IMPROVING THE SAFETY OF AN OLD AUSTRIAN DAM

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ABSTRACT

Updating of the design flood for the 90-year old Gosau dam in the Austrian Salzkammergut region to meet present-day safety standards made it necessary for the owner and operator, Energie AG Oberoesterreich, to raise the dam's discharge capacity from approximately 40m³/s to 70m³/s by providing an overflow spillway section at the dam crest. Two energy dissipation alternatives were considered, one with a stilling basin and one with a ski-jump. The complexity of the situation led the owner to resort to hydraulic scale-model tests for the design studies. The results proved both alternatives to be technically feasible. In the end, the ski-jump variant was chosen and the design submitted to the authorities. In addition, a bottom outlet connecting to the upstream end of the existing spillway tunnel was provided to enable water-level drawdown in the case of emergency. This was studied in a further model test. The results have shown that both the bottom outlet and the old spillway can be expected to work perfectly well. Following approval by the Water Right Authority, construction was commenced in the autumn of 2003 and completed in the summer of 2004.

INTRODUCTION

The Gosau dam is situated in the geographical center of Austria, in the well-known Salzkammergut lake district. Hydro-power development in the Gosau valley goes back to the pioneering period of Austrian electricity generation. As early as 1907, the predecessors of the present owner prepared a project providing five power stations connected in a cascade between the lakes Hintere Gosausee and Hallstätter See. The Gosau dam was constructed in 1910-11 in order to enhance the reservoir capacity of Vordere Gosausee. The dam raised the water level of this natural lake by about 15m. Owing to the extraordinary beauty of its surroundings, this new Gosausee lake has come to be one of Austria's most outstanding tourist attractions (Fig. 1).

The inflow to Gosausee is difficult to measure accurately because of the karstic character of the Dachstein massif, in which the reservoir is situated. A study conducted by Professor Gutknecht (Vienna University of Technology) gave 70m³/s for the 5000-year flood. This result led to the decision to provide an overflow spillway section at the dam

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Figure 1. Gosausee Lake and Dachstein Massif (2,996m a.s.l.)

crest, in addition to the old spillway located in the right bank. The new spillway is intended to handle the entire flow of 70m³/s, so as to ensure the safety of the dam even in the case of failure of the old spillway tunnel. Furthermore, a bottom outlet was built to help draw down the reservoir level in an emergency.

DESCRIPTION OF THE PLANT

Gosau Dam

The dam is an embankment 50m long at the crest and 17m in overall height, consisting of rubble and moraine material with the upstream and downstream slopes inclined at 1:2. The core is a stone-masonry structure with cement mortar, increasing in thickness from 3m at the top to 5m at the bottom. The upstream dam face consists of stone paving in cement mortar on fill material cemented with limewash. On the downstream face, the top layer is planted with grass. The usable storage of the reservoir is 25 million m³, of which one third was added by the dam raising the water level of the natural lake.

Spillway

The old spillway structure (with automatic flap), capable of passing about 40m³/s, is located on the right, separated from the dam. This is followed by a tunnel approximately 2.30m in diameter, conveying the flow to the Gosau stream. With the new flood-relief works completed, floods will be discharged both by the newly built overflow section and

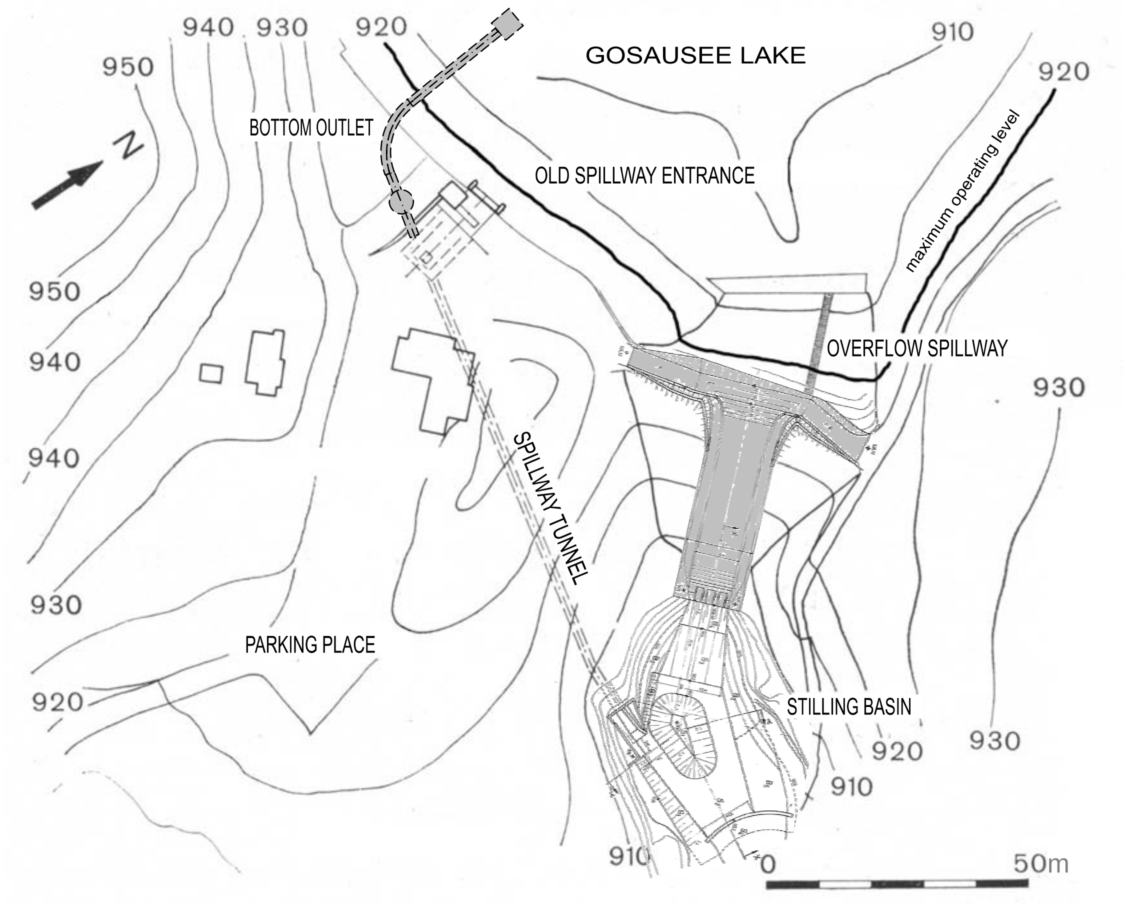


Figure 2. Plan View of Gosau Dam

chute and by the old spillway. The distribution of the flow is mainly dictated by the different levels of the two spillway facilities. The flap of the old spillway has been replaced by a fixed overflow sill. The new maximum operating level is 1.65m lower than the original top-water level, leaving an extra slice of reservoir capacity to be used for flood retention, but this had to be omitted in the design of the spillway.

In addition, the old spillway tunnel was altered to discharge not much more than 20m³/s for the design flood of HQ_{5000} = 70m³/s, permitting the remaining flow of about 50m³/s to be evacuated over the spillway section. For this purpose, a steel pipe was installed to serve as a throttling device in the inclined shaft of the original plant. The jet emerging below the pipe is aerated through two pipes 400mm in internal diameter, which rise to join the bottom outlet aeration facility.

The junction with the new bottom outlet is situated where the inclined shaft meets the spillway tunnel. In this tunnel section, the bottom and walls were steel-plated over a length of 10m as a protection against the oblique impact of the jet. Eighty-six meters further downstream, the discharge tunnel joins the side of the newly constructed natural-stone paved stilling basin, which forms part of the spillway over the dam crest.

Bottom Outlet

Connecting to the upstream end of the spillway tunnel, the new bottom outlet tunnel is shotcrete-lined and about 60m in length with a horseshoe cross-section of 4.57 m^2. The lakeside inlet is equipped with a coarse rack, consisting of sections that can be swung open. The bottom of the tunnel inlet is 14.35m below the maximum operating level. Two pressure-resistant slide gates, closing an internal area of 1.30m by 1.45m, were installed in a circular shaft about 20m in depth, provided in front of the dam. The two gates are followed by a steel-plated horseshoe cross-section connection tunnel joining the discharge tunnel of the old spillway about 14m further downstream. The bottom outlet is aerated via a steel pipe 600m in diameter rising to just below the shaft cover and continuing towards a separate aeration structure.

HYDRAULIC SCALE-MODEL TEST: SPILLWAY

Test Set-up

Constructed to scale 1:15, the spillway model was about 10m long by about 5m wide. The old spillway tunnel was accurately modeled over its outlet zone. The model was built mainly in concrete and brick; the chute and ski-jump, where necessary, were modeled in plastic or wood. The stilling-basin was paved with stones answering the criteria of similitude to study erosion and sedimentation phenomena.

Criteria of Similitude

The hydraulic model was run according to Froude’s criterion of similitude. For the selected scale of 1:15, the conversion functions corresponded to the following relationships:

Flow time:	One hour on the model corresponds to approximately 3h50min on the prototype;
Velocity:	1m/s on the model corresponds to 3.87m/s on the prototype;
Flow rate:	1 liter per second on the model corresponds to 0.87m^3/s on the prototype.

The scour protection material was modeled by particle sizes of up to or greater than 1kg, corresponding to a size of up to 5 tonnes in the prototype.

Operating Conditions

The design flood for the new spillway was selected as HQ_{5000} = 70m^3/s. In addition, several loading cases were defined which included the old spillway, for example, Q_1 = 0m^3/s and Q_2 = 70m^3/s (Q_1 = discharge through the old spillway tunnel, Q_2 = discharge through the new spillway).

<u>Spillway Area</u>

The model tests showed that the configuration of the inlet to the chute needed careful design. Even minor deviations of the overflow section from the dam axis or crest resulted in asymmetrical flow towards the chute. As proposed by the designer, the cross section of the chute is divided into three parts. Spillway discharges not exceeding 25m³/s should be handled by the central part of the chute. Its lateral channels are planned to be planted with grass and should not have to be provided with new soil after each flood.

Energy Dissipation

As mentioned before, two alternatives had to be studied:

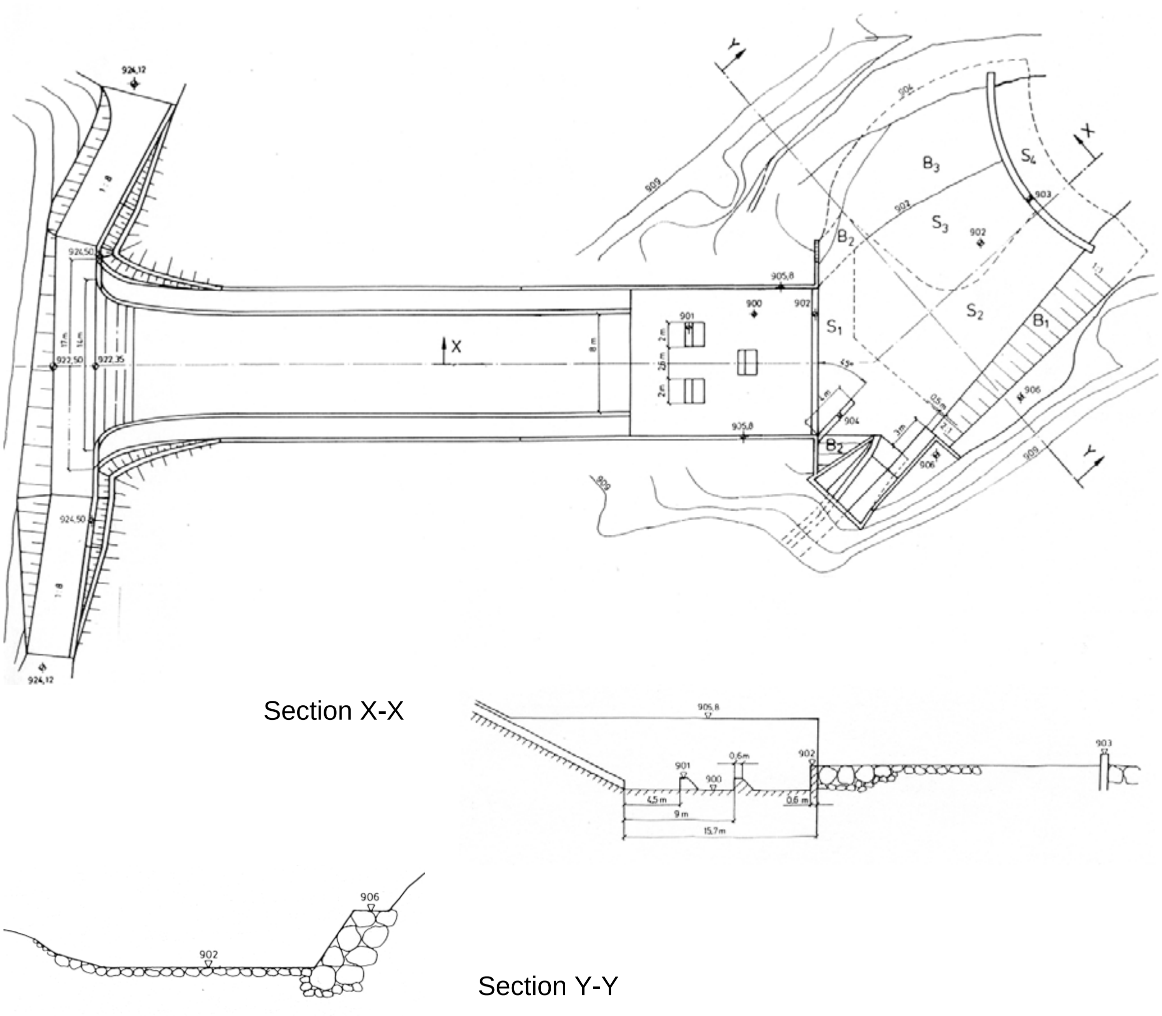
<u>Stilling-basin alternative</u>: consisting of inlet, chute, and stilling basin; the first test result showed:

- Overtopping of the dam before the maximum required flow was reached;
- Substantial shock waves at the beginning of the chute;
- No satisfactory energy dissipation in the stilling basin – formation of eddies, the surface roller traveled off;
- Unfavorable flow from the stilling basin – erosion, with the flow climbing the opposite valley-slope, thus presenting a stability hazard.

This led to changes and optimizations (Fig. 3):

- Inlet to the chute: provide for symmetrical geometry and for higher lateral walls at the inlet.
- Stilling-basin geometry: lower it by 2m and shorten it by 4m, install 3 baffles, lower the side walls by 1.20m; in addition, heighten the sill at the end of the natural-stone paved stilling basin by 1m (to a maximum overflow depth of 1.5m).
- In order to relieve the load on the opposite valley-slope (B1), provide a deflection wall on the right-hand end of the stilling basin. Geometry: deviating from the end wall of the stilling basin by 45° in plan, 4m long and rising 2m above the end sill of the stilling basin (Fig. 5).
- Lengthen the outlet from the existing spillway by 3m. This caused the emerging jet to deviate slightly to the left, thus relieving the opposite valley-slope.
- Define the areas needing protection.

Study of potential inlet choking revealed no recognizable risk.



Section X-X

Section Y-Y

Figure 3. Overflow Spillway; Stilling-basin Alternative

Ski-jump alternative: Initial condition: Inlet and chute identical to stilling basin alternative. The first results showed:

- Unsatisfactory jet take-off and impact situation.
- Flow hitting the opposite valley-slope, jeopardizing its stability.
- Impinging water welling up in the impact area;
- Additional erosion involving the risk of undercutting the foot of slopes to the left and right of the ski-jump.

In view of the site topography – opposite valley-slope oblique to the chute direction – and erosion occurring in the impact area, particular attention was given to the throw of the jet from the ski-jump and the impact surface, with the aim of minimizing the load on the impact area and, hence, bottom erosion, while observing a safe distance from the adjoining slopes.

These considerations led to alterations and optimizations (Fig. 4):

- Reduce the jet width from 12m to 7.20m; this was done asymmetrically to deflect the jet slightly to the left.
- Provide splitters of varying geometries in order to split the jet in the longitudinal and transverse directions. During a flood discharge of 70m³/s, the impact center point is situated about 20m downstream of the front edge of the ski-jump (Fig. 6).
- Create a "primary" scour pit no more than 2m deep to still the plunging jet and encourage steady flow towards the sill at the downstream end of the pit (a greater scour depth was not feasible for the above-mentioned topographical reasons).
- Define the areas needing stabilization, such as stones weighing 4 or 5 tonnes in the prototype, which have to be placed in the area of the primary scour pit.

The Institute for Hydraulic Engineering and Water Resources Management suggested slope stabilization for both alternatives and integrated this into the respective design proposals. The foundation depth required for geotechnical and stability reasons remained to be defined during the detailed design studies.

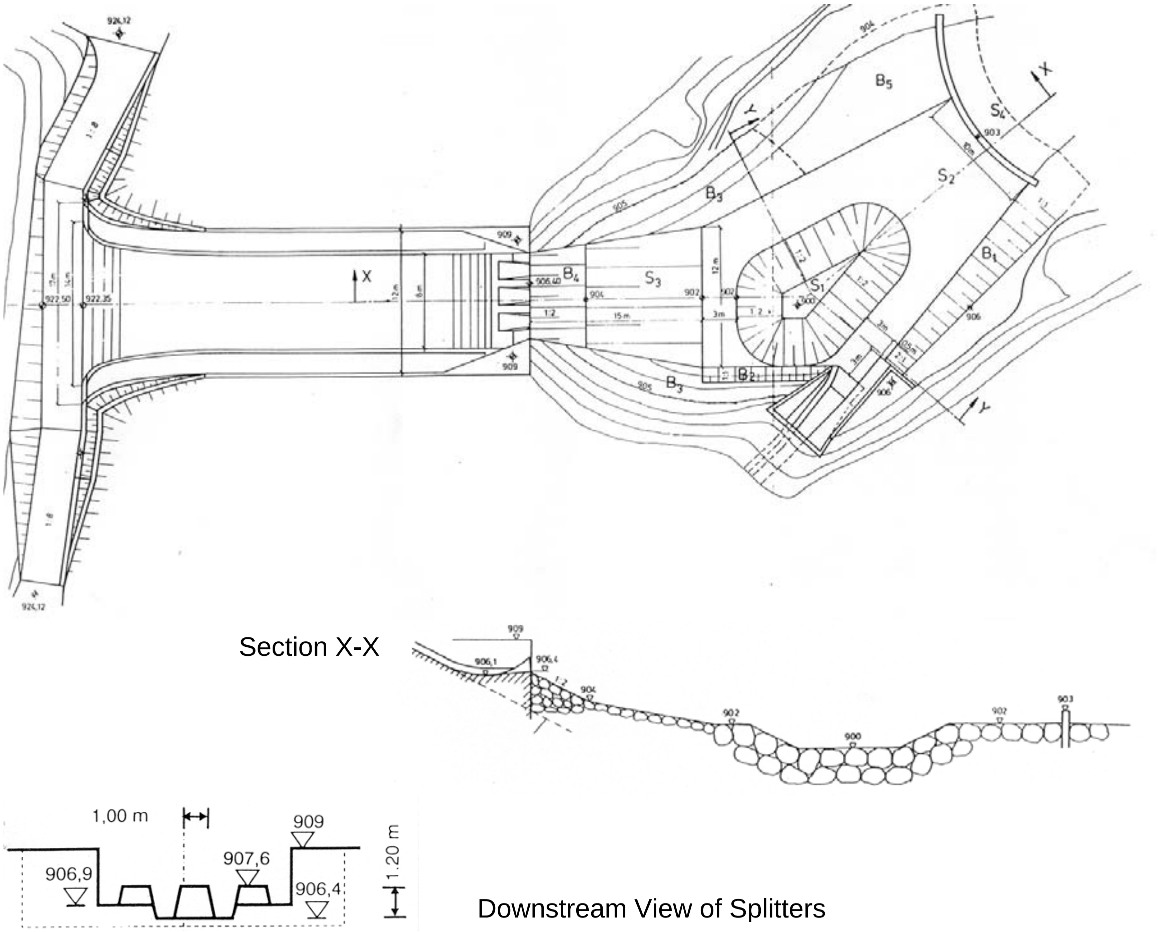


Figure 4. Overflow Spillway; Ski-jump Alternative

Figure 5. Stilling-basin Alternative (Q_1 = 70 m³/s, Q_2 = 0 m³/s)

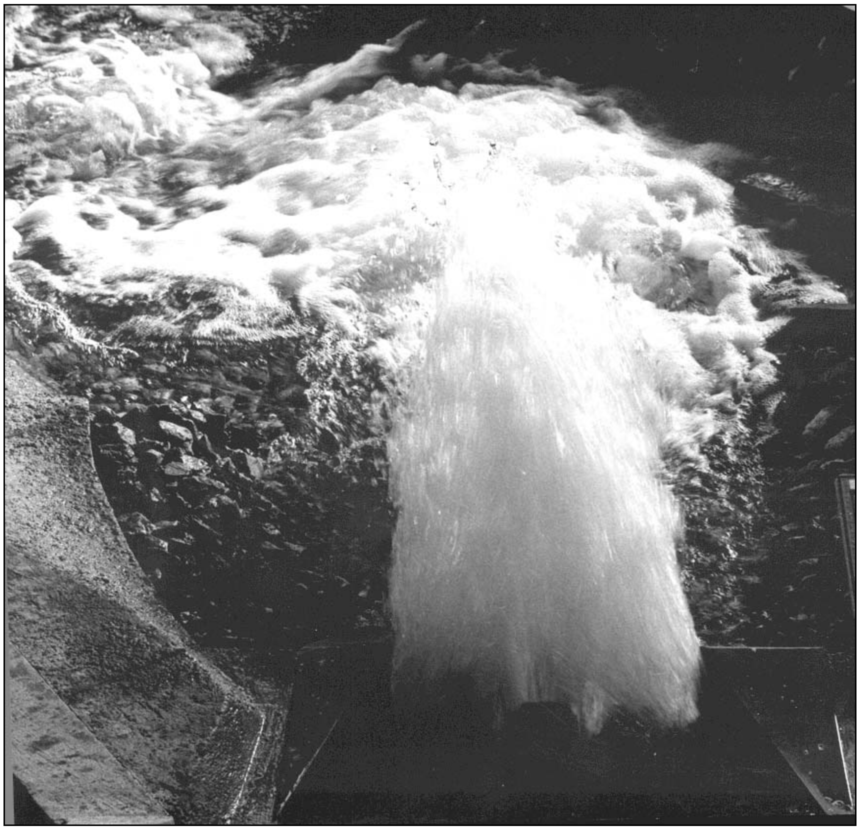


Figure 6. Ski-jump Alternative (Q_1 = 70 m³/s, Q_2 = 0 m³/s)

Conclusion and Design Proposal

Both alternatives were tested in detail and optimized on the model. Both proved technically feasible, ensuring energy dissipation despite the difficult topography. Neither of the two showed a clear hydraulic advantage over the other.

The Client, Energy AG Oberoesterreich, finally based its decision on the construction-cost factor. A further criterion to be considered was that the Gosausee area is a nature reserve and a popular tourist attraction. In the end, the Client decided in favor of the ski-jump alternative. This was then submitted to the Water Right Authority, which gave its approval.

HYDRAULIC SCALE-MODEL TEST: BOTTOM OUTLET

Another scale model test was carried out to throw light on the following areas of uncertainty:

- Flow to and from the bottom-outlet gates;
- Geometry of the junction between the bottom-outlet and spillway tunnels, including the problem of flow pattern in the discharge tunnel following the spillway tunnel;
- Position and dimension of the throttling facility to restrict the flood discharge through the old structure;
- Aeration of the bottom outlet and the throttling structure;
- Discharge capacity of the bottom outlet and spillway for various reservoir levels and operating conditions.

Potential undesirable effects, such as water filling the entire cross-section of the discharge tunnel (causing slug flow), had to be identified.

Test Set-up

The hydraulic model (Fig. 7) was constructed entirely in transparent plastic, to a scale of 1:15. Water was supplied through two separate inlet basins made of brickwork, allowing different heads to be tested for the bottom outlet and the spillway. The bottom and the walls of the discharge tunnel were lined with a plastic mat in the model to simulate the natural roughness on the prototype (shotcrete on a smooth surface, $k_s = 60$). Model roughness was checked by means of differential-pressure and surface-curve measurements and gave good agreement with the assumed prototype roughness.

Model Laws

The conversion functions were the same as for the spillway tests given above. Modeling the aeration device was based on the assumption that the air requirements measured in the model are at best equal to, but normally less than, the corresponding prototype value. The forces acting to introduce air into the water-air-mix are reduced in the model, whereas the

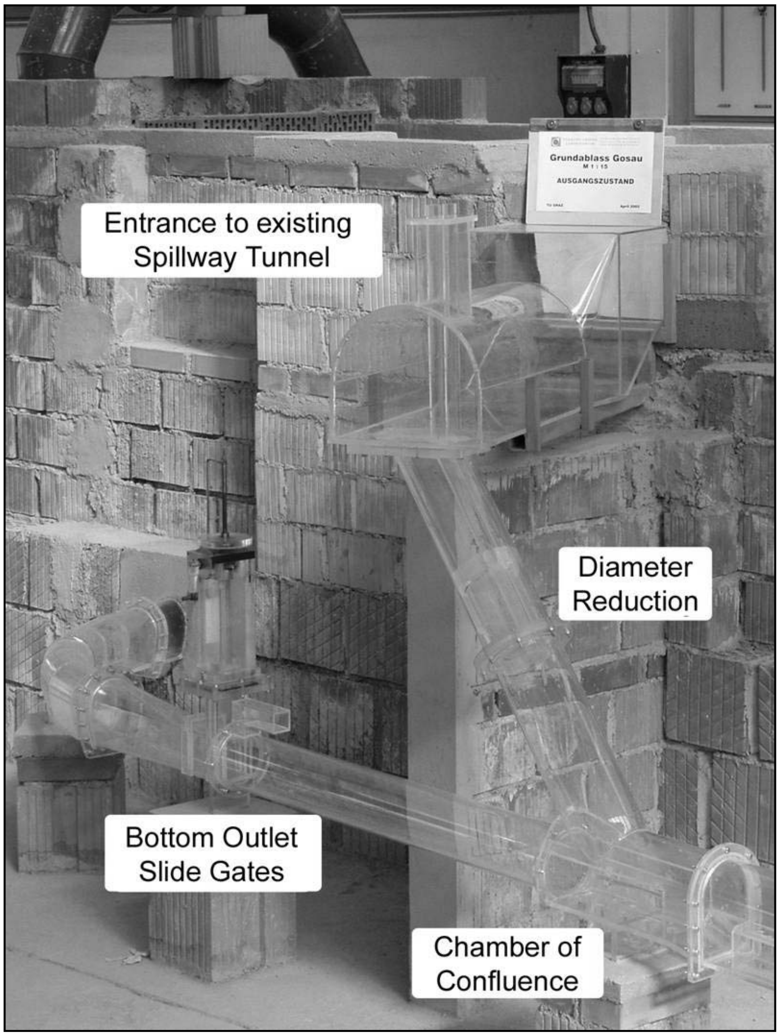


Figure 7. Hydraulic Model of Bottom Outlet and Spillway Tunnel

surface tension acting against air entrainment is the same in the model and in the prototype. This results in correspondingly higher air requirements for the prototype, which fact was allowed for in the design of the aeration device.

Water Supply to the Model

The tests were run for different flows, with the old spillway and the new bottom outlet being operated both separately and simultaneously. Account was taken of flood discharge over the dam crest by raising the tailwater level accordingly.

The selection of the flow to be supplied to the bottom outlet was based on the decision of the Water Right Authority to impose a limit of 15m³/s on the tunnel discharge under normal conditions. In spite of that, the bottom outlet was designed for a discharge of 30m³/s to permit the rapid drawdown of the reservoir level in an emergency. The Authority also decreed that only in an emergency should the bottom outlet be operated along with the altered spillway. In such an exceptional case, the total flow in the common discharge tunnel was not to exceed 30m³/s.

Test Results

Bottom-outlet operation (Fig. 8): The tests have shown that no major problems are expected. The flow downstream of the gates forms a straight rooster-tail jet before reaching the junction. In the discharge tunnel, the flow depth increases from the junction to the tunnel portal (supercritical flow), but with sufficient space remaining between the water surface and the tunnel roof for the flows that were studied.

Operating the original spillway (Fig. 9): The good hydraulic functioning of the spillway has been maintained after the adaptations. The desired flow limitation to about 20m³/s has been accomplished, for the throttle position and configuration that were studied, by choosing a throttle diameter of 130cm. However, the deflection forces of the water jet as well as the high turbulence of the water-air mix made it necessary to add a length of 5m to the steel-plated section in the outlet of the inclined shaft.

Simultaneous operation of bottom outlet and spillway (Fig. 10): The kinetic energy of the jet emerging below the slide gate displaces the water body towards the junction area. As long as the aeration device is in good working order, no counter pressure can build up behind the gate, so that the flow and, hence, the discharge performance of the tunnel are maintained. In the junction area, the jet shooting down from the throttle is carried along by the horizontal flow from the bottom outlet. This not only reduces the load on the bottom, but causes an increased reflection of the jet to the roof. This effect is the greater, the higher the flow through the bottom outlet.

Flow in the tunnel is without pressure up to a total discharge of 35m³/s. As the flow is further increased, free-surface flow changes into flow under pressure and the tunnel cross-section closes up. When the flow velocities are high, water tends to fill the tunnel cross-section quite suddenly, with the risk of causing a water hammer and, hence, damage to the lining. Undesirable effects may be experienced when compressed air bubbles emerge at the tunnel outlets.

Figure 8. Model Test of Bottom Outlet Operation (Q_{BO} = 30 m³/s)

Figure 9. Spillway Operation (Q_{SP} = 20 m³/s)

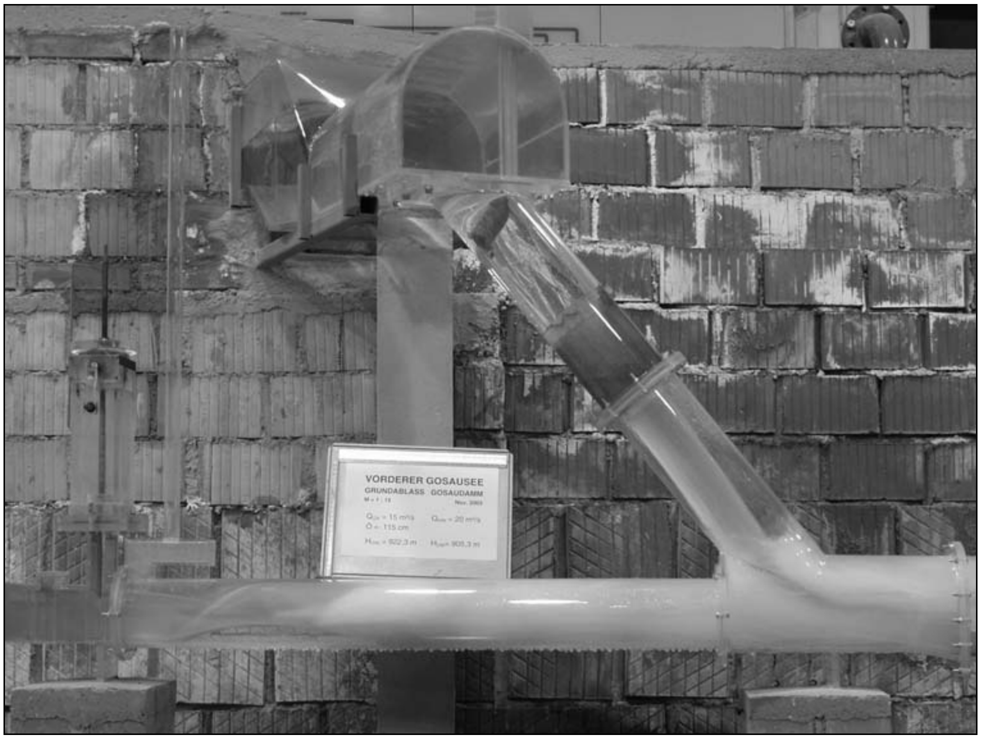


Figure 10. Simultaneous Operation of Bottom Outlet and Spillway
(Q_{BO} = 15 m³/s, Q_{SP} = 20 m³/s)

CONSTRUCTION

Engineering Structures

Following the completion of the model tests, work at the Gosau dam was started in the autumn of 2003. Driving the bottom outlet tunnel was possible only during the winter season, when inflow to the reservoir stops and the water level is drawn down by power station operation. The work had to be scheduled so that all the flood-relief structures were operative by the time melt-water reached the portal of the bottom outlet.

The overflow spillway section and the chute were constructed from the crest. A road about 80m long had to be built from the downstream side, along the Gosau stream, to provide access to the construction sites of the ski-jump, the stilling basin, and the sill at the end of the natural-stone paved stilling basin. This also served as an approach road to the spillway tunnel, whose cross-section had to be enlarged. The bottom outlet was driven from the downstream side, with the reservoir level drawn down. At the same time work was started on the gate shaft, which was sunk from the area in front of the dam. Access to the bottom-outlet site was via a lakeside ramp, which now serves as an approach to the inlet structure. The bottom outlet was excavated without blasting, by means of small equipment with hydro-cutters, using the New Austrian Tunneling Method.

Work was stopped for only a short period in winter and was completed on schedule in the June of 2004, following a contract period of 10 months.

Accompanying Ecological Measures

During the final phase of the design studies, the help of the Institute for Ecology in Salzburg was summoned for developing an ecological concept for the project. This has led to a great number of landscape compensation measures. Dam surfaces once paved with stones were planted with grass so as to make them blend with the surrounding landscape. Special techniques were used to grass the chute, bright concrete surfaces were darkened, and the metal-covered ski-jump was painted dark green (Fig. 11). The stilling basin was completely covered with fill and planted with vegetation recovered prior to the construction work.

The ramp provided on the lake shore near the restaurant, which served as an access to the bottom-outlet site, can now be used as an improved approach to the boat mooring area (Fig. 12). New concrete walls were provided with limestone surfacing to match up better with the surrounding landscape. Certain sections of the lake shore were raised above the maximum operating level and planted with grass to allow access to the water. No artificial measures were taken in the remaining shore areas, allowing natural succession to proceed.

Figure 11. Overflow Spillway after Revegetation of Chute and Stilling Basin

Figure 12. Boat Mooring Area in front of the old Spillway Tunnel

Project Cost

The total project cost amounted to 2.5 million euros, with about 0.5 million euros accounting for planning and design, 1.5million euros for construction, and 0.5 million euros for electrical and mechanical equipment. The ecological measures cost about 50,000 euros.