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Investigation of Flow Pattern in the Vicinity of Lateral Intake at the U-Shape Bend Channels

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ABSTRACT

Diversion flows are generated either naturally by cutoffs or braiding pattern in meandering rivers, or artificially through intake from rivers or channels. The pattern of diversion flows are totally three dimensional and non-uniform. This causes formation of separation zone and vortex flow in the vicinity of the inner wall in diversion channel. It affects the diversion flow rate and has always attracted the attention of hydraulic engineers and researchers study lateral intakes. In order to understand the condition of separation zone at intakes in curved channels, a U-shape flume, with a rectangular cross-section and fixed bed and boundaries, was constructed. A straight channel with a rectangular cross-section was also utilized as the diversion channel. The experiments were carried out in different conditions in the bend. These are: different intake locations (θ), diversion angles (ϕ) and Froude Numbers (Fr). By drawing flow pattern at the intake, the length and width of the separation zone were measured in the diversion channel for each experiment. Also for more the investigation, numerical simulation have been by using of ANSYS software. This is to observe the impact of intake location, diversion angle and flow regime on vortex flow dimension in lateral intake.

Keywords: lateral intake, intake location, diversion angle, separation zone, vortex flow

1. 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 (Raudkivi 1993).

Neary et al. (1999) carried out some experiments on a lateral intake at 90 degrees with a straight channel and concluded that the formation of diversion flow is due to the presence of transverse hydraulic gradient at intake entrance. He also found out that the pressure variation at intake entrance is in such away that it decreases at inner intake entrance while increasing near 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 (Figure 1). In addition, vortex flow in the separation zone is also three dimensional at the inner entrance of the diversion channel (zone A). This affects the rate of the relative diversion flow (Q_r= the ratio of the diversion flow (Q_d) to the main channel flow (Q_m)) and is also proportional to the shape of the diversion channel cross-section.

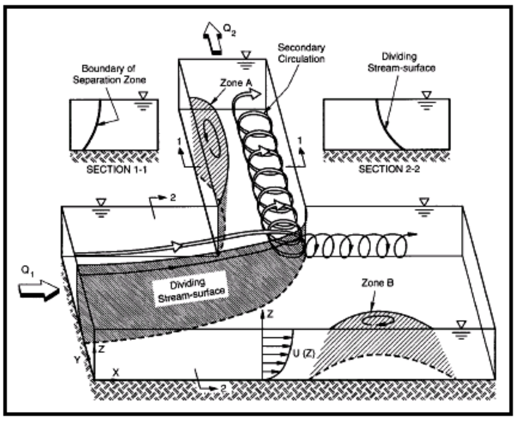

Figure 1- Three dimensional flow pattern in lateral intake (Neary et al. 1999)

Investigations carried out along bend cross-sections of the curved channels revealed flow velocity decreases as water depth increases. The transverse slope also decreases from the outer bend toward 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 toward the inner bend (Bergs 1990). Those who have studied on the bend channels (e.g. Bergs 1990, Booij 2002 and Blanckaert 2002) suggest using a U-shape (180°) channel when experimenting on the secondary flow, as the secondary flow can be fully developed in such conditions.

Considering the flow pattern in the bends, Razvan (1989), Novak (1990) and Rauedkivi (1993) suggest the preferable location for the intake may be the outer bend. They also consider (θ) and (ϕ) to be the important geometric parameters that can greatly diminish the effect of the vortex flows or in other words the separation zone at intake entrance.

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 where the lateral intakes are located in curved channels.

2. PHYSICAL MODEL CHARACTERISTICS

The main objective of the current study was to investigate the effect of diversion angle and intake location, in various flow conditions (Fr= 0.27, 0.41 and 0.55), on the separation zone in river bend. 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 (Bergs 1990).

Flume dimensions are: 0.6 m wide, 0.6 m high and 2.6 m radius of curvature to the centerline 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 (Fig. 2).

Raudkivi (1993) 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 rigid bed rectangular cross section of 0.25 m wide, 0.35 m high and 1.1 m long (Fig. 2). Water discharge was measured by an ultrasonic flow meter and a triangular shape crested weir in the main and diversion channel, respectively.

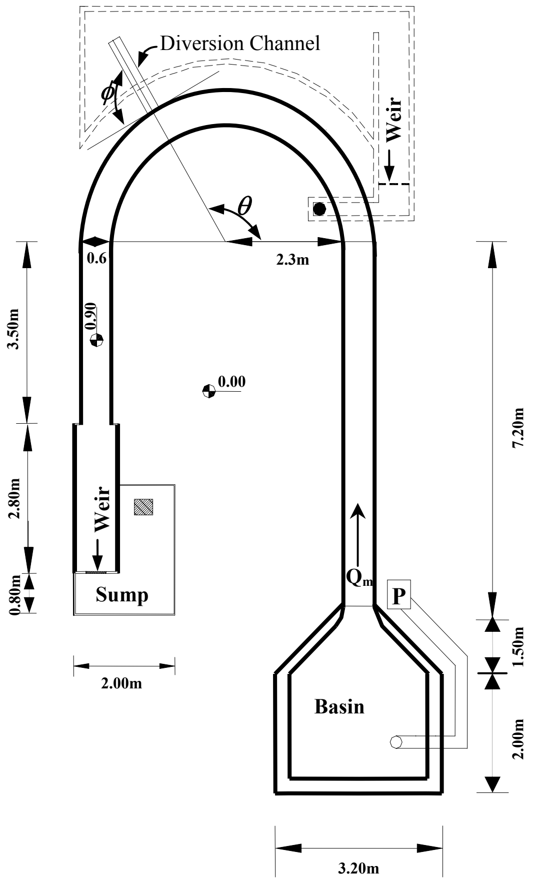

Figure 2- Experimental layout

3. EXPERIMENTAL PROCEDURES

In order to carry out the experiments, the effective parameters such as (θ), (ϕ), (Q_m) and (Fr) were considered variable while some other parameters such as (B), (b), (R) and the flow depth upstream of the intake (y=0.15m) were constant. The intake location was also selected in the outer bend of the model. Since the objective of the experiments was to study and investigate (θ) in the outer bend, the locations were selected in the first ($\theta=40^\circ, 75^\circ$) and second half of the bend ($\theta=115^\circ$), respectively. Considering the fact that the range of diversion angles is still debatable in the literature, they were selected to cover all the angles ($\phi=45^\circ, 60^\circ, 75^\circ$ and 90°) experimented previously by other researchers (Vanoni 1975, Razvan 1989 and Novak 1990).

Flow depth and rates in the experiments were chosen to cover sub-critical flows in a large range. For every intake location and diversion angle, flow rates of 30, 45 and 60 lit/s with the constant flow depth of 0.15m were applied to work out Fr values of 0.27, 0.41 and 0.55, respectively.

Figure (3) shows the geometry properties of the separation zone in the intake entrance, it is necessary to point out that the geometry parameters (y, b, B, R) were considered constant in the experimental setup, hence the dimensionless parameters R/B, b/B and y/B could be ignored in the above equations. In this way, (θ), (ϕ) and flow characteristics (Fr) were the variable parameters in the experiments.

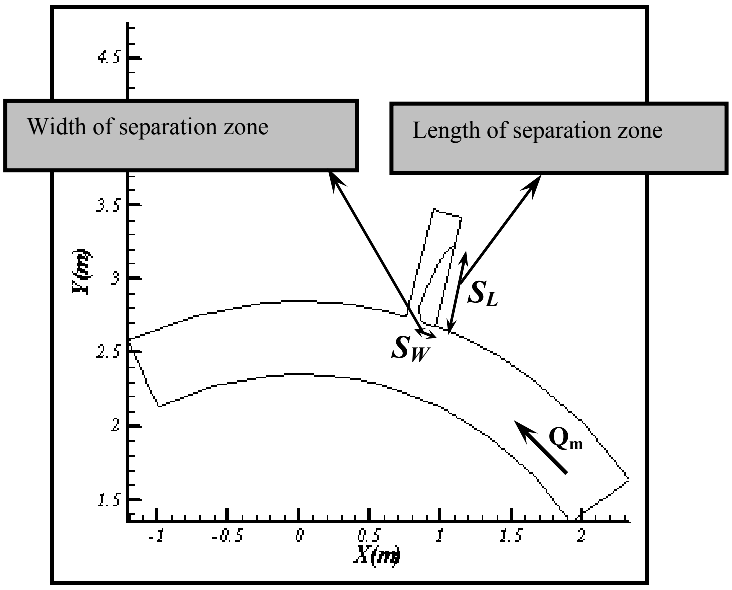

Figure 3- Geometry of the separation zone

To draw flow pattern in the vicinity of the intake, flow velocities were measured by a 2D side-looking probe ADV manufactured by SonTek Inc. (Kraus *et al.* 1994) and mounted on a coordinate meter allowing the probe to move from one measurement vertical to another and, in a given vertical, to go down and up from one measurement point to another. ADV technology is based on the measuring method known as pulse-to-pulse coherent (Zedel *et al.* 1996). The acoustic sensor of the 2D probe is mounted on a rigid stem 40 cm long and is composed of one transiting transducer and two receiving transducers. For the 2D probe the x-axis (main flow direction), the y-axis and the two receivers are all in the same plane.

Tec-plot software was utilized to plot flow pattern for every single case (Figure 4-a). The (S_W) and (S_L) of the separation zone were measured in each plotted pattern (Pirestani, 2004) (Figure 4-b).

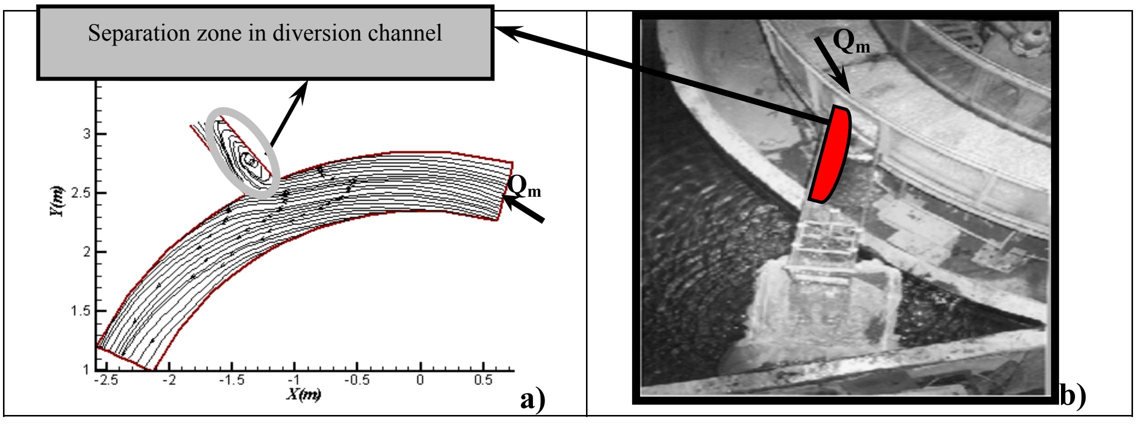

Figure 4-a- Separation zone in the entrance of the intake ($\theta=115^\circ$, $\phi=75^\circ$ and Fr=0.41), b- A picture of the separation zone in the vicinity of the inner wall of the lateral intake.

Also for more the investigation, numerical simulation have been by using of ANSYS model. This is to observe the impact of intake location, diversion angle and flow regime on dimension separation zone, diverted flow and high velocity (VR) in the vicinity of lateral intake (Figure 5).

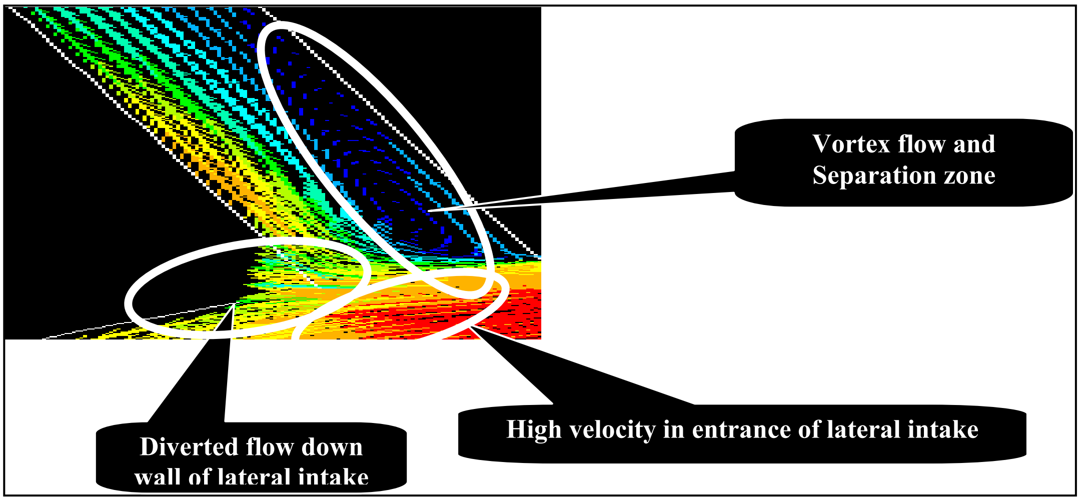

Figure 5- Numerical simulation of flow pattern by ANSYS model.

The diversion flow rate in each case was also measured by using a triangular spillway installed at the end of the outlet basin. Horizontal (U) and (V) components of velocity were calculated from measured tangential (U_θ) and radial (U_r) by equation (1) and hence velocity resultant (VR) was obtained by equation (2) to plot velocity contours. Figure (6-b) shows the velocity resultant contours for (θ=75), (ϕ=75) and (Fr=0.27) in the vicinity of the intake.

$$\begin{cases} U = U_r \mathrm{Cos}\theta - U_\theta \mathrm{Sin}\theta \\ V = U_r \mathrm{Sin}\theta + U_\theta \mathrm{Cos}\theta \end{cases} \tag{1}$$

$$VR = \sqrt{V^2 + U^2} \tag{2}$$

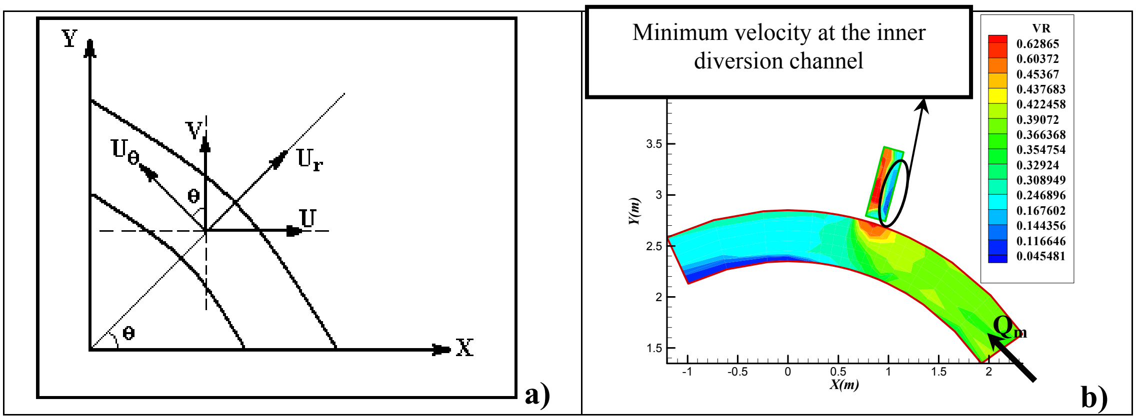

Figure 6- a- Velocity components in polar and Cartesian coordinate systems,
b- Contour velocity in the vicinity of the intake for experiment of (θ=75°, ϕ=75° and Fr=0.27)

4. RESULTS ANALYSIS

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 (Figure 4-a). Likewise, streamline is even more affected by the intake in the outer bend.

To non-dimensionless measured S_L and S_W, these values were divided by b. S_L/b and S_W/b were plotted against Q_r for different θ and ϕ values (Figures 8 and 9). This illustrates that S_L/b and S_W/b are inversely related to the Q_r for all θ and ϕ values. As illustrated in these figures, increasing S_L/b and S_W/b leads to increasing retarding (i.e. separation zone) in the diversion channel which lessens flow diversion and reduction in Q_r.

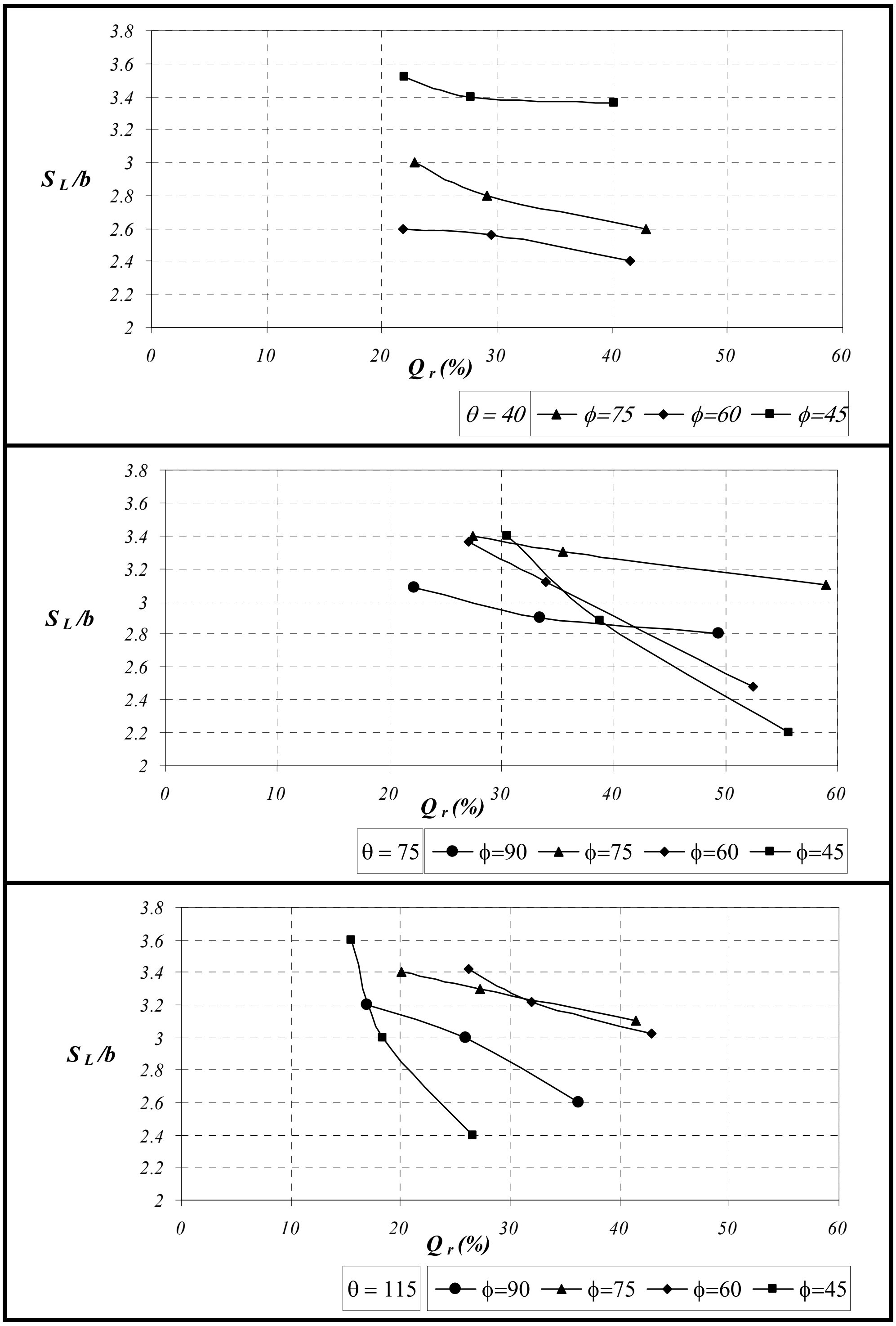

Figure 8- Experimental variations of Q_r and S_L/b for different values of θ and ϕ

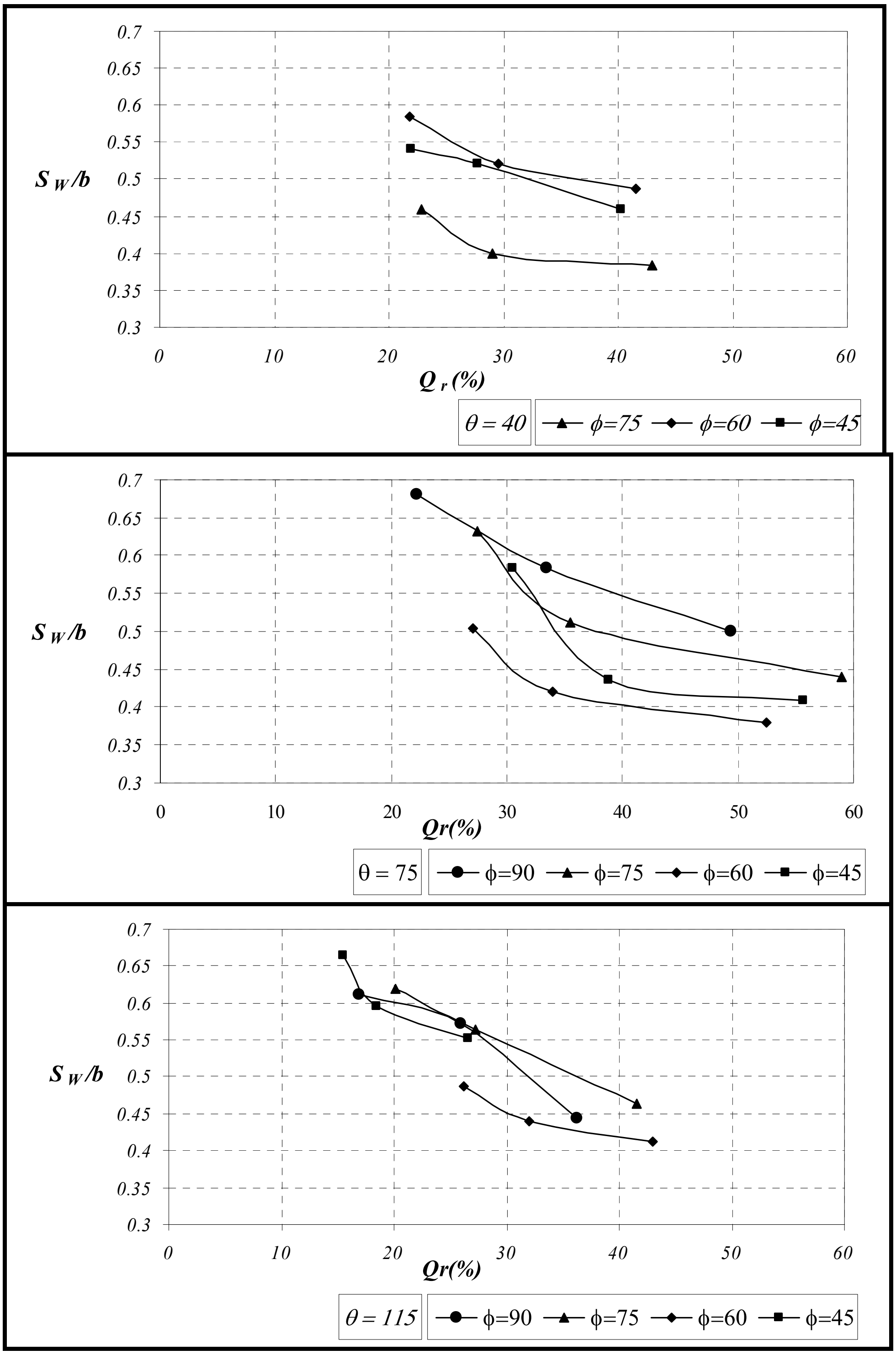

Figure 9- Experimental variations of Q_r and S_W/b for different values of θ and ϕ

Figures (10) and (11) also show plotted values of S_L/b and S_W/b against Fr for different θ and ϕ values, this confirms that S_L/b and S_W/b are directly proportional to Fr which is good evidence on the extension of separation zone with an increase in Fr values. This is in conformation with hydraulic gradient and water surface variation in the vicinity of lateral intake (Pirestani *et al.*, 2005).

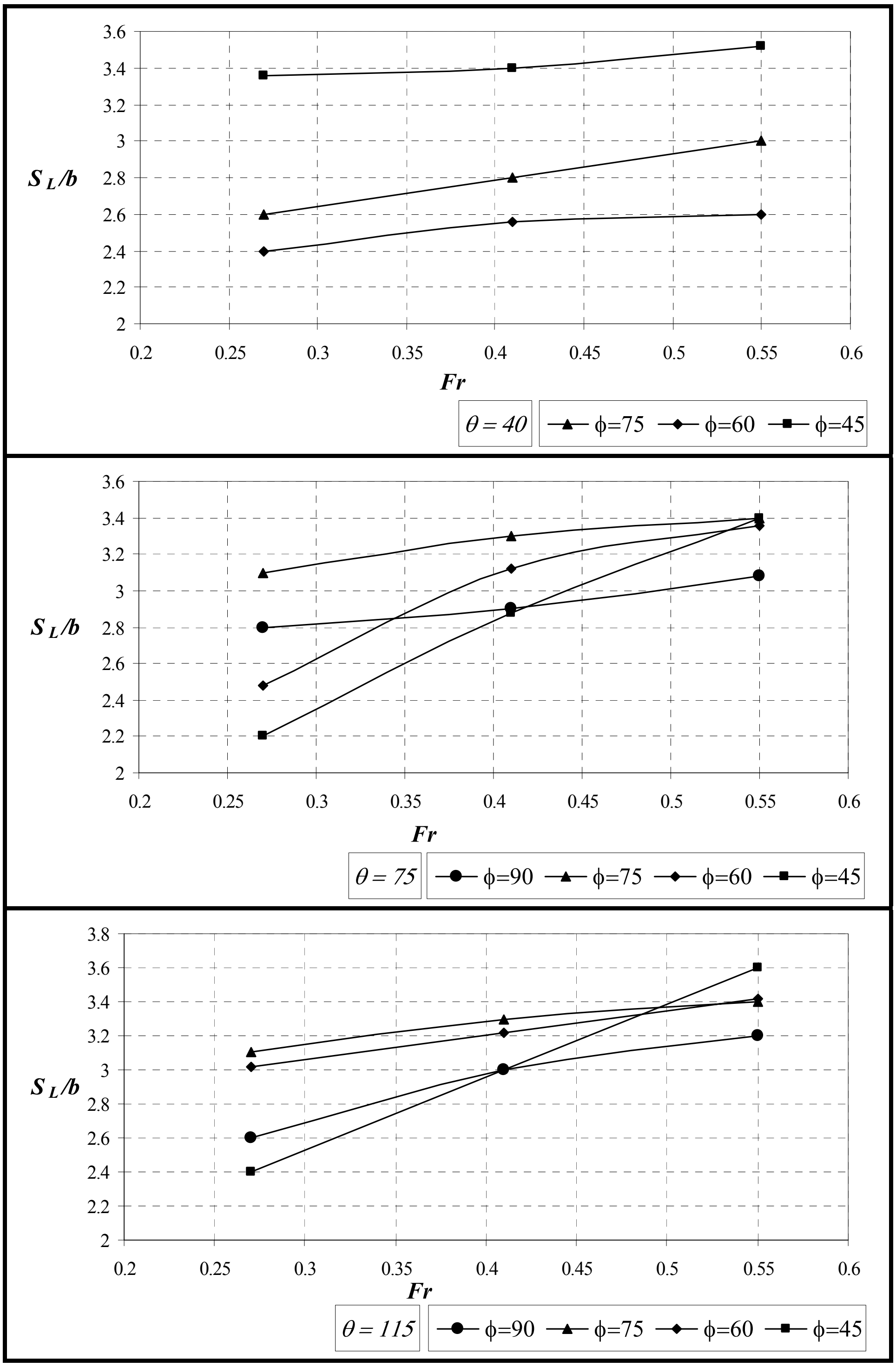

Figure 10- Experimental variations of Fr and S_L/b for different values of θ and ϕ

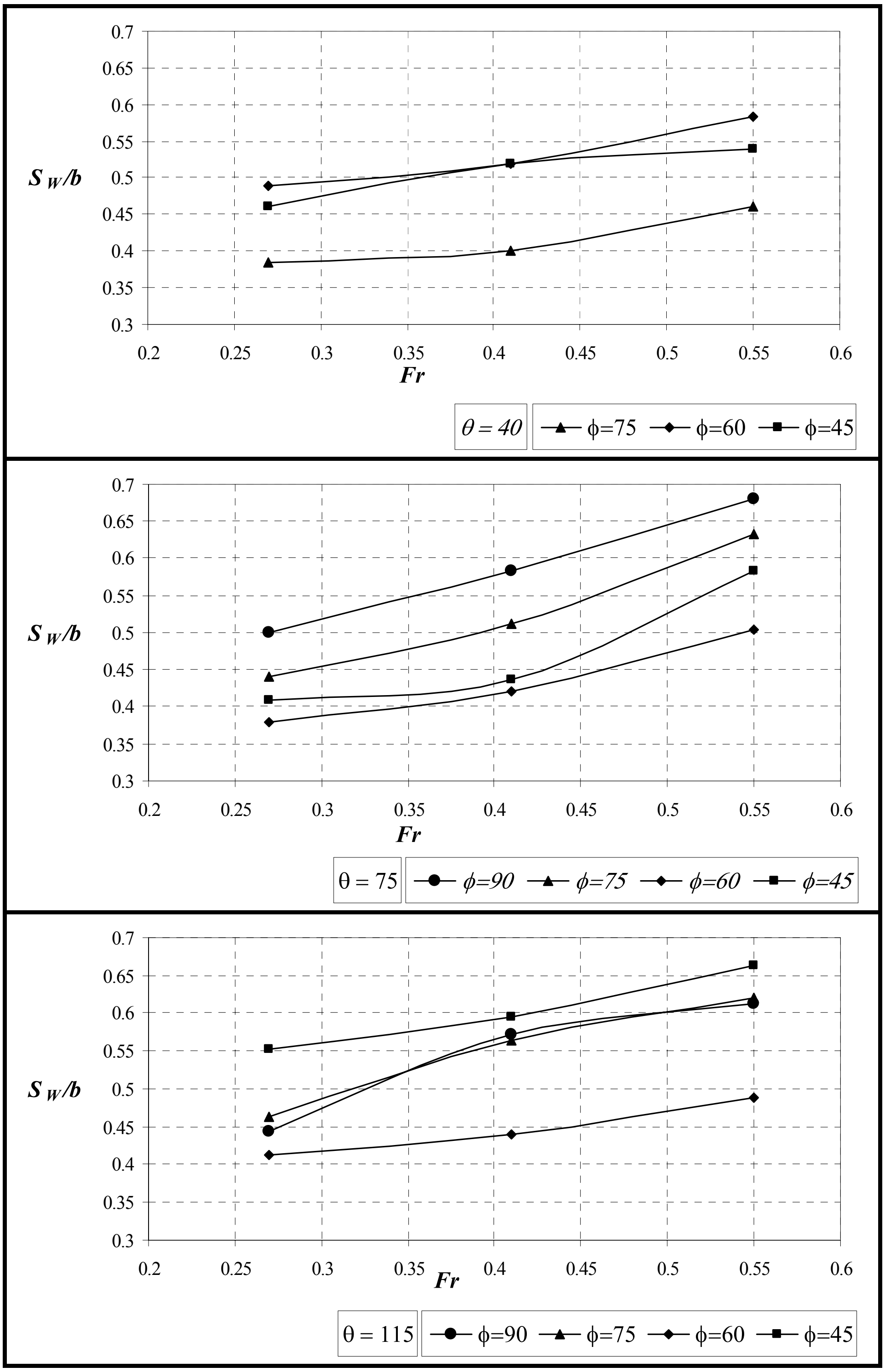

Figure 11- Experimental variations of Fr and S_W/b for different values of θ and ϕ

5. C0NCLUSIONS

Results obtained from experiments and numerical simulation by ANSYS show that as streamline approaches the intake in the main channel, it is diverted party by the intake.

At the inner wall of the diversion channel, vortex flow is generated which develops a separation zone with the minimum resultant velocity of (VR). This becomes fully developed vertically up wards.

The separation zone, formed near the inner wall of the diversion channel, is a vortex flow area where the velocity resultant (VR) approaches its minimum value. Dimensions of the separation zone are defined by length and width where their dimensionless forms are the ratio of each to diversion channel width, theses ratios have shown to be inversely and directly proportional to flow rate and Froude Number values, respectively. Hence an increase in the values of the so called ratios as well as Froude Number leads to a decrease in diversion flow.

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