Performance of Sills on Stilling Basin of Barrage with Various Open Gates

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Abstract. This research aimed to investigate safeguarding the hydraulic structures. In the barrage model, the performance of continuous sills with different cases of open gates was investigated experimentally in the laboratory. The experimental works are implemented in laboratory of technical institute of Kut. There are several closed gates and how symmetry and asymmetry with different discharges and sills arrangements are carried out. The results were recorded and analysed. The discussion has illustrated the impact of sills in confining the hydraulic jumps in the stilling basin’s paved region and reducing the near-bed velocity that cooperates in reduction the scouring case near the stilling basin.

1. Introduction
Several researchers define hydraulic jump (H.J) in many ways. [1-3] studies have discussed the definition of this phenomenon where it, which principally means the transformation from a super-critical flow state to a sub-critical flow state. This phenomenon is considered an efficient tool to dissipate the excessed energy. Turbulent mixing along (H.J) creates dissipation of energy for super-critical flow up to 85 percent depending on incoming Froude No. Fr (Chow, 1959) [1]. [4-8] have determined the endpoint of the hydraulic jump in this manner. To increase hydraulic structures' energy dissipation efficiency, sills are used with a stilling basin to confine the hydraulic jump.

Alikhani et al. [9] conducted laboratory experiments to assess the impacts of the continuous vertical sill and its position on controlling the depth and length of a forced jump in a stilling basin without considering tailwater depth variable and fully controlled by downstream river environmental conditions. Many model investigations were discussed to develop (H.J) in the stilling basin [10-11]. Saleh, O. K., et al. [12] discussed the importance of end sill in sudden expansion to eliminate or reduce anticipated scour size. Experimentally, Aziz F. E. et al. [13] studied the curved sill's impact with varied sizes and energy dissipation arrangements. The study presented that the curved sill generates more stability for flow and good efficiency in energy dissipation.

F. Moghadam et al. [14] discussed the impact of the continuous sill on forced (H Js). The study compared the results of experiments and the classical hydraulic jump. [15-16] Investigations of roughness and its effect on hydraulic jumps' length are performed. Deng et al. [17] investigated the fluctuation of pressure for (H.J) with end sill.

Debaeche and Achour [18] investigated the influence of a continuous sill on the (HJ) in a triangle channel. Mardani et al. [19] experimentally discussed the impact of utilizing blocks on the hydraulic jump in different arrangements of blocks and different hydraulic conditions.

Abdelmonem [20] investigated the effect of a new tool by utilizing a hanging pendulum as energy dissipater. the results approved the efficiency of a new technique in energy dissipation.
The pendulum sill's impact with fixed weight is experimentally discussed by Khairy et al. (2018) [21]. The study approved the advantage of pendulum sill as an energy dissipater in some cases with sluice gates. While Abd El Ghany [22] conducted the experimental works with pendulum sill filled partially with sand, changing the weight is utilized. The experimental outcomes illustrated that utilizing the pendulum sill raised the rate of energy dissipation. Y.A. Moussa [23] investigated the performance of varied shapes, distances and heights of sills on scouring properties under impact the submerged jump, the study presented the great impact of sills on examined parameters, especially the sill's right-angle side. While the effect of Froude No. of tailwater of hydraulic structures are investigated by Shamkhi et al. [24] with varied cases of open gates of the barrage. The study deduced the relationship between the depth of scouring, length of scour and Froude number. The study determined the best and worst scenarios of open gates of the barrage.

The present study investigates the sill arrangements performance with different open gates of the barrage. The energy dissipation, hydraulic jump length and velocity gradients at the end of the stilling basin are studied. The type of used flow is free to flow condition.

Abbreviations

| Symbol | Description |
|--------|-------------|
| $H_o$  | depth of upstream flow |
| $L_s$  | distance of sill from sluice gate |
| $y_j$  | super critical flow depth ($y_j = C_c * w$) |
| $E_1$  | energy at $H_o$ |
| $E_2$  | energy at end of stilling basin |
| $B$    | flume width |
| $W$    | opening height of gate |
| $y_s$  | tail water depth |
| $L_j$  | length of jump |
| $V_j$  | velocity of jet flow at $y_j$ |
| $Fr$   | incoming Froude No. |
| $b$    | width of opened gate |

2. Experimental works

All of the present study's experimental works are conducted in the hydraulic laboratory of Kut Technical Institute, Iraq. Herein, the used flume, models of the barrage, materials of the bed and a description of the applied operation before each run and the studied experimental tests are presented. The flume directs tests with a system of closed-loop flow. Its dimensions are 20 m in length and 0.5 m in net width. It is made up of sidewalls of transparent, toughened glass 0.5 m in height. The used flume is displayed in Fig. 3.1. At the inlet of the flume, a supplied v-notch of 90° is utilized to calculate the discharge. At the end of downstream, a moveable sliding vertical gate is fixed. All depth measurement processes are executed depending on three movable carriages with point gauges, which have an accuracy of (± 0.1) mm and set on brass rail specifically at the flume sides top handrail. In this respect, researcher discussed the impact of continuous sill in the stilling basin of the barrage. Where we compared the different arrangements of sills. The inclined front face of sills is made by 45° with a constant height of 1 cm.
The used distribution of sill is illustrated in Fig. 2 and Table (1) below that explain the number and spaced between used sills.

**Table 1. Different arrangements of sills**

| symbol | Position of used sill |
|--------|-----------------------|
| 1      | No sill case          |
| 2      | S1 Location 1         |
| 3      | S2 Location (1 + 2)   |
| 4      | S3 Location (1 + 2 + 3) |
| 5      | S4 Location (1 + 2 + 3 + 4) |
| 6      | S5 Location (1 + 3)   |
| 7      | S6 Location (1 + 4)   |

Seven arrangements of sill cases accompanied with ten scenarios of open gates are conducted in this study. The constant openness of open gates and tailwater depth 3 and 8 cm, respectively. The used discharges and Froude number are shown in Table 2. Velocity meter (mini water I) with three grades of measurements. Velocity was measured at a constant elevation from the bed 1.5 cm to represent the shear velocity near the bed and at three positions to define the velocity gradients.

**Table 2. Range of discharges and incoming Froude No.**

| No. of opened gates | Q l/s   | H0 (m) | Fr    |
|---------------------|---------|--------|-------|
| 1                   | 2       | 6.8-7.5 | 5.788-6.38 |
| 2                   | 3       | 6.8-10.7 | 3.86-6.07 |
| 3                   | 4       | 6.8-13.3 | 2.89-4.94 |
| 4                   | 5       | 6.8-13.3 | 2.31-4.50 |
| 5                   | 6       | 9-13.3  | 2.56-3.78 |

The contraction coefficient value under sluice gates was considered $C_c = 0.61$ (according to Henderson [25]). So, the $y_j=C_c \times \frac{W}{L_j}$

(1)

3. **Dimensional analysis**

The theorem of Buckingham ($\pi$) was utilized to correlate between the dependent variables and independent variables, as shown below [26]:

$$\frac{L_j}{y_j}, \quad \frac{V_x}{V_j} = f(\frac{Fr}{y_j}, \quad \frac{L_j}{y_j})$$

(2)

Where $V_x$ is the velocity near the bed at the end of stilling basin.
4. Analysis and discussions
Explanation of impact for sills over the stilling basin was carried out by utilizing the dimensional analysis and discussing the experimental results. The effect of Froude No., position of sill according to sluice gate and arrangements of the sill on length of (H.J) and gradient of velocity beyond the sill. According to Fig.3(a), the length of (H.J) increases with the incoming Froude number for different open gates. Also, Fig.3(a) illustrates the impact of changing the open gates on the hydraulic jump’s length, where the relative length of (H.J) is increased with a varied rate according to the barrage’s open gates. The same pattern exists in different sill arrangement cases, as shown in Fig.3(b). The rate of increasing the length of jump in case (1, 2, 5, 6) gates lower the rate available in case five and six gates because of the flux momentum. The same observations are existed in the case of velocity, as shown in Fig.4.

![Figure 3. Relation between Lj/yj and Fr (a) No sill cases (b) Various cases of sill](image)

As shown in Fig.4, it's illustrated that the velocity near the bed is increased by increasing the incoming Fr No. the increasing pattern are obtained for all cases (three, five, six gates) as shown in fig.4.

![Figure 4. Effect of Froude No. on near bed relative velocity](image)
In Fig. 5, the gradients of velocity and the flow stream are differentiating according to open gates' arrangements. Where in the case of separating gates, the gradient in velocity was more as illustrates in the case of (1,6) as compared with cases (1,2) and (3,4) open gates.

![Figure 5](image)

**Figure 5.** Velocity gradient for various cases of two open gates (No sill case)

### 4.1 Effect of sill position on hydraulic jump length

There are three models of sills (S2, S5, S6) in addition to the effect of end sill (S1), as shown in Fig. 6. For six open gates, it was found that the end sill effect S1 (Ls/yj = 33) generates a reduction value (16%) in relative length if hydraulic jump at (Fr= 3.8).

Moreover, as the sill moves closer to the end of the stilling basin S2 (Ls/yj=21) generates a reduction in relative length if hydraulic jump with 23% compared to the no-sill case. Also, the impact of S5 and S6 (Ls/yj = 6, 12, respectively) were close. So, it was obtained that both sill cases generate maximum reduction (60%) if compared with no-sill cases in the relative length of hydraulic jump at Fr= 3.8.

It is clear that, as the sill moves to be close to the gate, the sill's ability to control the hydraulic jump behind the gate is increased. Hence the reduction of jump length is achieved. The same matter in the case of four open gates, as the sill be closer to the gate, the sill ability to control the hydraulic jump behind the gate increased.

![Figure 6](image)

(a)
4.2 Effect of sill position on velocity gradients
The effect of sill position on velocity near bed is illustrated in Fig. 7. The least value of relative energy is governed when sill be closer to the sluice gates. It’s evident the effectivity of sill is increased in reduction the value of velocity near bed.

4.3 Effect of sill arrangements on length of (H.J)
The effect of sill arrangements is clearly illustrated in changing the arrangements of sills where Fig.8(a) presents the relation between Lj/yj and the gate Fr for four open gates (2, 3, 4, 5). The effect of sill arrangements on the relative length of the hydraulic jump evident. The value of Fr ranges (2.9-5.67). At Fr = 5.67, the value Lj/yj of the best case of sill arrangement (S4) is 45% less than no sill case. Also, all arrangements of sills were useful in this case. The same pattern is obtained in the rest cases of open gates. In all open gates, the S4 arrangement reduces the length of (H.J), about 70% compared with no sill case, as shown in Fig.8 (b). Also, the effect of sill arrangement is increased with increasing the Fr number.
Effect of sill arrangements on near bed relative velocity

The impact of sill arrangements on near bed relative velocity is studied with seven cases of sill distribution. Case (1,2) illustrates the effect of sill arrangements on velocity gradient. The best scenario of sills is S4. The velocity gradient in the S4 case is (32%) if compared with no sill case. Also, the effect of sill nearness represents in the S6 case that is close to the S4 case. This evident to the significant role to the nearness of sill. The same pattern was found in the rest of the cases, as shown below in Figures (9, 10 and 11).

Figure 8. Froude No. versus (Lj/yj) (with various sill arrangement) for two and four open gates

Figure 9. Relation of velocity gradients with distance along stream flow (Five open gates) with sill

Figure 10. Relation of velocity gradients along stream flow (all open gates) with various cases of sills
5. Regression analysis

Multiple linear regression was utilized by S.P.S.S. software for correlating the variables (dependent and independent), as shown below:

\[ Y = C + X_1 \text{Fr} + X_2 \frac{L_s}{y_j} + X_3 \frac{b}{B} \]  

Where \( Y = \) dependent variable \( \ln \left( \frac{L_j}{y_j} \right) \); \( \ln \left( \frac{V}{V_j} \right) \)

\( C = \) intercept of equation (2); \( X_1, X_2, X_3 \) are the coefficients of the independent parameters.

The Fig.12 and Fig.13 illustrated the comparison between experimental and estimated data.

|                  | \( Y \) | \( C \) | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( R^2(\%) \) |
|------------------|--------|--------|--------|--------|--------|----------|
| \( \frac{L_j}{y_j} \) | 1.281 | 1.891  | 0.521  | 0.298  |        | 87.5     |
| \( \frac{V}{V_j} \) | 0.118 | 0.423  | 0.741  | 0.238  |        | 78       |

Figure 11. Relation of velocity gradients along stream flow (Four open gates)

Figure 12. Illustrated the comparison between experimental and estimated data

Figure 13. Illustrated the comparison between experimental and estimated data
6. Conclusion
In this study, the characteristic of flow from sluice-gates of the barrage, including the length of jump and near-bed relative velocity, were studied experimentally. Also, the performance of continuous sills on hydraulic jump and velocity gradients were investigated and could be summarized:

- The continuous sills over aprons of barrage greatly impact flow and could cooperate in barrage's safety operation if compared with no sill case.
- The length of the hydraulic jump increases with increasing incoming Froude number.
- The closer sill to the sluice gates effectively shortens the hydraulic jump's length and reduces near bed relative velocity.
- The separating of working sluice gates effectively shortens the hydraulic jump length and decreases the near-bed velocity compared with adjacent gates.
- The arrangements of sills are effected issue in decreasing the jump length and velocity near the bed.

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