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The Effects of Scales on Modeling of Flow Patterns Over Spillway

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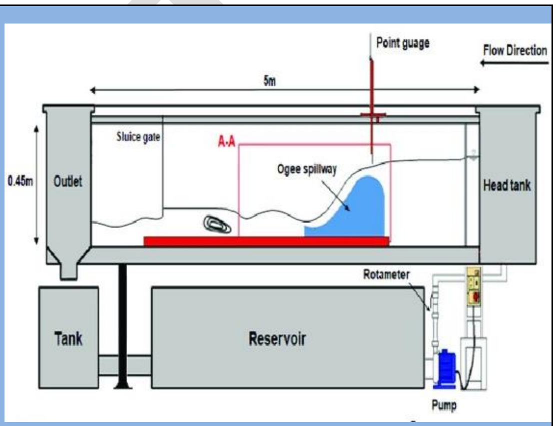
Abstract: Climate changes leading to extreme events when the occurrence and intensity of severe phenomena have impeded the development and rehabilitation of hydraulic infrastructure, such as weirs and spillways according to these new conditions. The scale physical model is one of the most important methods for designing these hydraulic structures. The selection of the model scale is necessary for model operation accuracy and design performance because of the effect of this process on design parameters resulting from the model. Scale effects can be seen through the large effect of some forces on the model that are not effective in reality, such as surface tension and viscosity forces, whose effect can be seen on the model with a relatively small scale, but are not effective on the structure at the actual size. The present study is trying to know how the physical model scales affect flow patterns over the spillway of small dam (less than 15m height) and the extent of this effect. Three physical model scales (1/30, 1/75, and 1/100) were used and compared with the actual size of the structure by numerical model (FLOW 3D). The physical and numerical models were tested with discharge values of (250, 350, 500, 750, and 1000) m3/s to evaluate the rating curve, discharge coefficients, pressure distributions, and energy dissipation. The results show the scale has significantly impacted the results, and it is preferable to avoid small scales. The 1/30 scale aligned more closely with the numerical model (the actual dimensions of the spillway) and strikes a compromise between measurement precision and expense. Therefore; the present study recommended using the scale 1/30 physical model or more for small dam spillway design.



Keywords: Spillway design, Numerical Model, Physical Models, Flow-3D, Flow Simulation, and Modeling Scale.

Introduction

Climate changes and dam projects on the shared river basins caused a significant water quantity fluctuation in Iraq [1-4]. The extremes in hydrological events, the long periods of drought, and the low water resources resulting from these climate changes have given the impetus to invest in the available water resources through water harvesting projects. These projects depend on constructing small dams (less than 15 m) to store flood water resulting from rainfall and use it during the dry season. Most of these dams are designed according to simple safety requirements, considering that they do not require many requirements (especially spillway) since they are on seasonal valley courses (rainy season only) and are built at relatively low financial costs. As mentioned earlier, climate change has led to extreme weather events, whether drought or flooding, which have caused natural disasters that have resulted in many losses of life and property. There is a general trend towards constructing many of these dams to address the crisis of water scarcity and consumption for various purposes. Therefore; it is required to know the design requirements for this type of dam and whether they are the same requirements as large dams built on perennial rivers? How can reduce the costs of construction, design and ensure safe performance so that any disasters can be avoided in the future?

The physical models have been extensively utilized for a long time to analyze and replicate the intricate flow patterns over the spillway [5]. Dams in Iraqi water harvesting projects, which are classified as small dams (less than 15 meters high), are particularly affected by the comparatively high design costs caused by the physical model. Take the Iraqi Al-Massad dam as an example; its physical model accounts for about 7% of the whole cost, this includes both building and operating costs. Sometimes, for design purposes, more than one scenario is needed which means reconstruction of the physical models. So, the cost will be greater, which requires accuracy in designing and operating the physical model. Therefore, choosing the scale is very important to ensure the accuracy of this model. The research problem includes several questions:

Does the scale have an impact on the accuracy and efficiency of the physical model.

What is the extent of this influence and is it possible to know the limits of this influence.

If modifying the physical model to test more than one operating scenario would be expensive, can a numerical model be used with the physical model?

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Physical And Numerical Modeles Flow Simulation

In some years, after a dramatic water shortage, flood water exceeded the predicted value, which caused emergency problems related to dams and spillways. To address and study operational efficiency problems, several scenarios must be examined and tested to evaluate this efficiency. Physical models can simulate the complex flow patterns over the spillway. A physical model is time-consuming and has relatively high costs. So, an accurate physical model design is required to provide efficient results and an efficient design spillway. The effect of the physical model scale is the most significant parameter that may be used to readily capture flow pattern behavior such as cavitation and surface tension. Adopting the physical model scale is very important as it is related to the cost and the accuracy of the results that can be obtained from model operation. For example, adopting a small scale can lead to the simulation of the flow over the spillway, including the appearance of forces affecting the operation of the model that do not exist in reality, such as the effect of surface tension and boundary layer. In contrast, these forces do not affect the flow at the actual spillway size.

To predict and test the efficiency of the spillway design, implementing more than one scenario, such as modifying the dimensions or components of the structure, is needed. This process is difficult and expensive in physical models when the numerical model can simulate the flow process with the different scenarios quickly and without high cost.

For the numerical model to be adopted in the design and operation of the spillway, it must be calibrated and compatible with the physical model. So, the efficiency of the design of the physical model is required, which in turn depends on adopting the appropriate scale. The three-dimensional Navier-Stokes equations, which include the conservation of mass and momentum, are numerically solved using computational fluid dynamics (CFD) models [6]. Many commercial (CFD) programs exist today that can simulate fluid flow; these include, but are not limited to, Ansys Fluent & CFX, Flow-3D, OpenFOAM, Power Flow, SimScale, COMSOL Multiphysics, Autodesk CFD, and many more [7-17]. Researching overflow spillways and comparing program outcomes to experimental models are the primary foci of their work.

Moreover, a numerical investigation was carried out by [18] using Fluent-3D with the k-Ɛ turbulence model. The objective was to compare the water surface level of the CFD model with data collected in the laboratory. The findings showed a satisfactory agreement between the two at various discharge levels. However, the commercial program Flow-3D is the one with which spillway models are most often utilized. Several literatures have used the Flow-3D software to study the spillway flow pattern in simulation, and their findings show a good agreement with the actual data [19-22]. Another option for simulating spillway flow patterns is OpenFOAM, an open-source platform [23]. This study's results demonstrate that the experimental and simulation models are more in accord. Accordingly, [24] comparing and predicting hydraulic jump characteristics using CFD programs of Flow-3D and Open FOAM. According to their research, some factors for both platform codes were better than the other.

The present study examines the possibility of determining the appropriate scale for operating the physical model that can be adopted to calibrate the numerical model for use in designing a spillway of a small dam. A numerical model tests more than one scenario without significant additional costs needed to modify the physical model for each scenario. Choosing the appropriate scale also balances the accuracy of flow simulation with the cost of designing and operating the physical model, as the cost increases with the increase in the model's size. Also, the effort and time can be shortened through a numerical model that can be run on several scenarios by calibrating it with a single physical model (specific scale) whose outputs match the numerical model.

Many researchers have attempted to simulate spillway flow patterns using physical and numerical models. The operation of physical models has limitations because of the high cost and the scale effects of these models. Potential flow theory or Navier–Stokes equations can be used to simulate the ogee spillway flow pattern by applying numerical models (2D and 3D) using flow 3D software.

The agreement between the numerical and physical model is the most considerable parameter of the previous studies without consideration for the limitations and problems of physical model applications, such as the effects of scales and human error, especially on a small scale.

Literature Review of Ogee Spillway for Dams

This section elucidates the extent of the study dedicated to exploring physical, numerical, and composite modeling, the three fundamental methodologies of hydraulic modeling, and the influence of the physical model's size on the hydraulic properties of small dams. The review for the previous study included in the present study (60 papers and thesis) showed about 66% of the literature that studied ogee spillways for small dams used CFD software with 45% studied ogee spillways for small dams used the CFD software with physical model.

Also, it showed 25% of the previous study that studied ogee spillways for small dams used the scale effect for physical model on hydraulic properties (used range scale 1/40, 1/50, 1/60, 180, and 1/110). Therefore, the present study may increase the experience of engineers and designers regarding the extent of the effects of the scale on the accuracy of using physical models in design, as the review of previous studies showed that this problem represents the least percentage that has been studied by researchers, especially with regard to small dams.

Fig.1, shows the statistical percentages of the work of literature, which were divided according to the problem facing the study area.

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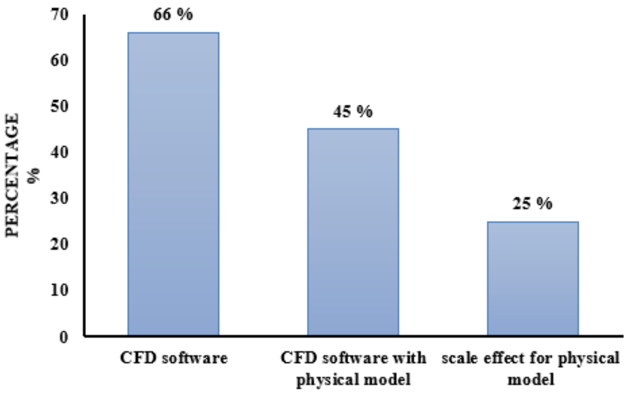

Figure (1): Percentages for the Literature Review of Ogee Spillways in Dams.

Methodology

In the present study, to determine the extent of the scale's influence on the accuracy of the results on the physical model, three different scales were adopted according to the dimensions of the open channel in the Hydraulics Laboratory of the College of Engineering at the University of Anbar, Iraq. The open channel is 17 meters long, surrounded by glass, and has a cross-sectional of 50*50 cm. The open channel discharge ranges are (4 - 110) m3/hr. As shown in Fig.2, the flow cell is attached to the pipe intake and confirms the measurement with a V-notch weir.

Figure (2): The open channel V-notch weir.

A numerical model (Flow-3D) is applied to determine the most appropriate and most compatible scale for the physical model with the numerical model. The numerical model data is compared with the data of the three physical models of the spillway model as part of the 3D simulation process. Data from each physical model are compared with the results obtained from the numerical model, which include rating curves, discharge coefficients, pressure distribution, and energy dissipation. A comparison is achieved to evaluate the effects of scale on the operation of the physical model and determine the scale of the physical model with more agreement with the numerical model. Fig.3 shows the flow chart for the methodology in the present study.

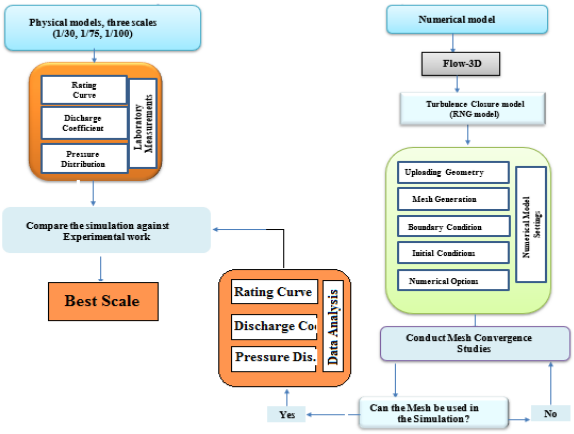

Figure (3): Research approaches used to accomplish the set aims.

Experimental Setup and Similarity Functions

The current study adopts a proposed small dam in the Harran Valley region in eastern Iraq to harvest rainwater for irrigation and agriculture. The dam centerline coordinate is (33°47'4.98"N, 45°35'34.51"E). The mean annual rainfall ranges from 150 to 600 mm, and the mean annual evaporation is 2100 mm. The height of the proposed dam's spillway is (10m), its length is (100m) and it is of the type (Ogee).

The distorted model was chosen to be compatible with the dimensions available in the hydraulic laboratory and the channel in it. Five different flow rates were used for which experimental models were evaluated: 250 m3/s, 350 m3/s, 500 m3/s, 750 m3/s, and 1000 m3/s (according to the

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observed data at the dam site). Using the Froude-Manning similarity law with deformed scales Lv (1:30, 1:75, and 1:100) and Lr (1:200) between the model and the prototype, laboratory tests were performed, and the model was built for a 100 m wide dam spillway [25]. This similarity was achieved using the following equations. (1-3):

$$Qr = Lr * Lv^{1.5} \tag{1}$$

$$Vr = Lv^{0.5} \tag{2}$$

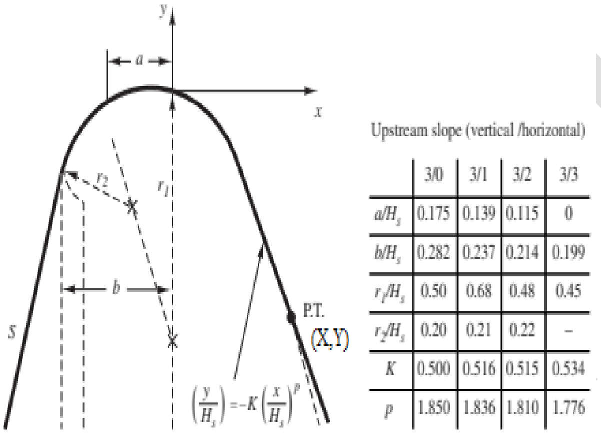
$$Tr = Lr * Lv^{-0.5} \tag{3}$$

The model's water flow rate is Qm, whereas the prototype's flow rate is Qp. The flow rate scale is Qr, which equals Qm/Qp. The length scale is Lr, the velocity scale is Vr, and the time scale is tr. Table 1 shows the ratio of the model lengths to the prototype lengths using the scales Lv (1:30, 1:75, 1:100), and Lr = 200.

Table (1): The scale factor, according to Froud number.

Model Scale	Qr	Vr	Tr
1:30	1/32863.35	1/5.47	1/36.5
1:75	1/129903.8	1/8.66	1/23.1
1:100	1/200000	1/10	1/20

The geometry of spillway distorted models is adopted according to the (U.S. Waterways Experimental Station) which proposed simple crest profiles that have been found to agree with actual prototype measurements. Fig.4 shows the spillway crest profile geometry according to the U.S. Waterways Experimental Station [26].



Upstream slope (vertical /horizontal)

	3/0	3/1	3/2	3/3
a/H_s	0.175	0.139	0.115	0
b/H_s	0.282	0.237	0.214	0.199
r_1/H_s	0.50	0.68	0.48	0.45
r_2/H_s	0.20	0.21	0.22	–
K	0.500	0.516	0.515	0.534
p	1.850	1.836	1.810	1.776

Figure (4): Spillway crest profile.

The spillway model is constructed using steel material with three different scales (1:30, 1:75, 1:100), and the dimensions of these models are shown in Table 2.

Table (2): Dimensions of the spillway for the three physical models.

Parameters Dimensions for Spillway (cm)	Scale 1/30 (cm)	Scale 1/75 (cm)	Scale 1/100 (cm)
Design head (Hd)	5.8	1.87	1.21
Spillway length (L)	50	50	50
Dam height (P)	33.34	13.34	10
a= 0.175 Hd	1.015	0.327	0.212
b= 0.282 Hd	1.635	0.527	0.341
r1= 0.5 Hd	2.9	0.935	0.605
r2= 0.2 Hd	1.16	0.374	0.242
Radius of toe (P/4)	10	5	5
X= 1.096 Hd	6.357	2.05	1.32
Y= - 0.59 Hd	- 3.422	- 1.103	- 0.714

Each physical model operates with five discharge values and measurements for water level and piezometer readings set up along the spillway, as shown in Fig. 5, to estimate the pressure distribution. There are four points to set piezometers in each model with a precision of about 1 mm.

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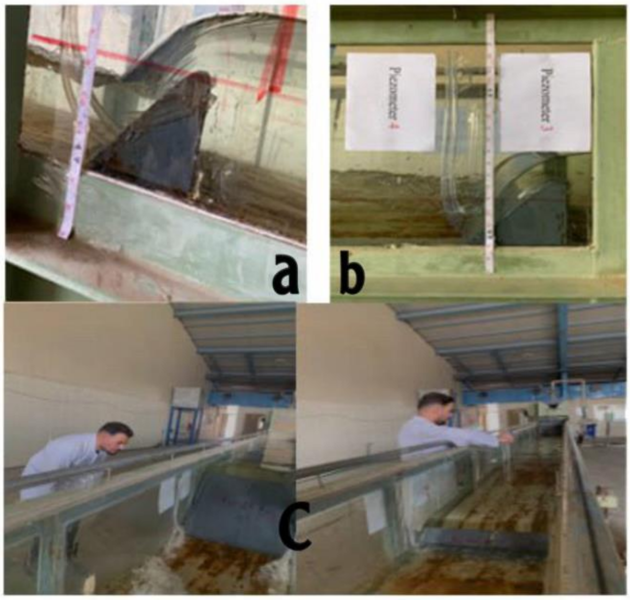

Figure (5): Piezometers setting; a: (scale 1:75), b: (scale 1:100), c: (scale 1:30).

Numerical Model

In recent years, numerical findings have emerged as a viable alternative to costly and time-consuming laboratory methods for tackling complex issues [28]. Fluent-2D and Flow-3D are popular commercial programs for simulating spillway flows and solving the steady-state and unstable three-dimensional Reynold averaged Navier Stokes (RANS) equations. Eqs. (4-9) shows the traditional forms of the RANS and continuity equations:

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (4)$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2vS_{ij} + \tau_{ij}\right) \qquad (5)$$

In this context, uj represents the average velocity of the cartesian components, xj denotes the cartesian coordinates (where j = 1, 2, 3), p denotes pressure, t denotes time, ρ denotes density, and v denotes dynamic viscosity. In this context, Sij represents the strain rate tensor, and τij represents the Reynolds stress tensor [27,28].

$$\frac{\partial(uA_x)}{\partial x} + \frac{\partial(vA_y)}{\partial y} + \frac{\partial(wA_z)}{\partial z} = 0 \qquad (6)$$

$$\frac{\partial u}{\partial t} + \frac{1}{V_f}\left(uA_x\frac{\partial u}{\partial x} + vA_y\frac{\partial u}{\partial y} + wA_z\frac{\partial u}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial x} + G_x + f_x \qquad (7)$$

$$\frac{\partial v}{\partial t} + \frac{1}{V_f}\left(uA_x\frac{\partial v}{\partial x} + vA_y\frac{\partial v}{\partial y} + wA_z\frac{\partial v}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial y} + G_y + f_y \qquad (8)$$

$$\frac{\partial w}{\partial t} + \frac{1}{V_f}\left(uA_x\frac{\partial w}{\partial x} + vA_y\frac{\partial w}{\partial y} + wA_z\frac{\partial w}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial p}{\partial z} + G_z + f_z \qquad (9)$$

where u, v, and w denote the velocity components in the x, y, z, and ρ directions, stands for the fluid density, Ax, Ay, and Az denote the flow cross-sectional area, t=time, p=pressure, (fx, fy, and fz) denote the viscosity acceleration in three directions, (Gx, Gy, and Gz) are local accelerations. Vf is the fluid's volume fraction [29].

The governing equations of flow across spillways were solved using the Finite Volume Method (FVM) in both systems. When compared to FDM and FEM, the FVM technique has much more excellent traction in the hydraulics community. In contrast to the FVM approach, which uses various mesh types to represent distinct computational domains, the FDM method requires structural meshes.

Numerical Model Simulation

Numerical modeling has been an essential tool for researchers analyzing spillway flow patterns in the last ten years. The 3D ogee spillway is modeled in the present study using the numerical model Flow-3D v11.0.4, a 3D computational fluid dynamics model. The user may activate one of many calculation models to fulfil hydraulic properties. To adapt to the numerical solution process, Flow-3D employs the self-corrective approach and automatically sets the convergence criterion. It solves the fluid flow-describing continuity and Navier-Stokes equations using a method based on the FVM. It uses the RNG k-ε model, which has been renormalized. the Flow-3D incorporates Cartesian coordinates to discretize the computational domain into a hexahedral mesh of variable sizes. listed five possible states for the spillway model's computational domain cell simulation: fully fluid, partially solid, partially fluid, or empty cell. Fig. 6 shows the procedure involved in using Flow-3D for modeling.

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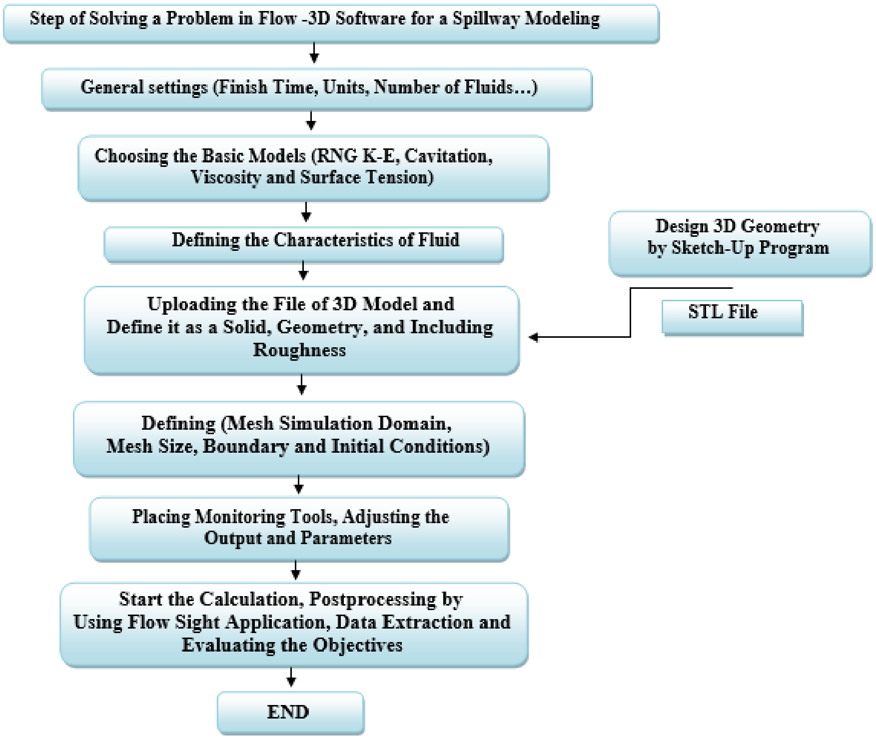

Figure (6): The Flow-3D program has a spillway modeling methodology.

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Geometry and Mesh

The success in reaching the numerical solutions for the governing equations of the CFD issue is heavily dependent on meshing or grid generation, the second pivotal phase of preprocessing after geometry creation. It is responsible for over 60% of all CFD projects. A mesh may often be categorized using several standards. The grid may be classified as tetrahedral, pyramidal, triangular prism, or hexahedral in a three-dimensional domain and quadrilateral or triangle grid in a two-dimensional domain. The connection between nearby cells determines whether a grid is organized or unstructured (non-uniform). Hexahedral mesh, which may be uniform or non-uniform, is generated by the Flow-3D platform using Cartesian coordinates (see Fig. 7).

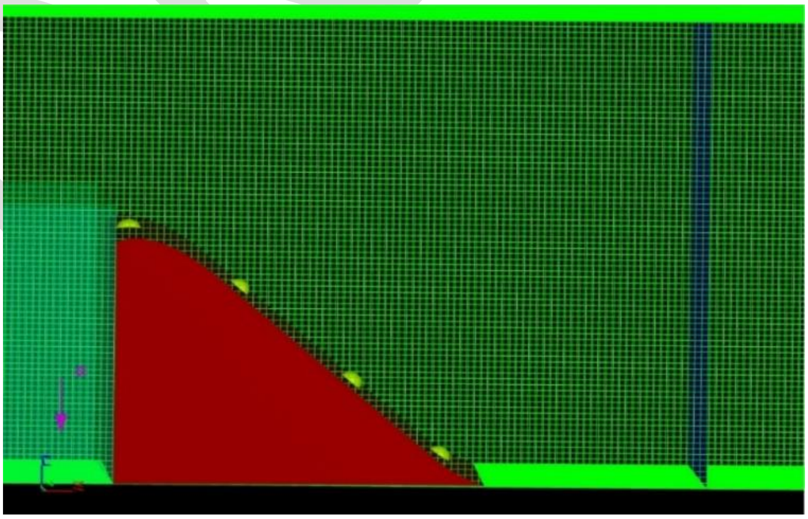

Figure (7): The grid for the spillway model.

Separate software is required to design more complicated structures, including drainage channels. Stereo (STL) files may be opened and used on the Flow-3D platform. Various computer-aided design (CAD) programs, including AutoCAD, FreeCAD, Solid Works, SketchUp, Fusion360, and many more, use this format. Since STL files are often used for 3D printing, they are more precise than others. Each triangle cell represents a flat surface, and STL files generate a model with a triangular mesh. The FAVOR technology allows for more triangles, accurate modeling, and learning time. Fig. 8 shows the final product of the 3D engineering model of the small dam's spillway, which was created using Sketch-up (2021), and the geometry is then loaded into Flow-3D (V11.0.4) after being converted to STL file format .

Estimation of form roughness is an additional Flow-3D software component required to finish geometry settings. Thus, it was assumed that 0.6 mm would be the roughness constant employed [30]. Six boundary conditions in Flow-3D—X-min, X-max, Y-min, Y-max, Z-min, and Z-max—represent the border of the hexahedral mesh block. For the sake of this investigation, let's say that X-min is the upstream spillway, X-max is the downstream spillway, Y-min is the right-side spillway, Y-max is the left-side spillway, Z-max, Z-min is the top and bottom computational domain. To construct a spillway model, the Flow-3D platform allows the following kinds of boundary conditions to be defined, (Volume flow rate, Specified pressure, Wall, and Outflow).

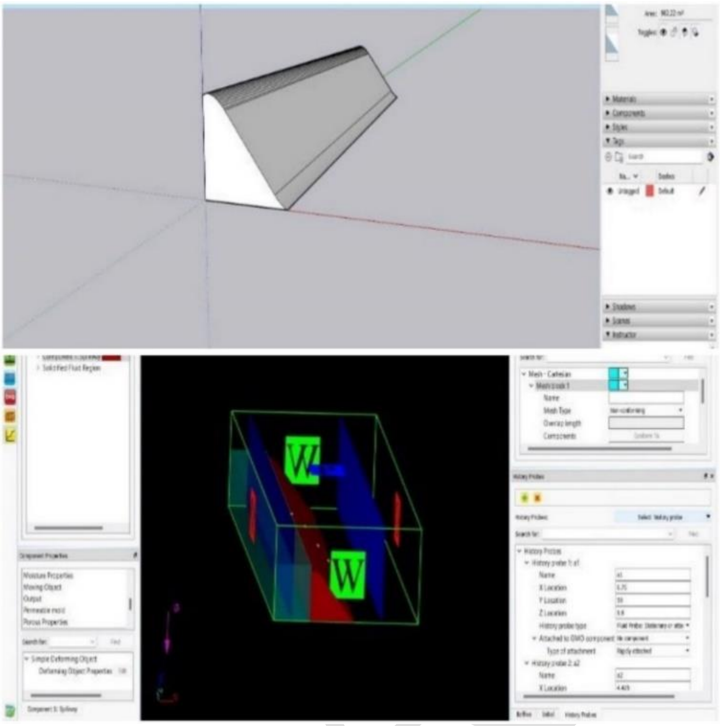

Figure (8): A 3D model created in Sketch-Up and rendered in Flow-3D.

Results and Discussion

All hydraulic data, such as velocity, pressure, and water depth, are accessible during the thirty-second simulation that runs through five discharges. The fundamental purpose of the simulation is to precisely compare the results of the numerical model with those of the three physical (laboratory) models to ascertain data convergence. The results from the Flow-3D simulation software were closely matched by the model's (1/30) discharge coefficient, Rating curve (Figs. 9&10), and Piezometer reading curve (Figs. 11,12 and 13). However, the other two models (1/75, 1/100) showed significantly different results. The physical and numerical models did not observe or measure a negative pressure value when three different discharges were considered (250 m3/s, 500 m3/s, and 1000 m3/s). This demonstrates that the water outflow route is devoid of cavitation, as shown in Figs. (11, 12, and 13). Using discharge data from the numerical model, the physical model, and the estimated theoretical values according to the USBR (1987), the water head above the crest of the spillway with discharge results can be compared. The two physical models (1/75 and 1/100) showed the water level significantly off. There is a strong agreement between the numerical model anticipated level and the level measured by the physical model scale (1/30).

The discharge coefficient clearly shows the difference between the models, and it can be noted that the best discharge coefficient for the numerical model and the three physical models is between the discharges (600 – 800 m3/s). The CFD model and USBR (1987) agree well with the physical model of scale (1/30), while the numerical model results are significantly different from the physical model scales (1/75 and 1/100). In contrast to the physical model based on the USBR standard curve, the numerical model offers a more accurate representation of the flow over the spillway crest for modest dams.

In terms of accuracy and computing cost (time), mesh sensitivity analysis may find the optimal mesh cell size [31]. The sensitivity analysis for the program (Flow-3D) determines the appropriate cell size, which allows the model findings to be independent of the imposed cell size. Flow-3D is now limited to using just hexahedral and triangular grids. A wide range of uniform mesh sizes (10, 23, 45, 70, and 100 cm) are used to run the numerical model platforms. The mesh independence is being studied by positioning four probes at the spillway crest. Fig. 14 depicts the relationship between the probe line depth and the spillway crest velocity using the Flow-3D program. A 2nd-order polynomial fit curve is constructed to observe the data's convergence precisely. Fig. 15 indicates that findings are consistent throughout 10–23 cm mesh sizes. Thus, it's safe to ignore the difference. The spillway curve was determined by Flow-3d using the FAVOR algorithm and the Cartesian network structure. The model size was reduced when this approach was used. The spillway, for instance, stood at a height of 10 m. The simulation resulted in a decision to reduce the spillway height to 9.9 m. Consequently, it can be said that this decrease has no significant effect on the credibility of the results and may be overlooked.

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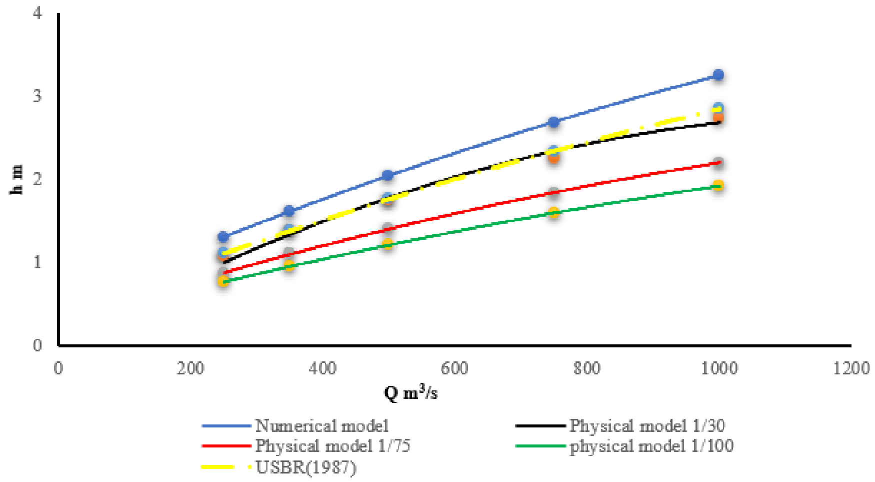

Figure (9): The rating curve for prototype comparison between physical models, numerical model, and USBR (1987).

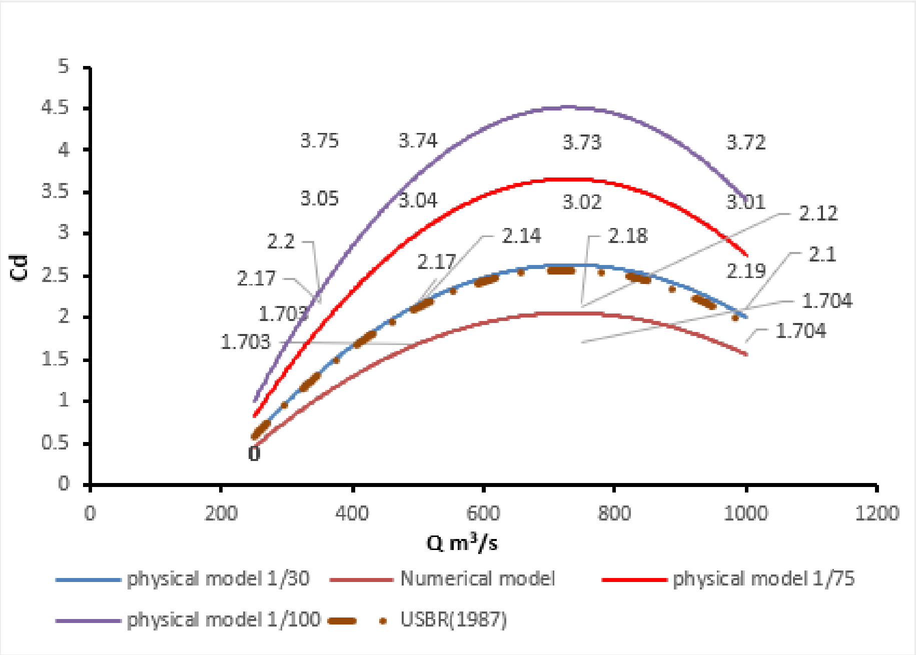

Figure (10): The discharge coefficients compare physical models, numerical model, and USBR (1987).

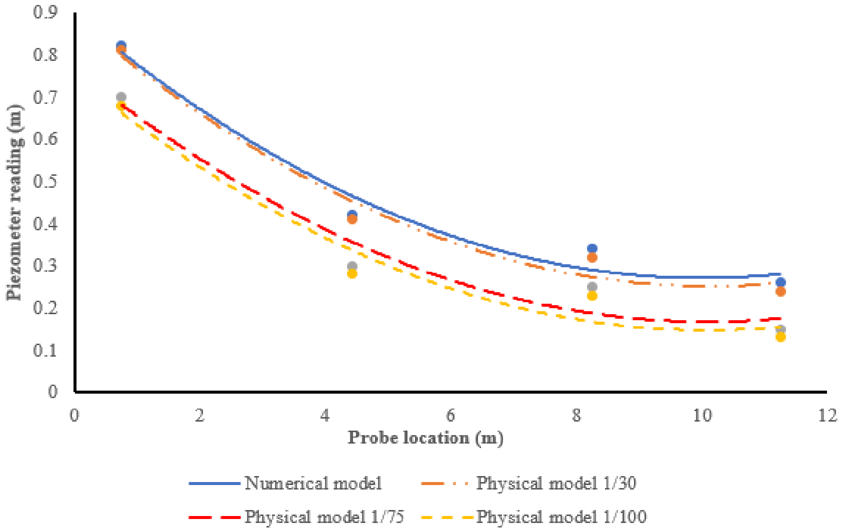

Figure (11): Piezometer reading the comparison between physical models and numerical model in discharge 250 m^3/s.

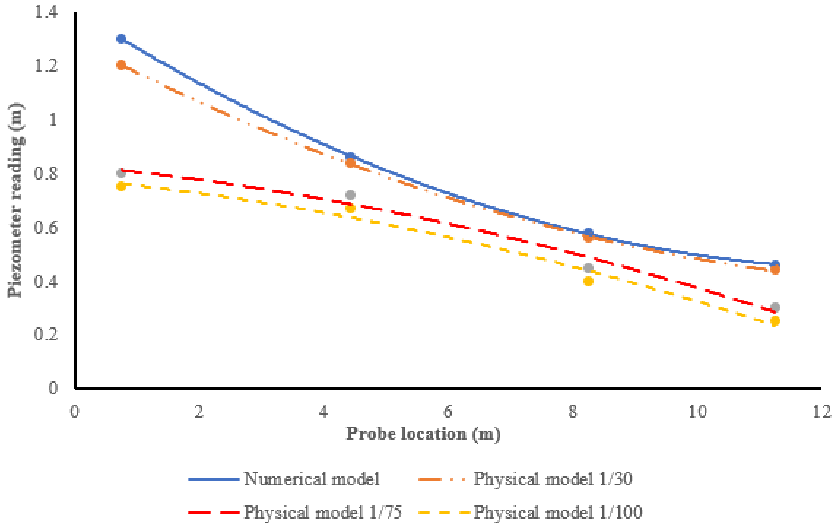

Figure (12): Piezometer reading the comparison between physical models and numerical model in discharge 500 m^3/s.

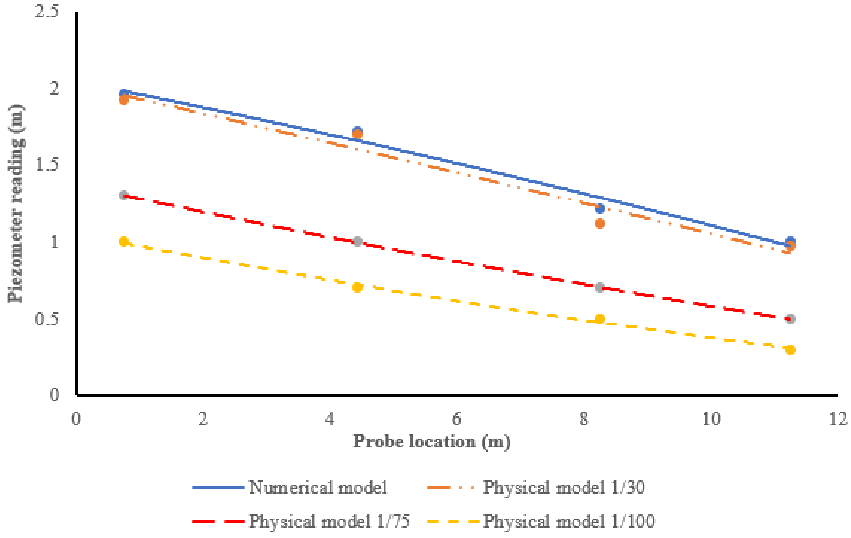

Figure (13): Piezometer reading the comparison between physical models and numerical model in discharge 1000 m^3/s.

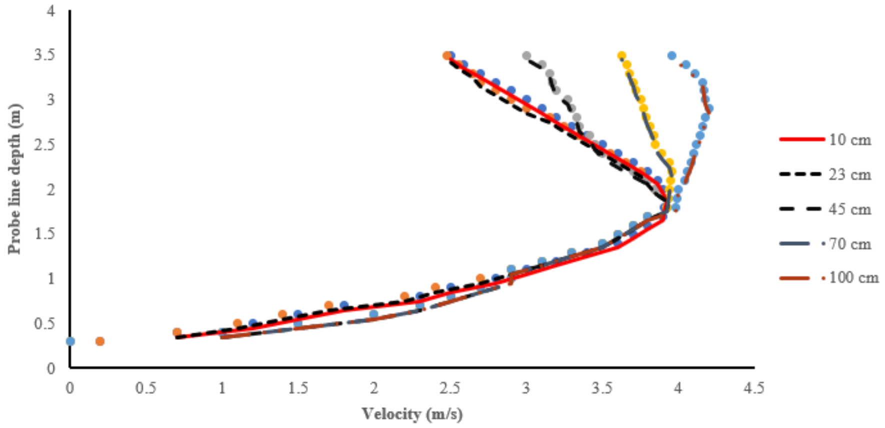

Figure (14): A second-order fit curve for the distribution of velocities at the spillway crest.

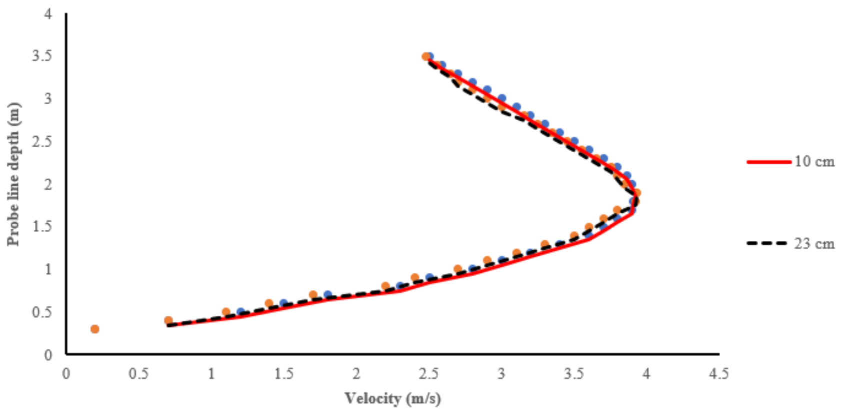

Figure (15): Flow-3D software's velocity sensitivity study for 23 and 10 cm mesh sizes.

The reliability of the findings was assessed by calculating the R-squared value for the rating curve, discharge coefficient, and pressure readings in piezometers. Table 3 shows all three laboratory models and the model in the Flow-3D simulation. The correlation coefficient (R2) is a statistical measure that describes the strength and direction of the relationship between two variables. It ranges from -1 to 1, where -1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no correlation. It's used to understand how changes in one variable are associated with changes in another., calculated using Eq. (10), the rating curve, discharge coefficients, piezometer reading, represented by $(yi^{\wedge})$, (yi), respectively [32-34].

$$R^2 = \frac{\sum_{i=1}^{n}(yi^{\wedge} - y^{-})^2}{\sum_{i=1}^{n}(yi - y^{-})^2} \qquad (10)$$

Table (3): Comparison of R-squared both physical models with numerical model.

Models	R-squared % (rating curve)	R-squared % (discharge coefficients)	R-squared % (piezometer reading)
1:30	0.842	0.7785	0.9325
1:75	0.679	0.561	0.8557
1:100	0.588	0.454	0.8034

Table (4): Comparison of Avg. (discharge coefficients and Energy Dissipation) both physical models with numerical model.

Models	Avg.(Cd) numeric model	Avg.(Cd) physical model	Avg. Energy Dissipation %
1:30	1.7034	2.188	56.1
1:75	1.7034	3.034	58.2
1:100	1.7034	3.752	**65.86**
Num.model	--------	-------	**54.38**

According to Table 3 and Table 4, the Flow-3D platform is a numerical model that gave results highly correlated with the physical model scale (1/30). In contrast, the results of the two physical models (1/75 and 1/100) were not highly correlated with the numerical model.

The reason for these differences, according to the two physical models, is the phenomenon of surface tension specific to the Weber number. Also, the occurrence of the phenomenon of viscosity is particular to the Reynolds number because the height of the water above the spillway was small (h < 3 cm) when the discharge was (1000 m3/s). This affects the readings of the pressure piezometer and gives significant error rates, and these two phenomena do not exist in the site Prototype.

Conclusions

In the present study, efforts have been put into using physical and numerical models to investigate the spillway's hydraulic features. More efficient and faster determination of spillway hydraulic parameters is now possible because of advances in CFD technology. The current study used the numerical model to determine the accuracy of the physical models to represent the flow patterns passing over the crest of an Ogee spillway. The results indicate that the physical model at a scale of (1:30) best matched the numerical model for the given discharge range. In other words, the smaller scale, i.e. (1:75 or 1:100), affects the accuracy of the measurement, as some forces, such as surface tension and viscosity effects, appear because of the small size of the model parameters when these forces have not affected the flow over the spillway in its actual size. Based on the results of the present study and for efficient design of the spillway, a physical model with a scale of 1/30 or more (1/20, 1/25) can be used to calibrate and operate the numerical model, which can be used to test more than one scenario in the design without a high additional cost, according to the present investigation, that:

The physical model's rating curve and discharge coefficients were compared to the numerical model and USBR (1987) data. Results show excellent agreement between the model's physical scale (1/30) and the numerical model, no good agreement between the numerical model and two physical model scales (1/75 and 1/100), average rating curve error for scales (1/30, 1/75, and 1/100) with numerical model of (3.156, 6.424, and 8.218 %) respectively, and average discharge coefficient error of (4.429, 8.77, and 10.918 %) respectively. (3, 6, and 8 %) rating curve for the USBR respectively, and (4.2, 8.5, and 10.5 %) discharge coefficient for the USBR with physical models and numerical model.

The physical model of scale (1/30) agreed with the numerical Flow-3D model of the turbulent flow findings on flow parameters, including water depth and pressures.

At the downstream end of the arched spillway, cavitation does not occur in the present simulation, but it may be simulated above the spillway using the numerical model.

When planning design small dams, a scale of 1:30 or less may be used, and the results can be compared using a numerical model (Fluent or Flow-3D).

This research demonstrates that the CFD numerical model offers designers a powerful instrument that, with

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appropriate validation, might decrease the design and operating expenses of small dams.

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