The material extraction for the Kühtai Dam

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ABSTRACT: For the construction of the Kühtai embankment dam, a total fill volume of 6.9 mio m³ is required. The main sources of the material are the overburden and hard rock of the Längental valley. The required rock material is produced in a quarry developed at the eastern reservoir slope. The rock mass consists mainly of granodiorite gneiss. To estimate the production volume a 3D rock contour model was developed. The total production volume is 2.2 mio m³ of hard rock and 3.2 mio m³ of overburden. The produced material has to fit the requirements of the dam zoning, considering mass balance and sequence of construction. The bench and overall slope stability is evaluated by stability calculations, visual inspections, engineering-geological mapping, geodetic monitoring and terrestrial laser scanning. The finale bench faces are blasted by pre-splitting method. Preparation for production has started in 2020 and production began in 2022.

Keywords: Kühtai Dam, rock slopes, quarry, blast design, monitoring.

1 KÜHTAI PUMPED-STORAGE POWER PLANT

TIWAG-Tiroler Wasserkraft AG is currently expanding the Sellrain-Silz power plant scheme (Finstertal and Längental reservoirs, Kühtai and Silz power plants) by adding a second upper stage reservoir with new intakes from the central Ötztal and Stubai valleys. The new Kühtai reservoir with a full supply level of 2140 m.a.s.l. and volume capacity of 31 million m³, is part of the project. It will be connected to the existing Finstertal reservoir (full supply level: 2322 m.a.s.l., volume capacity: 60 million m³) via the Kühtai 2 power plant. The Kühtai Dam is an earth core rockfill dam (ECRD), with a maximum height of approximately 140 m above the lowest foundation level (Boes et al. 2007).

2 MATERIAL SOURCES FOR THE DAM

For the construction of the Kühtai embankment dam a total fill volume of 6.9 million m³ is required. The main sources of the material are the natural overburden and hard rock of the Längental valley (Figure 1) and to a lesser extent excavated tunnel material. The dam is divided into a total of six zones, five of which have a specified sieve curve that requires material processing. The distribution of each zone is the result of a mass balance study between the available materials in the reservoir zone and the technical requirements for the dam materials. The main objectives were, firstly, to avoid the need for permanent muck deposits, secondly, to avoid the need to transport material to the construction site and, thirdly, to increase the volume of the reservoir. All the material extraction is located below the full supply level of 2140 m.a.s.l.

Figure 1. Overview of the eastern slope of the reservoir (November 2022): (1) top bench, (2) 1st bench, (3) 2nd bench, (4) removed overburden, (5) stock piles, (6) exposed rock surface, (7) outlet adduction tunnel, (8) reservoir side path tunnel, (9) reservoir side path, (10) head of reservoir, (11) rockfall protection dam, (12) dam foundation and stationary material treatment plant, (13) temporary access road to (9).

3 RESERVOIR DESIGN

The design for approval by authorities including geological/geotechnical investigations in the reservoir area started in October 2006. The main investigations were carried out in 2007 with additional investigations in 2008. The Austrian Reservoir Commission reviewed the application in November 2009 and the EIA process started in December 2009. After 6.5 years the EIA was approved in June 2016. The tender design process started in 2017. After various complaints and appeal procedures, all high courts finally confirmed the EIA approval in June 2020. Preliminary works started in April 2020, including construction site clearance, foundation works for site installation, access roads, installation of rockfall and avalanche protection. The preliminary works included additional investigations such as percussion and core drilling to detail the knowledge of the rock surface and permeability of the overburden in the reservoir area (Perzlmaier et al. 2022). In the approved EIA project, the original quarry layout for the hard rock production was located on the orographic right reservoir slope with a total length of approximately 600 m and a total height of 130 m with an overall slope angle of 56°. The first bench was designed at an elevation of 2145 m.a.s.l., which is 5 m above the full supply level (2140 m.a.s.l.). The first and second benches reached a height of 20 m. The following benches down to the quarry floor were designed with a height of 16 m and a width of 8 m. The bench face angles were 80°. During the tender design phase, the engineering and geotechnical information was reviewed in detail, resulting in a design adjustment due to the unfavorable orientation of a principle discontinuity set that dips out of the slope at 50°. The first bench was lowered to an elevation of 2120 m.a.s.l. and the overall slope angle was changed to 46°. The bench height was reduced to 12.5 m with a width of 8.8 m. The bench face angle was also flattened to 75°. In order to mitigate the volume loss due to the change in geometry, it was necessary to extend the quarry laterally by 25 m to the N and 250 m to the S. The actual layout consists of 8 benches and a reduced overall height of 100 m. The location of the first bench required particular attention in the design process due to the requirements that the cut slopes should not have excessive heights and secondly, to penetrate deep enough into the rock mass with little or no rock cover on the first benches. The soil slopes in the reservoir are generally designed with a slope angle of 25° in the reservoir. In order to protect the reservoir area during construction against rockfall from the natural slopes on the orographic left side, a 900 m long protection dam was designed at an elevation of 2000 m.a.s.l.. The reservoir head was designed as a shallow water zone as part of the ecological compensatory measures in the project. An overview of the reservoir layout is shown in Figure 2.

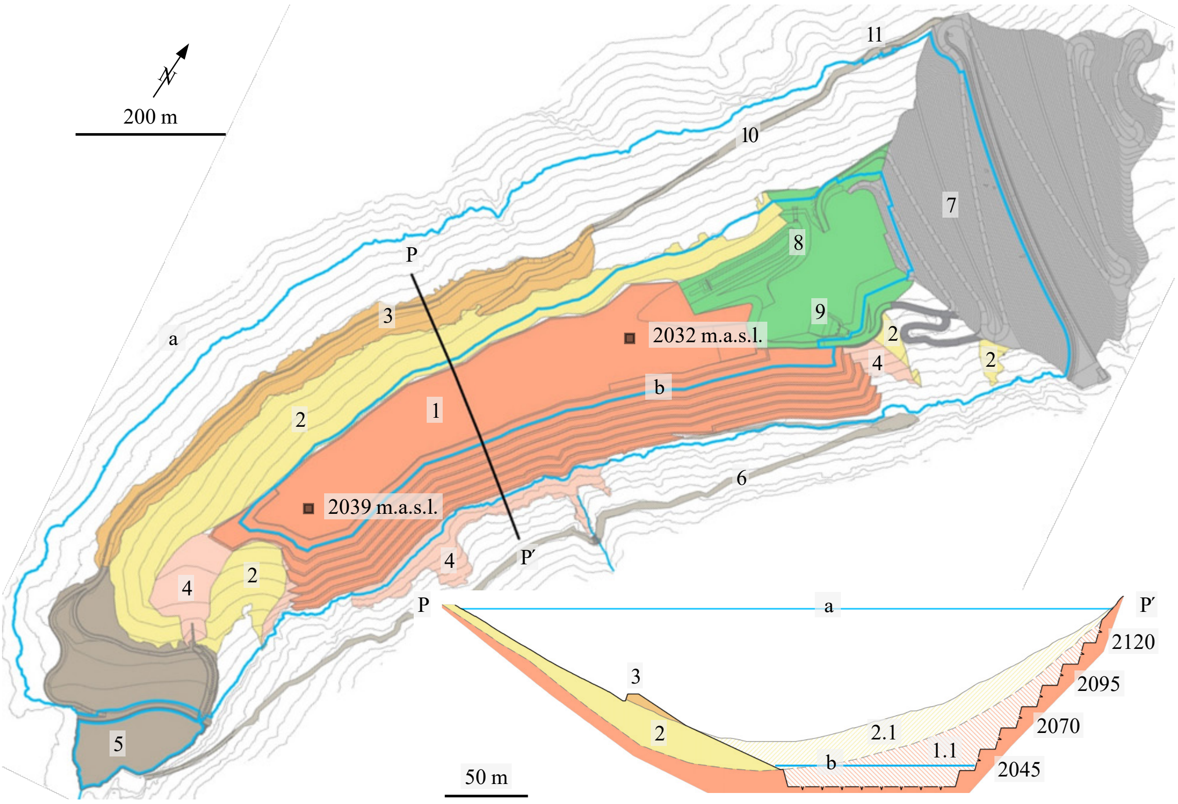

Figure 2. Layout of the reservoir: (1) quarry, (2) soil slopes, (X.1) excavation volume, (3) rockfall protection dam, (4) exposed rock surface, (5) reservoir head, (6) reservoir side path, (7) Kühtai dam, (8) intake bottom outlet, (9) intake/outlet tailrace tunnel, (10) reservoir access road, (11) spillway intake, (a) full supply level - 2140 m.a.s.l. (b) drawdown level – 2049 m.s.a.l.

4 GEOLOGICAL OVERVIEW

The Längental valley is a high alpine valley characterized by interglacial and postglacial erosion and sedimentation processes. Glacial erosion has created a narrow U-shaped valley. The natural overburden reaches thicknesses between 20 and 30 m and is made up of glacial deposits, interglacial and postglacial fluviatile deposits. These deposits are interlocked with colluvial and rockfall deposits from the valley slopes. Due to the Quaternary development of the valley, where the deposits are reworked and mixed, the grain size distribution is almost independent of the facies. The majority of the sediments are well graded sand-gravel mixtures with a silt content between 10 and 20 % and a varying cobble and boulder content. Only the fluviatile sediments show a slightly poorer graded grain size distribution with little or no fines, but are not relevant in terms of volume. The bedrock in the reservoir area where the quarry is located is part of the Ötztal-Stubai Complex (Eastern Alps) and the rock types area are mainly strong to very strong granodiorite gneiss (orthogneiss) with little to no foliation. Occasionally, Amphibolite, mica schist, quartzite, aplite dikes and chloritized schist are present. In the central part of the quarry a 20 to 30 m thick mica schist layer is developed. The granodiorite gneiss is the same rock type that was mined for the construction of the Finstertal rockfill dam. The rock mass is expected to be of good to very good quality with RQD values of 60 – 100 %. Lower RQD values are expected in the central part of the quarry. Three principle discontinuity sets are defined. The foliation (sf) and associated discontinuities (k4) strike E-W with sub-vertical dip to the S and N. The second discontinuity set (k5) dips towards the E at 65°. The third set (k2) dips to the NW at 50° and is developed slope parallel. Set (k2) is interpreted as surface near relaxation joints. The block shape is prismatic to equidimensional with volumes between 0.5 to 2 m³ and occasionally reaching 50 m³. The faults in the reservoir area are mainly developed parallel to the foliation and the set (k5). The deformation of the rock mass is brittle with a high degree of fracturing in the vicinity of the faults. A connected groundwater aquifer is present in the overburden (valley fill). The aquifer is fed from the upper Längental valley during the meltwater season and by natural groundwater flow. The groundwater discharge from the slopes is mainly on top of a well compacted moraine close to the bedrock. The permeability of the overburden varies from 10^{-6} to 10^{-4} m/s. Groundwater flow in the rock mass is limited to joints and faults and can be slightly pressurized in the central part of the valley.

5 ROCK CONTOUR MODEL & MASS BALANCE

As part of the geological and geotechnical investigations, the rock contour line was investigated as detailed as possible. This was achieved by 29 percussion drillings, 36 core drillings, 10 geoseismic and 5 geoelectric profiles during the different design stages. The information was used to create a model with 2 m contour lines for the reservoir and the dam foundation. Combined with virgin terrain and natural rock outcrops, a two-layer spatial model was generated. This provided input for the integrative design process for the required volume of hard rock (quarry layout), the volume of overburden, and excavation volume for the dam foundation. The distribution and size of the dam zones were optimized based on the model. The total production volume for hard rock is estimated at 2.2 million m³, of which 90 % is predicted to be of granodiorite gneiss for the dam fill. Due to the steep rock contour, 60 % of the total volume is located below elevation 2045 m.a.s.l. (Figure 3). The overburden volume is estimated at 3.4 million m³ plus an additional 0.8 million m³ of the excavation for the dam foundation. The total tunnel muck volume is estimated at 0.7 million m³. In order to verify the model during construction, a geodetic survey is carried out for each bench after the overburden is removed and before blasting. After the first production year down to 2095 m.a.s.l. in 2022, the model is in good correlation with the actual rock line. The model is continuously updated to estimate the actual excavated volume, which is done by volume calculations based on the as-built terrain scanned with a terrestrial laser scanner and the updated rock contour model.

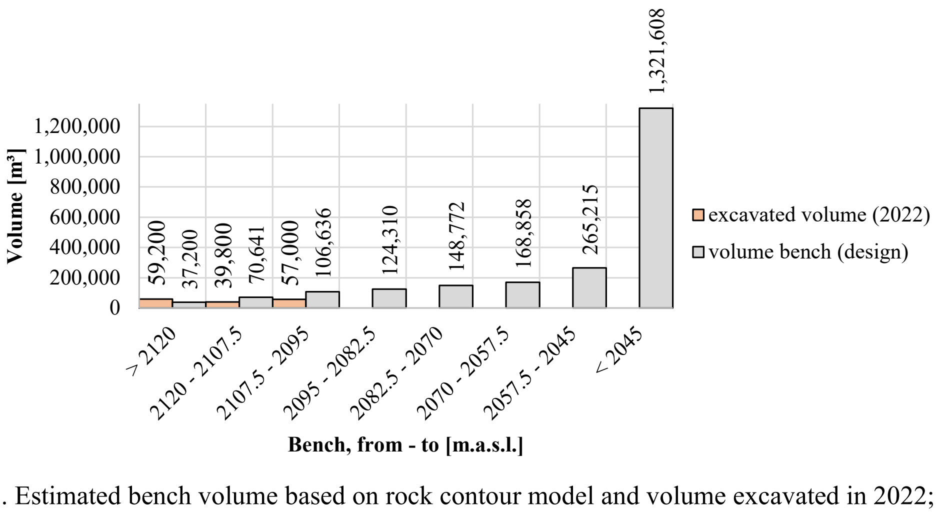

Figure 3. Estimated bench volume based on rock contour model and volume excavated in 2022; note that only the first bench was excavated 100 %.

6 EXCAVATION METHODS AND MATERIAL TREATMENT

To develop the first bench of the quarry, extensive earthworks were required in the southern part to remove the overburden from the rock surface down to elevation 2120 m.a.s.l.. Temporary access roads and ramps were constructed from the valley floor to the top of the quarry. An area of 1.5 ha was excavated between August 2021 and March 2022 using crawler and walking excavators. Blasting of the first bench had to be adopted due to the steep and irregular rock surface, were drilling from the top was not possible. Thus blasting was performed by laterally drilled and fanned out blast holes. This approach required a highly flexible blasting scheme that was adapted on a case-by-case basis. Temporary ramps were required along the bench due to the irregular rock surface with resulting slope heights of more than 15 m. Excavation of the 600 m long section took in total three months. The blast holes were drilled using a Sandvik Ranger DX 800. The remaining 250 m to the north could be blasted using a standard blast design from the top of an access road constructed during the preliminary works. The standard blast design for the first benches with little rock cover is a two-stage approach (Figure 4). The first step is to profile the natural rock slope at the toe by fanning out the boreholes towards the final bench face. The second step is the production blasting, where firstly the pre-splitting holes are drilled at an angle of 75° and a spacing of 1.5 m followed by the production blast holes. The spacing and burden of the production blast holes can be adjusted according to the block sizes required for each dam zone. For the first benches, a spacing of 2.5 m and a burden between 2 m to 3 m was used. The borehole length is 14 m with a diameter of 82 mm. The production holes are charged by pumpable emulsion explosive Hydromite 100 including one booster APB-25 for each hole. Each hole is loaded with approximately 71 kg of explosive over a length of 11 m with a stemming of 3 m. The pre-split holes are charged with cartridge emulsion explosive Emulex 2 plus. The largest production blast was in November 2022 with approximately 12,500 m³. The total volume of rock mined in 2022 is estimated with 156.000 m³, the total length of drilled production holes is 33,000 m and 87 t of explosives have been used. The average block size was approximately 0.5 m³. The logistical challenge of the mine operation is that the existing overburden must be removed for each bench, requiring extensive earthworks prior to production blasting. About 350,000 m³ of overburden was removed in 2022. The hard rock and overburden material is pre-selected in the reservoir area before being sent the stationary treatment or going directly to the shell zones of dam. The pre-selection of the material <400 mm is done by two mobile crushers with a capacity of 750 t/h, and with traser screens. The rocks required for the slope protection are selected manually by excavators.

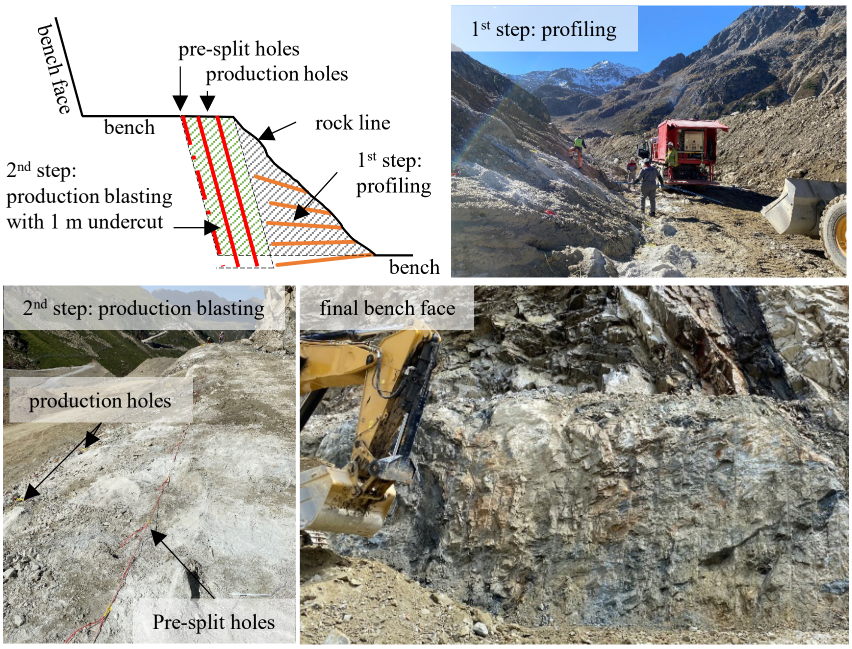

Figure 4. Blasting scheme and field impression of the work steps for the upper benches in 2022.

7 GEOTECHNICAL MONITORING & SAFETY MEASURES

Geotechnical monitoring of the reservoir area was developed and implemented during the EIA project phase. The natural reservoir slopes have been monitored since then. The initial monitoring program consists of 33 geodetic monitoring points, 5 inclinometers and 2 groundwater monitoring wells. During construction the monitoring program will be expanded or reduced as new structures are built. By 2022, a total of 49 geodetic monitoring points were installed and measured at least twice a year. In 2021, a total of 19 groundwater monitoring wells were measured. Due to construction works some of these wells have been excavated and are no longer available, 5 of the monitoring wells are equipped with piezometers for continues data logging. In 2022, 6 additional piezometers (closed system) were installed in the reservoir area. These piezometers will be part of the monitoring program during operation of the reservoir. 4 are located on the orographic left side along the rockfall protection dam in the natural overburden close to the rock line and 2 are located in the rock slopes of the quarry. The slope stability for the benches and the overall slopes was assessed prior to construction using kinematic and limit equilibrium methods for the designed slope orientations. Performance assessment and monitoring of the slopes during construction is carried out by engineering geological mapping, visual inspection by the mine engineer and geologist compared with geodetic monitoring and terrestrial laser scanning (TLS). This information is reviewed periodically and the design assumptions are checked against the encountered conditions. The geodetic monitoring consists of 10 monitoring sections distributed along the 900 m long quarry wall. Initially, each section is designed with two optical targets mounted directly on the rock face. The upper optical targets are located on the second bench and the second optical targets will be installed close to the slope toe of the final slope. First optical targets were installed by end of 2022. To get a full spatial and comprehensive monitoring of the slopes, TLS is carried out using a Riegl VZ-4000. This allows to identify and quantify wedge failures and outbreaks along the slopes. In addition, the orientations of the discontinuities and faults in the rock mass are analyzed based on the high resolution 3D point cloud. The point spacing for each scan is set at 2 cm. To cover the entire quarry area, 3 scan positions are required. These are located on the opposite of the valley, with 2 position at the rockfall protection dam and one above the dam in the natural slope. The monitoring frequency of the optical targets and the TLS is monthly. Based on the results, the frequency will be adjusted as required. As part of the safety measures during mining, the blasted slopes are scaled by a 150 t excavator and all loose material is removed from the final benches, including the construction of a protection berm at the benches where required. The steep natural slope above the quarry is scaled manually by hand, small explosive and walking excavators to remove loose blocks or potential wedges after each snowmelt session. This area is accessible from the reservoir side path. In 2022, an area of approximately 1.47 ha was scaled. Access to the quarry is restricted during periods of heavy rainfall. After the first year of material extraction, no movements, slope failures or mayor outbreaks were observed along the quarry walls.

8 OUTLOOK

Material extraction is highly dependent on the construction sequence of the dam fill. By the end of November 2022, approximately 0.75 million m³ of material was used for the dam fill. Assuming a continuous construction sequence, four filling periods are planned until the completion of the Kühtai dam in 2025. The largest volumes for the dam fill are expected in 2023 and 2024.

9 REFERENCES

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