass
- 3 Hydraulic fracturing test series in selected boreholes (total 25 tests) for in-situ rock stress characterization
- 4 Hydraulic tests in selected borehole sections in each borehole (total 40 tests) for hydraulic parameters including hydraulic pressure build-up to steady-state formation pressure conditions
- Periodic measurements of total outflow of each borehole

2.2 Test boundary conditions

Time limitations for drilling and testing of the horizontal to upward vertical inclined boreholes made it necessary to test in two or three boreholes at the same time without the aid of the drill rig. Drilling and testing had to be adapted to the limited space in the exploration tunnel and the cross cuts (height: 3.5 m; width: 3.5 m). Water pressures of up to 50 bar were expected due to the 500 m overburden.

Mobilization of equipment to the drill sites was done only once because of the complex logistics. Equipment was moved via a cable car to an existing tunnel which lead to the crest of the Lake Limmern dam, from there via another cable car to the bottom of the Lake Limmern dam and finally via the exploration tunnel to the drill sites.

Depending on the test boundary conditions, particular installation and testing equipment as well as optimized testing procedure was needed.

2.3 Installation equipment

The installation of the borehole test equipment was done using electrical driven winches and pulleys (Fig. 4). Light scaffolds were used to access the borehole. A small utility vehicle enabled the transport of equipment to the test site and from one drill site to another.

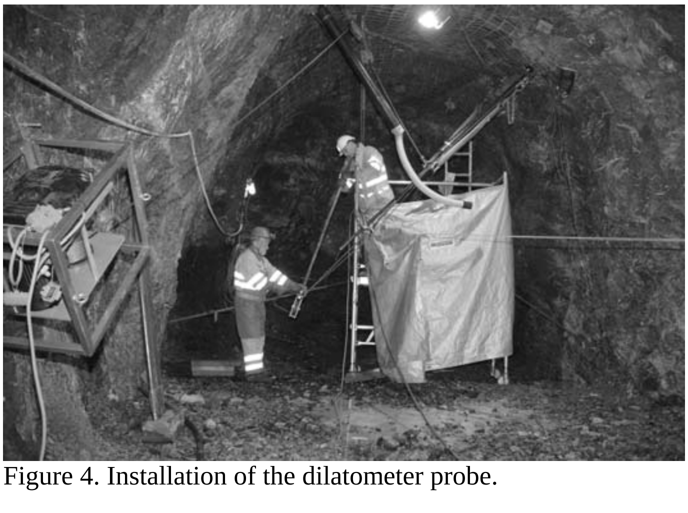

Figure 4. Installation of the dilatometer probe.

2.4 Test equipment

The dilatometer probe and hydraulic fracturing system were installed with the same 1.5 m length installation rods.

The dilatometer probe and the packers of the hydraulic test equipment were inflated with compressed air, generated by a compressor to avoid using a large number of nitrogen bottles.

The data acquisition of each testing method was installed in a small car trailer which was also used for material transportation to the site and within the tunnel.

2.4.1 Hydraulic test equipment

For hydraulic testing in upward inclined boreholes, special considerations are necessary.

The formation will be drained via the upward inclined borehole which can lead to partly unsaturated conditions around the borehole. If testing is done using conventional double-packer systems the initial pressure recovery in each test interval will be delayed as the zone is re-saturated. In low transmissivity intervals the formation pressure recovers very slowly.

Air in an unsaturated borehole cannot be completely removed by simply saturating the test interval when the double-packer system is set. The residual gas phase in the test interval can influence the test results.

Additionally, hydraulic bypasses from the test interval via the packer seats or via joints into other formation sections cannot be clearly identified with the double-packer system.

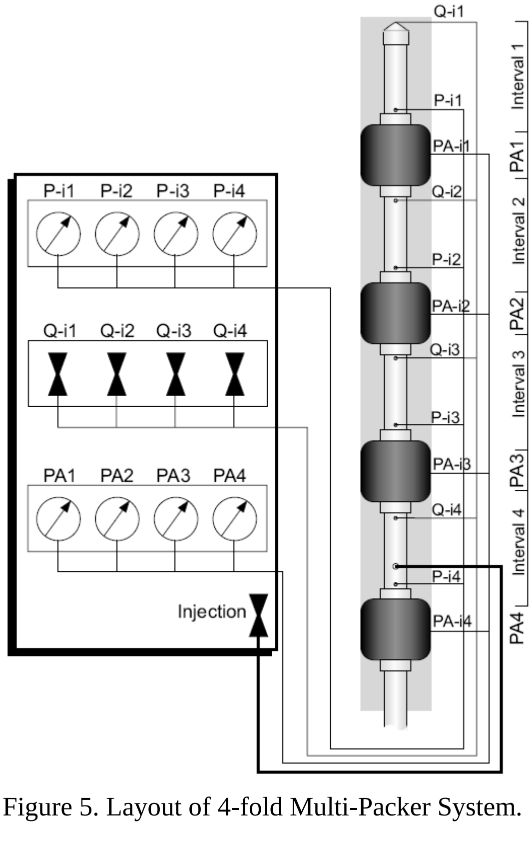

Figure 5. Layout of 4-fold Multi-Packer System.

Another test methodology and system configuration was required to guarantee reliable formation pressures and hydraulic conductivities within cost-effective time periods.

Based on multi-packer systems for investigations of radioactive waste disposal (underground laboratories), two 4-fold multi-packer systems were designed and manufactured (Fig. 5).

The custom-made multi-packer systems offer several advantages over the conventional double-packer testing system in upward inclined boreholes:

- saturation of the entire borehole after setting packer Nr. 4 (closest to the well head) via injection line
- degassing the borehole via extraction line (Q1-line)
- simultaneously monitoring all 4 test intervals
- injection and extraction lines for each test interval
- parallel testing in different intervals (e.g. interval 1 and 3 or 2 and 4)
- long-term monitoring of pressure recovery while testing in other intervals or over the night/weekend
- optional cross hole tests

2.5 Hydraulic test procedure

After installation of the multi-packer system and inflation of packer Nr. 4, the entire borehole was saturated with water via the injection line. Then the other packers were inflated one after another. The subsequent pressure recovery was monitored until steady-state pressure conditions were approached.

The following hydraulic test procedures were applied depending on the static pressure recovery of each test interval after packer inflation:

- Pulse Test (positive pressure pulse)
- Constant Head Test (injection or withdrawal test with constant pressure difference)
- Constant Rate Test (injection or withdrawal test with constant flow rate)
- Pressure recovery after Constant Head/Rate Test

2.6 Test performance

The in-situ testing started with the optical borehole scanning, followed by hydraulic and dilatometer tests. Packer seats and test intervals were selected by evaluating the cores and the borehole scans. The availability and accessibility of the boreholes determined the testing sequence.

Towards the end of the test campaign hydraulic fracturing tests were performed in three vertical upwardly inclined boreholes after dilatometer and hydraulic tests have been completed.

Packer seats locations were not re-used for later testing methods to avoid any artificial effects on the test data.

The drilling and testing campaign was harmonized by constant communication between customer, drilling and testing companies.

Three separate test and installation equipment systems were assembled for dilatometer, hydraulic and hydraulic fracturing testing. One test crew consisting of a test engineer and a technician was used for each testing method. Two to three testing crews worked parallel and used the same installation equipment for the same borehole. In case of special system installations or retrievals, the testing crews supported each other.

The field work was done within 9 hour day-shifts from Monday to Friday. All borehole tests have been accomplished within 9 weeks and 3 weeks after completion of the drilling campaign.

2.7 *Results*

All borehole tests were completed within the required 9 week time period and within tendered costs.

The performed in-situ tests included:

- 40 hydraulic tests (constant head/rate injection, withdrawal and pulse injection tests)
- 55 dilatometer tests (3 loading cycles/test)
- 23 hydraulic fracturing tests and 18 impression packer tests

To measure maximum hydraulic heads during snow melting time in spring one multi-packer system was left installed for several weeks in a transmissive borehole after the testing campaign.

The 4-fold multi-packer systems delivered reliable hydraulic parameters and proved to be time and cost effective.

The dilatometer and hydraulic fracturing tests were executed without problems. Dilatometer tests supplied reliable ranges of in-situ rock E- and D-modules. Hydraulic fracturing tests defined principal stresses of the investigated rock masses and verified existing stress models.

All borehole testing methods delivered new detailed knowledge about hydraulic and geotechnical properties of the bedrock of the future caverns.

The obtained hydraulic heads and conductivities as well as the E-and D-modules and the principal rock mass stresses provided beneficial results for the construction of the future caverns.

3 CONCLUSION

In-situ testing at the Linth-Limmern pump storage power station enlargement project proved that even under challenging conditions in-situ investigations of future large caverns can be completed on time and in a cost effective way. The obtained information about the site has proven valuable and should result in improved site safety and lower construction costs.