The new Mutsee dam
Fabio Tognola, Marc Balissat

Abstract: The new Mutsee dam is part of the new pumped-storage power plant Limmern, presently under construction. With his 1000 MW installed capacity, this plant will be the largest pumped-storage power station in Switzerland. The plant includes a new underground powerhouse located close to the existing Limmern arch dam, at an altitude of about 1700 m a.s.l., and uses the about 600 m gross head between the Limmern reservoir (92 mio m³) and the existing Mutsee natural lake. With the new dam at Mutsee the maximum water level of this natural lake will be raised up by 28 m. The live storage of the reservoir will be so increased from 9 mio to 24 mio m³. The new dam is designed as a conventional gravity dam with 68 blocks of 15 m width each. The dam reaches a maximum height of 35 m, while the total concrete volume is 250000 m³. An ungated spillway extends over 5 dam blocks and is designed in order to release the maximal pumps discharge (160 m³/s). The particular location of the dam in a high mountain area and the fact that the excavation material of the powerhouse shall be transported to the dam site by a cableway is particularly challenging from the logistic point of view.

1. Introduction

The Linth-Limmern Scheme has been under operation for more than 40 years. It consists of a 120 m high arch dam impounding a reservoir of 92 mio m³, a headrace tunnel and a pressure shaft leading to an underground powerhouse with two units at Tierfehd. The gross turbine head is 1050 m. A compensating basin allows regulation of the discharge for the downstream course of the Linth River and the next scheme plant in Lintal. Water of the natural lake of Mutsee located 630 m higher than the Limmern Lake is collected and turbine in a small underground powerhouse next to the main reservoir.

The actual development plan under the name of Linthal 2015 (Fig. 1) consists in establishing a high capacity pumped storage scheme (1000 MW) between the Mutsee and the Limmern lakes. For this purpose the capacity of the Mutsee reservoir will be increased from 9 mio to 24 mio m³ by raising the level of the natural lake by 28 m.

This will be achieved by erecting a more than 1 km long gravity dam along a smooth ridge on the South side of the natural lake. The new scheme consists of a water intake and a 500 long headrace tunnel leading to two large diameter pressure shafts. An underground powerhouse with 4 reversible pump-turbines (4 x 250 MW) will be built next to the Limmern reservoir. Access to the powerhouse shall be provided from downstream by an inclined gallery (inclination: 23%) equipped with a cable-railway.

The new Mutsee dam is located at a high altitude with severe climatic conditions as they prevail at this elevati-

2. Geological conditions

The Mutsee dam site is located on sedimentary rocks which are disposed in successive scales. The geological layers (Fig. 2) rise slightly from the South towards the
dam site, lie at the dam site almost horizontally and fall down within some 100 m steeply towards North as they form a brow wrinkle. The upper layers in the dam area consist of tertiary sediments (so called Pectinit schists, sandstone and Discocycline limestone) covering the underlying rocks made of sediments of the Chalk and Malm periods (various types of limestone).

One of the main issues is the water tightness of the dam foundation. Beside some disturbed and sheared zones the tertiary sediments are generally impervious. However the protective layer of rocks resisting to karstification is relatively thin (only 20 to 50 m thick). The rock in the first 15 m is often loosened up and exhibits fissures and shear planes that can carry water. The main water carrying feature is formed by a ESE-WNW cleavage system that plunges nearly vertically. Furthermore the shear and disturbed zones such as the Muttsee Bruch can be considered as water carrying too. Two ground depressions have been noticed in the dam area. They can be considered as sinkholes (dolines) caused by an underlying karst system.

On the East side of the dam the Chalk layers that are prone to karstification lie at a deeper level. The rock mass is however characterized there by overtopping and shearing of several layers and is highly fissured. It may be therefore locally less watertight.

3. New dam layout

3.1 General requirements for the dam concept

The relative remoteness of the dam site calls for a limited volume of construction material to be brought up by cableway from a lower level since environmental considerations do not allow operation of a quarry next to the lake. Essentially selected muck of the excavation works for the powerhouse cavern and access galleries shall be transported to the dam site. Other environmental considerations request also to limit the extension of the dam footprint. These various constraints led to the early choice of a concrete gravity dam.

The foundation rock exhibits generally a good strength and as the height of the dam will not exceed 35 m induced stresses will remain relatively low. The main problem lies with the permeability of the foundation that is linked on one hand to single fracture zones in the upper rock layers and on the other hand to the deeper karstified rock formation. The first aspect shall be treated by constructional measures such as blanketing and grouting, while the

![Figure 2. Geological cross-section of the Muttsee dam site.](image)

![Figure 3. Alternative dam axis alignments.](image)

![Figure 4. Plan view of the Muttsee dam.](image)
second one will influence the location of the dam axis that shall take into account a sufficient thickness of the upper rock layers because of their relative imperviousness. Appropriate grouting and drainage works in the dam foundation shall complete the underground treatment. The Mutsee lake as upper reservoir of a pumped storage scheme will be subjected to rapid water level variations. Stability of the lake shores and watertightness of the foreland on the upstream side of the dam have therefore to be carefully examined.

Construction of the Mutsee dam is not on the critical path of the Linth-Limmern 2015 project. Nevertheless the construction schedule shall take into account the restricted supply chain of materials (mainly cement and aggregates) and the limited length of the construction periods per year (5 to 6 months). Low temperatures especially during night will have also an influence on concrete curing procedure.

3.2 Alignment of the dam axis

Several dam axis alignments have been examined in a preliminary design phase (Fig. 3). The criteria considered for the definition of these alignments may be summarized as follows:

- a minimum thickness of the Pectinite schists (and other surface rock types) to benefit of their impervious as upper foundation layers;
- some distance to the small ponds on the South side that are under environmental protection;
- a geometrical alignment as simple as possible.

The line 1 corresponds to a preliminary approach with a composite concrete dam consisting of a gravity section in the center and on the West side and an arch dam section on the East side where the dam is the highest. This solution was discarded as the apparent economy of concrete will be ousted by the volume required for the abutment blocks of the arch dam. Furthermore the dam axis was too close to one of the doline that was found in the subsequent investigations.

The line 2 was an attempt to place the dam further North and to take advantage of a maximum thickness of the relatively impervious surface rock layers. Nevertheless this alternative was discarded as the right abutment could not be properly imbedded in the rock and the thickness of the talus deposits on the left abutment was excessive.

The line 3 corresponds to a dam with a continuous curved alignment without a sharp bend. This was selected to avoid possible abnormal behavior of the dam as it sometimes occurs with a composite axis. This solution was eventually not retained as it crossed the left bank scree with a significant thickness of deposits and would have required a larger volume of concrete.

The lines 4a and 4b represent the last optimization steps for the location of the dam axis. Crossing of the talus deposits at the left bank has been moved 50 m further South in order to intercept the minimum thickness of these deposits. Eventually the line 4b has been retained with some minor geometrical simplifications as the definitive alignment of the dam axis. The final dam plan view is presented in Figure 4.

4. Characteristics of the dam

4.1 Generalities

From a structural point of view the new Mutsee dam is a conventional gravity dam with 68 independent blocks, whose length is generally 15 m at the dam axis. The
on is located at the upstream toe of the dam. This gallery continues in the foundation rock of the left bank up to the end of the diaphragm. The inspection gallery is accessible from the downstream toe of the dam through five adits located at low points of the ground.

On the right bank the construction of the dam will make it impossible for surface waters (rainwater and water resulting from the melting of snow) to naturally flow towards the lake. Therefore, this water shall be collected and channelled through the access adits into the inspection gallery. From here, the water is evacuated together with the leakage water through an inclined borehole towards the old headrace tunnel. The latter is closed with a concrete plug below the dam axis and used as a winter access to the dam. An elevator installed in a vertical shaft is connecting the access gallery to the service house on the right bank. From here, it is also possible to directly access the dam's inspection gallery through an underground passage.

4.2 Spillway and bottom outlet

The spillway of the dam extends over five blocks to the left bank, where the dam reaches its maximum height. The spillway is made up of five ungated sills at elevation 2474.60 m a.s.l. (Figure 7). Four of these sills are 14.40 m wide and the fifth has a width of 15.0 m. Thus, the total effective length of the spillway reaches 72.60 m. A stilling basin is designed at the downstream end of the spillway in order to improve the energy dissipation. The maximum peak during the design flood (1000 years return period) is relatively small (40 m³/s) because of the very small size of the catchment area. On the other hand, the spillway is designed for the worst scenario of over-pumping at maximum capacity of the plant (160 m³/s) over the normal top water level. It should be noted that in order to reduce the risk of over-pumping two independent water level measuring systems are provided. This load case may therefore be considered as an exceptional operational case.

Since the design flood volume (245,000 m³) is smaller than the storage volume between the normal top water level and the spillway elevation (380,000 m³), it is expected that the water level will not reach the spillway elevation during flooding. Nevertheless for safety reasons the spillway is designed in order to allow the passage of the peak flow of 40 m³/s without exceeding the maximum water level (2475.00 m a.s.l.). In case of over-pumping the water level reaches 2475.60 m a.s.l. and is still 0.40 m lower than the dam crest elevation.

The bottom outlet is located in one of the spillway blocks. The bottom outlet is designed as an horizontal rectangular conduit with a section of 1.0 x 1.2 m and a total length of 25 m. The upstream stretch, up to the two identical side gates (for revision and service), is entirely steel lined whereas the downstream stretch is made of an open channel. At the end of the channel a concrete block allows energy dissipation before releasing the water in the stilling basin of the spillway. The access to the valve chamber is given through the inspection gallery of the dam. It has to be noticed, that the relatively high location of the bottom outlet only allows a partial emptying of the Muttsee reservoir. For achieving a complete lowering of the water level a valve will be provided in the concrete plug in the old headrace tunnel.

4.3 Grouting works

Contact grouting is provided on the entire surface of the dam foundation to a depth of 3 m in the rock. A grout curtain down to a depth of 20 m is also envisaged at the upstream toe of the dam to reduce seepage and uplift pressure (Fig. 5 and 7). The grout curtain extends on the left bank under the jet-grouting diaphragm. The grouting works are generally carried out from the inspection gallery. Once the grouting works are completed, drain holes will be drilled from the gallery to further reduce the uplift in the foundation.

In order to prevent seepage through fissures in the bottom of the new impounding, which are difficult to seal by local treatments, it is envisaged to provide the rock surface with a waterproof lining (Figure 4). This consists of a layer of reinforced shotcrete with an approximate thickness of 15 cm. Since the imperviousness of the natural lake is considered satisfactory, the waterproofing treatment only affects the new submerged surfaces between the maximum water level of the natural lake and the new dam over a surface of approximately 15,000 m².

4.4 Monitoring instrumentation

The displacements of the dam are measured in five sections by means of a direct and an inverted pendulum,
both provided with a reading station at the level of the inspection gallery (Figure 5). This system allows to measure absolute displacements at two different levels of the dam. Furthermore, thermometers to determine the thermal state of the dam are installed at each measuring section. The monitoring equipment is completed by measures of uplift pressure in the foundation and seepage in the inspection gallery. Geodetic measurements and a levelling of the dam crest are also included in the monitoring program.

5. Dam construction program and procedures

Given the severe weather conditions and the short summer working seasons, the construction of the new dam is planned over a period of six years between 2010 and 2015. The work program provides for the preparation of the job site installations during the first two seasons (2010 and 2011). The start of the excavation for the dam foundation and casting of a few small blocks are also envisaged during these seasons. The main blocks of the dam are casted throughout three seasons between 2012 and 2014, during which the average volume of concrete placed per season is 80,000 m³. The maximum daily casted volume is expected to reach about 2000 m³. The completion of the crest and other finishing operations are envisaged during the last working season in 2015. In addition to job site installations, it is foreseen to install an aggregate crushing plant and two concrete batching plants at the dam site. All material used for the preparation of the concrete comes from underground excavation of the powerplant and appurtenant galleries and is transported from the Limmern reservoir to Mulltsee with the use of a cableway.

Preliminary tests have been carried out on aggregates coming from an exploratory tunnel in the powerhouse area. This allowed to design a concrete mix containing 150 kg/m³ CEM I and 100 kg/m³ of fly ash. Final testing to confirm the final concrete mix-design is currently under way. Despite the fairly low average temperatures at the job site, a post-cooling of concrete with the use of coils is suggested. This procedure is limited to the lower lifts of the higher blocks, where the dam width is the largest. In fact, while the maximum temperature of the concrete should not be a problem during the hydration phase, numerical analyses indicate that the thermal gradient between centre and facing of the blocks could reach critical values during the winter months following casting. It is considered that cooling of the concrete is simpler and less expensive compared to other procedures such as thermal insulation of the blocks during winter months.

Authors:
Fabio Tognola, Lombardi Engineering Ltd
CH-6648 Minusio, Switzerland
Marc Balissat, Stucky S.A., Rue du Lac 33
CH-1020 Renens, Switzerland