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ON MOVEMENT OF SUSPENDED PARTICLES IN TURBULENT FLOW

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The analysis of mud structures operating experience enabled to represent their positive sides and reveal design deficiencies. To develop mathematical models of the mudflows movement is of great importance and drawing up design diagrams of structures requires bringing out distinctive features of the movement of suspended particles by turbulent water. On the basis of experimental investigations carried out to define carrying capacity of the flow has been ascertained that the ratio of coefficients of resistance with saturated suspended particles and clean fluid with high concentrations always greater than a unit, when in many known research works it is believed that this ratio is less than a unit. The obtained experimental results are rigorously substantiated theoretically. The course of the change of the ratio of mixture resistance coefficient and clear water runs in the following way: at first increase of coefficient C leads to decrease of $f_{pw}/f_w<1$ *to a minimum value, then it starts increasing till a unit and more than unit.*

Key words: *turbulence, diffusion, fluid, coefficient of resistance, pulsating energy.*

Introduction

Scientists of many countries worked at issues of the movement of suspended particles in a turbulent stream. The principle difficulty here lies in the fact that different models of turbulence are not sufficiently perfect and up to now are subjects of theoretical and experimental study. As far back as in the middle of the last century academician A.N. Kolmogorov carried out study of the issue, the main ideas on locally isotropic turbulence of the stream being underlay in a so-cold $k-\varepsilon$ model of turbulence [1]. Later his hypotheses were used for closure of equations describing the movement of temperature heterogeneous streams [2] and suspended particles in turbulent stream [3,4]. In his fundamental works F.I.Frankl formulated equations of momentum and energy of turbulent pulsation fluid and hard components of flow, taking into account interaction between hard particles and fluid [5,6].Issues concerning the force of interaction between hard particles and fluid in their pulsating movement were also considered by J.O.Hinze [7,8]. Mud streams are formed as a result of interaction of a number of natural factors: hydrometeorological, climatic, geomorphologic, hydrological.

Formation of mud torrents in basins of mountain rivers in the main is conditioned by heavy falls of rain, hence, defining the regime of precipitations and establishing design characteristics of downpours has a certain importance for determining basic parameters of mudflows. However, the analysis of meteorological conditions, corresponding to heavy mud streams occurring in the Republic of Armenia and Nagorno-Karabakh Republic has shown that mud streams formation not always is in close agreement with heavy precipitations. This is explained by the fact that for formation of mudflows it is necessary that the basin was sufficiently wetted by earlier rains and that on slopes there were sufficiently much amount of easily sliding down the slope material. Heavy precipitations preceding a mudflow are typical of almost all mud streams occurring in basins of mountain rivers [23]. A mud stream is composed of a mixture of water and loose conglomerate – sediment. These flows are characterized by suddenness of formation, a short-run action and a great collapsing force. Moving mud streams in their way destroy settlements, buildings, various structures and facilities, roads, flooded gardens and fell trees, vineyards, and other agricultural areas. Running down through a channel the stream entails more and more particles of different nature and the force of gravity moves them along the sloping surface they are resting as deposited large particles and eventually the stream is transformed in a fast-moving and full of energy turbulent mud-and-stone stream containing a great amount of sediment.

Mud streams in mountainous regions are triggered by brief and heavy fall of rains, heavy snowmelt, as well as break of obstructions, etc. At that it is quite natural that in the given basin shaped like centres or on water catchment hill slopes must be enough material containing tiny clay particles, sand, gravel, stones, and even boulders. Mud streams are characterized by strongly pronounced upper section (slope i=0,4-0,2), transition zone (i=0,2-0,5), and the lower or deposition section (i=0,05-0,01) [3,18,20].

Conflict settings

Development of the theory of turbulence of homogeneous and heterogeneous flows is now underway based on closure of equations completion procedure, by using various models of $k-\varepsilon$ and $k-\overline{u_i^{/}u_j^{/}}-\varepsilon$ type and preparation of numerical methods for solution of the equations. A specific point at that is determination of the ratio of resistance coefficients with maximum suspension of particles and clear water of various concentrations.

Research results

Experimental unit is composed of a rectangular metallic tray of 20m length, 0.37m width, and 0,24m height. By special devices the tray can be installed at different slope angles. At the top of the tray are mounted feed tank designed for feeding fluid flow, equipped with triangular measuring weir gauge and metering hopper for feeding of hared particles (sand) in desired quantity.

Sediment carrying stream passing through the operating section of the tray gets into a collecting tank. At the end of each experiment sand arriving into the tank is removed, dried out, and weighed. Then weight flow of hard particles is determined, which enables, in its turn, also to control operation of the metering hopper.

In the course of experimental study sand of six grain-size composition and weighted average diameter d=0,9mm, 1,10 mm; 2,64 mm; 7,85 mm; 8,5 mm, and 14,0 mm was used. The experimental tray was installed at the following slopes: i=0,01; 0,02; 0,03; 0,05; 0,08, and 0,15.

Water discharge changed within the range Q_w =10 l/s – 52 l/s. Hard particles consumption changed within Q_p= 0,059 kg/s – 10,5 kg/s. By variation of fluid and hard discharges such state of the flow was reached, when quantity of transported by them hard material met carrying capacity of the flow. It means that a nonessential addition of sand will cause their deposition. Such procedure has been repeated for all inclined positions of the experimental tray for different fluid and hard discharge and silt grain-size compositions. Then for identical conditions the tray was fed by clear water of discharge equal to fluid component of double-component flow. Thus , 90 experimental points have been obtained. On the basis of these data the following Chezy coefficients of mixture C_{wp}, clear water C_w of ratios $C_{wp}=\frac{u_{wp}}{\sqrt{R_{wp}i}}$, $C_w=\frac{u_w}{\sqrt{R_w i}}$ and their relationship $\frac{C_{wp}}{C_w}=\frac{u_{wp}}{u_w}\sqrt{\frac{R_w}{R_{wp}}}$, therefore, and $\frac{f_{wp}}{f_w}$.

To obtain energy of sediment suspension, i.e. energy that the stream consumes to support hard particles in suspended state in the flow recommendations of F.I. Frankle and I.O. Hinze [5-8] can be used. To complete equations derived by these authors connections between pulsing characteristics have been used and corresponding averaged hydraulic parameters of the flow not only of gradient type (in the form of Bussenesck) applicable for small-scale turbulence, but also of convection type, which would hold for the large-scale turbulence. On such an approach can be found in [8,9], where it is pointed out that in general energy balance of turbulent pulsations the sediment suspension energy takes a place between small-scale and large scale turbulence. As a result for the suspension energy relevant to mass unit of the mixture (G) of homogeneous slow-changing flow we get

$$G = -(1+\beta C) g W_C C(1-C) + K_1 W_C C \, , \tag{1}$$

$$\beta = \frac{\rho_p - \rho_w}{\rho_w} \, . \tag{2}$$

where ρ_w and ρ_p are fluid density and hard particles, respectively, C is concentration (volumetric), g is acceleration of gravity, W_C is hydraulic size of hard particles in tight fall, K_1 is experimental constant equal to unit by order.

In case of slight water turbidity and absence of the second member Eq. (1) can be written as

$$G = -\beta g W_C C \, , \tag{3}$$

For a one-dimensional smoothly changing motion toward X, for equation of energy balance of turbulent pulsing we have

$$\frac{\partial}{\partial y}(\nu + \frac{\nu_t}{\sigma k}\frac{\partial k}{\partial y}) + P_r + G - \varepsilon = 0 \, , \tag{4}$$

where

$$P_r = \nu_t (\frac{du}{dy})^2 \, . \tag{5}$$

Between pulsation kinetic energy (k) and energy dissipation (ε) exist the Kolmogorov-Prandtl ratio

$$\nu_t = C\mu \frac{k^2}{\varepsilon} \, . \tag{6}$$

As it has been shown in [2, 3, 4, 8] in a number of applied problems, including the one under discussion, the first member in Eq.(4) presenting molecular and turbulent diffusion of pulsations kinetic energy, is smaller than in comparison with other members and to the first approximation can be neglected. It should be noted that the presence of this member in no way change the conclusion we will arrive without it. Hence, after the first member has been neglected and substitution of G and P_r according to Eq.(3) and (5), Eq.(4) will have the following form:

$$\beta W_C C g - \nu_t (\frac{du}{dy})^2 + \varepsilon = 0 \, , \tag{7}$$

or making use of the mass conservation equation

$$W_C C + \frac{\nu_t}{\sigma_C}\frac{dC^2}{dy} = 0 \, , \tag{8}$$

we get

$$-\beta g \frac{\nu_t}{\sigma_C}\frac{dC}{dy} - \nu_t (\frac{du}{dy})^2 + \varepsilon = 0 \, , \tag{9}$$

Equation of momentum for the problem under study will have the following form

$$\nu_t \frac{du}{dy} = u_*^2 (1 - \frac{y}{H}) \,, \tag{10}$$

where H s the depth of the flow, u_*^2 is the friction velocity.
Joint resolution of Eqs. (9) and (10) gives

$$\varepsilon = \frac{u_*^4}{\nu_t} (1 - \frac{y}{H})^2 (1 + \frac{\frac{\beta g}{\sigma c} \frac{dc}{dy}}{(\frac{du}{dy})^2}) \,. \tag{11}$$

Hence, making use of Eq.(6). we have

$$k = \frac{u_*^2}{C_\mu^{1/2}} (1 - \frac{y}{H}) \left[1 + \frac{\beta g}{\sigma C} \frac{dC}{dy} / (\frac{du}{dy})^2 \right]^{1/2} \,. \tag{12}$$

From Eq.(12) follows that pulsing energy of the flow inhomogeneous fluid decreases in comparison with existing flow of clear water since $\frac{dC}{dy} < 0$.

Energy dissipation equation for the present problem can be written in the following form

$$C_{1\varepsilon} \frac{\varepsilon}{k} \left[\nu_t (\frac{du}{dy})^2 + (1 - C_{3\varepsilon}) \beta g \frac{\nu_t}{\sigma C} \frac{dC}{dy} \right] - C_{2\varepsilon} \varepsilon = 0 \,. \tag{13}$$

or

$$\varepsilon = \frac{C_{1\varepsilon}}{C_{2\varepsilon}} \nu_t \left[(\frac{du}{dy})^2 + (1 - C_{3\varepsilon}) \beta g \frac{1}{\sigma C} \frac{dC}{dy} \right] . \tag{14}$$

From this it follows that energy dissipation of the flow also decreases in comparison with that of the clear water. In accordance with the forgoing we arrive at conclusions that the resistance coefficients of the flow with suspended particles are smaller than corresponding flow of clear water. This conclusion is borne out by experimental and theoretical researches [15,16]. However, it is necessary to take into consideration that in all experiments both fineness of hard particles and their concentration were small (C=0,0017-0,004, d=0,105).

Therefore dependence expressed in Eq.(11) is satisfied for that flows. When the coefficient of sediment is great energy of the flow is spent on suspension of hard particles and is determined by Eq.(10). Inasmuch as increase of concentration leads to gradual decrease of the first member of Eq.(1), and second one increases, then to determine the value of C, G assumes zero value (when $f_{pw} = f_w$), after which G takes positive value and then increases. Then the summand at the unit in parentheses of Eq. (11) becomes positive, which will cause increase of turbulent pulsations energy, therefore dissipation energy. As a result the ratio f_{pw} / f_w being greater than unit firstly slowly increased with C till C=0,3, then begins abrupt increase. The fact that the above mentioned ratio is greater than unit and increases with concentration is also evidenced by available research works in the field of hydraulic transport through pipes and pneumatic tube transport [17].

Conclusion

The foregoing enables to arrive at a conclusion that the course of change of the ratio of coefficients of resistance f_{pw}/f_w takes place in the following way – when C=0 then $f_{pw}/f_w = 1$. Further increase of C leads to decrease $f_{pw}/f_w < 1$ till some minimum value, then it starts increasing till to unit and larger than unit.

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ՏՈՒՐԲՈՒԼԵՆՏ ՀՈՍԱՆՔՈՒՄ ԿԱԽՎԱԾ ՄԱՍՆԻԿՆԵՐԻ ՇԱՐԺՄԱՆ ՄԱՍԻՆ

Հ.Վ. Թոքմաջյան

Շուշիի տեխնոլոգիական համալսարան

Հեղեղատար կառուցվածքների շահագործման փորձի ուսումնասիրությունները թույլ տվեցին պատկերացում կազմել դրանց դրական կողմերի վերաբերյալ և հայտնաբերել կոնստրուկտիվ թերությունները: Հեղեղային հոսքերի շարժման գործընթացի մաթեմատիկական մոդելների ստեղծման և կոնստրուկցիաների հաշվային սխեմաների կազմման համար կարևոր նշանակություն ունի տուրբուլենտ հոսանքում կախյալ մասնիկների շարժման յուրահատկությունների բացահայտումը: Փորձնական հետազոտությունների արդյունքում, որոնք իրականացվել են հոսանքի տեղափոխման հատկության ունակության բացահայտման նպատակով, պարզվել է, որ մեծ կոնցենտրացիաների դեպքում դիմադրության գործակցի հարաբերակցությունը կախյալ մասնիկներով հագեցած հեղուկի և մաքուր հեղուկի գործակցի հետ միշտ մեծ է մեկից, և դա այն դեպքում, երբ բազմաթից հայտնի հետազոտություններում պնդվում է, որ այն փոքր է մեկից: Ստացված փորձնական հետազոտությունների արդյունքները հիմնավորվում են տեսականորեն: Մաքուր ջրի խառնուրդի դիմադրության գործակիցների հարաբերության փոփոխման ընթացքը իրականանում է հետևյալ ձևով. սկզբում C գործակցի մեծացումը հանգեցնում է $f_{pw} / f_w < 1$ փոքրացմանը՝ մինչև որոշակի նվազագույն արժեքի: Այնուհետև այն սկսում է մեծանալ՝ մինչև մեկ և ավելին:

Բանալի բառեր. Տուրբուլենտություն, դիֆուզիա, հեղուկ, դիմադրության գործակից, պուլսացիոն էներգիա:

О ДВИЖЕНИИ ВЗВЕШАННЫХ ЧАСТИЦ В ТУРБУЛЕНТНОМ ПОТОКЕ

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Анализ опыта эксплуатации селезащитных сооружений позволили представить их положительные стороны и выявить конструктивные недостатки. Важное значение для разработки математических моделей процесса движения селевых потоков и составления расчетных схем конструкций имеет выявления особенности движения взвешенных частиц в турбулентном потоке. На основании экспериментальных исследований, проведенных с целью определения транспортирующей способности потока, установлено, что отношение коэффициентов сопротивления с предельно насыщенными взвешенными частицами и чистой жидкости при больших концентрациях всегда больше единицы, в то время, когда во многих известных исследованиях утверждается, что оно меньше единицы. Полученные экспериментальные результаты обосновывается теоретически. Ход изменения отношения коэффициентов сопротивления смесей чистой воды происходит следующим образом: сначала увеличение коэффициента С приводит к уменьшению $f_{pw}/f_w < 1$ до некоторого минимального значения. Далее оно начинает возрастать до единицы и больше

Ключевые слова: турбулентность, диффузия, жидкость, коэффициент сопротивления, пульсационная энергия.