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RESEARCH ARTICLE

Performance Against Cavity Index and Discharge Coefficient between Broad and Sharp Crested Weirs

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ABSTRACT

The purpose of this research is examining the performance of rectangular broad and sharp crested weirs in terms of cavity index and discharge coefficient. For this purpose, a computational fluid dynamics CFD code FLUENT is applied. Firstly, the code verified by applies on the experiments work of Hagre *et al* 1994 the results show excellent agreements between CFD and Hager *et al* 1994. Secondly the code applied on both broad and sharp crested weirs. The results demonstrate that broad crested weirs have a lower discharge coefficient than sharp crested weirs, implying that broad crested weirs have a lower ability to discharge flow than sharp crested weirs. While the cavity index of a broad crested weir is lower than that of a sharp crested weir, the risk of cavitation is lower for a broad crested weir. Finally, designers should use caution when deciding which type of crest to use in their designs.

Keywords: CFD; Sharp crested weir; Broad crested weir, Cavity index, Discharge coefficient.

1. INTRODUCTION

A weir is a hydraulic device used to measure flow and raise water levels for a variety of purposes. Weirs are grouped into four classes based on the combination of crest width: sharp, narrow, ogee, and broad crested weirs. If the streamlines remain parallel to the bed and the pressure distribution is hydrostatic, the weir is considered a broad crested weir (BCW); otherwise, the weir is considered a sharp crested weir (SCW) (Montes, 1969). Critical flow condition is a function of crest length for broad crested weirs, and it will occur on the weir crest (Felder & Chanson, 2021). Weirs come in a variety of geometrical shapes, including rectangular, triangular, and round. The discharge coefficient and cavitation coefficient are used to assess the performance of weirs. The risk of cavitation in hydraulic structures is determined by a number of elements, including the cavity index value, the duration of the operation, the roughness of the boundary, alignment, and the strength of the boundary materials (Falvey, 1990). With changing upstream head, the discharge coefficient for sharp and broad crested is change. In a broad crested weir, increasing the head has a low effect on the discharge coefficient (Imanian *et al*, 2021). Many studies have been done on the discharge coefficient of sharp and broad crested weirs, but few have been done on the cavitation coefficient of both types of weirs. In the present study, the performance of both sharp crested weir and broad crested weir were studied in terms of discharge coefficient and cavitation using FLUENT code.

1.1 Flow over Weirs

The general equation of discharge passing through weirs can be written as follows: Consider a rectangular weir; velocity at any depth (h) bellow energy grade line equal to $\sqrt{2gh}$ the discharge per unit width can be determined as: (Henderson, 1985, p.175).

$$q = \int_{V_o^2/2g}^{h_o+V_o^2/2g} \sqrt{2gh}\,dh$$

$$= \frac{2}{3}\sqrt{2g}\left[\left(h_o + \frac{V_o^2}{2g}\right)^{3/2} - \left(\frac{V_o^2}{2g}\right)^{3/2}\right]$$

The above equation is also written as:

$$Q = \frac{2}{3} C_d \sqrt{2g}\, L h_o^{3/2}$$

Where: h_o: is the flow depth over the weir (m), V_o: is the approach velocity (m/s)

In general, broad crested weirs can be classified according to ratio of height of water above the weir to the top width of the weir (Rao and Muralidhar, 1963) see Figure 1:

1- long-crested weir when $h_0/B_w < 0.1$

2- true broad-crested weir when $0.1 < h_0/B_w < 0.4$

3- narrow-crested weirs when $0.4 < h_0/B_w < 1.5$

4- sharp crested weir when $h_0/B_w > 1.5$

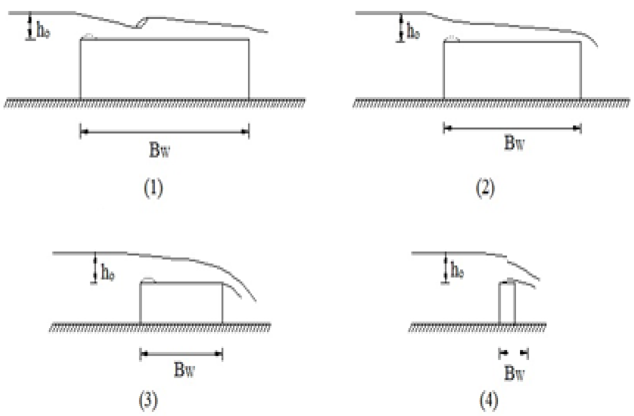

Figure 1 Weir types

1.2 Cavity Index

Cavitation may occur when flowing water passes through hydraulic structures, particularly when the velocity is high and the pressure is low. The minimal cavity index is used to determine whether or not cavitation is likely to take place. If the cavity index is less than the critical value, cavitation will occur. The cavity index of both weir types is determined using the following equation (Frizell & Mefford, 1991) to compare the performance of both types of weirs:

$$\sigma = \frac{(P - P_v)}{0.5\rho V^2}$$

Where:-

P: is the pressure of flowing water over the crest at the particular temperature,

P_v: is the vapor pressure at the specific temperature, ρ: is the density of the water and the average velocity

2. MATERIAL AND METHODS

2.1. Computational Fluid Dynamics (CFD) Modeling

Numerical models are used to solve the governing equations of fluid flow in computational fluid dynamics. There are several flow simulation codes available; in this work, the FLUENT code is used, which is based on the finite volume method. The Navier-Stokes equations are the governing equations for fluid flow. The following is the governing equation for steady two-dimensional flow:

$$\frac{\partial}{\partial x_j}\rho \bar{U}_i \bar{U}_j = -\rho g_i - \frac{\partial \bar{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu\left(\frac{\partial \bar{U}_i}{\partial x_j} + \frac{\partial \bar{U}_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right) + F' \dots\dots\dots\dots\dots\dots 1$$

Where:

P: is pressure,

g is acceleration due to gravity.

μ is the fluid viscosity.

F' is the body force

In the governing equation the Reynolds stress form can be modeled using turbulence models, so the turbulence modeling can be defined as a computational procedure for modeling the Reynolds stress (Piradeepan, 2002).

2.2. $k - \varepsilon$ Turbulence Model

This turbulence model is one of the most practical. In terms of modeling industrial flow, it performs adequately. The $k - \varepsilon$ turbulent equations consists two equations kinetic energy and dissipation rate (Ahmed & Aziz 2016). Both equations are written as follows:

$$\frac{\partial(\rho k)}{\partial t} + div(\rho k U) = div\left[\frac{\mu_t}{\sigma_k} grad k\right] + 2\mu_t S_{ij}.S_{ij} - \rho\varepsilon \dots\dots\dots\dots\dots 2$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + div(\rho \varepsilon U) = div\left[\frac{\mu_t}{\sigma_\varepsilon} grad\varepsilon\right] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t S_{ij}.S_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \dots\dots 3$$

σ_k: is Prandtl number connect the diffusivity of k to the eddy viscosity, typically the value of 1.0 is used.

σ_ε: is Prandtl number connect the diffusivity of ε to the eddy viscosity, typically the value of 1.3 is used. The value of $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are 1.44 and 1.92 respectively.

2.3. Mesh Generation and Boundary condition

The two-dimensional fluid domain is created using ANSYS design modular. The mesh is generated using hexahedron mesh type with the maximum element size of 0.005 m. The fluid domain is 2D with thickness of one element see Figure 2. The inlet boundary is fixed with normal velocity and flow depth and the outlet with the average pressure of zero.

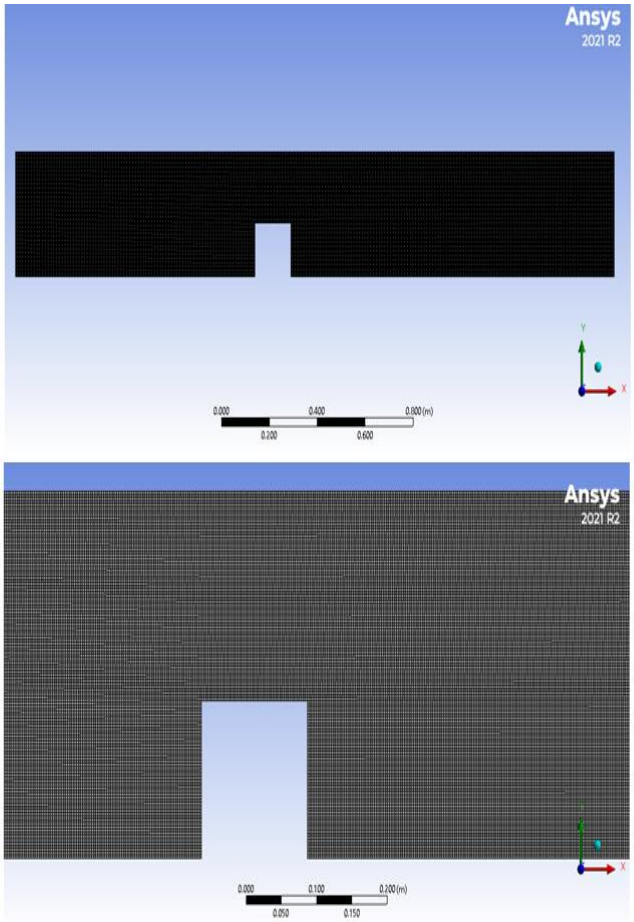

Figure 2 Hexahedral mesh

3. RESULTS AND DISCUSSIONS

3.1. Code validation

The experimental data of (Hager & Schwalt, 1994) is provided to verify the FLUENT results. A horizontal rectangular weir with a cross section of 499 mm wide and a height of 700 mm is used in the experiment. The waterway is 7 m long; with a 401 mm height broad crested weir placed 2172 mm from the outlet. The experimental discharge crossed over the crest at 25.98 l/s, with a head of 10.79 cm above the weir. FLUENT is used to simulate the model, which uses the $k - \varepsilon$ turbulence model with a maximum mesh size of 0.005 mm. Figure 3 shows the comparative water surface profile obtained from FLUENT and experimental data.

As can be seen from the graph, there was excellent agreement between them. Except for a minor deviation downstream, where the jump occurs. Because of the strong aeration at the jump location, the FLUENT code using the $k - \varepsilon$ turbulence model accurately predicts the water surface profile of flow over the weir. However, the anticipated and observed results diverge to some acceptable extent.

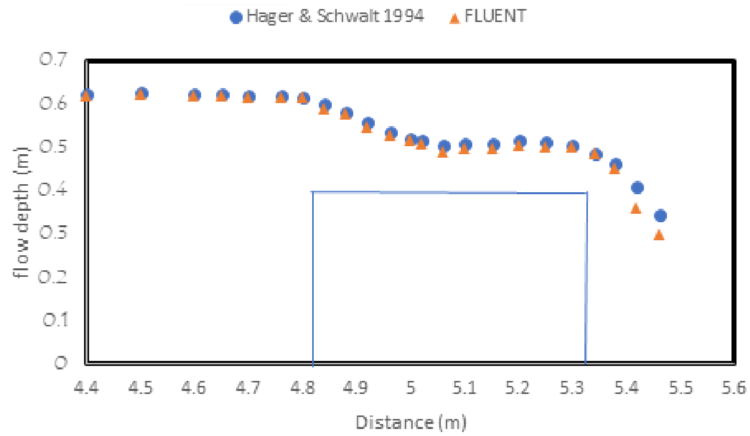

Figure 3 The predicted and observed water surface profile over broad crested weir of (Hager & Schwalt, 1994)

3.2. Discharge Coefficient comparison between sharp and broad crested weir

Several runs were performed using FLUENT for different discharges (0.0332, 0.0542, 0.0752, 0.0956, 0.135419 and 0.0153) m^3/s over both sharp and broad crested weir and Figure 3 represents the water volume fraction for 0.0332 (m^3/s) for both BCW and SCW.

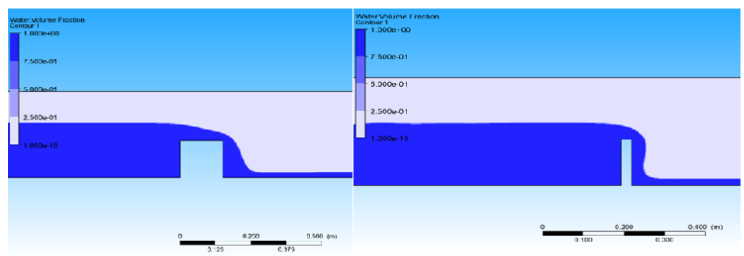

Figure 4 represents the water volume fraction for 0.0332 (m^3/s) for both BCW and SCW

The discharge coefficients for both cases for different discharge are shown in figure 5. It was indicated that for similar discharge sharp crested weir has higher discharge coefficient. This refer to the performance of sharp crested weir is more than the performance of broad crested weir, since sharp weirs permits higher discharge for the same water surface elevation. Generally, the discharge coefficient is increased as head above crest discharge, but this reverse in higher discharges since the downstream is affected by submergence. When (H/P) is greater than one the discharge coefficient is sharply reduced due to the downstream water level.

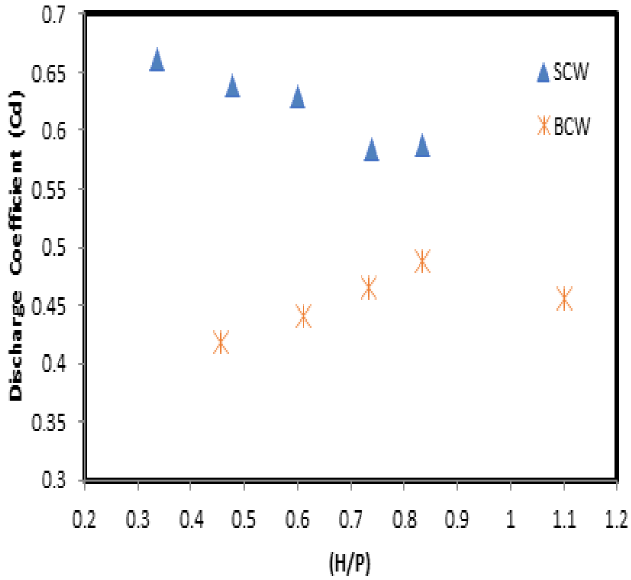

Figure 5 Discharge coefficient comparison of broad and sharp crested weir

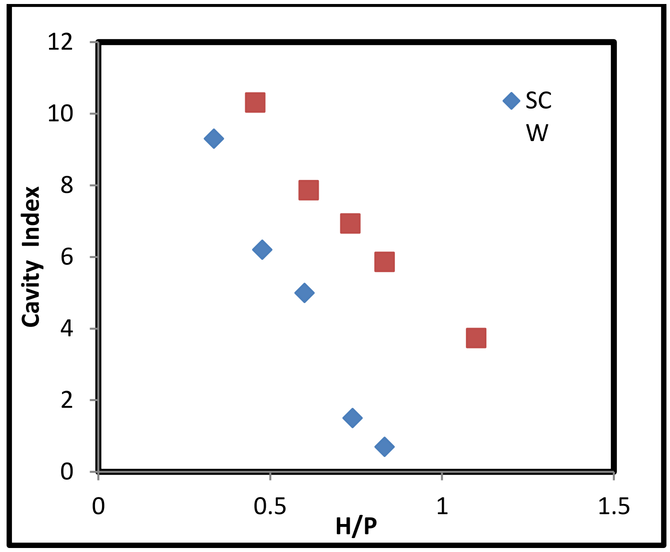

Figure 6 Cavity index comparison of broad and sharp crested weir

3.3. Pressure distribution comparison of sharp and broad crested weir and cavitation index

For a sharp crested weir the negative pressure is expected over the crest and at the downstream face of the weir and as the discharge decreases, its value will increase. While for the broad crested weir a negative pressure may be expected only at the downstream face of the weir. The cavity index is determined for different flow heads over sharp and broad crested weirs for similar discharges. Figure 6 illustrates the comparing results. The results showed that the sharp crested weir has a greater cavity index than the broad crested weir, indicating that the likelihood of cavitation is higher. (Frizell and Renna, 2011) discovered that the crucial cavitation index lies between (0.7-0.8). The cavitation index was 0.7 at the crest of the sharp crested weir for maximum head over the crest, indicating that cavitation is more likely to occur at higher discharges when velocity is highest. Cavitation is unlikely to occur at the broad crested weir since the cavitation index is greater than the critical value for all discharges.

4. Conclusion

In the present study, the performance of broad and sharp crested weir is investigated in terms of discharge coefficient and cavity index. The following conclusions were obtained:

A sharp crested weir performs significantly better than a broad crested weir when it comes to discharge passing. For the same discharge, the head over the crest of a sharp crested weir is less than that of a broad crested weir; this shows that a sharp crested weir's discharge coefficient is greater than that of a broad crested weir. A sharp crested weir's crest is more likely to experience negative pressure than a broad crested weir's crest, while a broad crested weir's cavity index is higher than a sharp crested weir's. The cavity index over the sharp crested weir achieves the critical value of 0.73 at greater discharge, but the cavity index over the broad crested weir exceeds the critical value at all flow rates. Cavitation is more likely to occur in a sharp crested weir than in a broad crested weir.

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