The Positioning of a Hydropower Plant Into a River Using the Hydraulic Modelling,
a Case of Sava River HPP Chain Development

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Introduction

The positioning of the hydropower structure into a river demands a judgement of the location and of the structure position from many different points of view, considering some security conditions (the conditions of the stability, flood safety, operational safety,...), some economical conditions (the investment costs, the operational costs, the maintenance costs,...), the environmental impacts (flood safety, the flow regime, the living conditions for the aquatic and riverside flora and fauna,...) and many other aspects.

From the civil point of view one of the basic conditions in the hydropower structures planning is reaching of a minimum impact of the built in structure on the stability of the river. Therefore the basic rule is that all the kinetic energy, which is produced by our structure, must be dissipated inside the structure, or at least reduced in a manner in which the downstream riverbed can be able to carry it without any damage. The maximum permissible load of the downstream riverbed is, of course, different from one location to another, which means that every single location must be adequately tested in order to identify all the impacts, involved at a particular location. But just as much as to the dissipation efficiency of the structure, our concern should be devoted to other aspects.

The economic interest of the investor is of course to minimize the investment and the operating costs, and at the same time to maximize the economic efficiency of the HPP. Since it is usually impossible to reach all this at the same time, it is necessary to accept some compromises, and to reach the optimum balance between the input and the output of the project. In many cases it is impossible to reach a sufficient saving without adequate investment in some expensive and detailed studies and researches.

This paper presents the results of a model study, which was performed to determine the optimum shape of the right river embankment from the hydraulic point of view. During the research also the aspect of the operational security, concerning the stability of the downstream embankments and the riverbed was considered, but in this paper we would only like to explain the impact of the embankment shape on the economy of the structure.

1. Facility and Model Description

1.1 Facility Description

The Lower Sava river HPP chain consists of six low-head run-of-river power stations. Each of them consists of a dam with five spillways of 15 m width and of a turbine structure with three generator sets. The first two power plants were built with bulb turbines, the rest of the chain is designed with the Kaplan turbines of the same characteristics. The installed power is P_i = 43 MW at operating head of 10 m and discharge of Q_i = 500 m^3/s.

1.2 Hydraulic Model Description

The hydraulic model extended over 2km of the riverbed including the complete HPP dam structure. The model was built in the undistorted model scale 1:50. The observed and measured parameters were: water discharge, velocities, water levels, flow patterns, sediment transport and erosion. The modeled location was for the HPP Boštanj, which is the second of six planned power plants in the chain, but because of the resemblance of the locations and structures, all the results of the research can be directly implemented in all the other HPPs of the chain.

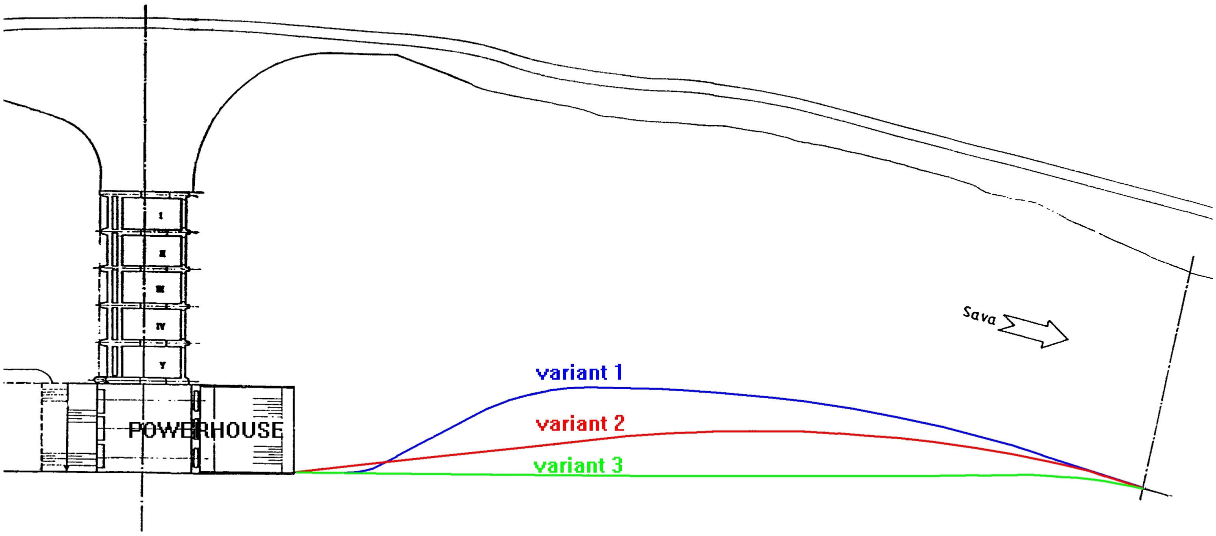

Fig. 1: The Situation of the Dam and the Tested Solutions

Three variants of the right downstream embankment were tested:

- Variant 1 represents the minimum intervention extent and also the minimum investment costs, since the embankment line practically follows the line of the natural river bank.
- Variant 2 represents the intermediate solution between both extreme ones.
- Variant 3 represents the maximum intervention extent and also the maximum investment costs, considering the amount of the necessary excavation and also the size of the land, which should be bought in that case.

2. Model test results

2.1 Velocity Profile

Changing the right embankment shape influences greatly on the velocity distribution across the water profile. On the Fig.2 we can clearly see that the main stream moves more and more to the right, as we straighten the embankment curve. Also the maximum velocity of the profile more and more increases, as the flow straightens. From the hydraulic point of view, concerning the velocity profile, there is no obstacle for use of any of the variants. The only consequence of the right embankment straightening is that the recurring vortex in the inactive area of the profile enlarges, and enables the deposition of the fine sediment behind the spillway section of the dam. This has no harmful influence on the evacuation of the higher discharges, because the transport capacity during the flood waves is much higher than at the time of the sediment deposition.

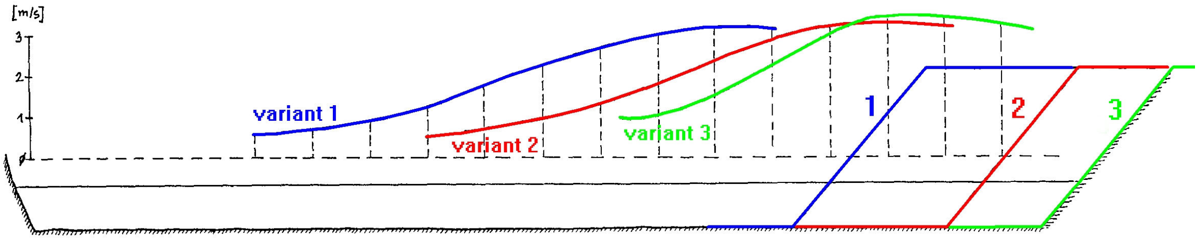

Fig. 2: The Velocity Profiles for the Different Variants of the Right Embankment

2.2 Shear Velocities

The equability of the shear velocities distribution alongside the right embankment is normally the greater, as the embankment shape straightens. This is also the situation in our case. In Fig.3 we can see the irregularity of the shear velocity distribution in the upstream half of the section, which is the consequence of the rounded shape of the right embankment, stretched over the whole turbine outlet width. The most equable shear velocities distribution is achieved in the variant 2, where also the highest values of the shear velocity don't exceed 3,2m/s. Considering the shear velocity distribution the variant 1 is less acceptable, but other two variants are both totally acceptable for the final project.

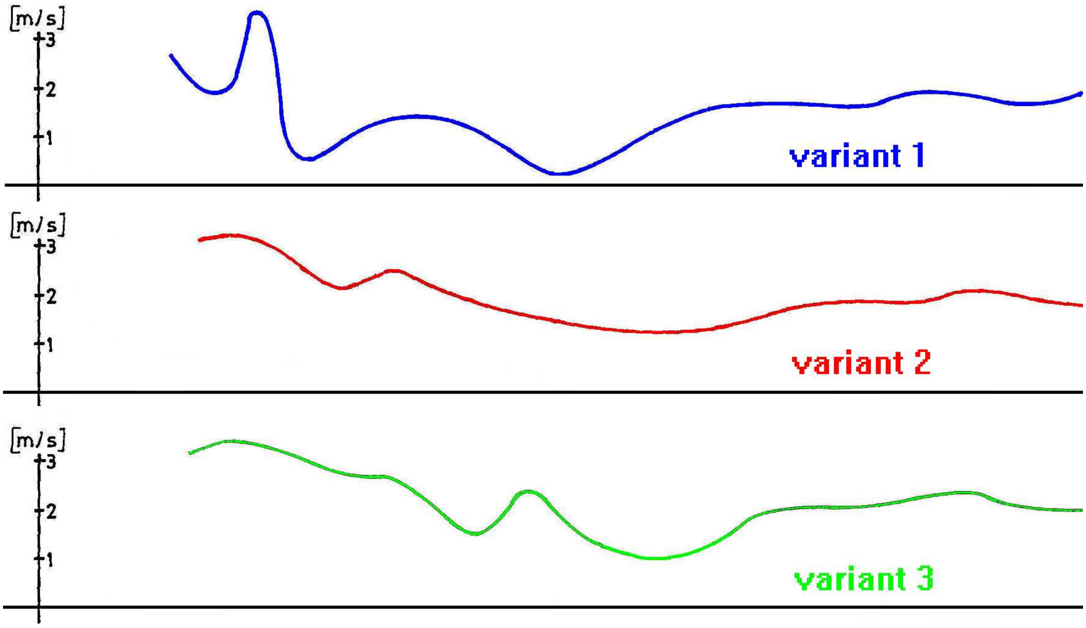

Fig. 3: The Shear Velocity Distribution Alongside the Right Embankment, for the Different Variants

2.3 Water Level Profile

The longitudinal profiles of the tail-water level alongside the testing section of the right embankment were for all three variants different. As shown on the Fig.4, the water surface slope shapes according to the shape of the right embankment.

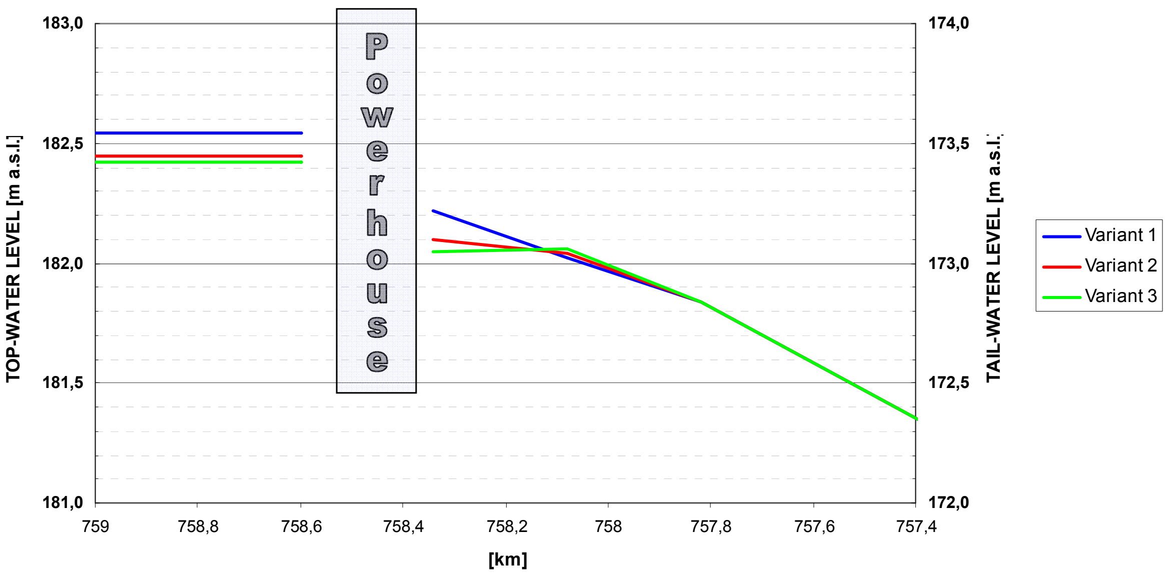

Fig. 4: The Water Level Profile for the Different Variants

The actual tail-water level is measured immediately downstream of the turbine outlet, and this is the point of the largest interest for the investor. If we are able to lower the tail-water at the same water discharge, we can get larger net head of the turbine, which means that in that case it is possible to increase the power of the generators, until the top water head reaches the nominal level.

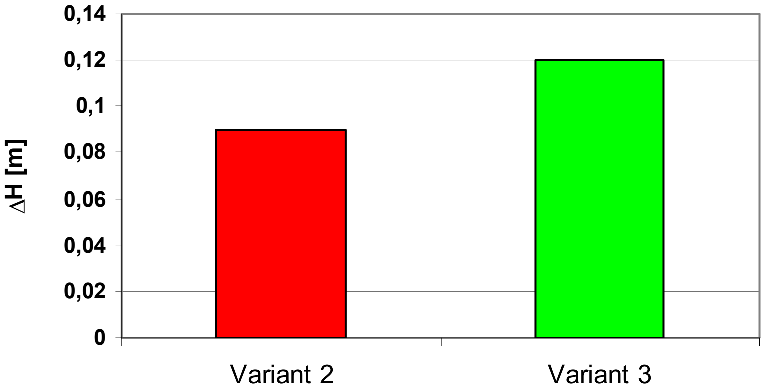

Fig. 5: The Gain in the Net Head of the Turbines for the Different Variants in comparison to the initial design – variant 1

3. Conclusions

The model tests have shown clearly, that shaping the river banks downstream of the hydro power plant is important also from the economic point of view, and not only from the security aspect. The gain for the investor is important even though it seems small. But we must consider the fact, that the hydro power plants have a very long functioning period, which is for the civil part closer to 100 years than to the usually considered 30 years. For our case the net head difference of 0.09m in variant 2, which was chosen as a final solution, gives the investor extra 6 to 14 million EUR profit in a period of 30 years of normal operation of the entire HPP chain on Sava river. The investment costs during the construction are negligible in comparison to the profit during the operation.

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The Authors

J. Mlačnik finished his undergraduate studies in 1987 at the Hydraulics Division of the Faculty of Civil and Geodetic Engineering of the University of Ljubljana. He started working as a researcher in hydraulic laboratory of Institute for Hydraulic Research (at that time Water Management Institute) in 1988. Since 2000 he works as a manager and a head expert of Institute for Hydraulic Research. His experience covers most of all physical modelling of hydraulic phenomena and field measurements in domain of hydraulics, hydrology and hydrographical surveys. He also deals with mathematical modelling in field of hydraulics and in most recent period he is making a great effort in introducing hybrid models into the Slovenian hydraulic research practice.

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Martin Bombač finished his undergraduate studies in 2005 at the Hydraulics Division of the Faculty of Civil and Geodetic Engineering of the University of Ljubljana with the graduation project Hydraulic Optimization of the Intake Part of the Run-of-river Power Plants. He started working as a researcher in hydraulic laboratory of Institute for Hydraulic Research in 2005, where he is mostly engaged in combining the mathematical and physical hydraulic modelling.

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