Identifying Number: **MPC-315**
Continuation, Year 23, Second Year

Project Title:

Analysis of Compound Channel Flow with Two-Dimensional Models

University:

South Dakota State University

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Description of Research Problem:

Reliable flow and soil data are crucial for accurate prediction of bridge scour depths in cohesive soils. Hydraulic analysis of bridge waterways is commonly conducted using one-dimensional river models such as HEC-RAS. One-dimensional river models may not predict the velocity distributions at bridge crossings accurately when two-dimensional flow effects are important. Typical examples include compound channels, skewed bridges, and bridges located on river bends. A recent study (Ting et al., 2010) showed that compound channel flow caused HEC-RAS to under-predict the approach flow velocity by almost a factor of two at the Highway 13 Bridge over the Big Sioux River Bridge near Flandreau, South Dakota. If the flow velocities computed by HEC-RAS were used, the predicted total pier scour depth at the Flandreau bridge site produced by the two major floods on June 21 and July 4, 1993 would be zero instead of the 8.5 ft measured by the United States Geological Survey (USGS).

A compound channel comprises a central deeper portion (main channel) flanked by left and right overbanks (floodplain). Complex flow interactions often occur between floodplain and main channel of a compound channel at river crossings. Exchange of flow between the two portions arises as the approach flow contracts into the channel and through the bridge opening, and then expands to re-establish across the floodplain. This process leads to the formation of large eddies in the shear layer in the flow region between the channel and floodplain, and creates ineffective flow areas upstream and downstream of the bridge crossing. The resulting flow field is often far from one-dimensional. Two-dimensional flow analysis can define the magnitude and direction of shear stress along with detailed geometry of streamlines around a structure. The need to predict two-dimensional flow effects at bridge crossings becomes even more important when predicting contraction scour where the results may be very sensitive to how the width of the approach flow is defined.

South Dakota Department of Transportation (SDDOT) currently has FESWMS and RMA2, which are both programs with the capability to model two-dimensional (2-D) flow around highway structures. However, little is known about the improvements that may be expected from the use of two-dimensional models and there are few guidelines on what the most cost effective ways are to apply these models. SDDOT needs to be able to identify settings in which a two-dimensional model would be beneficial, and to determine what degree of effort needs to be invested in data collection to produce an effective model. Once these factors are understood, site-specific 2-D models can be utilized to properly analyze structures subject to compound channel flow and design the structure to minimize damage caused by scour.

Research Objectives:

This research has three primary objectives. First, determine if the computed stream flow velocities of two-dimensional river models and the resulting scour predictions are comparable with field measurements at the Highway 13 Bridge near Flandreau. The complex floodplain geometry at the Flandreau bridge site makes this an ideal site to test and evaluate 2-D flow models for bridge hydraulics calculations. Second, conduct sensitivity analysis to determine the critical input parameters for 2-D flow models, with an emphasis on the optimal density of channel and overbank topography data. Third, determine the applicability of 2-D flow models for use on streams and rivers with compound channel flow around a structure and identify cost effective ways to utilize these models.

Research Approach / Methods:

The project will include the following tasks:

(1) Meet with the technical panel to review project scope, discuss issues, and review the work plan. Researchers will provide minutes of meeting.
(2) Conduct a literature search on two-dimensional flow effects at bridge crossings. Contact other state DOTs and agencies to determine their

current practices to analyze two-dimensional flow effects at bridge crossings.

(3) Working with USGS, conduct field surveys at the Flandreau bridge site and collect ground surface elevation and flow data required to run and calibrate the two-dimensional models.

(4) Validate the two-dimensional models by comparing model output with USGS flow data collected on March 30 and July 7, 1993.

(5) Conduct additional tests for a range of flow discharges (e.g., 2-yr, 50-yr and 100-yr floods) to determine how the hydraulics of the site varies with flow discharge.

(6) Identity the site characteristics that produce the two-dimensional flow effects classified as compound channel flow.

(7) Conduct similar tests using HEC-RAS and compare to the results obtained by the two-dimensional models.

(8) Run the two-dimensional models at several levels of sophistication (e.g., different mesh resolutions, details of inflow boundary conditions) to identify the most cost-effective data collection effort.

(9) Synthesize all the results obtained and develop procedures and guidelines that engineers can use to refine the hydraulic analysis of bridge crossings, using 1-D and/or 2-D models as well as other analytical approaches. The focus of this task will be on assessing the hydraulic factors affecting bridge scour (see, for example, HEC-18), and on designing structures to minimize damage caused by scour.

(10) Prepare a final report and executive summary of the literature survey, research methodology, findings, conclusions and recommendations.

(11) Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

MPC Critical Issues Addressed by Research:

15. Improved infrastructure design

16. Infrastructure Longevity. Improved predictions of compound channel flow would assist in the design of new structures and in determining the locations of scour countermeasures for existing structures. Potential benefits would include improved foundation design at highway structures, increased longevity of structures, and cost savings on construction for bridge foundations and scour countermeasures due to more reliable flow and scour predictions.

Contributions/Potential Applications of Research:

This research will develop guidelines for using 2-D flow models in hydraulic analysis of highway structures for designing scour countermeasures and predicting scour around bridges subject to compound channel flow in South Dakota.

Potential Technology Transfer Benefits:

Practical design methodologies for design engineers.

Time Duration:

July 1, 2010 through June 30, 2011

Total Project Cost:

$43,728

MPC Funds Requested:

$17,487

Source of Matching Funds:

South Dakota Department of Transportation: $26,241

TRB Keywords:

Compound Channel Flow, Numerical Modeling, Two-Dimensional Flows, Bridge Scour

References:

HEC-18 (2001). "Evaluating Scour at Bridges." Fourth Edition, Hydraulic Engineering Circular No.18, Federal Highway Administration, Washington, D. C.

Ting, F. C. K., Jones, A. L. and Larsen, R. J. (2010). "Evaluation of SRICOS Method on Cohesive Soils in South Dakota." MPC Report No. 08-195, Mountain-Plains Consortium (MPC), United States Department of Transportation.