TERRAIN MEASUREMENTS AT HRIČOV – MIKŠOVÁ – POVAŽSKÁ BYSTRICA HHP GROUP

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The water structures Hričov – Mikšová – Považská Bystrica are a group of channel hydro power plants (HPP) on the Váh Cascade. Modelling methods verified on other channel hydro power plants are easily applicable in their case. In 2006 were by our department provided terrain measurements and hydraulic research on these water structure systems. The results of measurements were used for the better calibration of hydro dynamical model of these power plants. The presented paper describes this process. This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-046302.

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1. Introduction

In 2006, the Department of Hydraulic Engineering performed terrain measurements of water level regime of Hričov – Mikšová – Považská Bystrica HPP group. The purpose of these measurements had been the measurement of water level regime along the diversion channel during in advance planned operation (flow rate) of particular hydropower plants.

Based on these measurements, the hydraulic characteristics of the channel (roughness coefficients of wetted perimeter according to the channel stages) had been determined. Subsequently it had been possible to calibrate the hydrodynamic model of this channel hydropower plant group for the purpose of the diversion channel's water level regime computations.

2. Hydraulic links within concerned stage of the Váh Cascade

The Hričov – Mikšová – Považská Bystrica group of channel hydropower plants begins in the Hričov Reservoir and ends in the Nosice Reservoir. These hydropower plants are directly hydraulically linked, i.e. the backwater of downstream HPP always reaches the upstream HPP.

The hydropower plants are spots, where the time behavior of the flow can be defined and in fact also controlled. Therefore the whole group in computational consideration can be divided in 3 stages:

1. Hričov – Mikšová,
2. Mikšová – Považská Bystrica,
3. Považská Bystrica – Nosice.

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3. Methodology of verification of roughness coefficient in diversion channels

Verification of roughness coefficient is possible only by direct measurement during operation in following possible ways:

– steady state measurement – steady non-uniform flow in the channel, attained by continuous start on required flow rate through hydropower plant – minimizing of wave transition effects in the channel,

– unsteady state measurement – unsteady non-uniform flow (used only in case, when attaining of steady state is not possible, results are less precise).

Determination of roughness coefficient by measurement for steady state

Measurement for steady state consists of following steps:

– attaining of steady state without any flow before the beginning of the measurements – steady water levels in diversion channels and compensation reservoirs are necessary not only for the probes calibration but also as initial conditions for mathematical modelling,

– attaining of steady flow state.

Conditions for attaining steady flow state vary in order to the type of the diversion channel. Measuring profiles have to be situated in sufficient distance from impounding structures in the channel. Frequency of data acquiring (water level measurement), once per minute, is usually sufficient for major part of hydrodynamic processes.

For roughness coefficient calculation of measured stage by steady non-uniform flow the standard step method has been used with its appropriate formulas for hydraulic characteristics:

$$\Delta y = Q^2 \left[\xi \left(\frac{1}{A_1^2} - \frac{1}{A_2^2} \right) + \frac{l}{\bar{K}^2} \right] , \qquad \bar{K}^2 = \bar{A}^2 \, \bar{C}^2 \, \bar{R} ,$$
$$\bar{A} = \frac{A_1 + A_2}{2} , \qquad \bar{P}_{\mathrm{w}} = \frac{P_{\mathrm{w}1} + P_{\mathrm{w}2}}{2} , \qquad \bar{R} = \frac{\bar{A}}{\bar{P}_{\mathrm{w}}} , \qquad \bar{C} = \frac{1}{n} \, \bar{R}^{1/6} , \tag{1}$$

where Δy is water level elevation change between downstream and upstream profiles [m]; Q steady flow rate [$\mathrm{m^3\,s^{-1}}$]; ξ kinetic energy change coefficient [$\mathrm{m^{-1}\,s^2}$]; A_1, A_2 flow area of downstream and upstream profile [$\mathrm{m^2}$]; l length of the stage [m]; $\bar{K}$ average flow-rate module [$\mathrm{m^3\,s^{-1}}$]; $\bar{A}$ average flow area [$\mathrm{m^2}$]; $\bar{C}$ Chezy velocity coefficient – Manning's expression [$\mathrm{m^{1/2}\,s^{-1}}$]; $\bar{R}$ average hydraulic radius [m]; $\bar{P}_{\mathrm{w}}$ average wetted perimeter [m]; $P_{\mathrm{w}1}$, $P_{\mathrm{w}2}$ wetted perimeter of downstream and upstream profile [m]; n Manning roughness coefficient [$\mathrm{m^{-1/3}\,s}$].

The kinetic energy change coefficient can be expressed in the following form:

$$\xi = \frac{\alpha}{2\,g} \left[1 + c \,\mathrm{sign} \left(\frac{1}{A_1^2} - \frac{1}{A_2^2} \right) \right] , \qquad \alpha = \frac{\int_A v^3 \,\mathrm{d}A}{A \, \bar{v}^3} , \tag{2}$$

where α is weighted velocity coefficient [–]; c expansion or contraction loss coefficient [–]; A flow area [$\mathrm{m^2}$]; v local velocity [$\mathrm{m\,s^{-1}}$]; $\bar{v}$ average section velocity [$\mathrm{m\,s^{-1}}$].

Substitute stages of the inlet and outlet channels can be considered prismatic, and therefore for the roughness computations the coefficients values $\alpha = 1$ and $c = 0$ were considered.

Final formula for roughness coefficient computation is obtained by adjusting upper formulas of the standard step method (1) :

$$n = \sqrt{\frac{\Delta y - Q^2\,\xi\left(\frac{1}{A_1^2} - \frac{1}{A_2^2}\right)}{l}\,\frac{\bar{A}}{Q}\,\bar{R}^{2/3}} \ . \tag{3}$$

Analysis of this formula (3) shows, that the final computation error is relied on accuracy of difference measurement between upstream profile (y_2) and downstream profile water level elevation (y_1). In regard to limited precision of measurement (centimetres) and other surround influences such as water surface waving (e.g. caused by wind), it is needed to attain maximum difference of measured water levels, what is succeeded in formula (1) by maximum flow rate in channel and maximum length of measured stage.

Very important parameter, which is affecting the precision of the calculations, is the flow rate Q. The value of the flow rate is not measured directly, but it is determined from the power output of the HPP according the functionality determined by guarantee measurements :

$$Q_\mathrm{t} = \frac{P}{9.81\,\eta\,H_\mathrm{c}} \ , \tag{4}$$

where Q_t is turbine discharge [$\mathrm{m^3\,s^{-1}}$]; H_c net head of the HPP [m]; η total energy transformation efficiency of the HPP [–]; P power output [kW].

Determination of roughness coefficient by measurement for unsteady state

Measurement results for unsteady state can be used only for indirect assessment of roughness coefficient from several different scenarios of measurements.

For data processing a hydrodynamic model (HDM) for modelling unsteady non-uniform flow has been used according to following scheme :

- calibration of the HDM for maximal flow rate scenario,
- verification of the HDM for other scenarios.

Used HDM is based on numerical solution of Saint-Venant partial differential equation system as follows :

$$\begin{gathered} \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q_\ell = 0 \ , \\ \frac{\partial(\beta\,Q\,\bar{v})}{\partial x} + \frac{\partial Q}{\partial t} + g\,A\,\frac{\partial y}{\partial x} = g\,A\,(S_0 - S_\mathrm{f}) + q_\ell\,v_\ell \ , \end{gathered} \tag{5}$$

where Q is flow rate [$\mathrm{m^3\,s^{-1}}$]; A flow area [$\mathrm{m^2}$]; q_ℓ density of lateral side inflow or outflow [$\mathrm{m^2\,s^{-1}}$]; x profile distance from the beginning in flow direction [m]; t time [s]; $\bar{v}$ average section velocity [$\mathrm{m\,s^{-1}}$]; y water level [m]; g gravitation acceleration [$\mathrm{m\,s^{-2}}$]; β velocity correction factor [–]; S_0 bottom slope [–]; S_f friction slope [–]; v_ℓ velocity component of side inflow or outflow [$\mathrm{m\,s^{-1}}$].

Compared to steady state modelling, the velocity correction factor has got a different form for the dynamic modelling :

$$\beta = \frac{\int_A v^2\,\mathrm{d}A}{A\,\bar{v}^2} \ . \tag{6}$$

But for modelling of the flow in a simple channel with wide trapezoidal cross-sections can be the coefficient value β assumed equal to 1.

The roughness coefficient value is contained in the friction slope expressed on the base of common conditions for 1D model development:

$$S_{\mathrm{f}} = \frac{Q\,|Q|\,n^2}{R^{4/3}\,A^2}\ . \tag{7}$$

For conversion of foregoing equation system to numerical solution by the finite differences method has been used Preissmann implicit scheme with weight coefficient 0.67.

4. Terrain measurements (measurements 'in situ')

At the beginning of the July 2006 took place a survey of the diversion channels and water structures at considered stage of the Váh River (stage from Hričov down to Považská Bystrica). Following locations for measuring profiles were determined:

Measuring profiles: (numbering and downstream stationing in diversion channel, km 0.00 = HPP Hričov)	
nr. 1 – km 3.836	left bank, 300 m above the Oblazov bridge – stairway
nr. 2 – km 11.100	left bank, 50 m under Bytča footbridge – stairway
nr. 3 – km 15.300	left bank, 50 m above Starovec bridge – stairway
nr. 4 – km 15.900	left bank, 500 m under Starovec bridge – stairway
nr. 5 – km 19.670	right bank, under Považská Bystrica bridge – stairway
nr. 6 – km 23.350	right bank, opposite Považské Podhradie mansion – stairway

Tab.1: Description of measuring profiles

Measurement scenarios were determined according to the agreement with the dispatch centre of the HPP operator (Slovenské elektrárne, Inc., Vodné elektrárne Works). These scenarios including all requests were implanted in operation control of the HPPs for concerned days by the dispatch centre.

The 'in situ' measurement had been scheduled for August 15$^{\mathrm{th}}$–16$^{\mathrm{th}}$, 2006. On the August 14$^{\mathrm{th}}$, 2006 were the measuring devices installed in the measuring profiles. The measurement itself had been realized on August 15$^{\mathrm{th}}$ and 16$^{\mathrm{th}}$, 2006.

The measured time behaviour of water level in measuring profiles has been supplemented with data from the hydropower plant dispatch centre in Trenčín. The dispatch centre provided real time data on discharge, upstream water level and downstream water level of Hričov, Mikšová and Považská Bystrica hydropower plants acquired in one minute time step.

An integral part of the terrain measurements had been geodetic measurements of reference height points in measuring profiles. These measurements were necessary for water surface elevation determination. The sample of the measured values processing is in Table 2.

5. Application of the terrain measurements results

A practical application op the measurement results is a mathematical model of water flow in the Hričov – Mikšová energetic channel, which is the most complicated of the entire Váh Cascade in the mathematical modelling point of view. The Starovecký Reservoir situated above the Mikšová HPP has a significant effect on the water flow in the modelled channel (Fig. 1).

The measurement of channel's hydrodynamic parameters for peak operation of the HPP was realized in the end of the year 2000. The peak operation with a discharge of

interchannel		Hričov HPP – Mikšová HPP	
interchannel stage		outlet	inlet
bottom elevation : beginning–end	[m a.s.l.]	310.07–310.69	309.14–310.07
length	[m]	4 000	12 418
bottom width	[m]	30	26
bank slopes 1 :		2.75	2

Outlet channel of the Hričov HPP

Date of the measurement		15/8/2006
Computational hour		11:00
Downstream profile, water level	[m a.s.l.]	316.53
Upstream profile, water level	[m a.s.l.]	316.68
Average flow-rate	[$m^3 s^{-1}$]	200
Channel roughness	[$m^{-1/3} s$]	0.0246

Inlet channel of the Mikšová HPP

Date of the measurement		15/8/2006
Computational hour		11:00
Downstream profile, water level	[m a.s.l.]	316.37
Upstream profile, water level	[m a.s.l.]	316.57
Average flow-rate	[$m^3 s^{-1}$]	200
Channel roughness	[$m^{-1/3} s$]	0.0160

Tab.2: Sample of the measured values processing for Hričov-Mikšová channel in table form

$Q = 300\,\mathrm{m^3\,s^{-1}}$ was realized between 7:00 and 9:30 with a 15 minute start and a 15 minute shut-down of the HPPs at the measured stage.

The first version of the mathematical model with a constant lateral inflow from the Starovecký Reservoir (in 2000) was based on the anticipation of the validity of standard values of the rougness coefficient for a concrete surface of the inlet channel, $n = 0.013$. The comparison of modelling results based on this anticipation is shown in Fig. 2. The best conformity of the model with the measurements was achieved for the roughness coefficient value of $n = 0.016$.

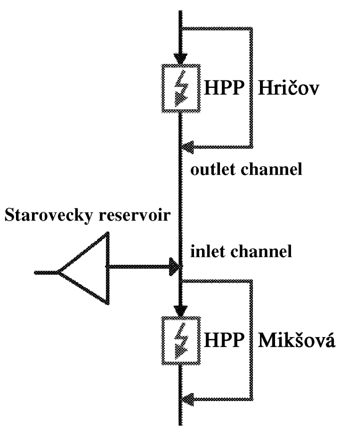

Fig.1: Scheme of the Hričov – Mikšová channel

Such a practice of using the roughness coefficient of the channel's bottom as a 'tuning knob' is not acceptable without the measurement of the mentioned hydrodynamic parameter directly on site.

The application of the results of the roughness coefficient determination in 2006 along with the improvement of the mathematical model by including the possibility of an interaction with a lateral reservoir led to significantly better results (Fig. 2).

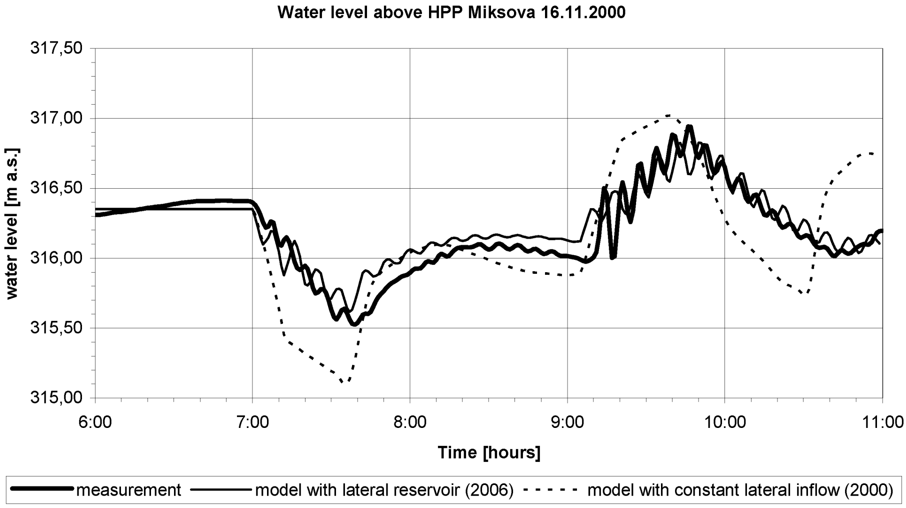

Fig.2: The comparison of water level course above the Mikšová HPP with the 2000 and 2006 models

For a better conformity of the measurements and the 2006 mathematical model, the bottom of the Starovecký Reservoir should be surveyed. In the 2006 model were used map-based data of the Starovecký Reservoir.

6. Conclusion

Based on the measuring results the hydraulic parameters (roughness coefficients of wetted perimeter of the diversion channels) were determined in stage from Hričov down to Považská Bystrica. The diversion channels were sectionalized into inlet and outlet sections of separate diversion channels. The inlet sections showed the roughness coefficient value $n \approx 0.016$, the outlet sections $n \approx 0.024-0.027$. This state is only slightly deviating from projected state (projected values of roughness coefficient). The hydraulic losses in these channels are only minimally increased and thus the power generation of the HPP group is not negatively effected by the hydraulic parameters in the channels.

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