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Scour Characteristics Downstream of In-Stream River Restoration Structures: Log and J-Hook Vanes Comparison

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ABSTRACT: River and stream restoration structure's design features has been an active field of research for hydraulic engineers. Generally, these low-environmental impact structures minimize the impact on natural contexts in needless of frequent human interventions during the operation and are used for riverbank protection, river grade controlling and improving the aquatic habitat. The main objective of this paper aims to compare scour downstream of two different low-head control structures; Log-Vane and J-Hook vane. The analysis contains the results of laboratory experiments conducted at the PITLAB hydraulic laboratory of University of Pisa and a detailed comparison of scour hole characteristics, highlighting similitudes and differences in the respective ranges of application. All tests have been done in clear water conditions using uniform sand as channel bed material.

Keywords: Log-Vane, J-Hook, Hydraulic Structures, River Restoration, River Grade-Control, Scour

1 INTRODUCTION

River restoration projects aim to increase ecosystem goods and services, and ideally convert damaged freshwater systems into sustainable ones whilst protecting downstream and coastal ecosystems (Palmer et al. 2005). In-stream grade-control structures like J-Hook Vanes and Log-Vanes, as single-arm submerged structures, are used to stabilize the riverbed and riverbank protection. In the presence of these types of in-stream structures, secondary flow leads to scour pools. Jansen et al. 1979, Odgaard and Spoljaric 1986, Odgaard and Mosconi 1987 and Odgaard and Wang 1991 gave major contributions on submerged vanes hydraulic. In the scientific literature, there are few comprehensive studies on scour downstream of in-stream grade-control structures. The classical literature on local scour includes important researches like Schoklitsch (1932), Veronese (1937), Hassan and Narayanan (1985), Farhoudi and Smith (1985), Mason and Arumugam (1985), Bormann and Julien (1991), Whittaker and Jaggi (1996), Robinson et al. (1998) and Dey and Sarkar (2006a and b, 2008).

There are few contributions focused on scour downstream of grade-control structures. Shields et al. (1995) to investigate the effects of stone grade-control structures on fish migration have done a field measurement study in north-west Mississippi. Rosgen (2001) presented design details of a series of in-stream structures including J-Hook Vane and Log-Vane. Bhuiyan et al. (2007) compared the scour development downstream of W-weirs with the previous study's results. Scurlock et al. (2011, 2012a and b) conducted experimental study on different types of in-stream structures including Cross-Vane and W-weir. Pagliara and Kurdistani (2013) and Pagliara et al. (2013) analyzed the scour geometry in straight rivers downstream of Cross-Vane and J-Hook Vane structures respectively. Recently Pagliara et al. (2014) studied scour hole characteristics and morphology downstream of rock W-weir in clear water condition. The main purpose of this study is to compare the scour geometry and pattern downstream of Log-Vane and J-Hook Vane structures in horizontal straight channels.

2 EXPERIMENTAL SETUP

Both J-Hook Vane and Log-Vane experiments have been carried out in a horizontal channel 0.8 m wide, 20 m long and 0.75 m deep located in the PITLAB hydraulic laboratory of the University of Pisa. An overhead tank supplied stable inflow. The flow discharge was measured using a calibrated tank with a precision of ±0.0001 m^3s^{-1}. An ultrasonic distance meter "Baumer" sensor with precision of 0.001 m has been used to read the water surface profile and the bathymetry of the mobile bed. Figure1a shows a plan, a stream wise view A-A and a cross section D-D of the channel when Log-Vane is installed and Fig. 1b shows view A'-A' and a cross section D'-D' when J-Hook Vane is installed. In Fig. 1, α is the vane angle in respect to the river bank, l is the length and h_{st} is the height of the structure.

In Fig. 1, Δy 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 and l'_m is the ridge length.

According to Pagliara and Kurdistani (2013), densimetric particle Froude number is defined as $\mathsf{F}_d = Q'/(l \cdot h_{st} \cdot [g \cdot (G_s - 1) \cdot d_{50}]^{0.5})$, where $Q' = (b/B) \cdot Q$ is the effective flow discharge, $G_s = \rho_s/\rho$, in which ρ_s is the bed material density and ρ the water density, d_{50} is the mean particle diameter and g the gravitational acceleration. Uniform non-cohesive sand with $\sigma = (d_{84}/d_{16})^{1/2}$=1.16, G_s = 2.60 and d_{50} = 1.70 mm was used. The channel bed was carefully leveled at the beginning of each experiment. All the tests have been conducted in clear water condition.

Two series of experiments were carried out. The first series included tests on Log-Vane in a horizontal channel with different α and different values of the height of the structure, discharge and Δy. The second series of experiments were done for J-Hook Vane with α = 20° (Pagliara et al. 2013). The duration of tests was long enough in order to reach an equilibrium bed condition depending on the single test (between one to three hours). Figure 2a depicts view from upstream of J-Hook Vane during a test run and Fig. 2b shows the view from downstream of Log-Vane at the end of an experiment.

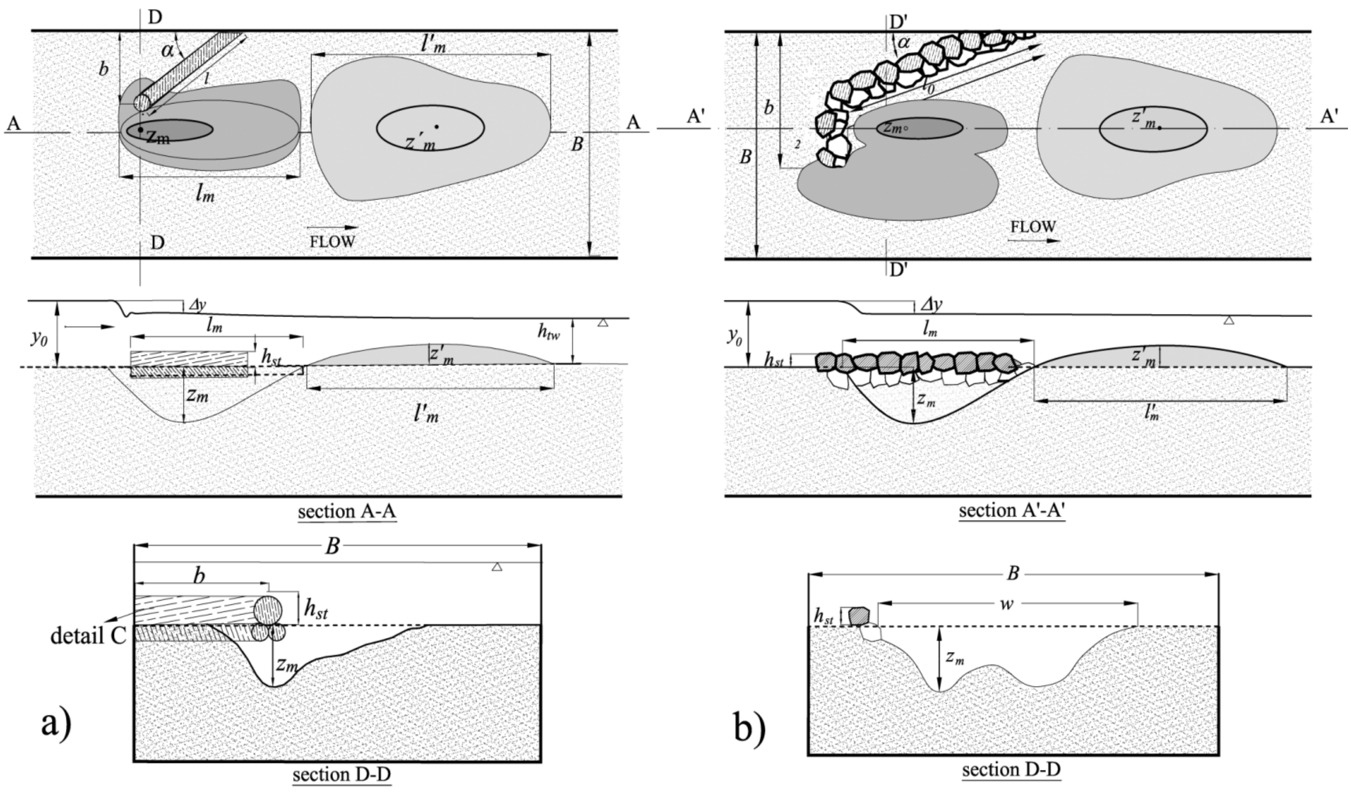

Figure 1. Experimental setup a) Log-Vane b) J-Hook Vane.

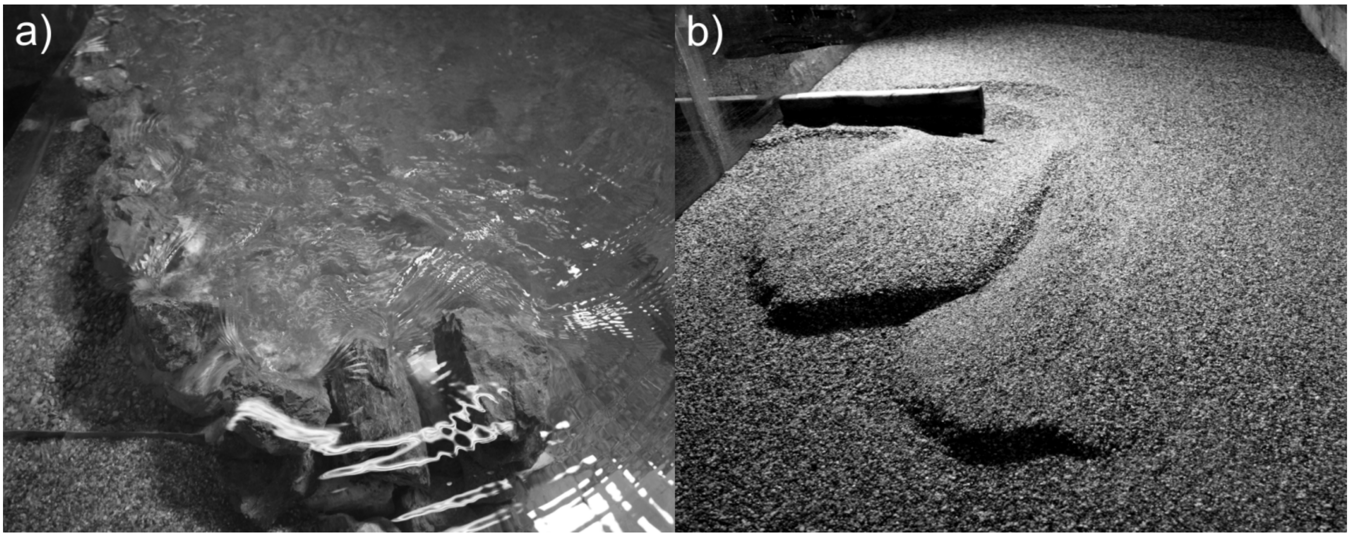

Figure 2. a) view from upstream of J-Hook Vane during a test run b) view from downstream of Log-Vane at the end of an experiment.

3 SCOUR MORPHOLOGY

Pagliara and Kurdistani (2013) and Pagliara et al. (2013) using dimensional analysis obtained analytical functions in order to predict the main scour parameters such as maximum scour depth, maximum scour length, maximum height and length of the ridge. For the maximum scour depth the main variables are:

$$f\ (z_m, l, h_{st}, h_{tw}, B, \Delta y, Q, \rho_s, \rho, g, d_{50}, \alpha) = 0 \tag{1}$$

where *f* is functional symbol.

Based on incomplete self-similarity (Barenblatt 1987), eq. (1) can be expressed in a power-law expression as follows:

$$\frac{z_m}{h_{st}} = a \cdot f'(\sin\alpha)^c \cdot (\frac{h_{tw}}{h_{st}})^e \cdot \emptyset(\mathrm{F}_d, \frac{\Delta y}{h_{st}}) \tag{2}$$

where *f'* and Φ are functional symbols and *a*, *c* and *e* are constants.

Pagliara and Kurdistani (2013) introducing a non-dimensional scour parameter η = $\mathsf{F}^2_d \cdot \Delta y/h_{st}$, classified the scour pattern downstream of different in-stream grade-control structures. Pagliara et al. (2013) for J-Hook Vane in the range of 0.02 < η < 4, presented three types of morphologies, Type1: long scour-long ridge; Type 2: short scour-long ridge; Type 3: short scour-short ridge. Log-Vane experiments results leads to define two other types of scour formation. In Type A, the dune is developed beside the scour hole close to the channel bank while in Type B the dune is developed along the scour hole towards the center of the channel. Comparison of Log-Vane and J-Hook Vane results are shown in Fig. 3. This figure describes that for each scour type A or B, there are three zones which zone 1 characterizes long scour-long ridge, zone 2 characterizes short scour-long ridge and zone 3 characterizes short scour-short ridge. The hatched zone is the transition area between Type A and Type B. Figure 4 shows maps of different scour morphologies downstream of Log-Vane and J-Hook Vane. It indicates, if l_m/B and l'_m/B are both greater than 1, that a long scour-long ridge is formed. When l_m/B < 1 and l'_m/B > 1 a short scour-long ridge occurs and in the case of l_m/B and l'_m/B are both smaller than 1, morphology formation is short scour-short ridge.

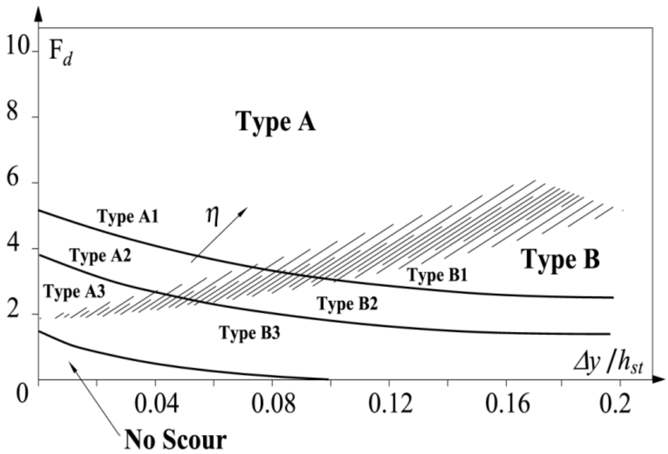

Figure 3. Scour typology.

Figure 4 (a-d) shows different morphology types based on different hydraulic conditions. Figure 4a depicts scour Type A1 downstream of J-Hook Vane when F_d = 4.1, $\Delta y/h_{st}$ = 0.07, α = 20°. It shows long scour-long ridge scour form develops towards the channel bank. Figure 4b describes scour Type B1 downstream of J-Hook Vane when F_d = 3.4, $\Delta y/h_{st}$ = 0.2, α = 20°. It is clear that long scour-long ridge scour forms towards the center of the channel. Figure 4c presents scour Type A3 downstream of Log-Vane when F_d = 2.54, $\Delta y/h_{st}$ = 0.03, α = 60°. It shows that short scour-short ridge is formed close to the channel bank. Figure 4d shows scour Type B3 when F_d = 2, $\Delta y/h_{st}$ = 0.048, α = 90°. It appears that short scour-short ridge occurred towards the center of the channel.

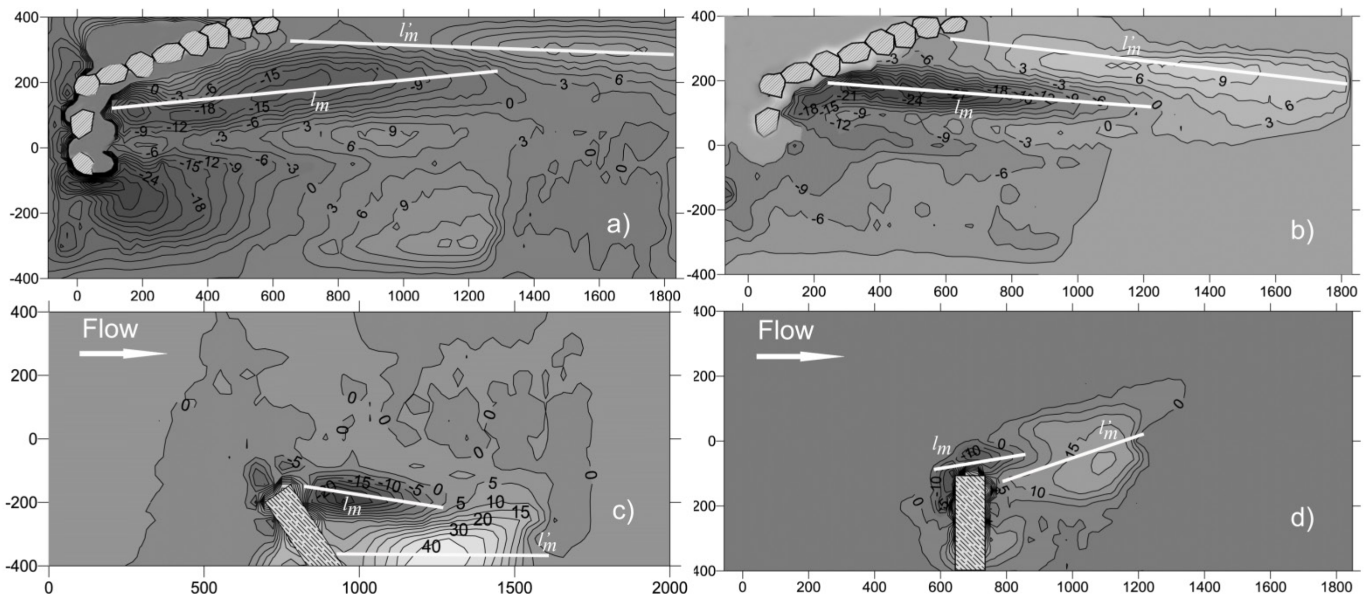

Figure 4: a) scour Type A1 downstream of J-Hook Vane when F_d = 4.1, $\Delta y/h_{st}$ = 0.07, α = 20°; b) scour Type B1 downstream of J-Hook Vane when F_d = 3.4, $\Delta y/h_{st}$ = 0.2, α = 20°; c) presents scour Type A3 downstream of Log-Vane when F_d = 2.54, $\Delta y/h_{st}$ = 0.03, α = 60°; d) shows scour Type B3 when F_d = 2, $\Delta y/h_{st}$ = 0.048, α = 90°.

4 MAXIMUM SCOUR DEPTH

Figure 5 demonstrates all the experimental data of Log-Vane and J-Hook Vane and shows that is possible to derive a simple equation valid for both Log-Vane and J-Hook Vane structures and effect of angle of vane installation α is negligible. As it appears from Fig. 5, tailwater depth is an important parameter to predict the scour parameters. Figure 5 shows the maximum scour depth data downstream of Log-Vane and J-Hook Vane classified as a function of η, using the non-dimensional tailwater h_{tw}/h_{st} as parameter. It indicates that the phenomenon can be expressed by eq. (3); r^2 = 0.77.

$$\frac{z_m}{h_{st}} = 1.6 \cdot \left(\frac{h_{tw}}{h_{st}}\right)^{-0.5} \cdot \eta^{0.3} \tag{3}$$

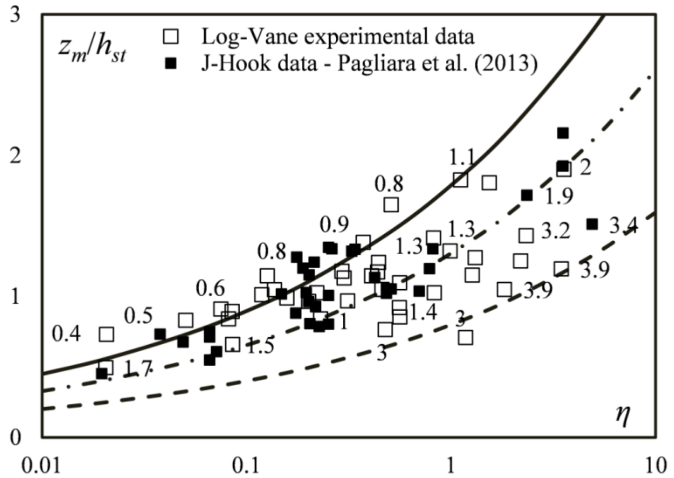

Figure 5. Comparison of observed data of Log-Vane and J-Hook Vane with eq. (3).

5 CONCLUSIONS

The main scour parameters for different combinations of hydraulic conditions downstream of Log-Vanes and J-Hook Vanes have been studied. Results showed that tail water is an important variable to predict the maximum scour depth. The effect of the vane installation angle α on the maximum scour depth is negligible. The results show that by increasing η, the maximum scour depth increase while increasing tailwater depth decreases the maximum scour depth. Results showed that the vane installation angle α also is not an effective parameter on scour formation. Scour typology included two major types of scour. Type A where "the dune is developed beside the scour hole close to the channel bank" and Type B where "the dune is developed along the scour hole towards the center of the channel". Combination of results of Pagliara et al. (2013) with Log-Vane observed data indicates that there are three zones for each morphology type. Zone 1: long scour-long ridge; Zone 2: short scour-short ridge and Zone 3: short scour-short ridge.

NOTATION

B	structure width
B	channel width
d_{50}	mean particle diameter
f	functional symbol
F_d	densimetric Froude number = $Q'/\{l \cdot h_{st}[g(G_s-1)d_{50}]^{0.5}\}$
G	gravitational acceleration
G_s	ρ_s/ρ
h_{st}	height of the structure (average height of the stones)
l	length of the structure
l_m	scour length downstream of the structure
l'_m	ridge length
Q	flow discharge
Q'	effective flow discharge
y_0	approach flow depth
z_m	maximum scour depth downstream of the structure
z'_m	maximum ridge height
Δy	difference between water surface upstream and downstream of the structure
α	vane angle
Φ	functional symbol
η	$F_d^2 \cdot \Delta y/h_{st}$
P	water density
ρ_s	bed material density
σ	particle uniformity factor = $(d_{84}/d_{16})^{0.5}$

REFERENCES

Barenblatt GI. 1987. Dimensional Analysis. Gordon and Breach Science Publishers. ISBN: 3-7186-0438-8.Bhuiyan F, Hey RD,Wormleaton PR. 2007. hydraulic Evaluation of W-Weir for River Restoration. Journal of Hydraulic Engineering, ASCE 133(6):596–609.

Bormann NE, Julian PY. 1991. Scour Downstream of Grade-Control Structures.Journal of Hydraulic Engineering, ASCE 117(5): 579–594.

Dey S, Sarkar A. 2006a. Scour downstream of an apron due to submerged horizontal jets. Journal of Hydraulic Engineering, ASCE 132(3), 246-257.

Dey S, Sarkar A. 2006b. Response of velocity and turbulence in submerged wall jets to abrupt changes from smooth to rough beds and its application to scour downstream of an apron. Journal of Fluid Mechanics 556: 387–419.

Dey S, Sarkar A 2008. Characteristics of submerged jets in evolving scour hole downstream of an apron. Journal of Engineering Mechanics 134(11): 927–936.

Farhoudi J, Smith KVH. 1985. Local scour profile downstream of hydraulic jump. Journal of Hydraulic Research 23(4): 343–358.

Hassan NMKN, Narayanan R. 1985. Local scour downstream of an apron. Journal of Hydraulic Engineering 111(11): 1371–1385.

Jansen PPh, Bendegom L. van, Berg J. van den, Vries M de, Zanen A. (eds). 1979. Principles of river engineering. Pitman Publishing Ltd.: London, England.

Mason PJ, Arumugam K. 1985. Free Jet Scour Below Dams and Flipbuckets. Journal of Hydraulic Engineering, ASCE 111(2): 220–235.

Odgard AJ, Mosconi CE. 1987. Stream bank Protection by Submerged Vanes. Journal of Hydraulic Engineering, ASCE 113(4): 520–536.

Odgard AJ, Spoljaric A. 1986. Sediment Control by Submerged Vanes. Journal of Hydraulic Engineering, ASCE 112(12): 1164–1181.

Odgard AJ,Wang Y. 1991. Sediment Management with SubmergedVanes. II: Applications. Journal of Hydraulic Engineering, ASCE 117(3): 284–302.

Pagliara S, Kurdistani SM. 2013. Scour downstream of cross-vane structures. Journal of Hydro-Environment Research 7(4): 236–242.

Pagliara S, Kurdistani SM, Santucci I. 2013. Scour Downstream of J-Hook Vane Structures in Straight Horizontal Channels. Acta Geophysica 61(5): 1211–1228.

Pagliara S, Kurdistani S, Cammarata L. 2014. Scour of Clear Water Rock W-Weirs in Straight Rivers. Journal of Hydraulic Engineering, ASCE 140(4): 06014002.

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad Shah, J., Galat, D.J., Gloss, S., Goodwin, P., Hart, D.H., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Srivastava, P. & Sudduth, E. (2005) Standards for ecologically successful river restoration. Journal of Applied Ecology, 42, 208–217.

Robinson KM, Rice CE, Kadavy KC. 1998. Design of rock chutes. ASAE Paper (American Society of Agricultural Engineers) 41(3): 621–626.

Rosgen DL. 2001. The Cross-Vane, W-Veir and J-Hook Vane Structures: Their Description, Design and Application for Stream Stabilization and River Restoration. Proc., Wetland Engineering and River Restoration Conf.(CD-ROM), ASCE, Reston, Va.

Schoklitsch A. 1932. Kolkbildung unter uberfallstrahlen. Wasserwirtschaft 343. Q6

Scurlock SM, Thornton CI, Abt SR. 2011. One-Dimensional Modelong Techniques for Energy Dissipation in U-Weir Grade-Control Structures. World Environmental and Water Resources Congress, ASCE, 2496–2507.

Scurlock SM, Cox AL, Thornton CI, Baird DC. 2012a. Maximum Velocity Effects from Vane-Dike Installations in Channel Bends. World Environmental and Water Resources Congress, ASCE, 2614–2626.

Scurlock SM, Thornton CI, Abt SR. 2012b. Equilibrium Scour Downstream of Three-dimensional Grade-control Structures. Journal of Hydraulic Engineering 138(2): 167–176.

Shields FD, Jr, Knight SS, Cooper CM. 1995. Incised Stream Physical habitat Restoration with Stone Weirs. Regulated Rivers: Research and Management 10: 181–198.

Veronese A. 1937. Erosioni di fondo a valle di uno scarico. Annali dei Lavori Pubblci 75(9): 717–726 (in Italian).

Whittaker W, Jaggi M. 1996. Blockshwellen. Mitteilungen 91,Versuchsanstalt fur Wasserbrau, Hydrologie und Glaziologie. ETH:Zurich, Switzerland.