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Experimental Study of Scouring in the vicinity of Lateral Intake in U-Shape Channels

Experimental Study of Scouring in the vicinity of Lateral Intake in U-Shape Channels

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ABSTRACT: The effect of hydraulic and geometric parameters on scouring in the vicinity of lateral intakes is significant to identify stability of the structure. These also enable us to facilitate flow in to diversion channel, moreover, to exclude sediment transport in to the intake. The transverse pressure gradients in the vicinity of the intake induced regions of mean-velocity gradients, depth-varying surface of flow diversion and separation zone at the intake entrance in the diversion channel.

A number of researchers have shown that rate of scouring at the entrance of lateral intake is dependent upon discharge in the main channel Qm, depth of flow y, type of flow regime Fr, Diversion angle ϕ, radius of curvature in the bend R, intake location in the bend θ, width of the main channel B and width of diversion channel b.

However, in this research, experiments were carried out in a U-shape flume with a rectangular cross section of a moveable bed. The U-shape channel is 0.6 m wide, 0.6 m high and 2.6 m radius of curvature, diversion channel is also characterised by a rectangular moveable bed channel 0.25 m wide, 0.35 m high and 1.1 m long. In addition, intake channel is located at second half of the bend (θ=115°). Median diameter of bed sediment was selected 1.3 mm. These experiments showed that the variations of the scour hole at the entrance of the lateral intake depends on the main channel hydraulic parameters and diversion angle of the intake channel in bends.

I. INTRODUCTION

Some of the most substantial factors that should be taken into consideration in designing lateral intakes are to facilitate water conveyance into the intake channel as well as exclusion of sediment inflow and its deposition at intake entrance. This can remarkably increase the efficiency of the intake [1].

Reference [2] carried out some experiments on a lateral intake at 90° with a straight channel. They concluded that the formation of diversion flow is due to the presence of transverse hydraulic gradient at intake entrance. They also found out that the pressure variation at intake entrance is such that to decrease at the inner intake entrance and increase in outer intake entrance. It is also proportional to the water level variation at intake entrance. The diversion flow rate is dependent on the surface of the dividing stream-flow. The equilibrium between longitudinal pressure gradient as well as shear and centrifugal forces causes a secondary clockwise flow in the outer entrance of the diversion channel. The flow pattern in lateral intakes is so that there is a possibility of particle accumulation and sedimentation near the inner entrance of the diversion channel [2].

Investigations carried out along bend cross-sections of the curved channels revealed that the flow velocity decreases as the depth increases. The transverse slope also decreases from the outer bend towards the inner bend direction. This occurs due to pressure gradient in the bend. Therefore, the boundary layer is affected by a dynamic pressure gradient which leads to the formation of a spiral flow in the bend. The existing conditions cause the sediments to migrate from outer bend towards the inner bend [3]. Those who have studied on the bend channels suggest using a U-shape (180°) channel when experimenting on the secondary flow, as the secondary flow can be fully developed in such conditions [3, 4 and 5].

Considering the flow pattern in the bends, many researchers suggest the preferable location for the intake to be the outer bend [1, 6, 7 and 8]. Reference [7] has preferred intake location in 3/4 of central angle in the second half of the bend channel (Figure. 1).

In addition, diversion angle of the intake has been the subject of some studies. Reference [9] concluded that optimum diversion angle varies with diversion rate ($Q_r = Q_D/Q_m$) and intake location in channel bend. Reference [7] defined the best diversion angle as where separation zone in the intake is a minimum value.

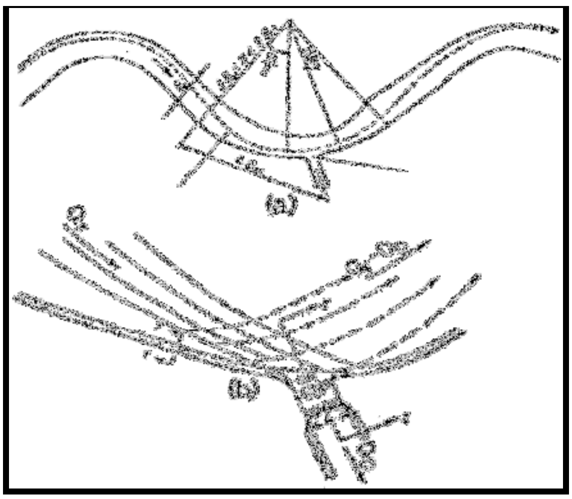

Figure 1. Intake Location without Dam in the Bend Channel (Razvan, 1989).

Optimum diversion angle was also determined experimentally by some investigators and proved to vary a wide range of 30-65° [7].

The water-intake sediment problem is illustrated a lateral intake adjoining the Ohio River. The sandbar formed in the intake for bay is an indication that the intake is withdrawing a significant amount of sediment and that the performance of the plant is diminished because of the resulting non-uniform approach flow. One strategy to mitigate such a problem is to separate mechanically the sediment from the water and eject it from the intake. Such an approach is rather expensive and may impact adversely the river environment by disturbing the local sediment regime [2 and 10].

As the above investigations show the flow pattern can be complex and three dimensional in the vicinity of the lateral intakes in straight channels. The complexity of the flow greatly increases and entails more investigations to have a better understanding of scouring where the lateral intakes are located in curved channels.

II. Dimensional Analysis

In order to study the effects of the hydraulic parameters, it is necessary to be familiar with the dimensional analysis. It is possible to approach and study a phenomenon and its characteristics by utilizing dimensional analysis. Applying the dimensional analysis to a problem is based on the assumption that, it can be expressed through introduction of some compatible equations which express the relationship of different parameters with each other. The first procedure in dimensional analysis is to specify the contributing parameters. Thereafter, existing techniques are applied to find the relationship between these parameters. The obtained relationship should be meaningful, easily applicable and compatible with any unit systems. After specifying the contributing parameters in the dimensional analysis, the number of the dimensionless parameters can be obtained by using existing theories. In this research, the effective parameters on the geometry of the dividing zone and diversion flow were considered as follows: water density ρ, dynamic viscosity μ, depth of flow in the main channel y, flow velocity V, acceleration of gravity g, width of the main channel B, the width of diversion channel b, θ, ϕ, the main channel radius of curvature R, mean bed material size D_{50} and bed material density ρ_S. Dimensionless parameter for maximum scour hole depth H_S was obtained by applying the dimensional analysis and π theory [11]:

$$\frac{H_S}{B} = f(Fr, Fr^*, \mathrm{Re}^*, \frac{y}{B}, \varphi, \theta) \qquad (1)$$

Where:

$$Fr^* = \frac{u_*^2}{g(G_S - 1)D_{50}} \qquad (2)$$

$$\mathrm{Re}^* = \frac{\rho u_* D_{50}}{\mu} \qquad (3)$$

$$G_S = \frac{\rho_S}{\rho} \qquad (4)$$

u*= shear velocity (m/sec). Fr* and Re* are negligible by considering a constant value for D_{50} and also intake location is constant, therefore (1) is simplified as:

$$\frac{H_S}{B} = f(Fr, \frac{y}{B}, \frac{R}{B}, \varphi) \qquad (5)$$

III. Experimental Setup

The main objective of the current study is to investigate the effect of constant intake location θ=115°, different diversion angles (ϕ= 45°, 60°, 75° and 90°) and various flow conditions, under different flow depths and discharge values, on the scour hole in the vicinity of the lateral intake. As secondary current is fully developed in 180° channel, experiments were carried out in a U-shape rectangular flume of rigid bed and boundaries; as such models simulate the most critical condition [3].

Flume dimensions are: 0.6 m wide B, 0.6 m high and 2.6 m radius of curvature to the centerline R with a ratio of R/B equals 4.3. A straight rectangular channel with dimension of 0.6 m wide, 0.6 m high and 7.2 m long is located upstream of the bend section. In addition, to remove gate effect on the water level in bend channel, a straight rectangular channel built with the same cross section and 3.5 m long downstream of the bend section (Figure. 2).

Reference [1] suggested the width ratio of diversion channel to the main channel to be in the range of 0.4-0.5. Therefore, horizontal diversion channel designed with

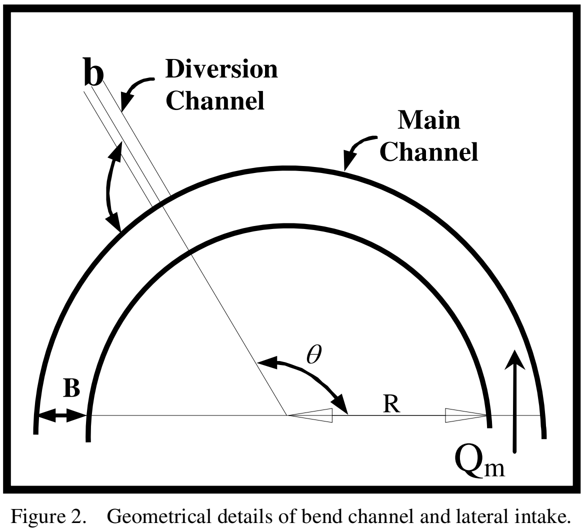

Figure 2. Geometrical details of bend channel and lateral intake.

rigid bed rectangular cross section of 0.25 m wide (b), 0.35 m high and 1.1 m long (Figure. 2). Discharge of main channel is measured by ultrasonic flow meter and a triangular sharp crested weir was used to measure the flow in diversion channel.

Experiments were conducted to investigate scour hole variations adjacent to the lateral intake for 10 and 15 cm water depths under 10, 15 and 20 lit/sec discharge values (i.e. Fr= 0.09, 0.14, 0.18, 0.25 and 0.34) for clear water condition (Table. I). This was based on the ratio of the mean and critical velocities to be less than one, where critical velocity is a function of median bed material size [12]. Bed material size was selected to have uniform distribution with median D_{50} of 1.3 mm and standard deviation of 1.31 [13].

After installing the intake channel for each diversion angle, bed material, with a thickness of 20 cm and zero slope, were placed along the diversion and in the main channels (3 m upstream and downstream of diversion channel).

With the start of experiments, bed materials near the intake entrance began to scour, this took approximately about 5 hours to reach an equilibrium state (Pirestani, 2004), after which experiment was ceased to measure the bed profile variation by a digital point gauge.

IV. Results and Discussions

To investigate flow pattern in the vicinity of lateral intake, two dimensional near bed velocity measurements were made.

In the main channel, as flow approaches the entrance of the intake, hydraulic gradient increases and streamline is influenced by diversion channel. This leads to gradual flow diversion toward the intake. Likewise, streamline is even more affected by the intake in the outer bend (Figure. 3).

TABLE I.
VARIABLE PARAMETERS IN THE EXPERIMENTS

φ	y (cm)	Q_m (lit/sec)	Fr	Re
90	15	10	0.09	11033.9
90	15	15	0.14	16550.8
90	15	20	0.18	22067.7
90	10	15	0.25	12413.1
90	10	20	0.34	16550.8
75	15	10	0.09	11033.9
75	15	15	0.14	16550.8
75	15	20	0.18	22067.7
75	10	15	0.25	12413.1
75	10	20	0.34	16550.8
60	15	10	0.09	11033.9
60	15	15	0.14	16550.8
60	15	20	0.18	22067.7
60	10	15	0.25	12413.1
60	10	20	0.34	16550.8
45	15	10	0.09	11033.9
45	15	15	0.14	16550.8
45	15	20	0.18	22067.7
45	10	15	0.25	12413.1
45	10	20	0.34	16550.8

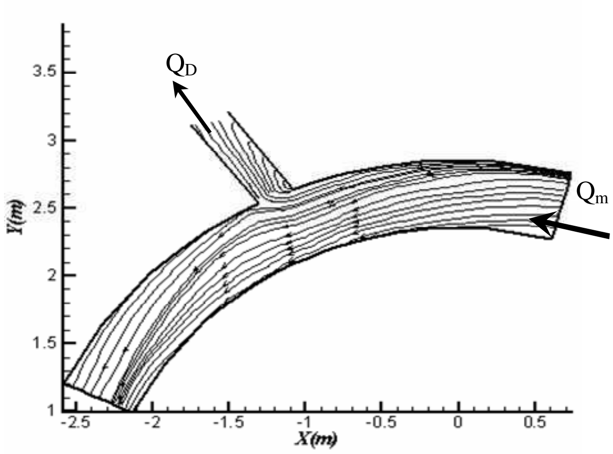

Figure 3. Flow pattern near bed in the vicinity of lateral intake (θ=115°, ϕ=75°, Fr=0.27, y=15 cm).

Variation of water surface profile drown in figure (4) illustrates that it is resulted by hydraulic gradient, which is actually reduced near inner entrance of the diversion channel so that it could reach its minimum level approximately in the middle of the entrance where separation zone initiates in the diversion channel. Thereafter, it tends to have a rising trend where it reaches its maximum level near outer entrance. This is stagnation point in the main channel where it is the end of dividing streamline, velocity head reaches its minimum value approximately to null hence energy level equals to the flow depth. From this point, water surface begins a decreasing trend so far from intake in the main channel, where the influence of the intake on water surface profile disappears [14]. This condition effectively plays an important role in separation zone formation while inciting about reverse flow near channel bed in downstream corner of intake entrance directed from the main towards the diversion channel [15]. These factors are effective in bed elevation variations, which ultimately lead to form scour hole [14]. As a result, some of the washed out sediments are transported downstream of the main channel as some other diverted into the intake, through which some deposited in the separation zone and the rest downstream.

Plots of Fr versus ratios of maximum depth H_S and Length L_S of scour hole to the main channel width B for each diversion angle were sketched by observed data

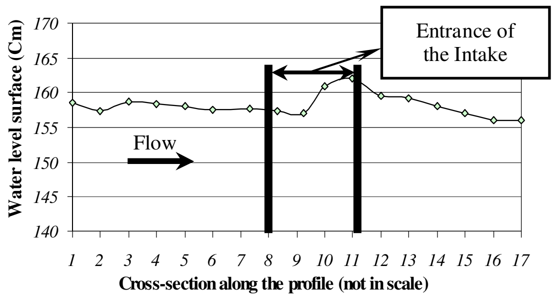

Figure 4. Water surface profile variations near the lateral intake in the main Channel (not in scale).

(Figures. 5 and 6). These shows that in all diversion angles, H_S/B and L_S/B have an increasing trend with an increase Fr values. However, a discontinuity is noticeable where $0.18<Fr<0.25$, this illustrates the effect of upstream flow depth, in the main channel, on scour hole dimensions.

Diversion angle ϕ and H_S/B values were also plotted for different Fr values (Figure. 7). These represent diversion angle of 60° in comparison to the others has generated the deepest scour hole under constant depth of 15 cm upstream, which corresponds to the maximum diversion flow rate Q_r under the same condition (Figure 8). However, when flow depth is decreased to 10 cm, Figure (8) tends to follow an increasing trend which reflects the significance of flow depth on the dimensions of the scour hole.

For all the experiments under different y/B, ϕ and Fr values, the following relationship was optimized by using Solver menu in Excel Software.

$$\frac{H_S}{B} = 0.7314 Fr^{0.691} \phi^{0.231} \left(\frac{y}{B}\right)^{0.293} \qquad (6)$$

In which, ϕ is in radians, y, B and H_S are in metres.

Equation (6) was obtained by trial and error, as the computed values from the equation and observed data proved to have the minimum root mean square values in comparison with applying other mathematical forms in equation (6). Observed values of (H_S/B) was plotted against the computed ones (Figure. 9).

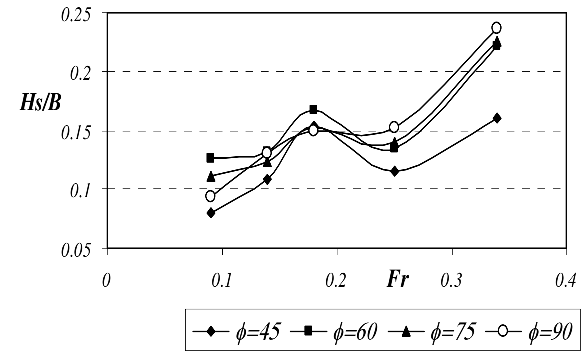

Figure 5. Variation of measured (H_S/B) for different (Fr) under different (ϕ) values.

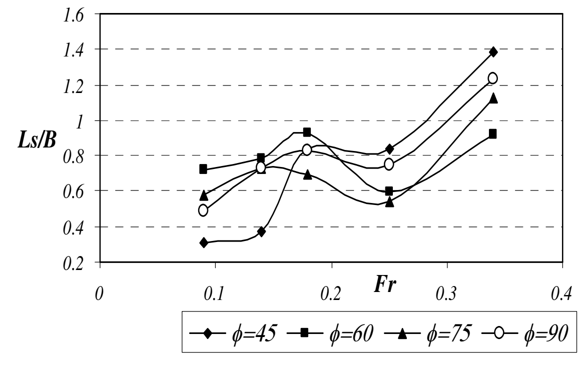

Figure 5. Variation of measured (L_S/B) for different (Fr) under different (ϕ) values.

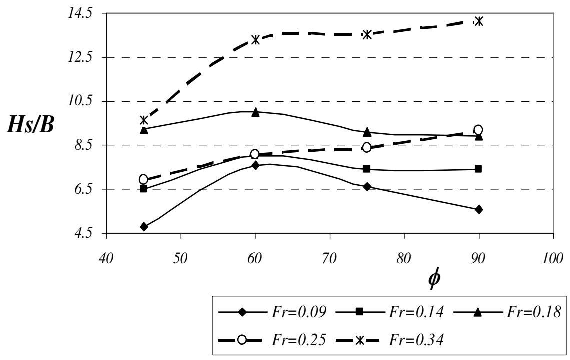

Figure 7. Variation of measured (H_S/B) for different (ϕ) under different (Fr) values.

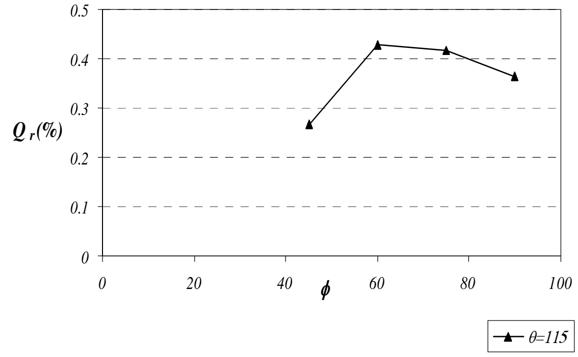

Figure 8. Variation of measured (Qr) for different (ϕ) under $\theta=115^{\circ}$.

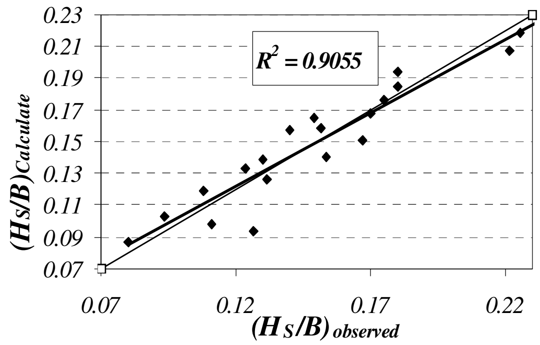

Figure 9. Observed and calculated maximum scour hole depth

V. Conclusion

Based on observations were made from analysis of the data, the following concluding remarks were obtained:

- As streamline approaches the intake in the main channel, it is diverted party by it. The effect of this on water surface profile is in such a way that it profile has a decreasing trend from the inner wall of the diversion channel to the mid-point of the entrance where it reaches its least value, thereafter an increasing upwards trend begins so that it should reach its most value at the outer wall of the diversion channel where tangential velocity is approximately equal to zero at this point which is called stagnation point.

- For all different diversion angles, H_S/B and L_S/B are directly related to the Fr values.
- Flow depth variations upstream of the intake, in the main channel, plays a significant role in the scour hole dimensions.
- By analysis observed data experimental, empirical relationship was presented to estimate the maximum scour hole depth for lateral intakes in U-shape channels.

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