ISBN: 978-1-948012-16-4

Contemporary Issues in Computing (CIC)

DOI: <http://doi.org/10.26480/cic.01.2020.64.66>

CrossMark

RESEARCH ARTICLE

COMPUTATIONAL ANALYSIS OF EFFECT OF WATER IMPURITY ON A RIVERBANK PARTICLE

Debasish Biswas^a, Arijit Dutta^a, Sanchayan Mukherjee^a, Asis Mazumdar^b^aDepartment of Mechanical Engineering, Kalyani Government Engineering College, Kalyani-741235, West Bengal, India.^bProfessor & Director, School of Water Resources Engineering, Jadavpur University, Kolkata, West Bengal, PIN-700032, India*Corresponding Author e-mail: debasishmechanical@yahoo.co.in

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 20 October 2020

Accepted 22 November 2020

Available online 01 December 2020

ABSTRACT

The continuous flow of water through a river makes the riverbank quite dynamic in nature. The stability of a riverbank surface depends on many factors, as the sediment particles of the riverbank are subjected to wide variety of forces and these forces, in turn, depend on numerous factors. Water impurity is one of the most significant among them. Again, water level in a riverbank system continuously changes with time. The change of the water level has a telling effect on the stability of a bank surface. In the present work microscopic analysis has been made to compute stability of the bank surface by considering both pure and impure (high-density) water and the varying water level for different volume of liquid entrapped between the particles. An already-published "Truncated Pyramid Model (TPM)" for particle arrangement has been used and the principle of angular momentum has been applied for determination of escape velocity or separation speed which is the key parameter to quantify the erodibility of the bank surface. Here, three volumes of liquid bridge have been considered (10 nl, 20 nl and 30 nl). And the effect of water impurity and entrapped water volume on escape velocity has been presented graphically vis-a-vis different inter-particle distances.

KEYWORDS

Truncated pyramid model, Escape velocity, Inter-particle distance, Riverbank stability, Water impurity, Liquid-bridge volume.

1. INTRODUCTION

Rivers have a dominant influence on Indian culture, lifestyle, society, economy, tourism and many others things. So it is very important and also beneficial to know more about the rivers and the stability criteria associated with it. The stability of a riverbank surface depends on many factors which makes the analysis very much complicated. Riverbank stability is related to bank erosion. A higher rate of erosion implies less stability of the bank surface. So to have an idea about bank stability, it is very much important and rather imperative to compute the riverbank erosion. Escape velocity or separation speed of the grains is the key parameter for finding erosion rate.

A number of previous researchers (Abderrezzak et al., 2014, Odgaard and Mosconi, 1987, Carroll et al., 2004) have investigated riverbank erosion through experimentation, which are basically case studies for a particular river system. Such kind of investigation is a time consuming affair and involves considerable cost. Even after that, results obtained are usually very specific as these results may or may not match with other river systems. So, a general approach that provides a generalized analysis of the bank failure or bank stability is the need of the hour. Microscopic approach is such kind of an approach.

An analytical model (Truncated Pyramid Model) especially suited for micro-level analysis of particle interaction has been developed by Mukherjee and Mazumdar, 2010. Mukherjee, S., 2011 has found out that

the particle escape velocity is a strong function of the particle size under cohesive force. Mukherjee and Mazumdar, 2011 have made a comparative study between pure water and saline water with respect to riverbank erosion. Osman and Thorne, 1988 and Darby and Thorne, 1996 have investigated stability of the bank surface considering pore water pressure and hydrostatic force.. They have shown the adverse effect of salinity on the cohesive force between the particles in micro-level.

In the present study, variation of escape velocity have been studied with the variation of inter-particle distance under the action of cohesive force between two grains, pore pressure force, hydrostatic force and the submerged weight of the particle. Higher escape velocity implies that greater force is required to dislodge the grain from the bank surface, which indicates a stable bank surface. Here, situations comprising of both pure water (density = 1000 kg/m³) and impure water (density = 1025 kg/m³) have been investigated to study the effect of density of the flowing water on riverbank stability. Also the dynamic effect of the water level (both the case of rising and falling for fully submerged bank situation) on the stability of bank surface is investigated. Soulie et al., 2006 have shown that the capillary cohesion is a strong function of water entrapped volume. They have developed an expression of the force of cohesion between two differently sized grains which is as follows:

$$F_{c_p} = \pi \sigma \sqrt{R_{p_1} * R_{p_2}} \left[c + \exp \left(a * \frac{D_p}{R_p} + b \right) \right] \quad (1)$$

Quick Response Code	This paper was presented at	Access this article online	
	International Conference on Contemporary Issues in Computing (ICCIC-2020) - Virtual IETE Sector V, Salt Lake, Kolkata From 25th-26th July 2020	Website: www.intelcomp-design.com	DOI: 10.26480/cic.01.2020.64.66

Where coefficients a, b and c are depends on water bridge volume as

$$a = -1.1 \left(\frac{\nabla}{R_p^3} \right)^{-0.53} \quad (2a)$$

$$b = \left(-0.148 \ln \left(\frac{\nabla}{R_p^3} \right) - 0.96 \right) \phi^2 - 0.0082 \ln \left(\frac{\nabla}{R_p^3} \right) + 0.48 \quad (2b)$$

$$c = 0.0018 \ln \left(\frac{\nabla}{R_p^3} \right) + 0.078 \quad (2c)$$

The value of ϕ for pure water is 0° . And according to Bakker et al., 2003 the variation depends on the solid surface nature and it varies from 15° to 50° . According to Morgan, 1963 this value may be assumed to be 25° for impure water.

Likos and Lu, 2002 modeled the pore-pressure force between two unsaturated grains and to describe the pore-pressure force in microscopic level they developed an equation as follows:

$$F_{p_p} = P_w \times \pi \times r_2^2 + 2 \times \pi \times r_2 \times \sigma \quad (3)$$

Here, r_2 can be determined as

$$r_2 = \frac{R_p}{\cos \beta} [\sin \beta + \cos \beta - 1] \quad (4)$$

The effect of these two forces along with particle submerged weight force and hydrostatic force on TPM has been analyzed in the present study. Both the falling and the rising water level for fully submerged particle have been taken into consideration to analyze the influence of dynamic behavior of the river water level on the stability of the bank surface. Conservation of angular momentum principle has been applied to find out the escape velocity of the grains for three different volumes (10 nl, 20 nl and 30 nl) of water entrapped between two grains. Microscopic view of the particles in TPM has been shown in Fig. 1.

Figure 1: Microscopic view of particle arrangement in TPM with the enlarging view of two neighbouring particles.

2. MODEL FRAMEWORK WITH FORCE DISTRIBUTION

TPM assumes that each particle sits on top of two neighbouring particles with a small quantity of volume entrapped between them. The size of the particle in the TPM will increase row-wise and column-wise from the top and left corner. This implies that bigger particles settle down at the bottom and away from the surface. For the simplicity of the analysis particle size in the present case has been assumed to be constant. Particle 11, being the top most and the left most is the least stable and is the most vulnerable particle. Different forces acting on the particle 11 with the direction of action has been shown in Fig. 2. As the point A is the point of contact between the particles 11 and 21, this point will act as the instantaneous centre of rotation. So the moment has been taken about that point.

Figure 2: Free body diagram of the particle 11 subjected to different forces. Also visible are their moments about the point A (point of contact with the leftmost particle in the lower row).

3. GENERALIZED EQUATIONS FOR PARTICLE ESCAPE VELOCITY

Considering planar analysis, hydrostatic force per unit length in horizontal direction can be written as

$$F_x = F_H = P_{avg} \times A_x = \rho_w \times g \times h_c \times A_x = \rho_w \times g \times \frac{2}{3} \times \overline{AE} \times \overline{AE} \quad (5)$$

Hydrostatic force per unit length in vertically upward direction

$$F_y = P \times A_y = \rho_w \times g \times h \times A_y = \rho_w \times g \times \overline{AE} \times \overline{FE} \quad (6)$$

Weight of the fluid block per unit length in vertically downward direction

$$W = m \times g = \rho_w \times g \times V = \rho_w \times g \times \left[\overline{FE} \times \overline{AE} - \frac{1}{2} \overline{FE} \times \overline{AF} \right] \quad (7)$$

(Assuming AFE is triangle)

Net hydrostatic force per unit length in vertically upward direction is given by

$$F_V = F_y - W \quad (8)$$

Resultant hydrostatic force per unit length is given by

$$F_{R_p} = \sqrt{(F_H)^2 + (F_V)^2} \quad (9)$$

And the direction of the hydrostatic force with horizontal direction is given by

$$\theta = \tan^{-1} \left(\frac{F_V}{F_H} \right) \quad (10)$$

Mass of the sediment particle is given by

$$m_p = \frac{4}{3} \pi R_p^3 \times \rho_p \quad (11)$$

Considering conservation of angular momentum and taking moment about the instantaneous centre A

$$F_{gs1} \times \overline{AC} + F_{C_p} \times (\overline{AE} + \overline{AD}) + F_{R_p} \times \overline{AP} + F_{p_p} \times (\overline{AE} + \overline{AD}) = I_A \times \alpha_p \quad (12a)$$

$$\Rightarrow F_{gs1} \times \frac{R_p}{2} + F_{C_p} \times \left(\frac{\sqrt{3}R_p}{2} + \frac{\sqrt{3}R_p}{2} \right) + F_{R_p} \times R_p \sin(60 - \theta) + F_{p_p} \times \left(\frac{\sqrt{3}R_p}{2} + \frac{\sqrt{3}R_p}{2} \right) = \frac{7}{5} \left(\frac{4}{3} \pi R_p^3 \times \rho_p \right) \times R_p^2 \times \alpha_p \quad (12b)$$

By solving above equation, angular acceleration of the particle is given by

$$\alpha_p = \frac{\frac{F_{gs1}}{2} + (F_{C_p} \times \sqrt{3}) + F_{R_p} \sin(60 - \theta) + (F_{p_p} \times \sqrt{3})}{\frac{7}{5} \left(\frac{4}{3} \pi R_p^3 \times \rho_p \right) \times R_p} \quad (13)$$

Linear acceleration ((in m/s²)) of the particle can now be derived from the angular acceleration as follows

$$f_p = \alpha_p \times R_p \quad (14)$$

Hence the escape velocity (in m/s) of the particle is written as

$$V_{ep} = \sqrt{(2 \times f_p \times R_p)} \quad (15)$$

3.1. Input parameters for analysis

The value of the input parameters considered in the present analysis are as follows

$$R_p = 0.4 \text{ mm};$$

$$P_p = 1000 \text{ kg/m}^3 \text{ and } \rho_s = 2650 \text{ kg/m}^3;$$

$$\sigma = 0.073 \text{ N/m (for pure water) and } \sigma = 0.0681 \text{ N/m (for impure water);}$$

$$\beta = 45^\circ;$$

$$\phi = 0^\circ \text{ (for pure water) and } \phi = 25^\circ \text{ (for impure water);}$$

$$P_w = 10 \text{ kPa.}$$

4. RESULTS AND DISCUSSION

Figure 3: Variation of escape velocity with inter-particle distance for 10 nl water bridge volume (a) For water level rising; (b) For water level falling.

Figure 4: Variation of escape velocity with inter-particle distance for 20 nl water bridge volume (a) For water level rising; (b) For water level falling.

Figure 5: Variation of escape velocity with inter-particle distance for 30 nl water bridge volume (a) For water level rising; (b) For water level falling.

Stability of the riverbank has been analyzed for different entrapped-water volumes in case of both rising and falling water level considering for both pure water and impure water with certain physical properties. From all the figures it is clear that the inter-particle distance has an adverse effect on the escape velocity of the particle. It is also evident from the figures that with the increasing liquid bridge volume escape velocity also increases. For the same volume of water content between the grains escape velocity is higher for impure water (with higher density) compared to pure water. It is also clear that the escape velocity is higher when the water level rises and vice versa.

5. CONCLUSIONS

From the present analysis it can be concluded that

- Inter-particle distance has an adverse effect on the particle escape velocity. This is due to weakening of the force of cohesion between particles with increasing inter-particle distance. This ups the erodibility of the bank.
- That the bank stability has an upward trend with water bridge volume proves the fact that water binds the particles together.
- For the same value of water content escape velocity is higher for higher-density water compared to that for pure water. Although the force of cohesion is less for the impure water, the hydrostatic force rises significantly owing to high density of the impure water. Hence the resultant escape velocity increases in case of impure water.
- For the same volume of water content escape velocity is less when water level lowers compared to when water level is on the rise. In case

of rising water level pore pressure helps to bind the particles together. Therefore, the stability is higher when water level moves upwards. On the contrary, as the water level moves downwards the gravitational force becomes predominant lowering the stability. So, the bank surface is more vulnerable when the water level drops.

REFERENCES

- Bakker, D. P., Klijnstra, J. W., Busscher, H. J., Van der Mei, H. C., 2003. The Effect of Dissolved Organic Carbon on Bacterial Adhesion to Conditioning Films Adsorbed on Glass from Natural Seawater Collected during Different Seasons, *Biofouling* 19(6), p. 391-397.
- Carroll, R. W. H., Warwick, J. J., James, A. I., Miller, J. R., 2004. Modeling Erosion and Overbank Deposition During Extreme Floods Conditions on Carson River, Nevada, *Journal of Hydrology* 297 (1-4), p. 1-21.
- Darby, S. E., Thorne, C. R., 1996. Stability analysis for steep, eroding, cohesive riverbanks, *Journal of Hydraulic Engineering*, 122 p. 443-454.
- El Kadi Abderrezak, K., Moran, A. D., Mosselman, E., Bouchard, J. P., Habersack, H., Aelbrecht, D., 2014. A Physical, Movable-bed Model for Non-uniform Sediment Transport, Fluvial Erosion and Bank Failure in Rivers, *Journal of Hydro-environment Research* 8 (2), p. 95-114.
- Likos J. W. and Lu N., June 2-5, 2002. Hysteresis of Capillary Cohesion in Unsaturated Soils, 15th ASCE Engineering Mechanics Conference Columbia University, New York, NY.
- Morgan, J., 1963. Introduction to University Physics, Allyn and Bacon, Inc., Boston MA, p. 13 - 37.
- Mukherjee, S., 2011. Application of Truncated Pyramid Model in determination of escape velocity of particles of different diameters in varying conditions, *International Journal of Soft Computing and Engineering (IJSCE)* 1(5), p. 75-79.
- Mukherjee, S., Mazumdar, A., 2010. Study of effect of the variation of inter-particle distance on the erodibility of a riverbank under cohesion with a new model, *Journal of Hydro-environment Research* 4 (3) p. 235-242.
- Mukherjee, S., Mazumdar, A., 2011. Influence of Inter-Particle Distance, Entrapped Water Volume and Salinity of Water on the Escape Velocity of Particles on a Riverbank, *Engineering, Scientific Research* 3, p. 763-770.
- Odgaard, A. J., Mosconi, C. E., 1987. Streambank Protection by Submerged Vanes, *Journal of Hydraulic Engineering*, ASCE 113(4), p. 520-536.
- Osman, A. M., Thorne, C. R., 1988. Riverbank stability analysis, I: Theory *Journal of Hydraulic Engineering* 114 (2) p. 134-150.
- Soulie, F., El Youssefi, M. S., Cherblanc, F. and Saix, C., 2006. Capillary Cohesion and Mechanical Strength of Polydisperse Granular Materials, *Eur. Phys. J. E.*, 21, p. 349 - 357.

NOMENCLATURE

R_p	radius of the particle (mm)
D_p	inter-particle distance (mm)
V	liquid bridge volume (nl)
ϕ	angle of contact (rad)
P_w	pore water pressure (N/m ²)
β	angle of water content index (rad)
σ	surface tension coefficient (N/m)
ρ_w	density of water (kg/m ³)
ρ_p	density of the particle (kg/m ³)
I_A	mass moment of inertia of the spherical particle (kg. m ²)
α_p	angular acceleration of the particle (rad/s ²)
f_p	linear acceleration of the particle (m/s ²)
m	mass of the water (kg)
m_p	mass of the spherical particle (kg)
g	acceleration due to gravity (m/s ²)