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POSSIBILITIES FOR MEASURING SMALL DISCHARGES USING A SIMPLE WEIR CONSTRUCTION

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SUMMARY

Measuring small flow rates often requires expensive equipment and is associated with inherent limitations. In practice, various measuring structures, such as weirs, are commonly constructed at specific locations to facilitate flow measurements. This paper proposes an innovative and low-cost measurement structure made from sewer pipes, incorporating a "V-notch" weir design that can be used under various conditions to measure flow simple and effectively. Laboratory calibration of the weir coefficient was carried out, and ten equations (models) were developed to minimize relative error. The experimental results were compared with existing equation expressions from the literature. Furthermore, the study explores the practical implementation of the proposed weir design. The aim of the study is to demonstrate the feasibility of this solution, highlighting its low construction cost and adaptability for application in diverse field conditions.

Key words: *low-cost, "v-notch", equation, measurement, pvc pipes, small discharge.*

INTRODUCTION

For measuring flow in open channels, various types of weirs are typically used, such as rectangular, trapezoidal, triangular ("V-notch"), and others. Measuring small flows (less than 1.0 l/s), however, poses challenges due to the influence of viscosity, surface tension, and the geometry of the weir itself [1], [2]. For this reason, many researchers have focused on the problem of measuring small flows using simple geometries. The most commonly used type of weir is usually the "V-notch" weir with a small angle or proportional weirs [1], [17], [3]. Measurement accuracy typically depends on the conditions under which measurements are conducted, the type of weir used, and most importantly, the discharge coefficient [4].

Previous studies have shown that the discharge coefficient often depends on the Reynolds number, which is influenced by the shape of the weir [1]. To ensure reliable and accurate measurements, calibration and testing of the weir are necessary [5]. This is typically conducted in laboratories under specific conditions using a weir model [5]. To achieve greater precision, calibration of the discharge coefficient is typically carried out by determining its dependence on specific parameters affecting the flow over the weir. For example, Milburn and Burney, while testing “V-notch” weirs, concluded that the discharge coefficient depends on the height of the overflow jet for flows between 10 and 20 l/s, which corresponds to larger flows [5].

Aydin and colleagues, in their examination of proportional weirs, concluded that the discharge coefficient exclusively depends on the Reynolds number for small flows below 5 l/s. Similar results were found by Rosley Jaafar [1], [6]. Šimon Pospišilik and Zbynek Zachoval studied “V-notch” weirs and determined that the discharge coefficient depends on the relative ratio of the overflow jet height to the vertex height (h_p/p) based on the central angle of the weir [7], [8].

The rationale for employing a V-notch weir in this study is to increase the overflow jet height at small discharge. For this reason, this study utilized a 90° “V-notch” weir made from sewer pipes [9]. The goal of the research is to present a novel, cost-effective design for a weir that can serve as a measuring construction for small flows. The proposed measuring construction is a simple, reusable, and cost-effective measuring structure for various types of measurements. This weir was calibrated and tested in a laboratory for flow values up to 0.7 l/s.

Ten equations (models) were proposed for calculating the discharge coefficient based on parameters affecting the flow over the weir. The forms of these models, along with their coefficients, were determined using regression analysis to minimize deviations between calculated and measured flow values. The proposed technical solution for the weir and the suggested models for estimating the discharge coefficient were compared with other equations provided by different authors. The aim was to verify the results of the proposed model against other equations proposed by various researchers to assess the reliability of the technical solution for the selected weir type [12]. Two models were ultimately identified as providing the lowest relative error in discharge estimation. These models were further validated under field conditions for small flow measurements [18].

MATERIAL AND METHOD

Description of the weir Construction and Design

The flow measurement weir construction is constructed from existing elements of sewer pipes, specifically from a piece of PVC pipe [16]. The outer construction consists of a "T" fitting with dimensions DN 200/200 mm, with the side and bottom ends of the "T" fitting sealed using DN 200 mm caps. On the side where the cap is located, an opening in the shape of a “V notch” weir was created, with the edges precisely finished according to the ISO 1438:2019 standard [3], [10]. The weir edges are shaped at an angle of 90°, and the thickness of the weir wall was designed based on the standards [5], [10].

At the top, inside the construction, a vertical pipe with a diameter of DN 110 mm is installed, fitted with a reducer of DN 110/160 mm. The vertical pipe inside the construction has circular side openings with a diameter of 10 mm, allowing water to flow through and serving as a stilling construction. Water flows vertically through the reducer into the DN 110 mm pipe and evenly exits through the openings into the lower part of the construction. When the water level in the construction rises, further water flow proceeds towards the “V-notch” weir.

A piezometer-like pipe is installed on the side, enabling water level measurement. The water level in the piezometer corresponds to the level at the weir itself. Using the piezometer, it is possible to effectively and accurately read the current level at the weir. The design and details of the weir construction are shown in Figure 1.

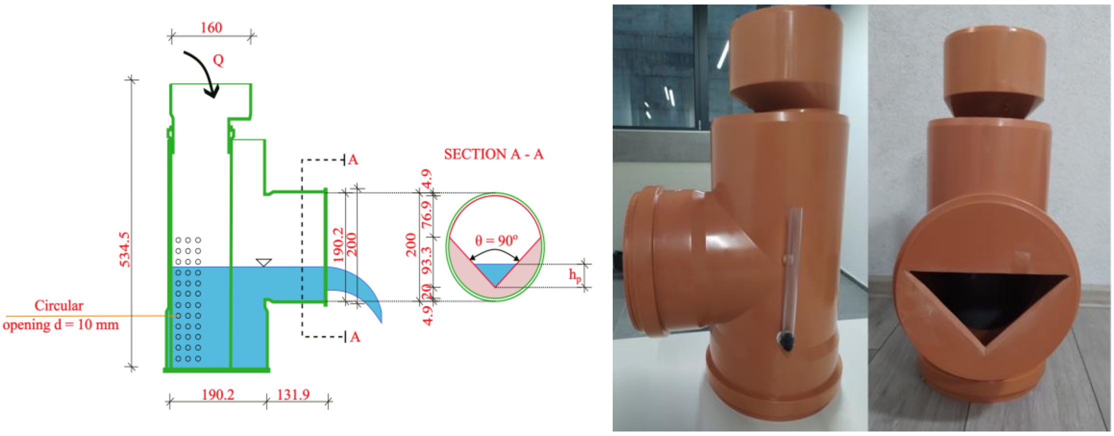


Figure 1. Details of the flow measurement construction

The geometric characteristics of this object, constructed from sewer pipe elements, are as follows: the total height of the construction is 52.3 cm, the width of the construction is 20 cm. The lower edge of the weir is positioned at a height of 13.3 cm, measured from the bottom surface of the construction, the crest height is p = 30 mm. Figure 2 shows the geometrical characteristics of the weir.

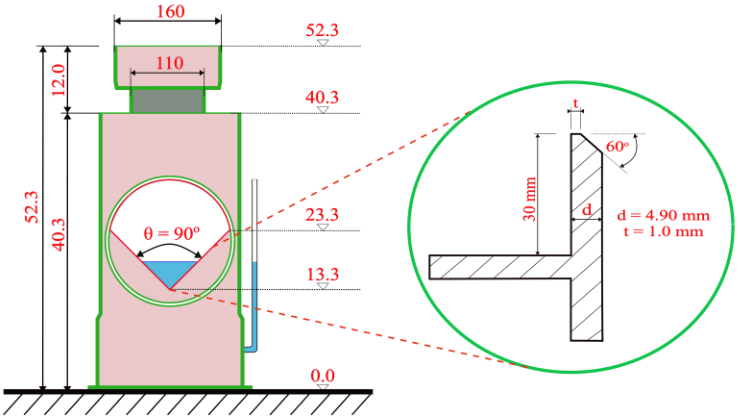


Figure 2. Geometric characteristics and details of the weir shaping

Flow curve (Q – hp)

The flow calculation for the “V-notch” Thomson weir in the case where θ = 90°, is based on the equation [7], [11]:

$$Q = \frac{8}{15} C_d \sqrt{2g} h_p^{5/2} \quad \text{(Equation 1)}$$

where: Q – is the flow rate, C_d – is the discharge coefficient, g – is the gravitational acceleration and h_p – is the water depth.

In the presented equation for the specific weir, the water depth hp, is measured, while the value of the discharge coefficient Cd, is determined during laboratory testing. During the laboratory experiments, the flow rate Q, and the water depth hp were directly measured. It was assumed in the laboratory tests that the discharge coefficient is a function of the following parameters:

$$C_d = f(h_p, \frac{h_p}{p}, R_e, W_b) \qquad \text{(Equation 2)}$$

h_p – water depth, p – the height of the weir relative to the bottom edge of the construction (p = 30 mm), R_e – Reynolds number, defined as $R_e = (h_p \cdot \sqrt{g \cdot h_p})/\nu$, ν – kinematic viscosity of water ($\nu = 10^{-6} m^2/s$), W_b – Weber number, defined as $W_b = (\rho \cdot 2 \cdot g \cdot h_p^2)/\sigma$, ρ – water density, σ – surface tension ($\sigma = 7.3 \cdot 10^6 kg/m$).

Proposed equation for calculation

The previously presented variables, which are functions of the discharge coefficient, were used in several equations (models) with the aim of achieving the best possible agreement between the measured discharge values and the calculated ones. A total of ten computational models for estimating the discharge coefficient have been proposed, as shown in the Table 1:

Table 1. Overview of the used models for estimating the overflow coefficient

Model	C_d	Equation (Model)	
Model 1	$C_{d,m1} = const$	$C_{d,m1} = 0.684$	(3)
Model 2	$C_{d,m2} = f(h_p)$	$C_{d,m2} = a_1 + a_2 \cdot h_p$	(4)
Model 3	$C_{d,m3} = f(h_p/p)$	$C_{d,m3} = a_1 + a_2 \cdot (h_p/p)$	(5)
Model 4	$C_{d,m4} = f(R_e)$	$C_{d,m4} = a_1 + a_2 \cdot (1/R_e^{a_3})$	(6)
Model 5	$C_{d,m5} = f(h_p/p, R_e)$	$C_{d,m5} = a_1 + a_2 \cdot (h_p/p) + a_3 \cdot (1/R_e^{a_4})$	(7)
Model 6	$C_{d,m6} = f(W_b)$	$C_{d,m6} = a_1 + a_2 \cdot (W_e^{a_3})$	(8)
Model 7	$C_{d,m7} = f(h_p/p)$	$C_{d,m3} = a_1 + a_2 \cdot (h_p/p)^{a_3}$	(9)
Model 8	$C_{d,m8} = f(W_b, R_e)$	$C_{d,m4} = a_1 + a_2 \cdot W_b^{a_3} + a_4 \cdot R_e^{a_5}$	(10)
Model 9	$C_{d,m9} = f(W_b)$	$C_{d,m4} = a_1 + a_2 \cdot (1/W_b)$	(11)
Model 10	$C_{d,m10} = f(W_b, R_e)$	$C_{d,m4} = a_1 + (1/W_b^{a_2}) + a_3 \cdot (1/R_e^{a_4})$	(12)

In the previously presented equations and are parameters whose values were determined through optimization, with the goal of minimizing the relative deviation from the measured flow values. The relative deviation between the measured and calculated flow values was used as a measure of agreement and is defined as follows [3], [7], [8]:

$$\varepsilon = \frac{(Q_{model} - Q_{measurement})}{Q_{measurement}} x100[\%] \qquad \text{(Equation 13)}$$

where: ε – relative error, Q_{model} – calculated flow value obtained based on equation (1) using the previously presented models for estimating the overflow coefficient, $Q_{measurement}$ – measured flow value during laboratory tests.

A large number of researchers have dealt with the problem of determining the overflow coefficient, or calibration. For example, Chanson et al. (2002) concluded that the overflow coefficient is constant and has a value of 0.58. In the studies conducted by King (1954) for different values of the central angle (90°, 60°, and 22.5°), for an angle of 90°, the value of the overflow coefficient depends on the height of the overflow jet [12]. He proposed the following equation [11]:

$$C_d = 0.589 / h_p^{0.03} \qquad \text{(Equation 14)}$$

A similar expression was derived by Hertzel (1938) for a central angle of up to 120° and proposed the equation in the following form [11]:

$$C_d = 0.597 / h_p^{0.051} \qquad \text{(Equation 15)}$$

In 1910, Barr-Strickland also proposed an expression for estimating the overflow coefficient as a function of the height of the overflow jet in the following form [11]:

$$C_d = 0.566 + 0.0157 / \sqrt{h_p} \qquad \text{(Equation 16)}$$

In the ISO 1438:2019 standard, in addition to recommendations for shaping the "V" overflow, tabulated values for the overflow coefficient for a “V-notch” overflow (90°) are provided [13], [14], [15]. These results were used for validation in this research.

Cone (1967) also conducted experimental studies related to the "V" overflow and proposed the following equation for estimating the flow as a function of the height of the overflow jet [13]:

$$Q = 1.3427 \cdot h_p^{2.48} \qquad \text{(Equation 17)}$$

where the height of the overflow jet is input in cm, and the flow is obtained in l/min.

Experimental testing, calibration and validation

The experimental investigation was conducted at the Hydrotechnical laboratory of the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. During the laboratory testing, multiple repetitions were carried out to ensure the accuracy and reliability of the results. The primary objective of the test was to determine the discharge coefficient by measuring the overflow jet height and corresponding flow rate. The experimental setup is show in Figure 3. The procedure involved several stages: water was pumped from a lower reservoir into a flow measurement facility using a pump. The overflow jet height, denoted as (*hp*) was measured using a piezometer. Water level readings in the piezometer were taken with a vernier-equipped ruler, with a resolution of 0.10 mm. Subsequently, the water overflowed into a graduated reservoir, which was used to determine the discharge by the volumetric method. The volume was read visually, while the time was measured with a stopwatch. The uncertainty in flow rate measurement arises primarily from the timing precision of the stopwatch and the accuracy of volume readings from the graduated reservoir. The timing error was estimated at 0.5 seconds. The ensure acceptable measurement quality, a relative error tolerance of less than ±5% was adopted as the criterion for flow rate accuracy. For various flow values controlled by a valve, the flow was pumped into the measurement construction, with a flow range from 0.00255 l/s to 0.70478 l/s.

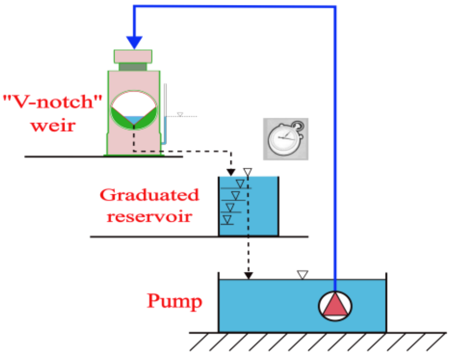


Figure 3. Schematic of laboratory testing

The validation of the measuring structure was carried out under field conditions, specifically for the case of measuring low flow rates at drainage outlets on the Medjedja earthen dam, located in the western part of Bosnia and Herzegovina. Prior to this, flow measurements were conducted using the volumetric method, in which five individual measurements were taken for each drainage pipe, and the average value of the obtained results was used as the representative discharge. Flow measurements using the measuring structure were performed by first appropriately positioning it beneath the drainage pipe, ensuring accurate reading of the water level via the piezometer. After installation, the uniformity of flow and possible turbulence were verified the water flowed uniformly toward the weir section, and to verify whether the elevation difference between the measuring structure and the drainage pipe introduced any additional turbulence. Once it was confirmed that the flow was not significantly affected by turbulence, and that the measuring structure could adequately stabilize the incoming water relative to the outlet elevation of the drainage pipes, the measurement process proceeded. The water level in the piezometer was visually read using a ruler for all three drainage pipes included in the testing. The appearance of the installed measuring structure placed beneath a drainage pipe is shown in Figure 4.

Figure 4. Display of drainage water flow measurement monitoring

RESULTS

Display of results of the model shape for estimation the overflow coefficient

After conducting experimental tests, calibration was performed, and the parameter values in equations (3) – (12) for estimating flow rates were determined. The parameter values were established using a genetic algorithm (using the Generalized Reduced Gradient (GRG) nonlinear method) in order to minimize the relative difference in flow estimation compared to the measured values. The obtained parameter values are shown in Table 2, with the range of parameter values between 0.001 and 0.8235.

Table 2. Display of the obtained parameter values in models (3) – (12)

Label	**Parmeter value**
Model 2	$a_1 = 0.6574; a_2 = 0.8235$
Model 3	$a_1 = 0.6703; a_2 = 0.0161$
Model 4	$a_1 = 0.6746; a_2 = 0.0196; a_3 = 0.0351$
Model 5	$a_1 = 0.7158; a_2 = 0.0146; a_3 = 0.0603; a_4 = 0.0315$
Model 6	$a_1 = 0.0038; a_2 = 0.5933; a_3 = 0.0179$
Model 7	$a_1 = 0.6796; a_2 = 0.001; a_3 = 0.4775$
Model 8	$a_1 = 0.1638; a_2 = 0.2329; a_3 = 0.0327; a_4 = 0.2206; a_5 = 0.0006$
Model 9	$a_1 = 0.6883; a_2 = 0.1995$
Model 10	$a_1 = 0.3577; a_2 = 0.0001; a_3 = 0.3356; a_4 = 0.0014$

Flow Curve Results

For the conducted laboratory tests, the flow values and the height of the overflow jet at the overflow construction were determined. The obtained proposed models were used to estimate the flow according to equation (1), with a comparison of the flow values for the same measured flows made against expressions proposed by other authors. The results are presented as $Q - hp$ curves, which provide a convenient basic for comparison.

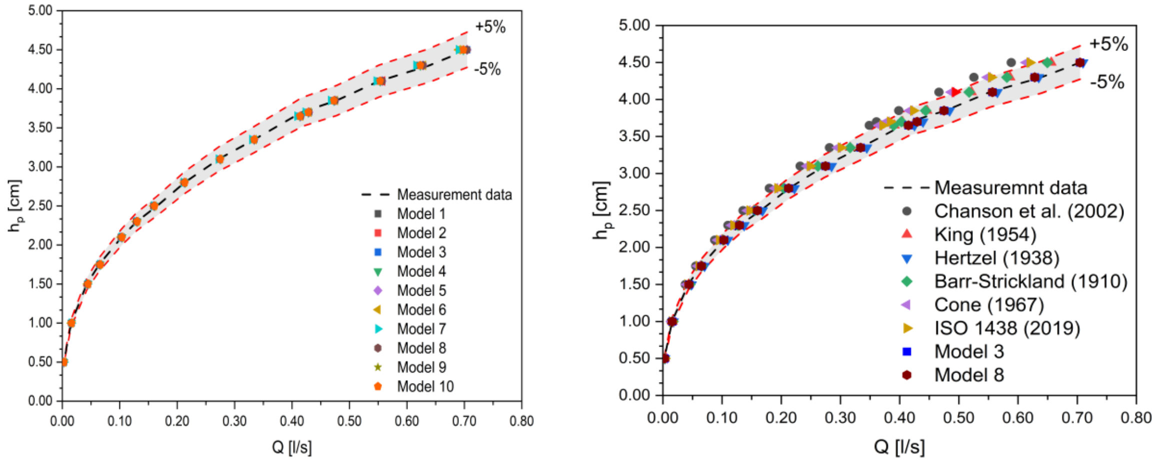


Figure 5. Display of flow curve results obtained from the model and from equations of other authors

Visually, all proposed models (1–10) exhibit good agreement with the measured values, confirming that the parameter optimization was effective. To identify the most accurate model for describing the flow curve across the measured range, a dimensionless comparison between calculated and measured discharges was performed, with the results presented in Figure 5.

Of the total 160 data points, 68 (42.5%) correspond to a dimensionless flow ratio below 1.0, while 92 (57.5%) correspond to values greater than or equal to 1.0. Comparison of computational and observed flow values shows in Figure 6.

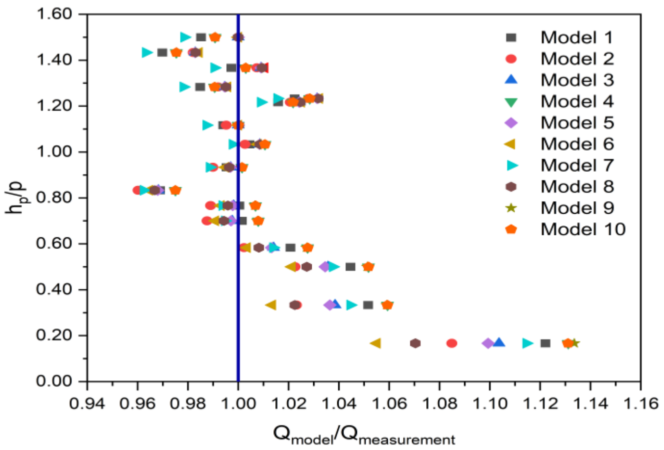


Figure 6. Comparison of computational and observed flow values

The objective of this study is not to propose numerous equations for evaluating the discharge coefficient but to recommend the simplest possible model as a function of the parameter that most significantly influences the flow rate. The best agreement was achieved with Models 3 and 8. The discharge coefficient in Model 3 is a function of the ratio $C_{d,m3} = f(h_p / p)$ with a total of two parameters (a_1

and a_2). Model 8 is somewhat more complex, represented as $C_{d,m8} = f(W_b, R_e)$, and has five parameters (a_1, a_2, a_3, a_4 and a_5). These two models have been selected as recommended because they encompass all analyzed parameters. Consequently, they were compared with the results proposed by other authors. The comparison results are presented using Q-Q diagrams and shown in Figure 7.

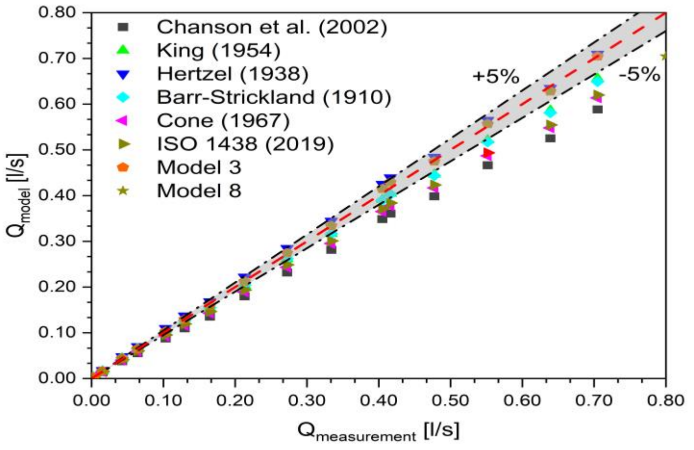


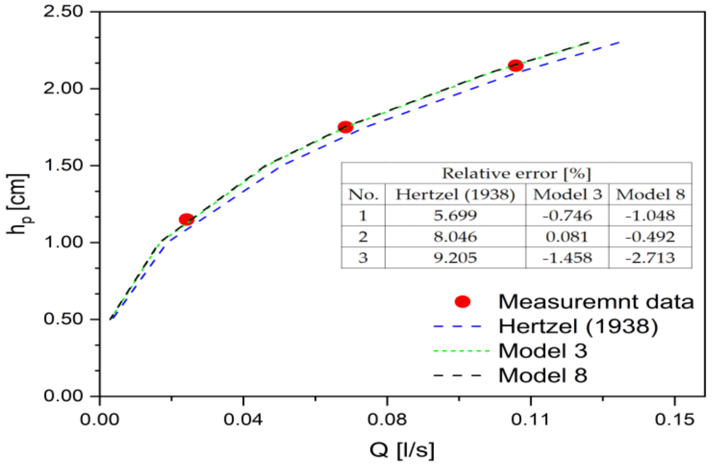
Figure 7. Comparison of results using Q-Q diagrams

As previously noted, the testing of the overflow structure was carried out by measuring flow rates from the drainage pipes. Table 3 presents the measured discharges alongside the calculated values obtained using the Hertzel (1938) equation, as well as Models 3 and 8.

Table 3. Results obtained from testing the measuring construction

No.	hp [cm]	Measured Flow [l/s]	Hertzel (1938)	Model 3	Model 8
1	2.15	0.110	0.11627	0.10918	0.10885
2	1.75	0.065	0.07023	0.06505	0.06468
3	1.15	0.023	0.02512	0.02266	0.02238

The obtained results show good agreement with the values measured from the drainage pipes. Particular attention should be given to the absolute deviation between the calculated and measured flow values. These results are presented in conjunction with the flow curve and discrete measurement points in Figure 8.



Relative error [%]

No.	Hertzel (1938)	Model 3	Model 8
1	5.699	-0.746	-1.048
2	8.046	0.081	-0.492
3	9.205	-1.458	-2.713

Figure 8. Measurement points and flow curve for the applied equation forms

Relative Error in Obtained Results

An important aspect to highlight is the distribution of relative error across the entire range of measured flow rates. The relative error was evaluated for all proposed models in order to identify the domains exhibiting the greatest discrepancies. For the two recommended models, Model 3 and Model 8, which demonstrated the lowest relative errors, a detailed comparison was made against the results obtained from equations reported by other authors. The relative error is shown in Figure 9. When analyzing the mean relative error over the observed flow range, Model 3 achieved the lowest value of 1.12%, while Model 8 exhibited a slightly higher, yet still negligible, mean error of 1.20%. The remaining models produced larger deviations, with the maximum recorded for Model 7, amounting to 1.6%.

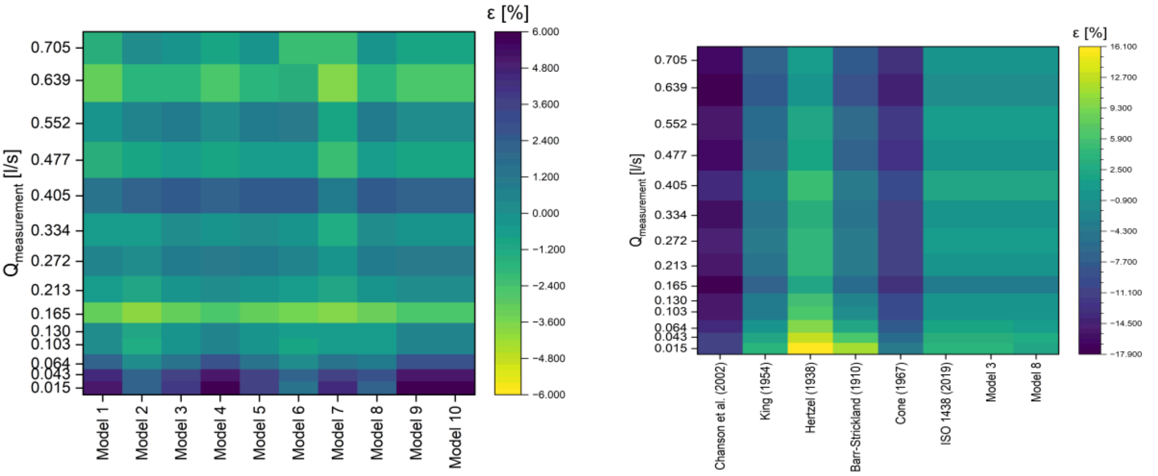


Figure 9. Relative error for proposed models (left) and based on other authors expressions (right)

DISCUSSION

Measuring small flow rates is relatively expensive and time-consuming, with accuracy dependent on numerous factors. To achieve greater precision and reliability, it is necessary to consider not only the quality of the measuring construction but also all influencing factors affecting the results. This study proposes the construction of a measuring construction using sewer pipes, forming a “V-notch” weir with a 90° angle. For the selected weir type and its design, a calibration of the discharge coefficient was performed through extensive laboratory experiments.

A total of ten equations (models) were proposed, based on the relationship $C_d = f(h_p, h_p/p, R_e, W_b)$. These models range from simple to complex forms, with parameters optimized to minimize relative error. Among the ten models, only two proved reliable for small flow values: Model 3, defined as $C_{d,m3} = f(h_p / p)$, and Model 8, defined as $C_{d,m8} = f(W_b, R_e)$. The other models showed relative errors exceeding 5%.

Regarding the comparison of results with equations proposed by other authors, the formula by Hertzel (1938) yielded the best results relative to observed flow values. However, within the examined flow range of ±5.0%, significant deviations were observed with expressions from Chanson et al. (2002), Barr-Strickland (1910), Cone (1967), and the ISO 1438 standard (2019). It is essential to note that these expressions were used as benchmarks to compare results for the proposed measuring construction, but their applicability depends on the specific conditions under which they were developed.

While Hertzel's (1938) expression showed good agreement in the considered flow range, it exhibited much larger relative errors (over 5.0%) during flow measurement tests on drainage pipes compared to Models 3 and 8 proposed in this study.

Among the proposed models, Model 3 and model 8 yield different results, with Model 3 demonstrating better agreement with measured flow values. Due to its simplicity, Model 3 is recommended as part of a technical solution for this measuring construction.

The proposed technical solution undoubtedly requires further improvement, with the aim of achieving automation and enabling continuous flow measurement. One potential enhancement of the measuring structure involves integrating a low-cost water level sensor (such as the HC-SE04, based on the Arduino platform), capable of continuously recording the water level. Using the proposed discharge models, such measurements can be used to determine real-time flow rates. This approach would enable long-term flow monitoring for various practical applications. In addition to improving the measuring structure itself, it is important to consider its compact spatial requirements, which allow for convenient installation in limited spaces. However, when deployed outdoors over extended periods, the accumulation of debris (e.g., leaves, sediment) may affect the accuracy of the measurements. To address this issue, a protective screen or debris trap may be incorporated as part of the solution. Despite these potential upgrades, it should be emphasized that the measuring structure requires minimal maintenance-limited mainly to occasional flushing in case of debris buildup. Its overall performance and reliability primarily depend on the quality of the PVC pipes used in its construction.

CONCLUSIONS

This study proposes an innovative, simple, cost-effective, and practical measuring construction for determining small discharge values, constructed from sewer pipes. The calibration of the discharge coefficient was performed for the specific measuring object, and a total of ten models were proposed. The parameters of these models were determined using optimization methods to achieve the lowest possible relative error. Out of the ten models, Model 3 is recommended for use due to its simplicity, involving only two parameters and expressed as $C_{d,m3} = f(h_p / p)$.

When compared to expressions proposed by other authors, significant deviations are noticeable. Among them, the expression by Hertzel (1938) provided the best agreement within the discharge value range; however, during test measurements, it exhibited a higher relative error compared to the proposed models. All the proposed equations for estimating the discharge coefficient correspond to the specific conditions for which they were designed.

Laboratory tests and field measurements have clearly shown that no additional turbulence or air entrainment occurs during flow. Once the water is stabilized within the measuring structure, it flows uniformly toward the weir. This enables efficient and reliable measurement of low flow rates.

For future research, the proposed measuring structure should be tested with other types of weirs, such as proportional weirs. Additionally, incorporating a sensor for level measurement is suggested to enable continuous level monitoring. This would allow the proposed model to directly determine discharge.

REFERENCES

[1] Aydin I, Ger AM, Hincal O. Measurement of small discharges in open channels by slit weir. Journal of Hydraulic Engineering. 2002 Feb;128(2):234-7. https://doi.org/10.1061/(ASCE)0733-9429(2002)128:2(234)

[2] Ikpe AE, Orhorhoro EK. Pressure Losses Analysis in Air Duct Flow Using Computational Fluid Dynamics (CFD). International Academic Journal of Science and Engineering. 2016;3(9):55-70.

[3] Clemmens AJ, Wahl TL, Bos MG, Replogle JA. Water measurement with flumes and weirs. International Institute for Land Reclamation and Impovement: Wageningen, The Netherlands. 2001 Aug 1:382.

[4] Aydin I, Altan-Sakarya AB, Ger AM. Performance of slit weir. Journal of Hydraulic engineering. 2006 Sep;132(9):987-9. https://doi.org/10.1061/(ASCE)0733-9429(2006)132:9(987)

[5] Workman SR, Higgins SF, Shearer SA. Monitoring subsurface drainage flow at remote locations. Applied Engineering in Agriculture. 2001;17(6):783. https://doi.org/10.13031/2013.6847

[6] Jaafar R. Head-Discharge relationships for rectangular flat-crested slit weir. Jurnal Intelek. 2015;10(1):49-54.

[7] Pospíšilík Š, Zachoval Z. Discharge coefficient, effective head and limit head in the Kindsvater-Shen formula for small discharges measured by thin-plate weirs with a triangular notch. Journal of Hydrology and Hydromechanics. 2023;71(1):35-48.

[8] Pospíšilík Š, Zachoval Z, Gabriel P. Flow over thin-plate weirs with a triangular notch–influence of the relative width of approach channel with a rectangular cross-section. Journal of Hydrology and Hydromechanics. 2024;72(2):199-206. https://doi.org/10.2478/johh-2024-0008.

[9] Usikalu MR. Simulation of Turbulent Flow in Pipes Using the Navier-Stokes Solver with Finite Volume Method. Association Journal of Interdisciplinary Technics in Engineering Mechanics. 2025 Sep 30;3(3):8-13. https://ajitem.org/index.php/journal/article/view/EM33002

[10] Vatankhah AR. Analytical solution for water surface profile along a side weir in a triangular channel. *Flow Measurement and Instrumentation.* 2012;23(1):76-79.

[11] Shen J. Discharge characteristics of triangular-notch thin-plate weirs. US Geological Survey; 1981.

[12] Weissmann, G., & Watanabe, J. (2023). Research on Innovative Practices of Civil Engineering Construction Technology. International Academic Journal of Innovative Research, 10(4), 25–30.

[13] El Hattab MH, Mijic A, Vernon D. Optimised triangular weir design for assessing the full-scale performance of green infrastructure. Water. 2019 Apr 14;11(4):773. https://doi.org/10.3390/w11040773

[14] Chanson H, Wang H. Unsteady discharge calibration of a large V-notch weir. Flow Measurement and Instrumentation. 2013 Mar 1;29:19-24. https://doi.org/10.1016/j.flowmeasinst.2012.10.010.

[15] Jevtić D, Zakić D. Experimental testing of certain thermo-physical and mechanical properties of eps concrete. Materijali i konstrukcije. 2009;52(2):35-45.

[16] Ferro V, Aydin I. New Theoretical solution of stage-discharge relationship for slit weirs. Journal of Irrigation and Drainage Engineering. 2018 Mar 1;144(3):06018001, https://doi.org/10.1061/(asce)ir.1943-4774.0001285.

[17] Alwetaishi N, Alzaed A. Smart construction materials for sustainable and resilient infrastructure innovations. Innovative Reviews in Engineering and Science. 2025;3(2):60-72.

[18] El-Ansary MY, Awad MA, Nassar AA, Farag AA. Calibration of three common flow measurement devices for open channels. Misr Journal of Agricultural Engineering. 2010 Jan 1;27(1):151-69. https://doi.org/10.21608/mjae.2010.107153