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EFFECT OF BEDLOAD SEDIMENT NATURAL COMPOSITION ON GEOMETRIC AND DINAMIC CHARACTERISTICS OF CHANNEL FORMS

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Abstract

The article brings up data on sediment diversity at watercourse bed and on their movement in the form of ridges. The ridge form movement of sediment leads to the reduction of reservoir volume and canal cross section area, which has an effect on their carrying capacity, filling of pump station forechambers and hydroelectric station pressure basins with sediment. The presence of sediment in flow leads to abrasive deterioration of pumps, water motors and pressure pipes and to other negative consequences. Research work tasks on the study of these effects have been examined with the purpose of preventing such negative consequences. On the basis of laboratory data diagrams and relationships were obtained for ridge length, height and movement velocity vs. sediment hydraulic and geometric sizes.

Key words: ridge shapes, bedload sediment, heterogeneous sediment composition, flow velocity, ridge length, heightand movement velocity.

ТАБИИЙ ТУБ ЧЎКМАЛАРИ ТАРКИБИНИ ЎЗАН ШАКЛЛАРИНИНГ ГЕОМЕТРИК ВА ДИНАМИК ХАРАКТЕРИСТИКАЛАРИГА ТАЪСИРИ

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Аннотация

Мақолада, сув оқадиган ўзанлар тубида ҳар хил таркибдаги лойқалар мавжудлиги ва улар жўяклар шаклида судралиб ҳаракатланиши келтирилган. Жўяклар шаклида ҳаракатланаётган лойқалар сув омборлари ҳажмини ҳамда каналларнинг кўндаланг кесимини кичрайтиради, насос станциялари аванкамералари ҳамда гидроэлектростанцияларнинг босимли бассейнларини лойқага тўлдириб, босимли қувурларда катта тезликда ҳаракатланиши натижасида уларни емиради ва бошқа салбий оқибатларга олиб келади. Уларни ўрганиш натижасида салбий ҳолатларнинг олдини олиш учун илмий тадқиқот ишларини ўтказиш масалалари кўриб чиқилган. Лаборатория натижалари асосида жўякларнинг узунлиги, баландлиги ва ҳаракатланиш тезлиги билан лойқаларнинг гидравлик ва геометрик ўлчамлари орасидаги боғланишларни кўрсатувчи графиклар ҳамда уларни ифодаловчи формулалар олинган.

Таянч сўзлар: жўякларнинг шакллари, оқим тубидаги лой чўкиндилар, турли таркибдаги лойқалар, оқим тезлиги, жўякларнинг узунлиги, баландлиги ва ҳаракатланиш тезлиги.

ВЛИЯНИЕ СОСТАВА ЕСТЕСТВЕННЫХ ДОННЫХ НАНОСОВ НА ГЕОМЕТРИЧЕСКИЕ И ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ РУСЛОВЫХ ФОРМ

Н.М. Икрамов, Т.Ш. Мажидов

Аннотация

В статье приведены данные о разнородности наносов на дне водотоков и их перемещении в виде гряд.Перемещение грядовых форм наносов приводит к уменьшению объемов водохранилищ, поперечных сечений каналов, заполнению наносами аванкамер насосных станций и напорных бассейнов гидроэлектростанций, что приводит к абразивному износу насосов, гидротурбин и напорных трубопроводов, а также к другим отрицательным последствиям. Рассмотрены задачи научно-исследовательских работ по изучению этих явлений в целях предотвращения их отрицательных последствий. На основе лабораторных данных получены графики и зависимости длины, высоты и скорости перемещения гряды от гидравлических и геометрических величин наносов.

Ключевые слова: грядовые формы, донные наносы, неоднородный состав наносов, скорость потока, длина, высота и скорость перемещения гряды.

Introduction. Periodical structures form on an erodible surface when it interacts with air or water flow. Such periodical structures can be seen on the bottom of all waterways and reservoirs, on snow surface, in hydro and pneumatic transport pipes. Data about wavelike movement of Karakum sands in shape of pocks, ridges and dunes are given in work [1]. Formation of ripples are observed even in the Pacific ocean under the action of deep current [2]. Movement disperse medium under influence of turbulent flow in the form of periodical structures yield a huge loss to the humanity, since it deforms river and man-made waterway channels and carries sand and snow into the sites of national economy and etc. This has made people fight against the negative consequences of this phenomenon since olden times.

For the first time they have started to study sediment movement in China in the 15th century. Channel control works were required for rivers in China (for instance, Huang He), which carry huge amount of sediment.

Later, with the development of navigation, the science about sediment movement has started to develop in Europe. First DuBua and later Dikon have carried out their research in this area. DuBua observed bedload form creation and movement in laboratory conditions, and Baumgarten observed bedload form movement in field conditions for the first time and measured the parameters in Garonne river.

It is impossible to solve the problem, related with formation and realization of bedload periodical structural forms in turbulent flow by analytical methods, since the process depends on many factors. In present, such problems are solved by laboratory research and the accuracy of obtained results are estimated with field observations. Discrepancy in estimated and observed parameters of ridges is mainly related with bedload structure variation in space and time, imperfection of measuring technology and methods. As a result of laboratory and field research until now huge amount of theoretical and empirical formulas have been obtained, which determine the connection of bedload form parameters to flow and sediment characteristics. Range of new tasks have been revealed, and their solution are yet to be obtained.

After Dikon and Engels's experimental research, in 1914 G.Jilbert's and E.Merfy's experimental work came out.

Some of the main works in development of science about sediment movement are V.N.Goncharov's and G.N.Lapshin's works.

B.F.Snishenko, Z.D.Kopaliani, G.V.Jeleznyakov, V.K.Debolskiy, Y.T.Borshevski, D.M.Kondep, R.I.Garde, S.Y.Pavlov, A.A.Stepanov, N.A.Kotlova, D.Saymons, E.Richardson, P.Sanghal, B.Singh, N.Y.Kondratyev and others have also brought in a huge contribution in studying bedload sediment movement.

T.Sh.Majidov have attempted to account sediment composition for qualitative and quantitative estimation of ridge characteristics in his works [3,4]. He conducted experiments with three groups of disperse soils, each of which is one homogeneous and one heterogeneous material with equal mean diameters.

Experimental research allowed Majidov to obtain formulas for ridge parameters with the account of sediment size in the following form:

- for ridge form length:

$$\frac{l_г}{d} = 1{,}3 \cdot 10^4 \left(\frac{\omega^2}{gd_{50}}\right)^{2,2} \exp\left(-1{,}58\frac{\vartheta}{\vartheta_0}\right) \quad (1)$$

where: ω – hydraulic size of particles with diameter d_{50};

- for ridge height:

$$h_г = \frac{q_T (gH)^{1,5}}{0{,}01179^{4,0}} \quad (2)$$

for heterogeneous composition of sediment;

$$h_г = \frac{q_T (gH)^{1,15}}{0{,}00529^{3,8}} \quad (3)$$

for homogeneous composition of sediment;

- for ridge movement velocity:

$$C_г = 4{,}0 \cdot 10^{-5} \left(\frac{\omega^2}{gd_{50}}\right)^{3,85} (\vartheta - \vartheta_0)^{2,25} \quad (4)$$

All the above listed works lack consideration of impact of sediment natural composition change on the length, height and velocity of ridge movement, therefore we decided to conduct additional research in this area.

Research methods.

The goal of the research is to estimate the impact of the various types of heterogeneous sediment of constant size on the length, height and velocity of channel ridge form movement.

The following research tasks were set:

1. Improving methods for accounting varieties of heterogeneous soils.

2. Checking the applicability for the coefficient of heterogeneity of mixtures as $\varepsilon = d_m/d_i$, involving the existing data on grain-size distribution of bedload heterogeneous sediment.

3. Set up the following relationship of flow characteristics and ridge parameters with the coefficient of mixture heterogeneity:

$$H, I, \vartheta, \vartheta_0, q_m = f(\varepsilon = d_m/d_i) \quad (5)$$

$$h_r, l_r, C_r = f(\varepsilon = d_{срв}/d_i) \quad (6)$$

4. Determining the impact of sediment mean size, composition and flow hydraulic characteristics on ridge parameters:

$$h_r, l_r, C_r = f(H, \vartheta, Q, I, \vartheta/\vartheta_0, d_m, d_{max}, d_m/d_i)$$

where: d_m – mean sediment diameter;

d_{max} – maximum sediment diameter;

d_i – particle sizes with corresponding probability (i=5,10, 15, 25, 35, 50, 60, 65, 70, 75, 85, 90, 95);

ϑ and ϑ_0 – mean and eroding flow velocity;

H – mean flow depth;

I – water surface slope;

q_m – bedload sediment discharge;

ε – coefficient of sediment heterogeneity;

h_r, l_r, C_r – height, length and velocity of ridge movement, accordingly.

Since it is difficult to estimate the impact of heterogeneity of various types of natural sediment on the process of bedload ridge formation and movement in field conditions, main experiments were onducted in laboratory conditions (tab.1,fig.1). Experimental research was conducted on hydraulic channel in the laboratory, field observations of ridge movement for various sediment composition were done on canals and rivers of the republic [5].

Results and Discussion.

Ridge length. Ridge length is one of the important ridge form characteristics. Almost in all the theoretical works, related with study of ridge formation mechanisms, ridge form lengths are studied. Since one of the goals of our research was to set the connection of ridge length of various sediment

Table 1

Grain-size distribution of artificially made sediment

No.	Type of sediment	Grain-size distribution in % mass, for particle size in mm									d_m, мм	$\varepsilon = \frac{d_m}{d_{50}}$
		10÷7	7÷5	5÷3	3÷2	2÷1	1÷0,5	0,5÷0,25	0,25÷0,1	<0,1		
1	Edge fractioned	-	-	56,75	2,25	2,75	4,5	14,9	14,25	4,6	2,49	0,83
2	Small fractioned	9,5	8,5	8,75	13,75	22,25	14,75	8,75	9,25	4,5	2,51	2,24
3	Large fractioned	-	-	36,5	27	18	11,5	5,07	1,31	0,62	2,53	1,24
4	Evenly fractioned	11,1	10,1	10,1	11,1	11,1	11,1	11,1	12,1	12,2	2,51	2,8
5	Mean fractioned	-	14,4	14,8	15,3	32,7	18,6	2,2	1,25	0,75	2,48	1,88
6	Homogeneous	-	-	-	100	-	-	-	-	-	2,50	1,0

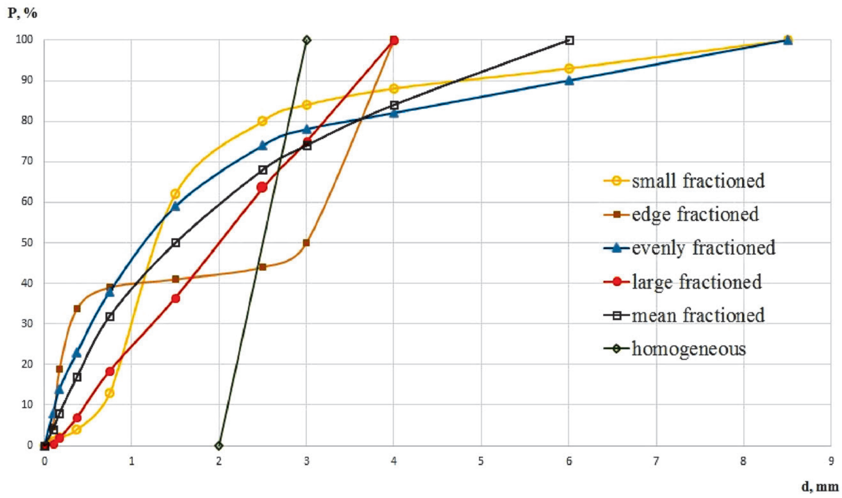

Fig.1. Grain-size distribution of experimented mixtures

composition with constant mean particle size and relative flow velocity, from the obtained experimental data we created graphical relationships of - $\ell_r / d = f(\vartheta / \vartheta_0)$ (fig.2).

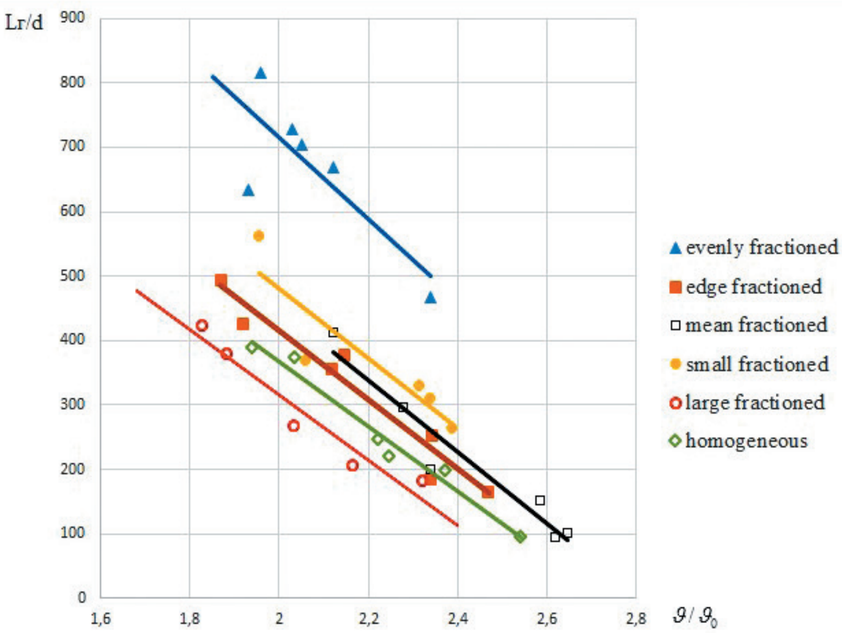

Fig.2. Plot of ridge length and sediment composition to the relative flow velocity

The following design formula was obtained on the basis of analytic and graphical relationship with accuracy of 0,8÷0,95:

$$\frac{l_г}{d} = -\left(49{,}9\varepsilon^2 - 127{,}4\varepsilon + 594\right) \text{x} \\ \text{x} \left(\frac{\vartheta}{\vartheta_0}\right) + 262{,}9\varepsilon^2 - 682{,}4\varepsilon + 1824 \tag{7}$$

Ridge height. Determining ridge height in channel flow is necessary for estimating bed roughness in determining channel hydraulic resistance, bedload sediment discharge and channel deformation calculations, also for setting threshold height in water intake structures, installation depth for pump station exhaust pipes and etc.

In order to set the connection of ridge height of various sediment composition with constant mean particle size and relative flow velocity, from the obtained experimental data we created graphical relationships of $h_r / d = f(\vartheta / \vartheta_0)$ - (fig.3).

$$\frac{h_г}{d} = -4{,}38 \cdot e^{0{,}23\cdot\varepsilon}\left(\frac{\vartheta}{\vartheta_0}\right)^2 - \left(9{,}2\varepsilon^2 - \right. \\ \left. - 35{,}8\varepsilon - 12{,}7\right)\left(\frac{\vartheta}{\vartheta_0} - 1{,}1\right) \tag{8}$$

Ridge movement velocity.

Ridge dynamic parameters, i.e. movement velocity is particularly important in designing channel deformation and bedload sediment discharge. Researchers have been studying these characteristics for almost two centuries. In order to set the connection of ridge movement velocity of various sediment composition with constant mean particle size and mean/scouring flow velocity, from the obtained experimental data we created graphical relationships of - $C_r = f(\vartheta - \vartheta_0)$ (fig.4).

The following design formula was obtained on the basis of the analysis of the graphical relationship with accuracy of 0,75÷0,9:

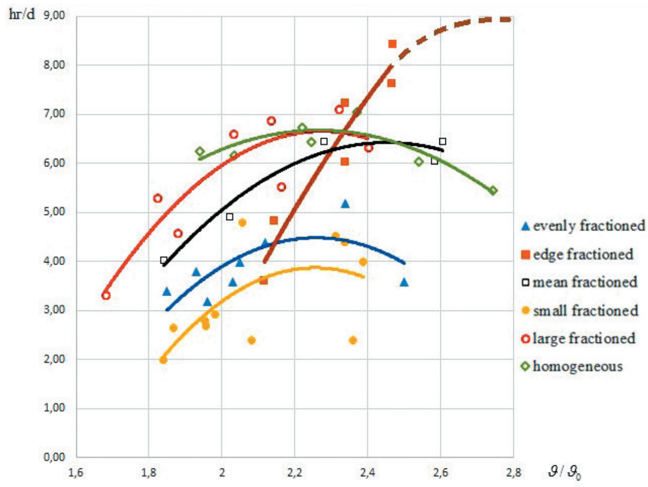

Fig. 3. Plot of ridge height and sediment composition to the relative flow velocity

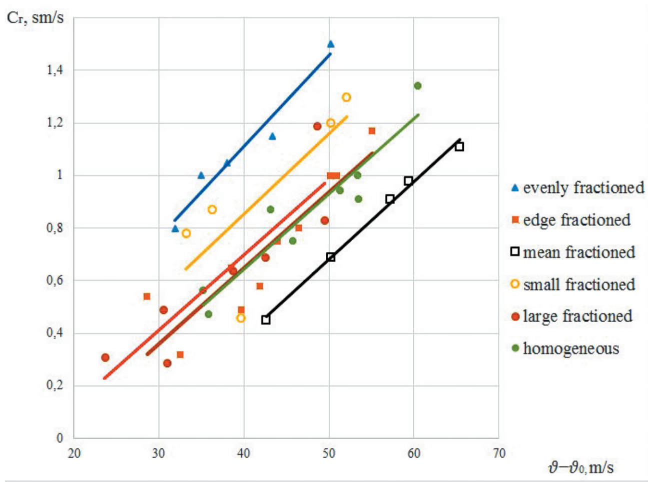

Fig.4. Plot of ridge movement velocity and sediment composition to the scouring flow velocity

$$C_г = \left(0{,}0026\varepsilon^2 - 0{,}0066\varepsilon + 0{,}033\right)\left(\vartheta - \vartheta_0\right) - 0{,}11\varepsilon^2 - 0{,}6 \qquad (9)$$

The relationships (7, 8, 9) obtained from experimental data give more precise determination for ridge length, height and movement velocity change depending on sediment composition heterogeneity of waterways in valley and piedmont regions.

Conclusions:

1. Bedload sediment movement in waterways take place in form of ridges.
2. Geometric and dynamic bed-load ridge characteristics depend on bedload sediment composition.
3. Relationships of heterogeneous bedload sediment ridge length, height, and moving velocity vs. flow relative velocity were obtained.
4. The obtained relationships show that sediment heterogeneity and flow relative velocity change has a direct effect on the bedload ridge form length, height and its moving velocity.
5. The increase of the relative flow velocity result in the decrease of ridge length.
6. The increase of the relative flow velocity up to 2,2÷2,4 result in the increase of ridge height at first, then in its decrease.
7. The increase of the difference between mean and scouring flow velocities result in the increase of ridge movement velocity from even to mean fracture composition.
8. The obtained relationships are applicable for waterways in valley and piedmont regions with more accuracy.

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