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I. Introduction

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

The hydraulic model tests of spillway sections and stilling basins of the Moste III HPP were performed by the Hydroinstitute in Ljubljana. The basic demand of this research was to ensure a complete dissipation of water flow energy inside the stilling basin in every possible operating mode up to Q100. Since there are only two spillway sections, in case of one blocked gate there is only a single section operating, which entails very large specific loads of the stilling basin. This appeared to be the main problem to be solved by this research.

The original design was a 25m long standard stilling basin with one row of baffle blocks ending with one step end sill. The originally designed version shown on Fig. 1, as also all known usual variants, which could possibly lead us to a positive solution, were tested on a hydraulic model built in a model scale 1:35. By the model tests it was established that all tested variants had the same weakness, which was explicitly asymmetric flow over the end sill (Fig. 3). Therefore, in all studied cases the part of the stilling basin situated behind the blocked spillway section was inactive. The consequence was a 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

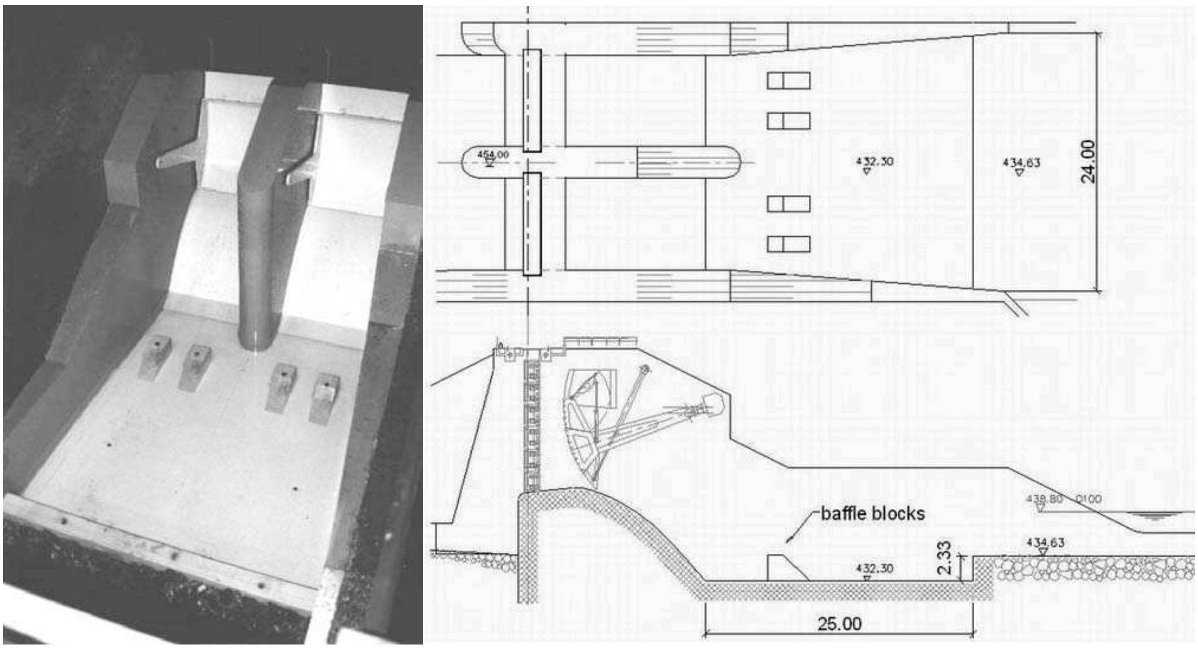

Figure 1. Spillways and stilling basin of the Moste III HPP – original design

transmitted into the downstream channel.

In order 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. This 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 economic criteria, we developed a stilling basin, which is unusual for the present type of the spillway section. The 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 meets the originally designed construction limits. The result of the research enables construction in only one construction phase without extending the time of construction.

II. Initial Design Research

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

A. *Geometric, Hydraulic and Hydrologic Conditions*

The stilling basin belongs into a group of short stilling basins; its length is reduced for about 40% regarding the 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.

Froude number F_1, which is one of the main criteria to be respected by shaping of the stilling basin and its elements, is in our case in the range between 3.7 and 6.4, depending on the operating mode. This is a 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: $Q_{100}=474m^3/s$, $Q_{1.000}=806m^3/s$, $Q_{10.000}=1185m^3/s$.

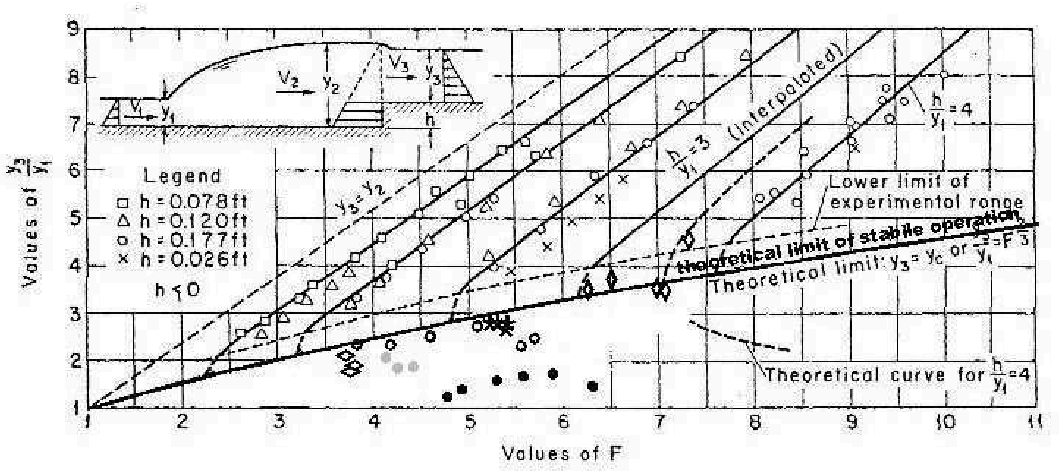

FIG. 15-13. Experimental relations among F, y_3/y_1, and h/y_1 for an abrupt rise. (*After Forster and Skrinde* [23].)

- paralell free surface discharge over both spillways
- paralell flow through gate a=2m
- free surface discharge over single spillway
- paralell flow through gate a=3m
- paralell flow through gate a=1m
- paralell flow through gate a=4m

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

B. Operating Conditions

The designer's claim was that the object has to be operating stably in all possible operating conditions within the discharge range up to Q_{100}. This includes also asymmetrical operation (one blocked spillway) with discharges into the tail water lower than normal tail water level for a handled discharge. Such requirement implies almost excessive operating conditions, which are not usual in the hydro-energetic projects design.

A final solution of the spillways should be able to pass:

- Q_{100} through a single spillway not higher than the normal top water level,
- $Q_{1.000}$ through both spillways not higher than the normal top water level,
- $Q_{10.000}$ through both spillways lower than the dam crown.

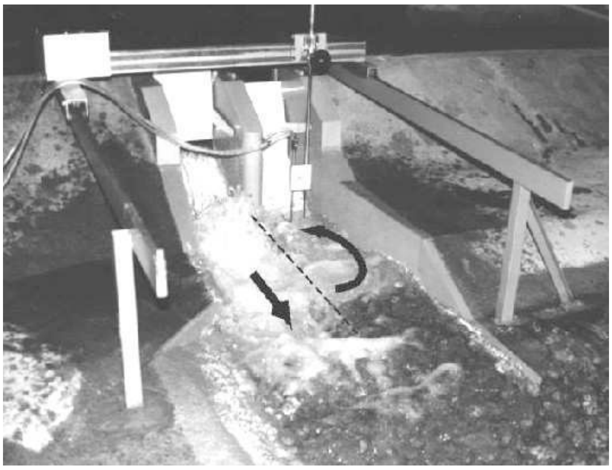

Figure 3. Original Design – Flow over a single spillway section, Q=312 m3/s, HTW = 437.7 m a.s.l. (regular tailwater level), gate opening a=4.0 m; the left margin of the main flow and a dominant vortex in an inactive half of the stilling basin can be clearly seen.

C. Research Tasks

For the originally designed shape of the stilling basin the research should:

- Determine the range of stabile operation,
- Determine the necessary measures to fulfill the above conditions.

If the original design of the stilling basin can not be fully optimized, the researcher should develop a new stilling basin, fulfilling all the above-mentioned conditions and, additionally, the following ones:

- The stilling basin width should stay unchanged,
- The bottom level and length of the stilling basin should be as close to the originally designed ones as possible,
- A uniform velocity distribution of subcritical flow over the end sill should be attained.

D. 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 the stilling basin and downstream of the end sill become very rough. The water jet through the 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 the dissipating elements (buckets, baffle blocks, end sill) and dimensions of the stilling basin were tested. Every variant was subject to the operating conditions mentioned above.

The final conclusion of an 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, is not able to function properly under the directed operating conditions.

There are only two solutions to achieve adequate efficiency of the stilling basin, either:

- diminishing of the third spillway of the same width as the specific discharge by increasing the width of the spillways or by adding existent two, 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.

III. DEVELOPMENT OF A NEW STILLING BASIN

After completion of a research of the originally designed stilling basin and its 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.

A. 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:

- minimum possible length of the stilling basin,
- minimum possible depth of the stilling basin,
- practicability of the civil structure,
- 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 the 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 the hydro energetic practice, which have mostly practical background. But in some cases like ours, there are exactly such practical reasons, which 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.

B. 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 levels.

After testing some simpler shapes of the stilling basin the resulting solution containing two vertical hanging baffles, combined with two bottom sills and an 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 in Figure 4.

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

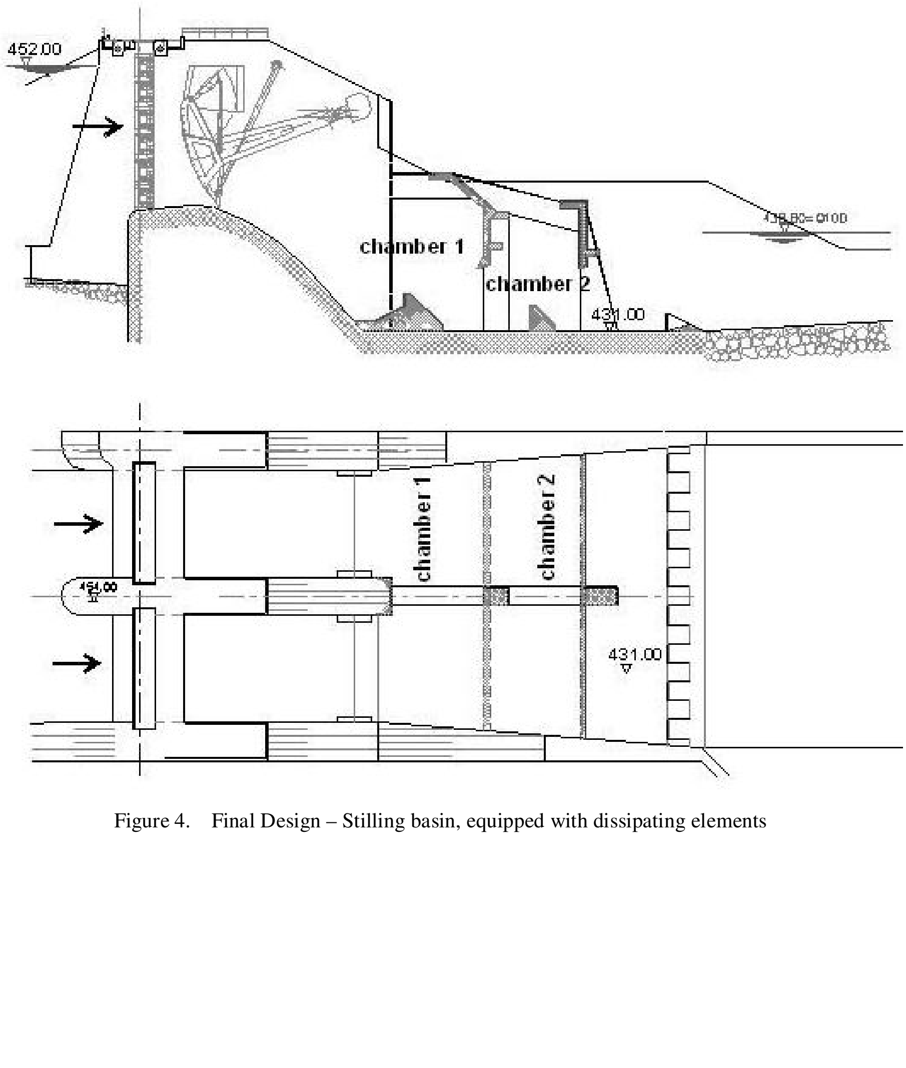

Figure 4. Final Design – Stilling basin, equipped with dissipating elements

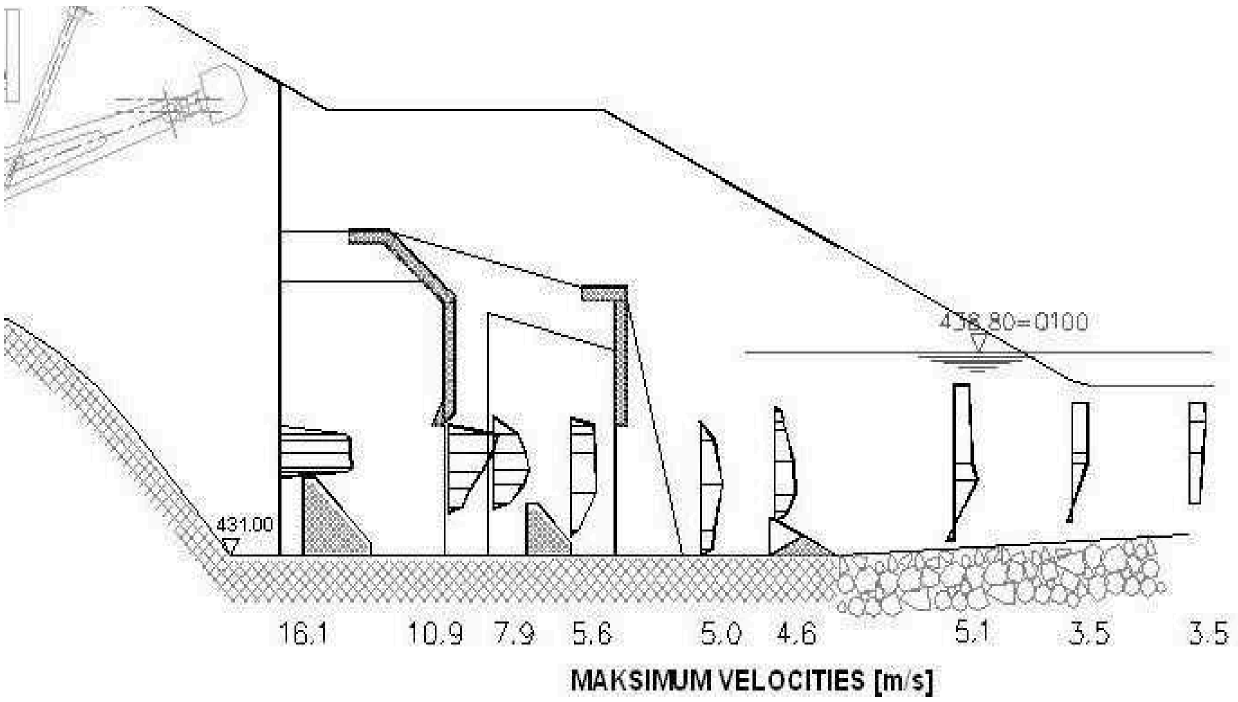

Figure 5. Intermediate Design – Velocity profile changing alongside the stilling basin

The emergency operation was also investigated during the model tests. Regarding the demands stated in chapter 1.2 the spillways and the 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. In order to fulfill this condition, some adjustments of the sidewall height had to be made. The greatest effort however was to

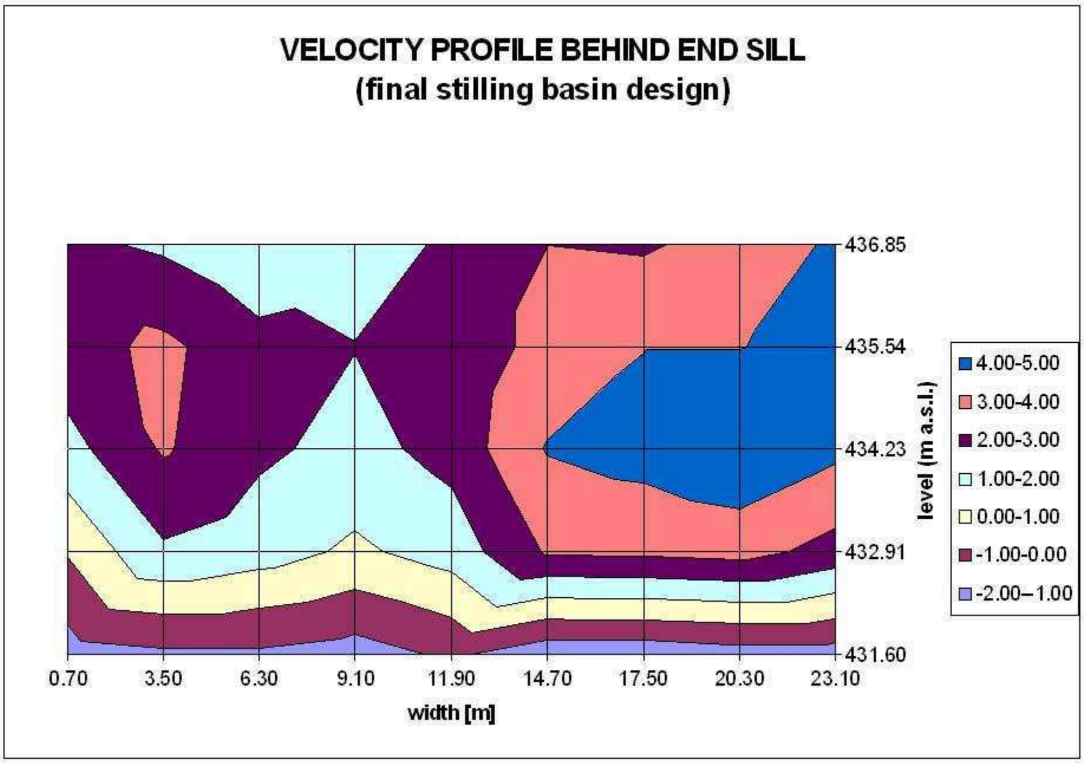

Figure 6. Final Design –Velocity profile in cross-section immediately downstream of the end sill; Flow over a single spillway section, Q=312 m3/s, H TW = 437.7 m a.s.l. (regular tail water level), gate opening a=4.0 m, right spillway in operation;

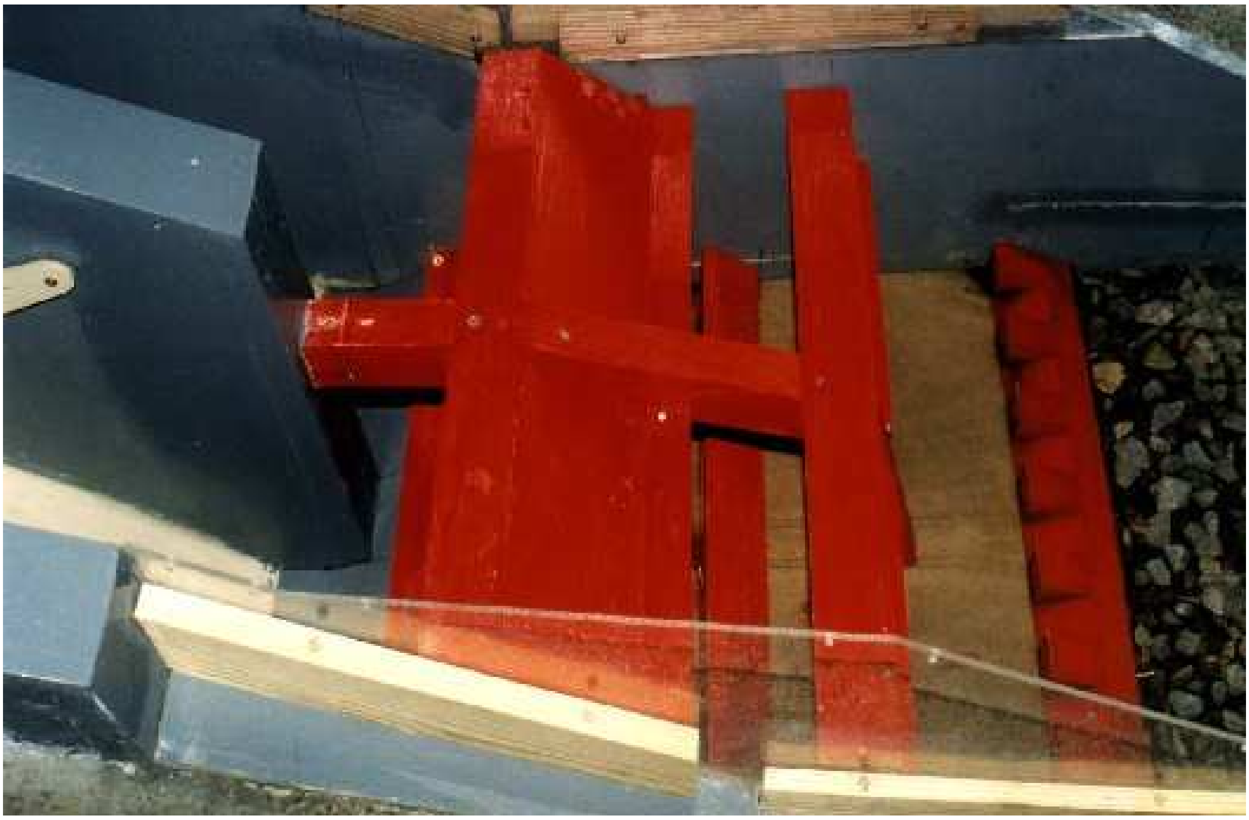

Figure 7. Final Design –The final shape of the stilling basin

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 sufficient energy dissipation inside each chamber. During emergency operation the energy dissipation inside the stilling basin still performs and the overflow passes over baffles top.

In 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, while the difference in maximum velocities between right and left half of the cross section amounts only 1m/s.

IV. CONCLUSIONS

The newly developed stilling basin is designed on a principle of a cascade. The stilling basin wholly meets the requirements from the beginning of the research. At the same time it has no negative influence on the discharge capacity. According to the tests, even in 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 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.

REFERENCES

[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