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ON DETERMINATION OF RELATIONSHIP BETWEEN MAXIMUM HYDRAULIC SIZE OF SUSPENDED PARTICLES AND TURBID FLOW PARAMETERS

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General direction of riverbed process on one or another section of the flow depends on the degree of silt saturated state. In case of the flow oversaturation occurs falling out of silt and sedimentation of the riverbed, and in case of insufficient saturation, on the contrary, the flow weighs particles of silt from the surface of the canal and wash out the riverbed. Such nature of suspension and deposition of particles is the principal cause determining the character of riverbed deformation. Peculiarities of river water turbidity parameters in various phases of water regime often differs from average annual indices and have not been enough studies. The problem of determination of maximum hydraulic size of suspended particles is reduced to finding that probable hydraulic size under which the particle will not settle-out at l distance. To reveal the relationship between maximum hydraulic size of suspended silt and parameters of flow spectral theory of turbulence, taking into consideration distribution of energy vortices by different frequencies. This is conditioned by a circumstance that sufficiently large solid particles in water can be suspended in the field of law frequency pulsation where small part of the flow energy is concentrated.

Key words: turbulence, hydraulic size, erosion, fluid, pulsation, thickness.

Introduction

Channel flows almost always contain and carry away a certain amount of solid particles and decomposing organic substances and inorganic biogenic matter, which come from a basin soil washout, erosion of riverbed ground and riversides as well as weathering. All these products of water erosion are classified into the following categories:

suspended sediments, bottom sediments, dissolved matter.

Suspended sediments and dissolved matter are most often transported by water masses and bottom sediments are periodically entrained into motion and travel over the riverbed (in near-bottom layer of flow by sliding and bouncing along the bottom).

One of the principal characteristics of sediment composition is hydraulic size (w - velocity of uniform non-natural fallout of grains in still water). In the general case the hydraulic size depends on density of the particle, its volume and shape, viscosity of fluid medium, turbidity and degree of the flow turbulence.

Many Soviet and foreign researchers have been studied problems related to hydraulic size of silt and sediment. Today determination of hydraulic size is done by the scale invented by Prof. Goncharov V.N. based on generalization of a large quantity of experimental data. The average specific weight of the majority of river sediment is assumed 2.65t/m^3.

Phenomena of suspension and movement by river water of sediments of density around 2,6 times higher than that of water long ago attracted attention of scientists. The results of theoretical and experimental studies [1] show that suspension state of sediments is conditioned by turbulent agitation of water in the stream and formation of vortices. The latter throws separate liquid masses into water column, formation of whirlpools, presence of transverse streams, velocity pulsation and other events are the main causes of silt particles penetration into turbulent flow column, suspension and their travel.

Silt particle moves upward in case when it is in water body, with suspension velocity higher than hydraulic size, otherwise will occur deposition of silt particle specified size. In channel flows the basic mass of sediment travels in suspended state and in lowland river amounts to 85 to 95 percent and in mountain rivers – from 75 to 85 percent of the total amount of sedimentation [1].

It is accepted to characterize the saturation degree of the water flow by suspended silt by turbidity (S) which is determined by gravimetric or volumetric quantity of silt contained in a unit water volume. Turbidity of water is an important hydrologic characteristics of which impact on river channel deformation, efficiency of water intake and water outlet works performance, reservoir sedimentation have been little studied.. Water turbidity distribution in the flow is described by the following equation of turbulent diffusion of suspended particles [1, 2, 3]

$$\frac{\partial S}{\partial t}=\frac{A}{\rho}(\frac{\partial^2 S}{\partial x^2}+\frac{\partial^2 S}{\partial y^2}+\frac{\partial^2 S}{\partial z^2})-(v\frac{\partial S}{\partial x}+u\frac{\partial S}{\partial y}+k\frac{\partial S}{\partial z})-W\frac{\partial S}{\partial y}, \qquad (1)$$

where A is coefficient of turbulent exchange, u, v, k are components of velocity vector, x. y, z are longitudinal, vertical (increases from the surface to the bottom) and transverse spatial coordinates, respectively, w is hydraulic size of suspended particles. The first term of the right-hand member of the equation defines the change of turbidity value S in view of turbulent displacement of mineral particles. The second term characterizes turbulent change under the influence of longitudinal (advection), transverse (dispersion), and vertical (convection) transportation of suspended particles. The last number of Eq.(1) reflects influence of gravity force on turbidity value S [3]. Influence of longitudinal displacement of suspended silt on water turbidity in the course of various phases of water regime most clearly appears when analyzing change of characteristics of silt flow along lengthy section of rivers. Change of turbidity on sections of rivers in this case is determined by the ratio of its actual value to turbidity, in accordance with carrying capacity of flow which depends on particulars of its hydraulic state. With all with other things being equal the depth and rate of the flow impacts on sedimentation rate, possibility of their stable (unstable) suspension, which determines content these particles on a certain horizon starting from water surface (bottom). According to [3] role of processes defining irregularity of turbidity distribution along rivers width and depth at that is negligible small. However, we believe that this hypothesis is valid only for lowland rivers.

Existing hydrometric grid in service in many countries doesn't allow to efficiently evaluate relatively quick time-dependent changes of turbidity owing to high discreteness of measurements and widely spaced stations performing suspended silt observations. It remains an open question on evaluation and prediction of arrival of suspended particles lower than economic objects [3].

Suspended silts are carried away in the water flow column under the action of vertical components of turbulent pulsation velocity. The condition of particles suspension can be written as

$$u' \geq w, \qquad (2)$$

where u' is upward directed vertical component of stream's velocity vector, w is hydraulic size of silt particles. Suspended silts in depth of flow are distributed very irregularly. The most large particles travel in lower layer where turbidity of flow reaches to considerable value, most small ones are distributed in full depth and their quantity decreases from bottom to the surface, Thus, water turbidity in rivers increases from the surface to the bottom at that for silts of larger fractions increase runs quicker, and for silts of larger fractions – slower as shown in Fig.1.

However, this regularity doesn't act in the flow movement after the dam rupture where large particles are concentrated on the wave crest [1].

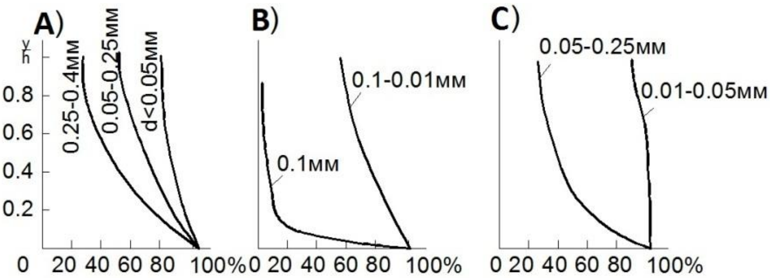

Figure 1 Silt content change in depth [3]

A) the Chnrchik river, B) the Volga river, C) the Sir-Daria river (according to Levi I.I.)

In relation to suspended silts transporting capacity of flow is of serious interest, that is that limiting turbulent which the flow can posses under the given hydraulic conditions. Carrying capacity of the flow depends not only on hydraulic characteristics of the flow but also on quantity, composition, dimensions, shape of particles and other properties of silts.

Consideration of all these factors presents considerable difficulties which explain availability of a grate number of formulae suggested for determination of carrying capacity of the flow.

Formulae for determining carrying capacity of flow can be divided into empirical and theoretical one. According to the Standard 3908-47 "Transporting capacity and sedimentation rate of water stream in channel" silts carrying capacity of water flow is determined by the following formula

$$\rho = BQ^{0,4}i, \quad (3)$$

where ρ is the transporting capacity (kg/m^3), Q is the flow of water in the channel (m^3/s), i is the grade of a free space, B is a coefficient assumed to be equal to 4700, 3000, 1100 и 600 for the hydraulic size w - $w \le 1{,}5$ mm/s, $w = 1{,}6 \div 3{,}5$ mm/s, $w = 3{,}6 \div 6{,}4$ mm/s, $W \ge 6{,}5$ mm/s, respectively [4].

Field investigations show that transporting capacity found by Eq.(3) gives understated results. For small values of the hydraulic size (W) it is suggested to introduce correction coefficient in Eq.(3) substituting B for $\frac{C}{w}$, where $C = 0{,}55 - 0{,}85$. Usually in calculation it is assumed that $C = 0{,}7$, then Eq.(3) can be written as [4]

$$\rho = \frac{C}{w} Q^{0,4} i_0, \quad (4)$$

where $i_0 = 10^4 i$

A number of researchers including Zamerin E.A., Gostunskii A.N., Khachatryan A.G., Shaumyan V.A., Abaliants S.Kh., Poslavskii V.V., Chekulaev G.S., Goncharov V.N., Lipatov K.G., Horst O.G., Mikheev P.V., et al have derived a well known formula for determining transporting capacity of flow.

The majority of formulae in use for determining transporting capacity of flow have been derived for conditions existing in irrigation channels. It follows that in solution of channel regulation problems, that is for flows of relatively large dimensions and containing silt particles of different size and nature, should be given careful attention to these formulae.

Generalizing obtained data on the rivers of Transcaucasia Zamarin E.A, suggested to define the carrying capacity of flow for weighted average values of hydraulic size ranging from 0,002 to 0,008 by the following empirical formula

$$\rho = 0{,}022\left(\frac{V}{\overline{w}}\right)^{1,5}\sqrt{Ri}\ . \qquad (5)$$

where $\overline{W}$ is the silt weighted average hydraulic size, V is average rate of the flow.

The most universal is the formula of Prof. Khachatryan A.G.

$$\rho = 0{,}69\frac{V^{1,5}}{(R\overline{w})^{0,333}}\ . \qquad (6)$$

Knowing actual turbidity of flow and its transporting capacity on a section under consideration enables to clear up the possible character of channel processes.

Tractional load according to its mechanical composition is composed of medium and coarse sands, gravel, pebble and stones. The composition of silts and character of their movement depends on hydraulic conditions of the channel flow. Quantitatively, the bed load is approximately 25% of the total, however, they play an important role in the formation of the channel.

When stream velocities are high and suspension of silt is of mass character the diagram of in depth distribution of turbidity has a usual form. With a sharp reduction or termination of the bed load arrival from upstream sections some velocity in depth redistribution occurs to the near-bottom velocity increase which is one of reasons of eroding capacity of clarified channel flow.

In engineering practice to regulate channels with the aim of finding possible character of channel processes it is important to determine maximum (critical) velocity of flow which characterizes crisis condition of a grain stability on the bottom. The maximum velocity can be defined using the formulae of Velikanov M.A., Shamov G.I., Goncharov V.N., Levy I.I., Knoroz V.S. Knowing the hydraulic size of silt in the channel and the depth of flow enables to gain some insight on the flow rate, under which these silts are deposited and under which they can start moving again, and on the contrary, knowing respective maximum velocity on the size one can get an idea on size of moving in the flow silts. To take into account the flow of bed load a number of empirical formulae have been suggested on the basis processing of data obtained by field investigations.

The main theoretical dependence for determining the carrying capacity of the flow is given Velikanov M.A. based on gravitational theory. Energy released during the transition of the flow mass from high marks to lower ones, is equal to the work of the liquid phase and suspension [5]. The differential equation of liquid phase steady motion of dispersoid of steady-state concentration of silts can be expressed as

$$g\bar{u}i(1-\bar{s}) = \bar{u}\frac{d}{dy}\left\{\overline{(1-s)u'v'}\right\} + \alpha g w\bar{s}(1-\bar{s}) \qquad (7)$$

In mountain conditions where the river channel and river feeding water basin are covered by rocks of relatively large size and hydraulic parameters are such that they do not suspend then the sediments contained in the bottom of flow under certain conditions start moving. This process begins after velocity of flow reaches limiting value and when particles lose their stable position on the bed and dart.

In the State Hydrology Institute, in a certain form, have been systemized available formulae for calculation of bedded sediment rate of flow and present specific recommendations for its calculation for various natural conditions.

Satisfactory can be considered accuracy of bedded sediment rate of flow calculation by a factor of two [6]. The reasons for unsatisfactory state of the problem have been in detail discussed in the paper of Kopaliani Z.D., and Kostyuchenko A.A. The main reasons are: 1) lack of clear definition of the term “bed load”; 2) lack of commonly accepted methods of differentiation of tractional, saltational and suspended silts; 3) insufficient consideration of specific character of natural conditions of rivers wherein occurs transportation of bedded silts (their size, slope, particle-size distribution, bedded particles transportation form), 4) poor accuracy of relations, used for calculation of bedded particles displacement [7].

There are various approaches to determine the flow of bedded sediments. To that end in the middle of 20th century a number of scientific workers attempted to derive universal formulae. However, in view of complexity, multifactorial nature, and poor studied process of bedded load transportation, a universal approach isn’t justified. Often techniques are applied for development of regional relationships, generalized for rivers of certain character and region [8,9].

Conflit settings

A problem has been set to determine dependence between maximum hydraulic size of suspended silts and parameters of flow and analysis of formulae in use.

Research results

Differentiated approach is applied for each type of hydraulic and morphological conditions and selected the corresponding dependences. More correct solution of the problem can be achieved by determining local dependence for the specific section of a given river since in spite of large amount of various formulas to perform calculation for hard particles transportation the single criterion to get reliable estimate can serve field data with detailed measurement all parameters: characteristics of the basin, water flow, bedded and suspended sediments, granular composition of the sediment being in motion, as well as bed silt. Only in such a case can the accepted dependences be assessed or newly developed ones with coefficients taking into account typical regional peculiarities both for moving particles and the entire basin [10].

To determine flow of tractional load a number of empirical formulas have been derived applicable for mountain river. Eghiazarov I.V. suggested to take as a base dependence for determining the flow of the tractional load, derived on the basis of the dimensionality method [10]

$$P = 15Q\rho\sqrt{i}\left(\frac{Ri}{\rho' f_0 d_{50}} - 1\right) \qquad (8)$$

where P is tractional load flow (kg/s), Q is water flow (m^3/s), i is the slope of river, R is the section of the hydraulic radius conditionally determining silt transportation, d_{50} is the median diameter of particles being in motion at the given water flow, h is the average depth of flow, and ρ' is defined by the equation below:

$$\rho' = \frac{\rho_s - \rho_w}{\rho_w}, \tag{9}$$

where ρ_s, ρ_w are density of silt and water, respectively (kg/m^3).

The value of the resistance coefficient f_0 is defined by the following equation:

$$f_0 = \frac{Ri}{\rho' d_{\max}}. \tag{10}$$

On the basis of carried out analysis (8) and formulas of a number of researchers from among a set of factors determining silt transport three main ones can be chosen: the flow average depth, the average rate of flow, and dimensions of moving particles, and the rest are their derivatives. On this basis the formula for determining bottom silt flow the below expression can be used [10]:

$$P = A\left(\frac{v}{v_0}\right)^{2,4}\left(\frac{d}{d_{\max}}\right)^{0,23}\left(\frac{h}{d}\right)^{-0,42} \tag{11}$$

where A is a dimension factor depending on composition of moving bedded silt. For the rivers of Armenia its value has been estimated to be 2,5 [10].

Both in natural channels and in hydraulic structures suspended particles are nonuniform. Therefore, it is often convenient in calculation to use the idea of an average hydraulic size which can be expressed as:

$$\underline{w} = \frac{\int_{w_{\min}}^{w_{\max}} wI(w)dw}{\int_{w_{\min}}^{w_{\max}} I(w)dw} \tag{12}$$

where $\underline{w}$, $w_{\max}$ and $w_{\min}$ are average, maximum, and minimum hydraulic size of suspended particles, respectively, $I(w)$ is relation of distribution of suspended particles according to the size can be established by Salakhov's formula [12]:

$$w_{\max} = 12.5n^2 \frac{u}{R^{1/3}} \tag{13}$$

where u is the flow rate, R is the hydraulic radius, n is a roughness coefficient. According to [13], friction speed for suspended transit particles can be defined by the below expression:

$$u_* = \frac{n\sqrt{g}}{R^{1/6}}\underline{u}. \tag{14}$$

Hydraulic parameters of the flow can be determined based on Velikanov M.A. hypothesis, according to which vertical instantaneous displacement of particles from the mean trajectory occurs in accordance with normal distribution law [14]

$$f(x) = \frac{1}{\sqrt{2\hbar}\sigma} e^{\frac{-x^2}{2\sigma^2}}, \tag{15}$$

where x is a random deviation of the particle from the mean trajectory, σ is the quadratic mean deviation.

Possibility that an arbitrary particle which in some definite cross-section is in y depth deposited not far than l distant

$$P = \frac{1}{\sqrt{\pi}} \cdot \int_{-\infty}^{\lambda} e^{-t^2} \cdot dt = \frac{1}{2} \cdot (1 + erf\lambda), \tag{16}$$

where

$$\lambda = 2.74 \frac{\frac{w\sqrt{\ell}}{u} - \frac{y}{\sqrt{\ell}}}{\sqrt{h} - 0.2}: \tag{17}$$

Possibility that a particle of w hydraulic size will not deposited at l distant is:

$$\Pi = 1 - P = \frac{1}{2}(1 - erf\lambda). \tag{18}$$

The actual problem is reduced to the determination of such probability of hydraulic size under which the particle will not be deposited at the l distant. In the result of simple mathematical transformations, we have

$$\frac{w}{u} = \left(\lambda \frac{\sqrt{h} - 0.2}{2.74} + \frac{y}{\sqrt{\ell}} \right) \frac{1}{\sqrt{\ell}}. \tag{19}$$

It is evident that the particle will be suspended if

$$w_{\max} \le \frac{\lambda}{2.74} \sqrt{\frac{h}{\ell}} \cdot u \tag{20}$$

The obtained relation shows that the maximum hydraulic size of suspended silts depends on the flow depth, The analysis of field experimental investigations show [15] that the results obtained by dependence (20) where the flow depth is the numerator, give more reliable results than results obtained by employing empirical formulae derived by other researchers, where the flow depth is in denominator.

Conclusion

1. The hypothesis to the effect that with all things being equal the depth and rate of the flow have an influence on deposition rate of mineral particles, possibility of their stable suspension, and that defines content of these particles on definite horizon, beginning from the surface of water and that

the role of processes determining irregularity of turbidity distribution depthward and widthward of rivers, at that is negligible small, and it is right only for lowland rivers.

2. The suggested empirical formulae for obtaining maximum hydraulic size suspended silts should be used carefully.

3. To reveal dependence between the maximum hydraulic size of suspended silts and parameters of the flow should be used spectral theory of turbulence, taking into consideration energy distribution in whirl of different frequencies. This is stipulated by a circumstance that largebsolid particles in water can be suspended in the field of pulsation at low frequencies, where is concentrated the largest part of the flow energy.

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Վ.Հ. Թոքմաջյան, Ա.Պ. Բալջյան, Դ.Ջ. Քամալյան
Շուշիի տեխնոլոգիական համալսարան

Հոսքի այս կամ այն տեղամասում հունային պրոցեսների ընդհանուր ուղղվածությունը կախված է դրանում բերվածքների հագեցվածության աստիճանից: Հոսանքի գերհագեցվածության դեպքում տեղի է ունենում բերվածքների նստեցում և հունի լցում, իսկ ոչ բավարար հագեցվածության դեքում՝ ընդհակառակը, հոսանքը հունի մակերևույթից լվանում է բերվածքների մասնիկներն ու մաքրում է հունը: Բերվածքների մասնիկների պարբերաբար լվացման և նստեցման տվյալ գործընթացը հանդիսանում է գետի հունի դեֆորմացիաների բնույթի որոշման հիմնական պատճառը: Ջրային ռեժիմների տարբեր փուլերում գետային ջրերի պղտորության բնութագրիչների յուրահատկությունները հաճախ տարբերվում են միջին բազմամյա բնութագրիչներից և քիչ են ուսումնասիրվում: Կախյալ մասնիկների առավելագույն հիդրավլիկական մեծության որոշման խնդիրը բերվում է այն հավանական հիդրավլիկական մեծության ստացմանը, որի դեպքում մասնիկը չի նստի l հեռավորության վրա: Կախյալ մասնիկների առավելագույն հիդրավլիկական

մեծության և պղտոր հոսքի բնութագրիչների կախվածության որոշման համար անհրաժեշտ է կիրառել տուրբուլենտության սպեկտրալ տեսությունը՝ հաշվի առնելով էներգիայի բաշխվածությունը տարբեր հաճախականությունների մրրիկներում: Դա պայմանավորված է այն հանգամանքով, որ բավարար մեծ կոշտ մասնիկները ջրում կարող են լվացվել ցածր հաճախականության տատանման դաշտում, որտեղ կենտրոնացված է հոսանքի էներգիայի ամենամեծ մասը:

Բանալի Բառեր. տուրբուլենտություն, հիդրավլիկական մեծություն, էրոզիյա, հեղուկ, տատանում, պղտորություն:

К ОПРЕДЕЛЕНИЮ ЗАВИСИМОСИ МАКСИМАЛЬНОЙ ГИДРАВЛИЧЕСКОЙ КРУПНОСТИ ВЗВЕШАННЫХ ЧАСТИЦ И ПАРАМЕТРОВ МУТНОГО ПОТОКА

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Общая направленность руслового процесса на том или ином участке потока зависит от степени насыщения его наносами. В случае перенасыщения потока происходит выпадение наносов и заиление русла, а в случае недостаточного насыщения, наоборот, поток взвешивает с поверхности русла частицы наносов и размывает русло. Такой характер периодического взвешивания и осаждения частиц наносов является основной причиной, определяющей характер деформаций русла рек. Особенности параметров мутности речных вод в разных фазах водного режима часто отличаются от среднемноголетних показателей и мало изучены. Задача по определению максимальной гидравлической крупности взвешенных частиц приводится к получению той вероятной гидравлической крупности, при которой частица не осядет на расстоянии l. Для выявлению зависимости максимальной гидравлической крупности взвешенных наносов и параметров потока следует применять спектральную теорию турбулентности, учитывая распределения энергии по вихрям разными частотами. Это обусловлено тем обстоятельством, что достаточно крупные твердые частицы в воде могут быть взвешены в поле пульсации низких частот, где сконцентрирована наибольшая часть энергии потока.

Ключевые слова: турбулентность, гидравлическая крупность, эрозия, жидкость, пульсация, мутность.