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The coefficient of discharge at the bottom intake weir with a screen of a circular perforated plate

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Abstract

The purpose of this study is to find the value of the discharge coefficient (*Cd*) on a sieve with a circular perforated plate so that it can be used for application in the field. The method used is to make a physical model test of the screen weir in the laboratory with a width of 40 cm and a length of 797 cm, then the screen is made variations in the diameter of the hole 6, 8, 10 and 12 mm, flowrate Q = 453–4 481 $cm^3 \cdot s^{-1}$ and the slope of the screen θ = 20–45°. The result was quite effective, the sediment did not enter above the screen and did not clog the screen even the catch was quite good about 80% of the screen rods. The discharge coefficient (*Cd*) is directly proportional to the square value of the number Froude (*Fr*), the slope of the screen (θ) and the ratio of distance, diameter of the screen (a:d) and inversely proportional to the value of the specific energy square (E). From modelling the average value of the discharge coefficient (*Cd*) between 0.1–2.75 with *NSE* = 0.71, *MAE* = 0 and *RMSE* = 0.12.

Key words: *bottom intake, circular perforated plate, discharge coefficient, screen*

INTRODUCTION

The bottom intake weir with screen is very safe for water flow in the river which is located on a relatively small mountain [DROBIR *et al*. 1999], steep slopes and irregular layer configurations [BOUVARD 1992]. The bottom intake weir with screen also functions flow breaker and energy dissipator [VENKATARAMAN *et al*. 1979]. If the screen gets blocked, then the water supply to the irrigation area decreases thereby reducing agricultural productivity. Besides current climate change and extreme events, there needs to be an appropriate strategy for the development of irrigation and water use control [ŁABĘDZKI 2009]. The analysis revealed a shift in the time of the decade with minimum groundwater content, for example in an area from three decades for layers of 0–10 cm to seven in terms of layers with a thickness of 0–40 cm so that it needed engineering to utilize river water for irrigation purposes [KOWALCZYK-JUŚKO *et al*. 2017]. Moreover, the river drains sediment which grain size of sediment particles tends to decrease along the water flow direction [BĄK, DĄBKOWSKI 2013].

An alternative solution that can be done is to use a screen with a circular perforated plate. The result was quite effective, the stones did not enter above the screen and did not clog the screen, even the water's catching capacity was quite good about 80% of the screens using longitudinal rods. However, for the purposes of field applications, an ideal coefficient of discharge (*Cd*) has not yet been found for screens from circular perforated plates. The discharge coefficient (*Cd*) for screens with a slope of 20–45% is recommended at 0.35–0.90 [SAHINER 2012], but in determining the *Cd* value the geometric shape of the screen is ignored. Other researchers also suggested that the *Cd* value must consider the flow conditions and the amount of discharge that enters the screen [KUMAR *et al*. 2010].

Then it is necessary to make a physical model that considers the screen length, the distance between screens and the slope of the screen will get a more accurate *Cd* value [WHITE *et al*. 1972]. Froude numbers greatly affect the flow conditions [RIGHETTI, LANZONI 2008]. The tendency of energy dissipation with increasing Froude number and screen opening ratio [VENKATARAMAN *et al*. 1979]. Under subcritical flow conditions [KUMAR *et al*. 2010], the value of the discharge coefficient is influenced by the screen opening area (ε) and the ratio between the screen distance (s) and the screen length (L). Based on other experimental studies [SUBRAMANYA 1990], the value of the discharge coefficient in subcritical flow influenced by the diameter of the rod (d), the screen distance (s) and the slope of the screen (θ). Also based on physical model tests taking into account the screen slope, screen geometry and screen distance [KAMANBEDAST, BEJESTAN 2008]. In studying in detail the flow characteristics above the screen [GHOSH, AHMAD 2005], the value of the discharge coefficient is influenced by the thickness of the screen rod (t), the screen distance (s) and the slope of the screen (θ).

In finding the discharge coefficient on a tyrol weir with a hollow plate-shaped screen, it has been done by making a model in a laboratory [SAHINER 2012]. The flow from the screen is then fed into the collection channel with a width of 0.6 m, a height of 0.3 cm and a length of 1.98 m.

The slope of the collecting channel is 0.01. Water flowing in the collecting duct then goes to the side overflow with a width of 0.7 m and a length of 6.5 m. In carrying out physical model tests in the laboratory carried out with 10 variations of discharge for each slope of the channel (θ_1 = 37.0°, θ_2 = 32.8° and θ_3 = 27.8°). The mathematical model [CASTILLO 2013] about the screen form factor, the distance between the screen holes and the slope of the screen is then presented in a computer application [OZKAYA 2015; ZERIHUN 2015] to facilitate the planning of screen holes in the tyrol weir. But the results are new mathematically [WHITE *et al*. 1972], so it is necessary to do an experiment as a correction to the mathematical model that has been made.

The purpose of this study is to find the value of the discharge coefficient (*Cd*) on a sieve with a circular perforated plate so that it can be used for application in the field used is to make a physical model test of the screen weir in the laboratory, to get the value of *Cd* discharge the screen length is fixed, because the filter length affects the value of the discharge coefficient (*Cd*) [CARRILLO *et al*. 2018; NAKAGAWA 1969; RIGHETTI *et al*. 2000].

METHODS

To get the value of the discharge coefficient (*Cd*) on a screen with a circular perforated plate, a physical model has been designed in the Hydraulics Laboratory, Faculty of Engineering, University of Brawijaya Malang. The stages of the activity are described as follows:

– create a model and layout of the screen weir building and its complementary buildings as presented as in Figure 1;
– the water flow from the upper reservoir enters the inlet then enters the channel and enters the outlet then empties into the lower reservoir; from the lower reservoir then pumped again to the upper reservoir using a pump with a capacity of 20 $dm^3 \cdot s^{-1}$.
– Thompson (triangular threshold) measuring device installed three in the upstream, downstream and downstream of the collecting channel to measure the test flow when testing the physical model;
– screen plates of iron plates with a thickness of 1 mm with circular holes with a screen tilt variation of 25°, 30°, 35°, and 45°; for each slope, seven variations of discharge will be made;
– point gauge to measure the level of water level in the flow of the model by three pieces;
– the upstream, downstream channel structure is made from mica material, to make it easier to monitor the behaviour of the flow from the side.

The measured variables are the height of the water above Thompson weirs and the upstream, downstream and channel collection channels, while the calculated:

1. Q_{inflow} is results of measurement of discharge from the inlet that enters the channel ($cm^3 \cdot s^{-1}$).
2. $Q_{\text{obs-tyrol}}$ is results of measurements of discharge from water entering the screen ($cm^3 \cdot s^{-1}$).
3. ω is ratio between the screen opening area (Ao) and the total screen area (A).
4. v is velocity ($cm^3 \cdot s^{-1}$).

$$v = \frac{Q_{\text{inflow}}}{By_1} \tag{1}$$

Where: B = channel width (cm), y_1 = upper water level (cm).

5. Fr is Froude number:

$$\text{Fr} = \frac{v}{\sqrt{g \cdot y_1}} \tag{2}$$

Where: g = acceleration of gravity ($cm \cdot s^{-2}$).

6. Hc is high water level in critical flow conditions (cm):

$$Hc = \sqrt[3]{\frac{q_{\text{inflow}}^2}{g}} \tag{3}$$

$$q_{inflow} = \frac{Q_{\text{inflow}}}{B} \tag{4}$$

Where: q_{inflow} = wide unity discharge in the inflow section ($cm^2\ s^{-1}$).

7. E is specific energy (cm):

$$E = \frac{3}{2} Hc \tag{5}$$

8. $Q_{\text{calc-tyrol}}$ is results of the calculation of discharge that enter the screen ($cm^3 \cdot s^{-1}$):

$$Q_{obs-calc} = \omega A \sqrt{2gE} \tag{6}$$

9. Cd is discharge coefficient:

$$Cd = \frac{Q_{\text{obs-tyrol}}}{Q_{\text{calc-tyrol}}} \tag{7}$$

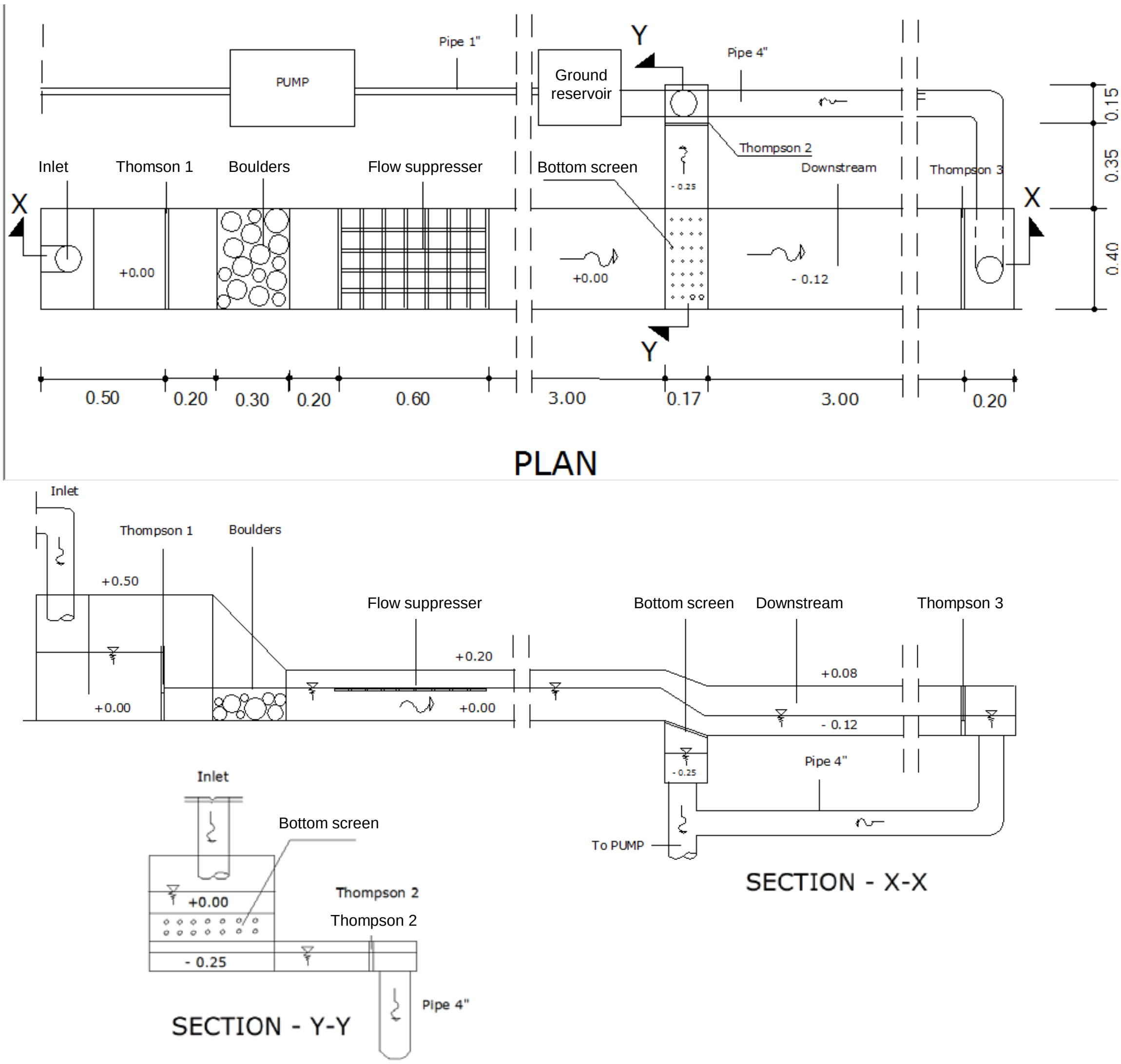

Fig. 1. Test plan of the tyrolean weir physical model in meters unit; source: own elaboration

From the results of the calculation of these variables relationships can be made between variables. To analyse the effect of each parameter is done using the coefficient of correlation.

RESULTS AND DISCUSSION

The main purpose of building a river intake is water intake, not sediment and debris. Debris and sediment must be separated from water. Filter with a perforated plate is very effective for separating water from sediment [SAHINER 2012]. Besides the filter, weir construction also influences the sediment separation process above it, this is stated in the form of variability, level and intensity of sediment separation [BAJKOWSKI 2010].

In the initial test carried out on a screen with a slope of 20° then the hole diameter (*d*) is 6 mm and the distance between holes (*a*) is 40 mm so the ratio of *a*:*d* is 5.667. Details of the circular plate screen shape including the hole diameter and the distance between holes are presented in Figure 2. The test results are then used to obtain the value of the discharge coefficient for each hole diameter variation of 6 mm, 8 mm, 10 mm and 12 mm while the slope of the screen is 20°, 25°, 30° and 45°. The results of the calculations at the initial test are presented in Table 1. *Cd* values were obtained at various screen slope variations θ and ratio *a*:*d*. At the slope θ_1 = 20° and d_1 = 6 mm, the water that enters the collection channel averages about 8–28%. The greater the discharge passing over the screen, the less water entering the collecting duct. This behaviour also occurs in screens with a diameter of d_2 = 8 mm and d_3 = 10 mm, but the bigger the hole, the greater the percentage of incoming water (d_4 = 12 mm, the incoming water is around 12–50%). Likewise, the greater the screen slope then the water catchment gets smaller, as in θ_3 = 30°, the screen diameter is d_1 = 6 mm, the water entering the collection channel is around 6–24%, so that the flow behaviour, screen opening area and screen slope greatly affect discharge of water entering the screen, which means the discharge multiplier factor (coefficient of discharge) must be taken into account in planning a screen weir with a circular perforated plate with slope 30–40% [BRUNELLA *et al.* 2003] Flow behaviour can be viewed from the number Froude (Fr) while the width of the screen opening can be represented by the ratio between the distance between the holes and the diameter of the hole (*a*:*d*). For the value

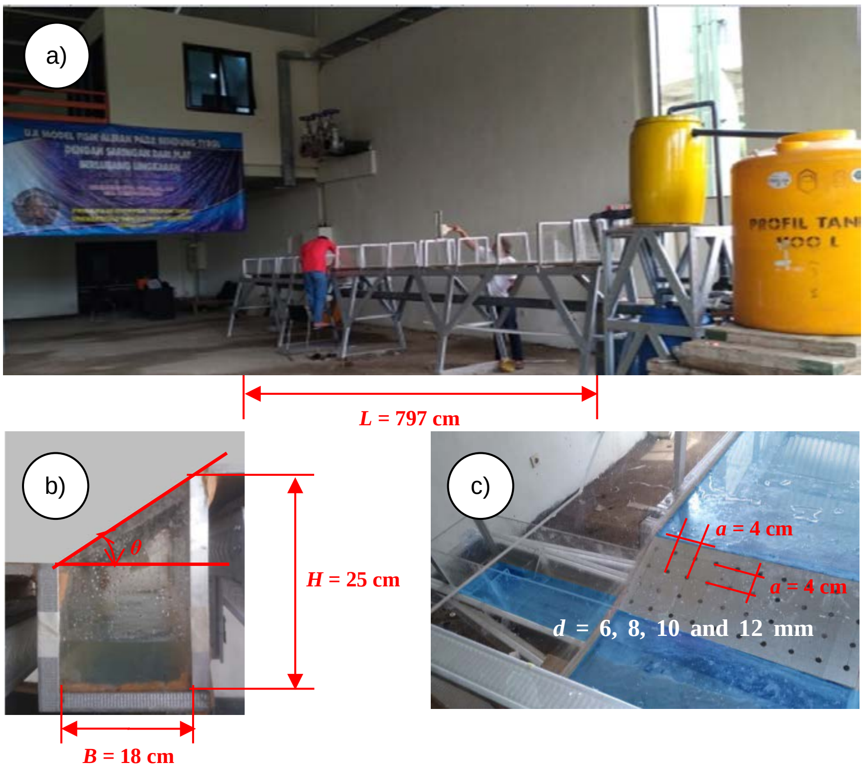

Fig. 2. The shape of the circular plate screen and the slope of the screen: a) physical model test channel, b) collecting channel, c) circular plate filter; source: own elaboration

Table 1. Calculation of discharge coefficient (*Cd*) with θ_1 = 20° and ratio *a*:*d* = 5.667

Q_{inflow}	$Q_{obs\text{-}tyrol}$	*ω*	*v*	Fr	*Hc*	*E*	$Q_{calc\text{-}tyrol}$	*Cd*
$cm^3 \cdot s^{-1}$			$(cm \cdot s^{-1})$		cm		$(cm^3 \cdot s^{-1})$	
453	80	0.015	22.67	1.024	0.044	0.065	102	0.787
792	126	0.015	33.01	1.360	0.133	0.200	178	0.711
1 250	170	0.015	44.63	1.703	0.332	0.497	281	0.605
1 837	221	0.015	57.41	2.049	0.717	1.075	413	0.535
2 565	260	0.015	71.25	2.398	1.397	2.096	576	0.451
3 443	302	0.015	86.08	2.748	2.518	3.777	773	0.391
4 481	373	0.015	93.35	2.721	4.264	6.396	1 007	0.371
							Average	0.550

Explanations: Q_{inflow} = discharge from the inlet; $Q_{obs\text{-}tyrol}$ = measurements of discharge from water entering the screen; *ω* = ratio between the screen opening area and the total screen area; *v* = velocity; Fr = Froude number; *Hc* = high water level in critical flow conditions; *E* = specific energy; $Q_{calc\text{-}tyrol}$ = calculation of discharge that enter the screen.
Source: own study.

of the slope of the screen can be presented in cos values [RIZAL *et al.* 2018]. The relationship between the values of Fr and *Cd* is presented in Figure 3, while the relationship between the values of E and *Cd* is presented in Figure 4.

Based on Figure 3, it can be seen that the physical model test results on the value of the Froude number (Fr) between 0.20 and 2.75 obtained the value of the discharge coefficient (*Cd*) between 0.10 and 2.75. The higher value of Froude, the smaller the coefficient of discharge. *Cd* values starting from the slope of the screen θ_1 = 20°, θ_2 = 25°, θ_3 = 30° continue to decrease, but in the screen with a slope of 45° *Cd* value is increasing again but still lower than *Cd* on the slope of the screen θ_1 = 20° and θ_2 = 25°.

This shows that there are other phenomena that influence the discharge coefficient factor besides the Froude number factor. However, although there are downward and rising trend discharge coefficients, in general, all discharge coefficient values for Froude numbers tend to follow the logarithmic equation with a correlation coefficient of around 60–75%, then the outlier value of the average discharge coefficient is almost the same as the value of the Froude number between 0.5 and 1.0.

Based on Figure 4, it can be seen that the physical model test results on the specific energy value 0.065–15 916 cm obtained the value of the discharge coefficient between 0.371–0.787. The higher the specific energy value, the smaller the coefficient of discharge, as the results of previous studies [KUMAR *et al.* 2010]. The relationship between the value of *E* and *Cd* tends to follow the logarithmic function with a correlation coefficient between 44–87%. The lowest correlation coefficient value at 30° screen slope is 0.440, while the highest at 45° screen slope is 0.867. In screen 30°, outliers of data occur quite a lot while in screens 20°, 25° and 45° outflows the average is quite

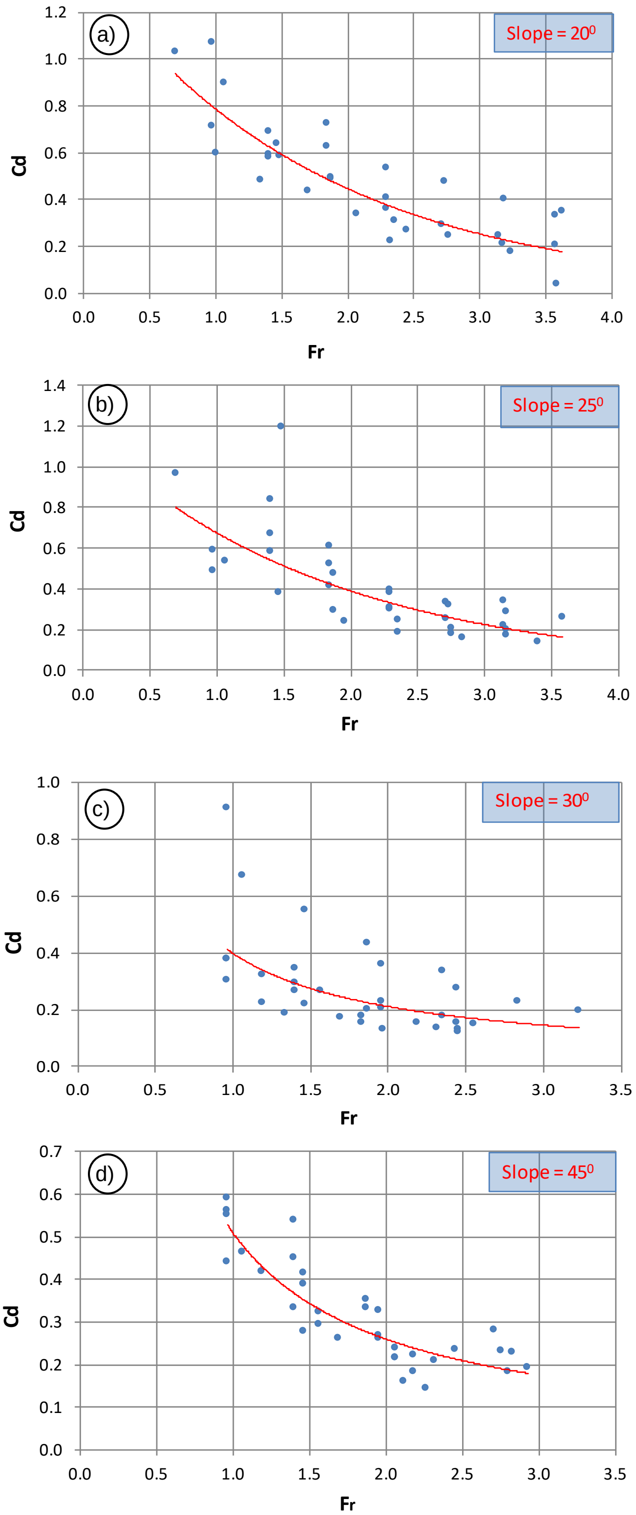

Fig. 3. Relationship between discharge coefficient (*Cd*) and Froude number (Fr) on screens slope: a) θ_1 = 20° b) θ_2 = 25° c) θ_3 = 30°, d) θ_4 = 45°; *d* = the hole diameter; source: own study

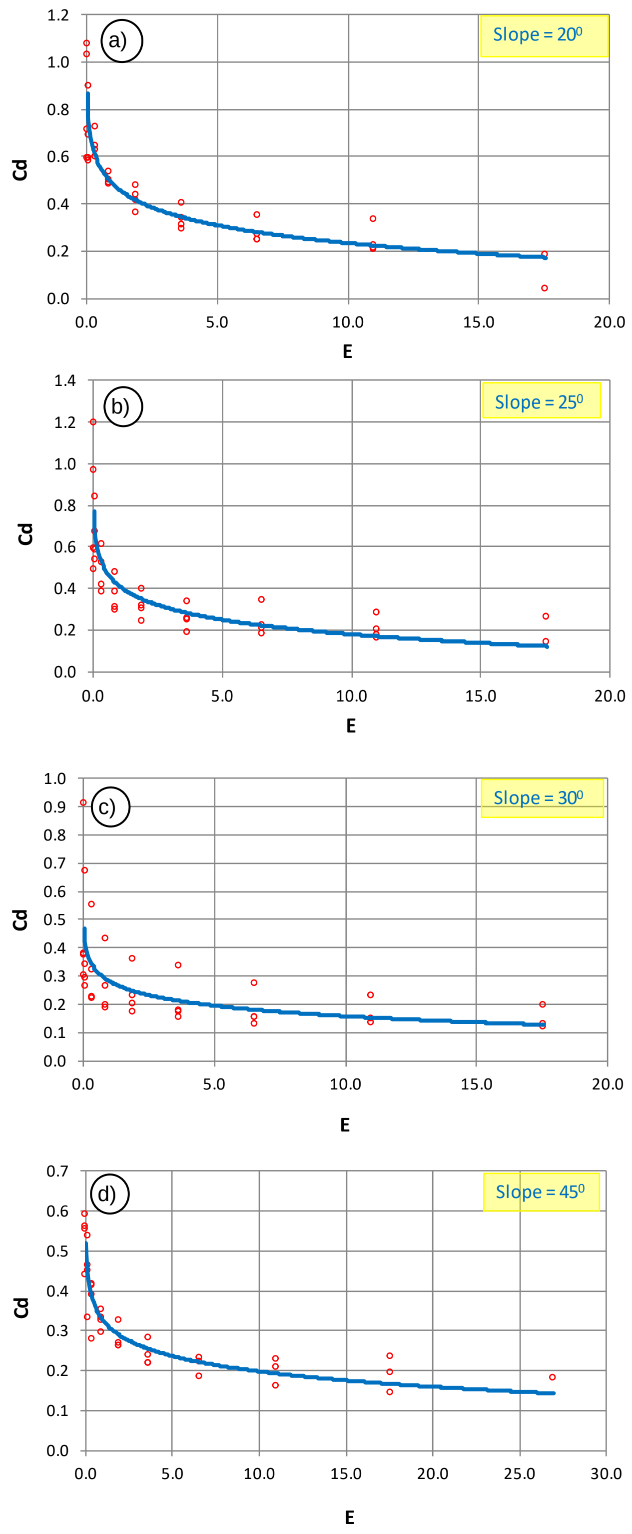

Fig. 4. Relationship between discharge coefficient (*Cd*) and specific energy (*E*) on screens slopes: a) θ_1 = 20°, b) θ_2 = 25°, c) θ_3 = 30°, d) θ_4 = 45°; *d* = the hole diameter; source: own study

low. Based on the description above, it turns out that the factors *E* and Fr are both influenced by the slope of the screen. Then it is further necessary to review how the effect of the slope itself on the value of the discharge coefficient (*Cd*). To review this, we take the relationship of the screen slope value to the discharge coefficient for each hole diameter in one of the debits. As in previous studies, the slope of θ is expressed in the function cos θ [RIZAL *et al.* 2018]. With variations in the hole diameter of 6 mm, 8 mm, 10 mm and 12 mm with a discharge Q_{inflow} = 453–4 481 $cm^3 \cdot s^{-1}$.

Based on Figure 5, the greater the slope (θ) of the screen, the discharge coefficient (*Cd*) decreases, likewise the greater the diameter (*d*) of the hole, the discharge coef-

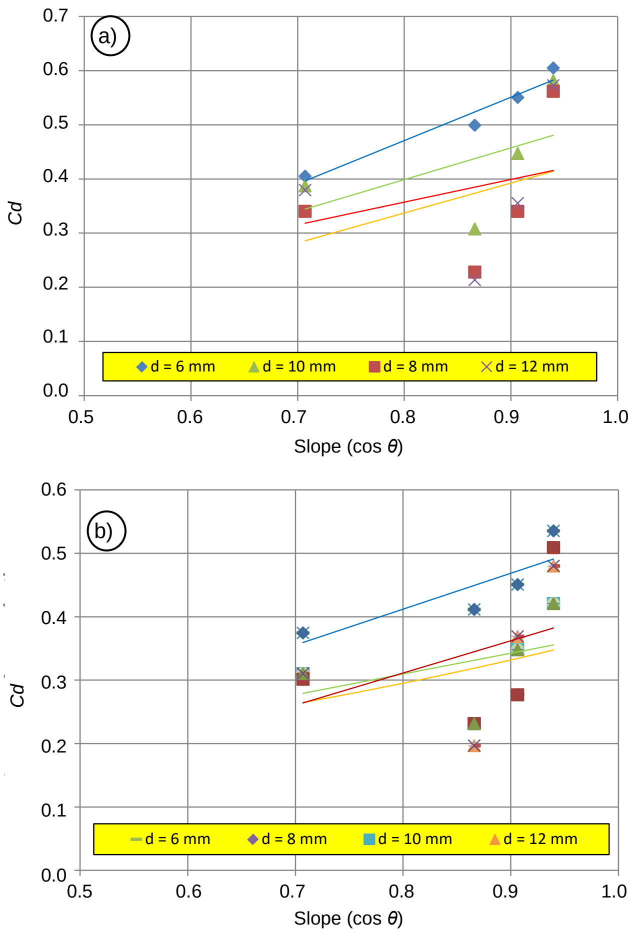

Fig. 5. Relationship between discharge coefficient (*Cd*) and slope (cos *θ*) at different discharge: a) *Q* = 1 250 $cm^3 \cdot s^{-1}$, b) *Q* = 1 837 $cm^3 \cdot s^{-1}$; source: own study

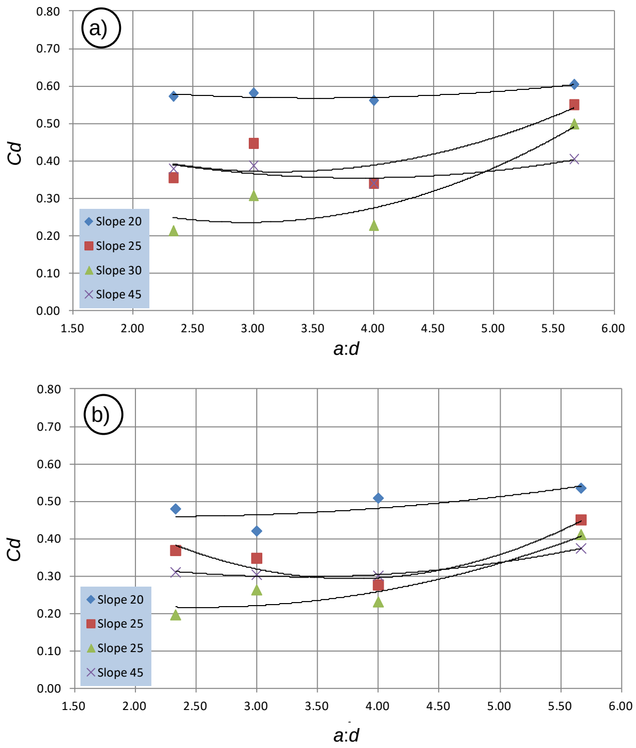

Fig. 6. Relationship between discharge coefficient (*Cd*) and ratio of distance and diameter of the hole (*a*:*d*) of screen at different discharge: a) *Q* = 1 250 $cm^3 \cdot s^{-1}$, b) *Q* = 1 837 $cm^3 \cdot s^{-1}$; source: own study

ficient (*Cd*) also decreases. At an inflow of 1 250 $cm^3 \cdot s^{-1}$, for screen slope θ_1 = 20° the value of the discharge coefficient (*Cd*) ranges from 0.562 to 0.605. At an inflow of 1 837 $cm^3 \cdot s^{-1}$, for screen slope θ_1 = 20° the value of the discharge coefficient (*Cd*) ranges from 0.421 to 0.535. This shows that the slope of the filter, the hole diameter affects the value of the discharge coefficient (*Cd*). Likewise with flow discharge, the greater the flowing flow, the lower the coefficient of discharge. On screen with d_1 = 6 mm and d_2 = 12 mm the decrease in *Cd* values is significant both at 1 250 $cm^3 \cdot s^{-1}$ and 1 837 $cm^3 \cdot s^{-1}$. Each diameter (*d*) hole is separated by a certain distance (*a*), so it is necessary to study how the effect of the ratio *a*:*d* ratio on the value of the discharge coefficient (*Cd*).

This shows that the diameter of the hole greatly affects the magnitude of the discharge coefficient. Hole dimensions are also related to hole spacing. To facilitate reviewing these two variables, the hole dimensions (*d*) and hole distances (*a*) are expressed in the form of a ratio between *a*:*d*.

Based on Figure 6, the discharge coefficient tends to increase with the increasing *a*:*d* ratio. However, at the slope of the screen 25° when *a*:*d* = 4, the discharge coefficient value experiences the lowest value (at *Q* = 1 250 $cm^3 \cdot s^{-1}$, value of *Cd* = 0.35, at *Q* = 1 837 $cm^3 \cdot s^{-1}$, value of *Cd* = 0.28). At the slope of the screen 45° the *Cd* value rises but not too large each increase the ratio of *a*:*d* is equal to the slope of the screen 20° also the increase is also not significant, especially on discharge *Q* = 1 250 $cm^3 \cdot s^{-1}$. But in general it can be concluded that the greater the ratio of *a*:*d*, the greater the value of *Cd*, which means that the diameter and the distance between screens affect the value of the discharge coefficient on the screen of a circular perforated plate. Then based on the description in the previous section, it can be concluded that the value of the discharge coefficient is influenced by energy specific factors (*E*), Froude numbers (Fr), slope of the screen (cos *θ*) and the ratio of distance and diameter of the hole (*a*:*d*). The relationship between *Cd* and *E* and Fr tends to follow logarithmic functions, whereas the relationship between *Cd* and cos *θ* and *a*:*d* tends to follow quadratic functions. To find out how much the relationship between these variables, then a statistical test was carried out on the relationship between *Cd* and *E*, Fr, cos *θ* and *a*:*d*. The results are presented in Table 2.

Based on the Table 2, it appears that the relationship between *Cd* and *E*, Fr, *θ* and *a*:*d* is quite significant, the value of *R* = 0.863, R^2 = 0.745. The same thing has been stated (KUMAR *et al*. [2010], RIGHETTI, LANZONI [2008]) that *Cd* is influenced by *E*, Fr and the slope of the screen. To get an equation model that states the relationship between *Cd* factors with *E*, Fr, *θ* and *a*:*d* the values of these variables are entered. The model formation data is taken on all the total data of the physical model test results in all screen diameters and all screen slopes with a total data of 140 data series, but in Table 4 it is presented for only 25° and 30° slopes with 8 mm and 10 mm screen diameters.

Table 2. Statistical tests linier programming on the relationship between discharge coefficient (*Cd*) and energy specific factors (*E*), Froude numbers (Fr), slope of the screen (cos *θ*) and the ratio of distance and diameter of the hole (*a*:*d*)

Model	*R*	R^2	Adjusted R^2	Standard error of the estimate	Change statistics			Durbin–Watson
					R^2 change	F change	sig. F change	
1	0.863[a]	0.745	0.738	119.785	0.745	98.841	0	0.397

Explanations: a = predictors: (constant), *E*, Fr, cos *θ* and *a*; *d*; b = dependent variable: *Cd*.
Source: own study.

Based on Table 3, an empirical model of the coefficient of discharge (*Cd*) was made on the screen with a circular flat palt following the rank function as follows:

$$Cd = \frac{0{,}227 Fr^{0.331} \cos\theta^{0.731} a{:}d^{0.323}}{E^{0.270}} \qquad (8)$$

Where: *Cd* = coefficient of discharge, *E* = specific energy, Fr = Froude number, *a*:*d* = ratio of distance and diameter of the hole, *θ* = screen slope.

The model accuracy test is carried out to ascertain how the accuracy of the model produced in this study does meet the rules in statistics. To test the accuracy of the model carried out with three types of test Nash–Sutcliffe efficiency (*NSE*) is a normalized statistic to determine the relative residual (noise) variance compared to the measured data variance (information). *NSE* shows how well the observational and simulation data plots correspond to line 1:1. In statistics, mean absolute error (*MAE*) is a quantity used to measure how close an estimate or prediction is to observational data. The mean absolute error (*MAE*) is the average absolute error of the model data to the observed data.

The average absolute error uses the same scale as the measured data. This is known as measurement accuracy which depends on the scale and therefore cannot be used to make comparisons between series with different scales. Root-mean-square error (*RMSE*) is an alternative method for evaluating forecasting techniques used to measure the accuracy of a model's forecast results. *RMSE* is the average value of the sum of the squares of the error, it can also state the size of the error generated by a forecast model. A low or near zero *RMSE* value indicates that the variation in values produced by a forecast model approaches the variation in its observations. The calculation of the discharge coefficient model including *NSE*, *MAE* and *RMSE* testing is presented in Table 4.

Table 3. Results of regression analysis and variance analysis of the discharge coefficient model with SPSS

Model		Unstandardized coefficients		Standardized coefficients	T	Sig.	Correlations		
		B	standard error	Beta			zero-order	partial	part
1	constant	0.227	48.546		–13.615	0.000			
	E	–0.270	0.030	–1.026	–9.148	0.000	–0.808	–0.619	–0.397
	Fr	0.331	0.153	0.245	2.161	0.032	–0.647	0.183	0.094
	cos *θ*	0.731	0.225	0.151	3.254	0.001	0.209	0.270	0.141
	a:*d*	0.323	0.073	0.199	4.433	0.000	0.222	0.356	0.192

Explanations: *E* = energy specific factors, Fr = Froude number, cos *θ* = slope of the screen, *a*:*d* = the ratio of distance and diameter of the hole.
Source: own study.

Table 4. Calculation of Nash–Sutcliffe efficiency (*NSE*), mean absolute error (*MAE*) and root-mean-square error (*RMSE*) discharge coefficient (*Cd*) models using additional data from other researchers with screen slope *θ* = 25° and *θ* = 30°

Screen slope *θ* = 25°						Screen slope *θ* = 30°					
d	*Oi*	*Si*	(*Oi* – *Si*)	$(Oi - Si)^2$	$(Oi - Oir)^2$	*d*	*Oi*	*Si*	(*Oi* – *Si*)	$(Oi - Si)^2$	$(Oi - Oir)^2$
8 mm	1.153	0.808	0.345	0.119	0.536	8 mm	0.443	0.873	–0.431	0.186	0.000
	0.628	0.635	–0.007	0.000	0.043		0.340	0.673	–0.333	0.111	0.007
	0.443	0.524	–0.081	0.007	0.000		0.253	0.507	–0.253	0.064	0.028
	0.340	0.446	–0.105	0.011	0.007		0.228	0.431	–0.203	0.041	0.037
	0.277	0.368	–0.091	0.008	0.021		0.231	0.356	–0.125	0.016	0.036
	0.216	0.327	–0.112	0.012	0.042		0.198	0.317	–0.118	0.014	0.050
	0.204	0.295	–0.091	0.008	0.047		0.174	0.274	–0.100	0.010	0.061
	0.181	0.258	–0.077	0.006	0.057		0.169	0.242	–0.073	0.005	0.064
10 mm	0.582	0.823	–0.241	0.058	0.026	10 mm	0.447	0.796	–0.349	0.122	0.001
	0.991	0.634	0.357	0.128	0.325		0.402	0.613	–0.211	0.045	0.000
	0.611	0.515	0.096	0.009	0.036		0.376	0.432	–0.056	0.003	0.002
	0.447	0.434	0.013	0.000	0.001		0.308	0.370	–0.063	0.004	0.013
	0.348	0.353	–0.005	0.000	0.005		0.264	0.324	–0.061	0.004	0.025
	0.283	0.298	–0.015	0.000	0.019		0.203	0.266	–0.063	0.004	0.048
	0.238	0.269	–0.030	0.001	0.033		0.174	0.241	–0.067	0.004	0.061
	0.194	0.244	–0.050	0.002	0.051		0.152	0.213	–0.061	0.004	0.072
Σ		7.231	–0.095	0.370	1.250	Σ		6.927	–2.565	0.635	0.504
NSE = 0.71						*MAE* = 0.00				*RMSE* = 0.121	

Explanations: *d* = hole diameter, *Oi* = discharge coefficient of observations, *Si* = discharge coefficient of the model results, *Oir* = discharge coefficient average of observations.
Source: own elaboration.

Values in the Table 4 show that the discharge coefficient model on a screen with a perforated plate using factors *E, Fr, a*:*d* and *θ*. *NSE* is close to 1 means that it is close to the results of observations or field measurements. *MAE* and *RMSE* are approaching zero means the error rate of theoretical calculation results on the field calculation results is very small.

A series of stages of research activities to obtain a model of the value of the discharge coefficient on the bottom screen weir have been carried out with phases ranging from calibration, validation and verification. Calibration is carried out on the measurement of discharges coming out of the inlet (Q_{inflow}), discharge in bottom screen ($Q_{\text{obs-tyrol}}$) and discharges entering the downstream channel ($Q_{\text{inflow}} - Q_{\text{obs-tyrol}}$). Incoming discharge values are calculated based on water level measurements above Thompson weir 1, 2 and 3 then are checked by discharge based on the calculation of water level in channels 1, 2 and 3. Validation is done is to find the relationship between variables *Cd* with *E*, *Cd* with Fr, *Cd* with slope screen (*θ*) and *Cd* with ratio *a*:*d*. The verification is done by testing the field equation model with the measurement results in the field then calculated the value of *NSE*, *MAE* and *RMSE*.

CONCLUSIONS

Tyrolean weir with a filter made from a perforated perforated plate is quite effective in capturing water on various screen tilts. After making a physical model obtained hydraulic factors that affect the amount of discharge that can be captured in the form of coefficient discharge (*Cd*). The discharge coefficient (*Cd*) is influenced by the specific energy value (*E*), the number Froude (Fr), the ratio between the screen distance and hole diameter (a:d) and the slope of the screen (*θ*).

The value of the coefficient of discharge (*Cd*) in the weir with the screen of a circular perforated plate is directly proportional to the rank value of the number Froude (Fr), the slope of the screen (*θ*), the ratio of the distance and diameter of the hole (*a*:*d*) and inversely proportional to the rank value of specific energy (*E*). This applies to the screen in sub-critical flow conditions with the formation of a straight hole shape and the slope of the screen between 20° and 45°. From modelling the value *NSE* = 0.71, *MAE* = 0 and *RMSE* = 0.12.

REFERENCES

BĄK Ł., DĄBKOWSKI S.L. 2013. Spatial distribution of sediments in Suchedniów reservoir. Journal of Water and Land Development. No. 19 p. 13–22. DOI https://doi.org/10.2478/jwld-2013-0011.

BAJKOWSKI S 2010. Sediment segregation on weirs of lowland rivers. Land Reclamation. No. 42 (1) p. 177–185. DOI https://doi.org/10.2478/v10060-008-0076-4.

BOUVARD M. 1992. Mobile barrages and intakes on sediment transporting rivers. Rotterdam. Balkema Publ. ISBN 90-6191-150-8 pp. 2-4.

BRUNELLA S., HAGER W.H., HANS E.M.H.E. 2003. Hydraulics of bottom rack intake. Journal of Hydraulic Engineering. No. 1 p. 2–10.

CARRILLO J.M., GARCÍA J.T., CASTILLO L.G. 2018. Empirical, dimensional and inspectional analysis in the design of bottom intake racks. Water. Vol. 10. Iss. 8, 1035. DOI https://doi.org/10.3390/w10081035.

CASTILLO L.G. 2013. Flow and sediment transport through bottom racks. CFD application and verification with experimental measurements [online]. Proceedings of 2013 IAHR Congress. Beijing. Tsinghua University Press. [Access 10.01.2019]. Available at: https://www.upct.es/hidrom/publicaciones/congresos/2013_Chengdu_Flow_and_sediment_transport.pdf

DROBIR H., KIENBERGER V., KROUZECKY N. 1999. The wetted rack length of the tyrolean weir [online]. Proceedings 28 IAHR Conf. Graz, Austria. [Access 10.01.2019]. Available at: http://hydraulics.unibs.it/hydraulics/wp-content/uploads/2012/04/Tyrolean_intake.pdf

GHOSH S., AHMAD Z. 2005. Characteristics of flow over bottom racks [online]. Water and Energy International. No. 2 p. 47–55. [Access 10.01.2019]. Available at: http://www.indianjournals.com/ijor.aspx?target=ijor:wei&volume=63&issue=2&article=006

KOWALCZYK-JUŚKO A., MAZUR A., GRZYWNA A., LISTOSZ A., RYBICKI R., PYTKA A., DOROZHYNSKYY O., JÓŹWIAKOWSKI K., GIZIŃSKA-GÓRNA M. 2017. Evaluation of the possibilities of using water-damming devices on the Tyśmienica River to build small hydropower plants. Journal of Water and Land Development. No. 35 p. 113–119. DOI https://doi.org/10.1515/jwld-2017-0074.

KAMANBEDAST A.A., BEJESTAN M.S. 2008. Effects of slope and area opening on the discharge ratio in bottom intake structures. Journal of Applied Sciences. No. 14 p. 2631–2635. DOI https://scialert.net/abstract/?doi=jas.2008.2631.2635.

KUMAR S., AHMAD Z., KOTHYARI U.C., MITTAL M.K. 2010. Discharge diversion characteristics of trench weirs. Flow Measurement and Instrumentation. No. 21 p. 80–87. DOI https://doi.org/10.1016/j.flowmeasinst.2010.01.002

ŁABĘDZKI L. 2009. Expected development of irrigation in Poland in the context of climate change. Journal of Water and Land Development. No. 13b p. 17–29. DOI 10.2478/v10025-010-0002-0.

NAKAGAWA H. 1969. On hydraulic performance of bottom diversion works. Bulletin of Disaster Prevention Research Institute Kyoto University, Japan. No. 18 (3) p. 29–48.

RIGHETTI M., RIGON R., LANZONI S. 2000. Indagine sperimentale del deflusso attraverso una griglia di fondo a barre longitudinali [Experimental investigation of outflow through a bottom grid with longitudinal bars] [online]. Proceedings of the XXVII Convegno di Idraulica e Costruzioni Idrauliche, Genova, Italy. Vol. 3 p. 112–119. [Access 3.04.2018]. Available online: http://www.ing.unitn.it/~rigon/papers/righetti_etal.pdf

RIGHETTI M. LANZONI S. 2008. Experimental study of the flow field over bottom intake racks. Journal of Hydraulic Engineering. Vol. 134 p. 1–15. DOI https://doi.org/10.1061/(ASCE)0733-9429(2008)134:1(15)

RIZAL N.S., BISRI M., JUWONO P.T., DERMAWAN V. 2018. Determination of discharge coefficient in tyrol weir using screen from of circle with diameter and distance hole variation. International Journals of Civil and Engineering Technology. No. 6 p. 1546–1557. Article ID IJCIET_09_06_174.

SAHINER H. 2012. Hydraulic characteristics of tyrolean weirs having steel racks and circular-perforated entry. Thesis submitted in partial fulfillment of the requirements for the degree of master of science in the Department of Civil Engineering The Middle East Technical University, Ankara, Turkey pp. 23.

SUBRAMANYA K. 1990. Trench weir intake for mini hydro projects. Proceedings Hydromech and Water Resources Conf. IISc, Banglore p. 33–41.

OZKAYA H. 2015. Computer assisted hydraulic design of tyrolean weirs. Thesis submitted in partial fulfillment of the requirements for the degree of master of science in the Department of Civil Engineering The Middle East Technical University, Ankara, Turkey.

VENKATARAMAN P., NASSER M.S., RAMAMURTHY A.S. 1979. Flow behavior in power channels with bottom diversion works. Proceedings XVIII IAHR Conference. Cagliari, Italy. Vol. 4 p. 115–122.

WHITE J.K., CHARLTON J.A., RAMSAY C.A.W. 1972. On the design of bottom intakes for diverting stream flows. Proceedings International of Civil Engineering. London. Vol. 51. Iss. 2 p. 337–345. DOI https://doi.org/10.1680/iicep.1972.5956.

ZERIHUN Y.T. 2015. Numerical simulation of flow in open channel with bottom intake rack. Water Utility Journal. No. 1 p. 49–61.