Hydraulic model tests of the stilling basin for HPP Moste III

Jure Mlacnik
Institute for Hydraulic Research
Hajdrihova 28
Ljubljana
Slovenija

Dusan Ciuha
IBE, Consulting Engineers,
Hajdrihova 4
Ljubljana
Slovenija

Introduction

The company SEL d.d., which owns all the HP plants on Sava river in Slovenia plans to increase the installed power on HPP Moste, which was built in the beginning of fifties. HPP Moste is situated on Sava river approximately 4km north from well known tourist centre Bled. The construction of additional machine hall (HPP Moste II) and compensation basin, which is to enable the full power production of peak energy for both hydroelectric plants is planned. The project also includes a small 4MW HPP Moste III, situated in the body of the compensation basin dam.

The hydraulic model tests of spillway sections and stilling basins of HPP Moste III were performed in Hydroinstitute in Ljubljana. The basic demand of this research was to ensure the complete dissipation of water flow energy inside the stilling basin in every possible operating mode up to Q_{100}. Since there are only two spillway sections, in the case of one blocked gate there is only a single section operating, which entails very large specific loads of stilling basin. This appeared to be the main problem to be solved by this research.

The original design was 25m long standard stilling basin with one row of baffle blocks and ended with one step end sill. The originally designed version as also all known usual variants, which could possibly lead us to a positive solution, were tested on a hydraulic model built in model scale 1:35. The model tests established that all tested variants have the same weakness, that is explicitly asymmetric flow over the end sill. Therefore the part of the stilling basin, behind the blocked spillway section, was in all studied cases inactive. The consequence was very large specific discharge in the active part of the stilling basin. In such conditions only a part of energy dissipation can be performed inside the stilling basin, the rest of it is transmitted into the downstream channel.

To accomplish the effective dissipation inside the stilling basin it would be necessary to diminish specific discharge over the spillways, which is possible only with increasing the number of spillway sections. That requires a newly designed and much larger building than the original design, construction in two phases and also increase of construction time (costs!) for a whole season.

As the only possible solution, which can keep the construction in some reasonable limits according to technical and economical criteria, we developed a stilling basin, which is unusual for the present type of the spillway section. Given solution provides very good water flow arrangement over the end sill and excellent energy dissipation using the combination of bottom sills and scum boards. After extensive tuning of shape and disposition of all dissipative elements we reached a highly effective solution, which practically stays inside the originally designed construction limits. The result of the research enables construction in only one construction phase without extending the time of construction.

1. Initial design research

According to original design the stilling basin is 25m long joint structure for both spillway sections (Fig. 1). The middle spillway pier ends at the beginning of stilling basin with semicircular vertical ending. Stilling basin bottom is horizontal equipped with one row of baffle blocks and solid end sill, which should be able to ensure full dissipation within the stilling basin.

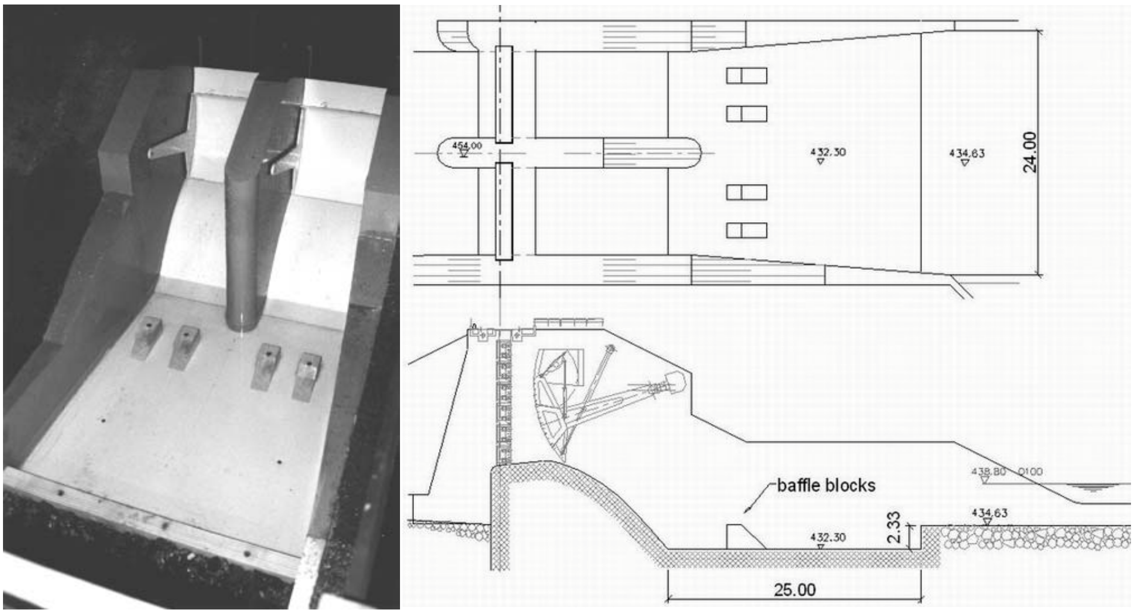

Fig. 1: Spillways and stilling basin of HPP Moste III – original design

1.1 Geometric, hydraulic and hydrologic conditions

The stilling basin belongs into a group of short stilling basins, its length is reduced for about 40% regarding to theoretical length of the stilling basin, calculated according to the geometrical and hydraulic parameters. On the graph below (Fig. 2) we can see that, in our case, in almost all operating conditions the comparable values lie under the theoretical limit of stabile stilling basin operation. This demands a use of baffle blocks and other dissipating elements, which must be optimized on a hydraulic model.

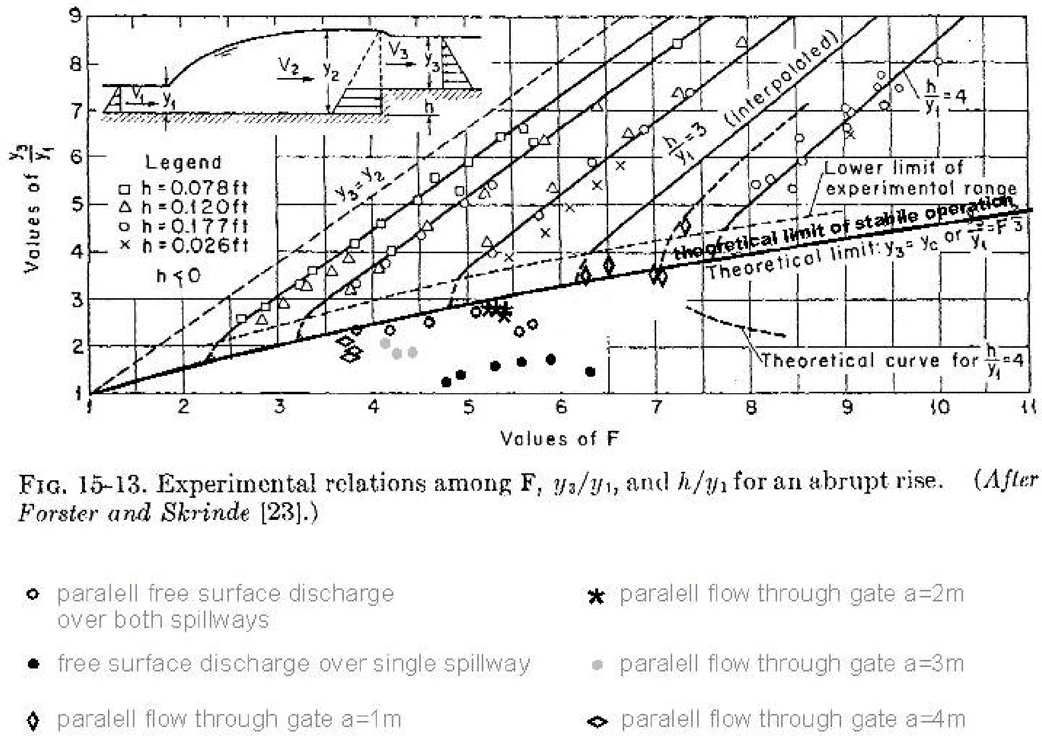

Fig. 2: Diagram which characterizes the initial efficiency of the stilling basin (source: Open-Channel Hydraulics, Ven Te Chow 1959 – after Forster and Skrinde)

Froude number F_1, which is one of the main criteria when shaping the stilling basin and its elements, is in our case in range between 3,7 and 6,4 dependable of operating mode. This is very unpleasant situation because it is very difficult to optimize the stilling basin when we can not determine the exact hydraulic regime of the structure. Therefore only a hydraulic model can give us an optimized solution.

The decisive hydrological values in our case were: Q_{100}=474m^3/s, $Q_{1.000}$=806m^3/s, $Q_{10.000}$=1185m^3/s.

1.2 Operating conditions

The designers claim was that the object has to be operating stabile in all possible operating conditions within discharge range up to Q_{100}. This includes also asymmetrical operation (one blocked spillway) with discharges into tail water lower than normal tail water level for a handled discharge. This demand brings us almost excessive operating conditions which are not usual in designing hydro-energetic projects.

The final solution of spillways should be able to pass :
- Q_{100} through a single spillway no higher than normal top water level,
- $Q_{1.000}$ through both spillways no higher than normal top water level,
- $Q_{10.000}$ through both spillways lower than dam crown.

1.3 Tasks of the research

For the originally designed shape of the stilling basin the research should:
- Determine the range of stabile operation,
- Determine the necessary measures to fulfil the above conditions.

If the original design of stilling basin can not be fully optimized the researcher should develop a new stilling basin, fulfilling all mentioned conditions and also:
- The stilling basin width should stay unchanged,
- The bottom level and length of stilling basin should be as close to the originally designed as possible,
- Attaining a uniform velocity distribution of subcritical flow over the end sill.

1.4 Results of the original design research

When operating symmetrically with equal discharge through both spillways, the stilling basin operates correctly up to discharge Q_{100}. However, in consequence of the too small water depth above the end sill, the flow over the end sill becomes in many cases critical.

When operating asymmetrically with total discharge through a single spillway, the hydraulic conditions in stilling basin and downstream of the end sill become very rough. The water jet through stilling basin remains undispersed, which causes overloading of the active half and a reverse secondary flow in the other half of the stilling basin (Fig. 3). The Froude numbers downstream of the end sill exceed 1,2 which brings us fully into a supercritical flow regime.

During further investigation many different variants of dissipating elements (buckets, baffle blocks, end sill) and dimensions of stilling basin were tested. Every variant was subject to operating conditions mentioned above.

The final conclusion of extensive experimenting is that the originally designed stilling basin, even deepened and bearably prolonged, no matter which type or combination of known and normally used dissipating elements we choose, isn't able to function properly under the directed operating conditions.

To achieve adequate efficiency of the stilling basin there are only two solutions , either:
- diminishing of specific discharge by increasing the width of the spillways or by adding the third spillway of the same width as the existent two ones, which is a very costly solution, or
- designing a new type of a stilling basin, which would be able to bear the directed operating conditions.

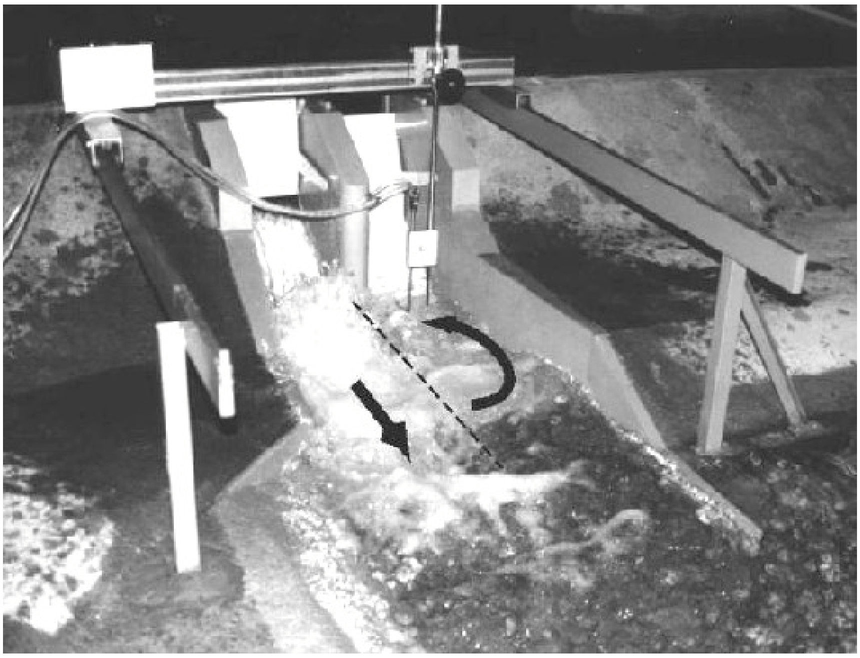

Fig 3: Original design – Flow over a single spillway section, Q=312 m^3/s , H_{TW} = 437.7 m a.s.l. (regular tailwater level), gate opening a=4.0 m; The left margin of main flow and a dominant vortex in an inactive half of the stilling basin can be clearly seen.

2. Development of a new stilling basin

After completion of a research of the originally designed stilling basin and it's variants, both possibilities were offered to the investor. Since it would still be possible to come to the same problems, as at the originally designed spillway, the second possibility, that is development of a new type of a stilling basin, was a logical choice.

2.1 Basic directions

When deciding about the type of a stilling basin, a major guidance was the investor's requirement, that the stilling basin must be able to function properly under all operating conditions up to a discharge Q_{100} over a single spillway section. According to the designer's limitations, the guiding rules during the development were:

- the minimum possible length of the stilling basin,
- the minimum possible depth of the stilling basin,
- the practicability of the civil structure,
- the economic suitability of the project.

Considering the distinctly asymmetric flow over the spillways into a joint stilling basin it was assumed that the only possible solution is a cascade type of a stilling basin. This is not the type that is usual in hydro engineering practice and therefore there are no widely known recipes for it's dimensioning. There are also some cogent reasons for avoiding such structures in hydro energetic practice, which have mostly practical background. But in some cases like ours, exactly the practical reasons can be strong enough to study such a solution. Namely, if we want to calm down the distinctly asymmetric flow, it is necessary to catch it into some sort of a basin and then establish the control over the outflow.

2.2 Resulting stilling basin

On the basis of conclusions of the original design research it became apparent, that for the attainment of sufficient energy dissipation within the stilling basin it is necessary to investigate the dissipation elements such as vertical hanging baffles, bottom sills and their combinations. This concrete structure should be able to convert the asymmetric flow into a uniform flow pattern on the outlet of the stilling basin in all the possible operating conditions for a very wide range of tail water level.

After testing some simpler shapes of stilling basin the resulting solution containing two vertical hanging baffles, combined with two bottom sills and end sill appeared to be the only effective shape of a stilling basin, able to function properly even with almost no tail water. The final design can be seen on Figure 4.

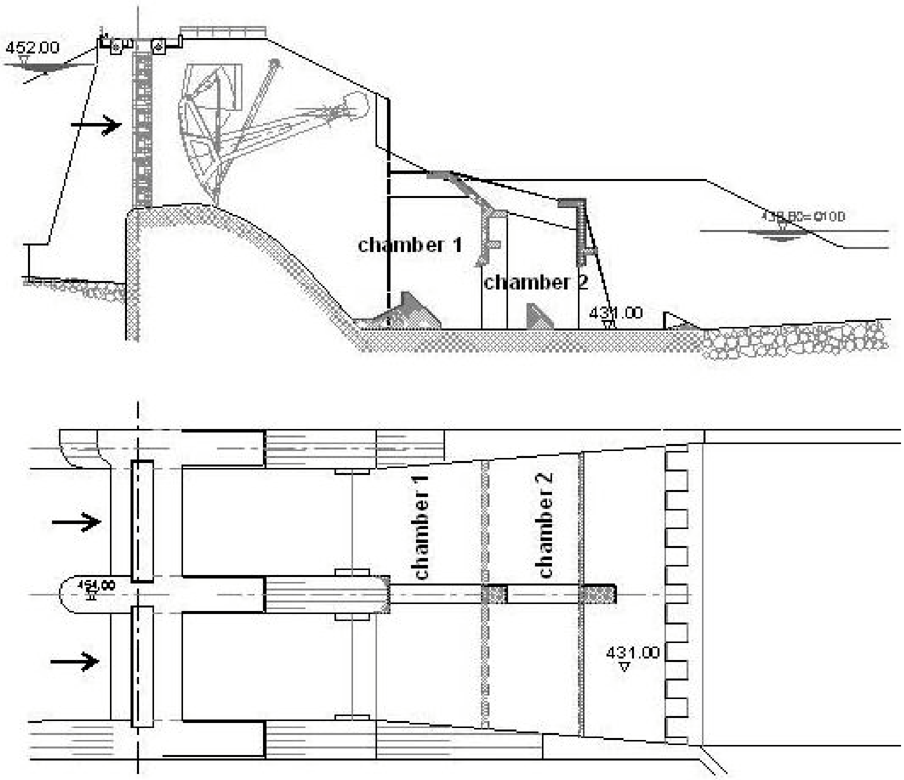

Fig 4: Final design – Stilling basin, equipped with dissipating elements

The elements of the stilling basin seem to be of very complex shapes. Of course in the early stage of the investigation it wasn't the case, but if all the conditions were to be fulfilled, also all the elements needed to be investigated and optimized.

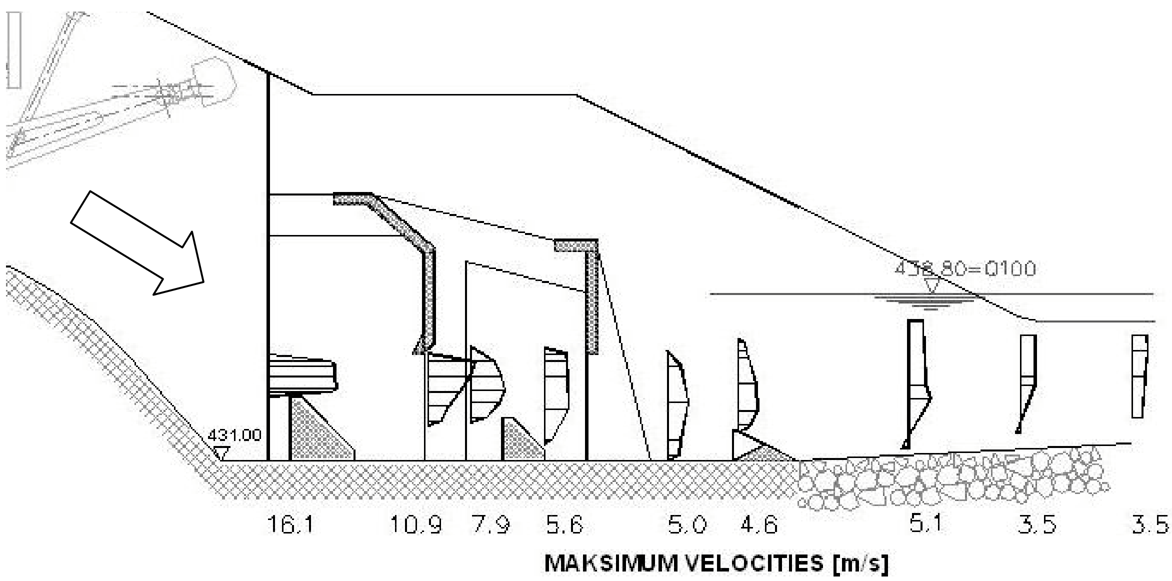

Fig 5: Intermediate design – Velocity profile changing alongside stilling basin

The emergency operation was also investigated during the model tests. Regarding the demands in chapter 1.2 the spillways and stilling basin must be able to pass the discharges $Q_{1.000}$ and $Q_{10.000}$ without any damage to the object or the surrounding structures. To achieve this condition, some adjustments of the side wall height had to be made. The greatest effort however was to reach the lowest possible water resistance of the vertical hanging baffle ceiling. The purpose of the ceiling is to diminish or even prevent the sprinkling from both chambers outside the stilling basin and also to direct the surface flow inside the chambers into the upstream direction. This way a recurrent vortex around a horizontal axis appears which enables a sufficient energy dissipation inside each chamber. During the emergency operation the energy dissipation inside the stilling basin still performs and the overflow passes over top of baffles.

On Figure 5 it can be seen that the velocity profile changes intensively alongside the stilling basin. From a very nonuniform velocity distribution at the beginning of the stilling basin (v_{max}>16m/s) it changes step by step after each dissipation element and reaches a practically uniform vertical distribution of the velocities 10 – 15m downstream of the end sill. The cross distribution immediately downstream of the end sill (Fig. 6) shows very uniform velocity profile. The only area with negative velocities lies close to the bottom and the velocities near the bottom do not exceed 2m/s, the difference in maximum velocities between right and left half of the cross section amounts only 1m/s.

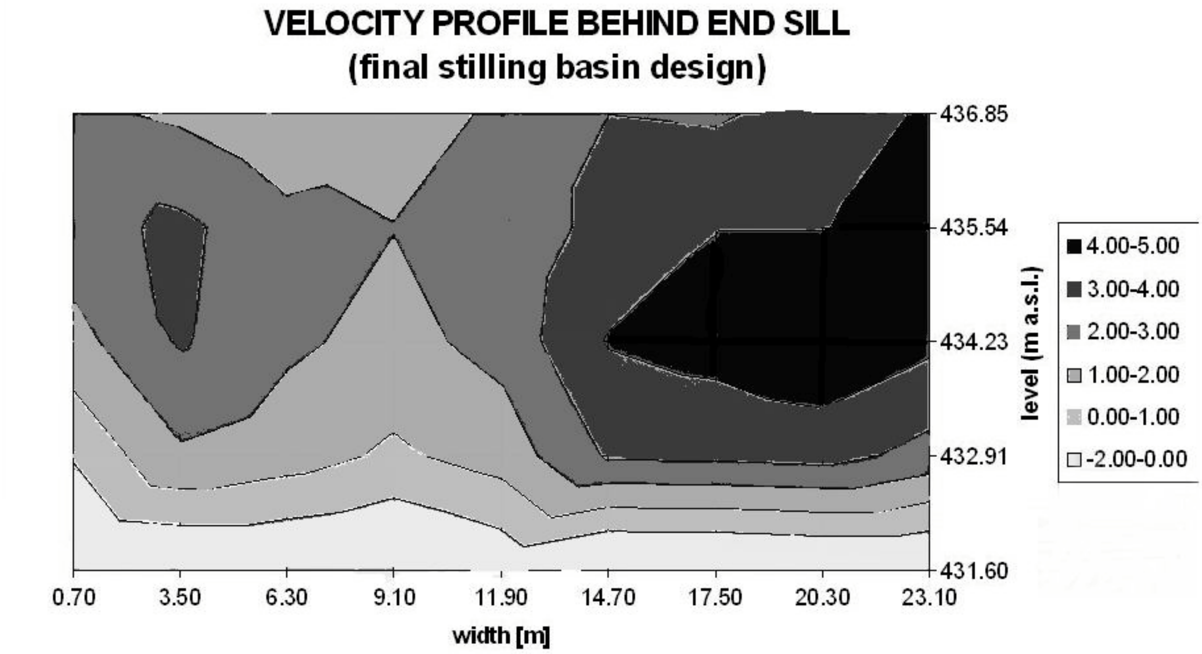

Fig 6: Final design –Velocity profile in cross-section immediately downstream of the end sill; Flow over a single spillway section, Q=312 m^3/s , H_{TW} = 437.7 m a.s.l. (regular tail water level), gate opening a=4.0 m, right spillway in operation;

3. Conclusions

The newly developed stilling basin is designed on a principle of a cascade. The stilling basin fully fulfils the requirements from the beginning of the research. At the same time it has no negative influence on discharge capacity. According to the tests even in a case of larger occlusion by debris (30 – 40%) it still operates with no influence on the top water level. It was however suggested to the investor, to reinvestigate the presence of debris during the flood waves. In a case of a distinctive debris discharge it should be better to consider the solution with more than two spillway sections to avoid such severe hydraulic conditions in the stilling basin.

Literature

1. **Mlacnik, J.**, “Hydraulic Model Tests of a spillwy sections HPP Moste III”, *Final research report*, 2003.

2. **Chow Ven Te**, “Open-Channel Hydraulics ”, 1959.

The Authors

J. Mlacnik 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 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.

D. Ciuha finished his undergraduate studies in 1977 at the Hydraulics Division of the Faculty of Civil and Geodetic Engineering of the University of Ljubljana. In 1976, he started working as a young engineer in the Ministry of the Environment and Spatial Planning. In 1978, he came to the Water Management Institute as a researcher and between 1987 and 1991 he worked as a manager of Hydraulic Laboratory Department. Since 1995 he has been employed in the Institute for Hydraulic Research as a research councillor and between 1997 and 1998 as a manager of the Institute for Hydraulic Research. In 2001, he joined the Ljubljana Community and the Institution for Environment Potection. Since 2004 he has been working in IBE, Consulting Engineers as a Design Engineer in Civil, Architectural and Surveying Department.
His experience covers most of all physical modelling of hydraulic phenomena and field observations and measurements in the domain of hydraulics, hydrology and hydrographical surveys as:
pipe systems under pressure, river diversion tunnels, weirs, spillways, stilling basins, power intakes and bottom outlets, gates, valves, hydraulic dissipators, harbours and marine structures, sediments transport in open channel flow, local scouring of river sediments, river engineering and regulations, influence of static and dynamic pressures on structures, cavitation and aeration, vortex formation, etc.