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MODELLING OF BED IN PROCESS OF PARTICLE SALTATION IN CHANNEL

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Abstract: *For numerical modelling particle saltation in channel with rough bed is important to define a bed configuration. The paper deals with the bed consisting of spherical particles of the different size then the saltating particle. In horizontal x-z plane the particles are arranged hexagonally. In vertical direction the particles are distributed according to Gaussian distribution. Before each collision of the saltating particle with bed the bed is shifted on a random distance and it is rotated by a random angle, so there is uniform probability to find a bed particle in any point of the x-z plane. The bed structure is chosen with aim to represent the natural bed as much as possible, thus the known information about distribution of the bed particles along y-direction is used and the location of bed particles in the x-z plane is controlled by principles of equal probability and minimal dense packing.*

Keywords: ***Bed structure, normal distribution, hexagonal packing.***

1. Introduction

It is important to define the bed configuration for successful modelling of solid particles motion in a channel. Usually the modelling of the motion consists of two basic parts: the equations of motion and the bed structure (see for example Chára at al., 2010). The more accurate the expressions for forces are the more precise is the solution – the trajectories of the particles. The same is also valid for the bed structure: the closer to the nature the bed structure is the more exact the particle's trajectories are. Therefore, modelling of bed structure close to the nature is very important for the accurate modelling of particle saltation.

2. Bed structure

2.1. Bed structure in model of Sekine and Kikkawa

The basis of present bed structure was taken from Sekine and Kikkawa (1992). They studied videotapes of saltation over an irregularly stacked bed composed of similar grains d_b. They experimentally found that bed grains are distributed with Gaussian distribution around mean bed level with standard deviation $\sigma = d_b/3$, see Fig. 1a. For modelling of saltation they used a cubing packing of bed grains in *x-z* plane, see Fig. 1b.

2.2. Bed structure in present model

In the model there is used the following bed arrangement. Bed consists of spherical particles; the size of bed particles d_b can be different from the size of saltating particles d_s. A small detached element of bed (bed sector) is created only in those areas where the saltating particle is going to collide with bed. The bed sector, which is created under saltating particle, consists of 19 or more particles packed hexagonally in *x-z* plane, see Fig. 2. Along *y* axis bed particles are distributed with Gaussian distribution similarly to Sekine and Kikkawa (1992).

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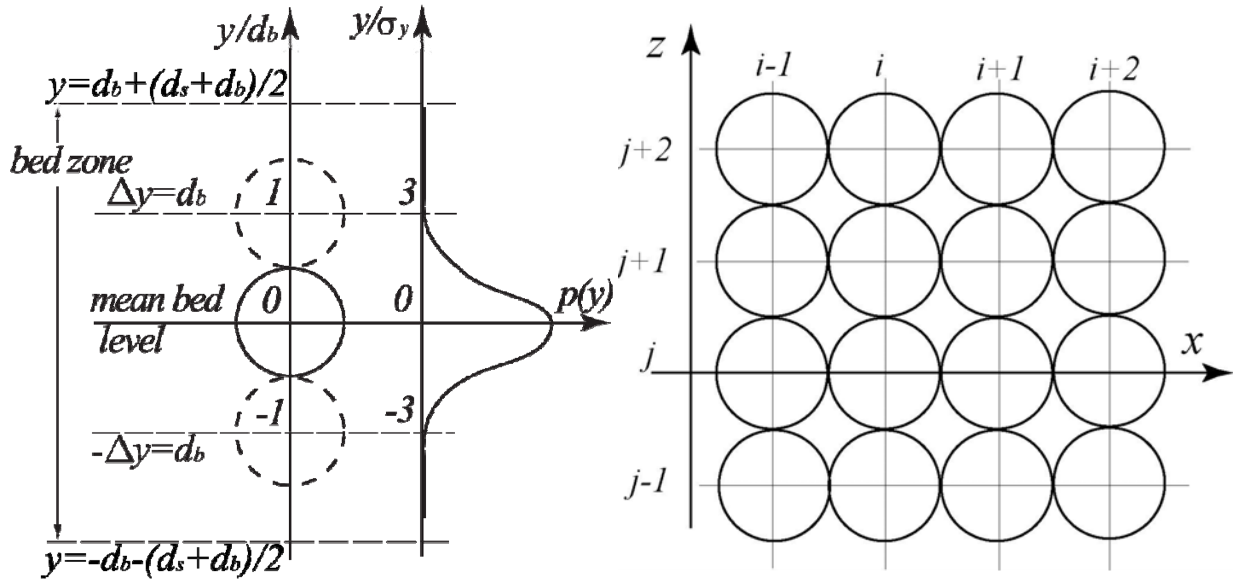

a) *b)*

Fig. 1. Bed structure according to Sekine and Kikkawa (1992). a) Distribution of particles in y-x plane and the bed zone; b) Distribution of particles in x-z plane with cube grid: $d_b \times d_b$.

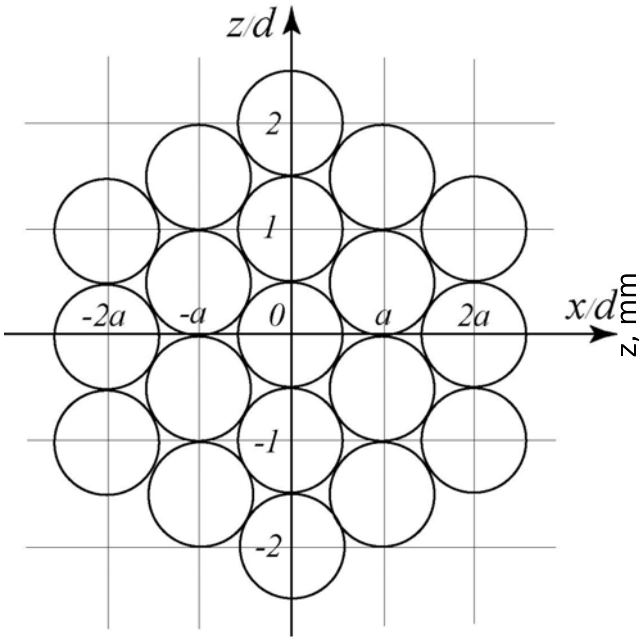

Fig. 2. Hexagonal arrangement of bed particles, present model. An element of grid has dimensions $d_b \times a d_b$, $a = \sqrt{3}/2$.

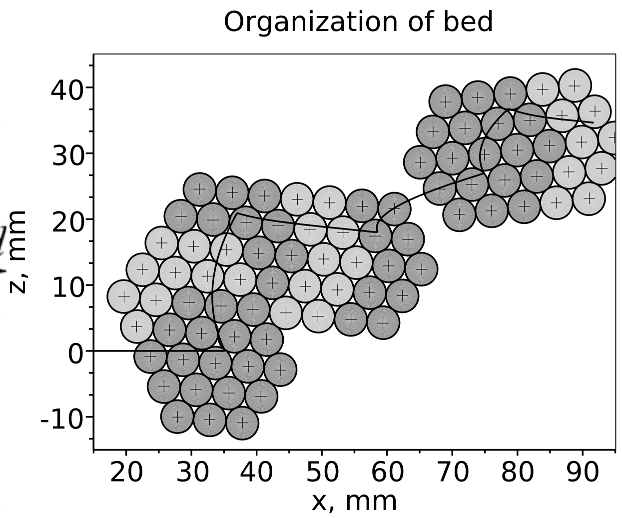

Fig. 3. The example of bed sector extension: bed sector consists of 19 particles extending with 10 added particles in the direction of particle movement (black line).

2.3. The building of bed

The equations of motion of saltating particle are solved numerically until the saltating particle enters in a bed zone, i.e. the zone, where collision of saltating particle and bed particle is possible. (The upper bound of the bed zone $y = d_b+(d_s+d_b)/2$, see Fig. 1a.) Later bed sector of 19 particles is created in an anticipated point of the particle collision. From this time distances between centre of saltating particle and the bed particles start to be calculated. If the shortest distance becomes less than the sum $(d_s+d_b)/2$, than the collision between the saltating particle and the certain bed particle will be registered. Otherwise the equations of the saltating particle motion will be solved again, until the collision occurs. After the collision, while the saltating particle continues its motion within the bed zone, distances between it and bed particles continue to be checked, that allows registering sequential collisions. If the saltating particle does not leave the bed zone, but leave the bed sector of 19 particles, than the additional 10 bed particles of the same organization will be added to extend the bed sector in the direction of the particle motion. It is repeated up to the moment, when saltating particle leaves the bed zone or sticks into the bed, see Fig. 3 and 4.

In order to avoid repeatability in mutual location of the saltating particle and the collided bed particle, the bed sector is shifted on a random distance and is turned by a random angle. The shift provides the uniform probability for finding a bed particle in whatever point of *x-z* plane, whereas the turn makes uniform distribution in the directions of bed particles' paired orientations. Thus the mutual location of the saltating particle and bed particles changes for each bed sector.

When the saltating particle enters in the bed zone ($-d_b-(d_s+d_b)/2; d_b+(d_s+d_b)/2$) the following steps will be conducted for building of the bed structure.

1. The centre of bed sector (x_0-, z_0-coordinates) is situated to the anticipated point of the particle collision.
2. Around the centre of bed sector 19 particles are arranged in hexagonal distribution (see Fig. 2); the local *x*-, *z*-coordinates of 19 bed particles are determined with respect to x_0-, z_0-coordinates of bed sector centre.
3. The x_0-, z_0-coordinates of the centre of bed sector shift randomly in rectangle $(1\times\sqrt{3}/2)\ d_b$; and the bed sector is turn by a random angle in *x-z* plane around its vertical axis, in order to make each impact unique, i.e. to avoid using the same bed organisation in the next bed sectors.
4. The y_0-coordinate of the centre of bed sector (mean bed level) is chosen within $(-0.20 \div 0.20)d_b$ interval by uniform distribution. It was done in order to make possible slight vertical difference between individual bed structures.
5. The *y*-coordinates of centres of 19 bed particle are seated to their place by normal distribution $f(y)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(y-y_0)^2}{2\sigma^2}\right)$ limited by (-3σ; 3σ) interval around y_0, where $\sigma = d_b/3$, according to Sekine and Kikkawa (1992).

These steps can create a rough bed like in nature condition. After the saltation particle leaves and then again enters the bed zone, the process of bed structure construction is repeated.

2.4. Sticking in the bed

The given bed structure has a parameter, which make possible to control the density of bed packing – i.e. the normal distribution parameter σ. The less σ the more consistent bed and the more difficult for saltating particle to penetrate through bed or even stick in it.

Using the parameter $\sigma = d_b/3$, which was defined experimentally (Sekine and Kikkawa, 1992), and small value of shear velocity u_* it is possible to get sticking a particle into bed, see Fig. 4. For various bed organisation the value of shear velocity u_*, at which particle sticks into bed, differs.

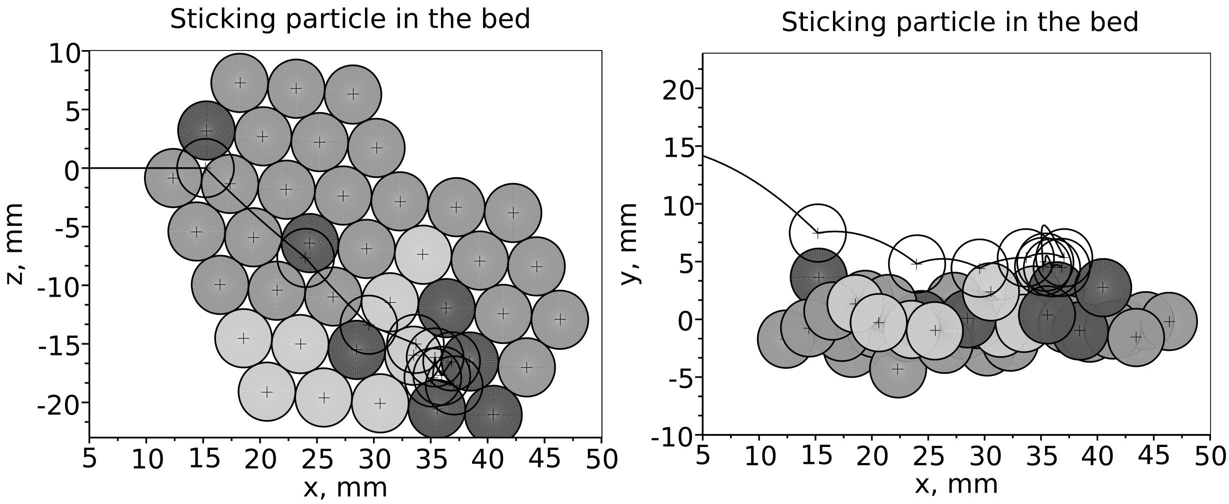

Fig. 4. Sticking saltating particle in the bed: saltating particle sticks in the bed at the 13th jump. Dark bed particles are the particles that take part in collision.
Diameters of particles $d_s = d_b = 5$ mm, $\sigma = d_b/3$, shear velocity $u_* = 0.025$ m/s.

3. Conclusions

Reasonable bed structure is necessary for accurate modelling of saltation particles motion. Present model of bed structure uses the experimental investigation of bed particles distribution in vertical direction in natural channels (Sekine and Kikkawa, 1992). The distribution of bed particles in horizontal plane is based on principle of bed packing with minimal space between neighbour particles - hexagonal packing. During a process of calculation of a saltating particle motion the bed is created only on a small place of presumed particle's collision. Each new part of bed (bed sector) differs from the other. There is a uniform probability to find a bed particle in whatever point of horizontal plane. The model make possible to describe various behaviour of saltating particle during its collision with bed, namely it allows observing such events as sequential collision of the saltating particle with bed particles and sticking it in the bed.

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