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Numerical Investigation of a Side Weir with an Inclined Ramp

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Abstract: Flow over side weirs is a typical case of spatially varied flow. In many complex hydraulic structures, outflow discharge from side weirs and also the types of water surface profiles over the side weir are difficult to predict. There are many significant researches that have investigated the hydraulic behavior of side weirs under different condition experimentally. Nowadays, because of the significant growth of hydraulic models that are capable of simulating many complex hydraulic problems, it is possible to investigate hydraulic phenomena from different aspects and reveal that to what extend changes in a particular parameter will affect the flow condition without requiring carrying out extra experiments. In this research, the effect of an inclined ramp which is place alongside of a side weir is investigated numerically. The simulation results have been compared to experimental results. The comparison shows that placing an inclined ramp will have a great impact on the flow condition over the side weir and also it will decrease the amount of outflow discharge.

Key words: Side weir · 3D -Simulation · Inclined Ramp · Experimental

INTRODUCTION

Because of various applications and also different types of flow conditions that can occur, Side weirs have attracted considerable interest among significant researchers. There are many significant researchers that have investigated side weirs in various conditions. For instance, Sharp crested side weirs have been investigated by many researchers such as Ackers, Collings, Frazer, Subramanya and Awasthy, Nandesamoorthy and Thomson, Singh et al. Yu-Tech, Cheong El-Khashab and Smith [1-9]. As there are many studies that have been carried out in straight channels, Agaccioglu and Yüksel investigated sharp crested side weirs in curved channels. They focused on hydraulic behavior of rectangular sharp crested weir at various locations along 1800 bend [10].

The concluded that the bend affects the lateral flow condition and vice versa. Namaee et al investigated a long broad crested side weir in a trapezoidal channel with significant rough bed under subcritical condition. They proposed an equation for discharge coefficient of side weirs based on their experiments and they compared it to other significant empirical equations. They concluded that because of many special factors that had influenced the discharge coefficient, the experimental discharge coefficient was much less than the predicted ones purposed by other empirical equations [11]. Namaee et al have also simulated these experiments numerically by one of the leading numerical models. They concluded that the numerical model was capable of simulating this phenomenon to a satisfactory extends except at upper section of the side weir where the flow diverts into the side weir. In this location because of the collision between the flow and the earthen material, a part of the lateral wall would be eroded in the experiments but in the numerical model, this part was assumed to be rigid [12]. However, their simulation results provided detailed analysis of flow pattern, pressure distributions in longitudinal and transverse sections over the side weir at specified locations.

As the numerical result of Namaee et al was in a good agreement with the experimental one, the present work studies another numerical model based on free-surface CFD (Computational Fluid Dynamics) model in which an inclined ramp is placed alongside of the side weir. The objective of the study is to determine to what extend an

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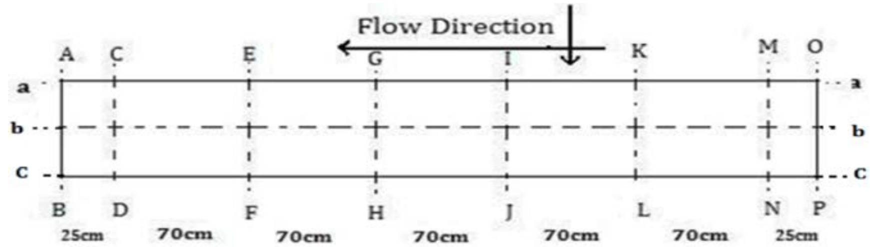

Fig. 1: Locations of measured hydrostatic pressures on the Weir Crest

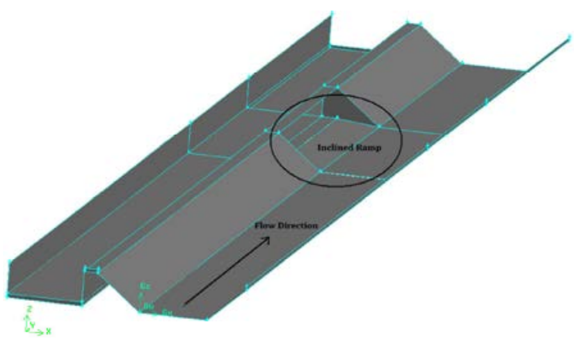

Fig. 2: Locations of measured hydrostatic pressures on the Weir Crest

inclined ramp will affect the characteristics of the flow over the side weir, aiming to get the interaction between the physical model and the numerical model, though the comparison of the data obtained. The simulation results will provide detailed analysis of flow pattern, pressure distributions in longitudinal and transverse sections over the side weir at specified locations and also the amount of simulated outflow discharge.

Experimental Measurements: Data collected includes the measurements of hydrostatic pressure at different locations both in the longitudinal and transverse direction of flow on the crest of the side weir and in the main channel. They were measured at 25cm from the upstream and downstream edge of the weir by means of pizometers installed at the bottom of the side weir. Fig. 1 shows locations of the measured hydrostatic pressures with alphabetic letters. Fig. 2 also shows the type of water surface profile over the side weir under subcritical condition. As it is clear in the Figure, the depth of flow rises from upstream of the side weir toward the downstream of the side weir. This type of water surface profile was seen both in the numerical and experimental situations.

Numerical Modeling: The commercially available CFD model FLUENT 6.3.26 software was applied. It is rather satisfactory software for the solution of equations that represents the free surface turbulent flow [13]. It uses the finite-volume method to solve the governing equations for a fluid. It also provides the capability to use different physical models such as incompressible or compressible, in viscid or viscous, laminar or turbulent, etc.

Introduction of The used Turbulence Model: In order to simulate this phenomenon, the standard model as introduced by Jones and Launder (Launder and Spalding (1974) was used [14]. The standard k-ε model has been the most widely used two equation models. It is a semi empirical model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). The model transport equation for k is derived from the exact equation, while the model transport equation for ε is obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart [15]

Free surface Tracking

VOF Method: Several methods have been used to approximate free surface. A simple, but powerful method is VOF. This method is shown to be more flexible and efficient than other methods for treating complicated free surface. It is designed for two or more immiscible fluids, where the position of the interface between the fluids is of interest [16]. In each cell of a mesh it is usual to use only one value for each dependent variable defining the fluid state. If a function named F is assumed whose value is unity at any point occupied by a certain fluid and zero. The average value of F in a cell would then represent the fractional volume of the cell occupied by a certain fluid. In particular, a unit value of F would correspond to a cell full of a certain fluid, while a zero value would indicate that the cell contained no this fluid. Cells with F values between zero and one must then contain a free surface.

For air-water flow field, a single set of momentum equation is shared by air and water and the volume fraction of each of the fluids in each computational cell is tracked throughout the domain. In each cell, the sum of the volume fractions of air and water is unity. So an additional variable, the volume fraction of air or water is introduced. If F^w denotes the volume fraction of water, then the volume fraction of air F^a can be expressed as

$$F_a = 1 - F_w \quad (1)$$

As long as the volume fraction of air and water is known at each location, the fields for all variables and properties are shared by air and water and represent volume-averaged values. Thus, the variables and properties in any given cell are either purely representative of water or air, or representative of a mixture of them, depending upon the volume fraction values.

In the existing numerical model, the flow equations are discretized with the non-linear third order Quadratic Upwind Interpolation of Convective Kinematics (QUICK) scheme of Leonard [17]. The discrete equations are solved in an iterative manner to steady-state using the SIMPLE (Semi Implicit Method for Pressure Linked Equations) algorithm of Patankar [18]. The solution is declared converged if the average residuals of the continuity, RANS and turbulence equations are below 10^{-6} of their original values. 3D multiphase model (Volume of Fluid) and standard k-ε turbulence model are used as said before.

Boundary Conditions and Mesh Geometry: The geometry of the model in this paper consists of a trapezoidal channel with the width of 1 meter and a diversion channel both with the length of 22 meters. A side weir with the length of 4 meters and the height of 5 centimeters placed at 12.44 meter upstream of the main channel. The bed slope of the channel is 0.001 which is the same as the experiment. Gambit which is mesh generation software is used in order to create the mesh geometry [19]. The mesh consists of 99180 cells, 300469 faces and 101976 nodes.

The upstream boundary condition in y direction was defined as "Pressured-inlet". "Pressured-outlet" boundary was set at the downstream of y direction. Boundary condition for the z direction was labeled as "symmetry" which implies that identical flows occur on the other side of the boundary and hence there is no drag. The "wall function" was applied in other parts of the model. The wall roughness was set using the roughness height computed from the manning formula. The acceleration of gravity was applied in the negative z-direction. The evolution in time was used as a relaxation to the final steady state. The steady state was checked through monitoring the flow kinetic energy. Physical model configurations were simulated during 34 seconds. It should be mentioned that the simulation was done for the inlet discharge of 110 lit/sec. Fig. 2 show location of inclined ramp throughout of the side weir.

RESULT AND DISCUSSION

Fig.3 shows the variation of flow at different time of simulation. As it is clear in the Fig.3 it will take 34 seconds for the flow to exist completely from the lateral channel. Fig. 4 shows variation of the velocity magnitude in the main channel. As it can be seen in Fig. 4, the flow at the upstream and the downstream of the side weir is subcritical. In subcritical flow, the flow upstream, downstream and along the length of the side weir remains subcritical at all points. The key feature to note is that the water level in the main channel increases along the weir in the downstream direction. Therefore, the head acting on the weir is greater at the downstream end than at the upstream end. As a result, the discharge intensity of the spill flow is not constant but increases in the downstream direction [4]. Fig. 5 shows the typical water surface profile over side weir at subcritical flow. Therefore, it is expected that the typical water surface profile shown in Fig.3 should occur over the side weir. However, because of the inclined ramp which is placed alongside of the side weir, the water surface profile is different.

Comparison Between the Numerical and Experimental Data: In order to investigate the effect of inclined ramp, the longitudinal and transverse pressure distributions over the side weir were calculated at specified points according to the location mentioned in Fig. 1. Fig. 6 to 11 show the result of the simulated longitudinal pressure distributions over the side weir and its comparison with experimental data, at axis a-a, b-b and c-c, respectively. As it is clear in these Figures, the pressure values over the side weir are much less than the experimental ones. Besides, the water surface profile over the side weir follows an unstructured algorithm which is totally different from the water surface profile over the broad

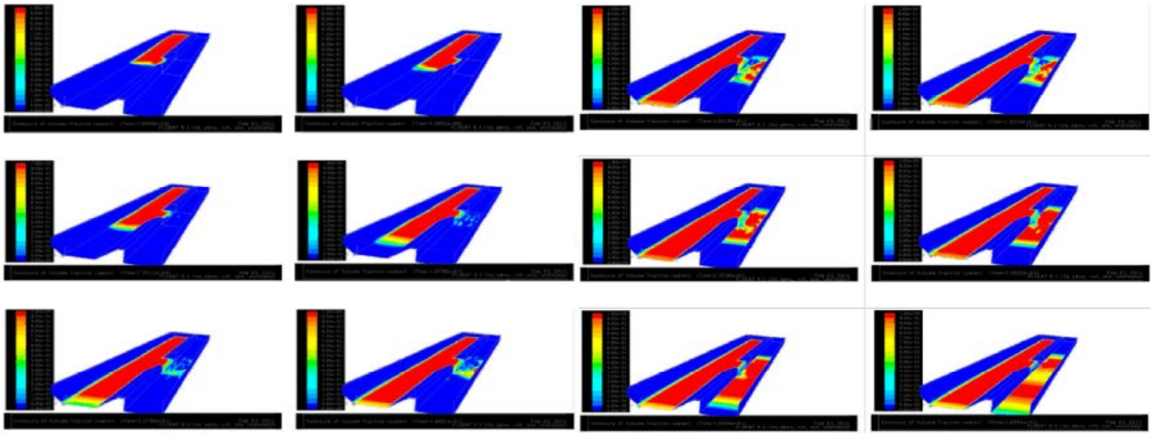

Fig. 3: The simulation process of flow at different times of simulation

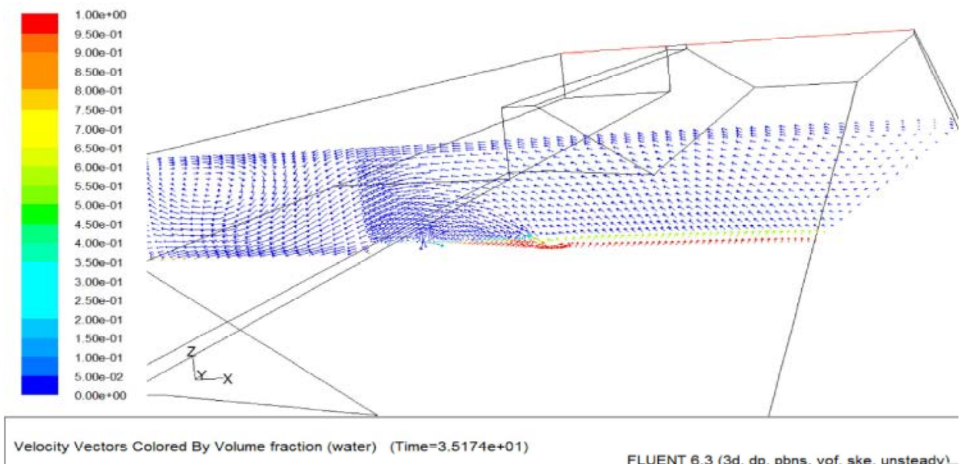

Fig. 4: variation of the velocity magnitude in the main channel

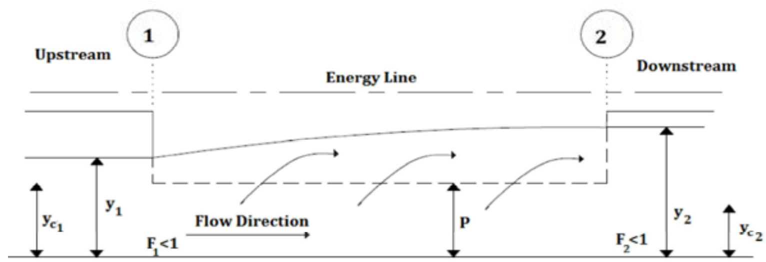

Fig. 5: Longitudinal Flow Profile at a Side weir under Sub-critical Condition (Subramanya 1972)

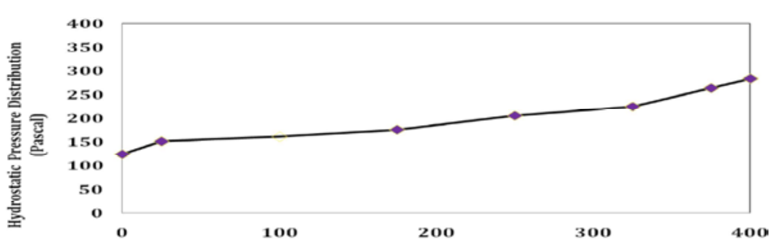

Fig. 6: Experimental Longitudinal contour of pressure distribution profile over the side weir at axis a-a

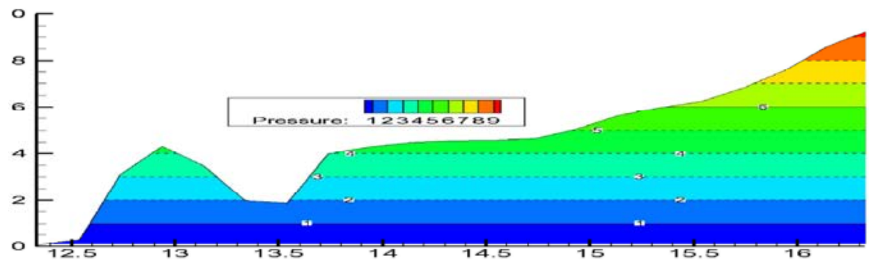

Fig. 7: Numerical longitudinal pressure distribution profile over the side weir at a-a axis

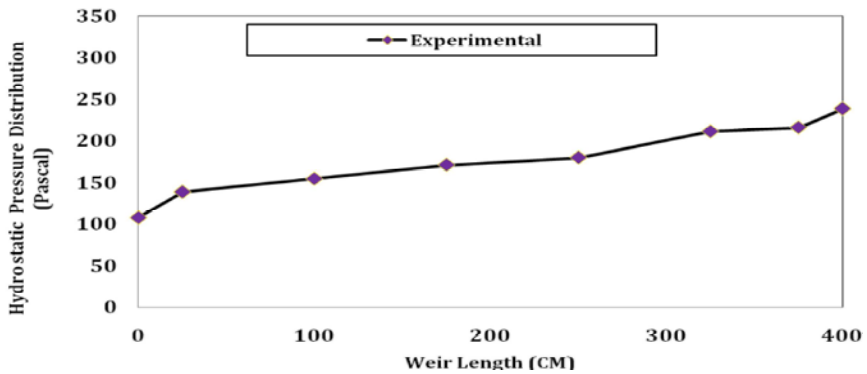

Fig. 8: Experimental longitudinal contour of pressure distribution profile over the side weir at axis b-b

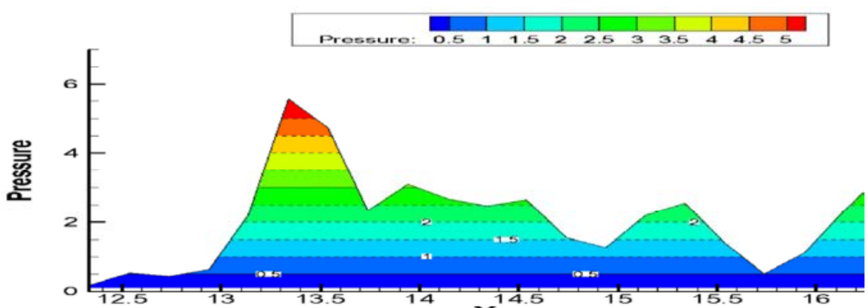

Fig. 9: Numerical longitudinal pressure distribution profile over the side weir at axis b-b

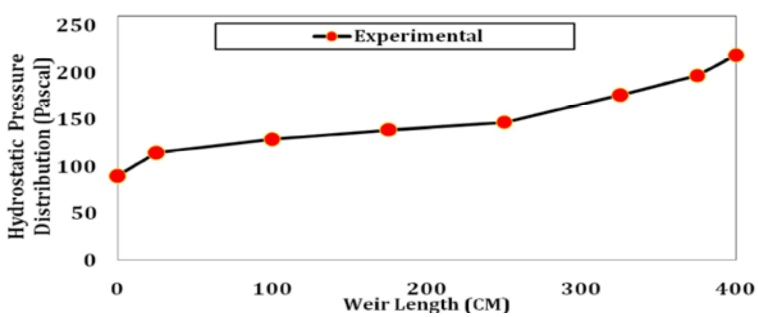

Fig. 10: Experimental longitudinal contour of pressure distribution profile over the side weir at axis c-c

crested side weir without inclined ramp. The reason for that is occurrence of reverse flow because of the existence of inclined ramp. Inclined ramp will not let the flow passes through the side weir and it pushes back the flow back into the main channel. Moreover, the amount of outlet discharge was also analyzed and it was concluded that it

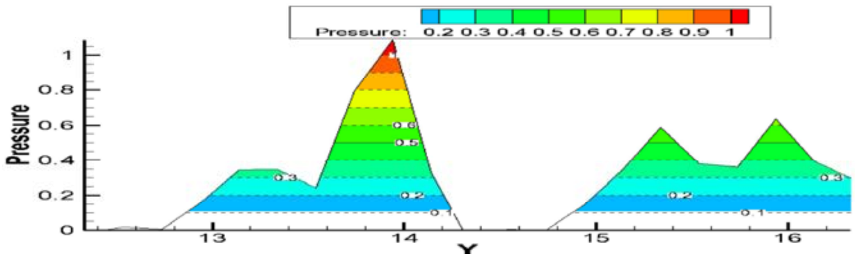

Fig. 11: Numerical longitudinal pressure distribution profile over the side weir at axis c-c

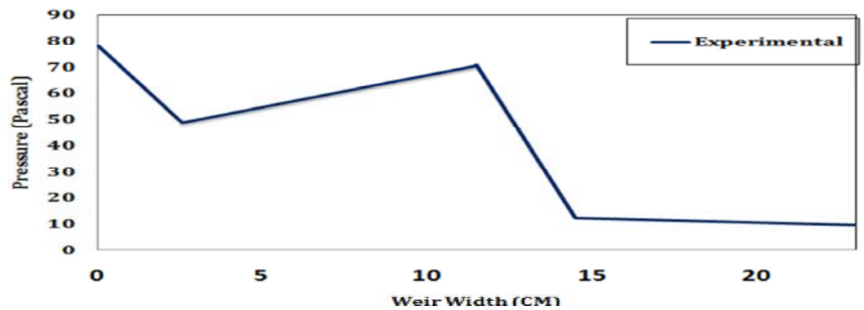

Fig. 12: Experimental transverse pressure distribution contour over the side weir at Section O-P

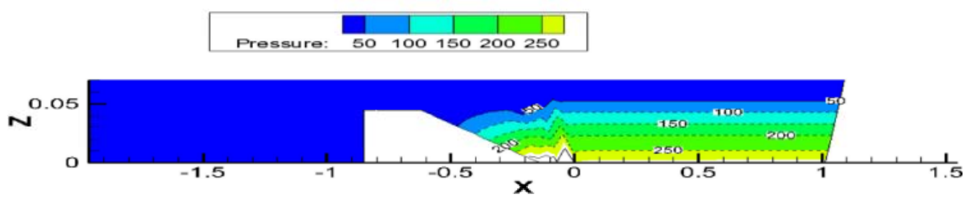

Fig. 13: Numerical transverse pressure distribution profile over the side weir at Section O-P

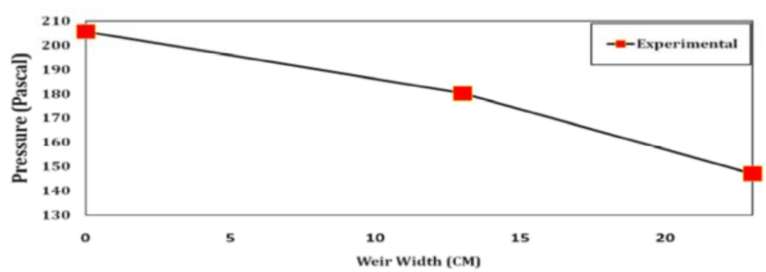

Fig. 14: Experimental transverse pressure distribution contour over the side weir at Section G-H

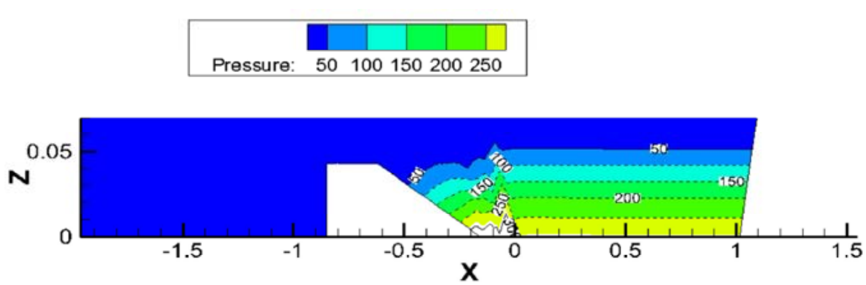

Fig. 15: Numerical transverse pressure distribution profile over the side weir at Section G-H

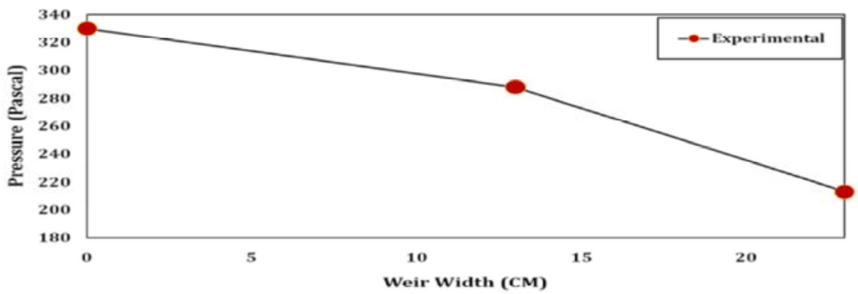

Fig. 16: Experimental transverse pressure distribution contour over the side weir at Section A-B

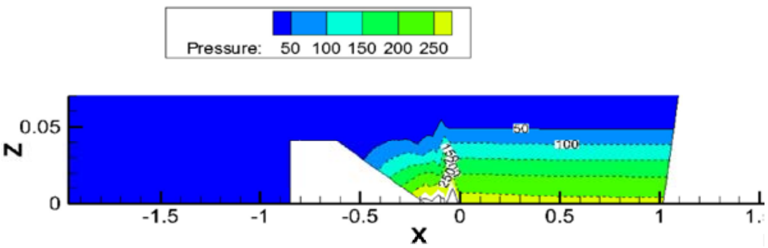

Fig. 17: Numerical transverse pressure distribution profile over the side weir at Section A-B

was about 39.43 lit/sec which is about 10lit/sec less than the experimental value. Fig. 12 to 17 show the numerical and experimental results of the transverse pressure distributions over the side weir at sections A-B and O-P, respectively. As it is clear in the above Figure, the experimental algorithm of pressure distribution of the side weir of is completely different with the simulated one.

CONCLUSION

As the experimental data for the case in which there was no inclined ramp existed, the flow over a broad crested side weir with an inclined ramp alongside of the side weir is numerically investigated by a one leading numerical model. This investigation shows that installation of an inclined ramp will decrease the amount of lateral outflow and because of the existence if reverse flow, the water surface profiles over the side weir were different from the typical type of water surfaces which were seen in the experiments. Moreover, the values of pressure over the simulated side weir were much less that the values of experimental pressure. The main objective of this paper was to reveal that to what extend a numerical model can be useful to investigate the different hydraulic phenomenon from different aspects without having necessity for extra experiments. The simulation results also shows that Turbulent model of k-ε is suitable for simulation of flow near side weir.

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