Conference Paper, Published Version

Shourian, M.; Neshabouri, S. Ali A. Salehi

Effect Of The Initial Location On Sand And Gravel Mining Pit Migration

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/99900

Vorgeschlagene Zitierweise/Suggested citation:
Shourian, M.; Neshabouri, S. Ali A. Salehi (2004): Effect Of The Initial Location On Sand And Gravel Mining Pit Migration. In: Chiew, Yee-Meng; Lim, Siow-Yong; Cheng, Nian-Sheng (Hg.): Proceedings 2nd International Conference on Scour and Erosion (ICSE-2). November 14.–17., 2004, Singapore. Singapore: Nanyang Technological University.

EFFECT OF THE INITIAL LOCATION ON SAND AND GRAVEL MINING PIT MIGRATION

M. SHOURIAN & S. ALI A. SALEHI NESHABOURI
Civil Engineering Department, University of Tarbiat Modarres, Tehran, Iran

Sand and gravel mining from riverbeds is a major supply of construction materials. A mining pit in a riverbed is very unstable and subject to scouring and deposition which results in migration of the pit. In this paper, migration of a rectangular pit in a straight channel bed composed of uniform sediments is simulated with *SSIIM* model. The numerical model solves the transient Navier-Stokes equations with the $\kappa - \varepsilon$ turbulence model. The sediment flow is calculated by solving the transient convection-diffusion equation for sediment concentration. Van Rijn's formula for sediment concentration is used as boundary condition for the bed. Sediment continuity for the cells close to the bed gives the bed changes with time. The effect of the initial location of the pit on the process of the migration is surveyed. Regression equations for the maximum scour depth, shape and speed of the migration of the pits are obtained.

1 Introduction

Because of the large quantity of sand and gravel in their beds, rivers have always been considered as a major source of sand and gravel for civil works. Acceptable quality, ease of extraction and economy are some of the reasons could be mentioned.

Unfortunately, specific laws and regulations regarding the safe in-stream mining have not been provided for users and officials. What should be taken into account are the effects of over-mining of sand and gravel, which can cause irreversible damages to the morphology of the rivers, and to the nearby structures. Pit migration, based on the hydraulic condition of the river and also the geometry of the pit could be in the downstream or upstream direction. A number of earlier studies have been carried out on numerical modelling of water and sediment transport. For a steady state situation, Toro et al. (1989) calculated the water flow in a partially closed channel using a fully three-dimensional model. Olsen and Skoglund (1994) calculated water and sediment flow for a steady situation in a sand trap with a free surface. Previous simulation of bed movements include Van Rijn (1987), using a two-dimensional width-averaged numerical model to simulate bed changes in dredged trenches. Olsen (1999) used a two-dimensional depth-averaged numerical model to calculate bed changes in a reservoir which was being flushed. Amongst the research works on the pit migration process and its effects on the river profile, we can refer to works by Chang (1987), Gill (1994), Lee et al. (1993), and Lee and Chen (1995). The first two works were mainly mathematical approach, while the works done by Lee et al., were experimental. Lee et al. (1993) investigated the temporal and spatial variations of rectangular pits in the laboratory. According to their observations, the migration of the pit can be divided into two sequential stages, a convection stage and a diffusion stage. In the convection stage, the maximum scour depth remains more or less constant; in the diffusion stage, the maximum scour depth decreases as time proceeds. They also developed the regression formulas to predict the deformation and migration of the pit based on the experimental data.

In this paper, a numerical model is used to simulate the pit migration in a channel bed. In this three-dimensional simulation, the effect of the initial length of the pit on the migration process is surveyed. This model, named SSIIM, was initially created to simulate the sediment movements in general river/channel geometries.

The SSII program was developed in 1990-91 by Nils Reidar B. Olsen. SSII is an abbreviation for Sediment Simulation In Intakes. The main motivation for making SSII was the difficulty to simulate fine sediment in physical models. The fine sediments, often, under 0.2 mm, are important on tubes. It was also an advantage to be able to simulate other problems as for example sediment filling of reservoir and channels. A disadvantage with the SSII program for practical situations was that a structured grid was used, and it was only possible to have one block for an outblocked region. A natural improvement was a multi-block model with general outblocking possibilities. So, a new water flow module for multi-block calculation was made. This model was added to SSII, and the resulting model was called SSIIM.

SSIIM is an abbreviation for Sediment Simulation In Intakes with Multiblock option. The program is made for use in River, Environmental, Hydraulic, and Sedimentation Engineering. The SSIIM program solves the Navier-stokes equations with the $\kappa - \varepsilon$ model on a three-dimensional almost non-orthogonal grid. A control volume method is used for the discretization, together with the power-law scheme or the second order upwind scheme. The SIMPLE method is used for the pressure coupling. An implicit solver is used, producing the velocity field in the geometry. The velocities are used when solving the convection-diffusion equations for different sediment sizes. This gives trap efficiency and sediment deposition pattern.

2 Theoretical basis

2.1 Water flow calculation

The Navier-stokes equations for turbulent flow in a general three-dimensional geometry are solved to obtain the water velocity. The $\kappa - \varepsilon$ model is used for calculating the turbulent shear stress. The Navier-stokes equations for in-compressible and constant density flow can be modeled as:

$$\frac{\partial U_{\mathrm{i}}}{\partial t} + U_j \frac{\partial U_{\mathrm{i}}}{\partial X_j} = \frac{1}{\rho} \frac{\partial}{\partial X_j} \left(- P\delta_{ij} - \rho \overline{u_i u_j} \right)$$

The eddy-viscosity concept with the $\kappa - \varepsilon$ turbulence model is used to model Reynolds stress term:

$$-\overline{u_i u_j} = \nu_T \left(\frac{\partial U_j}{\partial X_i} + \frac{\partial U_i}{\partial X_j} \right) + \frac{2}{3} k \delta_{ij}$$

The $\kappa - \varepsilon$ model calculates the eddy-viscosity as:

$$\nu_T = C_\mu \frac{k}{\varepsilon^2}$$

k is turbulent kinetic energy, defined by:

$$k \equiv \frac{1}{2}\overline{u_i u_j}$$

k is modelled as:

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial X_j} = \frac{\partial}{\partial X_j}\left(\frac{\nu_T}{\sigma_k}\frac{\partial k}{\partial X_j}\right) + P_k - \varepsilon$$

Where P_k is given by:

$$P_k = \nu_T \frac{\partial U_j}{\partial X_i}\left(\frac{\partial U_j}{\partial X_i} + \frac{\partial U_i}{\partial X_j}\right)$$

The dissipation of k is denoted ε , and modelled as:

$$\frac{\partial \varepsilon}{\partial t} + U_j \frac{\partial \varepsilon}{\partial X_j} = \frac{\partial}{\partial X_j}\left(\frac{\nu_T}{\sigma_k}\frac{\partial \varepsilon}{\partial X_j}\right) + C\varepsilon_1 \frac{\varepsilon}{k} P_k + C\varepsilon_2 \frac{\varepsilon^2}{k}$$

2.2 Sediment flow calculation

SSIIM calculates sediment transport by size fraction. Sediment transport is traditionally divided into bed load and suspended load. The suspended load can be calculated with the convection-diffusion equation for the sediment concentration, c

$$\frac{\partial c}{\partial t} + U_j \frac{\partial c}{\partial x_j} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x_j}\left(\Gamma_T \frac{\partial c}{\partial x_j}\right)$$

The fall velocity of the sediment particles is denoted w. The diffusion coefficient, Γ , is taken from the $\kappa - \varepsilon$ model by:

$$\Gamma = \frac{\nu_T}{S_C}$$

S_c is the Schmidt number set to 1.0 as default. For suspended load, Van Rijn (1987) developed a formula for the equilibrium sediment concentration, c_{bed}, close to the bed as:

$$c_{bed} = 0.015\frac{d^{0.3}}{a}\frac{\left[\dfrac{\tau - \tau_c}{\tau_c}\right]^{1.5}}{\left[\dfrac{(\rho_s - \rho_w)g}{\rho_w \nu^2}\right]^{0.1}}$$

a is a reference level set equal to the roughness height and ν is the viscosity of the water. In addition to the suspended load, the bed load, q_b, should be calculated. For this purpose, Van Rijn's formula for bed load is used:

$$\frac{q_b}{D_{50}^{1.5}\sqrt{\frac{(\rho_s-\rho_w)g}{\rho_w}}} = 0.053\frac{\left[\frac{\tau-\tau_c}{\tau_c}\right]^{1.5}}{D_{50}^{0.3}\left[\frac{(\rho_s-\rho_w)g}{\rho_w \nu^2}\right]^{0.1}}$$

The bed form height, Δ, was calculated by Van Rijn's equation (1987):

$$\frac{\Delta}{d} = 0.11\left(\frac{D_{50}}{d}\right)^{0.3}\left(1-e^{\left[\frac{\tau-\tau_c}{2\tau_c}\right]}\right)\left(25-\left[\frac{\tau-\tau_c}{\tau_c}\right]\right)$$

Where *d* is the water depth. The effective roughness was then computed as (Van Rijn, 1987):

$$K_s = 3D_{90} + 1.1\Delta\left(1-e^{\frac{25\Delta}{\lambda}}\right)$$

Where λ is the bed form length, calculated as $7.3d$.

3 Application

One of the purposes of creating SSIIM is to simulate the sediment movements in general river, channel geometries.

In order to verify the results of the tests, run no. 3 done by Lee et al. (1993) was tested by the model. The characteristics of the test are shown in table 1.

Table 1. Characteristics of run no. 3 of Lee tests

Sediment size	1.4 mm
Length of the pit	0.54 m
Width of the pit	0.60 m
Depth of the pit	0.04 m
Depth of the flow	0.078 m
Discharge	0.025 m^3/s
Long. Channel Slope	0.001

Length and width of the channel was selected equal to 17 and 0.6 m, respectively, like the experimental conditions. The numerical results are shown in figure1 and are compared with the observed results. The numerical results are satisfactory compared with the experimental data.

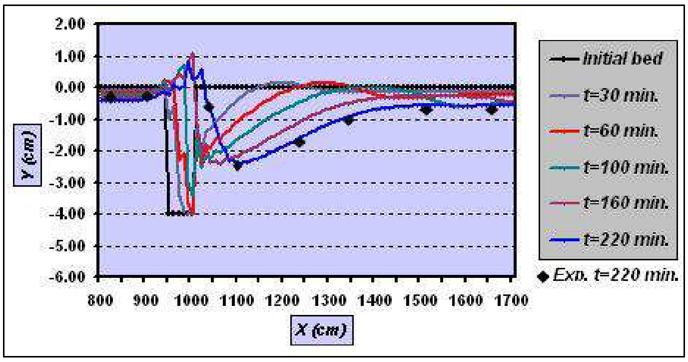


Fig.1- Numerical simulation of Run3 of Lee tests

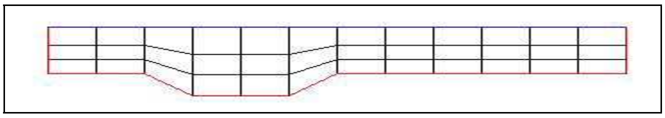
4 Analyses

In this part, effects of the initial location of the pit on pit migration process are studied. In order to study these phenomena, pits with different initial locations are defined and migration process is simulated by the model. Finally some relations are presented for the migration speed of the pit.

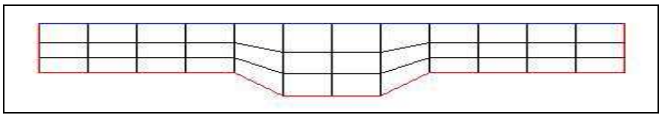
4.1 Effects of the Location of the Pit

In order to study the effects of the location of the pit, three different cases (based on the D: distance between axe of the pit and channel side) shown in figure 2a through c are simulated.

a) D = 10 cm



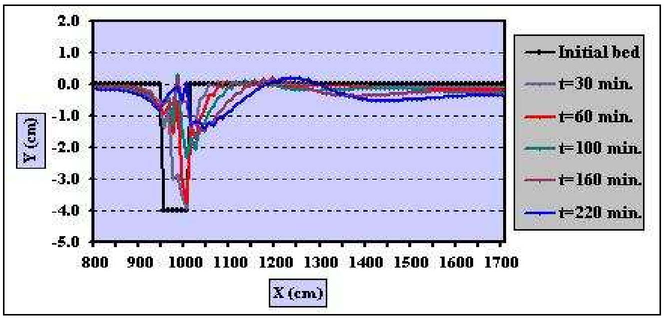
b) D = 20 cm



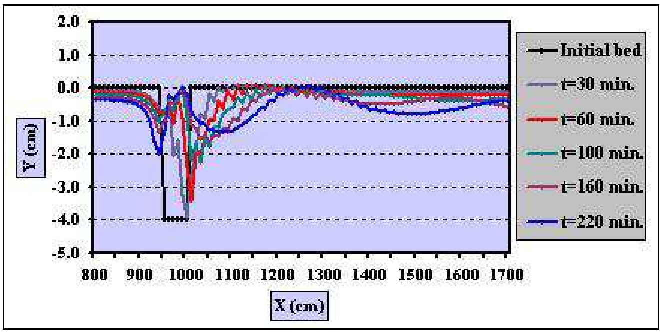
c) D = 30 cm

Fig.2 – Different initial pit locations

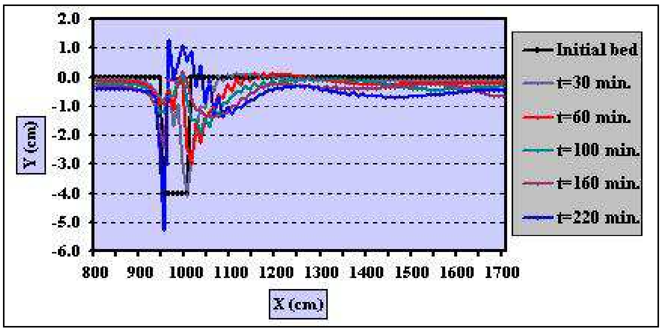
Results of the pit migration simulation are shown in figure 3a through c. In these figures t, x and y represent the time, location and bed elevation respectively.



a) D = 10 cm



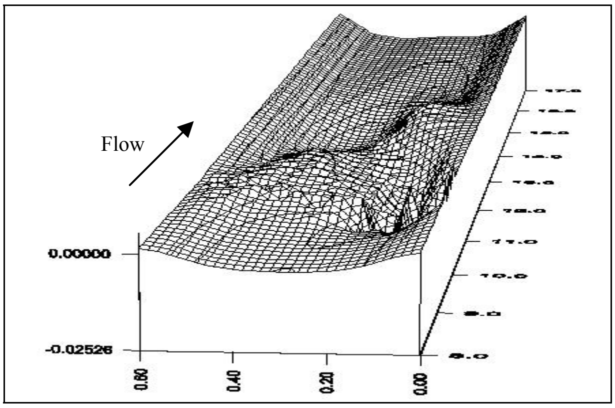
b) D = 20 cm



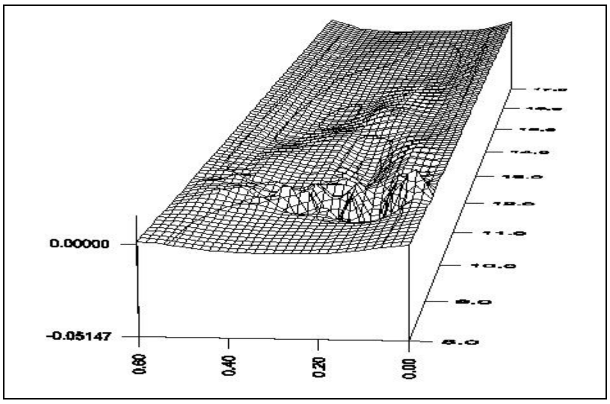
c) D = 30 cm

Fi.3-Numerical simulation of pit with different initial location

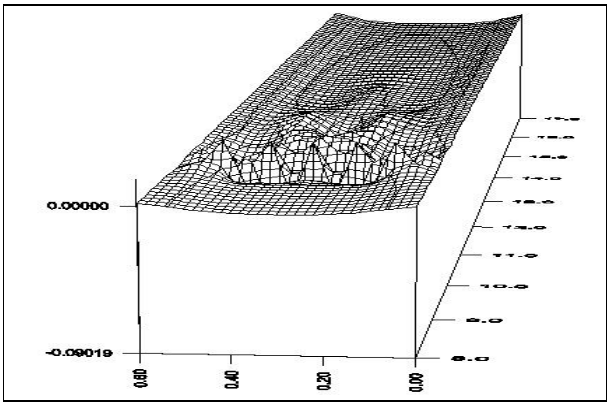
As can be seen in figure 3, closer the pit gets to the centre of channel, faster the aggradation process in downstream of the pit and degradation process in upstream of the pit ocurres. In figure 4, three-dimensional results are shown:



a) D = 10 cm



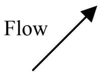
b) D = 20 cm



c) D = 30 cm

Fig. 4- Pits with different initial location (t=220 min.)

As can be seen in figure 4, closer the pit is to the centre of the channel, the pit diffusion towards the downstream of the pit is more uniform. Also, in this condition, the depth of



degradation is more than others.

4.1.1 Migration speed of the upstream boundary

In figure 5 migration of the upstream boundary of the pits with different initial locations is shown. As can be seen in figure 5, the pit that is closer to the centre of the channel has faster upstream boundary migration than the others.

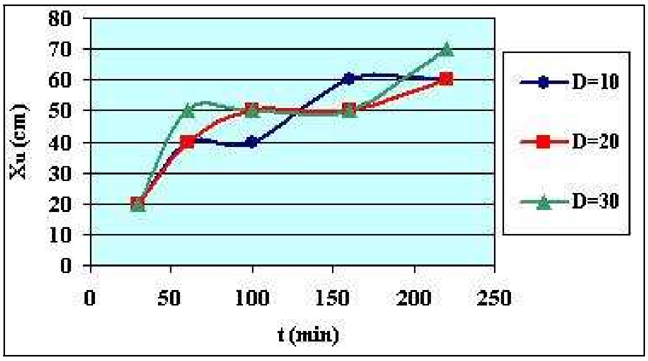


Fig.5 - Migration of the upstream boundary of the pit

In figure 6, migration speed of the upstream boundary of the pits for the last time step is shown. It is clear from this figure that by getting closer to the middle of the channel, migration speed of the upstream boundary increases. If dimensionless parameter D/B (distance form channel side/channel width) is considered as the pit location parameter, relation between migration speed of the upstream boundary and this parameter could be shown as below:

$$U_u/u_* = -0.0064(D/B)^2 - 0.0032(D/B) + 0.0018$$

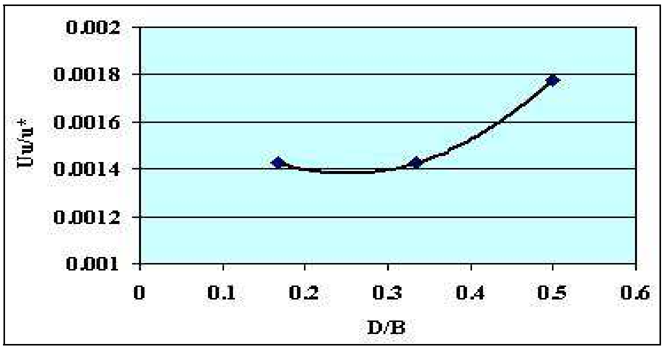


Fig.6 - Speed of the upstream boundary of the pit

4.1.2 Depth of the bottom of the pit

In figure 7, changes of the depths of the pits with different initial locations vs. time are shown. In this figure H represents the depth of the bottom of the pit.

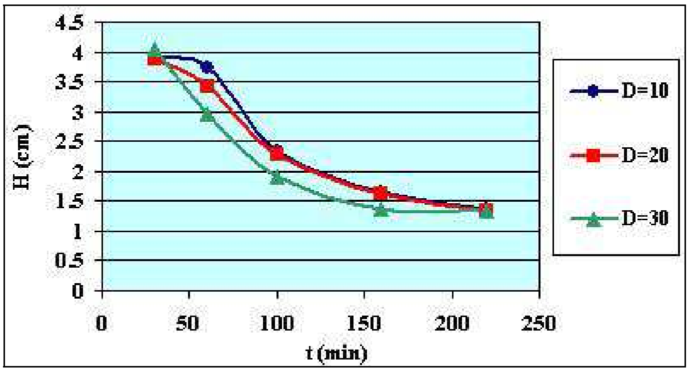


Fig.7 - Depth of the bottom of the pit

As shown in figure 7, pits with different initial locations, finally reach to the same depth but degradation ocurres faster in pits closer to the centre of the channel.

4.1.3 Migration speed of the bottom of the pit

In figure 8, movements of the bottom of the pits with different initial locations are shown at different time.

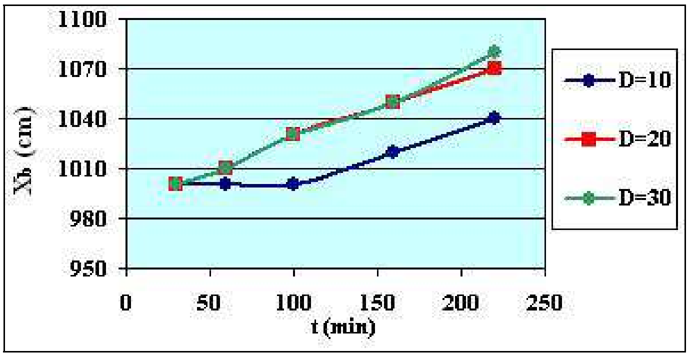


Fig.8 - Migration of the bottom of the pit

As can be seen in this figure, closer the pit is to the centre of the channel, migration of the bottom of the pit increases.
In figure 9, migration speed of the bottom of the pits vs. initial location of the pits is shown. As can be noticed from figure 9, by getting closer to the centre of the channel, migration speed of the bottom of the pit increases. The relation between migration speed of the bottom of the pit and initial location of the pit can be shown as below:

$$U_b/u_* = -0.0128(D/B)^2 + 0.028(D/B) - 0.0004$$

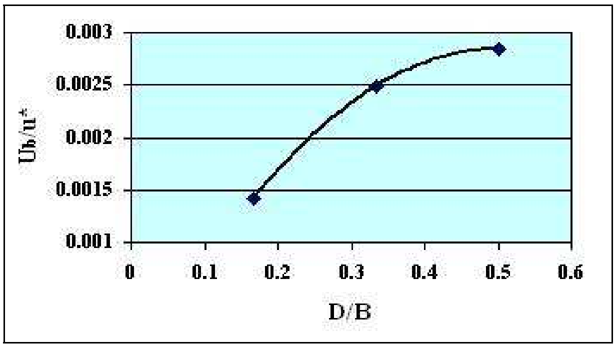


Fig.9 - Migration speed of the bottom of the pit

5 Conclusion

In this paper, effects of the initial location of the pit on the migration process of a pit are presented. It is found that closer the pit is to the centre of the pit, aggradation rate increases and degradation upstream of the pit begins faster and depth of the degradation increases. Also, pits closer to the centre of the pit reach sooner to the final depth which means that diffusion process has a faster rate. Finally it can be concluded that migration of the pits in the centre of the channel is faster than the pits closer to the sides.

6 References

–Migration of Rectangular Mining Pit Composed of Uniform Sediment, H. Lee, D. Fu, M. Song, Journal of Hydraulic Engineering, Vol. 119, No. 1, January, 1993.

–Numerical Simulation of the Pit Migration, H. Lien, K. Yeh, J. Yang.

–A Three-dimensional Numerical Model for Simulation of Sediment Movements in Water Intakes with Multiblock Option, User's manual, Nils Reidar B. Olsen, 2000.

–Hydrodynamics of Mining Pit in Erodible Bed under Steady Flow, Gill, M., Journal of Hydraulic Engineering, ASCE, Vol. 120, No. 11, pp. 1337-1348, Jan. 1994.