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## The influence of the shape the living section of the pressureless machine channel and the roughness of its wetted surface on the hydraulic resistance

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# The influence of the shape the living section of the pressureless machine channel and the roughness of its wetted surface on the hydraulic resistance

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**Abstract.** Turning to the question of those engineering problems, the solution of which can be used the results of this work, let us first of all select from the wide range of design cases related to pressureless channels, the main design case, which we will keep in mind in the future (as, so to speak, «starting»). Concerning the indicated main design case, we agree to consider the non-pressure movement of water in the prismatic channel (operating in summer conditions) along which uniform turbulent movement of water occurs, which is almost pure in the absence of waves and other phenomena that violate the uniform motion regime, assuming that if such phenomena are taking place, then they should be taken into account the introduction into the calculations of the relevant adjustments. The statement of the above problems in most cases boils down to the following, it is necessary to find a water slope such that its cross-sectional shape is stable (indelible) and the living cross-sectional area is smallest. It is known that such a problem, until recently, was solved by using the concept of "maximum permissible speed"  $V_{max}$  (related to the uniform movement of water). The magnitude of this speed was assigned (and is currently assigned) based on reference data on the type of soil (and in some cases depending on the depth of the water in the channel). Knowing  $V_{max}$  and the flow rate, one can easily find the cross-sectional area, as well as the channel slope (using formulas to determine the Shezi coefficient «C» or hydraulic friction coefficient  $\lambda$  and following the accepted value of the roughness coefficient). In engineering practice, when hydraulic calculations of the channels under consideration, we usually use the Shezy coefficient «C». Meanwhile, there is a shared opinion by us that, when performing the above calculations, it is more advisable to use the coefficient of hydraulic friction  $\lambda$ .

## 1. Introduction

Semi-empirical formulas for hydraulic friction coefficients are known in the literature  $\lambda$  pressure flow in a pipe of circular cross-section and pressure flow in a flat channel [1–3]. As is known, the value of «C» depends mainly on the roughness coefficient "n", the average value of which is considered the so-called "group roughness", which gives only a descriptive description of the state of the wetted surface. The absolute roughness expressed by  $\Delta$  is significantly more sensitive (compared to "n") assessment of the roughness of the wetted channel surfaces and therefore its introduction into the practice of hydraulic calculations increases their accuracy. In connection with this formulation of the question, in this work, research was carried out on the removal; the effect of the live section shape of the channel on the pressure loss in the case of a "smooth" wetted surface and the case of a channel with a rough wetted surface, as well as the influence of the "degree of roughness" of the wetted surface on the



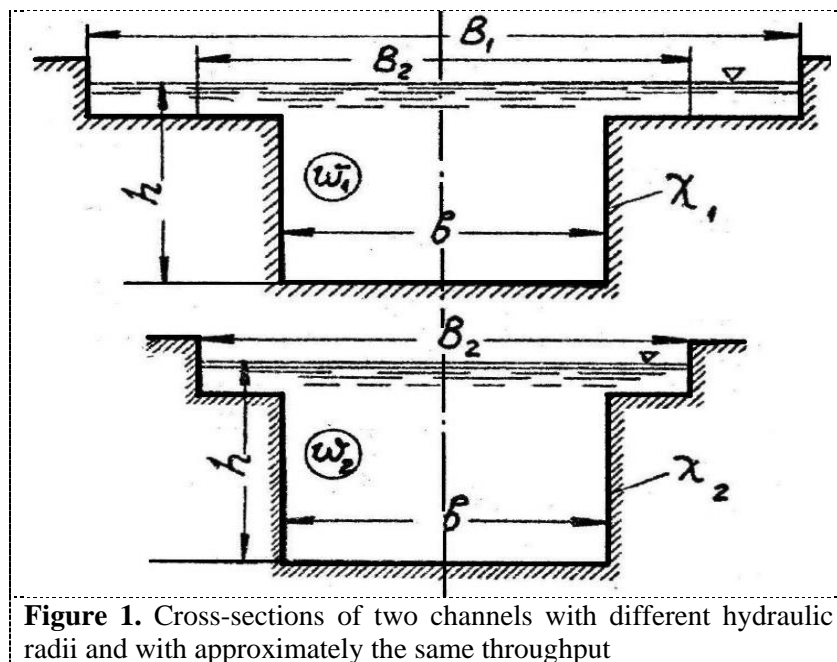
pressure loss [4–6]. These formulas (sometimes with some adjustments in the constants included in them) also apply to pressure-free flows in cylindrical channels. The hydraulic friction coefficient  $\lambda$  in the corresponding semi-empirical dependence for pressureless flow, this is attributed either to the hydraulic radius or to the hydraulic diameter of the pressureless channel. Thus, it is assumed that in two channels differing in the geometric shape of the cross-section, but having the same hydraulic radii, *ceteris paribus*, the coefficients of hydraulic friction should be equal to each other and equal to the coefficient of hydraulic friction of some fictitious plane flow with the considered hydraulic radius ( $\lambda_{R1} = \lambda_{R2} = \lambda_{R-h}$ ). It is precisely this kind of research that allows us to give the designer, as it seems to us, a complete method for solving one of the most important and urgent tasks of the practice of hydraulic engineering construction.

## 2. Method

Analysis of the operation of the machine channels of pumping stations in various modes, operating in various hydraulic conditions and various values  $h$  is the depth of flow,  $R$  is the hydraulic radius and  $\chi$  is the wetted perimeter of the live channel section, taking into account the influence of the channel shape and roughness on the pressure loss of the machine channels, is a method for studying the present work.

## 3. Results and discussion

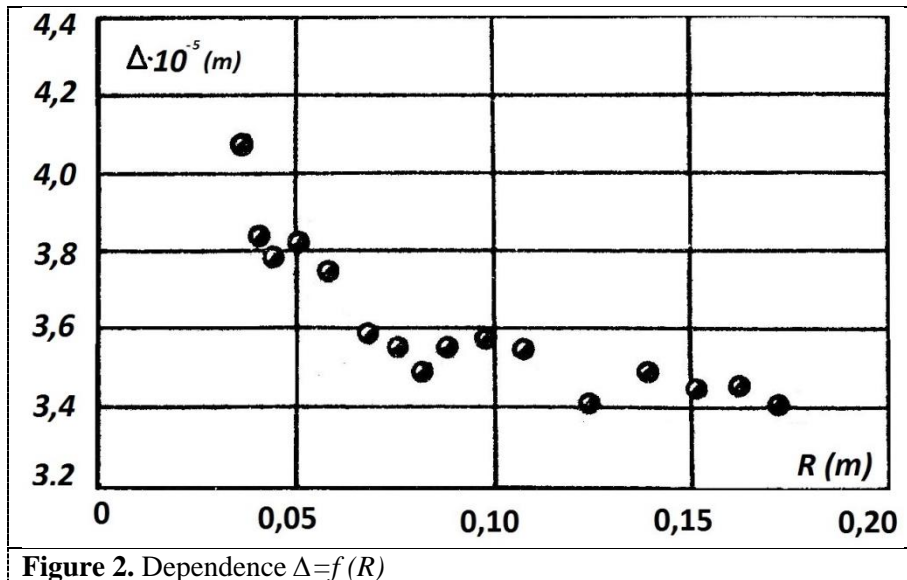
As the author of [7–11] rightly observes, using fairly simple calculations and reasoning, it can be established that for substantially different values of the hydraulic radius, the throughput of the two channels shown in figure 1 with different values of the wetted perimeter, but with approximately the same living area and the same slope will remain approximately the same.



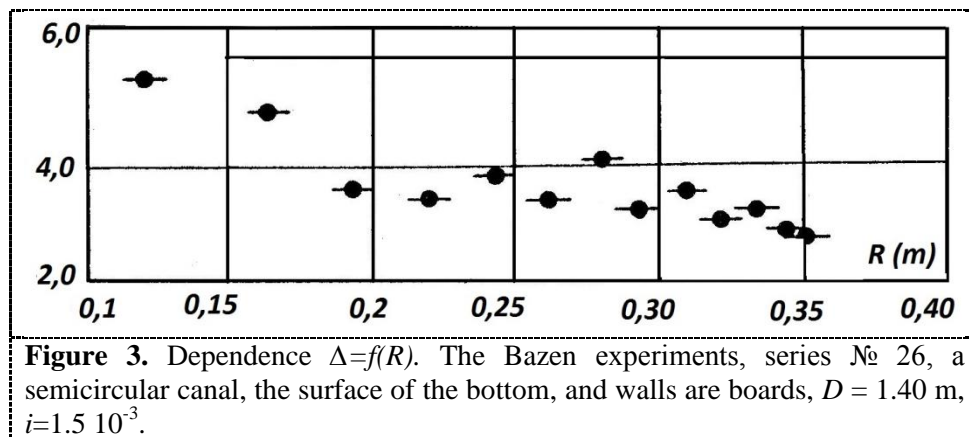
**Figure 1.** Cross-sections of two channels with different hydraulic radii and with approximately the same throughput

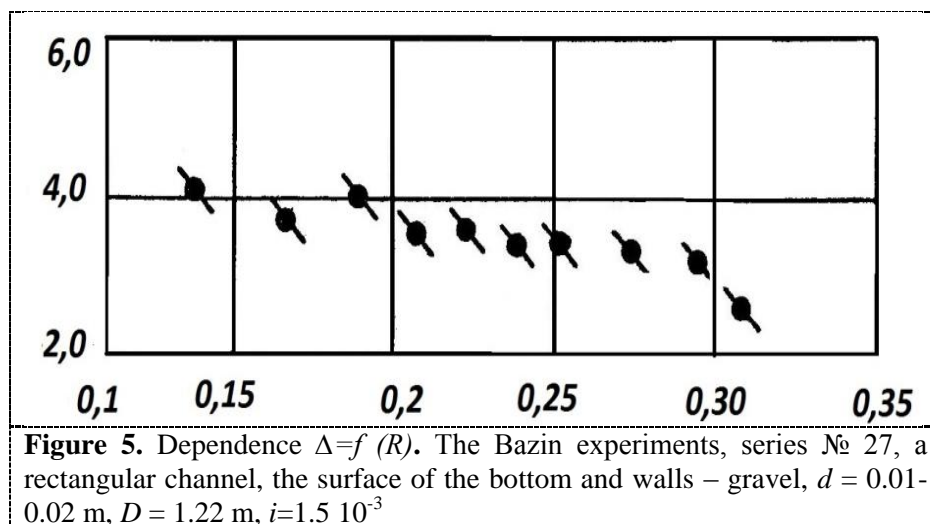
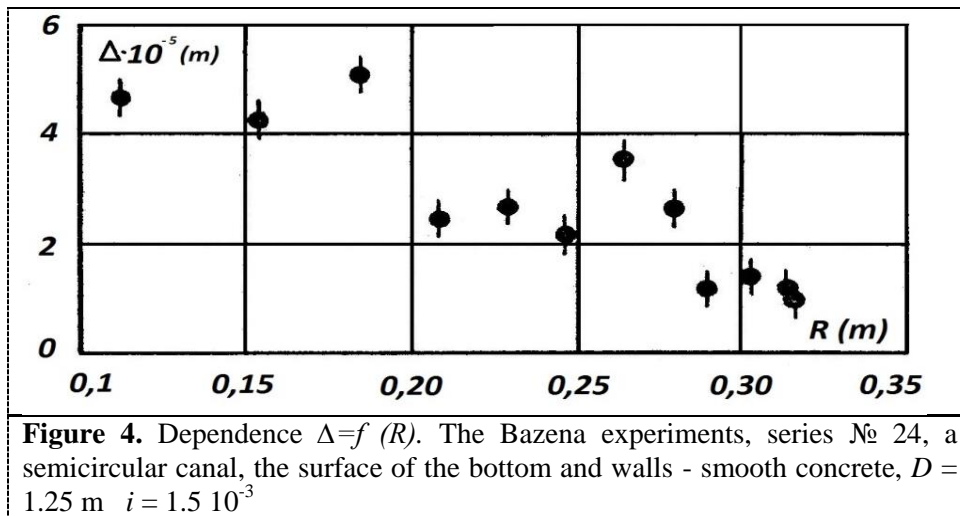
As an example of two channels with the same hydraulic radii, but with different throughputs, N.A. Kartvelishvili [12], points to channels of the rectangular section: one, for example, 2 m wide and 2 m deep, the other 4 m wide and 1 m deep. Hydraulically, the radius for both of these channels is  $2/3$  m, but, as experience shows, the channel capacity of a channel with a depth of 2 m is greater than the

channel capacity of a channel with a depth of 1 m. This circumstance was also reflected in the work of H. Wagner, devoted to the consideration of the problem of the coefficient of hydraulic friction for channels of the rectangular cross-section with technical roughness.

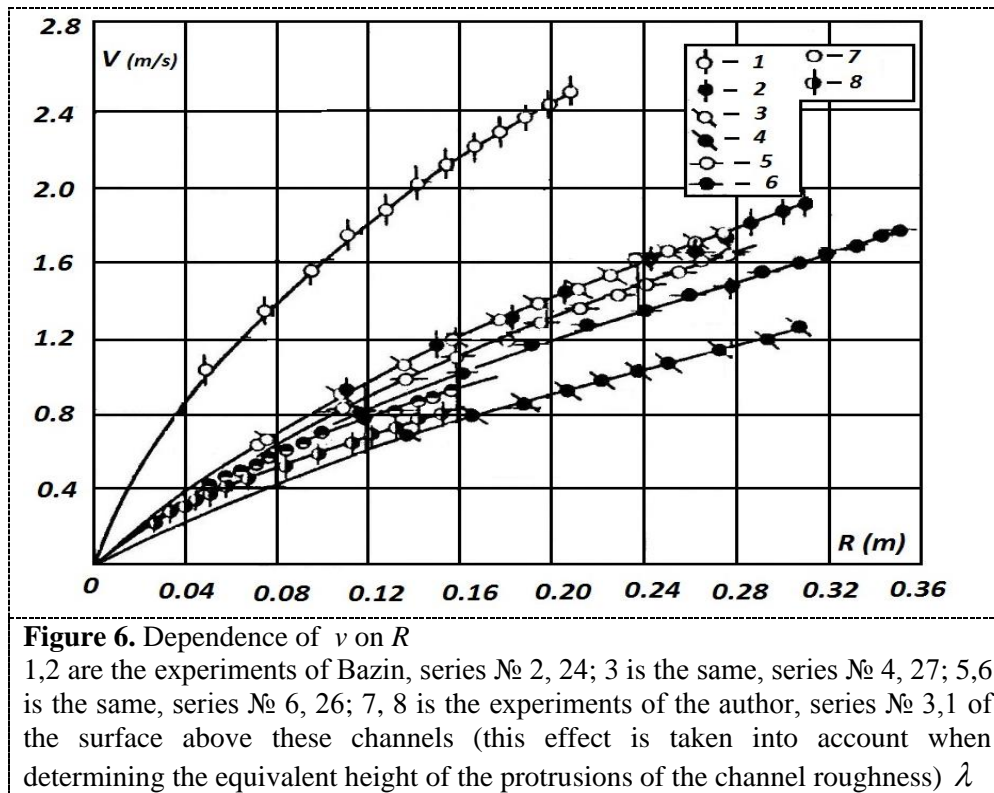


The author’s experiments, series № 7, the trapezoidal canal, the surface of the bottom and walls — smoothly rubbed concrete,  $d = 0.5-0.7$  sm,  $b_g = 0.16$  m,  $m = 1.732$ ,  $i = 0.001$ .





From a consideration of the results of Bazin’s experiments presented in channels of rectangular and circular cross-section with a wetted surface of wood, smoothly rubbed concrete and concrete with gravel recessed in it (experiments of series № 6, 26; 2, 24; 4, 27), the results of the experiments conducted in this work in rectangular and trapezoidal cross-section channels made of smooth-rubbed concrete, as well as some other data published in [13–16] and others, it follows that for pressureless channels with the correct cross-sectional shape cross-sections The hydraulic friction coefficients, as can be seen in figure 2, can have significantly different values for the same values of the hydraulic radius.



From the experimental data of Bazin given in [11], [17–19], it follows that for the same values of  $R$ , the value  $\lambda$  for a channel of the circular cross-section can be less than that for a channel of the rectangular cross-section by about 1.3 times. If in a certain range of Reynolds numbers on the graph ( $Re_R, \lambda_R$ ) to draw the corresponding curves for a channel of a very wide rectangular section, for a channel of a rectangular section of finite width, as well as for channels of a trapezoidal triangular and circular cross-section having the same slope and the same roughness of the wetted surface, it turns out that these curves will be located from top to bottom in the following order: a very wide channel, and then channels of a rectangular, trapezoidal, triangular and circular cross-section. Corresponding curves  $\lambda_R$  from the number  $Re_R$ , in this case, they will run approximately parallel to the curve for the law of “smooth resistance”.

It is pertinent to note that the indicated arrangement of the dependency curves  $\lambda_R$  of the Reynolds number will change significantly, and with it, the form of the curves themselves will change, if, for example, the value  $\lambda$  attributed not to the hydraulic radius, but the greatest depth  $h$  in the channel, i.e. calculate the value  $\lambda_h$  and Reynolds number  $Re_h = v_h/\nu$ .

The data published in the literature on water flows in channels with regular cross-sections of different geometric shapes (rectangular, trapezoidal, triangular, circular), as well as experimental data on the flow in rectangular and trapezoidal channels [20], obtained in this work, can be summarized in a graph in coordinates  $[(R/x)(\lambda_{na}/\lambda)\lambda_{na}/\lambda]$ , shown in figure 8. On the indicated graph, the points corresponding to the experimental data of Bazin and the authors of the present work are quite well located near the straight line, which has an equation of the form from where to determine  $\lambda$  it turns out the following cubic equation where  $\lambda$  is the experienced hydraulic friction coefficients;  $\lambda_{na}$

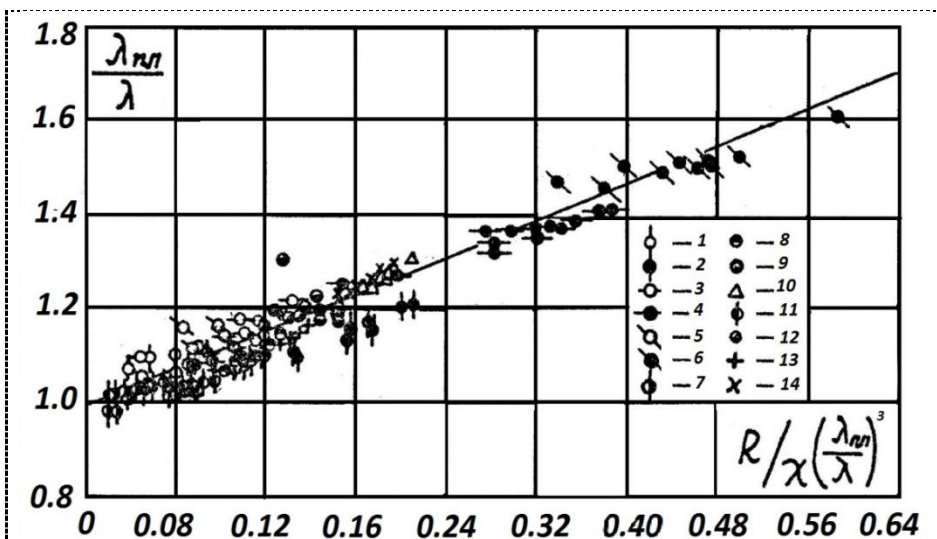
is the coefficient of hydraulic friction of a flat flow;  $R$  is the hydraulic radius;  $\chi$  is the wetted perimeter of the machine channel.

$$\lambda_{na} / \lambda = (R / \chi)(\lambda_{na} / \lambda)^3 + 1.0 \tag{1}$$

$$\lambda^3 - \lambda_{na} \lambda^2 + (R / \chi) \lambda_{na}^3 = 0 \tag{2}$$

Equation (2) can be resolved with known values  $\lambda_{na}, R$  and  $\chi$ .

From the foregoing, the following procedure for calculating the coefficient of hydraulic friction  $\lambda$  for pressureless machine channels of the correct cross-section.



**Fig. 7.** Dependence  $\lambda_{na} / \lambda = \left[ (R / \chi)(\lambda_{na} / \lambda)^3 \right]$

1 and 2 are the experiments of Bazin, a series № 2–24; rectangular and circular channels; the surface of the bottom and walls is smoothly rubbed concrete. 3 and 4 are the same, series № 6–26; rectangular and circular channels; the surface of the bottom and wall-boards. 5 and 6 are the same, series №4 – 27; rectangular and circular channels; the bottom surface and gravel walls  $L = 0.01–0.02$  m; 7 and 8 are the experiments of the author, performed at the Department of Hydraulics of the Leningrad Polytechnic Institute (LPI), series № 1-3; rectangular and trapezoidal channels; the surface of the bottom and walls is smoothly rubbed concrete. 9 is the Bazin Experiments, series № 21; trapezoidal canal; surface of the bottom and walls - boards;  $Q = 0.100-1.236$  m<sup>3</sup>/s;  $h = 0.1222-0.5267$  m;  $b = 1.0$  m;  $\theta = 450$ ;  $i = 1.5 * 10^{-3}$ . 10 is the same, series № 23; triangular channel; surface of the bottom and walls - boards;  $Q = 0.100-1.236$  m<sup>3</sup>/s;  $h = 0.2820-0.7232$  m;  $\theta = 450$ ,  $i = 4.9 * 10^{-3}$

The following channel information is believed to be known: cross-sectional dimensions (bottom width, slope coefficients, etc.), type of roughness (uniform, uneven), or equivalent absolute height of the roughness protrusions of the wetted surface  $\Delta_E$ , bias  $i$ , channel filling depth  $h$ . The sought quantities are hydraulic friction coefficient  $\lambda$  average flow rate  $v$ , water consumption  $Q$ .

$$1/\sqrt{\lambda_{ni}} = 4,061g11/(\frac{3.3}{Re n_h} + \frac{\Delta}{h}), \quad (3)$$

The values are calculated:  $\omega, \chi, R, v, = \sqrt{gRi}, \Delta = \Delta / R$  : from the law of hydraulic resistance for an unlimited wide (flat) channel, for example, with uneven roughness of the wetted surface (where  $Re_h = v^*_{iR}/\nu$ ;  $v^*$ - dynamic flow rate) value is calculated  $\lambda_{ni}$  for flat flow, with depth  $h$ . From the solution of cubic equation (2), the desired value is found  $\lambda$ .

#### 4. Conclusions

When determining the pressure loss in non-pressure machine channels having the “correct” cross-sectional shape, it should be borne in mind that the hydraulic radius is not a sufficiently representative parameter that takes into account all the uniqueness of the geometry of the living section of the channel (even for channels of the “correct” cross-section).

Based on the experimental data available in the literature and the experiments carried out in the course of the present work, we obtained and recommended calculated dependencies that allow us to determine the pressure loss for the “right” channels with different cross-sectional shapes and with different roughness of the wetted surface. In this case, the calculation results by our proposed method turn out to be more accurate than by the methods currently used (this position is confirmed by experiment – both by our experiments and the experiments of some other authors (2, 5, 6)).

The influence of the shape of the living section of the machine channel on the pressure loss (i.e., hydraulic friction coefficient  $\lambda$ ), manifested the more, the greater the relative roughness.

Taking into account (according to recommended dependencies) the effects of the cross-sectional shape and roughness on the magnitude of the pressure loss in the channels of the correct shape can give a significant economic effect during their design.



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