International Symposium on Hydraulic Structures

May 17th, 8:20 AM

Scour Morphology Downstream of Log-Frame Deflectors in Series

Sahameddin Mahmoudi Kurdistani  
*Università del Salento*, s.m.kurdistani@unisalento.it

Michele Palermo  
*University of Pisa*, michele.palermo@ing.unipi.it

Stefano Pagliara  
*University of Pisa*

Leila Sagvand Hassanabadi  
leila.hassanabadi@gmail.com

Follow this and additional works at: [https://digitalcommons.usu.edu/ishs](https://digitalcommons.usu.edu/ishs)

**Recommended Citation**  
Scour Morphology Downstream of Log-Frame Deflectors in Series

S.M. Kurdistani\(^1\), M. Palermo\(^4\), S. Pagliara\(^4\) & L.S. Hassanabadi\(^2\)

\(^1\)DESTEC-Department of Energy, Systems, Territory and Construction Engineering, Pisa, Italy
\(^2\)Department of Engineering for Innovation – University of Salento, Lecce, Italy

E-mail: michele.palermo@ing.unipi.it

Abstract: Stream deflectors are grade-control structures of common use to control riverbed evolution, stabilize channel alignment, protect stream banks, and rebuild the natural habitat. Among them, log-frame deflectors consist of a triangular log frame filled with rocks. Log-frame deflectors, constructed either singly or in series in low gradient meandering streams, divert base flows toward the center of the channel. Under certain hydraulic conditions, they modify both the depth and velocity of flow, resulting in scour pool formation and fish habitat improvement. The main purpose of the current study is to analyze the effect of the distance between log-frame deflectors on the scour morphology, when installed in series. Therefore, experimental tests have been carried out in a horizontal channel and in clear water conditions at the hydraulic laboratory of the University of Pisa. Results show that the meandering process in rivers is deeply influenced by the distance between log-frame deflectors, when located at both left and right river banks. Furthermore, scour characteristics and morphologies downstream of log-frame deflectors have been analyzed, resulting in useful suggestions for a correct design of such structure typology.

Keywords: Hydraulic structures, log-frame deflectors, morphology, scour, stream restoration.

1. Introduction

Woody stream restoration structures are a part of the natural channel design approach (Rosgen, 2001) to restore the dimension, pattern, and profile of a channel. Woody stream restoration structures, like log-deflectors and log-frame deflectors, as in-stream grade control structures, are used to stabilize riverbed, riverbanks, and improving aquatic habitat in rivers. Scour holes are resting pools for fish and help fish to migrate upstream for spawning. Occurring a scour hole toward the center of the channel and developing a ridge toward the riverbank lead to stabilize the riverbed and protect the riverbank. Local scour phenomena have been studied by Schoklitsch (1932), Veronese (1937), Hassan and Narayanan (1985), Farhoudi and Smith (2014), Mason and Arumugam (1985), Bormann and Julien (1991), Whittaker and Jaggi (1996), Robinson et al. (1998), and Dey and Sarkar (2006a, b, 2008).

In the literature, few experimental studies focused on the scour downstream of grade-control structures. Przedwojski (1995) investigated scour processes in rivers in the presence of groynes. He analyzed the effect of the groyne location on the scour depth, concluding that the maximum scour depth occurs when the groyne is located downstream of the bend apex. Pagliara and Kurdistani (2013, 2014) conducted a series of experiments on scour downstream of low-head grade-control structures in a straight channel for different bed slopes. Pagliara et al. (2015a, b) and Pagliara and Kurdistani (2017) investigated the scour morphology in straight rivers downstream of different type of grade-control structures such as log-vane, log-deflector and log-frame deflector structures. Kurdistani and Pagliara (2015) investigated the effect of the installation angle for woody structures and found that log deflectors need special consideration to avoid the occurrence of scour hole near the channel bank. Pagliara and Kurdistani (2015) studied the effect of the channel bend on the main scour parameter values and scour morphology downstream of J-hook vanes showing that the values of all scour parameters decrease with the tailwater depth and the bend radius. Pagliara et al. (2016) studied log sills scour morphology in curved and straight horizontal channels. Pagliara and Kurdistani (2017) found that using log-frame deflectors instead of log deflectors prevents scour formation close to the riverbank and consequently, provides a better riverbank protection. Kurdistani and Pagliara (2017) experimentally studied scour morphology downstream of cross-vanes in a curved channel, particularly focusing on the effect of the structure orientation.

Jamieson et al. (2013a) found that stream barbs divert the high velocity body of the river flow from the outer bend to avoid the bank erosion. Jamieson et al. (2013b) studied the turbulence and vorticity in a bend and they showed that increasing z-vorticity creates a scour hole near the barbs. Melville (1992) derived simple equations to estimate the maximum scour depth at bridge abutments. Based on Melville’s study, Kuhnle et al. (1999, 2002) carried out a series of experiments on scour around 90° and angled non-submerged spur dikes, respectively. Melville (2014) classified his
method for different types of structures and, based on the Shields critical velocity, derived a new equation to predict scour depth downstream of submerged weirs. Guan et al. (2014) investigated the flow patterns and turbulence in a scour hole downstream of a submerged weir. Guan et al. (2015) studied live-bed scour at submerged weirs. Bahrami and Shafai (2016) studied sediment management and flow patterns at river bend due to triangular vanes attached to the bank. They found that with multiple vanes in place, the thalweg was shifted toward the flume midway from the outer bank. The main target of the current study is to experimentally analyze the effect of the distance between log-frame deflectors on the scour characteristics and morphology around log-frame deflectors.

2. Experimental Setup

All the experiments on log-frame deflectors have been conducted in a horizontal channel 0.8 m wide, 20 m long and 0.75 m deep at the hydraulic laboratory of the University of Pisa. Stable inflow was supplied by an overhead tank. The flow discharge was measured using a calibrated tank with a precision of ±0.1 l/s. An ultrasonic distance meter sensor with precision of 0.001 m has been used to read the water surface profile and the bathymetry of the mobile bed. Figure 1 shows a plan and side views of experimental set-up, including the main geometric and hydraulic parameters. In Fig. 1, α is the deflector angle with respect to the river bank, \( l_s \) is the length and \( h_s \) is the height of the structure. \( \Delta y \) is the difference between the water surface upstream and downstream of the structure, \( B \) is the channel width, \( z_m \) is the maximum scour depth, \( l_m \) is the length of the scour, \( z'_m \) is the maximum height of the ridge, \( l'_m \) is the ridge length. Pagliara et al. (2015a, b) defined the densimetric particle Froude number as \( F_d = \frac{Q'}{(l_s h_s g (G_s - 1) d_{50}^{0.5})} \), where \( Q' = \frac{b}{B} Q \) is the effective flow discharge, \( G_s = \frac{\rho_s}{\rho} \), in which \( \rho_s \) is the bed material density and \( \rho \) the water density, \( d_{50} \) is the mean particle diameter and \( g \) the gravitational acceleration. Uniform non-cohesive sand with a \( \sigma = (d_{84}/d_{16})^{0.5} = 1.16 \), \( G_s = 2.60 \) and \( d_{50} = 1.70 \) mm was used. At the beginning of each experiment, the channel bed was carefully leveled (Fig. 2). All the tests have been conducted in clear water condition. The duration of tests was long enough to reach an equilibrium bed condition (between one to three hours, according to hydraulic conditions).

Experimental data are shown in Table 1. Experiments (1 – 8) are data relative to \( \lambda/B = 0 \) and they are adopted from Pagliara and Kurdistani (2017). The other 14 experiments were carried out for the present study and are relative to \( \lambda/B = 0.3125 \) and \( \lambda/B = 0.5 \).

---

**Figure 1.** (A) Plainview of the log-frame deflector, (B) longitudinal profile A-A and A’-A’.
Figure 2. Picture of the experimental apparatus before the test beginning.

Table 1. Experimental test ranges.

<table>
<thead>
<tr>
<th>Text</th>
<th>(Q) (m(^3)/s)</th>
<th>(\alpha)</th>
<th>(\Delta y) (m)</th>
<th>(h_0) (m)</th>
<th>(h_{\infty}) (m)</th>
<th>(\Delta / B)</th>
<th>(z_{\infty}) (m)</th>
<th>(z'_{\infty}) (m)</th>
<th>(l_0) (m)</th>
<th>(l'_{\infty}) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0011</td>
<td>0.055</td>
<td>0.0674</td>
<td>0.00</td>
<td>0.0300</td>
<td>0.0200</td>
<td>1.2410</td>
</tr>
<tr>
<td>2</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0017</td>
<td>0.055</td>
<td>0.0973</td>
<td>0.00</td>
<td>0.0350</td>
<td>0.0330</td>
<td>0.3790</td>
</tr>
<tr>
<td>3</td>
<td>0.045</td>
<td>30</td>
<td>0.663</td>
<td>0.0029</td>
<td>0.055</td>
<td>0.1240</td>
<td>0.00</td>
<td>0.0640</td>
<td>0.0250</td>
<td>0.5610</td>
</tr>
<tr>
<td>4</td>
<td>0.055</td>
<td>30</td>
<td>0.663</td>
<td>0.0098</td>
<td>0.055</td>
<td>0.1586</td>
<td>0.00</td>
<td>0.0480</td>
<td>0.0610</td>
<td>0.5940</td>
</tr>
<tr>
<td>5</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0080</td>
<td>0.085</td>
<td>0.0790</td>
<td>0.00</td>
<td>0.0770</td>
<td>0.0380</td>
<td>0.5480</td>
</tr>
<tr>
<td>6</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0025</td>
<td>0.085</td>
<td>0.1125</td>
<td>0.00</td>
<td>0.0620</td>
<td>0.0320</td>
<td>0.5550</td>
</tr>
<tr>
<td>7</td>
<td>0.045</td>
<td>30</td>
<td>0.663</td>
<td>0.0037</td>
<td>0.085</td>
<td>0.1509</td>
<td>0.00</td>
<td>0.0770</td>
<td>0.0370</td>
<td>0.5820</td>
</tr>
<tr>
<td>8</td>
<td>0.055</td>
<td>30</td>
<td>0.663</td>
<td>0.0015</td>
<td>0.085</td>
<td>0.1698</td>
<td>0.00</td>
<td>0.0640</td>
<td>0.0400</td>
<td>0.6170</td>
</tr>
<tr>
<td>9</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0051</td>
<td>0.055</td>
<td>0.0699</td>
<td>0.3125</td>
<td>0.0920</td>
<td>0.0350</td>
<td>0.8920</td>
</tr>
<tr>
<td>10</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0027</td>
<td>0.055</td>
<td>0.0993</td>
<td>0.3125</td>
<td>0.0920</td>
<td>0.0440</td>
<td>0.7170</td>
</tr>
<tr>
<td>11</td>
<td>0.045</td>
<td>30</td>
<td>0.663</td>
<td>0.0042</td>
<td>0.055</td>
<td>0.1372</td>
<td>0.3125</td>
<td>0.0650</td>
<td>0.0330</td>
<td>0.6850</td>
</tr>
<tr>
<td>12</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0020</td>
<td>0.085</td>
<td>0.0833</td>
<td>0.3125</td>
<td>0.0760</td>
<td>0.0460</td>
<td>0.6130</td>
</tr>
<tr>
<td>13</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0048</td>
<td>0.085</td>
<td>0.0978</td>
<td>0.3125</td>
<td>0.0960</td>
<td>0.0470</td>
<td>0.8670</td>
</tr>
<tr>
<td>14</td>
<td>0.055</td>
<td>30</td>
<td>0.663</td>
<td>0.0048</td>
<td>0.085</td>
<td>0.1698</td>
<td>0.3125</td>
<td>0.0650</td>
<td>0.0340</td>
<td>0.5800</td>
</tr>
<tr>
<td>15</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0032</td>
<td>0.055</td>
<td>0.0690</td>
<td>0.50</td>
<td>0.0810</td>
<td>0.0370</td>
<td>1.0020</td>
</tr>
<tr>
<td>16</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0026</td>
<td>0.055</td>
<td>0.0937</td>
<td>0.50</td>
<td>0.0790</td>
<td>0.0330</td>
<td>0.8280</td>
</tr>
<tr>
<td>17</td>
<td>0.045</td>
<td>30</td>
<td>0.663</td>
<td>0.0028</td>
<td>0.055</td>
<td>0.1305</td>
<td>0.50</td>
<td>0.0940</td>
<td>0.0470</td>
<td>0.7370</td>
</tr>
<tr>
<td>18</td>
<td>0.055</td>
<td>30</td>
<td>0.663</td>
<td>0.0028</td>
<td>0.055</td>
<td>0.1522</td>
<td>0.50</td>
<td>0.0830</td>
<td>0.0430</td>
<td>0.7090</td>
</tr>
<tr>
<td>19</td>
<td>0.020</td>
<td>30</td>
<td>0.663</td>
<td>0.0042</td>
<td>0.085</td>
<td>0.0829</td>
<td>0.50</td>
<td>0.0660</td>
<td>0.0400</td>
<td>0.5740</td>
</tr>
<tr>
<td>20</td>
<td>0.030</td>
<td>30</td>
<td>0.663</td>
<td>0.0010</td>
<td>0.085</td>
<td>0.1050</td>
<td>0.50</td>
<td>0.0850</td>
<td>0.0540</td>
<td>0.6730</td>
</tr>
<tr>
<td>21</td>
<td>0.045</td>
<td>30</td>
<td>0.663</td>
<td>0.0019</td>
<td>0.085</td>
<td>0.1418</td>
<td>0.50</td>
<td>0.0950</td>
<td>0.0410</td>
<td>0.7550</td>
</tr>
<tr>
<td>22</td>
<td>0.055</td>
<td>30</td>
<td>0.663</td>
<td>0.0038</td>
<td>0.085</td>
<td>0.1681</td>
<td>0.50</td>
<td>0.0840</td>
<td>0.0420</td>
<td>0.6810</td>
</tr>
</tbody>
</table>
3. Scour Morphology

Pagliara et al. (2015a) classified two different scour morphology types downstream of woody stream restoration structures: 1) type C includes just one scour hole at the end of each deflector, developing toward the center of the channel; and 2) type D includes two scour holes in which one scour hole occurs at the end of the deflector and the other close to the channel bank. Figure 3 shows the variation of morphology, due to the effect of the position of the structures for the same hydraulic condition ($F_d = 1.4, Δy/h_{st} = 0.05$). In addition, Figure 3 depicts that, independently of $λ$, morphology type C always occurs downstream of log-frame deflectors. Figure 3(a) shows the morphology type C downstream of two log-frame deflectors installed with zero longitudinal distance ($λ/B = 0$). It shows that the maximum ridge height occurs almost at the center of the channel. Conversely, Figure 3(b) shows that the maximum ridge heights move toward the channel banks for $λ/B = 0.3125$. Finally, Figure 3(c) shows the structure installation for $λ/B = 0.5$. In this case, the maximum ridge heights occur close to the channel bank. It can be noted that the length of the ridge occurred along the channel bank increases with $λ/B$, i.e., using a higher $λ/B$ ratio channel banks can be better protected. On the other hand, Figure 3 shows that the meandering process in rivers is deeply influenced by the distance between log-frame deflectors, when located at both left and right river banks.

![Image](image_url)

Figure 3. Effect of the distance between structures; a) $λ/B = 0$, b) $λ/B = 0.3125$, and c) $λ/B = 0.5$.

4. Scour Characteristics

Log-frame deflector scour process is governed by the following functional relationship:

$$f(z_m, h_{st}, h_{we}, l_d, B, Δy, Q', ρ_s, ρ, g, d_{50}) = 0$$ (1)

where $f$ is a functional symbol. According to Pagliara and Kurdistani (2013), based on dimensional analysis and incomplete self-similarity (Barenblatt 1987), the following non-dimensional functional expression can be derived from Eq. (1):
\[
\frac{z_m}{h_{st}} = f\left(\frac{l_{st}}{B}, \frac{h_{tw}}{h_{st}}, F_d, \frac{\Delta y}{h_{st}}\right)
\]  
(2)

where \( f \) is a functional symbol.

Using the same logic, non-dimensional parameter \( \lambda/B \) could be added to the Eq. (2):

\[
\frac{z_m}{h_{st}} = f\left(\frac{l_{st}}{B}, \frac{h_{tw}}{h_{st}}, F_d, \frac{\Delta y}{h_{st}}, \frac{\lambda}{B}\right)
\]  
(3)

According to Pagliara and Kurdistani (2013), the scour parameter \( \eta = F_d^2 \Delta y / h_{st} \) was used to derive empirical equations. Based on observed data, the general Eq. (4) for \( 0.001 < \eta < 4 \) has been derived to predict the maximum scour depth downstream of log-frame deflectors in straight channels follows (\( R^2 = 0.91 \)):

\[
\frac{z_m}{h_{st}} = 6.6 \left(1 + \frac{\lambda}{B}\right) \left(\frac{l_{st}}{B}\right) \left(\frac{h_{tw}}{h_{st}}\right)^{-1} \eta^{0.7}
\]  
(4)

Fig. 4 shows that Eq. (4) fits well the observed log-frame deflector data within the 30% of deviation with respect to the perfect agreement line, including maximum scour depth data for 90° and angled spur dikes observed by Kuhnle et al. (1999, 2002), log-frame deflectors data observed by Pagliara and Kurdistani (2017) and log-deflectors data obtained by Pagliara et al. (2015a).

![Figure 4. Comparison of calculated and measured values of \( z_m/h_{st} \).](image)

Functional relation Eq. (3) can be also adopted to determine the other scour parameters substituting \( z_m \) with the corresponding variables in the dimensional analysis process. Using current study data and considering the \( \lambda/B \) as a parameter, the maximum scour hole length could be estimated using Eq. (5) (\( R^2 = 0.81 \)):

\[
\frac{l_m}{h_{st}} = 35 \left(1 + \frac{\lambda}{B}\right) \left(\frac{l_{st}}{B}\right) \left(\frac{h_{tw}}{h_{st}}\right)^{-1} \eta^{0.4}
\]  
(5)

Fig. 5 reports all the experimental observations along with data of Pagliara and Kurdistani (2017).
Adopting the same approach and considering $\lambda/B$ as the additional parameter, Eqs. (6) and (7) have been derived to estimate the maximum height and length of the ridge, respectively:

$$\frac{z_m'}{h_{st}} = 4.6 \left( 1 + \frac{\lambda}{B} \right) \left( \frac{l_{st}}{B} \right) \left( \frac{h_{w}}{h_{st}} \right)^{-1.3} \eta^{0.7}$$  \hspace{1cm} (6)$$

$$\frac{l_m}{h_{st}} = 65 \left( 1 + \frac{\lambda}{B} \right) \left( \frac{l_{st}}{B} \right) \left( \frac{h_{w}}{h_{st}} \right)^{-1} \eta^{0.7}$$  \hspace{1cm} (7)$$

Figures 6 and 7 compare experimental data of maximum ridge height and length downstream of log-frame deflectors, including those derived from Pagliara and Kurdistani (2017).
5. Conclusion

A series of experiments was conducted to investigate the effect of distance between log-frame deflectors on scour morphology and scour characteristics downstream of log-frame deflectors. Based on dimensional analysis and considering $\lambda/B$ as additional parameter, empirical relationships were found to predict the main scour parameters for different combinations of hydraulic conditions and structures geometry. Densimetric Froude number, drop height, tailwater, and height of the structure are the main parameters influencing the maximum scour depth, maximum scour length, maximum ridge height, and maximum ridge length. Results showed that the values of all scour parameters increase with $\lambda/B$, for any hydraulic condition and log-frame deflectors structure geometry. Furthermore, independently from the distance between structures, morphology type C always occurs, i.e., the scour hole forms in the center of the channel at the end of the structure arm. It was also observed that the length of the ridge occurred along the channel bank increases with $\lambda/B$. It means that using a higher $\lambda/B$ ratio channel banks can be better protected. Finally, the meandering process in rivers is deeply influenced by the distance between log-frame deflectors, when located at both left and right river banks. As in-stream grade control structures are functioning as natural fish ladders in rivers, it is strongly recommended to use log-frame deflector instead of traditional log-deflector to create the scour hole as fish resting pools along with the riverbank protection.

6. References


