SCALE MODEL TEST FOR BED STABILITY IN THE RESERVOIR OF A POWER PLANT – CASE STUDY

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The Rott hydropower station and overflow weir on the River Saalach in Austria was built between 1941 and 1950. Since several parts of the plant are approaching the end of their service lives and for maintenance reasons, the old plant is being replaced by a new station downstream. Apart from energy generation, the main function of both the old and the new stations is to maintain the riverbed in the reservoir at a well-defined level to prevent erosion of the piers of a railway bridge across the reservoir. This paper describes the scale model tests conducted for the purpose of preparing operating rules for the gates of the new weir.

INTRODUCTION

The railway bridge over the River Saalach on the Salzburg–Munich line, was built in 1858-60, at river kilometer 2.960, where the river forms the border between Austria and Bavaria (Figure 1). Several “corrections” to the river channel about a decade later led to erosive action in the river bed, which risked to jeopardise the stability of the bridge piers.

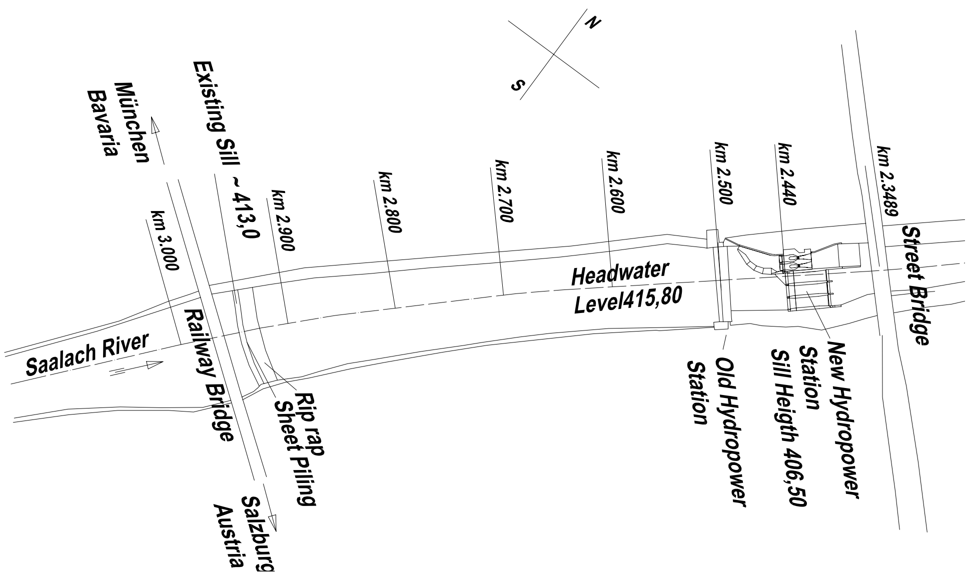

Figure 1: Layout

In order to prevent further degradation, the river-bed section around the bridge was widened from 28m to 55m. As this measure also failed to produce the desired result, a bottom sill was provided immediately downstream of the bridge, but inappropriate hydraulic design of the structure necessitated further safety measures to be taken downstream of it. During the 1940 flood, the sill was almost completely destroyed. Finally, between 1941 and 1950, a power station was built about 500m downstream of the bridge, for strategic reasons and in order to stabilize the river bed and supply the nearby city of Salzburg with electrical energy. Built as an overflow structure at river kilometer 2.500, the power station was equipped with four bottom outlets alternating with three turbines. The plant was designed for a flood discharge of approximately 1,000m³/s (Figure 2). The top water level was 415.80m (+/-0 in Figure 2) above datum. As a protective measure for the pier foundations of the railway bridge, the minimum water level was not allowed to drop below 413.50m. By 1960, sediments had accumulated to a maximum depth of 5m between the power station and the railway bridge, which, while demonstrating the efficiency of the measures taken, constituted another disturbance to the bed-load regime of the Saalach. This was due to the fact that a substantial proportion of the river’s sediments were deposited in the reservoir of a dam further upstream. The annual bed load of the Saalach, estimated at 80,000m³ per year under natural conditions, now reached not more than 10,000 to 15,000m³ per year at the power station.

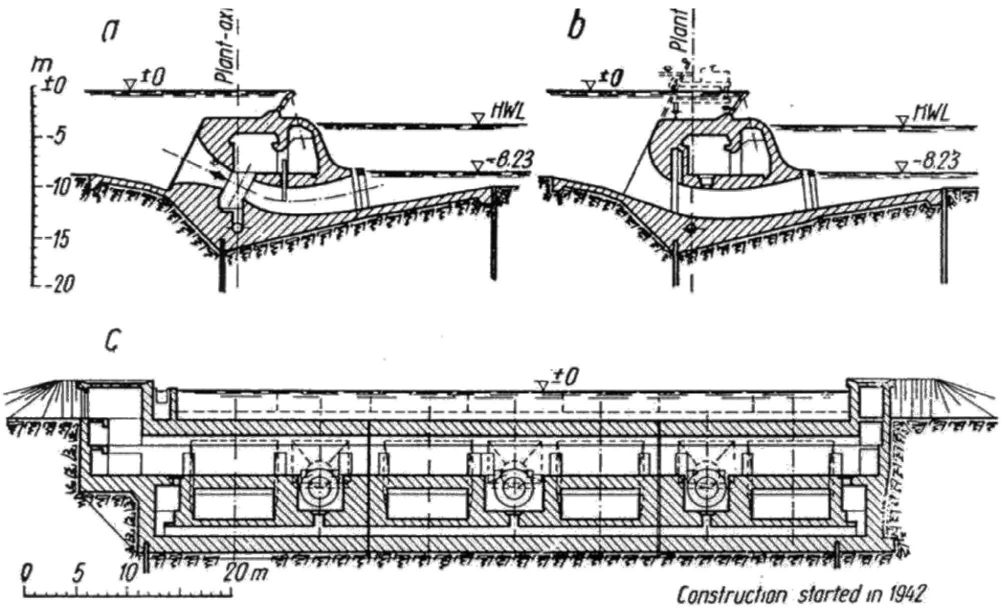

Figure 2: Rott-Freilassing power station – original plant

In order to make up for this deficiency, approximately 60,000m³ of sediment per year is at present recovered from the upstream reservoir and returned to the river downstream of the dam, with the aim of stopping river-bed erosion and raising the bottom level (to a well-defined extent). In the light of the substantial amount of staff needed for operating the power station, the increasing occurrence of damage to the mechanical equipment as well as the choking risk for the bottom outlets and their limited sediment discharge capacity, towards the end of the nineties of the last century the owner of the power station decided to construct a new power project approximately 50m downstream of the old plant. The new station consists of a powerhouse to the left, equipped with two horizontal-shaft Kaplan turbines (PIT design), and a weir structure to the right. The three weir bays of 9m width each can be closed by Tainter gates with hinged flaps on top. The weir crest is located at 406.50m (Figure 3). Apart from energy generation, the new power station was intended to fulfill the following functions for dealing with the sediment problems:

- Maintenance of the sediment cushion between the railway bridge and the new power station to support the piers of the railway bridge;
- To assist the passing of incoming sediment;
- Increased hydraulic discharge capacity for the weir (the new design flood being 1,600m³/s).

Main data:

H.W.L. (unchanged)	415.80m	Head	~ 10m
Annual energy	27.2GWh	Reservoir length	2.1km
MQ	44.1m³/s	HQ_1	310m³/s
MQ_{10}	630m³/s	HQ_{50}	850m³/s
HQ_{100}	~ 970m³/s	PMF	~ 1,600m³/s

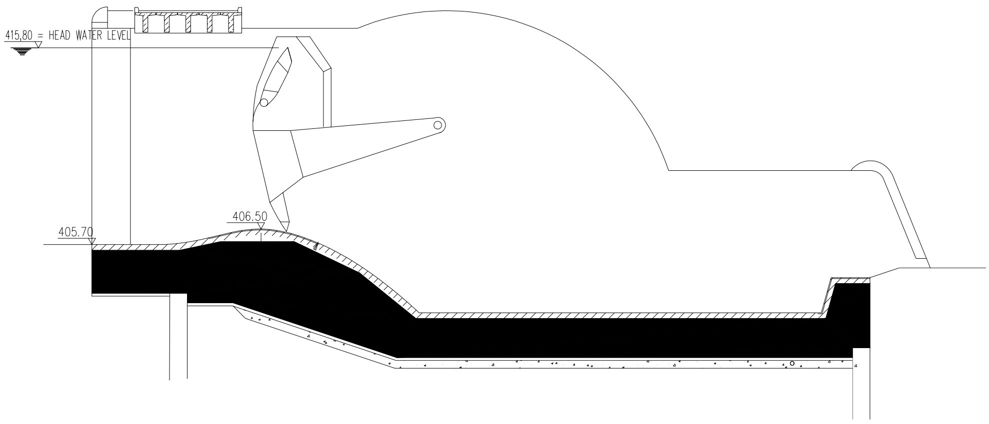

Figure 3: Rott-Freilassing power station – new plant, section through weir – spillway

The project submitted to the water-right authorities suggested the weir operating rules listed below, which were developed on the basis of theoretical considerations for the operation of the gates; the official permit provided that these rules be tested and, if necessary, optimised on a hydraulic scale model.

Weir operating rules as suggested in the submitted project (Diagram 1):

- Maintain top water level 415.80m up to a flow corresponding to the one-year flood of approximately 310m³/s;
- For higher flows, draw down of the reservoir level to 413.50m within a period still to be determined;
- Maintain reservoir level 413.50m up to a flow of approximately 800m³/s;
- For flows exceeding the 50-year flood of 850m³/s, allow them to pass to the discharge regime of the weir crest, all gates open.

SCALE MODEL TESTS

The hydraulic scale model tests were carried out at the Department for Hydraulic Engineering and Water Resources Management of the Graz University of Technology. The model covered a length of about 800m upstream and about 200m downstream of the weir. Upstream of the weir, the railway bridge with its foundation and what remains from the original bottom sill were reproduced. The slopes and the weir were constructed in concrete. The powerhouse on the left-hand side and the Tainter gates with the flaps on top were made of plastic (Trovidur) and plexiglass. The old power station was modelled over the portion situated below 407.50m (the level to which the old plant is planned to be demolished). The river bottom was modelled as a movable bed. The hydraulic model was operated as a non-distorted full model to a scale of 1:40, according to Froude’s law of similitude. Bed-load movement was simulated by means of ceramic sand of size fraction 0.5–1.2mm. The bed-load mix approximately corresponded to the prevailing grain diameter d_p = 21 to 22mm (extending to a range of between 19mm and 25mm).

In order to make allowance for the potential natural variation of bed-load transport for developing the weir operating rules, the boundary conditions were studied. For this purpose the tests were run both with and without sediment being added upstream of the railway bridge. In each case the constant peak flow of each individual flood was simulated over a period of about 10 hours, with the turbines shut throughout the test. The tests with sediment addition were based on an annual volume of approximately 60,000m³ per year. The sediment transport function was assumed as a linear relationship between flow and transported volume of bed load, with bed-load transport beginning at mean flow. The slope of the sediment-transport function was determined iteratively so as to make the annual volume of bed-load transport correspond to the above value. In addition, the water level above the weir were varied. The initial condition for the headwater bottom level was first selected on the basis of the result of the river-bed survey of March 2000. However, since following reservoir flushing in June 2002 while the model test was being run, the reservoir bottom above the power station had deepened by up to 1.5m. This new bottom level was used for the tests with sediment addition.

In Diagram 1, the headwater level upstream the new weir is shown plotted against flow for the individual tests, which are identified by numbers. The headwater levels studied were 415.80m (corresponding to the top water level), 414.65m, 414.0m, and 413.50m; the headwater levels above the new weir, with the gates completely open, resulted from the discharge curve of the weir (corresponding to Points 1 to 3a). This diagram includes all the eleven tests points (circles), the weir operating rules as proposed in the project submitted for approval (squares) and the final proposal developed on the basis of the model tests (diamonds).

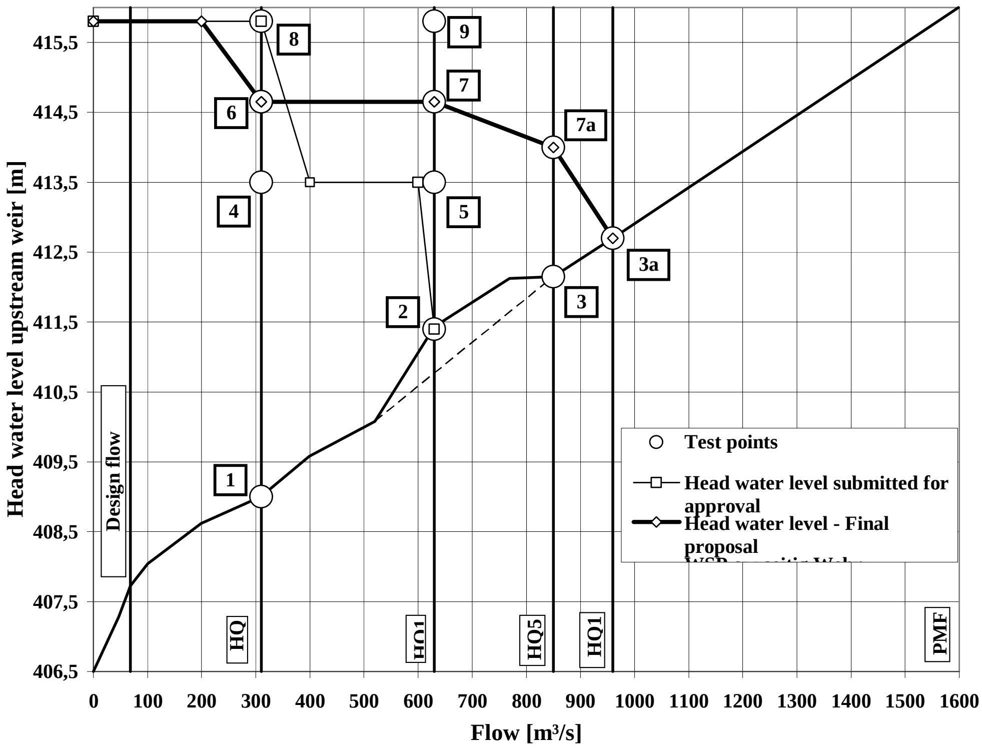

Diagram 1: Weir Operating Rules – development and final proposal

Diagram 2 shows the river-bottom levels for the tests without sediment addition. Tests at Points 1, 3, 3a: These three tests, conducted for different floods, demonstrated that, with the gates being completely open, the bed-load cushion between weir and railway bridge is dramatically mobilised.

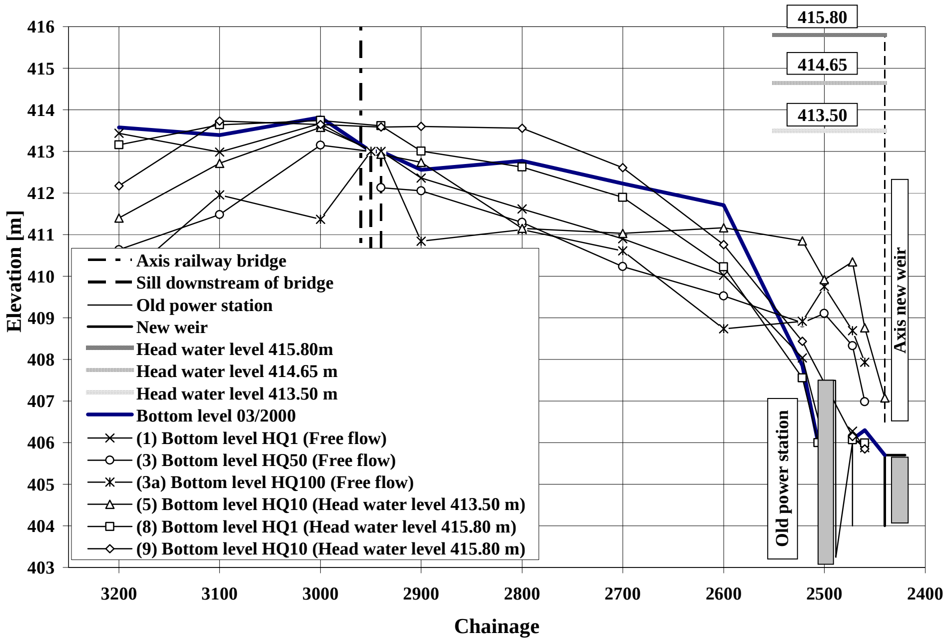

Diagram 2: Mean reservoir bottom levels – tests without sediment addition (selected from all the results)

Tests at Points 4 and 5: Point 4 gave only little moving tendency, that is, more or less stable conditions; for Test Point 5, the sediment cushion was reduced to a height of 1.5m, with the front of the cushion moving to a line directly above the new weir (sedimentation to about 410m). Tests at Points 8 and 9: The bottom level for Test Point 8 approximately corresponds to that of the existing power station. The test for Point 9 was performed only for the sake of completeness as in fact the authorities do not permit the top water level to be maintained during a 10-year flood. This test showed a clear sedimentation tendency upstream of the new weir as well as in the section of the railway bridge. In addition, the head of the sediment cushion was seen to travel downstream.

These test results gave a minimum bottom level of approximately 410m to ensure the stability of the railway bridge foundations (Diagram 2). In addition, the provision of sheet piling at least 8m in length downstream of the existing bottom sill was suggested, followed by a scour-protection apron of riprap.

The tests performed without sediment addition more or less confirmed the validity of the weir operating rules as suggested in the project submitted to the authorities: the top water level should be maintained to a flow corresponding to the one-year flood; for higher flows the headwater level should be drawn down in order to ensure the passage of bed load. This water level should be maintained as long as possible, as transition to the discharge regime for uncontrolled flow over the weir crest would cause the existing sediment cushion to start moving dramatically, which could lead to the emptying of sediments from the reservoir.

Using the results of the tests without sediment addition, the tests at the significant points selected for drawing up the weir operating rules (Diagram 1) were run, this time with sediment being added. Diagram 3 shows the river-bottom levels for the tests with sediment addition. The testing programme was extended by studying additional points for headwater surface level 414.65m. The reservoir bottom levels used in the tests are shown in Diagram 3. Test at Point 3: This test resulted in bed-load removal upstream and downstream of the railway bridge. The lowest erosion level downstream of the sheet piling was approximately 410m. This bottom level was seen to form all the way up to the old power station. The head of the bed-load cushion travelled in the direction of the new weir. Tests at Points 4 and 5: The test at Point 4 (HQ_1) gave only little movement at the bottom. The bottom level measured for Test 5 (HQ_{10}) approximately corresponded to that obtained in the test without sediment addition. Erosion downstream of the railway bridge lowered the bottom level to about 411.0m.

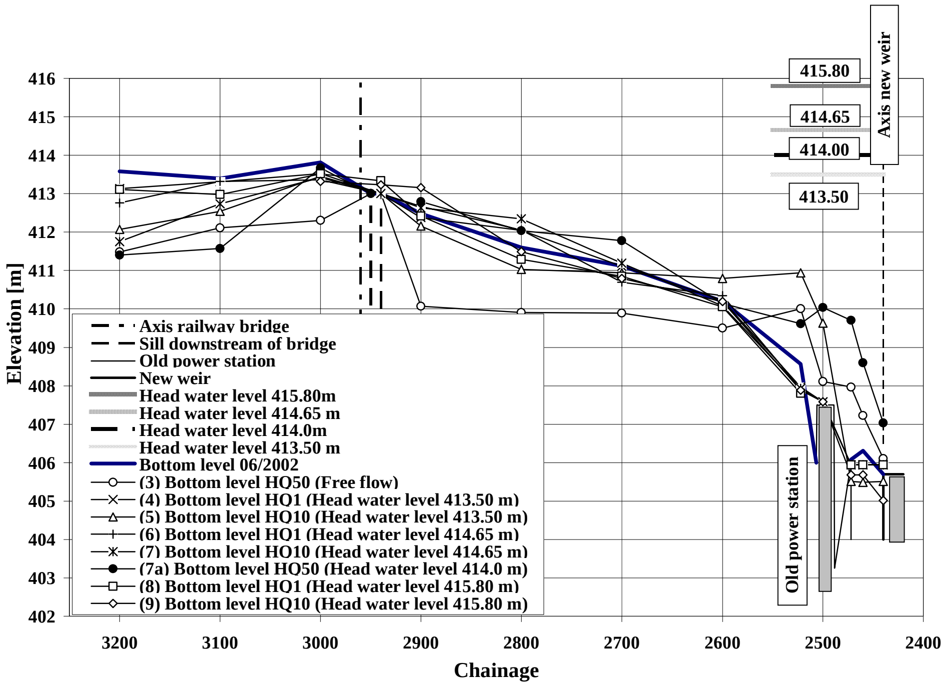

Diagram 3 : Mean reservoir bottom levels– tests with sediment addition (selected from all the results)

Tests at Points 6, 7, and 7a: Test Point 6 (HQ_1) yielded no bottom level changes in the reservoir. The advantage over keeping the headwater at top water level for this flow rate (corresponding to Point 8) is that no sediment accumulates around the railway bridge. The test at Point 7 for HQ_{10} produced a well-balanced bottom slope within the reservoir, rather than building up a steep bed-load front above the new weir as in the test at Point 5 with the headwater level at 413.50m. The test at Point 7a (HQ_{50}) served as an extension to the tests at Points 6 and 7. In this extreme case, sediment was removed upstream of the railway bridge, while the area around the bridge was largely kept free from bed load. Within the reservoir sediment was deposited to a depth of about 0.5m, a bed-load head formed and the bed-load cushion extended down to the new weir. Tests at Points 8 and 9: For Test Point 8 (HQ_1), no significant erosion or sediment accumulation was seen to occur. Sediment was deposited round the railway bridge (which fact led to conducting tests at Points 6 and 7, which were used as a basis for the Final Proposal, with the headwater level drawn down). The test at Point 9 (HQ_{10}) was again carried out for the sake of completeness. Maximum sediment deposition around the railway bridge reached 414.0m. The reservoir bottom level remained more or less the same.

RESULTS

Based on the results from all the tests, the weir operating rules were suggested indicated below and shown in Diagram 1. On the assumptions used in respect of sediment composition and transport rate, as well as the expected durations of the studied floods, these rules will ensure the passage of the incoming sediments, except for extreme events exceeding about HQ_{10}, which might necessitate subsequent flushing upstream and downstream of the weir.

Suggested weir operating rules:

- Maintain top water level 415.80m to a flow of $200m^3/s$;
- For larger flows up to HQ_1, draw down the reservoir surface by lifting the Tainter gates to 414.65m;
- Maintain reservoir surface level 414.65m to a flow of $630m^3/s$ corresponding to the HQ_{10};
- For flows larger than that, draw down the headwater level to 414.00m.
- For flows exceeding the 50-year flood of $850m^3/s$, pass to the discharge regime of the weir crest – all gates open.

SUMMARY

This paper describes the scale model tests conducted for the purpose of preparing operating rules for the gates of a new weir which replaces an existing one. The weir has the purpose of maintaining the riverbed in the reservoir at a well-defined level to prevent erosion. The methodology of the model tests is described; it can be applied to similar fluvial problems with minor modifications.