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IIHR FLUME STUDY

SCOPE OF WORK (DRAFT)

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STUDIES TO DETERMINE SCALE EFFECTS IN SMALL-SCALE MODELS OF FLOW FIELDS AT DIKES AND BENDWAY WEIRS

[Subject area: Open-channel flow and sedimentation (CHL-3)]

INTRODUCTION

Described here is a scope of work for two efforts conducted in support of an evaluation of micro-modeling, a form of hydraulic modeling. The efforts are described in two parts. One effort comprises a set of fixed-bed flume studies whose overall objective is to delineate and document scale effects in small-scale models of flow fields around hydraulic structures commonly used for alluvial-channel control. The scope of work proposes that tthis effort will be conducted by the Iowa Institute of Hydraulic Research (IIHR).

The second effort entails providing support in the use of large-scale particle image velocimetry (LSPIV) for recording and diagnosing flow fields around hydraulic models of elemental hydraulic structures and alluvial-channel features. The support will be provided to Mr Andy Gaines of the Army Corps of Engineers. He is about to conduct a set of loose-bed studies aimed at ascertaining scale effects on the hydraulic modeling of such structures and flow features.

PART I: FLUME STUDIES

The studies entail laboratory flume experiments aimed at establishing scale effects in small-scale models of flow fields around the following two elemental types of hydraulic structure commonly used for controlling channel-thalweg location:

1. dikes (a relatively narrow structure that extends above water surface); and,
2. bendway weirs (a submerged and broad-crested structure).

The flow field associated with each structure will be investigated for modeled conditions of each structure placed on a fixed, flat bed within a channel whose overall width is three times the length of the modeled structure. Hereinafter, these experiments are termed "fixed-flume" studies.

The information developed from the flume studies will aid interpretation of information obtained generally from loose-bed hydraulic models (especially small-scale, geometrically distorted models) used to investigate channel-stabilization issues. In particular, the information will aid interpretation of information produced by micro-models. It is intended that the information from the proposed fixed-flume studies be combined with information obtained from a companion study (conducted by Mr Andy Gaines of the Corps' Memphis District) focused on scale effects incurred with small-scale and vertically distorted loose-bed models.

Scale Effects
The flume studies will focus on scale effects consequent to varying degrees of similitude relaxation with variations of the following scale considerations:

Horizontal-length scale, X_r

Vertical distortion, G = vertical-length scale/horizontal-length scale, Y_r/X_r

Relative roughness, $(k/R)_r$

In which k = hydraulic-roughness height, R = hydraulic radius, and r = scale ratio.

These three scale considerations are of great practical importance when replicating the flow field around hydraulic structures such as dikes and bendway weirs. They influence key criteria that govern the similitude of the flow fields replicated in hydraulic models. Reynolds-number (inertia/viscous force) similitude and Froude-number (inertia/gravity force) similitude, notably, are directly affected by the three scale considerations. Weber-number (inertia/surface tension) similitude is an additional concerns for very small-scale models.

Lack of Reynolds-number similitude will be evident in differences in flow field around a structure such as a dike or a bendway weir. It is of interest to determine how relaxation of Reynolds-number similitude influences the flow field around a dike or bendway weir; e.g., affecting the strength and frequency of eddies. That information is of use in determining the veracity of results obtained when replicating dike performance in very small-scale models.

Lack of Froude-number similitude will influence flow profiles and patterns around a dike or a bendway weir. Loose-bed models typically do not attain Froude-number similitude, because they primarily focus on attaining mobile bed conditions rather than on explicit simulation of flow resistance. Lack of Froude-number similitude also may affect the flow field around a hydraulic structure, because the approach-flow velocity and its distribution are not scaled in accordance with gravitational forces. For a loose-bed model, proportionately greater velocity magnitudes and gradients usually result around modeled structures, such as bridge piers.

Additionally, lack of relative-roughness similitude will influence velocity gradients, and thereby result in lack of flow-profile and –pattern similitude.

The flume experiments will involve variations of X_r, G, and k/R. By monitoring the flow patterns around a simulated dike and bendway weir, the effects of lax similitude of Reynolds number, Froude number and relative roughness will be evident.

Program of Experiments
Table 1 indicates an overall total of three series of experiments would be carried out for the two basic structures (dike, bendway weir):

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Inlet and Outlet Conditions. These would be controlled by way of a headbox and a tailbox. The headbox would be sufficiently far upstream of the test location so that the simulated dike and bendway weir would be placed within a fully developed turbulent boundary layer flow that is representative of flow conditions in a river.

Bed Roughness. Aluminum sheets coated with fixed roughness elements would be placed along the invert of the flume. The flume's slope would be adjusted (steeper with greater roughness) to produce the same flow depth for a constant flow rate.

Model Dikes and Bendway Weirs. The basic length and width of the simulated dikes and bendway weirs would be proportioned to match those typically used for such structures.

Measurements and Observations

The effects of horizontal scale, vertical distortion, and relative roughness would be interpreted from series of images of the water-surface flow field around the simulated dike and bendway weir. Those images would comprise the main product of the flume studies. They would be recorded using a digital video camera, then quantified for velocities and flow patterns using particle-image velocimetery (LSPIV) and image-processing algorithms. The video camera would be positioned directly above the location of the simulated dike or bendway weir. Small, buoyant polypropylene beads (diameters of 3 mm and 0.5 mm; specific gravity of 0.90) would be used as imaging particles. They would be released upstream of the test section and collected downstream of it.

Additionally video-camera records would be made of the flow patterns throughout the flow depth around the simulated dike and bendway weir. Flow visualization would be facilitated with dye, which would reveal the major features over the depth of the flow field.

Analysis and Reporting

The recorded flow patterns would be converted into vector fields of flow. Changes in the flow fields would be interpreted in terms of Reynolds-number, Froude-number, and relative-roughness similitude. Selected features of the flow field (e.g., size of key vortices, vorticity and periodicity of key eddies) would determined. Degradation of simulation accuracy would be determined in several ways. On way will be by comparing selected flow features measured for the flow conditions studied. Curves would be developed that relate degradation of flow-field accuracy to X_r, G, and $(k/D)_r$. The curves would include an ordinate showing varying Reynolds number, and, for some cases, varying Froude number.

Of special interest in the analysis will an evaluation of misrepresented currents that likely may be problematical at full scale. With diminishing horizontal scale and enhanced vertical distortion, a model may not reveal currents that will cause problems for activities such as navigation and sediment scour/deposition.

The results of the flume studies would be documented in a comprehensive report submitted to the Corps of Engineers. The report would contain flow patterns determined by means of LSPIV, as well as all quantitative interpretations obtained from them. A videotape record of the flume tests would accompany the written report.

Schedule
The flume studies could be carried out in a six-month period. There is some advantage to allowing a one-year period over which to conduct them; e.g., the studies could be conducted interactively with the study conducted by Mr Gaines. The studies could begin immediately.

Personnel
If the flume studies were conducted at IIHR, Dr Marian Muste could carry out the studies, with oversight and interpretive involvement by Dr Robert Ettema. A graduate research assistant, who would conduct the flume tests as part of a thesis effort for attaining the Masters Degree, could aid them. Drs Muste and Ettema would interact closely with Dr Maynord, Mr Gaines, and Mr Davinroy of the Corps. Dr Muste and Dr Ettema would prepare a final report.

Budget
The main budget items would be the time involvement of Dr Muste and a Research Assistant. Dr Ettema would charge a modicum of time, as part of his involvement would be covered in part through his present contract with the Corps. The total budget estimate is $57,442, which would span the duration of the experiments; for fiscal year (FY) 99-00, the budget estimate is $9,516; for FY00-01, the budget estimate is $47,925. Table 2 provides details on the budget estimate.

PART 2. SUPPORT FOR LSPIV USE

IIHR would support Mr Andy Gaines in the use of large-scale particle-image velocimetry (LSPIV). Mr Gaines would use LSPIV as an effective means to obtain and document and analyze flow-velocity vectors delineating flow patterns at the several models of hydraulic-structure and morphologic features he will investigate in the course of his studies at the University of Missouri-Rolla and at the Corps's Memphis District.

Tasks
Based on discussions with Mr Gaines, stemming from his visit to IIHR on May 31 ~ June 1, it was tentatively decided that Mr Gaines would use a digital video camera to record images of the flow field associated with his loose-bed models of dikes, bendway weirs, and channel bends. Some initial guidance would be provided by IIHR to aid Mr Gaines in setting up the camera and in flow-seeding to delineate flow patterns. Subsequently, Mr Gaines would send to IIHR digital recordings of the video images. IIHR would image-process the images using IIHR's image-processing software. The images would be processed to produce vector fields of surface currents. The velocity fields would be returned to Mr Gaines for further analysis and interpretation aimed at discerning how model scale and vertical distortion affect model flow field.

The image-processing at IIHR would be done under the supervision of Dr Muste. In working with Mr Gaines, he would carry out the following specific activities:

1. ensure video images of adequate quality to obtain velocity vectors so as to delineate flow fields; and,
2. process the recorded images to obtain vector fields.

With regard to activity 1, it is envisioned that Dr Muste would spend about two days with Mr Gaines, assisting him with camera set up, flow seeding, and image-taking. This activity requires that Dr Muste travel to Rolla, where Mr Gaines is located.

An early effort with regard to item 2, is to designate/train a person at IIHR to process the images on a routine basis. Budgeting for this activity, therefore, would allow for an initial setup effort (adapting the existing process at IIHR so as to handle images sent by Mr Gaines, and ensuring that the designated/trained person can directly process the images). Budgeting then would be based on a rate per image sent for processing; a basic rate of $200/flow field. It is estimated herein that about one working day should be allowed for the actual processing: 0.5hr data transfer; 2hr screening images and setting processing parameters; 1hr analyzing output and refining processing parameters; 2hr data visualization using Tecplot; 1.5hr margin for unforeseen events (re-processing, correcting dubious vectors, etc.). It is of interest to note that real-time LSPIV is under development, but is not yet a available.

Schedule
The schedule for providing guidance in the setting up of Mr Gaines' LSPIV system, and in the provision of vector fields of velocity from LSPIV, would be developed in accordance with Mr Gaines' progress with his experiments. It is anticipated that the following schedule elements would apply:

1. In July or early August, Dr Muste would go to the University of Missouri-Rolla to spend two days assisting Mr Gaines in the setting up of his video-camera and seeding procedure for LSPIV.
2. Once Mr Gaines produces video images, he would send them to IIHR, which within one week would send him (email, regular mail) an electronic outcome of the resultant velocity vector field.

The schedule for LSPIV image processing would follow in tandem with Mr Gaines study schedule.

Budget
The budget estimate for Part 2 is indicated in Table 3. It comprises an basic cost of $4,941 for activities 1 and 2. Image processing is estimated at a rate of $220/flow field. It is anticipated that the budget estimate for FY99-00 would be $4,941; i.e., essentially setup and processing of initial images. The FY00-01 budget essentially would be image processing at $220/flow field.

Personnel

IIHR's activities would be conducted by Dr Marian Muste. He would be assisted by a graduate assistant, who would perform the routine image processing with Dr Muste. Dr Robert Ettema would assist in coordination of Part 2 activities (the present activities) with the fixed-flume experiments.

Table 1. List of Study Series
(Note: Flume widths to be 3 times structure widths)

Study Series	Structure	Varied Parameter	Structure Length (mm)	Flow Depth (mm)	Approx. X_r	Aspect Ratio	G	k/R
I-1	dike	X_r	400	80	10,000	5	1	smooth
			200	40	20,000	5	1	smooth
			100	20	40,000	5	1	smooth
			50	10	80,000	5	1	smooth
			25	5	160,000	5	1	smooth
I-2a	dike	Y_r	200	80	20,000	2.5	2	smooth
			200	160	"	1.25	4	smooth
			200	320	"	0.625	8	smooth
I-2b	dike	Y_r	50	20	80,000	2.5	2	smooth
			50	40	"	1.25	4	smooth
			50	80	"	0.625	8	smooth
			50	160	"	0.316	16	
1-2c	dike	Y_r	25	20	160,000	2.5	4	
			25	40	"	1.25	8	
I-3a	dike	k/R	200	40	20,000	2.5	2	0.01*
			200	40	"	1.25	4	0.05*
			200	40	"	0.625	8	0.1*
I-3b	dike	k/R	50	20	80,000	2.5	2	0.01*
			50	20	"	1.25	4	0.1*
			50	20	"	0.625	8	0.2*
I-3c	dike	k/R	25	10	80,000	2.5	2	0.01*
			25	10	"	0.625	8	0.2*
Series II	Bendway weir	Same as for dike						
Series III	Permeable dikes	Repeat Series 1-2b, plus baseline test with structure length = 400 mm and flow depth = 80 mm Initial permeability value to be provided by Corps of Engineers						
Total number of experiments ≈ 50; additional experiments to be run as needed to complete definition of trends								

* nominal value