INTRODUCTION

A weir is commonly used to raise water level of a river. Weirs are also functioned by hydraulic engineers to measure the flow discharge in the streams. Water flows over the top of the weir is not too deep. Many efforts have been done to diminish the scour hole by using a stilling basin, baffle block, end sill or the combination of that. The use of double-crested weir is also applied to reduce the scour as a consequence of the energy dissipation by multiple steps of head loss. In this study, scour behind double-crested weir is performed and compared to the one for single crest. Local scour data are collected from measurement results in Hydraulic Laboratory. Influence of the flow discharge and head loss to the development of local scour hole behind single and double-crested weirs are discussed. Results of experiments show the process of local scour behind the weir that is time dependent. When both of crests produce free hydraulic jump, a less scour hole behind the structure was occurred reached 43 % to the scour depth behind the weir with single crest. When submerged hydraulic jump developed behind the weir, shown results for both types are not significantly different. For both types of the weir, an increase of flow discharge produces larger of developed scour hole behind the weir, except for condition where the submerged hydraulic jump developed. It is also shown, with increasing the dissipated energy produce larger scour hole behind the weir.

Keywords: local scour, double-crested weir, discharge

SCOUR FORMULAS

For predicting the scour depth behind the weir, \( d_s \), various formulas have been developed. The scour depth, presented as an equilibrium maximum value, developed as a function of discharge, grain size diameter and tail water depth. This formula is summarized in Table 1 as the following (Provorova, 1999; Peterka, 1974; USBR, 1973; and Yulistiyanto, 2009).
Figure 1. Cascade Weir at Gadjah Wong River, Yogyakarta (The right picture was documented on 11 April 2010)

![Cascade Weir at Gadjah Wong River, Yogyakarta](image1)

Figure 2. Design of New Spillway just Upstream from the Old Weir, formed double-Crested Weir

![Design of New Spillway just Upstream from the Old Weir](image2)

Table 1. Formulas for predicting Scour Depth behind the Weir

<table>
<thead>
<tr>
<th>No</th>
<th>Formula</th>
<th>Equation</th>
<th>Explanation</th>
</tr>
</thead>
</table>
| 1  | Demle and Khatsuaria | \[ d_s = A (q h_o)^{0.5} - h_2 \] | Demle: \( A = 0.65 \)  
     |         |          | Khatsuaria: \( A = 0.9 \) |
| 2  | Mason (1989) | \[ d_s = 3.39 \frac{q^{0.6} (1 + \beta)^{0.3} h_2^{0.16}}{g^{0.3} d_m^{0.16}} \] | \( \beta \) = amount of air entrained |
RESEARCH METHOD

Data of local scour downstream from two types of weir are used to study scour characteristic for single and double crested weir. The data were collected from some experiments conducted at Hydraulic Laboratory, Gadjah Mada University. Experiments were done using recirculation tilting flume, with 6 m long and 0.075 m width. Figure 3 schematize flow structures through the double-crested weir and developed scour hole behind the weir. Scour depth, \( d_s \), length of scour hole, \( L_s \) and the position of maximum scour depth behind the weir, \( L'_s \), were measured by using point gauge, and the characteristic of scour hole were discussed.

The experiment data of local scour depth behind the weir are compared with the ones predicted by empirical formulas for single crest weir (Table 1).

DATA ANALYZED AND DISCUSSION

Figures 4 show schemes of flow for two cases of developed flow structure behind the weir, consist of free and submerged hydraulic jump. The first picture shows the hydraulic jumps developed behind both the front and the rear crests of the weir. If flow depth at tail water is sufficiently high, the hydraulic jump behind the rear crest is submerged, as presented in the second picture.

Interaction between Scour depth and time

The process of local scour behind the hydraulic structure is time dependent. It is often represented in graphical form by plotting the maximum scour depth against the time, as shown in Figures 5, given the local scour downstream of the weir normalized by depth of weir, \( d_s/P \), as a function of time, for variation of dissipated energy (\( \Delta H/P \)). Scour depth was measured until equilibrium was reached. The process of local scour behind a weir is relatively rapid in the initial minutes, and then continues to increase gradually reached an equilibrium depth.

For \( \Delta H/P \) equal to 1.0 and 0.82, the free hydraulic jumps as schematized at the first picture of Figure 4, were developed, however for \( \Delta H/P = 0.76 \) submerged hydraulic jump was found behind the rear crest. It is presented in Figures 5a and 5b, when free hydraulic jumps are developed behind both crests of the weir, a less scour hole behind the structure was occurred, compared with the one for scour behind single-crested weir (see the first and
second pictures of Figures 5). The scour depth behind double-crested weir reached 43% to the scour depth behind the weir with single crest. Figure 5c presents scour depth as a function of time for $\Delta H/P = 0.76$ (submerged hydraulic jump behind the rear crest), shown results for both types are not significantly different. With rising of the tail water influences to less function of the rear crest to dissipate the energy, consequently the developed scour hole is similar with the one of weir with single crest.

Interaction between Flow Discharge and Size of Scour Hole

Three parameters are measured and discussed; they are scour depth, length of scour hole, and the position of maximum scour depth. These are discussed as the following.

a. Scour Depth

Figure 6 presents influences of flow discharge with developed scour depth behind weir structure. It gives relation between scour depth, normalized by the weir height, and the unit flow discharge, for two types of weir with single and double-crested. For both types of the weir, and for all values of dissipate energy, an increase of flow discharge produces deeper scour depth behind the weir. Scour depth behind double-crested weir are shallower significantly compared to the one for single-crested weir, except for $\Delta H/P = 0.76$ with high discharge (see Figures 7). This exception is due to the occurrence of submerged hydraulic jump behind the rear crest of the weir. The submerged hydraulic jump is formed if the tail water is higher than the conjugate depth of the hydraulic jump, consequently it pushes the hydraulic jump to the upstream direction. The submerged hydraulic jump effect less function of the rear crest to dissipate energy.
Figure 7c. Flow Unit Discharge vs. Scour Depth, for $\Delta H/P = 0.76$

Figure 8 presents maximum scour depth from the water surface, $d_s + h_2$, developed behind both types of the weir, normalized by $H$, as a function of unit discharge, shown an increasing of scour depth as higher unit discharge. As mention in above, scour depth behind double-crested weir develops lower value compared with the single crested weir. In that figure, some formulas of local scour depth proposed by some researcher for single-crested weir are also plotted. It is shown that scour depth data collected from experiments done at Hydraulic Laboratory, Gadjah Mada University, are quietly comparable with the scour depth predicted by the existing formulas.

Figure 8. Comparison data with Existing Formulas

b. Positions of Maximum Scour Depth

Figure 9 presents position of maximum scour depth in the scour hole behind the weir, $L_s'$. The position of maximum scour depth, normalized by the head loss ($H$), is further with increasing the unit discharge. The position of maximum scour depth for weir with double-crested is closer to the endsill, compared to the one for single-crested.

Figure 9. Position of the Maximum Scour Depth

c. Length of Scour Hole

Figure 10 describes the length of scour hole behind the weir, as a function of the unit discharge. It is shown an increase of the length of the scour hole for higher unit discharge. The length of scour hole for weir with double-crested is about one half from the one of single-crested.

Figure 10. Length of Scour Hole

With paying attention for comparisons between weir with double and single crest, for its scour depth, length and position of maximum scour depth, it is concluded that by using weir with double
crests develops smaller size of scour hole behind the hydraulic structure.

**Interaction between Dissipated Energy and Size of Scour Hole**

The amount of energy released by the weir, interpreted by different elevation between upstream and downstream of the weir, have considerable effect on scour hole development behind the weir. These are presented in Figures 11 - 13. It can be seen from these graphs the relationship of dissipated energy with three parameters of scour hole, namely scour depth, length of scour hole and the position of maximum scour depth measured from the endsill. On variations of high water on the upstream and downstream of these turned out to provide significant changes of these three parameters of scour hole. As mention above, the weir is functioned to dissipate energy. The energy released by the weir induces scour behind the weir, consequently structure stability may decreased.

![Figure 11. Scour Depth vs. Dissipated energy](image1)

![Figure 12. Position of Maximum Scour Depth vs. Dissipated energy](image2)

![Figure 13. Length of Scour Hole vs. Dissipated energy](image3)

**CONCLUDING REMARKS**

Study of Local Scour behind single and double-crested weir is done. The following are remarked:

- The process of local scour behind the weir is time dependent. The scour depth increase rapidly in the initial minutes, then continue to increase gradually reached an equilibrium depth.
- Scour data behind two types of weir is analyzed. It is presented that when all crests of weir produce free hydraulic jump, a less scour hole behind the structure was occurred, compared with the one for scour behind single-crested weir.
- The scour depth behind double-crested weir reached 43 % to the scour depth behind the weir with single crest.
- When submerged hydraulic jump developed behind the weir, shown results for both types are not significantly different. With rising of the tail water influences to less function of the rear crest to dissipate the energy, consequently the developed scour hole is similar with the one of weir with single crest.
- For both types of the weir, and for all values of dissipated energy, an increase of flow discharge produces larger of developed scour hole behind the weir.
- With increasing the dissipated energy produce larger scour hole behind the weir, for both types of the weir.

**ACKNOWLEDGEMENT**

The author acknowledges the contribution from Novirwan, Mirza, and Jimmy Charles for their collected measurements data.

**REFERENCES**


