PENNSTATE

Office of Engineering Research Administration

The Pennsylvania State University
College of Engineering
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University Park, PA 16802

October 1, 2014

Mark Landers, Ph.D., P.E., D.WRE
Chief, Federal Interagency Sedimentation Project
1770 Corporate Drive, Suite 500
Norcross, GA 30093

Subject: PSU Proposal entitled "Accuracy evaluation and verification of FISP sediment samplers through CFD modeling"
(PSU OSP No. 176967 – Please reference this number on all related correspondence)

Dear Dr. Landers:

The Pennsylvania State University through the College of Engineering is pleased to submit the subject proposal prepared by Dr. Xiaofeng Liu. This has been reviewed and approved by the appropriate administrative personnel at Penn State.

The University has endorsed this proposal under the assumption that any resulting award would be made with terms and conditions applicable to institutions of higher education. If we can be of further assistance, please contact Lindsay Holyfield, Associate Coordinator of Grants and Contracts at (P) 814-863-5423 or email at lhh10@psu.edu. Technical questions should be directed to the PI, Dr. Xiaofeng Liu at (P) 814-863-2940 or email at xzl123@psu.edu.

Sincerely,

John W. Hanold

Dr. John W. Hanold
Interim Director of Sponsored Programs

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FEDERAL INTERAGENCY SEDIMENTATION PROJECT
PROPOSAL FORM

Proposal Title: Accuracy evaluation and verification of FISP sediment samplers through CFD modeling

Project Chief: Xiaofeng Liu

Project Chief Location: The Pennsylvania State University, University Park, PA

Proposed Start Date: January 1, 2015 Proposed End Date: December 31, 2015

Request: $29,636

1. **Relation to FISP goals**

This proposal seeks to use the state-of-art 3D computational fluid dynamics (CFD) to evaluate and verify the accuracy of FISP sediment samplers. Turbulent open channel flow and suspended sediment will be simulated around selected depth-integrating samplers. The intrusion effect of the samplers and their accuracy will be studied. Past investigations have mostly used laboratory experiments or field measurements. Though they resulted in a lot of useful information, the detailed 3D flow and suspended sediment distributions with the presence of the samplers, in comparison with the ground truth, are not clear. This lack of details is the major source of uncertainty in the measuring results. The proposed CFD modeling work, with careful calibrations, can reduce the uncertainty and improve the measurement accuracy.

As in many other engineering fields, high fidelity computational modeling has become a very useful tool in hydraulics and sediment transport. The FISP samplers have been used for decades since the time when computers were not widely available. Today we have the computational power and modeling tools to advance our knowledge about these widely used devices. The proposed CFD modeling work is a much needed research to assure these federally approved samplers are technically sound. It greatly contributes to the fulfillment of FISP's mission. The topic is also one of the specifically encouraged research focus areas for FY2015.

2. **Scientific Merit and Relevance**

The presence of the samplers (length scales of 20 inches for DH-2 and 42 inches for D-99) in the water column affects the surround flow fields, turbulence and suspended sediment concentration field. The vertical motion of the samplers (lowering and raising) further disturbs the flow. In addition, when the samplers are close to the river bottom (approaching the unsampled zone, 3.5 inches for DH-2 and 7.2 inches for D-99), the flow is squeezed in between the sampler and the sediment bed. The accelerated flow increases the suspension of the sediment into the water column and therefore disturbs the background concentration field. All the above are possible source of error and they directly affect the accuracy of the sampling results.

The scientific merit of the proposed CFD simulations is that for the first time the details of the flow field can be revealed at relatively low cost. The quantification of errors and uncertainty due to the intrusive nature of the samplers help evaluate and verify their accuracy. More importantly, best practices can be provided based on the modeling results. From the technical perspective of view, the CFD models built for the selected samplers can be easily extended to other types. The detailed documentation and case setups can be used by others in the future for much broader investigations.

3. **Methodology**

The open source CFD platform OpenFOAM® will be used in this project (http://www.openfoam.com). OpenFOAM® is a popular CFD developed by OpenCFD Ltd at ESI Group and distributed by the OpenFOAM® Foundation. Since its debut in the open source community, its user base from both academic and commercial organizations has expanded tremendously. The application areas are rather extensive and span a wide spectrum in engineering and sciences. OpenFOAM® is designed to capture complex flow features with a wide range of models for turbulence.

Due to the limits on budget and time for this project, only CFD simulations will be performed to evaluate and verify the accuracy of the selected FISP suspended sediment samplers. In the past, laboratory experiments and field campaigns have collected substantial amount of data. These data are very valuable for the calibration of the numerical models.

Two bag-type suspended sediment samplers are selected to be studied, i.e., DH-2 and US D-99 (see Figure 1). The two representative samplers are both depth-integrating collapsible-bag type. However, they operate in different flow and sediment transport conditions.

The DH-2 sampler weighs 30 pounds and can be operated by hand. On the other hand, D-99 sampler weighs 285 pounds and needs to be operated by a cable and reel system. The DH-2 sampler can be used in stream depths up to 37 ft using a 3/16-in internal diameter nozzle, 20 ft using a 1/4-in internal diameter nozzle, and 13 ft using a 5/16-in internal diameter nozzle. DH-2 can be used in stream velocities ranging from 2.0 to 6.0 ft/sec. In contrast, D-99 is capable of sampling to a depth of 78 ft with a 5/16-in internal diameter nozzle, 120 ft with a 1/4-in internal diameter nozzle, and 220 ft with a 3/16-in internal diameter nozzle. The sampler collected samples at acceptable inflow efficiencies in flow velocities of 2 to 4 feet per second (ft/sec) using a 3-liter bag and 3 to 15 ft/sec using a 6-liter bag. US D-99 is designed for deep swift rivers requiring the collection of a large volume sample.

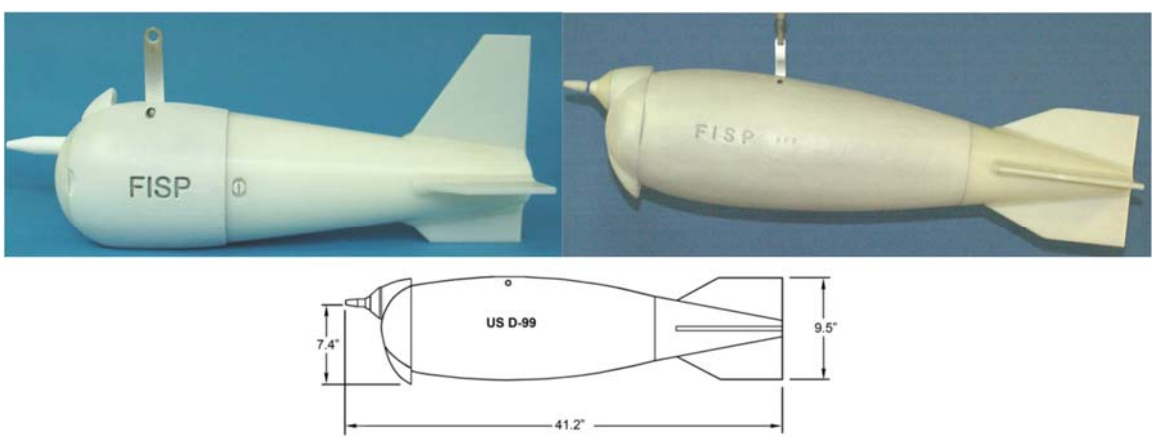

Figure 1. Pictures of the DH-2 (left) and D-99 (right). The bottom figure shows the dimensions of D-99.

The proposed work will be carried out in the following steps:

- Acquisition of the samplers. Two samplers, DH-2 and D-99 will be purchased from the USGS Hydrologic Instrumentation Facility. We will collect geometrical information of the samplers

from the literature (user manual, technical reports, etc., e.g., Johnny McGregor, 2006) for the purpose of computational modeling. Also, we will communicate with FISP and the manufacturing facility about how to get the detailed drawings of the samplers. In the worst case scenario of not enough geometrical information, we will use our 3D laser scanner to digitize (reverse-engineering) the surface of the samplers. In the past, we have digitized different objects (riprap rocks, gravels, etc.) using the same technique.

- From literature, collect available data from laboratory experiments and field measurements about the selected samplers. These data include inflow efficiency, operating velocity, transient rate, bag filling time, drift angle (for D-99) and other relevant information. These data will be used in the design of computational cases as well as model calibrations.

- Preparation of computational modeling cases. For depth-integrating measurements, the sampler is lowered into and then raised out of water column. As a result, there is a moving body inside the simulation domain. To cope with the moving body, an innovative computational approach called immersed boundary method will be used. An immersed boundary method uses a fixed background mesh and treats the moving boundaries (the samplers) implicitly. There are no body-fitted meshes for the samplers. Instead, a special treatment around the boundary makes sure the no-slip condition is satisfied. We have developed this new immersed boundary method through a research grant from U.S. Army Corps of Engineers. The background mesh (for a typical open channel) will be generated using the meshing tool from OpenFOAM® (*blockMesh*). If more complicated bathymetry is desired, commercial mesh software such as Pointwise will be used (PSU has campus license, no cost to this project).

  For both samplers, cases with different inflow velocities will be simulated. These velocities will be chosen in the applicable ranges of the samplers. Suspended sediment transport will also be simulated with representative sizes in the applicable regimes. We have developed suspended sediment transport model for Reynolds-Averaged Navier-Stokes (RANS) turbulence modeling framework (Liu, 2014). The key is at the bed where the suspension and settling take place.

- Results analysis. The result analysis will focus on the effect of the samplers on the surrounding flow field, turbulence, and suspended sediment concentration distribution. All of above affects the collected water-sediment sample in the bag. In each case, the resulting depth-integrated suspended sediment concentration from the simulation will be compared with values without samplers. The errors are functions of the flow velocity, flow depth, transit rate, and suspended sediment sizes. Plots of the functional relationships will be generated. These plots can be used to quantify the errors of measuring results in the field or simply as calibration curves.

The PI's group at PSU has been using OpenFOAM® for more than ten years and has developed a multitude of applications in hydraulics and sediment transport (http://water.engr.psu.edu/liu/). Many member organizations of FISP (e.g., USACE and USBR) have started to use OpenFOAM® as a valuable tool for their modeling needs. Through the years, the PI of this project has established and maintained good collaborative relationships with these FISM members.

4. **Timeline, budget (Feasibility), and partners**

This is a single year project (January 1, 2015 to December 31,205). The timeline of the project is as follows:

Project start	0
Order Samplers	Month 1
Geometry preparation and CAD drawings	Month 2
Collecting data from literature	Month 2
Perform the CFD simulations	Month 3-9
Result analysis and perform additional simulations if needed	Month 9-10
Reporting and result presentation	Month 11-12

The proposed budget includes the research time of the PI, hiring a graduate research assistant, and purchasing of the two suspended sediment samplers (DH-2 and D-99). The following is a breakdown of the cost. The details of the budget are appended to this proposal.

Labor		
	PI (0.45 summer month)	$4,360
	Graduate student (4 months)	$8,000
Fringe		$2,225
Materials		
	DH-2	$5,704
	US D-99	$486
	Others	$810
Indirect cost		$8,051
Total		$29,636

There is no cost share in this proposal. However, if the detailed geometrical information of the samplers is not available, we will use our 3D scanner.

References:

Waterways Experiment Station (unknown year), Operator's Manual for the US DH-2 depth-integrating collapsible-bag suspended-sediment sampler.

Johnny McGregor (2006). The US D-99: An isokinetic depth-integrating collapsible-bag suspended-sediment sampler.

X. Liu (2014). New near-wall treatment for suspended sediment transport simulations with high-Reynolds number (HRN) turbulence models. Journal of Hydraulic Engineering, 140(3):333-339.

September 29, 2014

Xiaofeng Liu, Ph.D., P.E.
Assistant Professor
Department of Civil and Environmental Engineering
Penn State University

Dear Dr. Liu,

As an engineer at the Technical Service Center of Bureau of Reclamation, I am pleased to write this letter in supporting the research activities described in your FISP proposal titled "***Accuracy Evaluation and Verification of FISP Sediment Samplers through CFD Modeling***".

As we have discussed, I am enthusiastic about leveraging our existing collaborations on three-dimensional computational hydraulics and sediment transport to provide guidance to your proposed work. USBR, as a member of the FISP, has a long history of using the sediment samplers; but the accuracy can be greatly understood and improved through CFD modeling approach you proposed to study. As a hydraulic engineer and model developer with more than 25 years of experience, I cannot say more about the importance of field data. However, the accuracy and uncertainty associated with these devices need to be understood and quantified. Improved quality of the measurement data benefits the overall quality of the work we do at USBR and other FISP member agencies as well.

I believe your expertise on computation fluid dynamics and hydraulics will make this project a success. I also look forward to the outcome of this project, which not only will achieve the stated goals but also serve as an example of using latest computational techniques to improve our ability in hydraulic measurements.

If you have any question, please don't hesitate to contact me.

Sincerely,

Yong Lai, Ph.D., Hydraulic Engineer
Technical Service Center
Bureau of Reclamation

Denver, CO