SWE-01

BEST FLOW CONDITION FOR LATERAL INTAKES OF IRRIGATION CANALS

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Keywords: Irrigation, Intake, Froude number, Experimental

ABSTRACT

It is the main goal of this study to investigate sediment delivery to an intake from trapezoidal canal. In this study, suspended sediment feed upstream of a lateral intake under different flow conditions. Intake angle was taken as 90 degree on a side of trapezoidal flume. From analysis of these data it was found that the flow patterns at the upstream of the intake has been modified in such a way that more water from surface layers are diverted compare to the case of intake from a rectangular flume. Therefore less suspended sediment enters the intake. Also it was found that in all tests the amount of sediment enters the intake reaches its minimum value at Froude Number between o.35'

INTRODUCTION

The study of flow division in open channels which has been, since long, under consideration by irrigation engineers, is much used in designing the irrigation and drainage networks. Water intakes are used to divert flow from a main channel in to irrigation system and from a river in to irrigation channels. The sediments delivery, if not restrained, may transmit into the channels and installations, thereupon, carrying and deposition of them in different parts. From among the afore-said problems are the following:

1- Reduction flow discharge capacity in the channels as a consequence of sedimentation. 2- Rough materials could lead to erosion of the channel walls. 3- Interruption of water source for dredging of the channels may cut providing water supplies to the farms. 4- Channel dredging costs expensively and are not economical. 5- Sedimentation facilitates the conditions for growing weeds that are harmful to the covers and result in leakage from the channels walls.

Figure 1 shows the great intake of Ohio River that gathering of sediments in the entrance of which causes decrease in the flow width, and so in the efficiency (Neary et.al 1999).

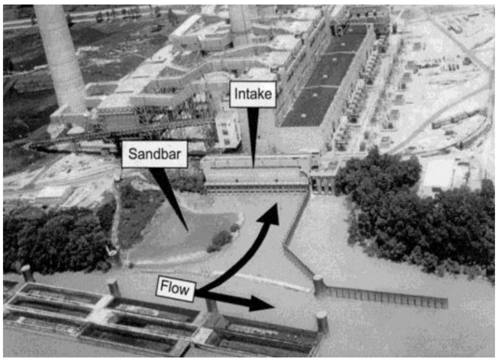

Figure 1: The great intake of Ohio River, where the gathering and sediments entry causes efficiency decline(Neary et.al 1999)..

Therefore, considering the sediment problem in the intake channels is of great importance. Extensive methods are tested and applied during the late years to control the sediments; the most common is the periodic dredging. Full knowledge of the diversion flow pattern is a necessary condition to study the intake sediments. The diversion flows are essentially 3- dimensional. Some features of them are represented in Figure 2. (Neary et.al 1999). These include a separation zone in the inside wall of the branch channel (Zone A), a contracted flow zone in the branch channel, a secondary circulation beside the outside wall of the branch channel, and a stagnation point near the junction downstream edge and the main channel (Zone C). The recirculation flow at the center of the separation zone is completely slow. The width of separation in the surface is more than that in the bed. At the junction downstream in the opposite wall there may be occurred a separation due to flow expansion (Zone B). The vertical velocity profile in open channels is nonuniform. According to the no-slip conditions, the velocity at the bed is necessarily zero, close to the water surface is high, and in between these two surfaces is logarithmic.

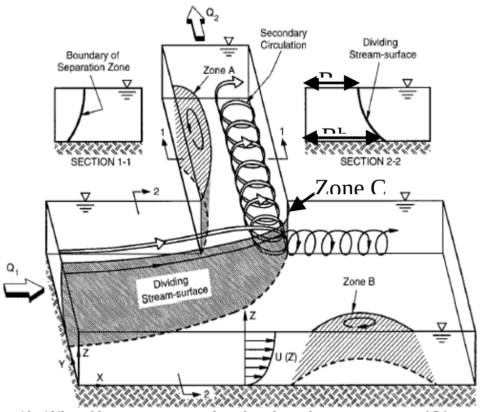

Figure 2: The flow pattern in the intake entrance (Neary et.al 1999).

As the flow comes close to the intake, it is accelerated laterally due to the suction pressure at the end of the intake. The acceleration divides the flow into two parts, one entering the inside of the intake, and the other continues to the downstream of the channel. The former is shown in Figure 2 by a surface called the Dividing Stream Surface (DSS) or stream tube. As seen in Figure 2 (section 2-2), in the main channels with rectangular section, the diversion flow width at the bed (B_b) is greater than that in the surface (B_s), which causes the sediments entry into the intake, resulting from their high density in the bed. The stream wise curvature in DSS yields imbalance among the transverse pressure gradient, the centrifugal force, and shear force, as a consequence of which a secondary current in clockwise direction is formed. Such a secondary vortex is also formed at along the main channel wall. The more this current advances toward downstream, the more reduces its strength primarily due to the fluid viscosity. The secondary current besides the separation zone along the inner wall of the branch channel (Zone A) gives rise to a complex 3-dimensional flow.

The extent of DSS in the main channel determines the rate of discharge to the branch channel. The diversion flow width or stream tube at each surface (plan) is defined as the distance from the main channel bank at the intake side to the stream line ending in the stagnation point near the corner of downstream junction of the intake and the main channel.

Taylor (1944) studied the flow in the 90 degree intake and proposed a graphical method for determining the flow pattern. The method was used also by Thomson (1949) for an analytical solution to the intake; though his assumptions based on the flow depth to be constant is not practicable. Also Tanaka (1957) and Murota (1958), assuming that the water depth in all channels is constant, analytically solved the flow problem. Hager (1984) presented a simple model to calculate the energy loss coefficient of the diversion flow into the intake. He supposed that the velocity variations at the entrance to the branch are insignificant. Also Hager (1992) obtained a formula for the energy loss coefficient of the flow. Neary et al. (1999) studied the lateral intake inflows numerically using the two equation turbulence models regardless of the water surface effect. Huang et al. (2002) performed a comprehensive numerical study using the 3D turbulence models, and validated the model using the data applied by Weber et al. (2001). The velocity data obtained from a laboratory flume showed that the flow in the branch channel is 3- dimensional. The results of this research showed that to describe the behavior of sediments transmission in diversion needs the knowledge of a 3-dimensional structure and demands advanced models techniques. Chechen (1967) (quoting Schoklitsch) in a study with the goal of a comparison between the lateral and frontal intakes showed that the inflowing sediments to the intakes are always affected by the roughness ratio ($\frac{K_s}{y_0}$) and the Reynolds Number $\mathrm{Re}_* = \frac{u_* d_{50}}{\nu}$, K_s is the bed roughness of the main channel, y_0 is the depth of water in the main channel, D_{50} the size of sedimentary particles, u_* the shear velocity, and ν the kinematic viscosity. Raudkivi (1993) investigated the effect of bed roughness on the sediments delivery into the intake. According to his study, the sediments delivery to the lateral intake decreases along with reduces of secondary currents strength, and this happens when the bed roughness coefficient increases. For intakes in bends, the decrease in the secondary currents strength leads to the increase of the sediments delivery as the bed roughness coefficient becomes greater. Barkdoll (1999) showed in his researches on the lateral intake, which are carried out in straight path with 90 degree intake angle, that the diversion flow ratio has the greatest effect on the sediment delivery ratio. Using experimental data and comparing it with a numerical model which solves the standard 3-dimensional equations RANS for unsteady turbulent flows, Ramamurthy et al. (2007) have shown that at the dividing flows, the mean exit angle of the streamlines for flow entering the branch larger at surface compared to the exit angles of the streamlines located at the bottom.

As it is said before, the stream tube dimensions are so effective on the rate of the suspended sediments delivery to the intake. The length and width of the stream tube change along with variations of the diversion flow ratio. With the help of experimental data as well as the 3-dimensional model SSIIM2, Karami Moghadam et al. (2010) studied the stream tube cases of the main channel, with inclined and vertical bank and conclude the stream tube width. They inferred that slopping the main channel bank improves the flow pattern and the stream tube width in inclined bank case, in contrast with the vertical case, increase in the surface and decreases in the bed much to the reduction of the sediments delivery. Also it is found out that as the flow diversion ratio increases, the stream tube width increases in the surface more vigorously. So, when the discharge ratio grows, more excessive discharge is provided from the surface than from the bed, consequently, in case the main channel flow contains sediments, much less of them delivery into the intake.

Although many researches are done on the flow pattern and the sediments in intakes, most of them are directed towards the transmission of the bed load and to the lateral intakes installed on rectangular channels, and none is carried out yet on the suspended load delivery and into the intakes installed on trapezoidal ones. So, in the present research the case is treated with the 30 degree water intake installed on trapezoidal channels.

MATERIAL AND METHODS

To study the flow and sediments in rivers and channels with inclined bank, some experiments are carried out in a non-recirculating long flume with a 30 degree branch channel. The experimental model was built in the hydraulic laboratory of Chamran University, Ahwaz, Iran. Figure 3 shows the setting of the laboratory equipment. The main channel and lateral channel were length 8 m and 5 m, with bed widths 22.5 cm and 20 cm, respectively. The main channel section was trapezoidal, and the branch channels, rectangular. The slope of the inclined bank was set at 1.5:1 (m=1.5). The heights of both channels were chosen at 70 cm, and Plexiglas's thickness equal to 10 cm is used as the channel walls. The branch channel was set at a distance of 5.5 m from the entrance of the channel. To adjust the discharge as well as the water depth in the channels, two sluice gates are installed at their ends. The water flow was issued from an underground source. To assure the flow expansion as well as low turbulence, a honeycomb was set up at the entrances of the main channel. The discharges from the main and branch channels were measured by means of two V-shaped weirs of 56 and 90 degree, respectively. The water depths in the upstream of the main channel were 10, 20 and 25 cm and the chosen Froude Number for the upstream of the main channel, 0.25, 0.30, 0.35, 0.40 and 0.45.

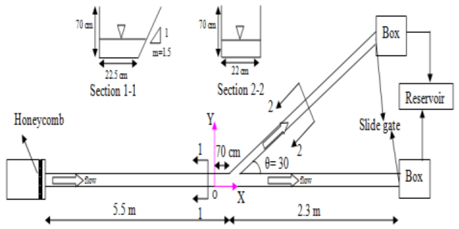

Figure 3: The experimental equipment plan of the present study

To perform any case of the experiment, first of all, the discharge of the main channel for the corresponding depth and Froud Number was calculated, then establishing this discharge in the main channel where both gates were completely down (free state), and after the flow being steady, the diversion flow ratio was measured using the V-shaped weirs. Afterwards, the gates were brought up to the extent that both the diversion flow ratio and the desired depth were safeguarded. At initial part of the main channel, there is a sediment injective source besides an electromotor with variable revolution which makes it possible that with different discharges, the sediment with the same concentration is injected. The applied sediments are from colored crystal with $\rho = 1.05$. At the end part of the main and branch channel there exists a basket to trap the sediments. In the experiments concerning suspended sediments, using the electromotor with variable revolution, the rate of the injected sediments in the main channel upstream was so adjusted that in all the cases of the experiment the concentration would be the same and equal to 1 $gr/lit/\sec$.

The sampling of the entered sediments the branch channel was regularly performed and measured by trapping, and after reaching the steady state the main sampling has begun. Each sediment test took 90 minutes to be carried out. After the termination of the experiments, the trapped sediments were gathered, dried, and then weighed.

RESULTS AND DISCUSSION

Table 1 shows what is done in the laboratory and in this part gives the corresponding explanations. As it is said before, the choice of the diversion flow is based on the free flow condition. Figure 4 displays the reverse proportion between the Froud Number and the diversion flow ratio. The reason is that in the free state (the end gates are completely open). At a constant depth, the more the Froud Numbers are, the higher the flow velocity would be, as a consequence of which, in the intake extent the momentum force is not sufficient to divert the stream, which lead to the reduction of the diversion flow. The ratio $\frac{k_s}{D_u}$ equal to 18.75E-6, 10.50E-6, and 8.73E-6 corresponds to, respectively, 10, 20 and 25 centimeters.

Because in the experiments the diversion flow ratios (Q_r) are different, the dimensionless parameter $\frac{G_r}{Q_r}$ is taken into use to judge the suspended load ratio (G_r). As said before, the sediment concentration in all the tests would be the same. Figure 5 shows the relation between Q_r and G_r.

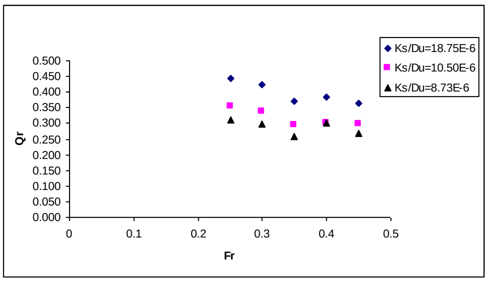

Figure 4: The relation between the Froud Number of the upstream and discharge ratio

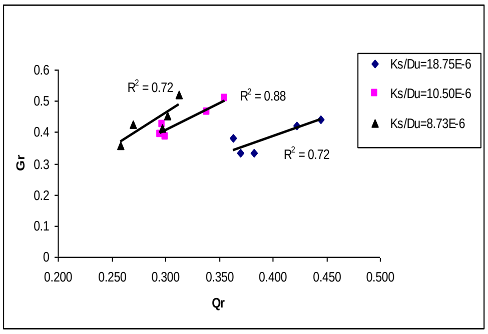

Figure 5: The relation between Q_r and G_r in different roughness ratio

It can see that in all three depths, the two ratios Q_r and G_r are in proportion to each other. It should be noted that the diversion flow ratios for each depth are chosen according to the flow free state, so for each depth they are positioned in a particular bound.

As one can see, the fitted slope line for the depth 10 cm is less than for the other two depths. At this depth, due to the secondary current strength, when Q_r increases, the rate of increasing the sediments entry to the intake is less than the two other depths. As maintained by Raudkivi (1993), the secondary current strength and the infiltrating sediments decline along with the increase of the roughness ratio. The roughness ratio corresponding to the depth 10 cm is high ($\frac{k_s}{D_u} = 18.75E-6$) followed by decrease of the infiltrating sediments. In Figure 6 the results in this study compared with those of Barkdoll et al., Shafai and Nazari, Bulle (quoting from Schoklitsch) and Hasanpour . Of course, it is not so likely that the tests in different lab conditions be similar, however, by considering the changes process one can predict the effect of the wall slope as well as the suspended load. The main reason of the difference in the increase pattern of the infiltrating sediments along the increase of diversion flow ratio is the performance of the experiments with different Froud Numbers under diverse geometric conditions of the main and branch channels.

In Hasanpour's work, an almost linear relation between the diversion flow ratio and the suspended load can be seen. There exists a turning point in Barkdoll's results from where on, any increase in the diversion flow ratio lead to a decrease in the infiltrating load ratio. The researches of Shafai and Nazari were done in a 90 degree bend intake with 60 degree intake angle which cause much less sediment entry compared to other's. Bulle made his experiments in 30 degree intake installed on a rectangular channel. Since in this study, the tests are also performed with the same angle at a 25 cm depth with the most suspended load ratio, so our results are in harmony with Bulle's.

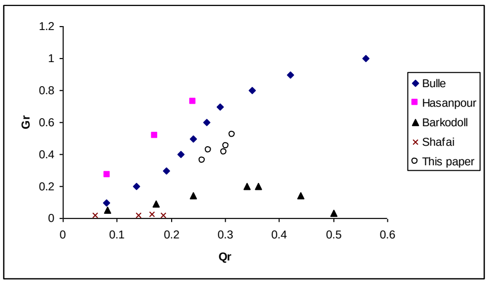

Figure 6: Comparison between the results of this study and others.

A comparison makes clear that with a constant infiltrating sediment ratio, the diversion flow ratio in this research is greater than that of Bulle, so $\frac{G_r}{Q_r}$ ratio is less than in Bulle's research, which shows that slopping the channel wall has a positive role in the decrease of the suspended load infiltration. The infiltrating sediment ratio for depths of 10 cm and 20 cm is less than in 25 cm depth; hence, the ratio $\frac{G_r}{Q_r}$ at these two depths is surely smaller than Bulle's.

The relation between $\frac{G_r}{Q_r}$ and the Froud Number at the upstream is represented in Figure 7. It is noticed that as the Froude number grows, in all the three depths we have decline in the rate of the infiltrating sediments to the intake, but in the bounded interval of Froude number 0.35-0.40 this rate reaches it's minimum, and after this bounds it shows a relative increase. The results for the two depths 20 cm and 25 cm are similar, but the value of $\frac{G_r}{Q_r}$ with a 10 cm depth shows a difference, the reason of which can be discerned in Figure 8. This Figure also shows the Dividing Stream Surface (DSS) for three depths 10, 20 and 25 centimeters. It is seen that the stream tube dimensions in 20 cm and 25 cm depths are close to each other, and less than for 10 cm, owing to the fact that the diversion flow ratios at 20 cm and 25 cm depths are almost the same, but at the depth of 10 cm is high (Table 1). At this depth ($\frac{k_s}{D_u} = 18.75E-6$), the transverse velocity distribution is so that G_r decreases too, making a considerable disparity between the value of $\frac{G_r}{Q_r}$ ratio in the 10 cm depth and that for the other two.

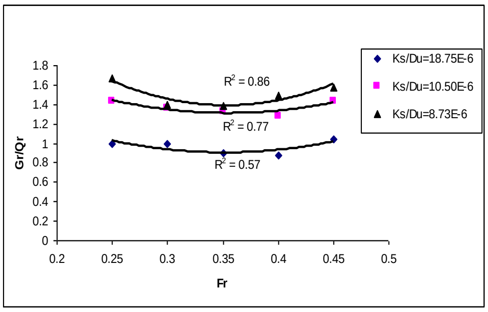

Figure 7: The effect of Froude Number of the upstream on the entering sediment ratio

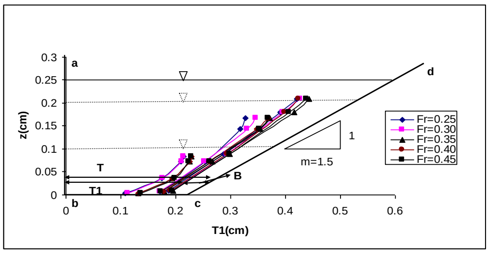

Figure 8: The Diversion Stream Surface (DSS) for different Froude numbers.

According to this Figure, it is recommended that in the irrigation channels after the determination of the diversion flow using the gates regulating the water surface, the depth of water should be so adjusted that the approaching Froude Number falls into the interval 0.35-0.40, supplying a minimum $\frac{G_r}{Q_r}$

SUMMARY AND CONCLUSIONS

In this research, with the help of some experiments, the entering suspended load to the 30 degree intake installed on the trapezoidal channel is studied. Using the obtained data, it is determined that the entered sediment ratio in a Froud Number between 0.35 and 0.45 (in the upstream of the main channel) is minimal. So, it is recommended that with the purpose of decrease in the suspended loads, the water depth in the irrigation channels be so adjusted that the Froud Number falls into this interval. Also it is proved that in a high roughness ratio, when the dividing flow ratio increases, the rate of increasing the sediments entry decreases. Generally, we conclude that the Froud number at the upstream of the main channel affects on the diversion flow ratio. The diversion flow ratio, in turn, has its impression on the secondary current strength, and more important than that, on the stream tube dimensions, both of great importance in the rate of the suspended load entry to the intake. The results of this paper are valid for the range of hydraulic parameters which tests were conducted. More tests have to be conducted for application purposes.

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