PRACE GEOGRAFICZNE, zeszyt 116

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2006

Nikolay B. Baryshnikov

HYDRAULIC RESISTANCE IN RIVER CHANNELS AND ITS RELATIONSHIP TO CHANNEL PROCESSES

Abstract: The author reviews methods of calculating hydraulic resistance in river channels. Factors determining the resistance, such as bottom dunes, bottom irregularities, channel form-factor, etc. are identified. Particular attention is paid to a mutual relationship between hydraulic resistance and the channel form-factor.

Key words: hydraulic resistance, Chézy and roughness coefficients, channel landforms and processes, anthropogenic impact.

Hydraulic resistance is a very important component of river hydraulics, because it is used for calculating river channel flow capacities, constructing backwater curves, etc. However, after 200 years of research a solution to the issue still seems very distant.

The main parameters defining hydraulic resistance adopted here are the Chézy (*C*), channel roughness (n) and hydraulic resistance (λ) coefficient. The latter is normally used in the calculation for various structures, while the two former coefficients are used in the evaluation of river channels.

Three main approaches can be identified in attempts to solve the issue (Baryshnikov, Samuseva 1999, Baryshnikov et al. 2003), i.e. approaches based on:

– $C = f(h,n)$ type formulae, where the *C* value is calculated on the basis of coarseness coefficients found in tables,
– $C = f(h/\Delta, Re)$ type formulae, where the *C* value is based on the height of the channel bottom features (Δ) and the Reynolds' value (*Re*),
– self-regulation of the flow channel system and the $C = f(h,I)$

Each of the approaches has its advantages and drawbacks. The first approach has been most widely applied in the calculation of river channel flow parameters. It has the disadvantage, however, that there is no theoretical support in physics for the roughness coefficient. When attempting to analyse its value using Pavlovski's equation the resulting *n* has alternating dimensions, which is not permissible for any physical measure. Indeed,

$n = h^y/C$ where $y = f(n)$. When y changes its value the dimension of the h^y parameter also changes followed by a change in the roughness coefficient.

Let us look more closely at the question of river channel resistance using the roughness coefficient. The n integral resistance magnitude can be presented as a sum of components

$$n = n_{sh}+n_g+n_f+n_d \quad (1)$$

where the indices mean that a given parameter takes into account the resistance of the bottom irregularities (*sh*), river dunes (*g*), channel cross section shape (*f*), additional resistance (*d*). Formula (1) is an absolute illustration and may characterise resistance only in a stable motion. For a non-stable motion two additional terms must be added to formula (1) to take into account this movement's properties .

More than 20 tables are currently used for the identification of the value of the roughness coefficient based on channel and floodplain descriptions. The tables most commonly used in Russia include those of M.F. Sribnog whose preparation involved the use of vast quantities of input information, and those of I.F. Karasev (1980). These latter tables are the Sribnog tables improved by the use of additional information. In the US the main tools include the tables of D. Bredli (see: Baryshnikov et al. 2003) and V.T. Chou (1969). The latter have been supplemented with a colour photograph album helping one to more precisely define the n value. However, all of the tables contain just one or two values of the roughness coefficient without taking into account its variation depending on depth. A degree of subjectivity is permissible in selecting the roughness values in these tables.

The second approach also has some disadvantages. One is lack of clarity with regard to the Δ parameter. Indeed, the analysis of critical velocity formulae (Baryshnikov, Popov 1988, Grishanin 1992), shows that instead of Δ the grain roughness is used, i.e. $\Delta = \alpha k_i$, where α is a factor, k_i is the largest sedimentary grain that accounts for 5% of the total (Goncharov 1962), and $\alpha = 0.7$. I.I. Levi, in turn, assumes $i = 10\%$ and there exist recommendations in this area too. The main drawback of this approach is the lack of a precise definition of the Δ value and the difficulty in establishing it for natural watercourses, especially in case of river dune regimen of bedload transport.

It must be noted here that the most complete analysis of this approach has been proposed by A.P. Zezhgda (1957) using field and laboratory data expressed in a graphic equation $\lambda= f(h/\Delta, Re)$. However, while the results of this study allow a practical solution to the issue of hydraulic resistance calculations for various structures, they are unacceptable for river channels, even in mountain rivers (Baryshnikov et al. 2003, Znamenskaya 1992).

The third approach is based on the principle of self regulation in the river flow channel system (Baryshnikov et al. 2003, Skorodumov 1960) and it seems to show great promise, but has yet to be developed to a sufficient level for general application. Attempts of various researchers to arrive at a calculation such as $C = f(h, I)$ cannot be accepted as successful. Such formulae are restricted and with just a limited regional application.

Russian State Hydrometeorological University conducted a study into the accuracy and reliability of the first approach in application. A number of formulae and hydraulic resistance calculation methods were evaluated using field data from more than 500 stations. The input data included mean flow speed, depth and water table gradient. The latter parameter was the least reliable where the measurement error margin (*Nastavlenie*

(Наставление)... 1978) ran at 15% and in certain circumstances, especially on mountain rivers even much higher. Objective parameters, often used in lowland rivers, included distances between stations, typically greater than between pools, and other phenomena such as wind and wave action. Poor skills of the observers acted as a subjective factor affecting results.

In an analysis of the impact of depth on the Chézy coefficient in small and medium-sized rivers the study revealed a number of $n = f(h)$ and $C = f(h)$ relationships. When looking at the relationships they are probably more comfortably presented in relative units as $n/\bar{n} = f(h/\bar{h})$ and $C/\bar{C} = f(h/\bar{h})$ or $n/n_{50} = f(h/h_{50})$ and $C/C_{50} = f(h/h_{50})$, where $\bar{n}$ and $\bar{C}$ stand for the roughness and Chézy factor values, averaged over the calculated period; n_{50} and C_{50} stand for those parameters at a probability of occurrence of 50%.

Five types of relationship were identified in the process. The main type involved relationships where the Chézy coefficient either increased or decreased with growing depth (Figures 1, 2). The rate of change of the parameters in those relationships differs greatly from channel to channel as indicated on Figures 1, 2. Factors influencing those curve types include the condition of the channel banks, the amount of vegetation, occurrence of coarse angular bedload, especially in mountain rivers, and the presence of various river channel landforms close to the gauging section.

Three additional types of relationship were identified. As depicted in Figure 3, the Chézy coefficient may be observed to increase or decrease with growing depth on several rivers after which the respective trend is reversed. This type of relationship between the Chézy and roughness coefficients on the one hand and the channel

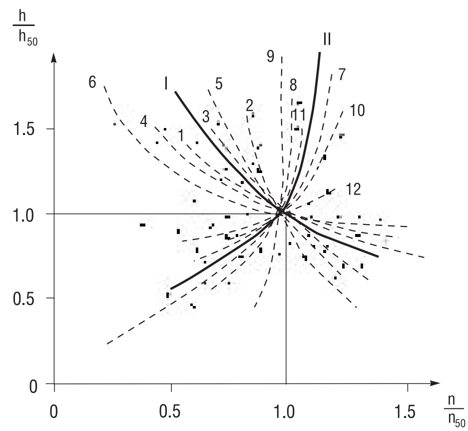

Figure 1. Relationships $n/n_{50} = f(h/h_{50})$ on mountain rivers

Explanations: I-II – averaged curves for groups of rivers, 1-12 – data obtained from research on particular rivers.

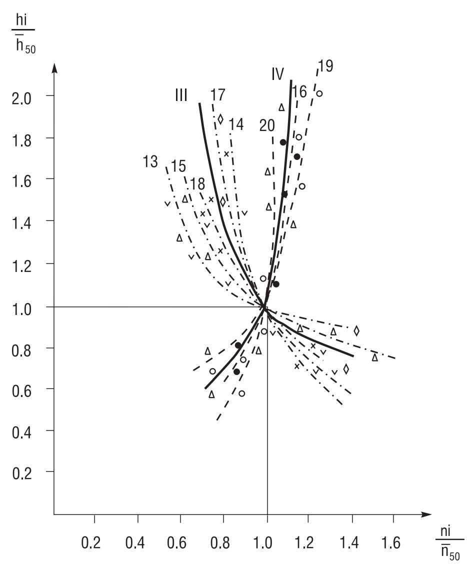

Figure 2. Relationships $n/n_{50} = f(h/h_{50})$ on lowland rivers

Explanations: III-IV – averaged curves for groups of rivers, 13-20 – data obtained from research on particular rivers.

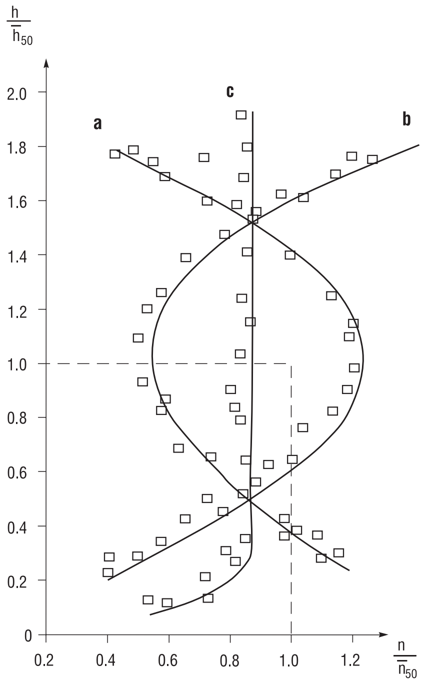

Figure 3. Relationships $n/n_{50} = f(h/h_{50})$

Explanations: different types of curves: a – type three, b – type four, c – type five.

depth on the other could be explained by bank vegetation and bank silting, and by the presence of various river channel landforms close to the gauging section.

A fifth type (Figure 3) of relationship was identified on large rivers and was characterised by a constant value of the Chézy coefficient regardless of depth.

Generally, the tables determining the roughness factor fail to account for the change in depth with the notable exception of the table of L.L. Lishtvan (Lishtvan, Aleksandrov 1961), but even there the roughness factor is related merely to defined depth ranges. Conversely, almost all Chézy factor formulae point to its straight, albeit weak (1/3 to 1/8), relationship to depth. Moreover, a majority of tables fail to take sufficient account of the influence of the cross-section form-factor on the roughness factor. This is primarily attributable to the lack of an adequate computation methodology that would take this impact on hydraulic resistance into account. However, recent advances made in this area (Karasev, Kovalenko 1994) give hope that a methodology will be developed in the very near future.

Recent RSHU studies have shown (Baryshnikov, Samuseva 1999, Baryshnikov et al. 2003), that the nature of the $n/\bar{n} = f(h/\bar{h})$ and $C/\bar{C} = f(h/\bar{h})$ relationships can reverse with time (Figure 4). As seen on Figure 4, it took three to five years for the falling Chézy factor values (recorded in 1967) to start increasing again (1970) as compared to increasing depths at Paziki (Пазики) village on the River Desna (Десна). This points to the need for a detailed description of the condition of the cross sections, which should be detailed on an annual basis in the hydrometeorological network.

The third approach seems to be showing the most prospect and while its practical implementation would require considerable expenditure and large research teams, the results could fully warrant the resources.

The relationships between the Chézy or roughness factors and depth are rather complex in nature as seen in Figure 1-4. On the other hand, the Chézy or hydraulic resistance factors bear a simply relationship to depth by a factor close to 0.17 in virtually all known formulae. This raises the question as to what causes the Chézy factor to either increase or decrease with increasing depth. An analysis of the input data revealed one of the main reasons for this behaviour, i.e. the channel form-factor. However, in analysing network data it must be borne in mind that hydrometeorological gauging sections tend to be located on reaches that are atypical as far as channel processes are concerned. Indeed, it would

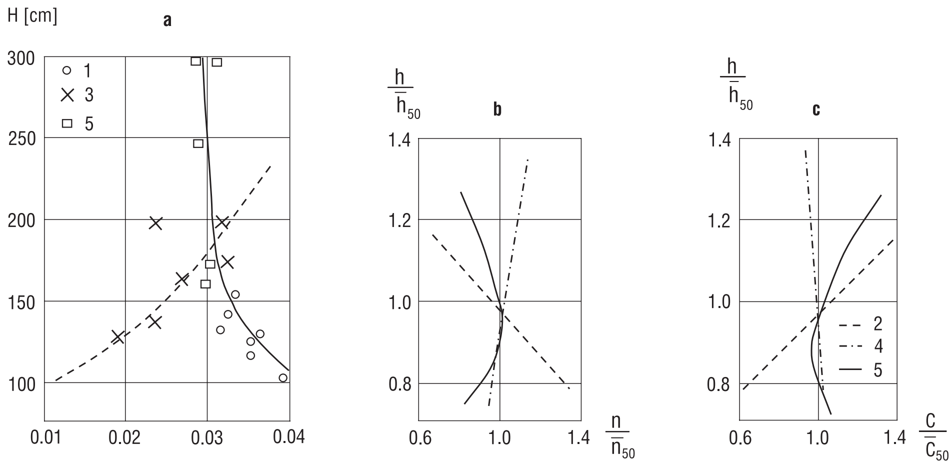

Figure 4. Relationships: a) $n = f(H)$ for the Volga (Волга) river, Il'movniki (Ильмовники) section; b) $n/n_{50} = f(h/h_{50})$; c) $C/C_{50} = f(h/h_{50})$ Desna river, Paziki section (input data not shown to simplify the chart)

Explanations: 1 – 1965; 2 – 1967; 3 – 1968; 4 – 1970; 5 – 1974.

be most desirable to set the gauging sections (*Nastavlenie (Наставление)* .... 1978) either along gap reaches or where the flood plain is narrow. Additionally there is normally little information about the type of channel processes and the channel shape at a given gauging section. The information gathered so far was primarily collected during fieldwork and pertains to the location and formation of the channel near the gauging sections. It allows the following conclusions to be drawn:

– where there are channel landforms downstream from the gauging section there is a backwater effect and the Chézy factor values tend to diminish with increasing depth,
– where there are channel landforms upstream of the gauging section the nature of the dependency of the Chézy factor from depth is more complex. At low water levels the Chézy factor is observed to increase. The rate of that change also varies, generally diminishing slightly as water levels increase,
– on small and medium rivers the condition of the channel banks, along with the occurrence of channel landforms, has a material impact on the nature of the Chézy factor vs. depth dependency. On lowland rivers vegetation (grass and trees) plays a role, while the amount of coarse angular material is crucial on mountain rivers.

This analysis shows that the complex issue of hydraulic resistance is still far from a final solution. Indeed, the strict interrelations between the considerable number of factors that determine parameters of hydraulic resistance are still not sufficiently understood. The poor quality of the field input data, especially the water table gradients, also plays a considerable negative role.

Human pressures are an important, but still insufficiently studied, additional influence on hydraulic resistance. Such pressures can be broken down into those exerted on climate, those on the drainage basin and those on the river system, i.e. the channel and the floodplain (Baryshnikov 1990, Baryshnikov, Samuseva 1999). While the latter two types of human pressure are widely discussed in literature, the impact on climate is a much less popular topic. As a result of global warming the frequency of occurrence of catastrophic floods on European rivers has increased. During the 20th century, in a majority of European countries, with their small territories and high population densities, valley floors were developed with housing and industry, greatly increasing hydraulic resistance and leading to higher water levels and catastrophic floods. An illustrative example of this phenomenon would be the Prague flood where several underground stations were flooded. While almost all Western European countries have experienced large floods causing a high degree of damage, particularly severe cases were those that affected Essex in the UK and the southern coast of France.

This study points not just to the need to continue research on the issue, but also to develop new guidelines for building hydroengineering structures within river channels and on valley floors which take into account the human impact on river systems.

References

Baryshnikov N.B. (Барышников Н.Б.), 1990, *Антропогенное воздействие на русловые процессы*, ЛГМИ, Ленинград.

Baryshnikov N.B. et al. (Барышников Н.Б. и др.), 2003, *Гидравлические сопротивления речных русел*, РГГМУ.

Baryshnikov N.B., Popov I.V. (Барышников Н.Б., Попов И.В.), 1988, *Динамика русловых потоков и русловые прооцессы*, Гидрометеоиздат, Ленинград.

Baryshnikov N.B., Samuseva E.A. (Барышников Н.Б., Самусева Е.А.), 1999, *Антропогенное воздействие на саморегулирующюся систему бассейн-речной поток-русло*, РГГМУ, Санкт Петерсбург.

Chou V.T., (Чоу В.Т.), 1969, *Гидравлика открытых каналов*, Стройиздат, Москва.

Goncharov V.N. (Гончаров В.Н.), 1962, *Динамика русловых потоков*, Гидрометеоиздат, Ленинград.

Grishanin K.V. (Гришанин К.В.), 1992, *Гидравлические сопротивления естественных русел*, Гидрометеоиздат, Ленинград.

Karasev I.F. (Карасев И.Ф.), 1980, *Речная гидрометрия и учёт водных ресурсов*, Гидрометеоиздат, Ленинград.

Karasev I.F., Kovalenko V.V. (Карасев И.Ф., Коваленко В.В.), 1994, *Стохастические методы речной гидравлики и гидрометрии*, Гидрометеоиздат, Санкт Петерсбург.

Lishtvan L.L., Aleksandrov A.A. (Лиштван Л.Л., Александров А.А.), 1961, *Наставление по изысканиям и проектированию мостовых переходов*, Глававтотранспроект.

Skorodumov D.E. (Скородумов Д.Е.), 1960, *Гидравлические основы экстаполяции кривых расходов воды до высших уровней*, Тр. ГГИ, 77.

Zezhgda A.P. (Зежгда А.П.), 1957, *Гидравлические потери на трение в каналах и трубопроводах*, Госстройиздат, Ленинград.

Znamenskaya N.S. (Знаменская Н.С.), 1992, *Гидравлическое моделирование русловых процессов*, Гидрометеоиздат, Ленинград.

Наставление гидрометеорологическим станциям и постам, 1978, 6, 1-3, Гидрометеоиздат, Ленинград.

Nikolay B. Baryshnikov
Department of Hydrometry
Russian State Hydrometeorological University
Malookhtinsky Ave 98
195196 St. Petersburg
Russia