The energy dissipation of Stepped Spillways experimentally and numerically

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ABSTRACT

A stepped spillway is a hydraulic structure, which is an integrated part of the dam, which allows the safe passage of overtopping flows. In this paper, experimental and numerical studies were carried out to investigate the effect different relative step height of spillways to get the best of dissipating the energy. Modelings of flow over spillway were carried out using a commercially available 3-D CFD model, FLOW-3D, which solves the RANS (Reynolds Averaged Navier-Stokes) equation. FLOW-3D was employed to analyze and obtain energy dissipation rate. The best geometry of the steps, through which the maximum energy dissipation can be achieved, was determined by reviewing related literature and inventing the proposed model in FLOW-3D.from resulting showed to the bets relative step height of spillways (hs/H) = 0.25.and the numerical models using FLOW-3D were found to be agreed well with the measured data for different experimental models.

KEYWORDS: Stepped spillway, FLOW-3D, energy dissipation.

1. Introduction

Stepped spillway was quite common in the 19th century and present practice is confined to simple geometries e.g. flat horizontal steps in prismatic chutes. Chanson (2002), investigate the flow resistance of skimming flows and associated form losses. Recent laboratory experiments were systematically performed with channel slopes ranging from 5.7º up to 55º and they are compared with existing laboratory and prototype data. Chanson (2004), study to provide a comprehensive study of transition flows down stepped chutes. Air–water flow measurements were conducted in two large facilities with slopes ranging from 3.4 to 22◦ and equipped with large step heights. Barani et al.(2005) investigate energy dissipation of flow overstepped spillways of different step shapes, Results show that the energy dissipation of flow on end sill and inclined stepped spillways are more than the plain one, it is increased by increasing the thickness of end sill or the adverse slope size. Hazzab and Chafi (2006), investigated experimentally the stepped spillways of flow and energy. Hubert Chanson (2008), study Stepped spillway flows are characterized by significant turbulent dissipation on the chute associated with strong free-surface aeration. Herein the validity of the Froude

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similitude is tested by re-analyzing three experimental data sets corresponding to moderate

slopes typical of embankment dams and storm waterways (α = 3.4 to 22°). The results are used to test the validity of the Froude similarity and to assess the scale effects and the experimental distortion to prototype stepped spillways. Rad and Teimouri (2010), evaluate energy dissipation in simple stepped s pillways by taking into accounts some parameters by numerical method and study the governing equations are solved by finite volume discretization method and the standard k−ε model is used for estimating the turbulence flow. Felder and Chanson, (2011), study was conducted in a moderate slope stepped chute (1V:2H) and five stepped configurations were tested for $0.7 < d_c/h < 1.9$. Detailed air-water flow measurements were performed for each configuration and the results were compared in terms of flow patterns, energy dissipation and flow resistance. Nikseresht et al. (2013) study, the two-phase flow over two types of step-pool spillway was investigated using two-phase schemes (Volume Of Fluid (VOF) and mixture) and various turbulence modeling. Rassaei and Rahbar (2014), used of the Fluent numerical model , which it works based on the finite volume method and for determination the free surface flow has been used the volume of fluid method (VOF) and for the turbulence flow has been used of the standard K-ε model. And they continue energy dissipation were calculated on per number of steps 5th and 10th and compared with experimental results of other researchers, and calculated the error rate and will be discussed performance of the FLUENT model. Morovati et al. (2016), study the effect of different number of pooled steps and discharge on flow pattern especially energy dissipation was investigated. The VOF method was used to simulate the flow surface and the k-ε (RNG) turbulence model was used for flow turbulence simulation. Mansoori et al. (2017), study, energy dissipation was investigated in a specific type of stepped spillways. The purpose was to achieve the highest level of energy dissipation in downstream of the spillway. It was performed by providing a specific type of geometry for step as a great roughness. In this paper study en energy dissipation of different stepped spillways as relative step height of spillways experimentally and numerically.

2. Experimental work

Experimental work was carried out in the Hydraulic and water Engineering Laboratory, Faculty of Engineering, Zagazig University, Egypt. The upper channel with 16.2 m length, 65cm depth and 66 cm width (Photo1) used for laboratory measurements. The lower one for measuring discharge by calibrated weir for equation $Q = 1.088*Y^{1.523}$, Where :Y is the height of water over the weir crest , Q :discharge., There are two point gauges was used, the first one was used over the upper flume to measure the depth of water over the weir crest and water surface profile. The other gauge was used in the lower flume in order to measure the water depth over calibrated wear to calculate the discharge. the mode of stepped spillways with different number as shown in photo(2).

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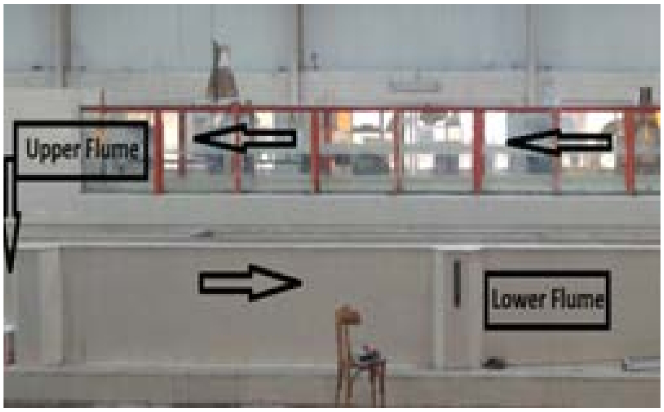
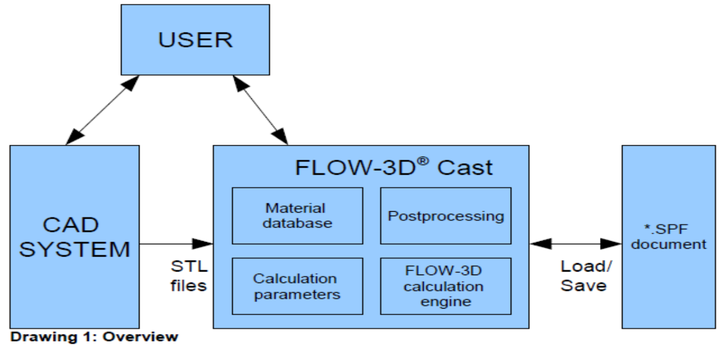


Photo (1) general view of laboratory apparatus and flow direction

Photo (2) stepped spillways for (hs/H) =0.17,0.25

3-The numerical model.

3-1 FLOW-3D: Overview



3-2 Equations:

On the Cartesian coordinate system(x, y, z) , governing equations for analysis of incompressible three dimensional flow are given by:

$$V_F \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(uA_x) + \frac{\partial}{\partial y}(uA_y) + \frac{\partial}{\partial z}(uA_z) = \frac{RSOR}{\rho}$$

Where, (u,v,w) are velocity components in the coordinate directions (x, y, z) , (A_x ,A_y ,A_z) are fractional areas open to flow in the coordinate directions (x, y, z) , ρ is density and **RSOR** is a density source term.

$$\frac{\partial u}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial u}{\partial x} + vA_y \frac{\partial u}{\partial y} + wA_z \frac{\partial u}{\partial z} \right) = -\frac{1}{\rho}\frac{\partial p}{\partial x} + G_x + f_x$$

$$\frac{\partial v}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial v}{\partial x} + vA_y \frac{\partial v}{\partial y} + wA_z \frac{\partial v}{\partial z} \right) = -\frac{1}{\rho}\frac{\partial p}{\partial y} + G_x + f_x$$

$$\frac{\partial w}{\partial t} + \frac{1}{V_F}\left(uA_x \frac{\partial w}{\partial x} + vA_y \frac{\partial w}{\partial y} + wA_z \frac{\partial w}{\partial z} \right) = -\frac{1}{\rho}\frac{\partial p}{\partial z} + G_x + f_x$$

Where, V_F is a fractional volume open to flow, p is pressure, (G_x, G_y, G_z) are body acceleration in the coordinate direction (x, y, z) , and (f_x,f_y, f_z) are viscous accelerations in the coordinate direction (x, y, z) .

In order to model a free surface, the boundary between water and air, the VOF function (volume of fluid, F) should be defined to meet the following governing equation. If F(x, y, z,t) is equal to 1, the control volume will be full of fluid, and if F is equal to 0, no fluid will exist in a control volume. Furthermore, in the case of a free water surface, F is shown to have the value between 0 and 1. Applying function F to equation (1):

$$\frac{\partial F}{\partial t}+\frac{1}{V_F}\left[\frac{\partial}{\partial x}\left(FA_x u\right)+\frac{\partial}{\partial y}\left(FA_y v\right)+\frac{\partial}{\partial z}\left(FA_z w\right)\right]=0$$

3-3 Numerical simulation algorithm:

The equation discredited using a finite difference method, whereas, a FLOW-3D adopts a finite volume method using a finite difference method plus a FAVOR (Fractional Area and Volume Obstacle Representation) method (Flow science, 2002).

After the analysis areas are divided by grids, the calculation is carried out based on a grid unit. That is, the velocity can be computed for the given pressure at each grid, and using the velocity, the value of a pressure equation in a form of a Poison equation can be calculated. Then, the velocity can be adjusted to the computed value. If it is necessary to calculate the free water surface, it is common to adopt a VOF using the fixed Eulerian method. The VOF method for FLOW-3D adopts accurate pressure and kinetic boundary conditions and describes movement between two fluids using a special numerical difference method in order to prevent the boundary face from smearing. A difference equation of the governing equation can be solved with an explicit method except for pressure term of momentum equation and flow velocity term of a continuity equation. Both SOR and SADI can be used in order to compute a pressure term satisfying a continuity equation.

3-4 the Process of Flow Simulation on the Stepped Spillways

Given to the geometry type of the models, meshing limits should be determined through mesh blocks, in which all considered size of the structure and free space are defined. As shown in Fig(1,2)., the rigid geometry constructed was added to FLOW-3D. Also, computational environment for the stepped spillways was created in FLOW -3D using mesh bocks.

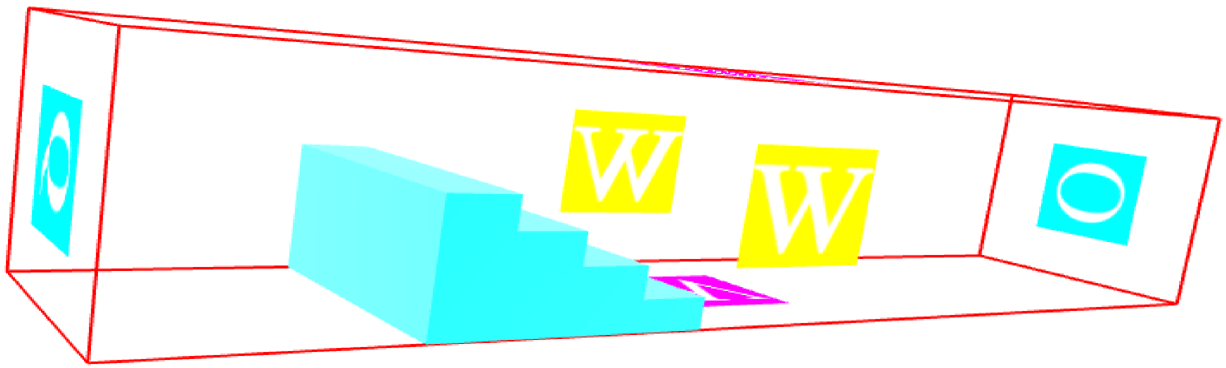


Fig (1) **boundary conditions applied in simulation**

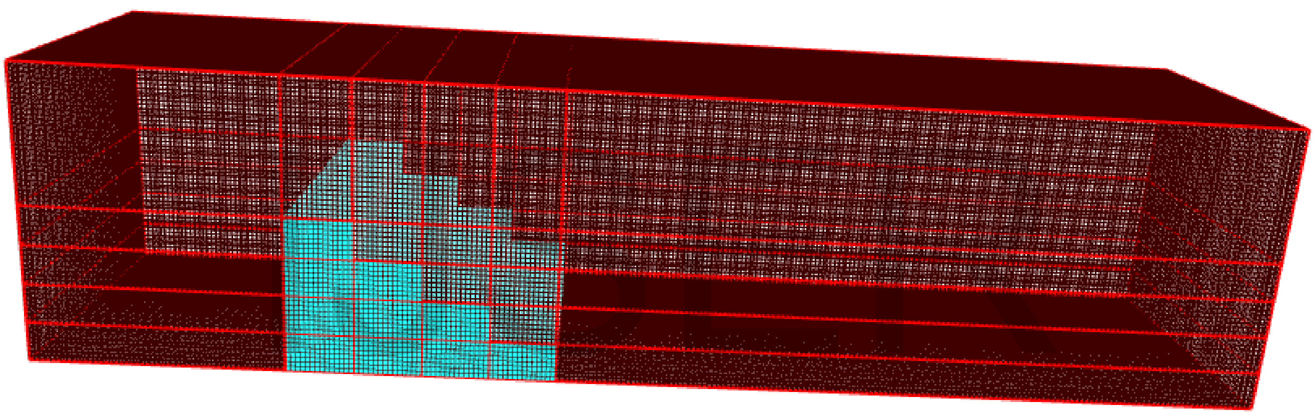


Fig.(2) Mesh block and computational cells

4- Analysis and discussion:

4-1 Effect of relative step height on the scour

The effect of relative step height of spillway with slop angle 30.65 degree on local scour was investigated experimentally. The relative step height of spill way are (h_s/H= 0.5, 0.33, 0.25, 0.17, 0.11), the relationship between $(E_0-E_2)/E_0$ and upstream Froude number (F_0) is shown in Fig. (3), for the different relative stepped spillway. This figure shows that, the maximum relative scour depth increases as Froude number increases, In Fig.(4) relationship between $(E_0-E_2)/E_0$ and specific discharge (q) and Fig.(5) relationship between (E0-E2)/E0 and relative height of spillway to critical depth (H/yc). The numerical simulation of

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different stepped spillways shown in fig.(6) that cleared Pressure contours , fig(7) showed Velocity magnitude, fig.(8) cleared Flow depth ,fig.(9) showed Turbulent dissipation, fig.(10) showed Turbulent energy and fig.(11) showed Pressure iteration residual, all figures for (hs/H)= 0.5, 0.33, 0.25, 0.17and 0.11 at discharge (Q = 40 l/s)

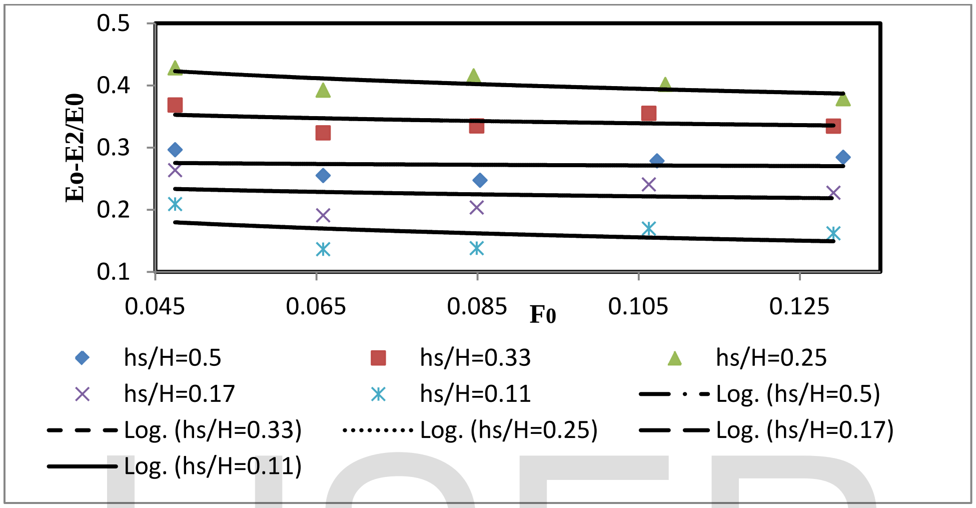

Fig.(3) The relationship between $(E_0-E_2)/E_0$ and F_0 for different relative stepped height of spillway (h_s/H).

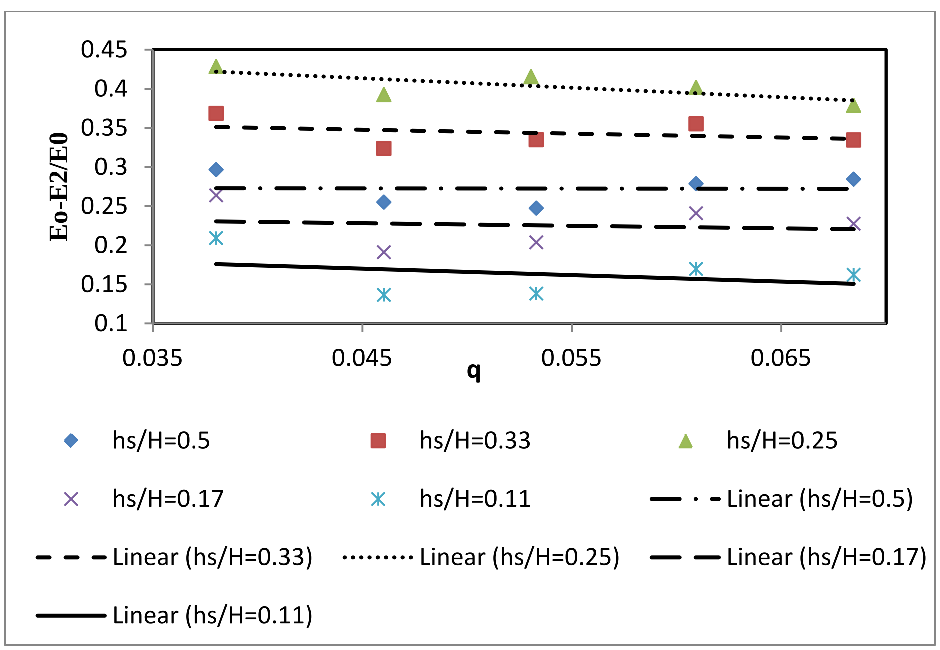

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Fig.(4) The relationship between $(E_0-E_2)/E_0$ and q for different relative stepped height of spillway (h_s/H).

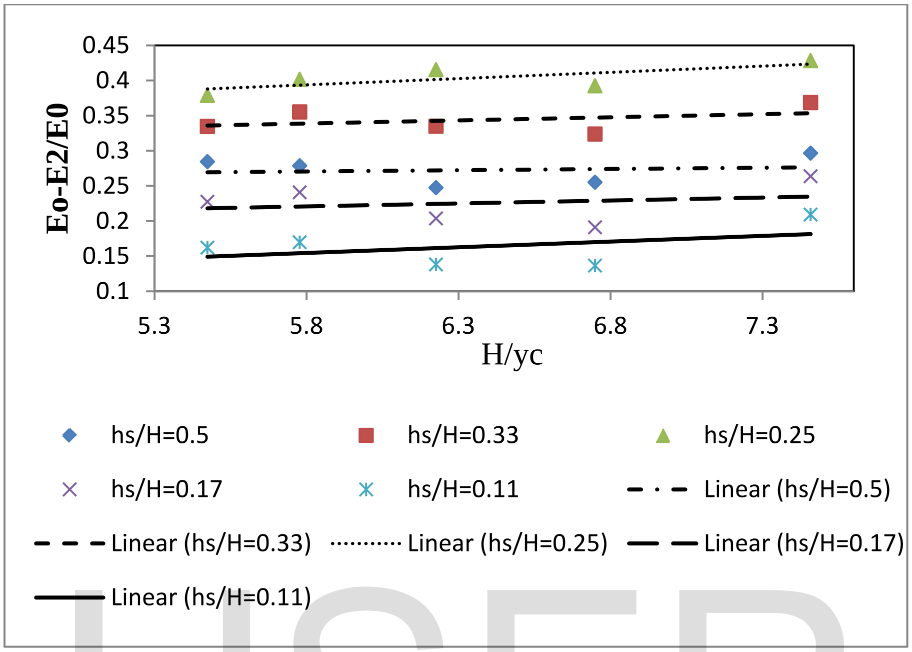
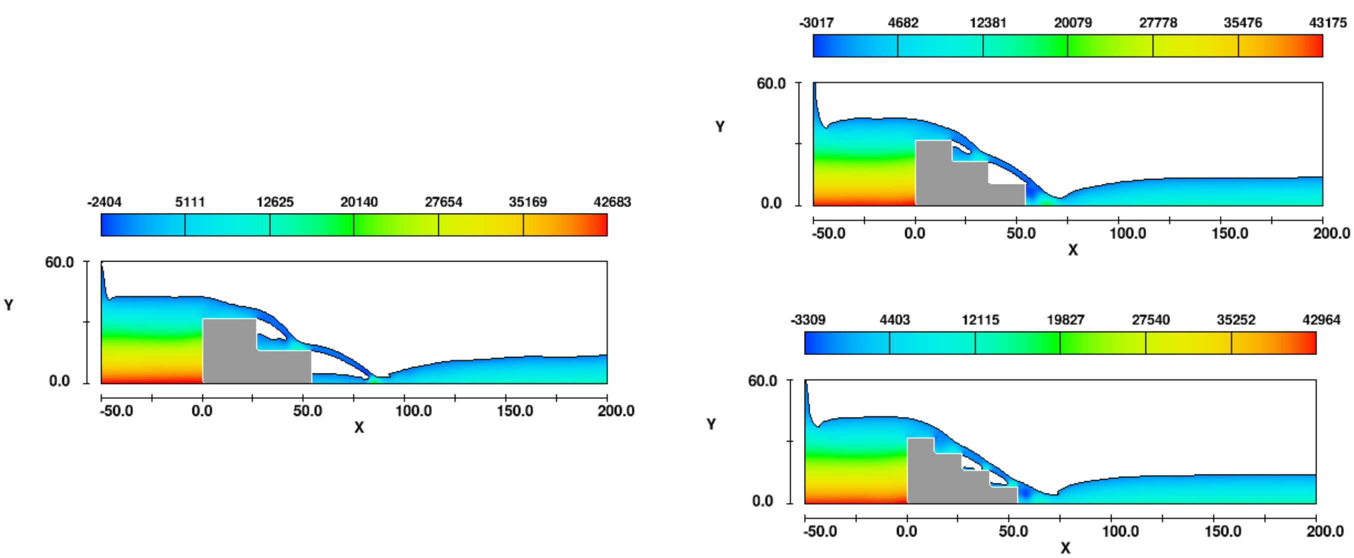
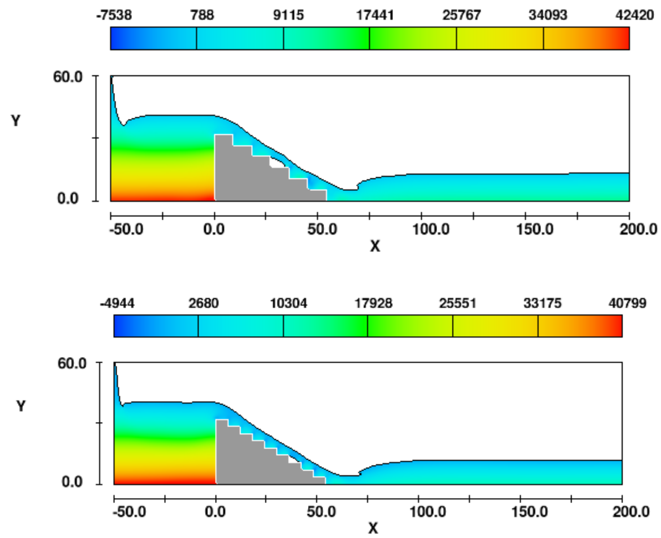


Fig.(5) The relationship between $(E_0-E_2)/E_0$ and H/y_c for different relative stepped height of spillway (h_s/H).





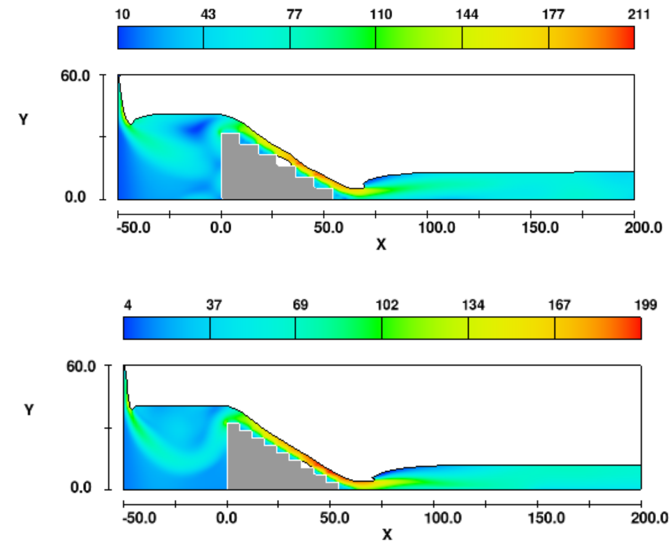
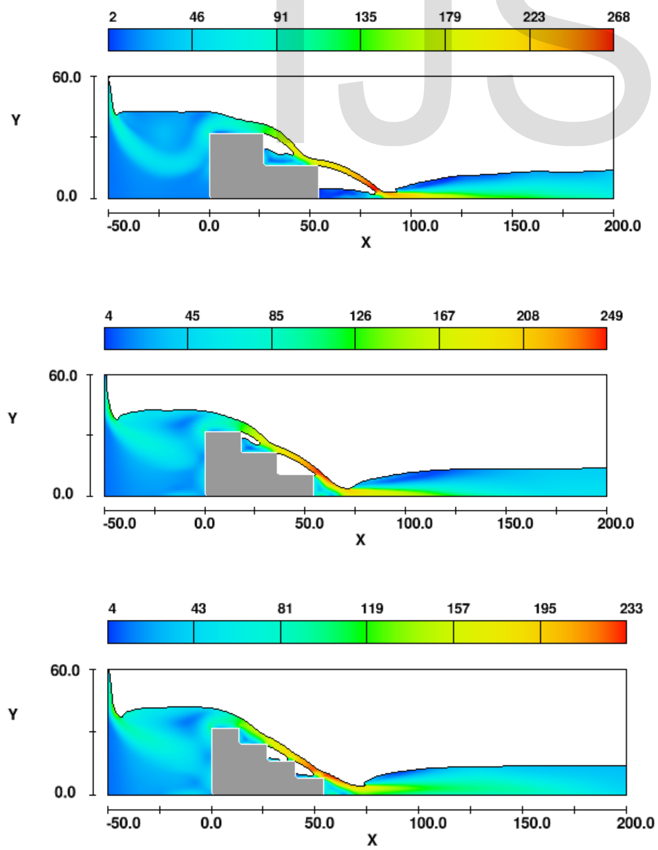
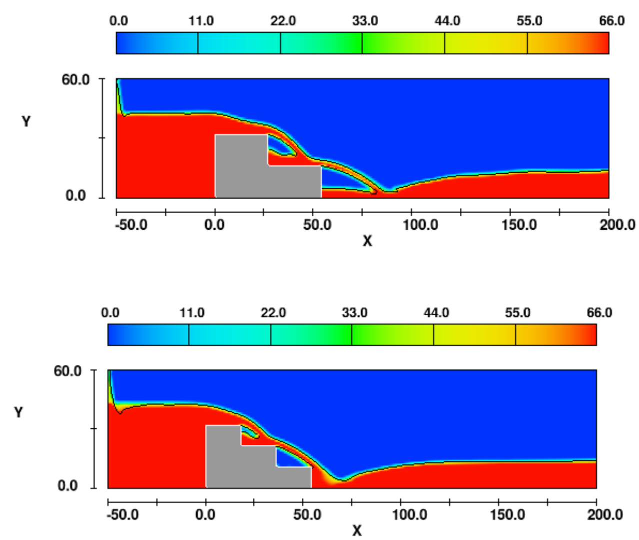


Fig.(6) Pressure contours for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s

Fig.(7) Velocity magnitude for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s





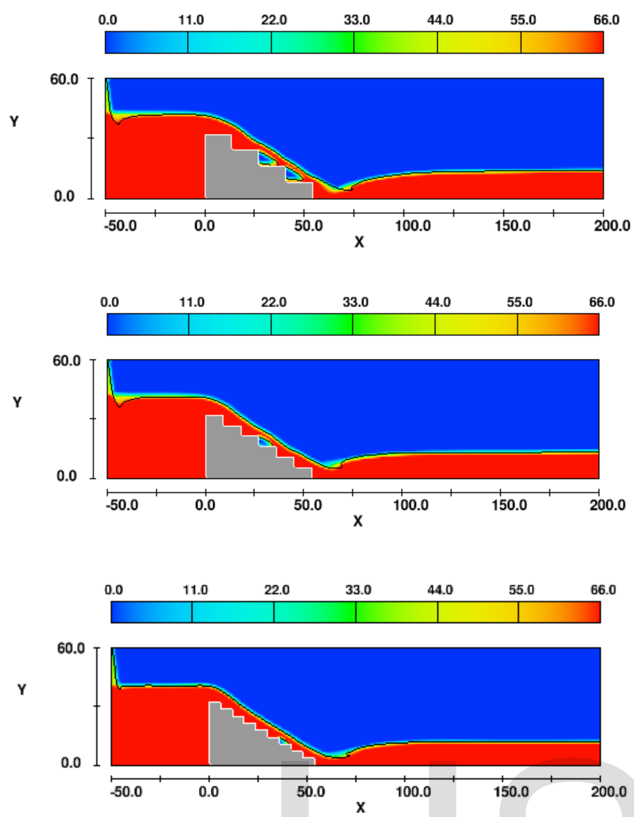


Fig.(8) Flow depth for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s

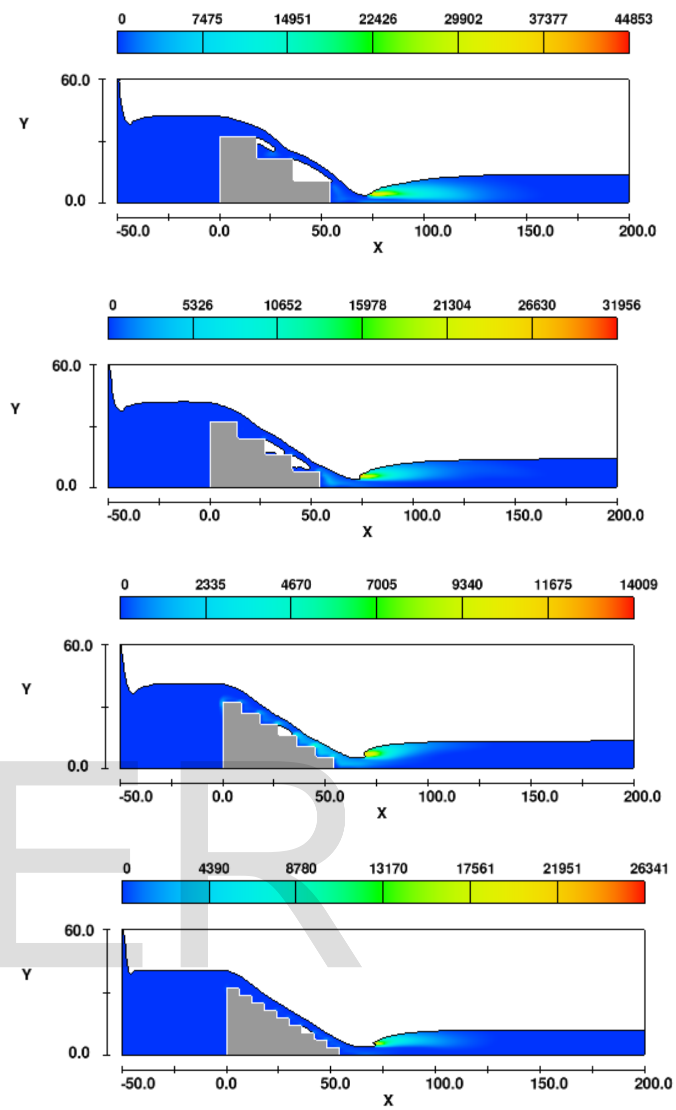
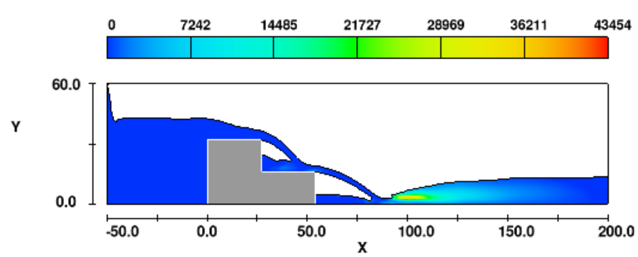


Fig.(9) Turbulent dissipation for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s



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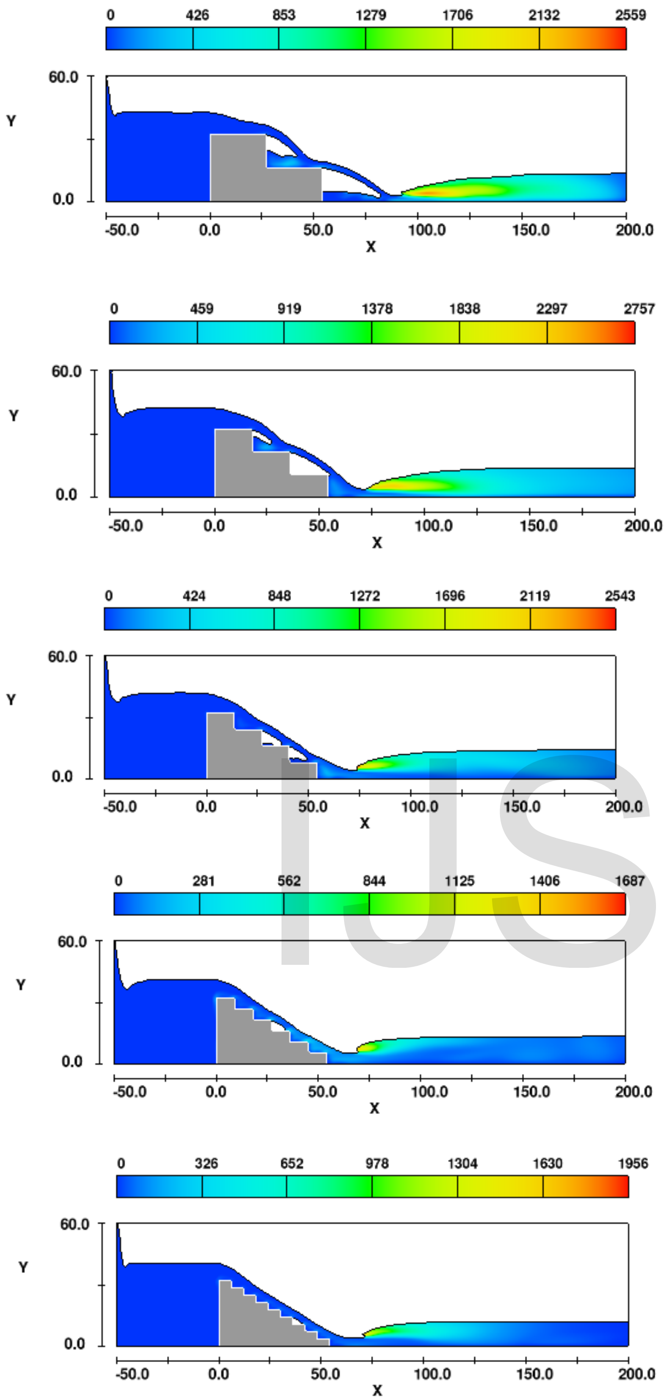

Fig.(10) Turbulent energy for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s

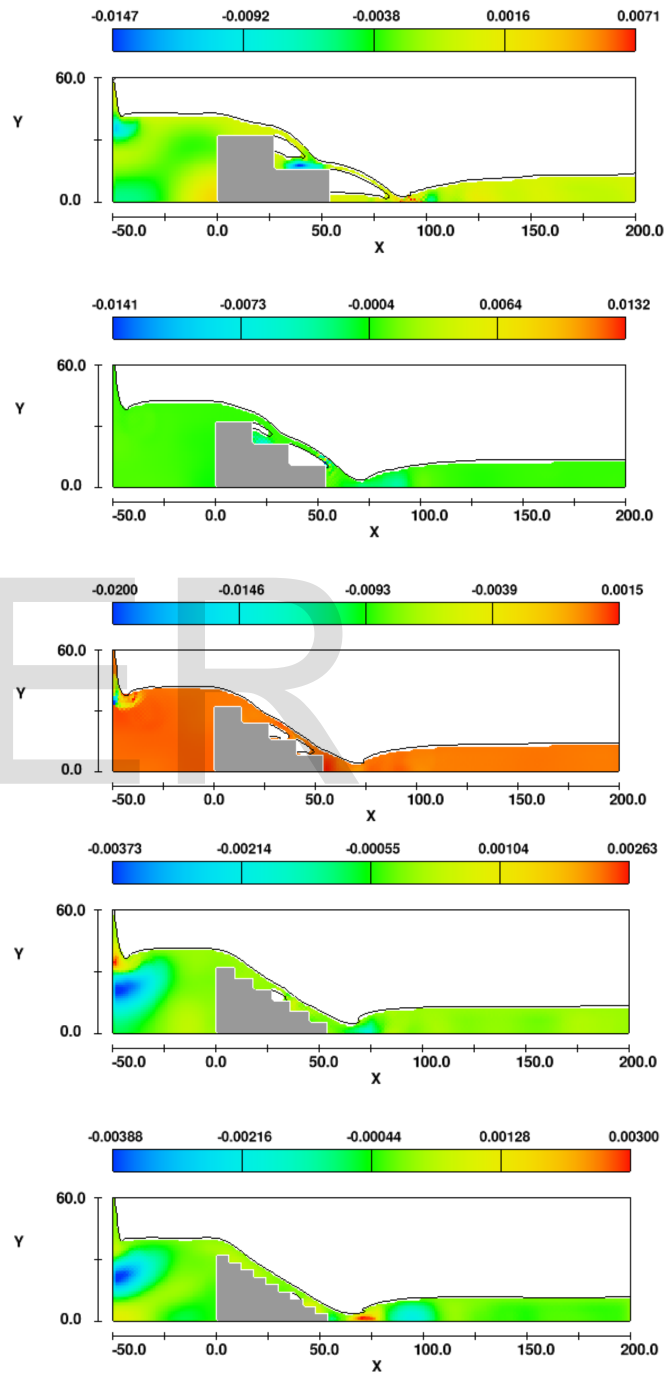

Fig.(11) Pressure iteration residual for (h_s/H)= 0.5, 0.33, 0.25, 0.17and 0.11) for Q = 40 l/s

5. Conclusions

In the present paper, experimental and numerical studies are implemented on stepped spillway It was found that: The maximum relative scour depth increases with increasing the upstream Froude number and increasing the discharge rate, the scour increase with the relative step height of spillway (h_s/H) that cleared in numerical simulations by Flow 3D program. The best relative step height of spillway (h_s/H) = 0.25, finally, the results of numerical models using Flow 3D were found to be agreed well with the measured data for different experimental models.

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