

# Heightening for hydro

Boosting the volume of Grimsel reservoir, in Switzerland, calls for two challenging dam heightening projects which are not the first, or last, for such upgrades in the country. Report by Patrick Reynolds



View over Vieux Emosson and Emosson reservoirs, in Switzerland

**A**mong the many times the need arises to upgrade a dam structure, often the cause is a new safety assessment undertaken in light of revised, and tighter, regulations. Other reasons, though, can be less reactive, such as may result from commercial or strategic decisions to increase the volume of a reservoir to obtain significantly greater storage for hydropower production.

The benefits that can be won from increasing the volume of existing reservoirs brings, in the process, the challenges of assessing the impounding structures to be heightened. The solutions determined best may see a range of works required from foundation improvement and partial demolition to fresh build and possibly changing the form of a dam, and possibly also additional associated infrastructure works.

Both heightening and safety upgrades feature in some dam projects being undertaken or in planning in Switzerland.

Among a number of heightening projects there are the planned increases in the volume of Grimsel reservoir, requiring two dams to be significantly raised and strengthened, and also the Vieux Emosson reservoir, as part of the enlarged Nant de Drance hydropower scheme.

Then, in terms of strengthening works alone there was the need at Les Toules dam following detection of movement and also the introduction of new seismic safety rules (see box).

## **Grimsel Introduction**

High in the Canton of Bern, near Grimsel Pass, the Grimsel reservoir is impounded at an

elevation approaching El. 2000m asl by two dams – Spitalamm and Seeuferegg – owned by Kraftwerke Oberhasli A.G. (KWO).

The catchment has abundant runoff, boasting rainfall of 2000mm-3000mm per year, but the flows are irregular with approximately 85% of the precipitation falling over May-September. Much of the runoff is impounded but significant flows pass downstream, requiring large outflows from the reservoir. Ever since the reservoir was built in the 1930s this has been seen as a loss to the region in terms of possible extra energy production.

Given the large surplus of runoff catchment, KWO has developed a plan to exploit some of the additional hydrological resource. Extra capacity is to be created to store more of the flow and have it available for more energy production, and power

Figure 1: Section of Spitallamm dam, Switzerland, showing part-demolition and new addition

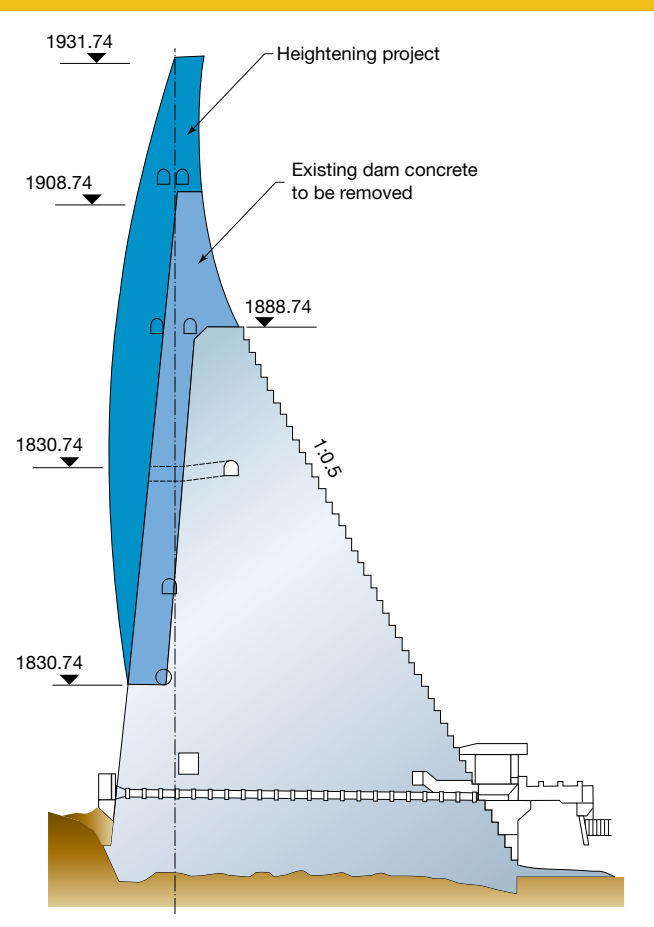
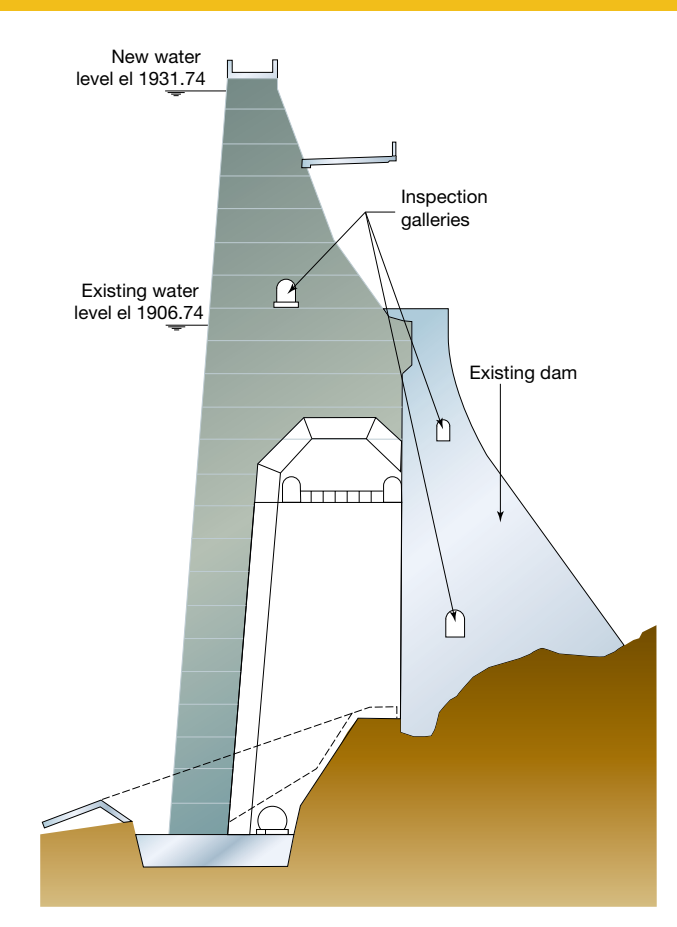


Figure 2: Section of Seeuferegg dam, Switzerland, with hollow concrete structure to be added



reserve, in winter when demand for electricity is seasonally greater.

The hydropower expansion scheme will require the two dams to be heightened and transformed in structural form, to different degrees, when the anticipated construction works commence later this decade. KWO's investment will increase the storage volume of the reservoir by approximately 75%.

**Expansion**

The first project to investigate enlarging Grimsel reservoir began barely after the reservoir had been impounded and hydropower production began in 1936. The geography of the reservoir area includes a long, flat valley that would afford a relatively large increase in storage volume for a comparatively modest rise in water level.

As electricity demand has continued to increase over the decades, the untapped through-flow at the reservoir has become more of a prize to secure. In its "KWO Plus" initiative, KWO has decided to enlarge the reservoir to obtain additional benefits, such as: seasonal balancing of water resources; more energy and power in reserve; contribution to flood protection along River Aare – and consequent cost reduction for other required mitigation works; and, strategic asset investment in era of anticipated climate

change impacting on hydrological balances.

KWO says the reservoir volume is to be increased from 95Mm<sup>3</sup> to 170Mm<sup>3</sup> with the extra volume to be obtained from a 23m raise in water level, requiring only about 0.87km<sup>2</sup> of additional land to be flooded. The additional storage will also increase energy reserves by 240GWh, taking the total to 510GWh – almost double the presently maximum availability.

The budget for the enlargement project is still in refinement but five years ago was given by KWO as SF260M, with an anticipated tolerance of +/- 20% to get the final cost. About 30% of the budget is expected to be spent on the complex rehabilitation and heightening work planned for Spitallamm dam alone. Only heightening work is required at Seeuferegg dam.

In each case, though, the dam is being mathematically modelled, taking the greater profile of face pressures but also considering foundation stability in light of increased uplift. The information from the analyses is cross-checked against monitoring data before design development proceeds. With the verified model and parameters, design development then enables the rehabilitation/heightening projects to be optimised for safety as well as the choice of technological approach and construction scheduling.

Further infrastructure works associated with Grimsel project includes slightly realigning a section of the Pass as a 700m long stretch of road will be flooded by the higher water level. A cable-stayed bridge is to be built to take the road over the new stretch of lake. The budget for the road realignment and bridge construction is approximately SF50M.

Stucky is undertaking the design work on the project. The planning and design development has been underway for the last few years.

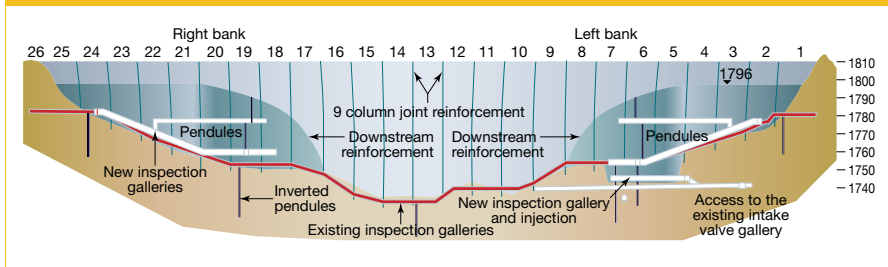
While construction schedule has yet to be finalised and the project is currently seeking a construction licence, pending resolution on environmental issues, KWO has said it expects the overall construction period to be about six years. The long construction period is partly due to the slow down and likely need to stop principal work at the high altitude site over the winter months.

**Heightening - Spitallamm Dam**

Spitallamm dam is a single curvature, concrete arch gravity structure that was commissioned 79 years ago. A fine example of its type, says Stucky, the dam is 114m high with a cylindrical upstream face, crest length of 258m and volume of 340,000m<sup>3</sup>.

To increase the height by the 23m, the structural type of Spitallamm dam is to be

Figure 3: Long section through strengthened Les Toules dam, Switzerland



transformed to construct a 137m high double-curvature arch dam. The construction work will involve some partial demolition to both key-in and establish suitable sufficient width to build the tall, double-curvature extension onto the cut-back, upstream face of the structure. The existing upstream face is not in good condition, the replacement of which is a further benefit of doing the upgrade work.

Foundation analysis is a vital part of the design work for the dam upgrade. Completed in 1932, the dam was mostly built on jointed granodiorite, an intrusive igneous rock. While there were no major joint sets found on the right bank, that area is partly founded upon mylonite, a metamorphic rock formed at zones of movement, or faults, in rocks. The focus of the foundation analysis is, therefore, on the right bank.

#### Heightening – Seeuferegg Dam

Seeuferegg dam is a 42m high gravity dam built on hard, jointed granodiorite.

Completed in the 1930s, the dam is to be increased in height by 23m by adding a major hollow concrete structure to the upstream face, relatively dwarfing the existing structure. Taking the height of Seeuferegg to 65m, the project will effectively transform the dam into a hollow gravity structure – a key advantage of which, especially for such a large proportional increase – is the reduction in uplift pressure due to drainage via the hollow cavities.

In terms of stability, the stress field is less of a concern in comparison to the jointed rock mass. Stability is determined principally by joint sets and analytical modelling uses joint-based design methods, drawing upon three different methods that will afford cross-checks: two are 2-D, plane approaches looking at general failure and observed joint weaknesses, respectively; the other is a 3-G geometric view drawing upon site observations of potential wedges.

Analytical findings show that for extreme loading, such as seismic shocks, even the present dam does

not comply with safety requirements for wedge stability, and remedial measures to the foundations are required in the left bank of the dam.

A range of remedial techniques were reviewed from both engineering and cost-benefit standpoints. The techniques range from gallery excavation and backfilling (“shear key” construction) to installation of prestressed anchors or deepening the foundation and its mass at areas of critical joints. From the analyses, the latter is favoured as it has greatest reduction in potential joint-induced problems. Also, the technique, being a mass construction solution, is highly adaptable to site conditions established during excavation and is arguably, therefore, the best approach for risk reduction.

#### Further heightening projects

Another important dam heightening project is at the Vieux Emosson dam, which is part of the Nant de Drance scheme in the Canton of Valais. The 45m high structure was built in the 1950s and is owned by Swiss federal rail company, Schweizerische Bundesbahnen (SBB).

The dam heightening plan came out of a proposal to increase the size of the reservoir serving the Nant de Drance pumped storage project. While presently under construction, the size of the pumped storage project is to be increased to 900MW, approval for which has just been gained. Construction is expected to start next year. Stucky is working on the project.

Other dam heightening projects in which Stucky was previously involved include the Luzzone arch dam, in the late 1990s.

Luzzone arch dam was built in the early 1960s as a 208m high structure on the Brenno di Luzzone River in the Canton of Ticino, and is one of the largest dams in the country. The dam has a gated spillway and impounds a 3.1km long reservoir. It is owned by Officine idroelettriche di Blenio SA.

The heightening project raised Luzzone dam by 17m to 225m, and this increased the storage in the reservoir by approximately 17%.

While there are have been other dam heightening projects abroad, in Angola and Iran, for Stucky there are further projects needed in Switzerland. ■

#### Safety at Les Toules

A further dam upgrade project in Switzerland, involving Stucky, was the rehabilitation work needed at the Les Toules arch dam. The project was needed to strengthen the structure for safety reasons rather than gaining extra height for other benefits.

##### Les Toules

Les Toules dam was recently upgraded for safety reasons but was an already heightened structure, having been both add to and raised in level significantly in the early 1960s only a short time after the basic form had been completed, in 1958. Located in the Canton of Valais, the Les Toules dam was developed to be a 86m high slender arch structure with a crest length of 460m across a wide valley. It is founded on alternating bands of subvertical gneiss and schist. The dam is owned by Forces Motrices du Grand-St-Bernard (FGB), which is held by Romand Energie as majority shareholder and Alpiq. The rehabilitation work at Les Toules was needed after surveys found some downstream displacements. Risk analysis called for the reservoir to be lowered as a precautionary measure while studies were undertaken to plan for remedial works.

A further impetus for strengthening the dam came from the introduction of more stringent regulations and recommendations for performance under seismic loading load. Safety checks with the new national assessment system indicated that the potential peak ground acceleration (PGA) was up to 3.3 times that used for the design of the structure in the 1950s. Additional studies established the horizontal and vertical components of the PGA to be 0.28g and 0.19g, respectively.

Les Toules was built without abutment thickening and shear keys, though there were pre-pack joints between the two stages of the dam build at the outset. From the remedial analysis, it was decided that the primary strengthening works would comprise: cantilever construction to effectively thicken the downstream face on each bank; formation of shear keys; and, some localised deepening of the foundation, by about 10m, at weaker rock. Construction challenges, in addition to the dam improvement works, include the logistics of access to the remote, high-altitude site and restrictions in winter months of November-March due to snow and also avalanche hazard. The project was recently completed.

#### References

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