Time dependent variation of river bed profile due to mining pit

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Abstract

Many rivers and their floodplains are the most essential source of aggregate for construction of roads, canals, concrete buildings and many other purposes. The improper mining of sand and gravel from rivers can result substantial damage to the rivers such as massive bank failure, increasing channel erosion of the upstream of the excavation site and downstream sedimentation.

This paper focused on the effect of pit dimensions on the bed topography, based on laboratory observations. For each test the bed topography and the water surface along the centerline of the flume was measured several times until arriving equilibrium in the bed profile.

In these tests the width of the pits was constant and equal to the flume width, while the length and the depth of the pits were different. The discharge flowing in the flume was constant too, but the flow depth was adjusted for four different values. The gathered data were analyzed to develop a relationship between the advancement rate of the pit along the river course.

Using dimensional analysis technique, an exponential relationship was developed between the initial dimensions of pit and the shear velocity of flow with the position of pit at each time interval for obtaining the migration pit. The relationship was validated by a series of tests and a good correlation was observed between the observed and the calculated values.

Key words: mining pit, river, sand and gravel

1. Introduction

Removal of sand and gravel from river bed subject to scouring and depositon, which results in migration of the pit and will cause to the structures in its path seriously at risk and also led to negative effects such as flow diversion and floodplain development, bed and beach erosion, decrease in river bed level. Also this threatens the stability and safety of structures with shallow foundations such as piers, Bridges regularity structures slope. In Iran due to removal of sands and gravels from inappropriate locations, too many Bridegs such as Balarud bridge, historic bridge Papilla, kahank bridge in Khuzestan province , Talaar and Alavi kola bridges in Mazandaran province have been ruined. Also, excessive removal of sand and gravel from Dinevar river in Kermanshah province, has caused irregularity and width increase in river direction. Since Similar problems are seen in karaj, Minab, Tajan, Zanjan-rud and Nazlochaei rivers, investigation of this problem will be very important and useful.

Korins and Laczay (1988), conducted a series of experiments to study the flow conditions around dredging pits and proposed an optimum size and shape of a dredging pit for the Danube river near Budapest, Hungary. Analytical work has been published by Fredsoe (1978), Yue and Anderson (1990), Cotton and Ottowaz-Chatupron(1990) and Gill (1994).

Lee et al. (1993) has investigated experimentally the migration of rectangular mining pit composed of uniform sediments.Their results showed that deformation and migration of mining pit can be categorized in 2 periods. The first period will start from the beginning of the experiments till the upstream boundary of mining pit moves to the original downstream end of the pit. the second period starts from that moment onward. The first period is named “convection period”, during which the maximum scour depth remain more or less constant, spatially and temporally. The second period is dominated “diffusion period”, in which maximum scouring depth decreases with time.Regression equations for maximum scouring depth, effective length and migration speed of mining pit are also presented.

Under the same conditions of Lee (1993) experiments, in an Alluvial bed and with uniform sediment, Farhadzadeh et al. (2001) physically investigated movement of rectangular pit with different ratios of length to width of the pit,. Their results showed that with increase or decrease in pit length, migration speed of the pit will increase or decrease proportionally.

Field and laboratory studies of Amini et al (2001), in Gavrud river in Kordestan province, showed that migration speed of the pit has a direct relationship with flow discharge and length pit, and it has an inverse relationship with pit depth. From the listed parameters, pit depth has the most effective parameters among the other parameters. since

all the previous researches about this case, have been done with d_{50}=1.4 mm and The same particle size distribution, it is necessary to investigate migration of mining pit with other particle size distribution and with different pit dimensions. As mentioned before, Lee et al. (1993) expressed that maximum scouring depth will occur at the end of convection period. This expression and the expressed formula by Lee need to be investigated carefully. Therefore, it is necessary to carry out experiments on this case. This paper is gained from experimental data and its results are based on dimensional analysis. The results have been analyzed and new equations for migration speed of mining pit have been introduced.

2.Data and Material

The experiments were carried out in a rectangular flume and consisted of 12 m long, 0.6 wide and 0.8 m in depth. A sill with height of 27 cm was built for preventing sediment movement. The flow was uniform and a triangular sharp edge weir were installed at the end of the channel which was used to measure discharge. A profiler was used to read the topography of the bed. d_{50} and σ_g of the experimental materials are 0.9mm and 1.4 respectively. Experiments have been done for 4 different of pit dimensions and 2 different hydraulic conditions (Table 1). The longitudinal slope of the sediment was set to 0.001. A rectangular control gate was used to adjust flow depth at the downstream of the flume. For creating the pit, a cubic metal mold with desired dimensions was used and was put into the desired location and the materials in it were removed. For preventing of moving bed materials, Water with low depth went through the flume. Afterwards, the level of the flow would be increased little by little.

When water level was increased enough, the metal mould would be removed. As the materials did not have any adhesion together, the corners of the materials fell and rectangular pit turned into trapezoidal pit. By using the control gate, the desired water level was adjusted and from this time onwards, the experiment would start.

No.	Q (lit/s)	Y (cm)	Fr	H_{pit} (cm)	L_{Pit} (cm)	B_{Pit} (cm)	Time (hour)	position	code
1	20	8.7	0.415	10	60	60	17.0	3.6	S1-106060-3.6
2	20	8.7	0.415	10	30	60	16.5	3.6	S1-103060-3.6
3	20	8.7	0.415	20	30	60	13.0	2.6	S1-203060-2.6
4	20	8.7	0.415	20	30	60	15.0	3.6	S1-203060-3.6
5	20	8.7	0.415	20	60	60	20.5	3.6	S1-206060-3.6
6	20	7.3	0.540	20	60	60	10.5	3.6	S2-206060-3.6
7	20	7.3	0.540	10	60	60	5.0	3.6	S2-106060-3.6
8	20	7.3	0.540	20	30	60	6.5	3.6	S2-203060-3.6
9	20	7.3	0.540	10	30	60	4.5	3.6	S2-103060-3.6

Table 1. experimental characteristics

3. Research Methodology

To describe the migration speeds of the pit at the two periods, The dependent variables are: migration speed in convection period u_{bc}, migration speed in diffusion period u_{bd}. The independent variables are H (original ,ining pit depth), L (original mining pit length), y (upstream flow depth), u*(upstream shear velocity), g (gravitational acceleration), ρ and ν (density and kinematic viscosity of water), ρ_s, d_m and σ_g (density, mean particle size and standard deviation of sediment), t(time), T_f (time of end of convection period)

The migration speed in convection period can be expressed as a function of the independent variables as:

$$U_{bc}=f_1\ (H\ ,L\ ,y\ ,U_*,g\ ,\rho\ ,\rho_s\ ,\nu\ ,d_m\ ,\sigma_g\ ,t,T_f) \quad (1)$$

In present study water and sediment densities are constant and can be omitted. By using Buckingham’s π method, the following dimensionless equation is obtained:

$$\frac{u_{bc}}{y} = f_3\left(\frac{H}{y}, \frac{L}{y}, \frac{\rho u_*^2}{(\rho_s-\rho)gD_m}, \frac{u_* D_m}{\vartheta}, \frac{D_m}{y}, \sigma_g, \frac{t}{T_f}\right) \quad (2)$$

Only one gradation of uniform particle size is used in this study,then $\frac{\rho u_*^2}{(\rho_s-\rho)gD_m}$ and $\frac{u_* D_m}{\vartheta}$ can be replaced by $\frac{u_*}{u_{*c}}$ (Breusers et al. 1977). Also $\frac{u_*-u_{*c}}{u_{*c}}$ can be equivalent by $\frac{u_*}{u_{*c}}$. it should be mentioned that y is much greater than d_m, so $\frac{D_m}{y}$ is neglectable. Therefore, the above equation can be simplified as follow:

$$\frac{u_{Bc}}{u_{*c}} = f_4\left(\frac{H}{y}, \frac{L}{y}, \frac{u_*-u_{*c}}{u_{*c}}, \frac{t}{T_f}\right) \quad (3)$$

experiments has been done for one particle size distribution. so geometric standard deviation (σ_g) term is neglectable too.

$$\frac{u_{Bc}}{u_{*c}} = f_4\left(\frac{H}{y}, \frac{L}{y}, \frac{u_* - u_{*c}}{u_{*c}}, \frac{t}{T_f}\right) \quad (4)$$

And finally, Equation for Migration speed of the mining pit in diffusion period can be expressed in the similar form, but with slight modifications:

$$\frac{u_{Bd}}{u_{*c}} = f_5\left(\frac{H}{y}, \frac{L}{y}, \frac{u_*}{u_{*c}}, \frac{t}{T_f}\right) \quad (5)$$

4. Results and Analysis

As the result of mining pit, slope will increase on this location and shear stress at the upstream of the pit will increase too. As the consequence and In duration of the experiments, water flow removed sediments from upstream of the pit. Meanwhile sediments brought from upstream is trapped in the pit because transported sediment as bed loads when arrive at the location of the pit, Since the water depth along the pit is high and velocity is low, bigger sediment particles will deposit at the upstream of the pit so that the pit was being transmitted by deposition in upstream. It must be mentioned that the flow has sediment transport capacity; and because of this, the degradation in downstream of the pit will occur. This procedure makes the pit move forward to downstream direction. During the experiments it was seen that maximum scouring depth decreased from beginning of the experiments. However, Lee et al.(1993), expressed that maximum scouring depth will occur at the end of convection period. This is the reason why H_{max} and L_e are seen in their formula for transmission velocity in diffusion period.

Experiments were done in two different series. In first series of the experiments, the depth of flow was 8.7cm. (Fig 1) shows the displacement of the upstream boundary pit with time For the first series of the experiments. since the slope of this diagram shows the velocity, it is clear that the pit with lower depth has greater migration speed rather than the pit with greater depth. Also the pit with lower length has greater migration speed than the pit with greater length. And in comparison with depth and length, depth is more effective than length. Process changing of the second series of the experiments is similar to the first one.

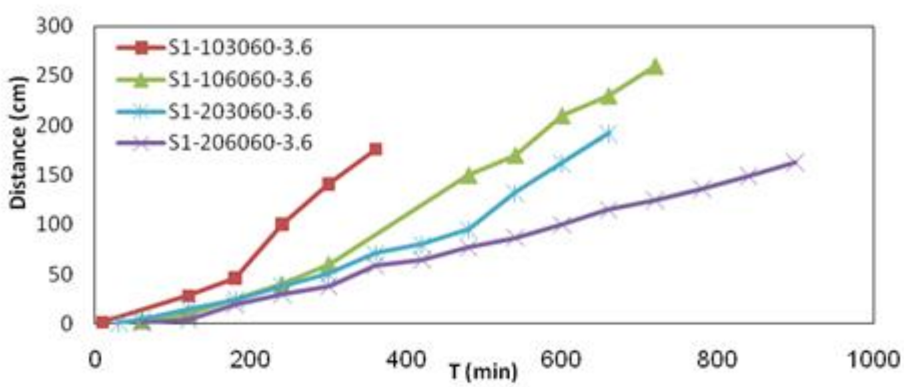

Fig1: displacement of upstream boundary mining pit for first series

Each diagram has two distinct slopes and in fact after a point, migration speed of the pit will increase. This point shows the end of convection period and the start of diffusion period. The first slope is for convection period (time duration that upstream edge of the pit reaches the downstream edge of the pit) and second slope is for diffusion period (from the end of convection period till the pit is filled). Figure 2 shows the displacement of the pit with time for the first and second series of experiments. since the slope of diffusion period is greater than convection period, so that the transmission speed of diffusion period is more than convection period. By Comparing the first and second series of experiments, it can be seen that in the second series of experiments in which the first depth of water is lower than the first series of experiments (y=7.3 cm), the slope of the diagram ,in other words, the transmission speed of the pit is greater. In second series of experiments, the water depth is lower, so the velocity and shear stress will be greater and it causes the sediments to move more quickly and therefore the pit is filled faster than the first series. As said before, Process changing of the second series of the experiments is the same with the first one. And it is clear that the pit with depth and length of 10cm and 30 cm respectively will have the most transmission, and the pit with depth and length of 20 cm and 60 cm respectively will have the least transmission in one series.

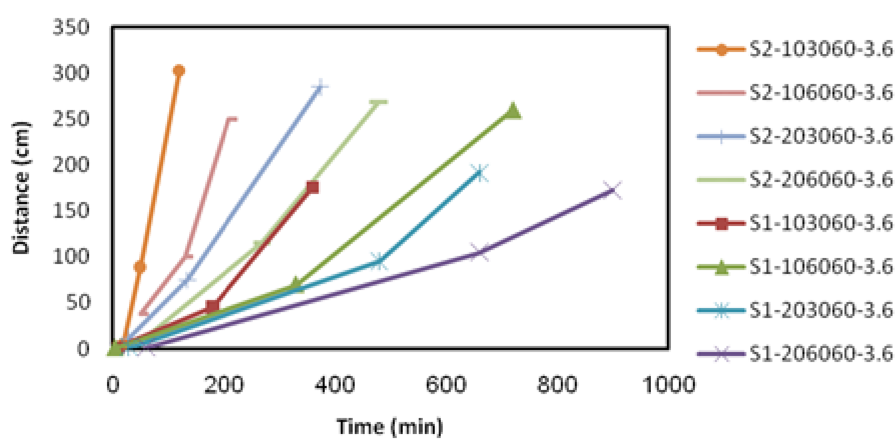

Fig2: Time variation of upstream boundary mining pit for 1th and 2nd series

For analyzing the effect of the pit location on downstream sill, two experiments with same dimensions and with different locations (2.6 m from downstream and 3.6m from downstream) have been carried out. Figure 3 shows the displacement of these two experiments with time. It can be seen that the pit which is closer to downstream sill will be filled 120 min earlier than the pit which is farther than the downstream sill. However, the slope of convection period for 2 experiment is almost the same. In the experiment related to the pit which is closer to downstream sill, the downstream section of the pit was almost stable in its place without any significant movements and the erosion of this section has become much less that the other pit . It is the reason why the pit is filled earlier and faster than the pit which is farther from downstream sill. In the pit which is farther from downstream sill, since the sediments are being deposited upstream of the pit, the process of erosion of the pit from downstream is being done simultaneously and this will cause the pit to be filled later than the other. It seems that this procedure can be a method for erosion control of downstream of pit by placing a sill near it.

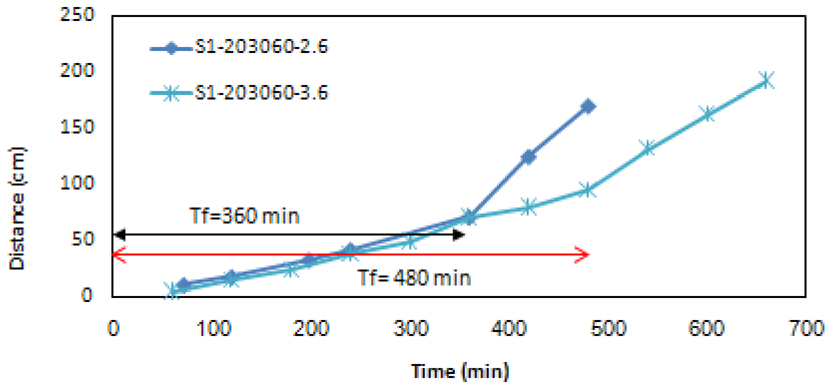

Fig3: comparing location of mining pit on downstream sill

By using equation (4) and two-third of the experimental data, a regression equation (equation 6) has been gained. Regression coefficient is 1. Figure 4 shows that all the data is located in range of ±20%. In this figure the accuracy of this equation is validated by one-third data and is showed by ●.

$$\frac{u_{bc}}{u_{*c}} = 0.060\left(\frac{H}{y}\right)^{-0.848}\left(\frac{L}{y}\right)^{1.108}\left(\frac{u_{*}-u_{*c}}{u_{*c}}\right)^{-2.303} \qquad (6)$$

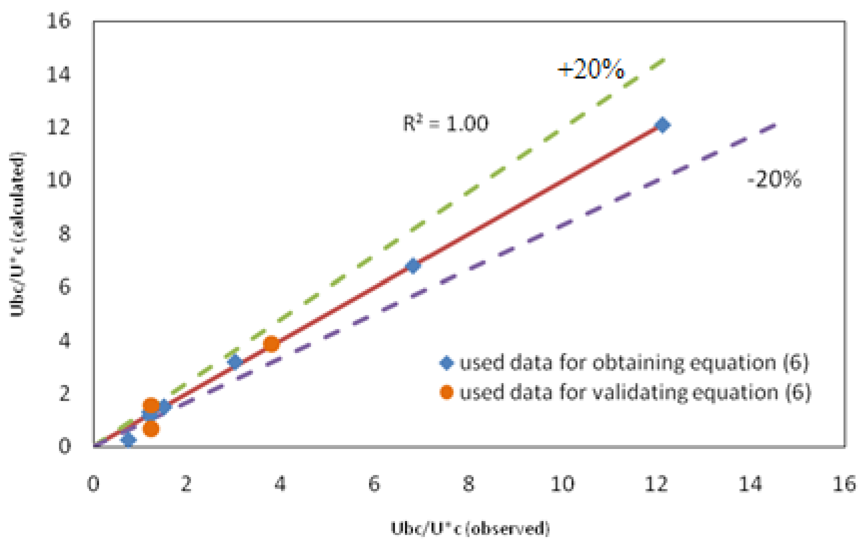

Fig4: functional relationship of migration speed of mining pit in convection period

equation 7 is based on calculation and observation of the migration speed of the pit of two-third of experimental data. Regression coefficient is 0.99 and almost all the data is in range of ±30%. In Figure 5 the accuracy of the presented equation is checked by 1/3 data and is shown by ● .

$$\frac{u_{bd}}{u_{*c}} = 221.362\left(\frac{H}{y}\right)^{-0.782}\left(\frac{L}{y}\right)^{-0.862}\left(\frac{u_*}{u_{*c}}\right)^{-16.039} \quad (7)$$

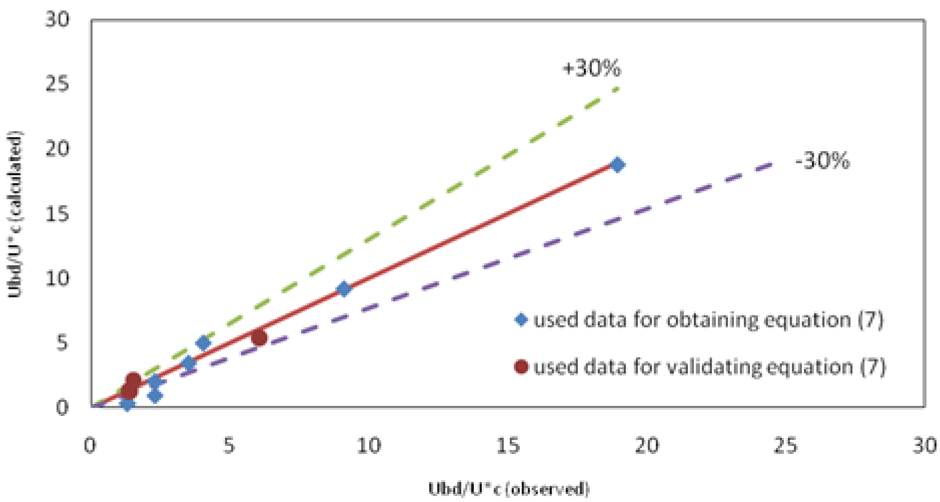

Fig5: functional relationship of migration speed of mining pit in diffusion period

5. Conclusions

It was seen that the pit with lower depth has greater speed transmission than the pit which is deeper. The pit with the least length has greater migration speed than the pit which is longer. In comparison with length and depth, depth is more effective.

Migration of the pit can be classified in two periods: 1- convection period 2- diffusion period. The time when the upstream boundary of the pit reaches the downstream boundary separates convection period and diffusion periods from each other.migration speed of the pit is constant in each period and has an inverse relationship with pit depth.

The empirical equations which are obtained from these experiments can be used as a general rule for the removal of sand and gravel from river bed.By use of pit dimension and flow characteristics, migration speed of the pit and its location can be predicted. The equations are compared to experimental data and the consequences are satisfactory.

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