DISCHARGE MEASUREMENT BY FULL-WIDTH VENTILATED THIN-PLATE WEIR

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Summary: *Current standards and literature of the Republic of Serbia recommend discharge measurements by full-width ventilated thin-plate weirs. The ventilation of full-width thin-plate weirs during hydrograph measurement has not been solved yet. Experimental research regarding the design of a new type of ventilating device for hydrograph measurement has been implemented at the hydraulic laboratory of the Faculty of Civil Engineering in Subotica in July and August 2015. Measurements, carried out from October 20th through December 5th of the same year, proved its functionality.*

Keywords: *thin-plate weir, free flow, weir ventilation*

1. INTRODUCTION

Water discharge over full-width, thin-plate weirs in case of non-submerged, ventilated overflow, in the Republic of Serbia is calculated by the following equation:

$$Q=m\sqrt{2g}\,BH^{3/2} \tag{1}$$

where m is the discharge coefficient, B is the width of the weir and H is the height of the nappe. Generally, the discharge coefficient is:

$$m=f\left(\text{Re},\text{We},\frac{H}{P},\frac{H}{B}\right) \tag{2}$$

where Re and We are Reynolds and Weber numbers, respectively, while P is the height of the weir [1].
The valid international standard [2-3] and the relevant literature in the Republic of Serbia [1, 4-6] recommends the following functions for the discharge coefficient:

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Table 1 Functions for the calculation of the discharge coefficient in case of thin-plate weirs

Bazin	Rehbock 1
$m=\left(0.405+\frac{0.003}{H}\right)\cdot\left[1+0.55\cdot\left(\frac{H}{H+P}\right)^2\right]$	$m=0.403+0.053\cdot\frac{H}{P}+\frac{0.0007}{H}$
0.005 m < H < 1 m 0.005 m < H < 1.24 m	0.005 m < H < 1 m H > 0.003 m 0.005 m < H < 1.24 m
P ≥ 0.5 m P > H P ≥ 0.5 m 0.24 m < P < 1.13 m	P ≥ 0.5 m P > H P ≥ 0.5 m 0.24 m < P < 1.13 m
B ≥ 0.5 m B ≥ H 0.2 m < B < 2 m	B ≥ 0.5 m B ≥ H 0.2 m < B < 2 m

Frese	SIA
$m=\left(0.41+\frac{0.0014}{H}\right)\cdot\left[1+0.55\cdot\left(\frac{H}{H+P}\right)^2\right]$	$m=0.41\cdot\left(1+\frac{1}{1000\cdot H+1.6}\right)\cdot\left[1+0.5\cdot\left(\frac{H}{H+P}\right)^2\right]$
0.005 m < H < 1 m H > 0.1 m	0.005 m < H < 1 m
P ≥ 0.5 m P > H	P ≥ 0.5 m P > H
B ≥ 0.5 m B ≥ H	B ≥ 0.5 m B ≥ H

Rehbock 2	Kindsvater-Carter (K-C)
$m=\frac{\left(0.602+0.083\cdot\frac{H}{P}\right)\cdot\frac{2}{3}\cdot(H+0.0012)^{\frac{3}{2}}}{H^{\frac{3}{2}}}$	$m=\frac{\left(0.602+0.075\cdot\frac{H}{P}\right)\cdot\frac{2}{3}\cdot(b-0.0009)\cdot(H+0.001)^{\frac{3}{2}}}{b\cdot H^{\frac{3}{2}}}$
0.03 m < H < 1 m	H > 0.3 m
0.06 m < P < 1 m	P ≥ 0.1 m
B > 0.3 m	B ≥ 0.15 m

For the ventilation of the nappe, the literature recommends installation of ventilation holes beneath the nappe in the channel walls [8-12], or using pipes for air supply [13-14]. The problem of inadequate ventilation ensured by the holes in the channel walls is due to the pozition of the holes, especially in the adherence of the nappe in the tranzition phase between clinging and free flow [15]. Ventilation by an air supply pipe is required time to time by forcing air through the pipe. This problem was confirmed by the experience gained in the hydraulic laboratory of the Faculty of Civil Engineering in Subotica (where tests were led by the author) [16-17]. In the same laboratory, the simplest and most efficient ventilation of the nappe has been achieved by running a finger across the nappe [17-19].

During July and August 2015, in the hydraulic laboratory of the Faculty of Civil Engineering in Subotica, the author of this paper experimentally tested a new type of nappe ventilation named as “artificial finger” or ventilation strip, which is a 3 cm wide metal sheet bended in a shape of letter “L” [20]. Using the artificial finger ensured sufficient air for the ventilation of the nappe. The first test was made during August and September of the same year in the same laboratory. The horizontal part of the artificial finger was tied to the downstream side of the weir, 3 mm below the crest level (right at the lower edge of the chamfered notch). The weir was in a 2,2 m long rectangular channel, at half of the channel's length. Having the weir located in such manner, the limit of submergence of the weir was defined. None of the two functions provided by the international standard were valid for the ventilated overflow.
Based on the results presented above regarding the ventilated nappe, it is obvious that the artificial finger, succesful in terms of aeration, induced unwanted influences on the overflow as well. Due to this fact, on October 20th of the same year, new tests started with the aim of enabling measurement of flow by full-width thin-plate weir equipped with the artificial finger without the unwanted effects.

2. TEST RIG DESCRIPTION

In the hydraulic laboratory of the Faculty of Civil Engineering in Subotica, a P=0,2013 m high, full-width thin-plate weir has been installed to the downstream end of a B=0,1 m wide and 2,2 m long channel:

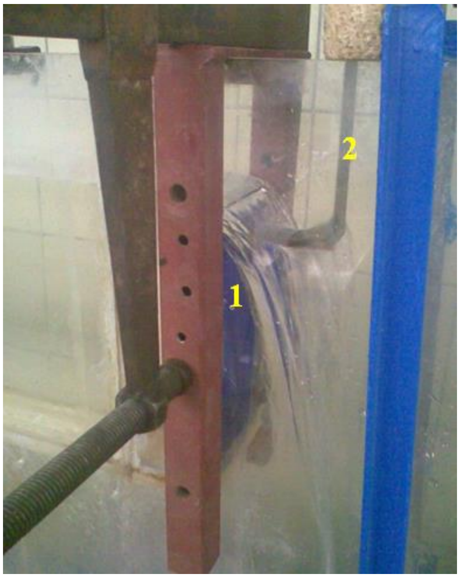

Figure 1: The operation of the full-width thin-plate weir (1) equipped with artificial finger (2)

The channel has been supplied by water from a storage tank by the means of a pump. The water already flown over the thin-plate weir was either returned to the storage tank, or it was derived to an intake vessel for measurement purposes. The plexiglass weir was 5 mm thick with crest thickness of 2 mm, and the notch angle of the dowstream side was 45^o.
The water level was measured 0,18 m upstream to the weir using a gauge of ±0,1 mm accuracy.
Derivation of water lasted at least 25 seconds. The weight of the water was measured by a scale of 5 grams accuracy (within the range of up to 15 kg) and 10 grams accuracy (up to 150 kg).
During water derivation the temperature of water was measured near to the upstream section. It varied between 19 and 21°C and in average it was 19,94°C during the whole period of measurement. Water density was established by a measuring cylindre of 1 dm^3 volume, calibrated for water temperature of 20°C. The density of water was 1 kg/dm^3, therefore the flow rate was calculated by the following equation:

$$Q=\frac{G_{sud+voda}-G_{sud}}{t}\ (l/s) \tag{3}$$

where: $G_{vessel+water}$ – is the combined weight of the vessel and the contained water (kg), G_{vessel} – is the weight of the vessel only (kg), and t – is the duration of water derivation (s).
The error in the discharge coefficient was calculated by the following equation:

$$\text{Error}=\frac{100\left(m_j-m_{(1)}\right)}{m_1}(\%) \tag{4}$$

where: m_j – is the discharge coefficient, calculated in accordance with one of the listed functions in Tab. 1, and $m_{(1)}$ – is the discharge coefficient calculated by equation (1).
Two arrangements were tested:
1. a weir without the artificial finger, and
2. a weir equipped with the artificial finger.

3. RESULTS OF THE MEASUREMENTS

The artificial finger was installed at the middle of the weir. Its height was established by testing. Having in mind that eventual backwater effect caused by the artifical finger had to be avoided, the horizontal part of the finger had to be installed at least Δz=0,016 m below the crest level.
In case of arrangement 1 a total of 118, and in case of arrangement 2 a total of 84 measurements have been complished.
Testing was carried out applying minor increments in flow rate, starting from zero to the maximum flow, and then back to zero in a similar procedure. During the phase of rising flow rate the nappe was not ventilated at the beginning, while later on the nappe got

separated from the plate. Therefore, nappe separation occurred at a particular point, denoted as "separation point". In the opposite process, the nappe adhered to the weir at once at a point denoted as "adherence point". As can be seen in Fig. 2 the adherence point was stable at H=0,01 m in both arrangements tested (with and without the artifical finger). The separation point was stable just in arrangement 2 (with finger installed): at a flow range Q=0,00043÷0,00044 m^3/s the height of the nappe jumped from H=0,0155 m to H=0,0171 m

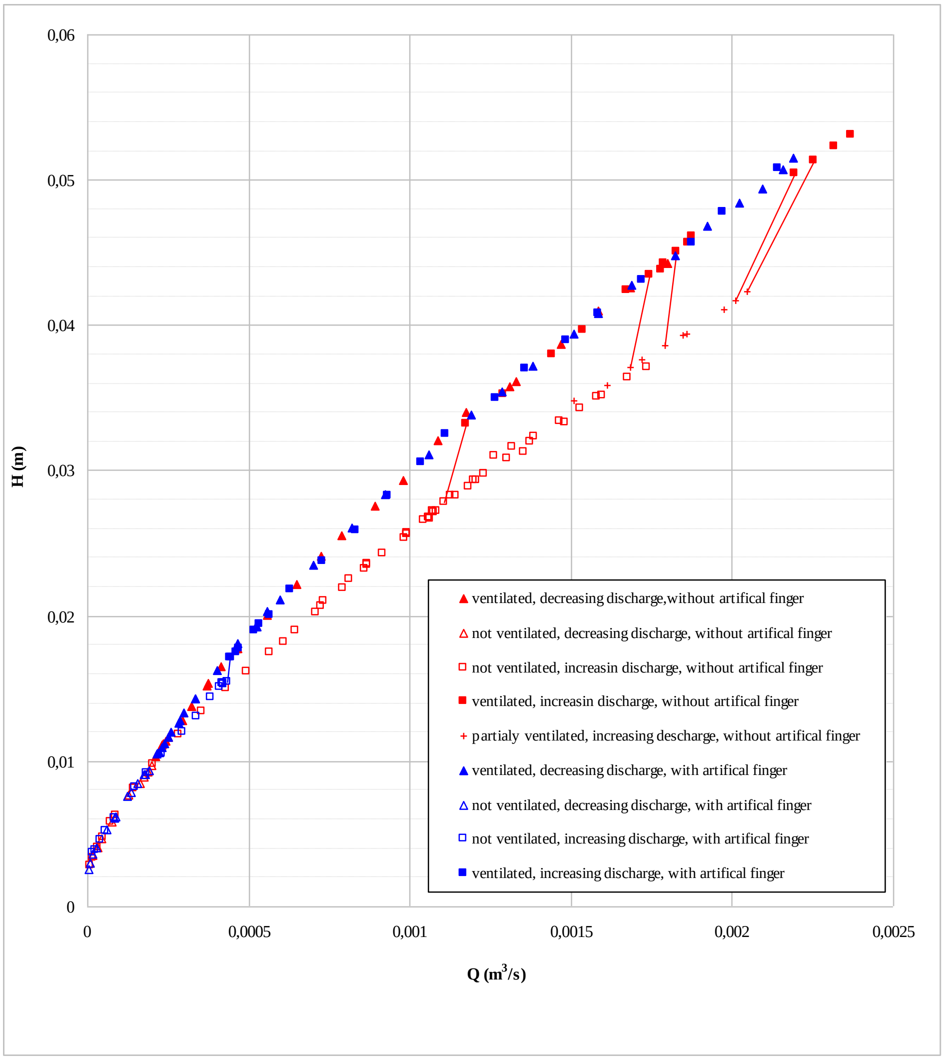

Figure 2: The dependence between the height of the nappe H and the flow rate Q for the investigated case

From the investigated cases carried out without the artificial finger or with it (installed to the appropriate position), in arrangement 1 the results of 42 experiments, while in arrangement 2 the results of 54 experiments have been selected for further analysis. Next, the coefficient of discharge was determined by equation (1) for the selected experiments, see Fig. 3.

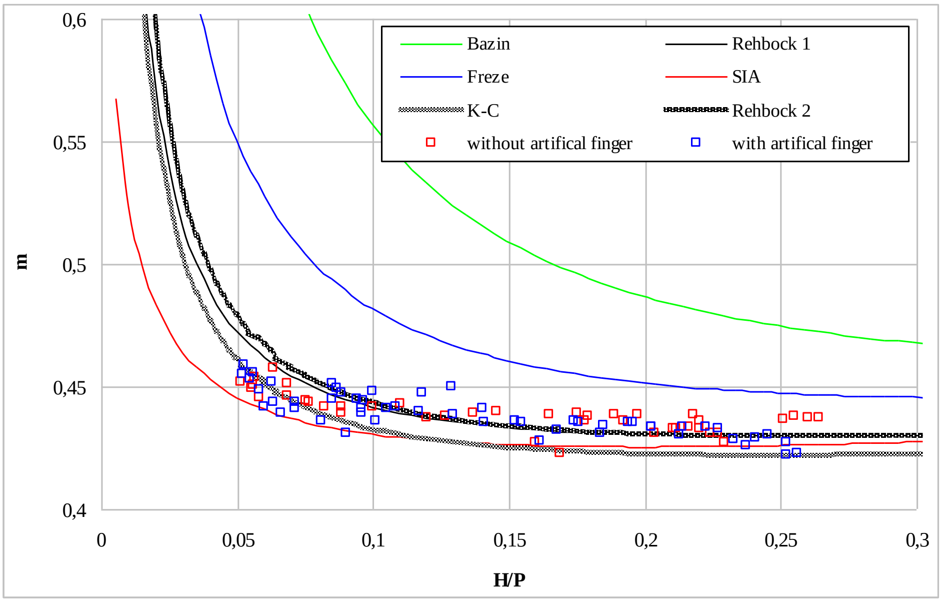

Figure 3: Discharge coefficient of the ventilated nappe m in the function of H/P

4. DISCUSSION

The application of the artificial finger did not change the adherence point in measuring flow rate in case of ventilated nappe, full-width, thin-plate weir. The benefit of using the articial finger in flow measurement is fixing the separation point to a particular discharge in case of a specific weir. In phase of rising discharge nappe ventilation occurs at overflow height H≥0,0171 m, while for the phase of dropping discharge at H≥0,01 m.
According to Fig. 3 the measured values of the discharge coefficients in the range of 0,05≤H/P<0,1 show discrepancy between -3,4 and +2,2% compared to the Kindsvater-Carter equation, and in the range of 0,1≤H/P<0,3 compared to the Rehbock 1 and Rehbock 2 equation the error is -2,9 i +2,3%.

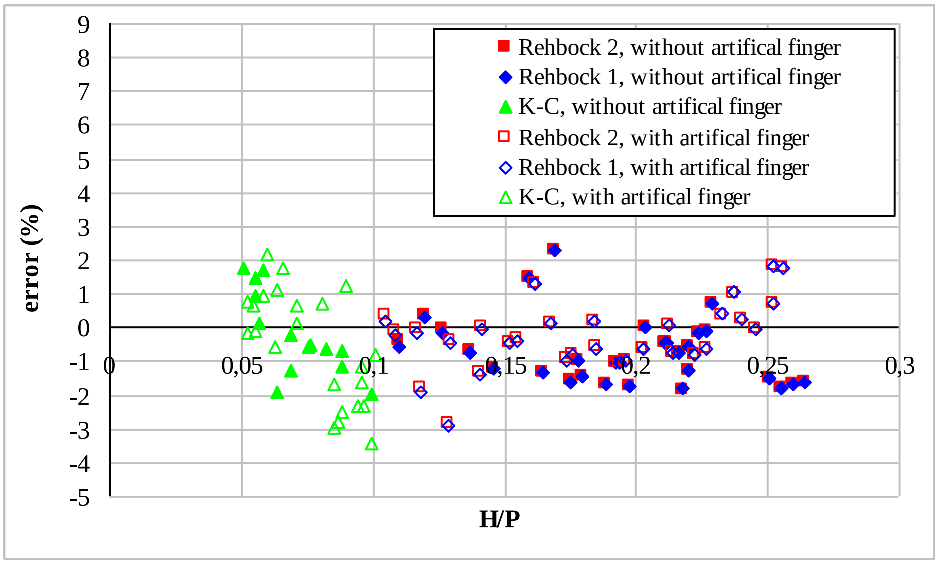

Figure 4: Error of the coefficient of discharge in the function of the nappe height H for thin-plate weir

By using the artificial finger, the discharge can be defined within error limits of -3,4 i +2,3% using discharge formulas from the international standard suitable for the range of the measurement, as described above.

According to the literature, the discharge over a thin-plate weir does not dependant of the Reynolds and the Weber numbers only if H≥0,03 m. The use of the artificial finger decreases this limit to

- H≥0,0171 m for the phase of increasing discharge, and to
- H≥0,01 m for the phase of decreasing discharge.

5. CONCLUSION

The presented artificial finger, tested on a full-width, thin-plate weir of height P=0,2 m, ensures ventilated flow for H≥0,0171 m in case of increasing discharge, and for H≥0,01 m in case of decreasing discharge.

Using formulae from the international standard in the appropriate H/P range, the coefficient of discharge can be determined within error range -3,4 and +2,3%.

The most suitable position of the artificial finger needs to be determined by further investigations for full-width, thin-plate weirs in free flow having different height/width ratio from the already investigated.

REFERENCES

[1] Aranđelović, D.: *Hidraulika u oblasti građevinarstva*. Univerzitet u Nišu, Građevinski-arhitektonski fakultet, Niš, 2000.
[2] International standard ISO 1438:2008(E). Hydrometry – Open channel flow measurement using thin-plate weirs. Switzerland: International Organization for Standardization 2008.
[3] International standard ISO 1438:2008 Technical Corrigendum 1. Hydrometry – Open channel flow measurement using thin-plate weirs Switzerland: International Organization for Standardization 2008.
[4] Hajdin, G.: *Mehanika fluida. Knjiga druga. Uvođenje u hidrauliku*. Univerzitet u Beogradu, Građevinski fakultet, Beograd, 2002.
[5] Kapor, R.: *Hidraulika*. Univerzitet u Beogradu, Građevinski fakultet, Beograd, 2008.
[6] Agroskin, I.I., Dmitrijev, G.T., Pikalov F.I.: *Hidraulika*. Udžbenici Sveučilišta u Zagrebu, Tagreb, 1969.
[7] Bagheri, S., Kabiri-Samani, A.R., Heidarpour, M.: Discharge coefficient of rectangular sharp-crested side weirs. Part I: Traditional weir equation. *Flow Measurement and Instrumentation*, **2014**, vol. 35, br. March 2014, str. 109–115.
[8] Chadwick, A., Morfett, J.: *Hydraulics in Civil and Environmental Engineering*. Third edition. E and FN Spon, London and New York, 1998.
[9] http://www.agis.agric.za/agric_engineering/pdf/IrrigationDesignFlowmeasurement.pdf, preuzeto 5.02.2016. *Irrigation User Manual*. ARC Institute for Agricultural Engineering, 2003, ISBN 1-919849-24-6.
[10] http://waterrights.utah.gov/distinfo/measurement_devices.pdf, preuzeto 5.02.2016. Gertrudys B. Adkins: Flow Mearurement Devices. 2006
[11] http://cclynchblog.com/criteria-for-proper-weir-design/, preuzeto 5.02.2016. Trey Campbell: Criteria for Proper Weir Design. Posted on July 23, 2012.
[12] https://books.google.rs/books?id=JaPAAgAAQBAJ&pg=SA52-PA6&lpg=SA52-PA6&dq=Full-width+Thin-plate+Weir%2Bventilation&source=bl&ots=evLC5T5zJ9&sig=dzu8TBUFVUeuVdPpY_fHA5GVxo8&hl=sr&sa=X&ved=0ahUKEwi23pm57N3KAhXE3iwKHc8EAHoQ6AEIRjAF#v=onepage&q=Full-width%20Thin-plate%20Weir%2Bventilation&f=false, preuzeto 5.02.2016.
Webster, J.G., Eren, H. (Edited by): *Measurement, Instrumentation, and Sensors Handbook. Second edition*. CRC Press Taylor and Francis Group, 2014.
[13] https://www.google.rs/search?q=Sharp-Crested+Weir%2Bventilation&tbm=isch&tbo=u&source=univ&sa=X&ei=zz6aVdKKJ4j7gwTCqY7gDQ&ved=0CCEQsAQ&biw=1920&bih=943#imgrc=4Yu4z849pnwwBM%3A, preuzeto 5.02.2016.
[14] Bos, M.G.: *Discharge Measurment Structures*. International Institute for Land Reclamation and Improvement, Wageningen, 1976.
[15] Zhang, X., Yuan, L., Peng, R., Chen, Z. Hydraulic Relations for Clinging Flow of Sharp-Crested Weir. *Journal of Hydraulic Engineering*, **2010**, vol. 136, br. 6, str. 385–390.

[16] Uhlarik, K.: *Modelsko ispitivanje oštroivičnog preliva pri slobodnom prelivanju vode u kanalu širine 25 cm. Diplomski rad*. Univerzitet u Novom Sadu, Građevinski fakultet u Subotici, Subotica, 2003.
[17] Čipa, R.: *Modelsko ispitivanje oštroivičnog preliva pri slobodnom prelivanju vode – posebnim osvrtom na visinu preliva. Završni rad Master akedemske studije*. Univerzitet u Novom Sadu, Građevinski fakultet u Subotici, Subotica, 2015.
[18] Budinski, Lj.: *Modelsko ispitivanje oštroivičnog preliva pri slobodnom prelivanju vode. Diplomski rad*. Univerzitet u Novom Sadu, Građevinski fakultet u Subotici, Subotica, 2001.
[19] Soldo, M.: *Modelsko ispitivanje oštroivičnog preliva pri slobodnom prelivanju vode zakošenog u horizontalnoj ravni. Diplomski rad*. Univerzitet u Novom Sadu, Građevinski fakultet u Subotici, Subotica, 2003.
[20] Dubac, E.: Merenje hidrograma otivanja nesuženim ovazdušenim oštroivičnim prelivom pri slobodnom prelivanju vode – sa posebnim osvrtom na visinu preliva. Završni rad Master akedemske studije. Univerzitet u Novom Sadu, Građevinski fakultet u Subotici, Subotica, 2015.

MERENJE PROTICAJA OŠTROIVIČNIM, AERISANIM PRELIVOM BEZ BOČNE KONTRAKCIJE

Rezime: *Postojeći standard i stručna literatura Republike Srbije preporučuju merenje proticaja vode oštroivičnim prelivom, pri aerisanom mlazu. Aeracija mlaza, prilikom merenja hidrograma oštroivičnim, nesuženim prelivom, još nije rešena. Tokom jula i avgusta 2015-e godine, u Hidrauličkoj laboratoriji Građevinskog fakulteta u Subotici, eksperimentalno je istraživan novi tip aeratora mlaza u ovu svrhu. Merenjem od 20. oktobra do 5. decembra iste godine dokazana je njegova valjanost.*

Ključne reči: *oštroivični preliv, nepotopljeno prelivanje, aerator mlaza*