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INFLUENCE OF ROUGHTY OF A RECTANGULAR OPEN CHANNEL ON FLOW SPEEDS AND WATER FLOW

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SUMMARY

This paper presents an analysis of water flow and flow velocity in an open channel of rectangular cross section as a function of channel roughness, ie Manning roughness coefficient. Three different cases of finishing the open channel of rectangular cross-section were analyzed, namely the concrete channel, the channel with smoothed cement mortar and the channel in very poor condition with shore erosion overgrown with sedges and large stones at the bottom of the channel.

Analyzes were performed on a rectangular channel 3.0 m wide and with water depths in the channel from 0.5 m to 1.5 m with a step of 0.1 m, for steady flow. The longitudinal fall of the bottom of the rectangular channel in all analyzed cases was 1%.u urađene na pravougaonom kanalu širine 3,0 m i sa dubinama vode u kanalu od 0,5 m do 1,5 m sa korakom od 0,1 m, za ustaljeno tečenje. Podužni pad dna pravougaonog kanala u svim analiziranim slučajevima je iznosio 1%.

The paper showed that higher Mannig roughness coefficients give lower water flow in the canal. The importance of the paper is reflected in the fact that for each of the three analyzed treatments of the rectangular channel, a quadratic function of water velocity and flow depending on the water depth in the channel was obtained. During the hydraulic calculation, the type of lining of the open rectangular channel should be taken into account in order for the dimensioned channel to be the most favorable in terms of maximum throughput.

Keywords: *rectangular open channel, channel roughness, steady flow, water velocity, water flow*

INTRODUCTION

The flow in the open channel is with a free water surface on which atmospheric pressure prevails. Atmospheric pressure is conditionally assumed to be equal to zero, so that the free surface of the water corresponds to the piezometric elevation, while the geodetic elevation corresponds to the bottom of the channel. Open channels belong to the group of hydraulically long (linear) objects with a dominant effect of friction.

In construction practice, flow in open channels is observed as a function of changing the shape of the water face and changing the flow parameters (speed, depth, ..) at a certain time. Considering the change of parameters in a certain time, we distinguish between stationary and non-stationary flows with gradual changes, and non-stationary flows with sudden changes. In stationary flows, the quantities by which they are described (velocity, water depth, force, and energy) do not change over time. Stationary flows can be uniform or non-uniform. The term uniform flow means a flow that has the same characteristics along its entire course. Uniform flow can occur only in prismatic channels, ie. in channels having a constant drop and a constant cross section. This means that such flow can only be achieved in artificially constructed channels [1,2,3].

In most cases, the flow in the open channel is three-dimensional, which means that the flow velocity has three components, while for most practical problems, one-dimensional analysis is used. For this reason, when solving practical problems, only one-dimensional flow in open channels is considered. This means that we adopt a mean velocity across the cross-section and that the vertical pressure distribution is hydrostatic.

For open channels, we solve the Bernoulli equation between two cross-sections, similar to flow in pipes. In open channels or natural watercourses, the geodetic height (z) is at the bottom of the riverbed, while the piezometric line (() coincides with the surface of the liquid in the open channel because of atmospheric pressure prevails on the free surface of the liquid. As with flow in pipes, so with open channels, the energy line (E) is located above the piezometric line (above the surface of the liquid) for the size of the so-called velocity heights, while the losses caused by the flow between the two selected cross-sections represent a drop in the energy line (Figure 2). [2] [4]

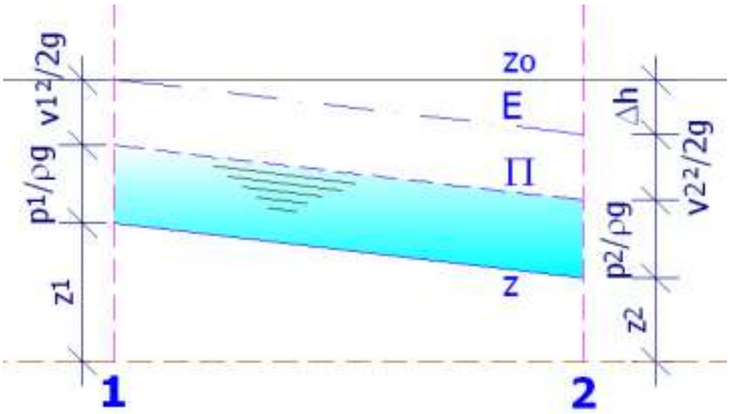

Figure 1. Graphical representation of the Bernoulli equation at open channel

The fall of the bottom of the riverbed, the fall of the piezometric as well as the fall of the energy line, and the fall of the free surface are usually small in size and change slightly. These are usually falls expressed in per mille. With open channels, it is necessary to know the cross-sectional area of the channel, as well as the wetted circumference and hydraulic radius (Figure 3), [2,4,5,6].

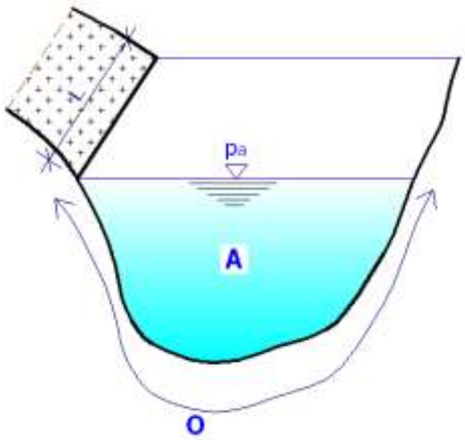

Figure 2. Cross-sectional area (A) and wetted circumference (O) of the open channel

In this paper, hydraulic analyzes of flow rate and water flow in a rectangular open channel 3.0 m wide and longitudinal fall of the channel bottom I = 0.01 for three different channel linings, with uniform stationary flow, are given.

UNIFORM STATIONARY WATER FLOW AND CHANNEL ROUGHNESS

In the case of uniform flow, the hydraulic characteristics of the flow are equal along its entire length. Hydraulic characteristics are flow cross section, bottom slope and coefficient of friction. In this case, both the water flow and the average flow rate are constant while the energy line becomes parallel to the free surface of the water in the channel and to the bottom of the channel. This means that the corresponding longitudinal falls (fall of the bottom of channel I, fall of the piezometric line I_0 and fall of the energy line I_E), medium flow velocities and flow cross-sections are equal to each other [2,7].

$$I = I_0 = I_E$$
$$v_1 = v_2 = v$$
$$A_1 = A_2 = A$$

Accordingly, the flow of water is constant (Q = constant). The depth of a channel where the flow is uniform is called the normal depth. The surface roughness of the channel is defined by the Mannig roughness coefficient, which is one of the energy loss coefficients. The stated coefficient describes the energy loss due to water friction and the lining of the open channel. It is important to note that the Manning coefficient varies considerably and depends on surface roughness, channel vegetation, channel irregularities, channel obstacles, channel shape, channel slope, temperature effects, erosion and suspended material in the channel. It is very important to choose the appropriate value of the Manning coefficient to obtain an accurate calculation and flow in the open channel.

The values of the Manning coefficient are empirical and the Manning coefficient is valid for uniform flow and for non-uniform gradually changing flow as well as for turbulent rough water flow. It is important that it cannot be used for turbulent smooth flow as well as for turbulent transient flow [8,9].

Natural riverbeds have irregular cross-sectional shapes, changes in the slope of the bottom and the meandering of the route, in contrast to the arranged artificial channels. In natural riverbeds, the longitudinal profile is constantly changing and there are frequent changes in hydraulic parameters along watercourses[10].

It is important to note that the error in measuring the flow of water in a canal or natural watercourse is directly proportional to the error in the value of the Manning roughness coefficient (n) [11,12].

Manning's formula is a sufficiently accurate approximation of turbulent rough flow so that it has long been used for flow calculations in pipes, and especially in large tunnel pipelines. The simplicity of natural and artificial watercourses, as well as sufficient accuracy for engineering calculations, make Manning's formula basic for calculations of flow velocities in canals and watercourses of different cross-sectional shapes [13,14,15].

CALCULATION OF RECTANGULAR CHANNEL WITH DIFFERENT ROUGH COEFFICIENTS

The flow of water in the canal depends on the roughness of the canal lining, ie. from the material with which the canal is lined as well as from the quality of the canal construction and the overgrowth of naturally derived watercourses. Using Manning's expression, a hydraulic calculation was performed to determine the flow in the channel of a rectangular cross-section 3.0 m wide and a longitudinal channel drop of 1%, while the roughness coefficient (channel lining) varied.

Three cases of finishing the rectangular channel were analyzed, namely: concrete lining ($n=0.014\ m^{-1/3}s$), smoothed cement mortar ($n=0.01\ m^{-1/3}s$) and channel in very poor condition with eroded sides, overgrown with sedges and with large stones at the bottom ($n = 0.04\ m^{-1/3}s$). Also, in the performed analyzes and calculations, the water depth in the canal is from 0.5 m to 1.5 m with a step of 0.1 m. For all analyzed cases, the cross-sectional area, wetted circumference and hydraulic radius had the same values, and the water flow rate in the rectangular channel as well as the water flow varied.

The results of the hydraulic calculation are shown in the following tables 1, 2, 3:

Table 1. Results of hydraulic calculation of rectangular channel for
Manning roughness coefficient n = 0.014 $m^{-1/3}s$ (concrete channel lining)

h_i	F_i	O_i	R_i	v_i	Q_i
m	m^2	m	m	m/s	m^3/s
0,5	1,50	4,00	0,38	3,71	5,57
0,6	1,80	4,20	0,43	4,06	7,31
0,7	2,10	4,40	0,48	4,36	9,16
0,8	2,40	4,60	0,52	4,63	11,12
0,9	2,70	4,80	0,56	4,87	13,15
1	3,00	5,00	0,60	5,08	15,25
1,1	3,30	5,20	0,63	5,28	17,42
1,2	3,60	5,40	0,67	5,45	19,64
1,3	3,90	5,60	0,70	5,61	21,90
1,4	4,20	5,80	0,72	5,76	24,21
1,5	4,50	6,00	0,75	5,90	26,56

Table 2. Results of hydraulic calculation of rectangular channel for
Manning roughness coefficient n = 0.01 $m^{-1/3}s$ (smoothed cement mortar as channel lining)

h_i	F_i	O_i	R_i	v_i	Q_i
m	m^2	m	m	m/s	m^3/s
0,5	1,50	4,00	0,38	5,20	7,80
0,6	1,80	4,20	0,43	5,69	10,24
0,7	2,10	4,40	0,48	6,11	12,83
0,8	2,40	4,60	0,52	6,48	15,56
0,9	2,70	4,80	0,56	6,82	18,41
1	3,00	5,00	0,60	7,12	21,35
1,1	3,30	5,20	0,63	7,39	24,38
1,2	3,60	5,40	0,67	7,63	27,49
1,3	3,90	5,60	0,70	7,86	30,66
1,4	4,20	5,80	0,72	8,07	33,89
1,5	4,50	6,00	0,75	8,26	37,18

Table 3. Results of hydraulic calculation of rectangular channel for
Manning roughness coefficient n = 0.04 $m^{-1/3}s$ (channel in very poor condition overgrown with sedge)

h_i	F_i	O_i	R_i	v_i	Q_i
m	m^2	m	m	m/s	m^3/s
0,5	1,50	4,00	0,38	1,30	1,95
0,6	1,80	4,20	0,43	1,42	2,56
0,7	2,10	4,40	0,48	1,53	3,21
0,8	2,40	4,60	0,52	1,62	3,89
0,9	2,70	4,80	0,56	1,70	4,60
1	3,00	5,00	0,60	1,78	5,34
1,1	3,30	5,20	0,63	1,85	6,10
1,2	3,60	5,40	0,67	1,91	6,87
1,3	3,90	5,60	0,70	1,96	7,67
1,4	4,20	5,80	0,72	2,02	8,47
1,5	4,50	6,00	0,75	2,06	9,29

In the following figures show the ratios of water flow and flow velocities in a rectangular channel 3.0 m wide and a longitudinal drop of 1% for different values of the Mannig roughness coefficient and water depth from 0.5 m to 1.5 m. Of special importance are the quadratic functions of the obtained curves - the ratio of flow rate and water flow depending on the depth of water in a rectangular channel, which is a mathematical function of the rectangular channel of the given characteristics and the corresponding roughness (Mannig's roughness coefficient). The obtained quadratic functions are polynomial functions of the second degree.

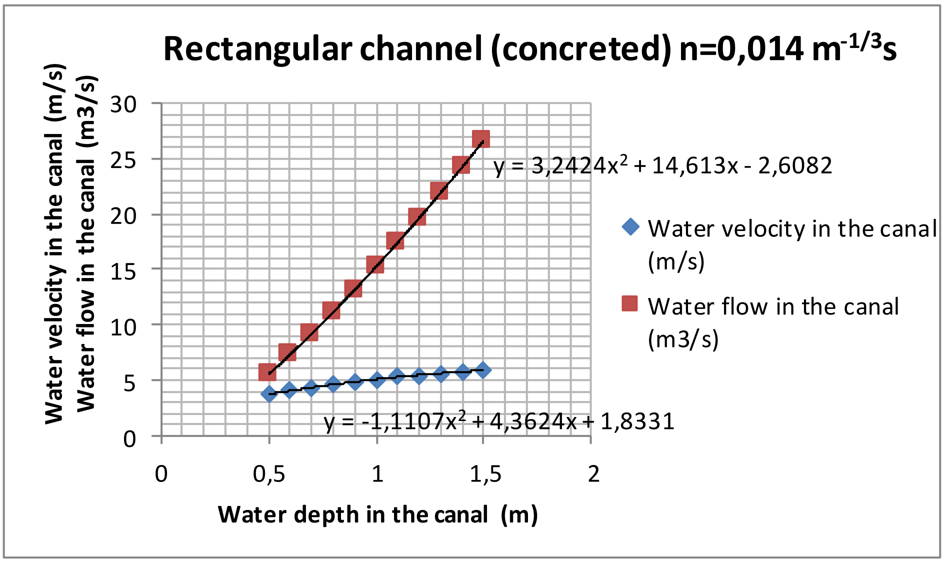

Figure 3. Curve of water flow and flow rate with obtained square functions for n=0,014 $m^{-1/3}s$

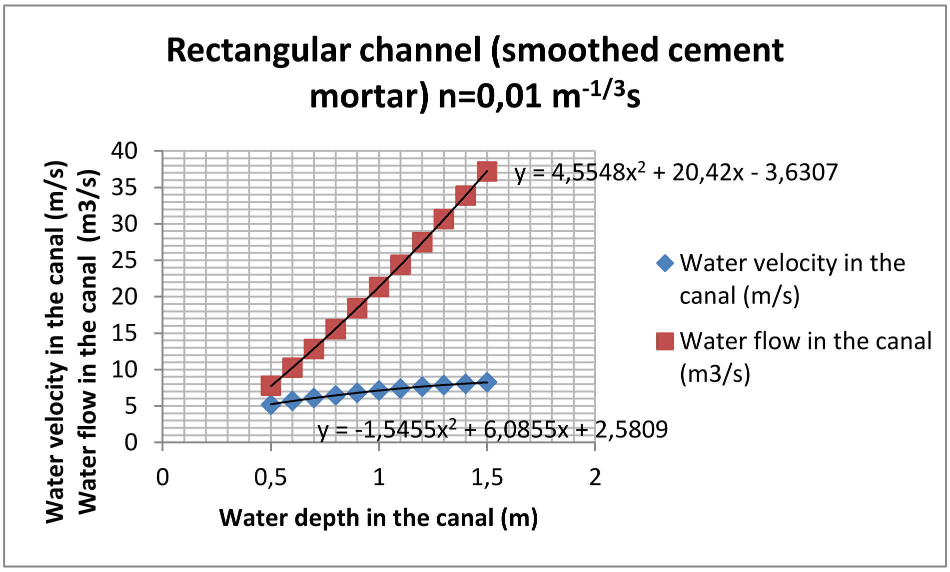

Figure 4. Curve of water flow and flow rate with obtained square functions for n=0,01 $m^{-1/3}s$

From figures 3, 4 and 5 it can be seen that the change in flow rate as a function of water depth in the rectangular channel has a negative coefficient or a number next to the square (with x^2) for all analyzed cases. The change in water flow as a function of water depth has a positive coefficient or number with x^2 for all analyzed cases.

The values of the coefficients along with x^2 control the speed at which the function grows or the "width" of the curve.

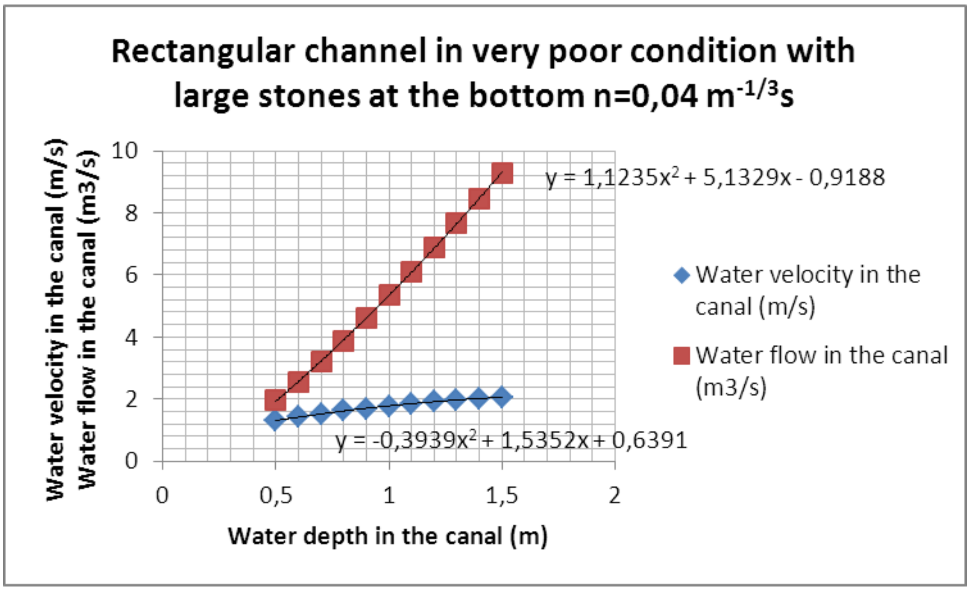

Figure 5. Curve of water flow and flow rate with obtained square functions for n=0,04 $m^{-1/3}s$

The flow rate and water flow in a rectangular channel of a given geometry and for a water depth of 0.5 m to 1.5 m are 40% higher in the channel with a finish of smoothed cement mortar compared to the concrete lining of the channel, while they are 400% higher channel finished in smoothing cement mortar over the channel in a bad state and with large stones on the bottom.

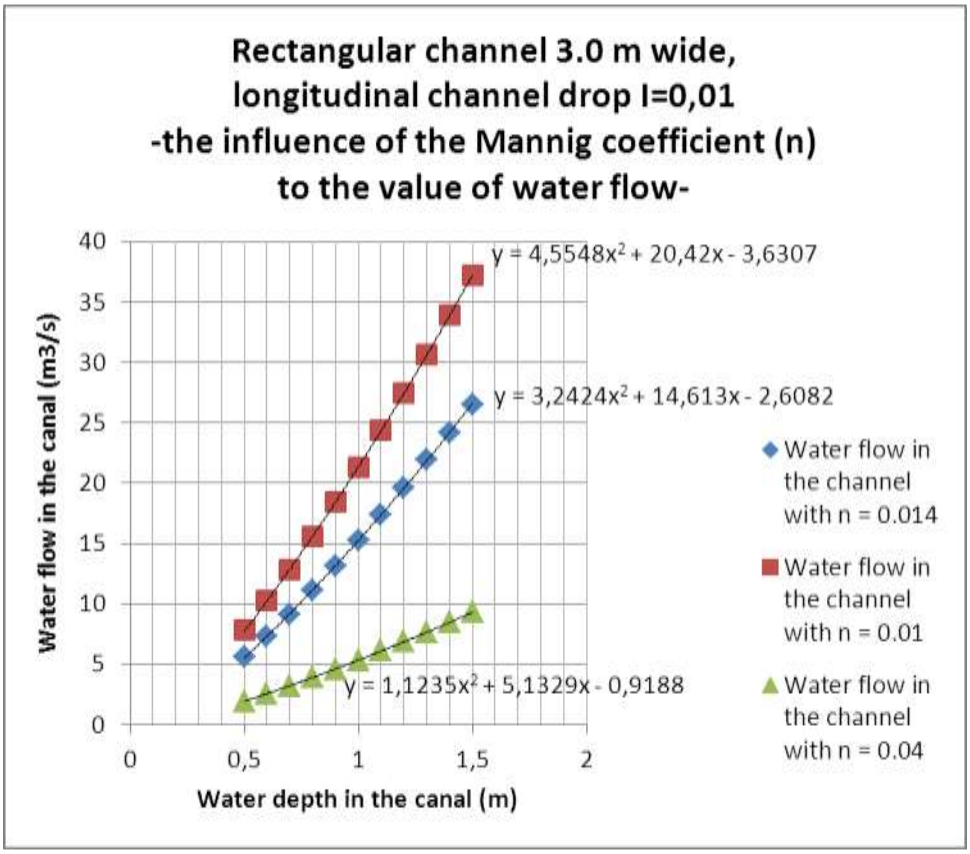

Figure 6. Water flow curves as a function of water depth with obtained square functions

If the Manning roughness coefficient (n) is lower, the higher the water flow velocity in the rectangular channel as well as the water flow, ie the higher the Manning roughness coefficient (n), the lower the flow velocities in the rectangular channel and the water flow. This is important in natural unmaintained watercourses where the capacity of the riverbed is significantly reduced, especially in summer (significant vegetation and overgrowth of the riverbed), which is given in the analyzed cases with the canal in poor condition where Manning's roughness coefficient n=0.04 $m^{-1/3}s$. These data are shown in tables 1, 2, and 3.

Maintenance of the canal is very important, because by maintaining the canal, it increases the throughput of the canal and the rapid evacuation of water in the event of a flood wave along a watercourse or canal.

CONCLUSIONS

In this paper, the relations of hydraulic radii (R), Manning roughness coefficient (n), water flow rate (v) and water flow (Q) in an open rectangular channel are analyzed. The slope of the canal bottom in the analyzed cases is the same and amounts to 1%. The width of the rectangular channel was 3.0 m for all analyzed cases. The variable size was the Manning roughness coefficient for a concrete channel, a channel with smoothed cement mortar and a channel in very poor condition with large stones on the bottom. The magnitudes of water flow rate and flow in a rectangular channel whose depth ranged from 0.5 m to 1.5 m with a step of 0.1 m were analyzed.

With a higher value of the Mannig coefficient of roughness, the water flow decreases, but also the magnitude of the flow velocities.

For water depth in a rectangular channel from 0.5 m to 1.5 m, with a step of 0.1 m, and for the analyzed roughness of the channel lining, the following can be concluded.

The flow of water in the channel with a finish of smoothed cement mortar in relation to the channel with concrete lining is 40% higher, and 400% higher in relation to the channel in very poor condition with large stones on the bottom. This ratio is valid for all analyzed water depths in a rectangular open channel for the three analyzed cases of channel roughness.

The significance of the paper is reflected in the obtained mathematical equations, ie. mathematical functions of the change of water flow rate and flow in relation to the water depth in a rectangular channel 3.0 m wide and a longitudinal drop of 1%.

For further research, the flow rate and water flow should be checked for other cross-sections of open canals, as well as the influence of longitudinal canal drop and roughness on the values of flow rate and water flow should be analyzed.

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