Using field measurements and indoor flume tests to improve quantitative design guidelines for instream flow control structures

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Introduction

The National Cooperative Highway Research Program (NCHRP) provided funding for research aimed towards improving quantitative design guidelines for instream flow control structures commonly installed to protect streambanks, improve aquatic habitat, or prevent undesired lateral migration in rivers. The initial stage of the project focused on a literature review and practitioner survey aimed to understand the current engineering design principles and effectiveness of these structures. Later phases of the project focus on small-scale and large-scale physical modeling, field observations and measurements, and numerical simulations. Here we provide an overview of the project and a quick look at each of the various stages.

A series of small-scale physical model tests have begun in St. Anthony Falls Laboratory's (SAFL) Tilting Bed Flume measuring three-dimensional flow velocities around flow control structures (rock vanes, J-hooks, cross vanes, etc.). The first stage of the project focused on measurements above an immobile bed of 6mm grain roughness. To date, researchers have characterized flow in the flume with no structure installed to serve as a baseline calibration scenario. The coming weeks will involve testing several structures with various attack angles and structure slopes. Upon completion of the fixed bed tests, a mobile sand bed will be installed and the series of tests repeated with focus shifting to monitoring areas of maximum scour in the region of each structure.

Additionally, field sites located in Minnesota, Virginia, and Illinois are providing unique datasets for numerical model calibration. During the Fall 2009, researchers from the University of Minnesota surveyed a reach along Shingle Creek in Brooklyn Park, MN where four structures were recently installed. The data collected from field sites, combined with that from indoor flume tests, will supplement the data collected in the SAFL Outdoor StreamLab (OSL) forming a robust dataset. This dataset will be used for calibrating a numerical model developed by SAFL's computational fluid dynamics team for their Virtual StreamLab (VSL). The results from this project will assist in quantitative design guidelines for instream flow control structures.

Project Overview

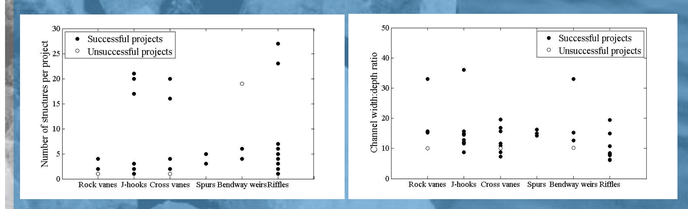
NCHRP Project 24-33: Development of Design Methods for In-Stream Flow Control Structures, aims to develop engineering standards for installing, monitoring, and maintaining these structures commonly used in stream restoration projects. It is estimated that nearly 50% of restoration projects fail, despite nearly $1 billion spent annually on the practice (Bernhardt et al., 2005; O'Neil and Fitch, 1992). Even though stream restoration efforts have been underway for several decades, design guidelines for rock structures are typically vague and based on experience rather than controlled experiments and quantitative data (Johnson et al., 2002).

The initial phase of this project involved an in-depth literature review and a comprehensive survey of previous practitioner experience with flow control structures (see figures below at left). The survey results were used to select the most frequently used structures that will be more closely examined in the physical modeling, field surveying, and numerical modeling portions of the project.

Currently the project is in Phase II, focusing on the detailed data collection of instream flow control structures using both large-scale and small-scale physical modeling, field observations and surveying, and computational numerical modeling. The large-scale physical modeling began during the summer of 2009 in the SAFL Outdoor StreamLab. During the Fall, researchers spent time surveying field-scale projects where instream flow control structures were recently installed. Both physical modeling and field observations will continue throughout the next year providing a wealth of data for the Virtual StreamLab.

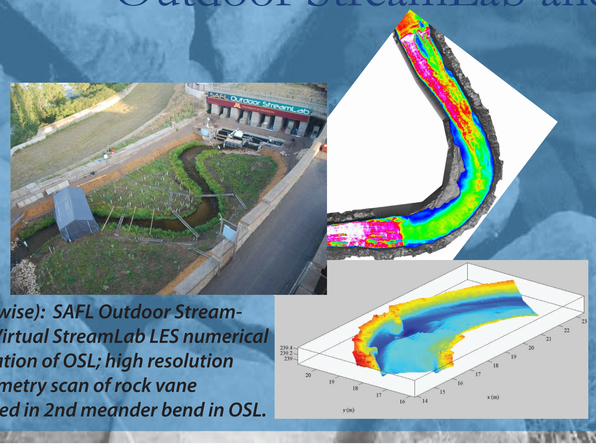
The Virtual StreamLab with be used to computationally compare the velocity and shear stress fields effected by various rock structures and design/installation guidelines.

The final phase of the NCHRP Project 24-33 will be to provide structure selection, installation, monitoring, and maintenance guidelines that can be used in future stream restoration projects.



Summary of some of the results from the survey completed during Phase 1 of the NCHRP Project 24-33. Left: Success of various structures vs. number of structures installedper project. Right: Success of various structures vs. channel aspect ratio.

Outdoor StreamLab and Virtual StreamLab



(clockwise): SAFL Outdoor Stream-Lab; Virtual StreamLab LES numerical simulation of OSL; high resolution bathymetry scan of rock vane installed in 2nd meander bend in OSL.

During the summer of 2009, a single rock vane was installed in the second meander bend in the OSL. Researchers collected high resolution Acoustic Doppler Velocimeter (ADV) data along 12 cross sections to characterized three dimensional turbulent flow characteristics before and after the structure was installed at both base flow (44 L/s) and bank full (280 L/s) conditions.

Using the data collected, the computational fluid dynamics modeling team can use numerical modeling to help design instream flow control structures in a more quantitative way. To date, initial simulations have been run for the base flow case in the OSL.

The summer of 2010 will see more structures installed within OSL, both single structures of other types (J-hooks, etc.), and multiple structures in line . Numerical simulations are ongoing.

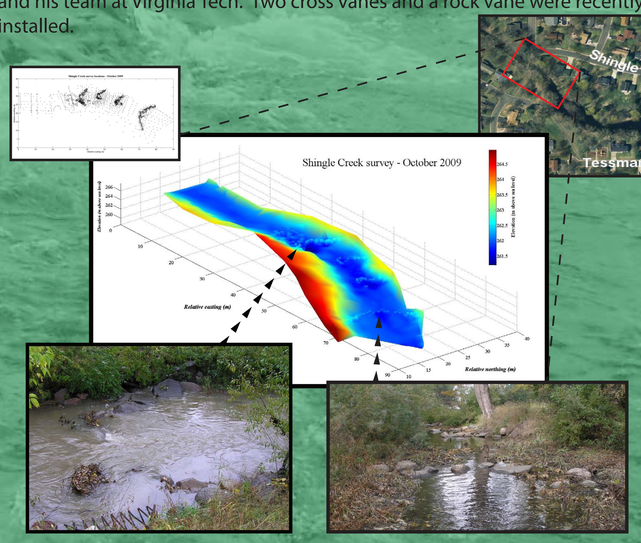
Field Measurements

The field work portion of the NCHRP project aims to collect data that can aid in calibrating the Virtual StreamLab (VSL) numerical model. Four field sites have been selected where structures were recently installed. The goal is to survey each site and structure before and after large flooding events to monitor any local scour that occurs, as well as collect velocity data along cross sections to aid the numerical modeling team in their simulations.

Sugar Creek in Illinois had a series of 19 bendaway weirs installed to prevent lateral migration into nearby farmland. Professor Bruce Rhoads at the University of Illinois and his team lead the surveying and monitoring of this field site.

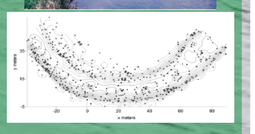
Rockfish River in Virginia is currently being monitored by Professor Panos Diplas and his team at Virginia Tech. Two cross vanes and a rock vane were recently installed.

Site	Structure	Bankfull width	Bankfull depth	Number of structures	Year installed	Base flow	Maximum discharge since installation	Available data
Sugar Creek, McLean, IL	Bendway weirs	20 m	1.5-2.0 m	19	1999	0.9 m^3/s	53 m^3/s	-USGS gage -Orthophotos from 1940 to present -Survey data in 2001/02
Nine Mile Creek, Bloomington, MN	Rock vanes	6 m	1.2 m	14	2009	0.5 m^3/s	14.6 m^3/s	-Metropolitan Council gage -Preproject survey
Rockfish River, Nelson County, VA	Rock vanes and cross vanes	30 m	2 m'	3	2006	2.4 m^3/s	32 m^3/s	-USGS gage -Orthophotos -Pre and post-project cross-sections
Shingle Creek, Brooklyn Park, MN	J-hooks & cross vanes	10 m	2 m	4	2006	??	??	-Watershed district gage -Project plans



Bendaway Weirs, Sugar Creek, McLean, IL. Photo: Bruce Rhoads c. 2003

Contoured survey data along meander bend in Sugar Creek.



Shingle Creek

Single Creek is an urban stream in Brooklyn Park, MN. In 2006, 2 cross vanes and 2 J-hooks were installed. This site was chosen for monitoring because of these structures, and the reach is bounded upstream by a long, straight, trapezoidal channel providing excellent boundary conditions for the numerical modeling team. The images at left are from the 2009 field season. During the 2010 snow melt, researchers will spend time collecting velocity data and surveying for any changes in streambed morphology resulting from spring flooding.

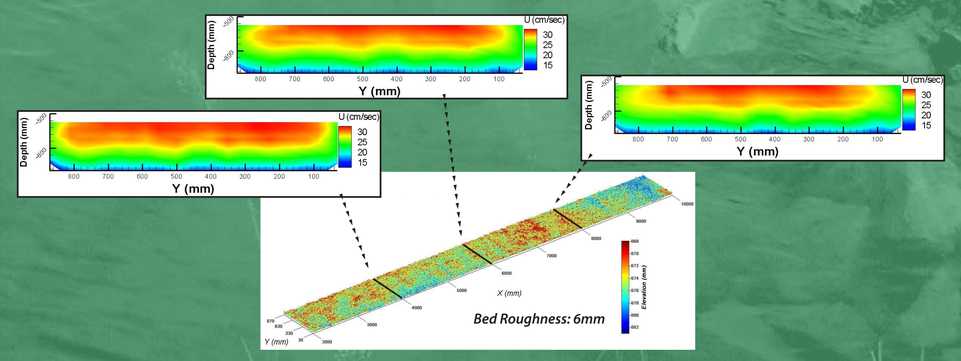
Indoor Experiments

The objective of the indoor small-scale physical modeling tests is to obtain high-resolution velocity data around a wide range of structures to use for validating the VSL numerical model. The SAFL Tilting Bed Flume is a 15-meter long, 0.9-meter wide flume with slope adjustment capabilites. It is also outfitted with SAFL's Data Acquisition (DAQ) carriage and software capabilities (image at right).

Testing has recently begun with the first rock structure installed above the fixed bed. Researchers worked together with the numerical modeling team to determine a list of structures to test using both a fixed bed with 6mm grain roughness as well as a mobile sand bed. During the mobile sand bed tests, a sonar transducer will be mounted over potential regions where maximum scour will occur. Previous observations of scour have shown that the time-average maximum scour depth occurs under conditions of clear water scour. This is when shear stresses are just below the threshold for bed mobility. Flow parameters will be adjusted accordingly during these phases.

Flow parameters for the fixed bed tests are: $Q_{water} = 0.035\ m^3/sec$; Depth = 0.16 m; Fr# = 0.2; Re# = 40,000;

ADV collecting data in the SAFL Tilting Bed Flume



Streamwise velocity plots at 4m, 6m, and 8m through test section. Rock structures will be mounted at 6m with various attack angles with respect to the river right flume wall

	Structure	Bed condition
1	Constructed riffle;no structure	Fixed bed
2	Rock vane	
3	Rock vane	
4	Bendway weir	
5	Bendway weir	
6	Cross vane	
7	J Hook	
8	Sand bed; no structure	Mobile bed
9	Rock vane	
10	Rock vane	
11	Rock vane	
12	Two rock vanes	
13	Bendway weir	
14	Bendway weir	
15	Bendway weir	
16	Two bendway weirs	
17	Cross vane	
18	J hook	

Proposed indoor experiments for fixed bed and mobile bed testing with in-stream flow control structures.

References and Acknowledgements

Rock vane in the SAFL Outdoor StreamLab. ADV measurements occuring upstream from the structure.

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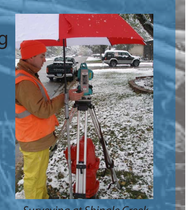

Surveying at Shingle Creek

ftp://ftp-fc.sc.egov.usda.gov/NDCSMC/Stream/GC_crossvane.jpg