

Impact of Surface Roughness on Discharge Coefficient of Crump Weirs: An Analytical Investigation

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ABSTRACT

Objective: This study examines the impact of surface roughness on the discharge coefficient (C_d) of Crump weirs through a comparative analysis of smooth-surface and rough-surface configurations:

Material and Methods: The experimental investigation utilized laboratory-scale Crump weir models with controlled surface roughness conditions. Different roughness regimes were created by applying uniform coatings of sand and gravel particles with varying grain sizes (k_s)

Results and Discussion: The results demonstrated significant effects of roughness, particularly under low-head conditions. A maximum C_d reduction of 12.8% was observed with minimal upstream head ($H/P < 0.2$) for high-roughness conditions. The influence of roughness exhibited progressive attenuation with increasing H/P ratios, and at $H/P > 0.5$, the effects of surface roughness became negligible

Conclusions: These findings suggest that smoother weir surfaces are preferable for low-flow precision, whereas roughness effects can be disregarded in high-flow conditions. Future research should investigate additional factors, such as slope variations and field-scale validation, to refine hydraulic modeling

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1. Introduction

Weirs are hydraulic structures widely used in water engineering projects, including irrigation and drainage networks, river diversions, and watershed management projects. Different types of weirs are categorized into three groups based on their crest length: broad-crested, sharp-crested, and short-crested weirs (Afaridegan et al. 2024; Bos 1976). The Crump weir falls into the short-crest weir category and has been welcomed by the hydraulic engineering community due to its ease of design and construction. A crump weir has a triangular shape in its longitudinal section and a rectangular shape in its plan (Zuikov, 2017). Sloping the upstream or downstream side of the crump weir and rounding its corners increases its discharge capacity. One of the reasons for using a broad-crested weir with sloping upstream and downstream faces is to reduce flow separation. Based on the reports, applying a vertical face to the broad-crested weir reduces its discharge capacity by 10 to 15% due to flow separation, particularly at high upstream heads (Sargison, Jane, and Percy, 2009). Brakeni et al. (2019) showed that small crump weirs in the straight path accurately measure low flows. The Crump weir, with a 2:1 upstream and 5:1 downstream slope, is not a significant barrier to salmon migration under low to high flow conditions (Rhodes and Servais 2004). In practical projects, crump weirs are usually constructed of concrete. In addition to cement and water, other materials, such as sand and gravel, are added to produce concrete. Over time, the surface of these weirs erodes, and their roughness increases as the flow passes over them. The increase in surface roughness leads to a more significant loss of flow energy, resulting in a reduction in discharge capacity (Torabi et al., 2018). Othman et al. (2011) examined the effect of surface roughness on the discharge coefficient of Cylindrical Weirs. To this end, they used three diameters for the weirs and three types of roughness to coat the surface of the crest. The obtained results showed that Cd values increase with increasing flow rate as well as with decreasing cylinder diameter; an increase in surface roughness of the weir can result in a significant reduction in Cd value.

Idrees et al. (2024) investigated the impact of surface roughness on the flow characteristics of a broad-crested weir. To this end, they employed two types of weir geometry, each coated with three types of surface roughness: cement, boulders, and gravel. They found that, on average, roughness reduces the discharge coefficient by about 3%.

Jalil et al. (2014) investigated the effects of surface roughness sizes on the discharge coefficient for broad-crested weirs. For this purpose, three models with different lengths of broad-crested weirs were tested. The surface of each model was roughened four times. They found that roughness affects the discharge coefficient, and the performance of a broad-crested weir improves with a decreased ratio of roughness to the weir height (K_s/P) and an increase in the total Head-to-Length ratio (H/L).

Ghobadian et al. (2013) investigated the impact of surface roughness on the discharge coefficient of Circular Weirs. They found that for a constant discharge, as the weir surface roughness increases, the upstream water level over the weir increases, and the discharge coefficient reduces.

Alboresha and Hatem (2021) studied the effect of height and surface roughness on the discharge coefficient (Cd) for different Board Crested Weirs models in a horizontal open

channel. To this end, four models made of cement, sand, gravel, and boulders were considered. The results showed that, in all cases, the weir height effect was directly proportional to the discharge coefficient. In contrast, the surface roughness effect was found to be inversely proportional to the coefficient C_d of the case study.

In this study, the effect of surface roughness on the discharge capacity of a crump weir is investigated.

2. Materials and Methods

A sketch of the rough crump weir is shown in Figure 1. As shown in this figure, the surface of this weir has been covered with sand or gravel to investigate the effect of roughness on its discharge capacity. This figure defines the depth and head of flow over the crest (at a sufficient upstream distance from the crest) by y and h_{up} , respectively. P is the height of the crest weir. The angles α and β define the upstream and downstream slopes. H is the upstream flow depth, the thickness of the roughness, and the mean diameter of the grain size of sand or gravel, which is considered the roughness amount (ks). y_1 and y_2 are the conjugate depths of the hydraulic jump.

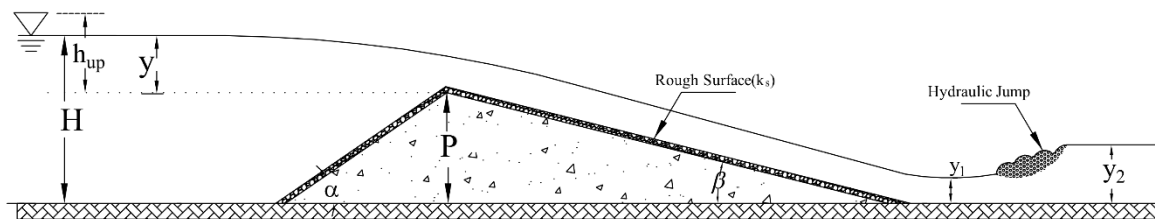


Figure 1- The sketch of the rough crump weir

As mentioned in the introduction section, the crump weir is categorized as a short-crested weir; therefore, Eq. 1 would illustrate its discharge capacity per width (Bos 1976).

$$q = \frac{2}{3} C_d \sqrt{\frac{2}{3} g h_{up}^{1.5}} \quad 1$$

In this equation, q represents the discharge capacity per width, C_d is the discharge coefficient, g is the acceleration due to gravity, and h_{up} is the head of flow over the crest at a sufficient distance from the crest. The involved parameters in the C_d of the rough crump weir are summarized in Eq.2. As presented in this equation, the C_d is proportional to P , y , and V : velocity of approached flow to the weir, ks , α , and β : the slope of upstream and downstream faces,

Respectively. ρ : flow density, μ : dynamic viscosity, and σ : surface tension.

$$C_d = f(P, y, V, ks, \alpha, \beta, \rho, \mu, g, \sigma) \quad 2$$

Using Π Buckingham's theorem as a dimensional analysis technique and considering the ρ , V , and P as the repetitive parameters, the dimensionless parameters presented in Eq. 3 are derived.

$$\underline{\rho, V, P} : \Pi(y) = \frac{y}{P} (H = y + P \xrightarrow{y \rightarrow H} \Pi(H) = \frac{H}{P})$$

$$\Pi(k_s) = \frac{k_s}{P}$$

$$\Pi(\alpha) = \alpha$$

$$\Pi(\beta) = \beta$$

$$\Pi(\mu) = Re$$

$$\Pi(g) = Fr$$

$$\Pi(\sigma) = We$$

$$C_d = f\left(\frac{k_s}{P}, \frac{k_s}{y}, \frac{H}{P}, \alpha, \beta, Fr, Re, We\right) \quad (3.a)$$

$$C_d = f\left(\frac{k_s}{P}, \frac{k_s}{y}, \frac{H}{P}, \alpha, \beta\right) \quad (3.b)$$

$$C_d = f\left(\frac{k_s}{y}, \frac{H}{P}, \alpha, \beta\right) \quad (3.c)$$

Where Fr is the Froude number, Re and We are Reynolds and Weber numbers. According to the results of the dimensional analysis technique, the effect of surface roughness on the C_d can be evaluated using two dimensionless parameters, including the ratio of upstream head to weir height (H/P) By simultaneously considering the relative roughness values (k_s/P) and the ratio of surface roughness to flow head (k_s/H) considering the k_s/P .

2.1. Dataset

To verify the relation between these parameters and C_d , Hussien's (2014) published data was used. She performed the experiments in a flume that was 17m long, 0.5 m wide, and 0.5 m deep. The sidewalls of the flume were made of Plexiglas, and a galvanized plate was considered for the flume bed. The heights of laboratory models of the Crump weir were 0.1 and 0.2 m. The angles of the upstream and downstream faces of the models were 26.5° and 11.3°, respectively. Hussien (2014) individually coated the surface of crump weir models with sand and gravel with specific grain sizes. The flow discharge was controlled by an electrical board of the flume and measured by a sharp crest installed at the end of the flume. The laboratory conditions of models and flow discharge used in this study are presented in

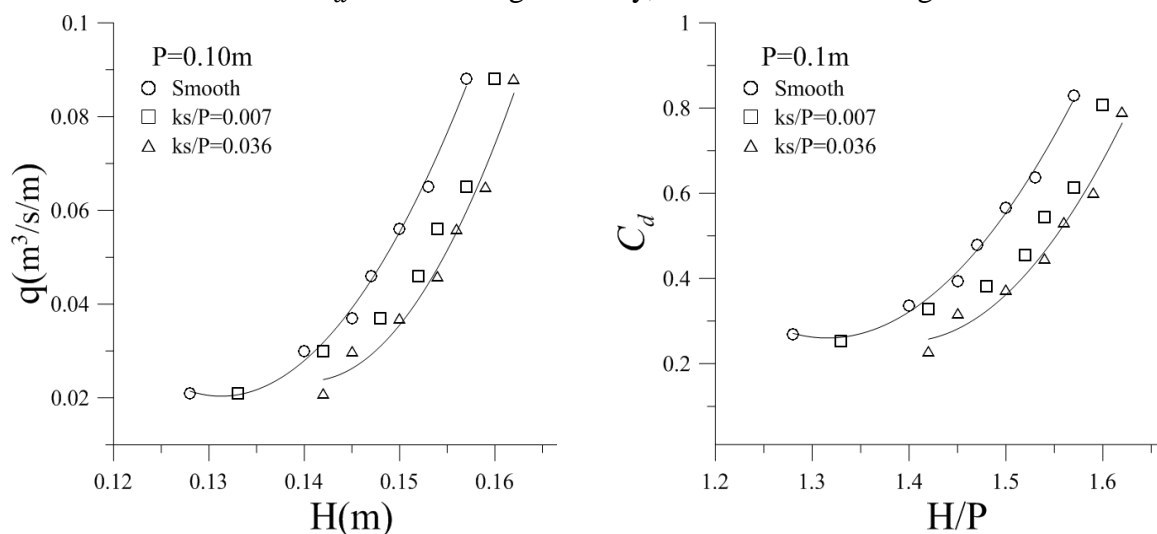
Table 1.

Table 1-Specifications of laboratory models and discharge				
P(m)	α (degree)	β (degree)	q(m ³ /s/m)	k_s (mm)
0.1,0.2	26.5	11.3	0.021	Smooth
				0.72
				0.088
				3.5

3. Results and discussion

This section presents the results obtained in this study. Since the Crump weir is usually constructed perpendicular to the flow path, the approach flow to the weir is subcritical, and its Froude number is less than one; therefore, the effect of the Froude number on the C_d is avoided. An attempt has been made to minimize the turbulent flow at the weir, assuming the effect of surface tension is negligible, so the impact of Reynolds and Weber numbers has not been considered. Therefore, equation (3.a) can be rewritten as equation (3.b). Since the content of this research focuses on the effect of surface roughness, the impact of upstream and downstream slopes (α and β) on the discharge coefficient has not been studied. During the research, their values were assumed to be constant. The evaluation curves of all three models in the presence of their surface roughness are shown in Figure 2. This figure shows that the discharge values per width (q) were plotted against the flow head over the crest (H). In this figure, the values of k_s/P indicate the surface roughness of each model. Circular symbols represent the information related to the smooth Crump weir, the data associated with the sand-coated models ($ksP = 0.004$ and 0.007) is represented by square symbols, and the information related to the gravel-coated models ($ksP = 0.018$ and 0.036) is represented by triangular symbols. A quadratic curve can model the performance curve of these weirs in the range of laboratory variables. The C_d of each model in the presence of its roughness was calculated based on Equation 1, and its results are shown in Figure 2, plotted against the relative upstream head (H/P).

The range of C_d of all the models varies between 0.2 and 0.8, considering that the range of H/P varies between 1.1 and 1.7. In a model with a height of 0.1 m, at low values of flow rates (upstream head), roughening the surface of the crest (using a gravel grain size) decreases the flow rate by approximately 12.8%. With an increasing flow rate, its effect on the discharge capacity (C_d) decreases by approximately 1.9 percent, making its impact manageable. The effect of both types of roughness (sand and gravel) on C_d is nearly identical at high discharge values. In the model with a height of 0.2 cm, as the roughness increases, the C_d value decreases by approximately 5 percent at low upstream head values. First, by increasing the upstream head, the effect of the flow on the C_d decreases significantly, which can even be ignored.



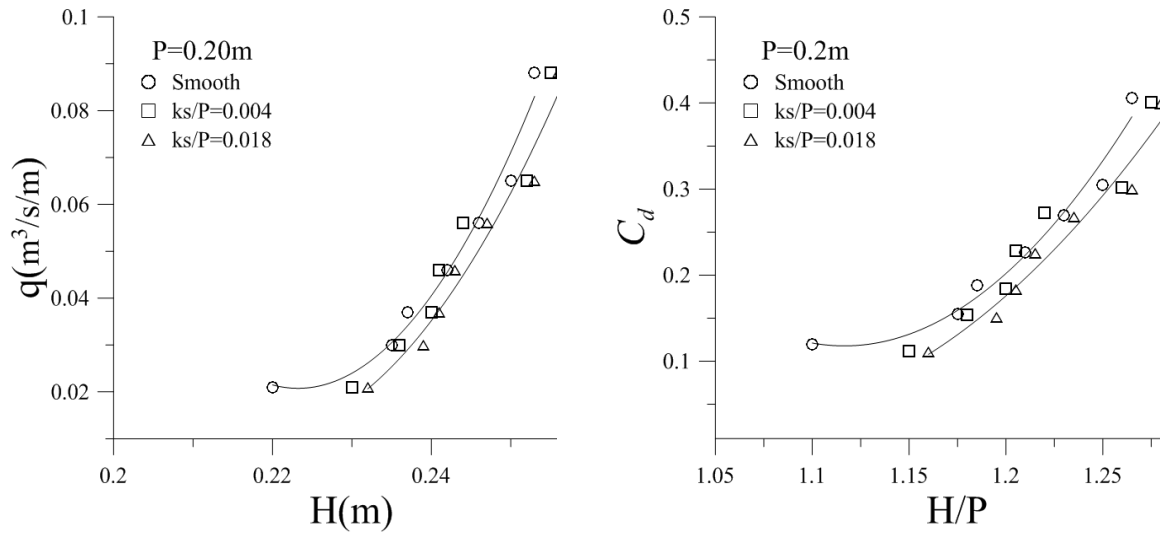
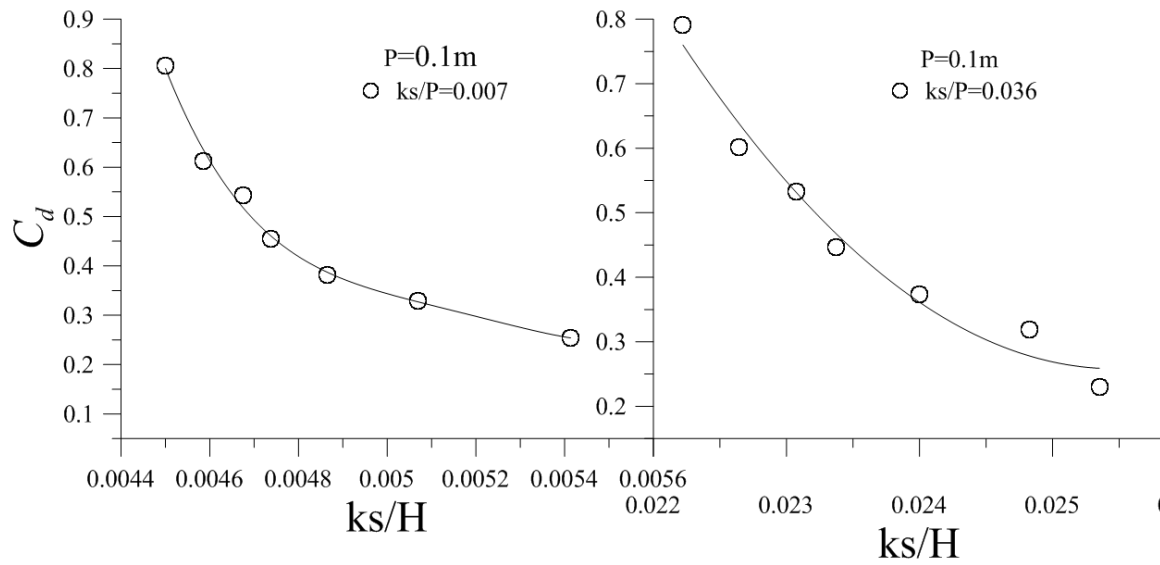


Figure 2- The rating curves and discharge coefficient of smooth and rough crump weirs

The values of the C_d versus the k_s/H are shown in Figure 3. As shown in this figure, for all models, the effect of roughness on the C_d is significant at low upstream head values, but it is significantly reduced with increasing flow rate.



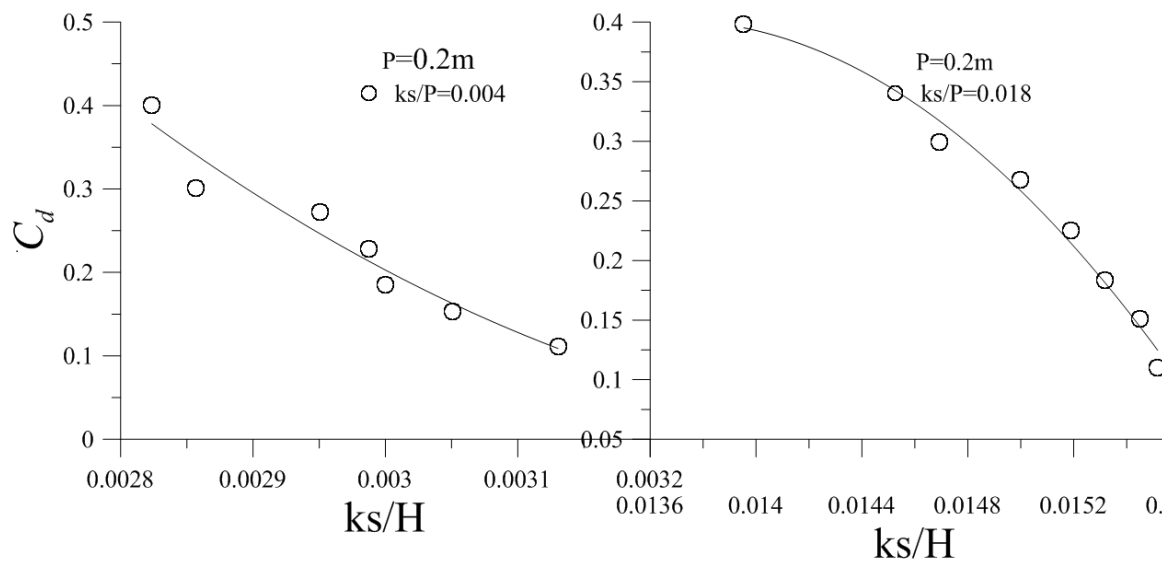


Figure 3- The values of the discharge coefficient versus the k_s/H

4. Conclusions

This study investigated the impact of surface roughness on the discharge coefficient (C_d) of Crump weirs under subcritical flow conditions. Results showed that roughness significantly reduces C_d at low upstream heads (H/P), with gravel-coated weirs experiencing a decrease in discharge capacity of up to 12.8%. In contrast, sand roughness had a comparable impact. However, this effect diminished at higher flow rates, becoming negligible (as low as 1.9%). The ratio k_s/H played a key role, with the influence of roughness weakening as H/P increased. These findings suggest that smoother weir surfaces are preferable for low-flow precision, whereas roughness effects can be disregarded in high-flow conditions. Future research should investigate additional factors, such as slope variations and field-scale validation, to refine hydraulic modeling. This work provides practical insights for optimizing Crump weir design in flow measurement applications.

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Conflict of Interest

The authors declare no conflict of interest.

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