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DEPENDENCE OF SALTATION PARAMETERS ON BED ROUGHNESS AND BED POROSITY

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Abstract: *In numerical models of bed load transport a bed structure of channel could be described by two parameters, a size of bed particles and a standard deviation of normal distribution of bed particles in the vertical direction. The present paper deals with the effect of bed parameters on average length and height of one jump of saltating particle. A new formula was proposed for bed roughness based on size and standard deviation of the normal distribution of the bed particles. The dependences of length and height of the jump on the diameter of the saltating and bed particles were determined for different variation of vertical distribution of the bed particles.*

Keywords: ***Saltation parameters, saltation length, saltation height, bed structure, normal distribution of bed particles, bed roughness.***

1. Introduction

Saltation is a type of bed-load transport of solid particles in natural channels. During saltation the conveyed particles move along rough bed periodically jumping and colliding with bed particles. Parameters of motion of solid particles and its behaviour depend significantly on bed structure.

The goal of the present paper is to find a dependence of average parameters of saltation motion, such as length and height of one jump, on size of bed particles and on their vertical distribution with respect to the bed plane.

Present research is conducted on the base of simulation models of motion of spherical particles in the channel with rough bed, (Lukerchenko et al., 2009).

2. Bed geometry

The present investigation is an extension of the preceding one, in which a model of rough bed was presented (Kharlamova et al., (2011). Saltating particle during its motion collides with bed particles. The bed particles are grouped on the bed in small areas, which are appearing exactly in that place where saltating particle tent to lend. All bed particles are spherical grains of the same size; the size can be the same or different from the size of saltating particle. Bed particles are organized in particular ways in horizontal and vertical directions. Projections of all particles onto horizontal plane touch each other forming a compact hexagonal lattice, Fig. 1*a*. In vertical direction the bed particles are distributed along y-axis according to Gaussian distribution with standard deviation σ around mean bed level, Fig. 1*b*. After collision of the saltating particle with a bed particle the bed particle remains in the same position, while the saltating particle after some energy dissipation continues its motion in the stream. The process of particle's motion continues in such a way until the saltating particle gets stuck into the space between bed particles or until it performs a given numbers of jumps.

The above mentioned bed model allows changing size of bed particles and their vertical distribution around given bed level, it means change of the bed structure. Thickness of bed layer and its porosity can be controlled by stochastic distribution of bed particles around mean bed level and by their size.

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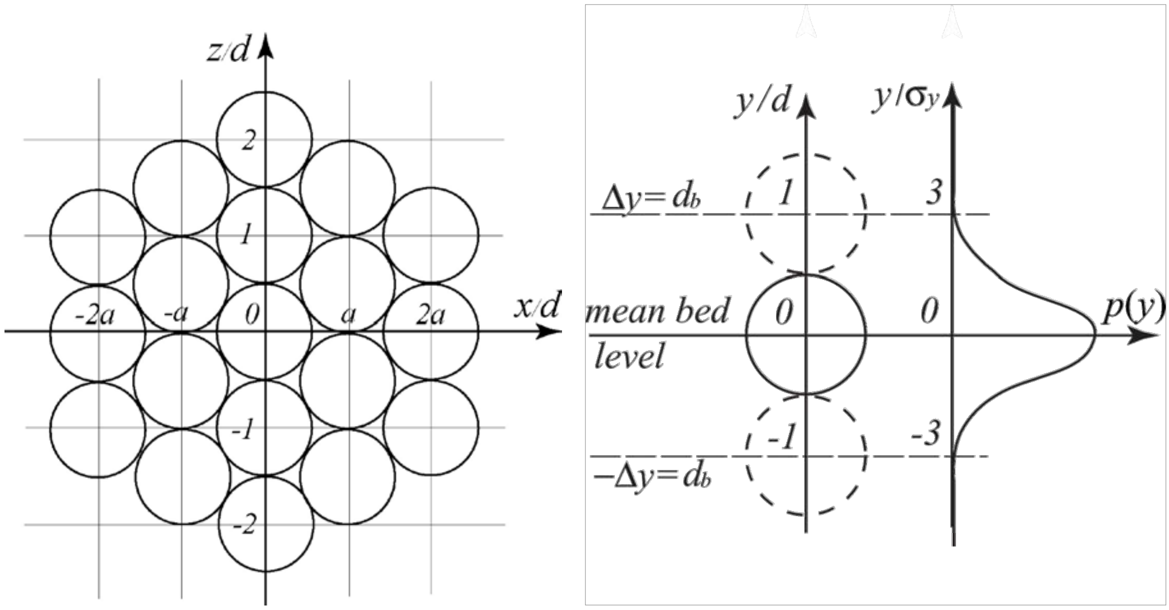


a) b)

Fig. 1. Bed structure in the present model: a) in the x-z plane particles form a compact hexagon; b) examples of distribution of bed particles along y-axis with Gaussian distribution with standard deviation σ = d_b/3 around mean bed level.

Twenty various bed geometries were analysed; these were formed by four different values of standard deviation, i.e. $\sigma = 0$, $0.08d_b$, $0.17d_b$ and $0.33d_b$; and by five different sizes of the bed particles, i.e. $d_b = 3$, 4, 5, 6 and 7 mm. Two sets of numerical experiment were conducted. The first simulation provided a situation where the size of saltating particle was equal to size of bed particles ($d = d_b$). In the second simulation the size of saltating particle remained constant and equal to 3 mm; size of the bed particles varied from 3 to 7 mm.

3. The investigation. Calculation of the shear velocity and bed roughness

In order to investigate the change of saltation parameters with variation of bed particle's sizes, it was assumed that the saltation process occurs in the channel with a constant flow rate, Q, and variable bed roughness. In this case it is necessary to know the relationship between bed roughness, k_s, and characteristic flow velocity – shear velocity, u_*.

In the literature there are several experimental studies which determine this connection: Wilson (1987), Yalin (1992), Van Rijn (1993), Sumer et al. (1996), Camenen et al. (2006). The work of Camenen et al. (2006) combines all experimental data from the abovementioned papers and presents a dependence of the equivalent bed roughness on different parameters such as bed shear stress, settling velocity of the bed particles and Froude number. However, the connection formula is very cumbersome and, as authors claim themselves, does not have any physical meaning:

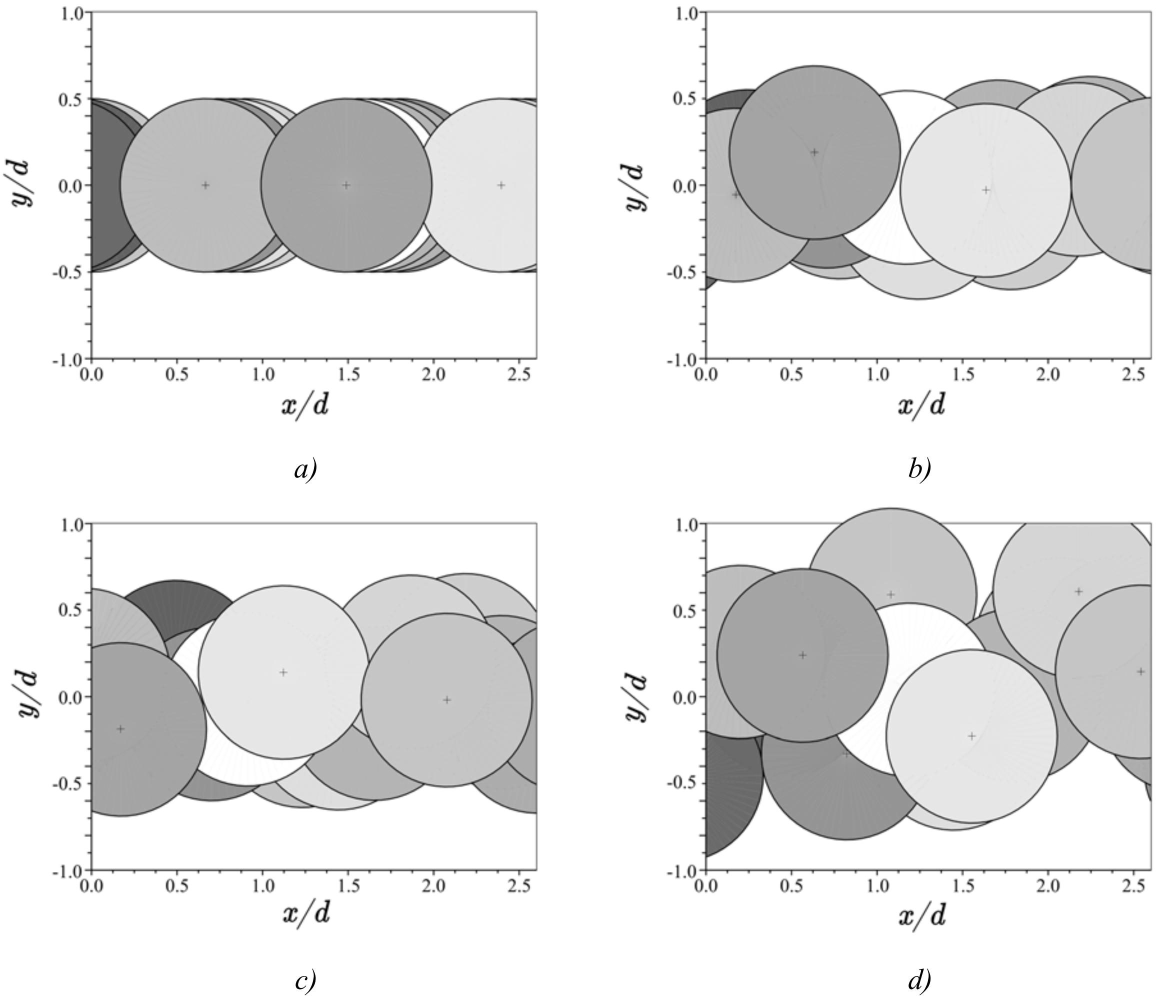
$$\frac{k_s}{d_b} = 0.6 + 1.8\, W_s^{1.2}\, F^{-2.4}\, \tau_*^{1.7}\,, \tag{1}$$

where $W_s = [(s-1)^2/(gv)]^{1/3}\, w_s$ – dimensionless settling velocity; s – ratio of solid particles' density and liquid density, for sand and water $s = 2.65$; g = 9.81 – gravitational acceleration; ν – kinematic viscosity of water; w_s – sedimentation (settling) velocity of the bed grains; $F = U_{av}/\sqrt{gH}$ – Froude number; $U_{av} = Q/(bH)$ – average velocity in the channel; Q – flow rate; H – water depth; b – width of the channel; $\tau_* = u_*^2/((s-1)\, g\, d_b)$ – dimensionless bed shear stress.

We proposed a simple relationship between bed roughness, k_s, and a size of bed particles, d_b, and their vertical distribution, σ :

$$k_s = 6\sigma + 0.5 d_b . \tag{2}$$

According to definition of the value of bed roughness, it is a distance between the smallest depression and the highest protrusion of bed formation, and it is also a random value in natural channels. According to (2) for standard deviation $\sigma = 0.33\, d_b$ the value $k_s = 2.5\, d_b$ is close to another simple formula for k_s, (Yalin, 1992): $k_s = 2\, d_b$, when the value of the bed shear stress τ_* is less than 1. When the standard deviation is equal zero, $\sigma = 0$, the bed roughness is minimum, $k_s = 0.5\, d_b$, as is clear from Fig. 1,2.



a) b)

c) d)

Fig. 2. Examples of distribution of bed particles:
a) standard deviation $\sigma = 0$, b) $\sigma = 0.08 d_b$, c) $\sigma = 0.17 d_b$, d) $\sigma = 0.33 d_b$.

Value of shear velocity, u_*, can be determined from the channel parameters, including bed roughness k_s and a logarithmic law distribution of turbulent velocity profile in an open channel:

$$u(y) = \frac{u_*}{\kappa} \ln\left(\frac{y}{y_0}\right), \quad y_0 = 0.11 \frac{\nu}{u_*} + 0.033 k_s . \tag{3}$$

Integrating (3) by depth of the channel and taking into account the width of the channel, a relationship between parameters of the channel and shear velocity can be obtained:

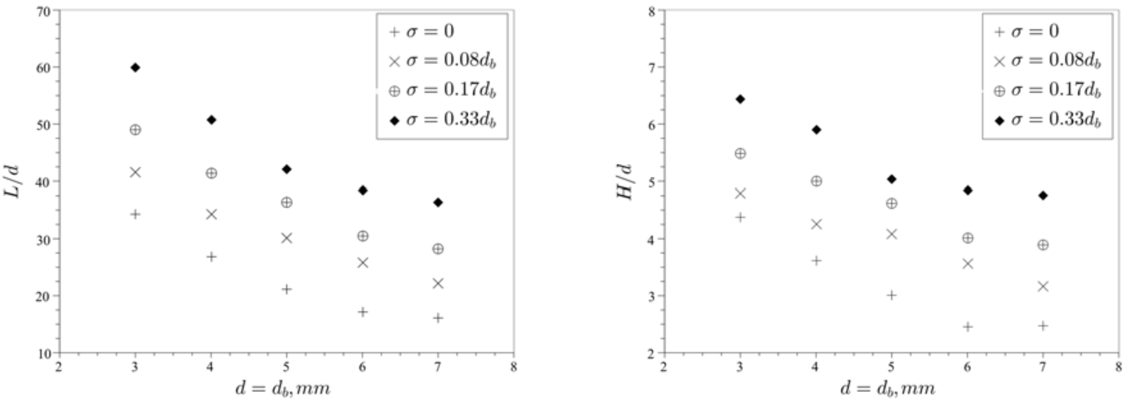
$$U_{av} = \frac{Q}{Hb} = \int_{y_0}^{H} u(y)dy\,, \tag{4}$$

$$\frac{Q}{Hb} = \frac{u_*}{\kappa}\ln\left(\frac{H}{y_0}\right) - \frac{u_*}{\kappa}\left(1-\frac{y_0}{H}\right). \tag{5}$$

Solving equation (5) and (2) the values of shear velocity and bed roughness can be obtained. For calculation of the values of these the following parameters of the channel, flow and particles were used: flow rate, Q, in channel is constant and equal $25\cdot 10^{-3}$ m^3/s, channel width, b, is 25 cm, depth of water, H, is 10 cm, kinematic viscosity, ν, and density of water, ρ, consequently equal 10^{-6} s/m^2 and 10^3 kg/m^3, density of solid particles (sand) is $2.65\cdot 10^3$ kg/m^3, and Karman constant $\kappa = 0.41$. The value of the flow rate Q was chosen so large so that it could allow realising a situation with developed, steady saltation when the saltating particle could perform up to 100 jumps.

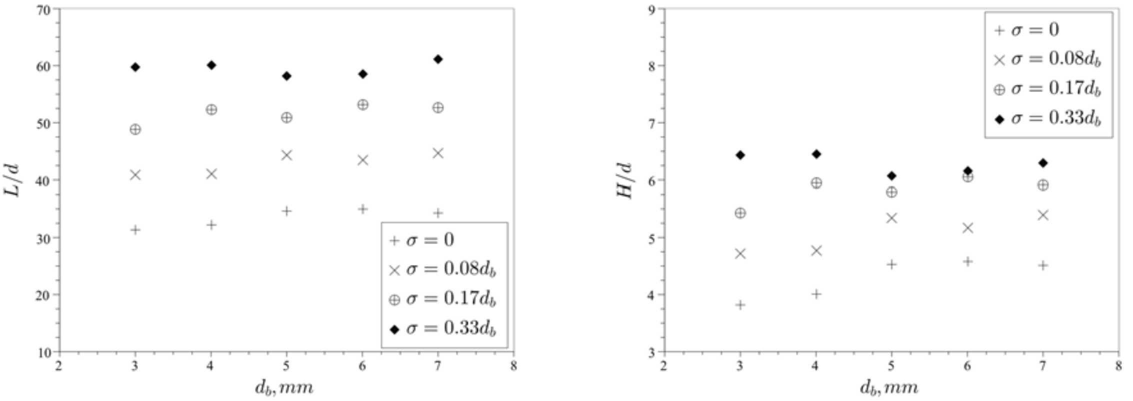
4. Results

In result of the first set of numerical experiment the average saltation parameters – length and height of one jump – were calculated. The size of bed particles and the saltating particle was the same and equaled consistently to 3, 4, 5, 6, 7 mm, and standard deviation in normal distribution, σ, was 0, 0.08, 0.17, and 0.33 d_b, see Fig. 3.



a) *b)*

Fig. 3. Dependences of average saltation length and height on diameter of saltating particle at various standard deviations, diameter of bed particles is the same as that of the saltating particle.



a) *b)*

Fig. 4. Dependences of average saltation length and height of one jump on diameter of the bed particles at various standard deviations, diameter of saltating particle is 3 mm.

As can be seen from the graphs, the dependences are nearly linear; parameters decrease with increasing the diameter and with decreasing the standard deviation. Thus the smaller saltating particle and bed porosity the longer its jumps.

In the second simulation set the size of saltating particle was constant and equal to 3 mm, sizes of bed particles equaled 3, 4, 5, 6, 7 mm, standard deviation equaled 0, 0.08, 0.17, and 0.33 d_b. The results of this simulation are shown in Fig. 4.

Saltating particle has approximately the same values of length and height of its jump at various sizes of bed particles. The larger standard deviation the larger length and height. The form of saltating jump does not change with various ratios between diameters of saltating and bed particles.

Saltating particle with 3 mm diameter at motion along porous bed (standard deviation $\sigma = 0.33\ d_b$, bed particles more then 5 mm) tends to stick into the holes in the bed and, as a consequence, makes a small numbers of jumps (20 from predesigned 100).

5. Conclusions

As a result of modelling different bed geometries saltation parameters (length, height of one jump) were obtained.

It was conducted that for the equal saltating and bed particles (less than $d \leq 5$ mm) the dependences of length and height on the diameter of particles ($d = d_b$) were nearly linear. The length and height of the jumps strongly depend on particle size d and on standard deviation σ - they increase with decreasing particle diameter d and with increasing standard deviation, σ (bed porosity).

For constant diameter of the saltating particle d and varying size of the bed particles d_b, other tendencies were observed. The length and height of the jumps with varying diameter of bed particles remain approximately constant with slight tendency to increase; they also increase with increasing bed porosity (σ). However, in the case of large bed porosity and small saltating particles, the saltating particles tend to stick into the bed among bed particles, and therefore they make only a limited numbers of jumps.

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