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REHABILITATION AND REFURBISHMENT OF AN INTAKE WEIR OF A DIVERSION-TYPE RUN-OF-RIVER PLANT

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ABSTRACT

A recently completed research study by the Institute of Hydraulic Engineering and Water Resources Management, Vienna University of Technology, commissioned by VERBUND Hydro Power GmbH, investigated the rehabilitation and refurbishment of the intake weir of an approximately 110 year-old diversion-type run-of-river plant by means of a physical hydraulic model. The existing weir consists currently of five different outlet bays and the intake of the headrace channel with a flushing structure. At this time a short fish ladder is installed in a lateral weir pier. Part of the project consisted of an extension of the weir by the retrofitting of a moveable hydropower module (so called “Roth-turbine”) into a new weir bay on one hand to increase the discharge capacity during flood events and on the other hand to generate electric energy by utilization of the residual water delivery into the diverted river stretch. Also, the placement of a combined vertical slot and pool fish passage at the weir site was planned according to the demands of the European water framework. This structure with negligible influences on the hydraulic conditions of the main intake weir was not considered in the hydraulic model.

The aim of the investigation was the determination of the discharge capacity of the complete weir and operation of specified individual weir bays for normal flood conditions and

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also during the construction phase. In this context also the energy dissipation downstream of the weir bays was investigated and measures for scour stabilization were developed. Special attention was also paid to the operation of this new weir bay with a rotatable powerhouse module (“Roth-turbine”) during flushing and flood water conditions in terms of the approaching flow, clogging, sediment aggradation, passage and flushing, including energy dissipation.

1. General project description

The Peggau diversion-type run-of-river plant (Figure 1) was built during the years 1906 to 1908. In 1963 the construction of a new powerhouse with deepening of the downstream section of the river Mur (Styria) was carried out.

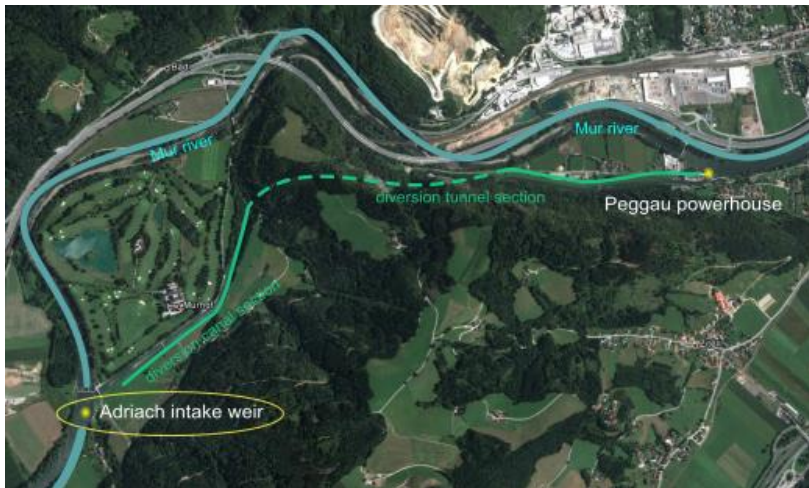


Fig. 1. Overview of the existing Peggau run-of-river plant with Adriach weir (source: Google maps)

The Mur river was dammed at river station 205.15 km by the Adriach weir (Figure 2). The length of the diversion canal is 3.14 km and has two open canal sections and one 1.10 km long tunnel section. The powerhouse is located at river station 200.60 km outside Deutschfeistritz town. The diverted river Mur reach has a length of 4.35 km.



Fig. 2. Upstream and downstream view of the existing Adriach weir with diversion canal (source: VERBUND)

At present the entire intake weir consists of the following main hydraulic structures: weir bay #1, sluice bay, weir bay #3, log chute, canal lock chamber, flushing outlet and diversion canal intake (Figure 3).

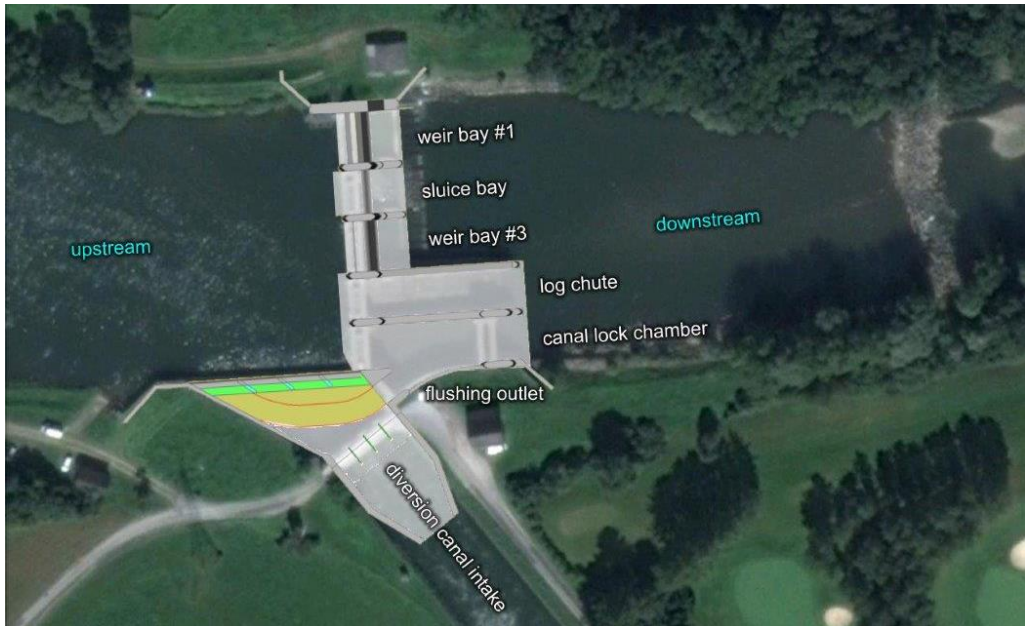


Fig. 3. Aerial view of the existing Adriach weir (source: Google maps)

The owner, VERBUND Hydro Power GmbH, of this hydropower plant planned a rehabilitation and refurbishment of the existing Adriach intake weir in terms of flood water control (Figure 4) with increase of the discharge capacity, the improvement of the energy dissipation downstream of the weir (Figure 5), and additionally an increase of the residual water delivery into the diverted river section according to the requirements of the European water framework.



Fig. 4. Downstream region during a Q30-flood water discharge (source: VERBUND)



Fig. 5. Downstream scour backfill at the energy dissipation area of weir bay#1and #3 and sluice bay (source: VERBUND)

The higher discharge capacity and additional water delivery should be provided by means of an extension of the Adriach weir by an extra lateral weir bay. An equipping of this with a moveable hydropower module (“Roth-turbine”) to generate electric energy (Figure 6 and Figure 7) was further planned. The installation of an improved fish passage at the weir site was also designed to fulfill the legal and environmental requirements.

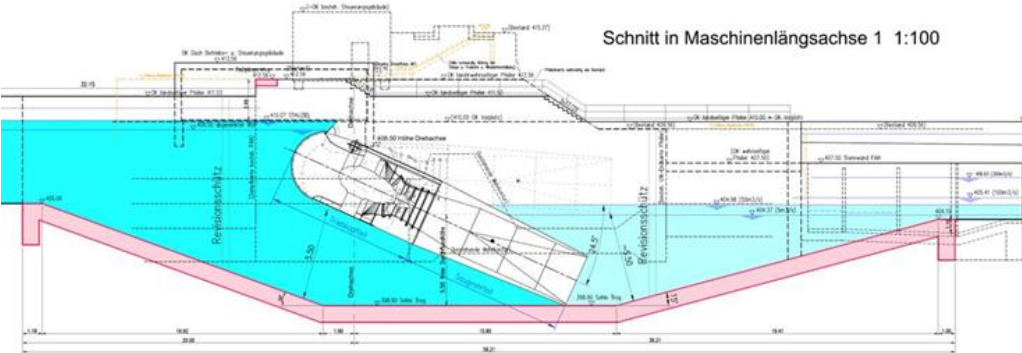


Fig. 6. Longitudinal section of the planned weir bay with a moveable (rotatable) powerhouse module (source: VERBUND)



Fig. 7. Layout of the new weir bay with powerhouse module and new fish passage (source: VERBUND)

2. Hydraulic model

The hydraulic model of the existing Adriach weir (Figure 8) was built in the Laboratory of the Institute of Hydraulic Engineering and Water Resources Management at the Vienna University of Technology. The full model in a scale of 1:40 represented a section of the river Mur from river station 204.936 km up to 205.770 km (stretch length 834 m, Figure 9).



Fig. 8. Upstream and downstream view on the initial model



Fig. 9. Aerial view of model domain

The model was built and operated according to Froude similarity. This gives the following scale factors (Table 1) for the conversion of the model to the prototype parameters:

Table 1. Scale factors for conversion from model to nature

length l	M_l	$1 : M_l$	$1 : 40$
velocity v	M_v	$1 : M_l^{1/2}$	$1 : 6.3$
discharge Q	M_Q	$1 : M_l^{5/2}$	$1 : 10, 100$

The upstream river bed was built with a fixed bed and the downstream section was provided with a moveable bed to assess the efficiency of the energy dissipation of the existing weir and the new bay with the implemented moveable Roth-turbine for the residual water flow. The riverbed material lay in a range of 25.0 mm up to 100 mm, in the model from 0.6 mm up to 2.5 mm this gives a $d_m \geq 1.0$ mm, which allows an adequate simulation of the sediment transport behavior. Relevant water discharges are given in Table 2.

Table 2. Relevant discharges at the weir site (prototype and model)

Discharge	Q_{Nature} , m ³ /s	Q_{Model} , l/s
HQ_{300}	1.550	153
$HQ_{100(reduced)}$	898	89
HQ_1	430	42
MQ	113	11
$Q_{Diversion\ canal}$	110	11
$Q_{Turbines}$	50	5

The water discharges were measured and regulated by means of two inductive flow meters and two valves, one measurement unit in the water supply pipe of the river Mur and the other in the diversion canal to the powerhouse. The upstream water level was measured at section 205.200 km, the downstream water level was adjusted according to a rating curve by a flap at the end of the model and measured by point gauges at section 204.940 km. For visualization of flow paths dye was injected in the concerned regions.

3. General aims of investigation

Numerous test series were executed to clarify the following questions:

- Determination of the discharge capacity of the individual weir bays.
- Determination of the discharge capacity of selected weir bay combinations (e.g. $n-1$ cases).
- Assessment of the energy dissipation and optimization of the stilling basins.
- Improvement of approaching flow and outflow conditions.
- Development of measures for downstream scour protection.
- Flushing of sediments through the weir bay with power module.

4. Selected test results

The following selected test results give an overview of the investigation:

4.1. Determination of the discharge capacity of individual weir bays (current status)

- Sluice bay (middle weir bay), span 12.00 m, length 17.70 m (Figure 10).
- Canal lock chamber, span 12.00 m, length 48.85 m (Figure 10).

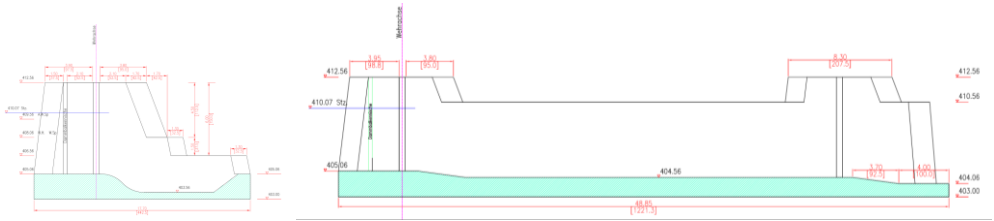


Fig. 10. Longitudinal sections of sluice bay and canal lock chamber

For the selected weir bays the following discharges were determined at the official approved reservoir level of 410.07 m.a.s.l. (Figure 11):

- Discharge sluice bay 225 m³/s (calculated 245 m³/s) at 410.07 m.a.s.l.
- Discharge canal lock chamber 210 m³/s (calculated 229 m³/s) at 410.07 m.a.s.l.
- Obviously the computed results obtained by a consulting firm overestimated these discharges, whereas those of other outlet bays were underestimated in the computations.

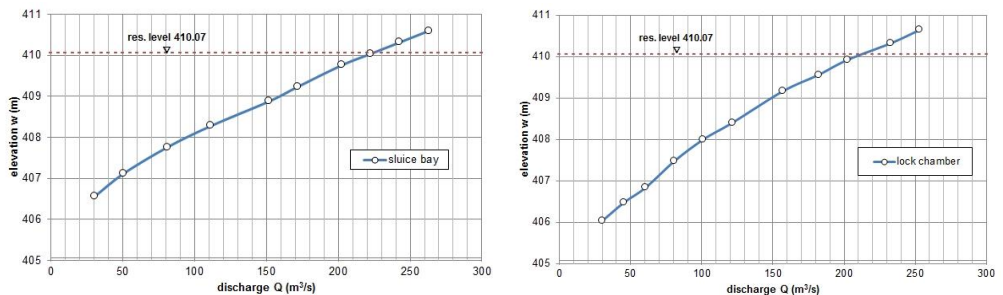


Fig. 11. Rating curves of sluice bay and canal lock chamber

4.2. Determination of the discharge capacity of selected load cases (current status)

For the public authority some other combinations of weir bay operations were tested too. The following Figure 12 shows the rating curves of two weir operational cases where also the diversion canal is discharging 110 m³/s.

- Load case: weir bay 1 (W1) + sluice bay (SB) + weir bay 3 (W3) + flushing outlet (FLU) + diversion canal (DIV).
- Load case: weir bay 1 (W1) + sluice bay (SB) + weir bay 3 (W3) + log chute (LOG) + diversion canal (DIV).

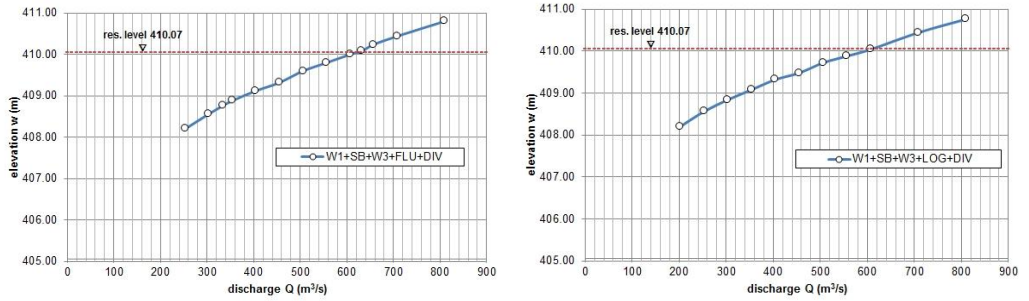


Fig. 12. Rating curves of two weir operational cases

The entire discharge for each load case can also be obtained within small differences by summing the individual discharges of the open weir bays.

For the selected load cases the following discharges were determined at the official approved reservoir level of 410.07 m.a.s.l.

- Load case: weir bay 1+ sluice bay + weir bay 3 + flushing outlet + diversion canal 620 m³/s.
- Load case: weir bay 1 + sluice bay + weir bay 3 + log chute + diversion canal 600 m³/s.

4.3. Assessment and improvement of the energy dissipation

During the passage of flood water complete destruction of the downstream river bed protection occurred. Particularly the region behind the sluice bay was heavily affected, but also the regions of the laterally located bays (Figure 13). Obviously the existing concrete stilling basins were built too short and also the log chute and lock chamber had no extra energy dissipators. Particularly the inclined end sill of the sluice bay could not contain the hydraulic jump; it formed a jet which produced a deep scour close behind the stilling basin (also in the prototype).



Fig. 13. Downstream region before and after tests with mobile riverbed

To improve this malfunction of the energy dissipation, the end sill of the sluice bay was raised by 80 cm and also the chamfer was removed to stabilize the hydraulic jump mainly within the stilling basin. Additionally a new secondary stilling basin was made by quarry stones embedded in concrete and stabilized with a fixed end sill. It should prevent further scouring of the riverbed by keeping the hydraulic jump within it. Nevertheless, a graded riprap layer on the downstream riverbed and bank was also necessary over a certain length to protect against massive scouring during strong flood events (Figure 14).



Fig. 14. Scour protection with second stilling basin, heightened end sill of the sluice bay, riprap protection of riverbed; weir bays discharging flood water, downstream region after flood discharges

4.4. Tests of the new weir bay with hydropower module

The rotatable turbine module with attached flap has a multi-function as gate and simultaneously it produces electric energy. During turbine operation it can also be partly raised for sediment flushing or the flap can be lowered to remove floating debris. In such a position the turbine utilizes a so-called ejector effect by an over-flowing and/or under-flowing of the module. The module consists of 2 installed turbines with a maximum discharge each of $25 \text{ m}^3/\text{s}$. A bent basket trash rack in front of the turbines should protect against the inflow of debris. The module can be lifted by means of a hydraulic hoist.



Fig. 15. Upstream and downstream view of the original model with the additional left weir bay

The new weir bay had originally a width of 10.70 m, a clearance of 5.50 m below the horizontal fully-open hydropower module (with 2 turbines, Figure 15). The trough invert was

originally designed at elevation 398.90 m.a.s.l, afterwards it was lifted during the optimization phase at 400.00 m.a.s.l. The discharge capacity of the weir bay with fully-open module at the reservoir level of 410.07 m.a.s.l. was maximum 450 m³/s. A flood water scenario at the weir site can be seen in Figure 16.



Fig. 16. Q_{100} -discharge, load case (n-1)

The approaching flow only with the power module fully-open took place mainly transverse to the forebay. The upstream widening of the left retaining wall had no influence on the inflow conditions; therefore, the left bank was shifted towards the middle of the river, also to gain more space for the new fish pass. Flow separation at the separation pier and mainly an underflow occurred during flood discharges with fully-open module (Figure 17).



Fig. 17. Flood water discharge through the new turbine weir bay with different left retaining wall designs

Under partly or fully-open turbine module conditions for flushing purposes, the jet leaving the module was very energy-rich and the dissipation occurred mainly on the river bed which was only protected by riprap. The downstream region concerned was totally eroded. As a consequence, this tailwater region was also protected with heavy quarry stones which were fixed in concrete. Other measures for an improved energy dissipation, e.g. with sills or baffles, were also tested but in terms of the electric energy production they reduced the net head (Figure 18). The downstream efflux due to turbine-only operation (max. residual water

discharge $2 \times 25 \text{ m}^3/\text{s} = 50 \text{ m}^3/\text{s}$) was calm and did not lead to any damages of the riprap protected river bed.

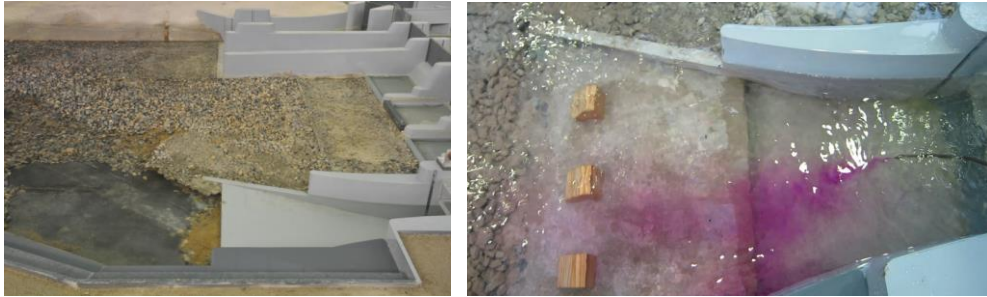


Fig. 18. Scour downstream of the turbine weir bay, energy dissipation devices behind the module draft tube

For sediment flushing the module could be raised (partly-rotated), the sediment (also larger stones) could be totally removed from the vicinity of the inclined intake and horizontal weir apron to the downstream side where it would be later steadily removed. With a longer period of turbine-only operation a certain deposition of sediment will occur at the upstream inner bend of the river bank, but during flood water events this sediment could be flushed away through the weir bays. To prevent a blow-out of the hydraulic jump downstream of the weir bay (module) a certain tailwater level should be reached by opening other weir bays before the module is partly opened. An opening of the turbine module should be done in accordance with the weir regulation rules during flood water discharges (Figure 19).



Fig. 19. Downstream view of the final model, flushing during a flood water discharge

5. Summary

This paper gives an excerpt of hydraulic model tests results for the rehabilitation and refurbishment of a 110 year-old intake weir of a diversion-type run-of-river plant. Numerous tests were executed to clarify relevant questions (see section 3) to obtain reliable basic information for the final structural design, construction and operation of the hydropower plant.

The tests revealed e.g. inadequate energy dissipation with strong scour formation in the downstream region of all weir bays. This malfunction could be improved by the construction of a secondary stilling basin, made with quarry stones embedded in concrete, and extended with a graded riprap layer over a certain downstream section. Furthermore, the approaching flow conditions to the turbine module could be optimized with a modified guidance wall at the left river bank. A sufficient flushing during flood water conditions was confirmed by the tests. A main task was also the development of a weir operation rule for the planned “new” Adriach weir.

Additionally, several other test arrangements e.g. with half turbine module, different bottom levels, clogging, etc. were also executed during this comprehensive investigation, but these results are not presented in this paper.

РЕХАБИЛИТАЦИЯ И ОБНОВЯВАНЕ НА ВОДОВЗЕМНОТО СЪОРЪЖЕНИЕ НА ДЕРИВАЦИОННА ВЕЦ

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Ключови думи: рехабилитация, централа на течащи води

РЕЗЮМЕ

Наскоро завършило изследване, проведено в Института по хидротехника и инженерна хидрология при ТУ Виена и възложено от VERBUND Hydro Power GmbH, анализира възстановяването и модернизацията на водовземането на една около 110-годишна деривационна централа на течащи води с помощта на физичен хидравличен модел. Съществуващият яз се състои понастоящем от пет различни полета, входно съоръжение за деривационния канал и промивно съоръжение. В момента се изгражда къс рибен проход в един от страничните стълбове. Част от проекта се състои в разширение на яза чрез преустройство с подвижен електроенергиен модул в ново поле с цел от една страна разширяване на пропускната способност в условия на високи води и от друга – производство на електроенергия от оползотворяване на отводнителното водно количество за нарушения участък. Предвижда се изграждането на комбиниран рибен проход с шлицови отвори и басейни. Но това съоръжение с пренебрежимо влияние върху хидравличната работа на водовземането се пренебрегна при изграждането на модела.

Цел на изследването беше определянето на пропускната способност на цялото съоръжение, както и отделните полета в строителни и експлоатационни условия. Беше изследвано и гасенето на енергията в долния участък със съответни мерки за укрепване. Специално внимание беше отделено на експлоатацията на новия подвижен електроенергиен модул при промиване и високи води в смисъл на подходящо течение, наносен отток и гасене на енергията.

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