EXPERIMENTAL EVALUATION OF ROUGHNESS COEFFICIENT OF A HPP HEADRACE CHANNEL

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In the present study, the of headrace channels roughness coefficients of five hydropower plants (HPP) were determined. The necesity of the study comes in the frame of nationally and worldwide trend, to increase the efficiency of electricity production, especially from renewable sources.

A very important aspect for a hydropower plant with open channel headrace is to limit the hydraulic losses which influence directly the total efficiency of the hydro power site. This can be done by improving the channel roughness coefficient which has a significant influence over the operating parameters of the plant. A high value of this coefficient decreases the global efficiency of the power plant, which can result in a significant loss of energy and a low energy efficiency.

The roughness coefficient was determined on the Bistrita river channel, in the sector between Vanatori HPP and Roznov HPP.

Keywords: roughness coefficient, headrace channel, efficiency.

1. General aspects

The overall objective of the energy sector strategy is to ensure conditions for its energy needs in medium and long term, with acceptable price, suitable for a modern market economy and a decent living standard in terms of quality and reliable energy supply with respect to the principles of sustainable development.

Considering the role of energy for society and all economic sectors, the development of this sector is performed under the supervision of the government, through the development and implementation of a sectoral strategy and in a short term by implementing a strategic related policies.

The role of this strategy is to define the main directions of the power system development in Romania between 2011-2035, given the socio-economic development and demographic situation existing in the electricity sector and the correlation to energy-environment policy of the European Union [1].

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This paper aims to determine the operating parameters of the headrace channels for the sector between Vanatori HPP and Racova HPP, in terms of the roughness coefficient.

This coefficient plays an important role in determining the overall efficiency of hydropower sites, having a direct influence on it [2, 3]. A high roughness coefficient leads to a significant decrease in the total efficiency of the plant, which has to be avoided in the current development in energy strategy.

2. Site description and measuring procedures

Figure 1 presents the analyzed hydropower sites on the Bistrita River: Vanatori HPP, Roznov HPP, Zanesti HPP, Costisa HPP, Buhusi HPP and Racova HPP. The hydropower plants are aerial type, with free level derivation, and placed in cascade.

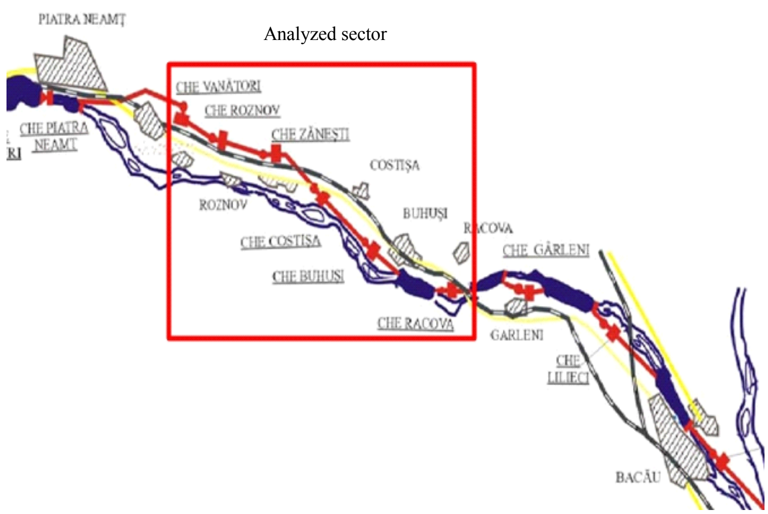

Fig. 1. Bistrita river hydropower site

To determine the headrace channel roughness coefficient it was neccesary to measure free surface water levels and flow rates which were used by the hydropower plants.

To measure the levels, 22 staff gauges were installed on the slide slopes of the channels, with 2 cm calibrations. The number and the position of the measuring sections was chosen considering the real in site conditions, so that the sections of the flow between two successive staff gauges could be considered approximately uniform and quasi steady. Figure 2 presents schematically the locations of the level measuring sections. All staff gauges were set with a GPS leveling precision, absolute elevation in relation to the Black Sea. The inclination for each staff gauge, *m*, is the same as the channel slide slopes.

The flow rates were determined from the operating characteristics of the turbines, based on the power output of the hydro units, that was measured. This indirect method allows the determination of the instantaneous or mean flow rate on a short time interval.

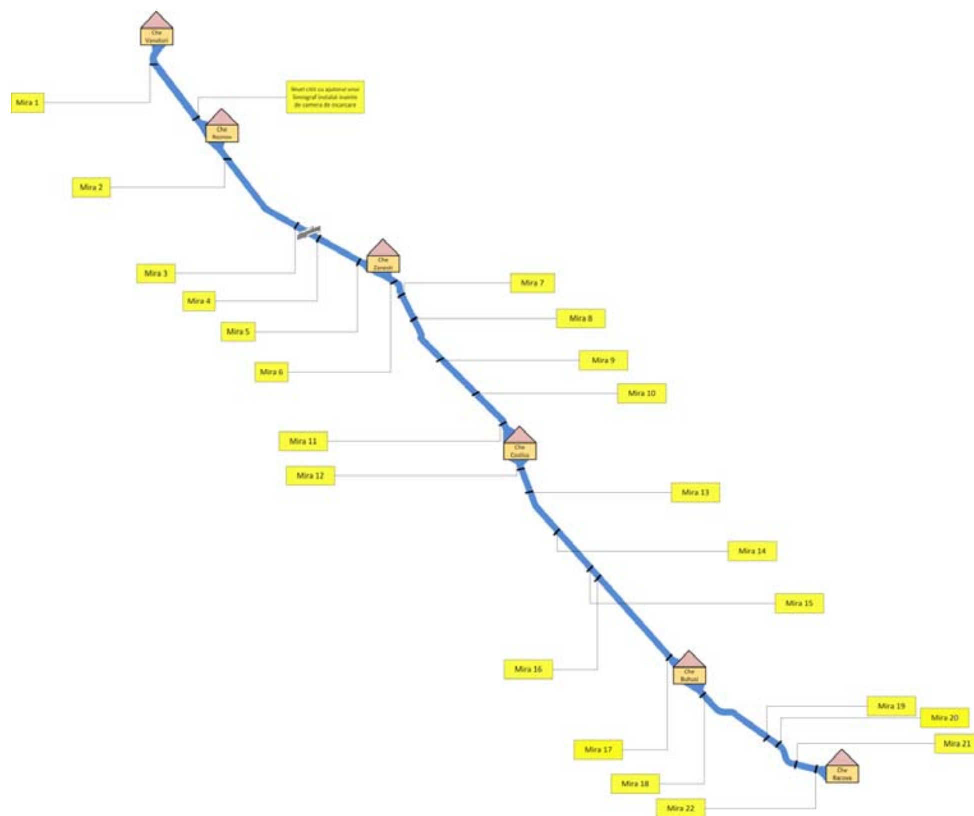

Fig. 2. The position of level measuring sections

In order to determine the roughness coefficient, only certain sections of the channel were selected. The time interval for each section had to meet the following criteria:

- the water flow in the channel has to be as close to a steady state condition;
- data from at least two observation periods were processesd, one during a continuous level rise in the channel (slow filling) and the other during a decrease of the level (slow drain), in order to eliminate the slight unsteadiness character of the flow.

- the observation periods in which level variations in limited sectors of the channel length were observed (due to positive of negative wave, caused by maneuvers of the HPP) were excluded.

3. Computation method

To compute the roughness coefficient on a given sector between sections *j* and *k*, the formula for energy slope is evaluated

$$J_{j-k} = i + \frac{1}{\Delta s_{j-k}}\left[\left(\overline{h}_j + \frac{\overline{v}_j^2}{2g}\right) - \left(\overline{h}_k + \frac{\overline{v}_k^2}{2g}\right)\right], \tag{1}$$

where i is the channel bottom slope of the analized sector and $\overline{h}$ is the average depth between two time steps, t-Δt and t in considered sections (j, k)

$$\overline{h}_{j,k} = \frac{1}{2}\left[h_{j,k}(t) + h_{j,k}(t-\Delta t)\right]. \tag{2}$$

Then, the Chezy coefficient is determined using Manning formula

$$C = \sqrt[6]{R}/n, \tag{3}$$

and from the flow equation

$$Q = AC(RJ)^{1/2}, \tag{4}$$

results the roughness coefficient

$$n = \frac{AR^{2/3}J^{1/2}}{Q}. \tag{5}$$

The cross section flow area, A, and the hydraulic radius, R, depend on the average depth, between sections j and k, $h_{j-k} = \left(\overline{h}_j + \overline{h}_k\right)/2$, as follows:

- cross section flow area, for a trapezoidal shaped channel

$$A = \left(b + mh_{j-k}\right)h_{j-k}, \tag{6}$$

- hydraulic radius

$$R = A/P, \tag{7}$$

- wetted perimeter

$$P = b + 2\left(1 + m^2\right)^{1/2} h_{j-k}, \tag{8}$$

During in site measurement campaign the channel flow regime was quasi-steady. Thus it was necessary to correct the flow rate values considered in each section using the unsteady continuity equation

$$\frac{\partial Q}{\partial s} + \frac{\partial A}{\partial t} = 0 \tag{9}$$

and the average flow on a sector was detemined as the mean value of two consecutive measuring sections

$$Q = \left(Q_j + Q_k\right)/2\,. \tag{10}$$

The roughness coefficients corresponding to a sector between two consecutives staff gauges and for selected time intervals, are calculated using the equation (5). Further, the global average roughness coefficients for each analyzed sector of the channel was determined in two ways:

- as arithmetic mean of all values obtained for each channel;
- as a weighted average taking into account the length of each sector.

4. Results

Figures 3-7 present water level variation along the analyzed sector, at different time steps. The measured data was processed according to the methodology presented in paragraph 3.

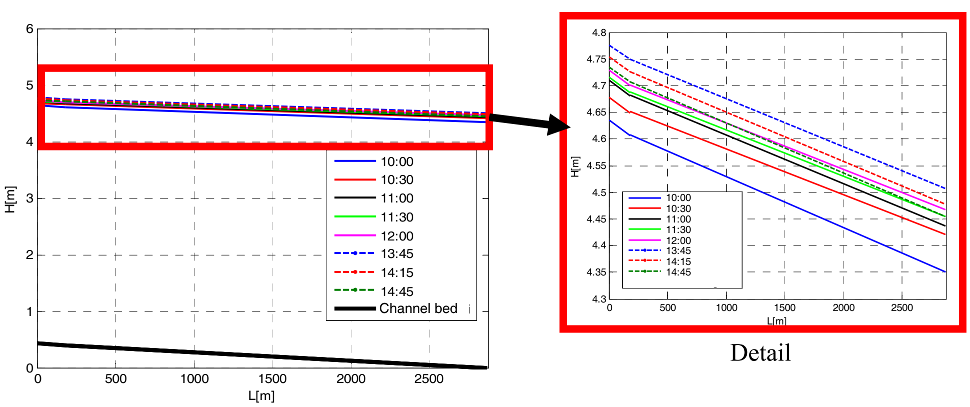

Fig. 3. Time variation of the water depth in the sector Vânători HPP and Roznov HPP

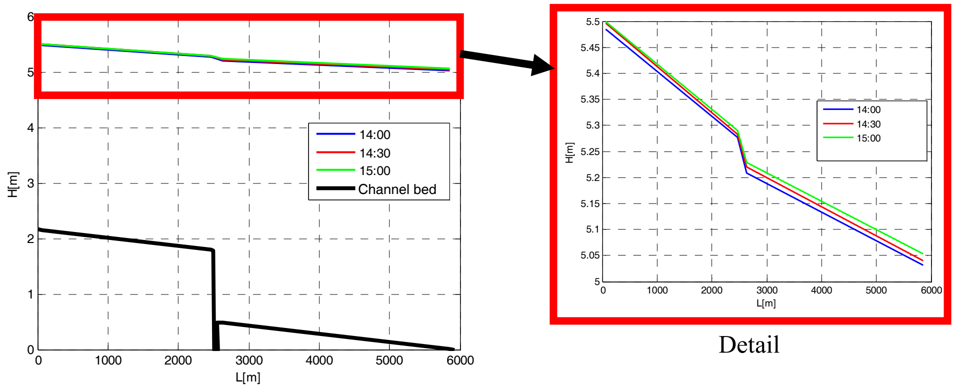

Fig. 4 Time variation of the water depth in the sector Roznov HPP and Zăneşti HPP

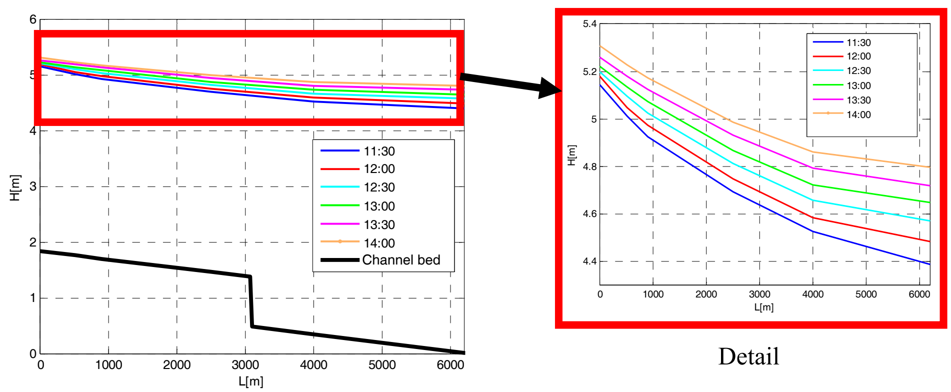

Fig. 5 Time variation of the water depth in the sector Zăneşti HPP and Costişa HPP

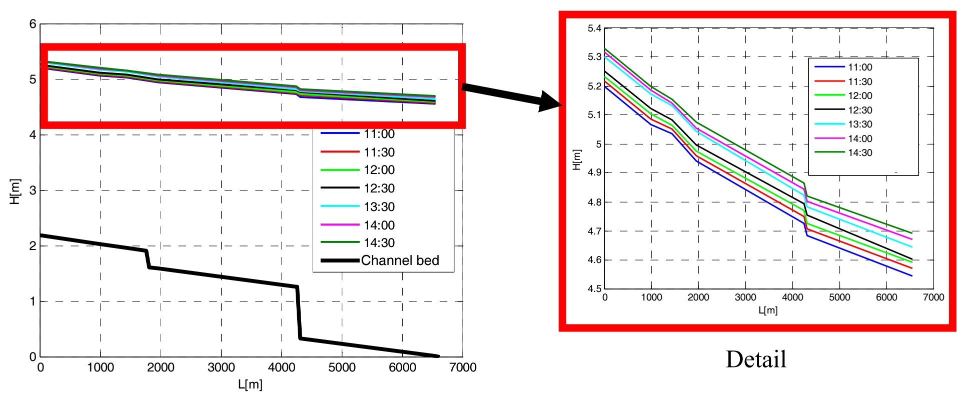

Fig. 6 Time variation of the water depth in the sector Costişa HPP and Buhuşi HPP

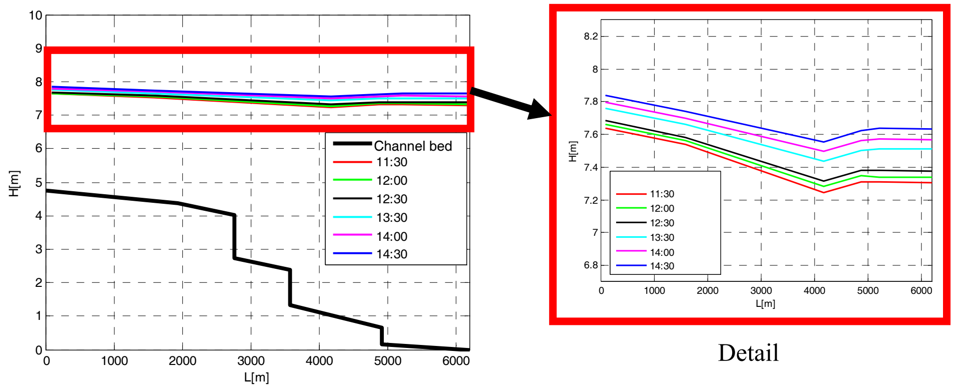

Fig. 7 Time variation of the water depth in the sector Buhusi HPP and Racova HPP

Two global roughness coefficient values for each channel were computed as the arithmetic mean of all the values calculated at each time step and their weighted average taking into consideration the length of which the determination was done [4]. The results are presented for each of the five studied channels in table 1.

Table 1

Global roughness coefficient

No.	Analyzed channel sector	Global roughness coefficient	
		Arithmetic mean	Weighted average
1	Vanatori HPP and Roznov HPP	0.0171	0.0171
2	Roznov HPP and Zanesti HPP	0.0177	0.0178
3	Zanesti HPP and Costisa HPP	0.0187	0.0208
4	Costisa HPP and Buhusi HPP	0.0165	0.0156
5	Buhusi HPP and Racova HPP	0.0150	0.0159

According to [5, 6] the roughness coefficients obtained in this study for the analyzed channel sectors, fit the following values:

- 0.015 – untidy masonry, stone masonry, grouted with care;
- 0.017 – crushed stone masonry in good condition, untidy poured concrete;
- 0.018 – channels with stable deposits of silt, coated with mud;
- 0.020 – stone laying untidy, pavement, channels carved into rock, neat.

5. Conclusions

This study evaluates the operation conditions of the headrace channel between Vanatori HPP and Racova HPP from the Bistrita River hydropower development. Other studies conducted in the past for some sectors of the channel, highlighted the ongoing trend of headrace deterioration, thus affecting HPPs operation supplied by the channel.

Comparing the values obtained from the experimental study with the ones found in the literature [5, 6] in was observed that:

- in some areas of the channel the silting level is high;
- the channels have a high vegetation development;
- channel slide slopes present possible separation of the concrete plates;
- joints between tiles are damaged with possible breakings.

Considering the fact that it has been a long period of time since the last revision and cleaning of the channel, it was expected the value of roughness coefficients to be higher than 0.016 which was the design limit. The large differences indicate that the channel condition deteriorated over time. So it is necessary to perform periodic revisions and repairs (at least every two years), and the works must be carried out rigorously and with high quality.

Also, it is recommended the centralization and unification of the elevation system in values reported to the Black Sea. Currently, three systems are used for reference (Baltic Sea, Black Sea and ICSE Piatra Neamt), making very difficult the accurate assessment leveling. It is also necessary to check and correct the benchmarks elevation, distance to them, bottom slope, geometry and dimension of the channel (especially on the channel between Buhusi HPP and Racova HPP, where many differnces were found between the in site situation and the situation from the documents).

Acknowledgment

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