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PHYSICAL MODELING OF DEFLECTOR ARMS IN A RIVER TABLE

by
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Environmental Resources Engineering
With Honors

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APPROVED

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Abstract

Stream deflectors are a restoration structure used to control bed and bank erosion and improve stream habitat, biodiversity, and aesthetics, yet little research has been conducted on stream deflector design. In this study different deflector designs were modeled using scaled wood geometries in a laboratory river table representing a restored stream. The model deflector arms were designed to represent the agency guidance for length and angle of rock deflector vanes. Vanes were given holes to replicate boulder gaps and key lengths to replicate boulder blocks common to rock vanes. A rapid assessment tool was used to evaluate the performance of each model deflector design, with failure of the vane defined by erosion rates of the river bank and bed. Patterns of failure varied mostly with respect to key size. Bed erosion such as head cuts did not vary on average with respect to key size. Bank erosion at the structure increased in models with shorter keys. The experiment determined longer key length with smaller or no holes had the least erosion. Future experiments should test vane sensitivity to a greater range of river table flow rates and river table sand sizes. This work increased our understanding of how stream restoration deflector structures affect their scour functions.

CONTENTS

INTRODUCTION

Stream restoration structures are designed to redirect stream flow and can improve water quality, stream habitat, biodiversity, and aesthetics (Rollins, 2003). The rock vane is one type of stream restoration structure that has the ability to provide bank protection and grade control for a stream (Rollins, 2003)**.** Rock vanes are made of boulders that are arranged within the channel to redirect scour toward the middle of the channel and off the outer bank at a meander bend. In addition to scour protection, rock vanes can aid in facilitating stream stability, decreasing flow velocity at the bank, maintaining channel capacity, improving fish habitat, are less costly compared to traditional structures, reducing channel erosion and sediment deposition (Rosgen, 2001). When structures such as rock vanes are utilized appropriately, they can assist in maintaining a stable dimension pattern, and profile of a stream (Rosgen, 2001). These structures have also been known to allow for revegetation in bank areas which would provide useful in the restoration of a degraded stream (Bhuiyan et al., 2010).

Until recently definitions of failure for river structures were not developed, but given the increased observation of failing projects the failures have been broken down into categories of design flaw, catastrophic events, and poor construction (Puckett et al., 2007). Design flaws can cause piping, sidecut, bank erosion at structure, undercut, upstream aggravation, downstream aggravation, headcut above structure, structure relocation, and structure missing (Rollins, 2003). Using current modeling techniques, failures of structures can be studied and predicted. One physical modeling tool for investigating river processes is the river table. By studying effects of varying model characteristics in a river table, a better understanding of stream processes, and structure failure can be attained.

OBJECTIVES

The objectives of my independent research were motivated by my interest in river restoration and the ability for a laboratory river table to represent the physical processes around restoration structures. Specifically, my objectives were to:

- Consult a field manual on stream restoration structure design and determine metrics for evaluating deflector arm designs, which varied key length, hole presence, hole size. Keys are the section of the deflector arms embedded within the stream bank. Holes are placed to represent gaps known to exist between boulders;
- Design a river table experiment to measure response variables of bed and bank erosion around different deflector arm designs / treatments;
- Execute the river table experiment and analyze how bed and bank erosion varied with deflector key length, hole presence, hole size;

MATERIALS AND EQUIPMENT

The experiments were conducted using a mobile bed river table. The river table was 2.1 m long, 0.9 m wide, 0.15 m deep. Sand was used as the substrate. Additional materials included scrap wood, a carving knife, camera, ruler, protractor, drill and drill bits, box saw, 500ml graduated cylinder, and tape measure. Since all equipment was provided in SUNY ESF Baker Lab room 106 or was borrowed, there were no costs for experimentation.

METHODOLOGY

1. Our laboratory vanes were designed to represent the length and angle of installation used in field rock vanes, but were made from thin slabs of wood and did not represent the

boulder width, roughness, and gaps. The deflector arm can be placed at a 20 to 30 degree angle from the bank, and the slope of the arm can be between 2 and 7 percent (Rollins, 2003). Although a 20 degree angle provides protection for the greatest length of stream bank (Rosgen, 2001) a 30 degree angle was used in experimentation due to ease of implementation. Profiles are shown in figures 3 and figure 4.

2. To model the deflector arm, wood was carved according to the guidelines. The deflector arms model size was determined from the model river in the river table. Model variables tested include key length, hole size, and absence of holes. Keys are the section of the deflector arms embedded within the stream bank. Holes are placed to represent gaps known to exist between boulders. Performance of each structure was determined by conducting 6 tests. Response variables to be observed include headcut, bank and downstream erosion, and undercutting.
3. The deflector arm models are shown in figure 6. Structures 1 through 3 have longer key lengths than 4 through 6. Structures 1 and 4 have no holes in their design. Structures 2,3,5,6 have holes which vary in size. Figure 5 details the design specifications of the deflector arm models. Assumptions and problems encountered during this step of the experiment are discussed in the results section.
4. A fixed geometry channel was carved into the river table to test the deflector arms. The channel geometry was replicated to limit variability in flow geometry and flowrate between tests of the deflector arm models. Flow geometry describes the angles at which the river flow approached the deflector arm due to the meander planimetry of the channel. Flowrate control was imprecise due to sensitivity of river table pump controls, and observed variations in flowrate were recorded (see figure 7) and their effect was

considered in the evaluation of performance for each structure. The inability to replicate the flowrate, required that the geometry treatments had to be analyzed without experimental replication.

5. Initial rankings of structure failure were given based on observation and best judgment immediately after each model experiment was conducted. Photographs were taken of the stream model to serve as a record which could aid in ensuring fair and equal ranking assignment.
6. A field assessment form (figure 1), and a table of failures and major indicators (figure 2) served as references in the development of a ranking system for structure performance. A scale for ranking failure of a structure is given as: nonexistent (0), minor presence (1), little presence (2), moderate presence (3), large presence (4), and extreme presence (5) (Rollins, 2003). A summary of failure was produced for each model (see figure 9), failures and successes are discussed in the results section. The summaries aided in the determination of the best deflector arm model. The before and after photos in figure 10 and figure 11 provide a visual demonstrating effects key size, hole size, and hole absence can have on the performance of the model.

RESULTS AND DISCUSSION

Performance of each deflector arm model was recorded in figure 9. According to the assessment, the best models were structures 1 and 2, which are characterized by little presence of head cut, nonexistent bank erosion, moderate to little downstream erosion, and minor to little undercutting, while the worst was structure 5, which is characterized by moderate head cut and downstream erosion, large presence of bank erosion and undercutting. Based on photo analysis structure 2 performed best of all structures due to low ranking in presence of erosion and hence minute change in stream geometry (see figure 10). By contrast, the photo analysis revealed structure 5 resulted in the greatest extent of downstream and bank erosion (see figure 11).

Stream restoration structures such as the deflector arm should deflect erosive outer bank flow toward the center of the stream (Zhou and Endreny, 2011). In our case, bank erosion was effected by certain model design parameters. Bank erosion extent and pattern varied most with respect to variation in deflector arm key size. Bank erosion at the vane increased in tests with models with a shorter key. There is no pattern in bank erosion at the vane with respect to presence of holes in the model. Head cut did not vary with respect to key size. There was a possible interaction between key size and hole size in the deflectors, but we did not explicitly test for interaction. Head cut increased with increasing deflector hole size. Head cut didn't appear to correlate with changes in key length size. A possible cause of this increase is increased turbulence in the channel water column due to the vortices generated by flow through the deflector holes. In future experimentation, more attention will be paid on initial conditions and meader boundaries because scour is known to depend on these structures (Zhou and Endreny, 2011). Downstream erosion was present with each structure and was not sensitive to key length or structure holes. In future investigations, more focus should be placed on key placement with respect to BF level because performance is affected by this (Bhuiyan et al., 2010).

Poor control over flowrate had a direct impact on erosion. Undercutting seemed to be mostly correlative with a high flowrate (see figure 9). This can be explained by an increase in sediment load caused by amplified flowrates. Our results were influenced by the fact that flowrate could not be replicated. Also, longer experimental runs should be conducted as to address the fact that bed scour and deposition occurs immediately after installation and diminishes over time (Bhuiyan et al., 2010).

CONCLUSION

Based on performance of the designed features and knowledge of how structures function, structure 2 would be most appropriate. Both structures 2 and 1 performed equally (attaining lowest failure rating of 7) but structure 1 does not best represent reality. In reality there is a flux through to gaps known to exist between boulders.

Issues were encountered during the investigation. One problem was the inability to have fine control over flowrate. This had a direct effect on erosion rates. Also, at the small scale at which the deflector arm models and river models were produced, examination of failure became difficult at times. A larger scale may facilitate better results in further investigation. Sensitivity of the river models (due to use of sand) to erosion was an issue as well. The low density of wood was an issue in structure implementation as the structures naturally tried to float. Different river table mediums can be tested to bester represent the landscape and soil characteristics, and different materials to produce deflector arms should be examined. A denser material may perform better due increased resistance to forces produced by flow. Testing materials of varying roughness to simulate boulder characteristics may aid in producing a better model as well.

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TABLES, CHARTS

Figure 1: Rock Cross Vane Rapid Assessment Tool

Table 1 Filed Assessment Form for the Rock Cross Vane Rapid Assessment Tool

Cross vane #
Date/Time
Notes

score each indicator from 0-5 based on guidebook

indicator	primary	secondary
F1. arm washout	P.03 drag and lift or tipping	S.01 improper alignment
		S.03 placed in a bend
		S.05 arms not tied in
		S.12 spacing of boulders
		S.14 undersized boulders
		S.18 insufficient backfill
	P.08 under-cutting	S.01 improper alignment
		S.03 placed in a bend
		S.08 arms too steep
		S.16 drop too high
		S.18 insufficient backfill
		S.19 no footers
		S.21 undersized rcv
F2. sill washout	P.03 drag and lift or tipping	S.10 sill too high
		S.12 spacing of boulders
		S.14 undersized boulders
		S.18 insufficient backfill
		S.21 undersized rcv
	P.08 under-cutting	S.02 backed into a pool
		S.08 arms too steep
		S.10 sill too high
		S.16 drop too high
		S.18 insufficient backfill
		S.19 no footers
		S.21 undersized rcv
F3. head cut	P.05 piping	S.12 spacing of boulders
		S.18 insufficient backfill
	P.07 side cutting	S.01 improper alignment
		S.03 placed in a bend
		S.05 arms not tied in
		S.06 arms too short
		S.09 arms washed out
		S.10 sill too high
		S.12 spacing of boulders
		S.21 undersized rcv
	P.08 under-cutting	S.02 backed into a pool
		S.03 placed in a bend
		S.08 arms too steep
		S.10 sill too high
		S.11 sill washed out
		S.16 drop too high
		S.18 insufficient backfill
		S.19 no footers

indicator	primary	secondary
F4. bank erosion at vane	P.01 direct contact of flow with banks	S.05 arms not tied in
		S.09 arms washed out
		S.12 spacing of boulders
		S.17 exposed banks
	P.02 flow directed at banks	S.01 improper alignment
		S.03 placed in a bend
	P.05 piping	S.12 spacing of boulders
		S.18 insufficient backfill
	P.07 side cutting	S.01 improper alignment
		S.03 placed in a bend
		S.05 arms not tied in
		S.06 arms too short
		S.09 arms washed out
		S.10 sill too high
		S.12 spacing of boulders
		S.21 undersized rcv
	P.08 undercutting	S.01 improper alignment
		S.03 placed in a bend
		S.08 arms too steep
		S.16 drop too high
		S.18 insufficient backfill
		S.19 no footers
		S.21 undersized rcv
F5. down-stream bank erosion	P.01 direct contact of flow with banks	S.05 arms not tied in
		S.06 arms too short
		S.09 arms washed out
		S.17 exposed banks
	P.02 flow directed at banks	S.01 improper alignment
		S.03 placed in a bend
	P.04 flow expan-sion out of vane	S.08 arms too steep
		S.13 boulders in pool
		S.21 undersized rcv
	P.07 side cutting	S.01 improper alignment
		S.03 placed in a bend
		S.05 arms not tied in
		S.06 arms too short
		S.09 arms washed out
		S.10 sill too high
		S.12 spacing of boulders
	P.09 weak jet / low velocity ratio	S.09 arms washed out
		S.15 drop too short
		S.20 oversized rcv
F6. insuffi-cient scour pool	P.06 protected from scour	S.09 arms washed into pool
		S.11 sill washed into pool
		S.13 boulders put in pool
	P.09 weak jet	S.04 placed on bedrock
		S.07 arms too flat
		S.09 arms washed out
		S.15 drop too short
		S.20 oversized rcv

(Puckett et al., 2007)

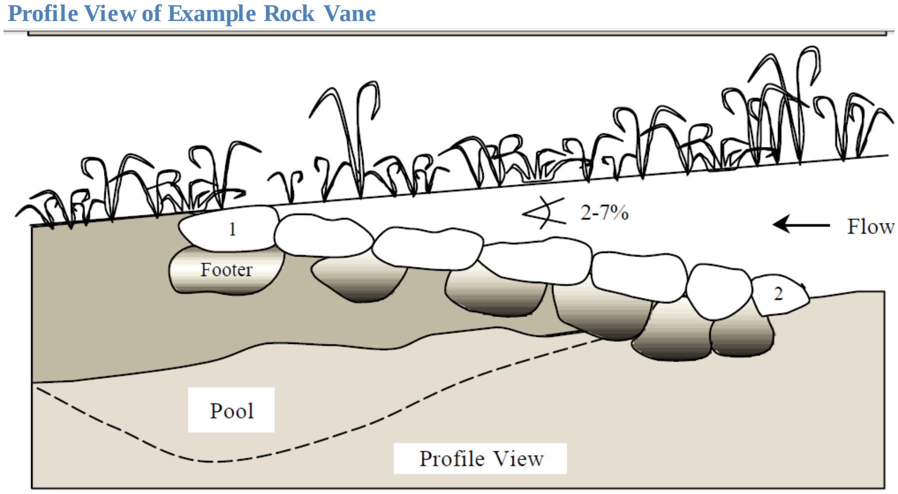
Figure 2: Failures and Major Indicators

Table 2 Failures and Major Indicators

Failure	Indicator
Lack of Durability	Arms washed out Sill washed out
Lack of Grade Control	Headcut
Lack of Bank Protection	Bank Erosion at Vane Downstream Bank Erosion
Lack of Pool/Pattern Development	Insufficient Scour Pool

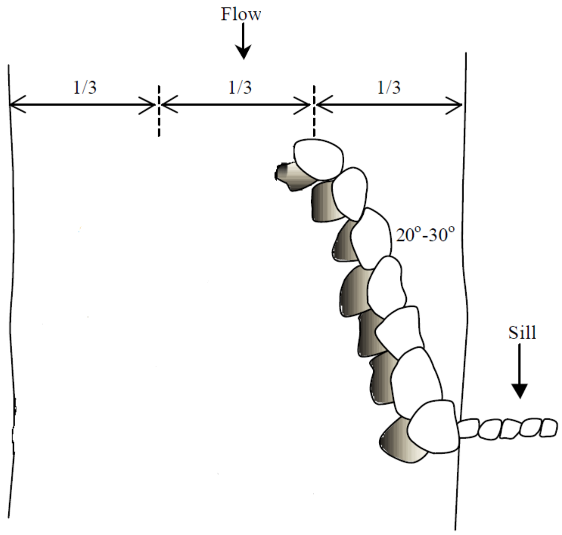
(Puckett et al., 2007)

Figure 3: Profile View of Example Rock Vane



(Rosgen, 2001)

Figure 4: Plan View of Example Rock Vane



(Rosgen, 2001) Plan View

Figure 5: Model Geometry

Rock Vane Models						
	angle of protrusion: 30 deg.		slope: 4 deg.		width (cm): 0.3	
	structure 1	structure 2	structure 3	structure 4	structure 5	structure 6
Vane length (cm)	2.33	2.33	2.33	2.33	2.33	2.33
key length (cm)	3.67	3.67	3.67	0.67	0.67	0.67
Drill bit size	N/A	1/16	5/64	N/A	1/16	5/64

Figure 6: Deflector Arm Models

Structure 1

Structure 2

Structure 3

Structure 4

Structure 5

Structure 6

Figure 7: River Model Characteristics

River Model						
	W, Stream width (cm): 3.5		D, water depth (cm): 0.5		S, sinuosity: 1.5	
	model 1	model 2	model 3	model 4	model 5	model 6
Q, flowrate (stage 15 on flow weir) (ml/min)	460	400	425	495	575	475

Figure 8: River Model

Figure 9: Model Failure Results

Failures						
Indicator	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
head cut	2	2	3	1	3	3
bank erosion at vane	1	1	2	2	4	1
down stream erosion	3	2	3	3	3	3
undercutting	1	2	1	4	4	1
total	7	7	9	10	14	8

Figure 10: Test 2 Before and After

Before After

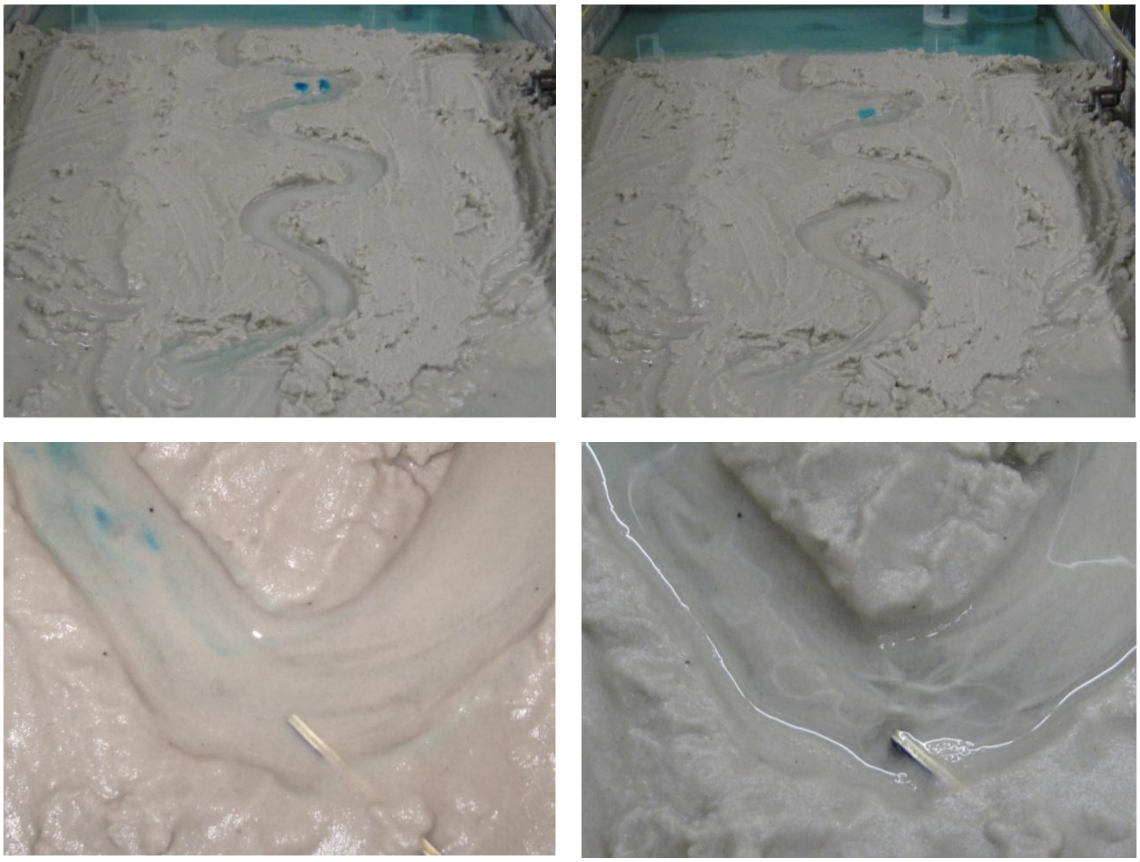


Figure 11: Test 5 Before and After

Before After