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Research Article

NUMERICAL INVESTIGATION OF THE FLOW PATTERN IN SIDE WEIRS USING FLUENT SOFTWARE

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ABSTRACT
Side weirs are included in hydraulic structure used diversion of extra water in urban sewage systems and also in irrigation and drainage systems as a water level adjuster. Hydraulic design of side weirs is complicated since the flow condition in the length of weir is various and it is not similar to the theoretical condition of a weir. Numerical simulation of flow pattern in weirs, considering the low cost and more simplicity rather than experimental model, is led to quicker cognition of hydraulic of flow in that kinds of structures. In this article we use FLUENT software for solving the numerical flow pattern which is based on finite volume method also we choose k-ε as turbulent model. The results of analysis shown as flow pattern, velocity counters distribution is X and Y directions.

Keywords: *Side Weirs, Flow Pattern, k-ε model.*

INTRODUCTION
Side weir is one of the most common structures for flow control and diversion in hydraulic laboratories, irrigation and drainage networks and water and waste water channels. Most of the times side weir direct water to downstream channel to control the flow and prevent rising flow in upstream channel. This action often should be done without too water level increasing in main channel. So a side weir almost is considered in restrictor for water level. Two following fundamental principles are used for all weirs:
- Water flow is spilt when the water level in mail channel reaches the surface of weir crown.
- With increasing the water level in main channel diversion discharge increased (Aghazadegan, 2009).

The mentioned principles have been expression in figure 1 and we can see these concepts clearly.

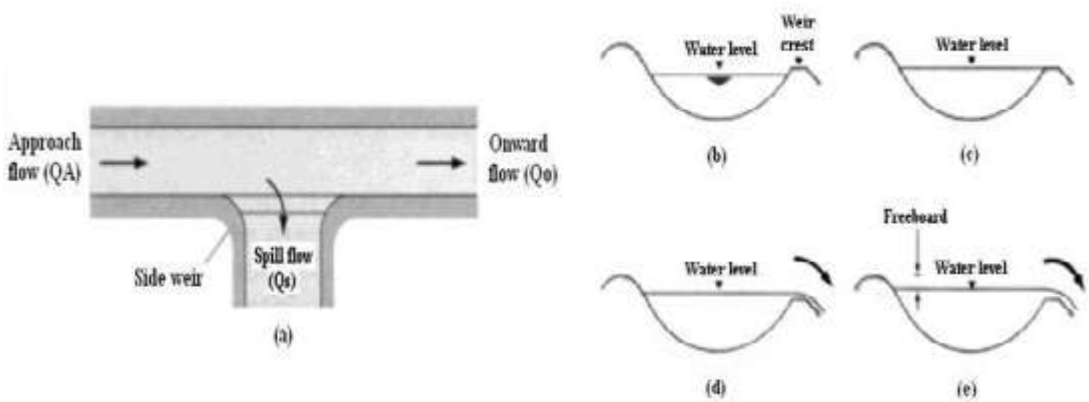

Figure 1: Side Weir – fundamental: (a) schematic plan and schematic sections showing (b) No flow over the weir (c) initiation of spill (d) weir spilling and (e) maximum diversion (May *et al*., 2003).

A side weir is often used in isolation- in other words, there is no direct control on the onward flow, other than is achieved as a result of the action of the side weir in diverting a proportion of the approaching flow. This may not be sufficient to meet the objectives of the designer in terms of the required division of flow.

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In certain cases it may, therefore, be necessary to consider installing an additional flow control structure in the parent channel at the downstream end of the side weir. Such an arrangement enables a wider range of performance criteria to be catered for, and allows the designer to examine a range of structure types in various combinations. The main options, with their associated performance criteria, are summarized in Table 1.

Table 1: Flow diversion options

Objective	Options								
	Side weir	Side weir plus orifice control structure	Side weir plus gated control structure	Gated control structures on both channel branches	Weir on both channel branches	Movable weirs on both channel branches	Gated control on onward branch only (see Note 3)	Gated control on off-take only (see Note 3)	Side weir plus flume control structure
1. Divert an increasing proportion of approach flow ($Q_S = K \times Q_A, K = fQ_A$)	✓	✓	✓	✓	× (See Note 1)	✓ •	✓	✓ •	✓
2. Limit onward flow to an absolute maximum ($Q_O < Q_M$)	×	✓	✓ •	✓ •	×	✓ •	✓ •	×	×
3. Divide flow in a pre-determined proportion that does not vary (e.g. $Q_S = 0{\cdot}6Q_A$)	×	×	✓ •	✓ •	✓ (See Note 2)	×	×	×	×
4. Fully flexible flow distribution (Q_S = 0 to Q_A)	×	×	×	✓	×	✓	×	×	×

Definitions
Q_A = approach flow, Q_S = diverted flow/spill flow, Q_O = onward flow (= $Q_A - Q_S$), Q_M = maximum onward flow

Notes
1. Weir crests have different elevations
2. Weir crests must have the same elevation – even so, the proportion of flow division may not remain accurately fixed throughout the flow range
3. A gated control structure may be automatic or manually operated

Key
✓ Appropriate ✓ May be appropriate × Not appropriate/not recommended • Operation of gates required as Q_A changes

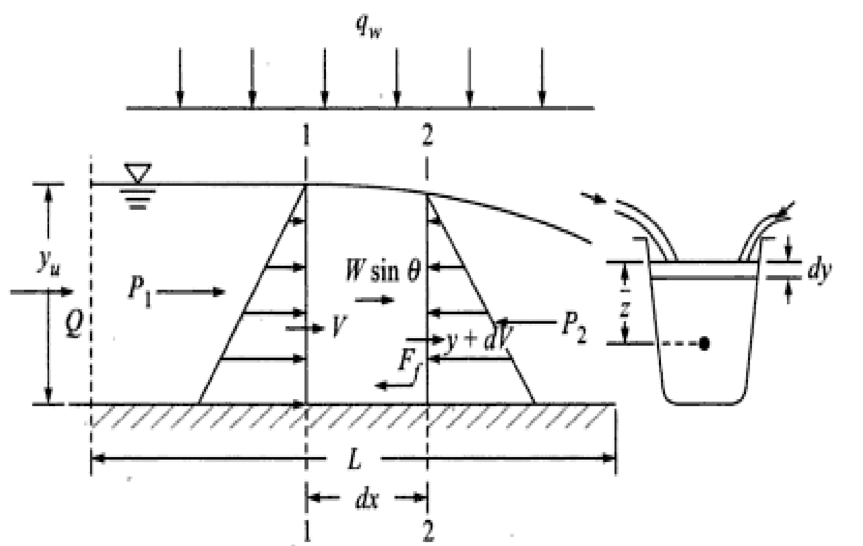

Figure 2: Sketch of Spatially varied flow

Flow in side weirs is a kind of spatial varied flows. A spatial varied flow is a permanent gradual varied flow which changes the varied discharge in the channel and varies along the amount of flow direction. According to the discharge variations, this type of flows is in divided in two groups:

1) Spatial varied flows with increased of flow.
2) Spatial varied flows with decreased of flow.

The dynamic equation of spatial varied flows with increased discharge according to the Figure 2 is generally achieved by the relation below:

$$\frac{dy}{dx}=\frac{S_0-S_f-\left(\frac{2\beta Q}{gA^2}\right)q^*}{\frac{1-\beta Q^2T}{gA^3}}=\frac{S_0-S_f-\left(\frac{2\beta Q}{gA^2}\right)q^*}{1-Fr^2} \quad (1)$$

Side weirs are usually small hydraulic structures in which the length of the weirs rating to the width is less than 3. Di Marchi (1934) could provide the hypothesis of rectangular and prismatic channel and the relation $S_0 - S_f = 0$ and $\alpha = 1$, in the direction of side weirs for the first time:

$$\frac{dy}{dx}=\frac{\frac{Q}{gB^2y^2}\left(-\frac{dQ}{dx}\right)}{1-\frac{Q^2}{gy^3B^2}}=\frac{Qy\left(-\frac{dQ}{dx}\right)}{gB^2y^3-Q^2} \quad (2)$$

On the other side discharge on the weir and in unit of its length equals to:

$$-\frac{dQ}{dx}=\frac{2}{3}C_M\sqrt{2g}(y-W)^{3/2} \quad (3)$$

Which in it C_M modules id intensity of flow, and is known Di Marchi's modules. By assuming that specific energy is fixed, the amount of flow intensity in each channel is achieved through the phrase below:

$$Q=By\sqrt{2g(E-y)} \quad (4)$$

With the combination of above relation and then integrating from two sides of the relation below which is known Di Marchi's module, the module is achieved.

$$x=\frac{3B}{2C_M}\left(\frac{2E-3W}{E-W}\sqrt{\frac{E-y}{y-W}}-3\sin^{-1}\sqrt{\frac{E-y}{E-W}}\right)+\ cte \quad (5)$$

In this relation X is the length of the side weir, B is the width of channel, E is specific energy, W is the height of weir and Y is the depth of flow (Hosseini *et al.,* 2002).

Reviewing Previous Studies

From the beginning of the previous century until now, the behavior of flow in side weirs has caught a lot of attention to itself and many studies which are experimental characteristics have been done, Di Marchi achieved for the first time in 1934 that the dynamic equation of spatial varied flows by decreasing discharge with the assumption that the equation energy dominant on flow is fixed, and to calculate the output discharge from the side weir of intensity of flows module which is named the Di Marchi coefficient.

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Table 2: The proposed equations for calculating the side weir discharge coefficient

Row	Name a researcher (Year)	Considerations	The equation for determining discharge coefficient (C_d)
1	Subramanya and Awasthy (1972)	$0 \leq W \leq 0.6$	$C_d = 0.864\sqrt{\frac{1-Fr_1^{\,2}}{2+Fr_1^{\,2}}}$
2	Utech (1972)		$C_d = 0.622 - 0.222Fr_1^{\,2}$
3	Thomson and Nadsamorty (1972)	$0 \leq W \leq 0.6$	$C_d = 0.864\sqrt{\frac{1-Fr_1^{\,2}}{2+Fr_1^{\,2}}}$
4	Ranga *et al.*, (1972)	$0 \leq W \leq 0.6$	$C_d = 0.81 - 0.6Fr_1$
5	Hager (1987)	$0.2 \leq W \leq 0.5$	$C_d = 0.485\left(\frac{2+Fr_1^{\,2}}{2+3Fr_1^{\,2}}\right)^{0.5}$
6	Cheong (1991)	W=0	$C_d = 0.45 - 0.22Fr_1^{\,2}$
7	Sing *et al.*, (1994)	W=0	$C_d = 0.33 - 0.018Fr_1 + 0.49\frac{W}{Y_1}$
8	Swami *et al.*, (1994)		$C_d = 0.447\left(\left(\frac{44.7W}{49W+Y}\right)^{6.67} + \left(\frac{Y-W}{Y}\right)^{6.67}\right)^{-0.15}$
9	Shafayee and Izadjoo (1995)		$C_d = -0.0759Fr_1^{\,2} - 0.7364\frac{W}{Y_1} - 0.0187\frac{L}{Y_1} + 0.199$
10	Ghodsian (1996)		$C_d = \left(0.611 + 0.075\left(\frac{Y-W}{W}\right)\right)\left(1 - 0.63Fr_1^{\,0.33}\right)$
11	Jalili *et al.*, (1996)		$C_d = 0.71 - 0.41Fr_1 - 0.22\left(\frac{W}{Y_1}\right)$
12	Borghei and Salehi (2002)		$C_d = 0.82 - 0.38Fr_1 - 0.22\left(\frac{W}{Y_1}\right) + 0.08\left(\frac{L}{B}\right)$

Since lake of accurate information about the Di Marchi's coefficient, this module is not trusted to use. Subramanya and Awasthy (1972) showed no interest in general equation differential of spatial varied flow with decreased Debi in a horizontal rectangular channel in which it has side weir with the height aero or limited and by doing examinations for the below and above critical flow, they provided relations to calculate the discharge's module for the side weirs with sharp edge (Subramanya *et al.*, 1972).

Utech (1972) after studding the works of Subramanya and Awasthy stated that the equation provided by the mentioned people has errors in height of the weir (w>0) and the Froude number ($Fr_1 > 0.6$) and it offered a relation to identify the module of intensive flow in the rectangular side weirs.

Thomson and Nadsamorty (1972) by doing a survey of intensive flows module done by Subramanya and Awasthy provided relation for calculating the module of flow discharging. Ranga *et al.,* (1972) in the hydraulic lab of Roorkee University in India had been studied to verify the Di Marchi's module at first to estimate whether it can discharge from the sharp edge and wide edge. Finally it resulted the relations for calculating the rate of discharge for each of the mentioned weirs (Ranga *et al*., 1979).

Hager (1987) by stating that the assumption of discharge's relation on normal weir is entrusted in side weirs offers a new formula for the side weirs. He stated that the module of intensive flow depends on the factors of speed rate to depth of flow, the angle of output flow and the shape of the channel (Hager, 1987).

Cheong (1991) concentrated his studies on the rectangular side weirs in the trapezoidal channels and he also provided a relation to calculate the module of discharging in this situation (Cheong, 1991). Sing *et al.,* (1994) indicated that though the intensity of flows module has the landed number of high position rating to the height of the weir and by using multiple regression they achieved a relation to calculate the module of discharging (Singh *et al.,* 1994).

In swami et al studies (1994) a new concept named the positional module of intensive of flow became the field of interest and to calculate the intensity of flows module in the sharp-edge weirs without partition in two sides of the channel they provided a relation (Swamee *et al.,* 1994). Shafayee and Izadjoo (1995) after presenting a computerized model to calculate the profile of water level along the side weir they offered a relation to calculate the module of flow discharging in the rectangular weirs with sharp edge (Shafayee *et al.,* 1995). In Jalili *et al.,* (1996) the effect of various parameters on the module of discharging was rarified (Jalili *et al.,* 1996). They showed that in supercritical flow's the assumption that the specific energy in fixed in the length of the weir is not correct.

Borghei and Salehi (2002) by considering the depth of the weir as the critical depth of side weir's Devi provided a relation to calculate the module of discharging. Hussein (2004) studied the one-dimensional mathematical model for hydraulic side weirs in hydraulic jumping condition (Vali, 2004). Uyumaz (2005) studied the side weir in triangular channels and provided a limited numerical model based on the assumption that the energy in the below critical and above critical of flow is fixed and also presented a profile for the water level (Uyumaz *et al.,* 1985).

Aghayari *et al.,* verified the effect of height and width of top of the rectangular lateral prismatic rectangular channel. Bozargian and Yazdandoost studied the profile of water level on the side weir in a channel with a non-prismatic geometry and trapezoidal level. In Table 2 some of the most important relation for calculating the module of side weir's discharging is mentioned with the name of the researchers.

The offered relations to calculate the module of side weir's discharge in the above table. W= the height of the top edge, L= the length of the weir, B= the width of the channel, Fr_1= the Froude number of flow before the weir and Y= the depth of water in every spot of channel.

The Characteristics of the Experimental for Studying

The experimental model for studying in terrestrial channel includes in the length 32m, width of channel 1m with manning coefficient 0.022, trapezoidal level with the length 4m and the width 80cm. The slope of the button of weir is considered zero. The schematic model is shown in figures 3 and 4.

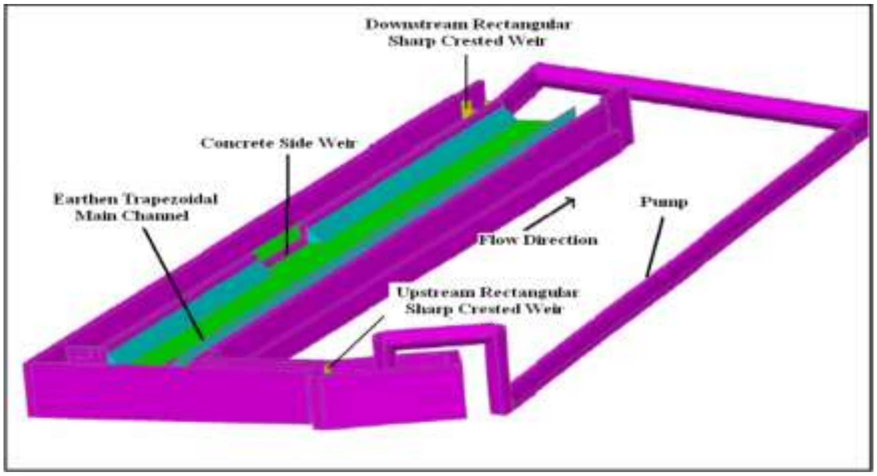

Figure 3: Laboratory Setup

Figure 4: Images from the side weir of the study

The Governing Equations on the Flow and Used Software

There are three ways to solve the related problems with fluid mechanics that include experimental methods, analytical and numerical. The progress of numerical in various sciences has been remarkable in recent decades.

Due to the high cost of experimental methods and the weakness of analytical methods in solving engineering problem, today, most researchers turn to the use of numerical methods.

The analysis and design of hydraulic structures to ensure greater efficiency and higher performances of the method depends upon deeper reflection on the flow behavior. The governing equations are solved by numerical methods to determine the flow parameters are providing in a wide range. These equations are generally formed by Navier-Stokes. Numerical solutions of these equations are non-linear due to the nature of its subtleties and solving the governing equation has always faced challenges. In the past few years due to the need for large computer memory solving these equations was impossible. Fortunately nowadays, solving these equations is provided for many people. In this regard, there are specialized applications that are designed for the intended flows can additionally reduce laboratory costs and largely save time. The numerical methods used in CFD are: Finite element method, finite volume method, finite difference and spectral methods (Shojayi *et al.*, 2008).

Among these methods, the methods FVM (final volume methods) is more applicable, especially when the modeling of the flow is incompressible most commercial software about computational fluid dynamic developed based on this method. To build our model we have used the fluid software. The Fluent software is the best software to modeling the fluid flow and transferring the heat in the complex geometry. This software is able to do the calculation with normal accuracy, double accuracy and a user can voluntarily choose each option. This software is based on the finite volume method that is a very powerful and suitable technique in computational fluid dynamics method. To make the numerical model, first the construct geometry is model must be built inside the Gambit software and then within the same program we can meshing our built structure arbitrarily. Then we will solve this built file in fluent software we use a two-dimensional fluent with a one-time event processor and in the next step we should choose the solving approach. Fluent has provided 3 approaches to solve: coupled explicit, coupled explicit, coupled implicit and segregated. These three formulas give very accurate results in a great extent for various fluids. In some cases it is possible one of the formulations functions better. For example using one of the methods based on the other methods might be solved faster. The segregated method is preferably used incompressible flows or mild flows. But coupled method is specifically designed for the compressible flow with high speed. In this research we have used the segregated method to solve the flow (Soltani *et al.*, 2008).

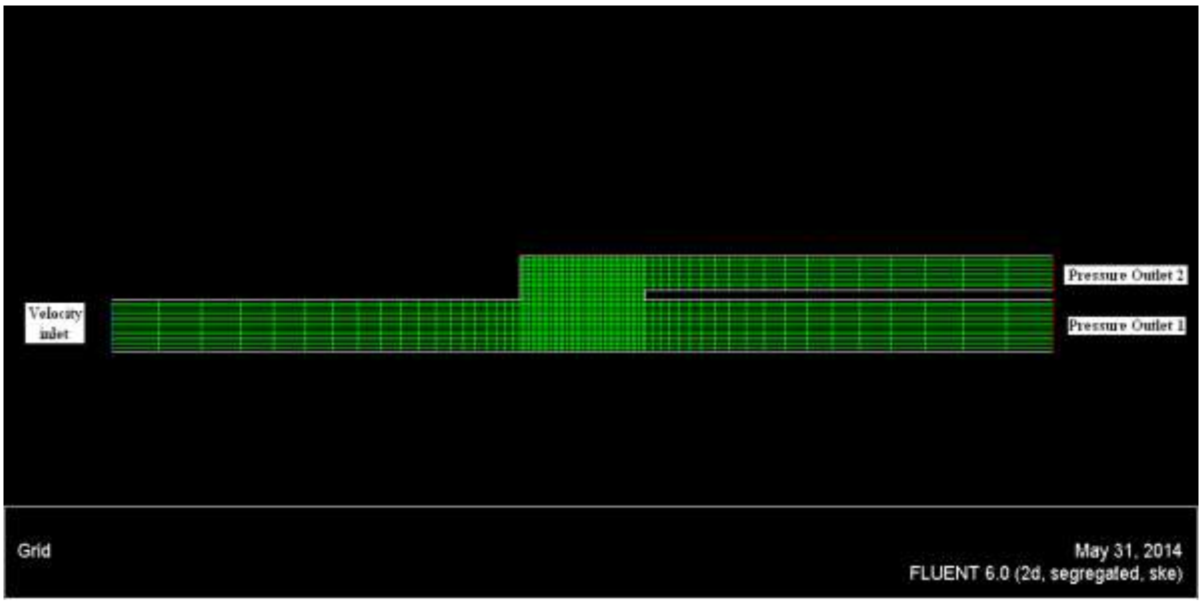

Figure 5: Geometric, meshing and boundary condition in model

We also chose K- ε as the turbulence model. K- ε model is fairly complete and general but it is transport properties of turbulence by the mean flow, influence the production and dissipation of turbulent is use useful. In this model two transport equations (partial differential equation: PDE), one for the turbulent kinetic energy (K) and the turbulent kinetic energy dissipation rate are solved. The K- ε standard model uses the below transport equations through which k, ε are treated in Fluent software:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\left[(\alpha+\frac{\alpha_t}{\sigma_k})\frac{\partial}{\partial x_j}\right)\right]\right]+G_k+G_b \qquad (6)$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_i}\left[\left(\left[(\alpha+\frac{\alpha_t}{\sigma_k})\frac{\partial \varepsilon}{\partial x_j}\right)\right]\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2s}\rho\frac{\varepsilon^2}{k}$$
(7)

$$k=\frac{1}{2}(\overline{u^2}+\overline{v^2}+\overline{w^2}) \qquad (8)$$

k= Kinetic energy (per unit mass) related to the turbulence

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α_t= Turbulence viscosity
The equations are included in five adjustable constant whose values are:
$O_k = 1.0$ $C_x = 0.09$ $C_1\varepsilon = 1.92$ $C_2\varepsilon = 1.92$ $\sigma\varepsilon = 1.30$
G_b = Terms of turbulent kinetic energy is due to buoyancy force.
G_k = Terms of turbulent kinetic energy is in medium speed due to gradient.
To access the flow pattern in the side weir structural geometry by using existing maps, was developed in Gambit software (Figure .5). As it is observed near the partition and the areas where there is high gradient. The meshing has been smaller.

RESULTS AND DISCUSSION

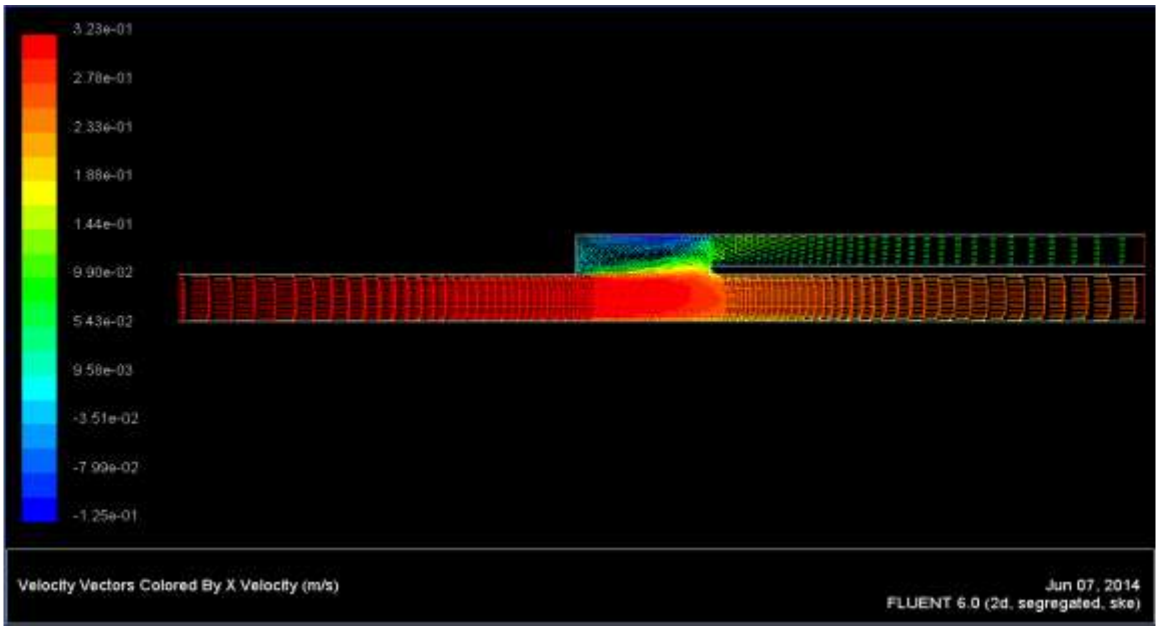

Figure 6: Display velocity vectors in x direction

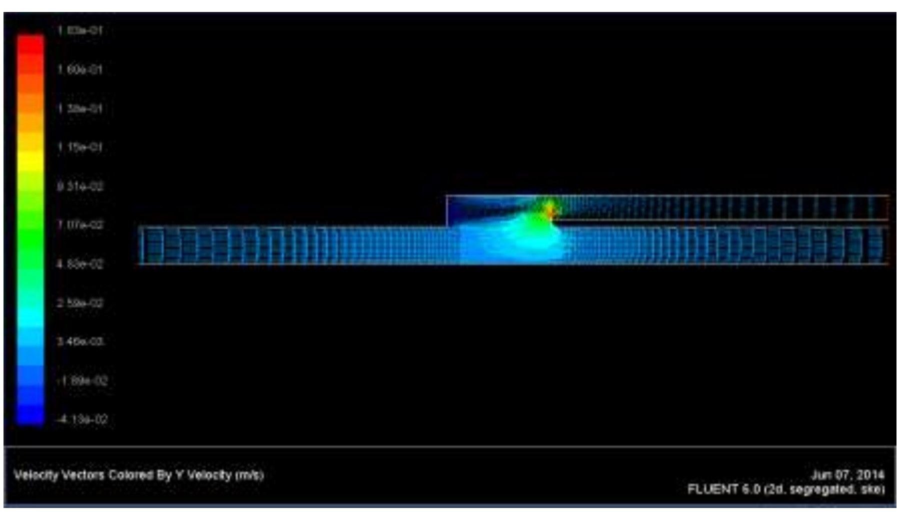

Figure 7: Display velocity vectors in x direction

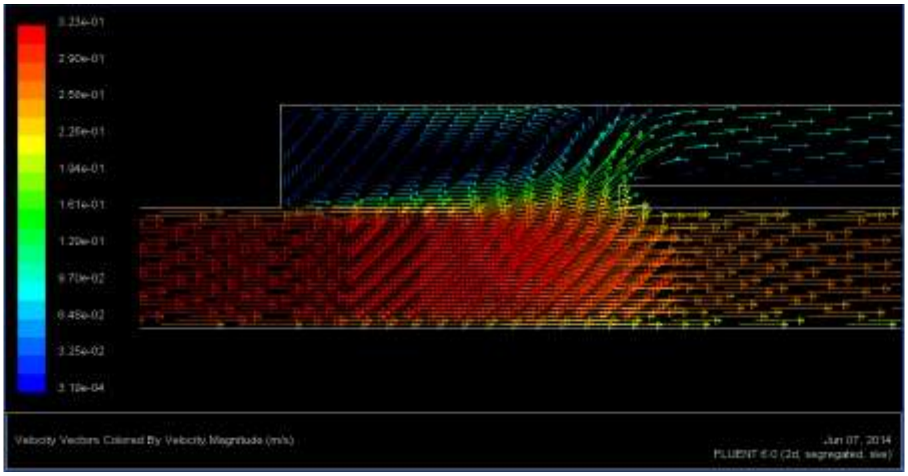

Figure 8: Display velocity vectors in side weir

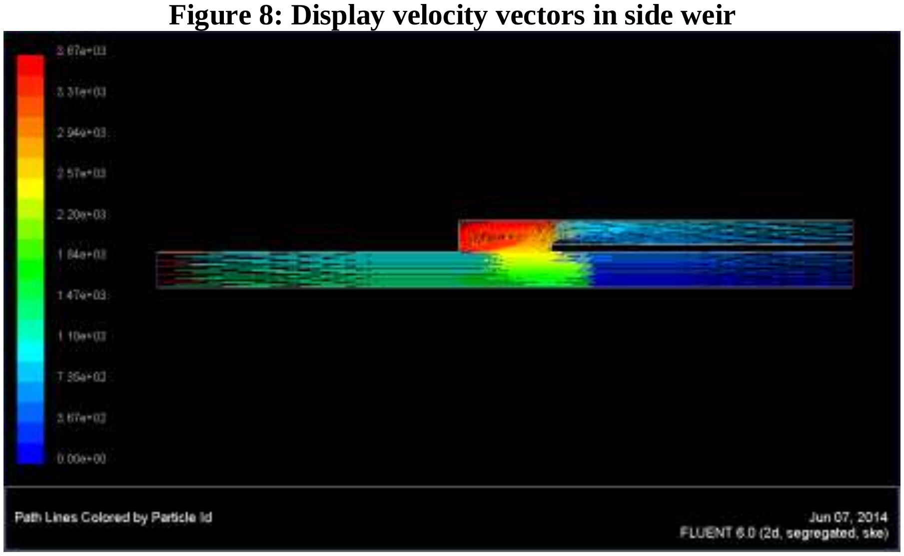

Figure 9: Display Flow Pattern in model

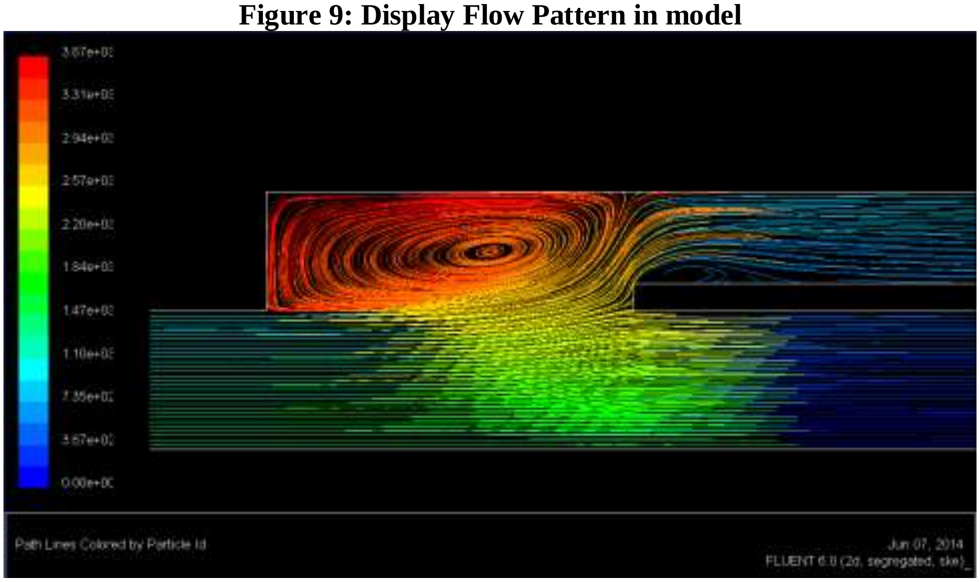

Figure 10: Display Flow Pattern in side weir

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As we can observe in Figure 5 we have used a velocity inlet condition and two pressure outlet conditions to solve. Then we transferred this geometry to the Fluent software according to the experimental data in this modeling, we considered the input velocity 0.30874 meters per second. By solving the flow of the flow lines. Velocity counters are in the directions of X and Y, as they are shown in figures 6 to 10.

Conclusion

According to the results obtained in this study it can be concluded the highest velocity vectors for +X occurred in the main channel (Figure 6). The highest velocity vectors for –X occurred in the vortex area (Figure 6). The highest values of the velocity vectors for +Y are also shown in Figure 7. Furthermore according to Figures 9 and 10 due to the flow crossing from the weir, two vortex flows are developed. According to the obtained result it can be concluded that the Fluent software has a high ability in flow in modeling inside the side weirs and by this software it is possible to obtain the related parameters in a desirable level.

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