# HEPP cavern Kühtai, excavation design and construction experience

Rupert Steiger
*TIWAG – Tiroler Wasserkraft AG, Innsbruck, Austria*

Peter Wetzlinger
*Swietelsky Tunnelbau, Salzburg, Austria*

ABSTRACT: The Pumped Storage Scheme Kühtai 2 located between the existing reservoir Finstertal and the currently under construction reservoir Kühtai is part of the expansion of the existing hydro power plant group Sellrain-Silz. The new power station is housed in a cavern at an altitude of 2000 meters above sea level near the village of Kühtai in Sellraintal.
The cavern is located within a gneiss formation (biotite-plagioclase gneiss), which is layered in bands and tectonically faulted.
As the design progressed, a number of variants were investigated, including the simulation of different geological conditions, the variation of distance between the individual caverns (double cavern solution with machine cavern and separate transformer cavern), the arrangement of tunnels surrounding the caverns and the complex construction process, until a solution was developed.
The paper provides an overview to the excavation design process as well as to the geotechnical design analyses, which were adopted, and the experience gained during the excavation of the caverns.

*Keywords: Cavern excavation design, construction experience.*

## 1 PROJECT OVERVIEW

TIWAG-Tiroler Wasserkraft AG is currently expanding the existing Sellrain-Silz power plant group with a second upper stage unit, consisting of the Kühtai reservoir, the Kühtai 2 power plant including headrace and tailrace tunnels as well as a 25 km long water adduction tunnel to the reservoir. The Kühtai 2 power plant is housed in a cavern and will have an installed capacity of 140 MW in turbine mode and 130 MW in pump mode.

The power cavern is situated between the existing reservoir Finstertal and the currently under construction reservoir Kühtai on the orographic right-hand side of Längental. A 1250 m long inclined penstock and a 525 m long tailrace tunnel provide the connection between both reservoirs (figure 1).

The cavern houses the mechanical and electrical plant components for the turbine and pump operation as well as equipment for the monitoring of the power plant.

The size and the shape of the cavern is optimized to meet geotechnical as well as space requirements of the individual components of the power plant.

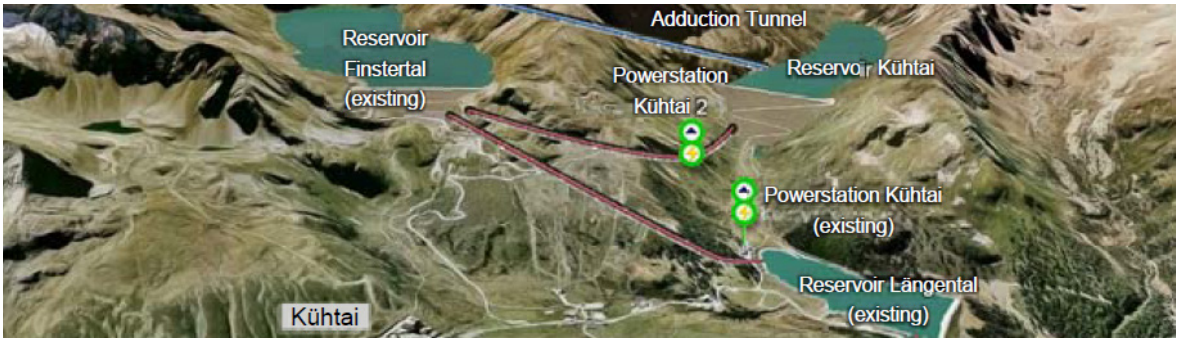


Figure 1. Project overview.

## 2 GEOLOGY

The project area is located in the Ötztal and Stubai Alps, both of them belong to the east alpine crystalline formation. The prevailing rock mass type in the cavern area is biotite-plagioclase gneiss, which is partly heavily folded. The fold axes generally strike in east-west direction. The three dominant fold systems in the area of the cavern roof are 180/15, 180/75 and 210/80. The distance between the individual folds is approx. 20 to 60 cm. Due to the complex rock structure, a changing foliation orientation is present in the cavern area.

## 3 DESIGN PROCESS

### *3.1 Study of variants*

In the course of the design process for the Kühtai 2 power plant, two cavern variants (single cavern & double cavern) were compared, taking into account the geotechnical requirements as well as the requirements for mechanical and electrical system components and maintenance during operation. Furthermore, it was determined that the cavern should have an inner lining in order to avoid the use of permanent bolting and permanent shotcrete. The longitudinal cavern axis was selected in such a way that foliation and faulting of the rock mass is orientated transversely to the cavern and unfavorable wedges are avoided.

Variant 1, single cavern solution:
In this variant, all electro - mechanical components such as turbines, transformers and control features should be accommodated in a 72.0 m long, 48.0 m high and 29.0 m wide cavern (figure 2). In this type of cavern, the two sets of machines are arranged side by side in cross section.

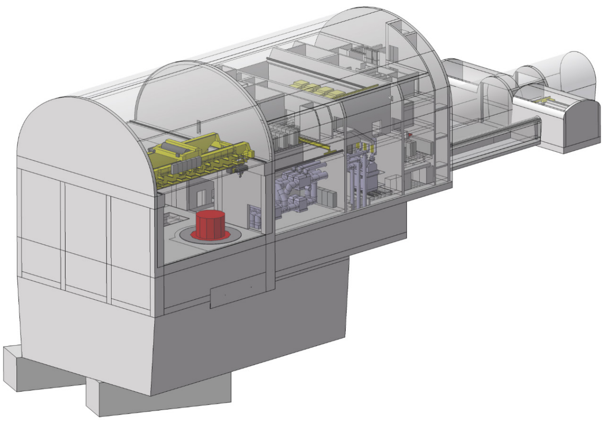

Figure 2. Single cavern solution.

Variant 2, double cavern solution:
In case of the double cavern solution, the machine cavern is 65.0 m long, 40.3 m high and 26.0 m wide. The two sets of machines are arranged side by side along the longitudinal axis of the machine cavern. The transformer cavern has a length of 55.0 m, a height of 17.6 m and a width of 15.5 m. The clear distance between the machine cavern and the transformer cavern is approx. 29 m. The transformer cavern is accessed from the machine cavern via the connecting cavern, which is 29.0 m long, 7.5 m high and 6.0 m wide. In addition to the connecting cavern, two converter caverns are arranged between the machine cavern and the transformer cavern. The converter caverns are 29.0 m long, 12.0 m high and 9.0 m wide. The size of the remaining rock pillars between the machine cavern and the transformer cavern were selected such, that they are able to resist the concentrated rock pressure. The layout of the double cavern solution is shown in figure 3.

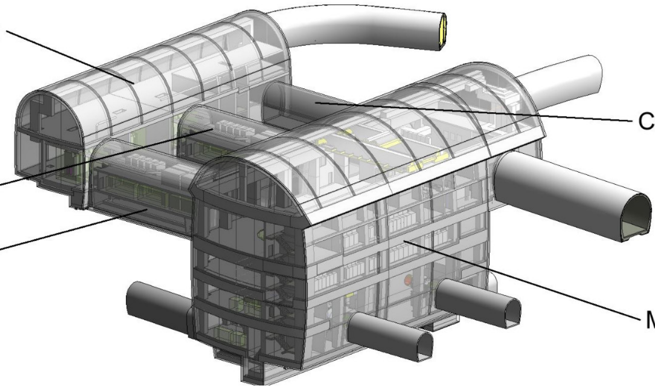


Figure 3. Double cavern solution.

The comparison of the two options revealed that separate machine and transformer caverns are favourable with regard to geotechnical, mechanical and electro-technical aspects as well as looking at the construction process and maintenance in the operating phase.

### *3.2 Excavation design*

#### *3.2.1 Excavation sequences*

The excavation design supposes that the excavation of the caverns (machine cavern, transformer cavern, converter cavern and the connection cavern) takes place in 5 phases.

Phase 1: All the tunnels surrounding the cavern (access tunnels, drainage tunnels ...) are excavated in advance of any cavern in order to avoid unfavourable stress redistribution to the cavern.
Phase 2: An exploratory tunnel is driven at the lowest point. The tunnel serves to verify the geological assumptions in detail and as a mucking tunnel for the lowest level of cavern excavation.
Phase 3: Advancing the top heading of the transformer cavern, followed by the top heading of the machine cavern plus the first bench in the machine cavern and the connecting cavern. The next stage is to complete the bench excavation in the transformer cavern and to excavate both converter caverns.
Phase 4: Concreting and anchoring of the crane abutments as well as casting the concrete lining in the vault of the machine cavern is carried out.
Phase 5: Finalising bench excavation in the machine cavern.

#### *3.2.2 Support measures*

Temporary support measures are applied to avoid progressive loosening of the surrounding rock mass and to retain unstable wedges during the excavation works. The support of the cavern using shotcrete and systematic bolting (figure 4) is installed immediately after each round of excavation. The entire cavern (machine cavern, transformer cavern, connection cavern, converter caverns 1 and 2) is supported by a 25 cm thick shotcrete lining reinforced with two layers of wire-mesh (AQ60) and lattice girders.

Grouted bolts with a length of 9 m, an ultimate load capacity of 440 kN and installed at 1.7 x 1.7 m centers are used in the machine cavern. In the transformer cavern, in the connection cavern and in the converter caverns 1 and 2 grouted bolts with a length of 6 m, an ultimate load capacity of 440 kN are installed at 1.7 x 1.7 m centers. Near the junctions of caverns the bolting pattern is condensed to a spacing of 0.85 x 0.85 m at centers.

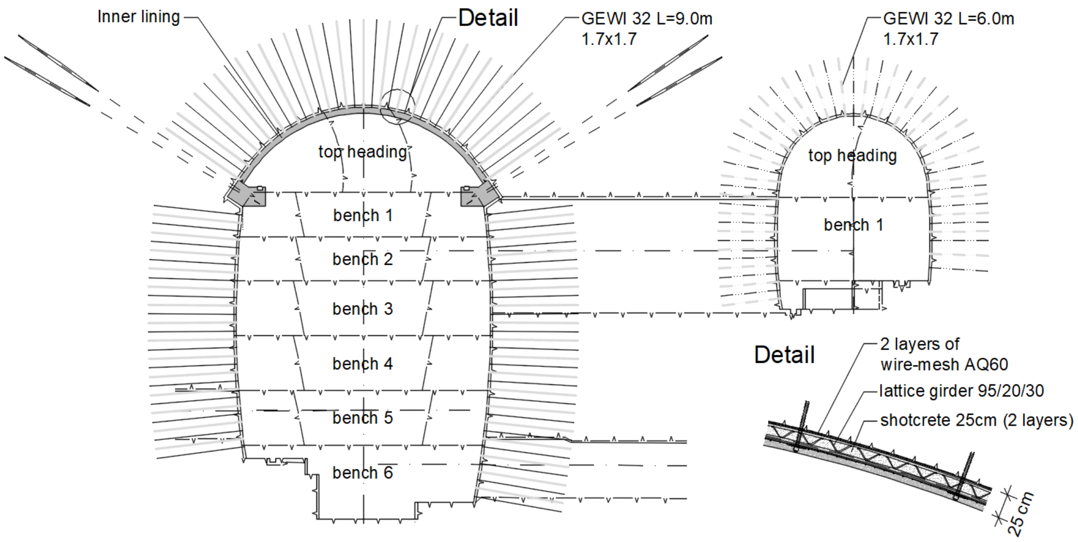


Figure 4. Support measures.

### *3.2.3 Inner lining machine cavern*

The temporary excavation support of the cavern is applied as described in chapter 3.2.2 using shotcrete and systematic bolting. To reduce maintenance efforts during the operation phase, no permanent bolts are installed in the cavern. A 60 cm thick concrete inner lining is placed in the top arch after the excavation of the first bench in the machine cavern instead. The inner lining consists of 8 individual arch elements with a slot of 50 cm between each element. The slots between the arch elements ensure that hydrostatic pressure cannot build up behind the inner lining. While excavating benches number 2 to 6 in the machine cavern and before the concrete columns are placed under the crane, the elephant's feet and the crane beams, which are situated underneath the top arch, serve as a foundation for the inner lining.

## 4 CONSTRUCTION EXPERIENCE

### *4.1 Excavation works*

The excavation work started on March 16, 2022 in the transformer cavern top heading. This work was completed on April 06, 2022. Subsequently, starting at the beginning of April 2022 until mid-July, the machine cavern roof, the connecting cavern as well as the first bench of the machine cavern were excavated (figure 5).

The top heading excavation of the machine cavern, the transformer cavern as well as the excavation of the converter caverns and the connecting cavern was carried out in the classic way (horizontal drill and blast in short excavation rounds) using standard underground construction equipment. The benches in the machine cavern and in the transformer cavern were excavated using vertical blasting, similar to the procedure in a quarry. The required vertical blast holes were drilled with a Sandvik ranger surface drill rig. It turned out that the individual blast holes can be produced very precisely and highly efficiently with this device.

The rock mass conditions and also the system behaviour largely correspond to the prognosis. Only during the excavation work at the elephant's feet in the machine cavern which is later used as an abutment for the crane beam and the inner lining did problems arise due to the sometimes very steep sloping foliation. As a result, parts of the elephant's feet were lost. It was discovered that an elephant's foot is difficult to realize with drill and blast in unfavourable geological conditions. Those parts of the elephant's foot that got lost were subsequently restored using shotcrete and additional bolting. Subsequently bench excavation followed in the transformer cavern, which lasted until the end of August. The excavation of the two converter caverns was completed at the beginning of September. Up to this point, all of the construction logistic (mucking and transport of construction materials) was accommodated via the cavern access tunnel.


Figure 5. Status of Work machine cavern 07 May 2022 (left), transformer cavern 29 May 2022 (right).

From July to the end of October 2022, no further excavation work was carried out in the machine cavern, since the installation of the crane beams and the inner lining, which is described in more detail in chapter 4.2, took place.

After the concrete construction work in the crown of the machine cavern was completed, the excavation of the remaining cavern took place until the end of February 2023. The exploratory and drainage tunnels, which enter into the bottom of the cavern were used for mucking and material supply. As a result, the access tunnel to the cavern could be kept clear for concrete placement.
In total 78500 m³ rock were excavated, 12500 m² shotcrete were applied and around 4300 rock bolts were installed during the 11,5 month construction period.

While excavating, it became apparent, that well-organized work preparation, targeted control of mass flow (mucking and transport of construction materials) and continuous geotechnical assessment of the structure’s behaviour is important to achieve high advance rates in the required quality (with regard to precise shape and controlled deformations). The maximum deformation of 40 mm (total radial displacement) was measured in the machine cavern during the top heading excavation.

## *4.2 Concrete construction inner lining*

In order to reduce the formwork placing effort and to avoid interference with M&E installation, the inner lining in the crown and the crane beams were installed before the excavation work was completed in the machine cavern. A Doka/Raffl formwork carriage was used for this work, which was supplemented by a specially manufactured hoist. The additional hoist allowed to move the formwork around 1.5 metres in height (see figure 6). The reinforcement could be placed directly on the lining form and raised to the required level when finished, hence eliminating the need for an additional scaffolding for the reinforcement installation. Furthermore, when designing the formwork carriage and the hoist, care was taken to allow that parts of the formwork and the entire hoist can be reused for inner lining installation in the transformer cavern.

The work started at the beginning of July 2022 with the installation of the crane beams, followed by the assembly of the formwork at the end of July. The first of a total of 8 crown segments, each 8 meter long, was concreted on August 15, 2022, the last segment at the end of September 2022. Both crane beams as well as the 8 segments of the inner lining including all the necessary preparatory work (assembly and disassembly of the formwork) could be placed within 4 months. Around 196 t of reinforcement and 2150 m3 of concrete were used for these works. The required materials (concrete, reinforcement, formwork, ...) were transported via the access tunnel, which means that no other work could be carried out at this time.

### *4.2.1 Protective measures for inner lining*

In order to protect the finished concrete structure from blast damage during the resumed excavation work, the crane beams were packed with wood and protective nets were attached below the inner lining, which were stretched out between the two crane beams.

The concrete was treated to protect it against premature dehydration by fixing foils on the individual crown segments (figure 6).

Figure 6. formwork carriage in low-position (left), finished inner lining (right).

## 5 CONCLUSION AND OUTLOOK

As a result of a competent construction process accompanied by good communication between everyone involved, the excavation of the Kühtai 2 power plant cavern could be completed without any major incidents and was handed over on schedule to the concrete construction team for placement of the internal structure.

Assuming that the construction process continues smoothly, the power plant will start operation in 2026 after five years of construction.

## REFERENCES

R. Steiger, M. R. Henzinger, W. Schubert, 3D numerical stability analysis of a power plant cavern. *In: EURO:TUN 2017.*