Transportation Pooled Fund Program TPF-5(446) Quarterly Progress Report

Quarter 1, January – March 2023

prepared by
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TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): _FHWA___________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *(i.e., SPR-2(XXX), SPR-3(XXX) or TPF-5(XXX)* *TPF-5(446)*	**Transportation Pooled Fund Program - Report Period:** ☒Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 1 – December 31)
Project Title: **High Performance Computational Fluid Dynamics (CFD) Modeling Services for Highway Hydraulics**	

Name of Project Manager(s): *Kornel Kerenyi*	**Phone Number:** *(202) 493-3142*	**E-Mail** *kornel.kerenyi@fhwa.dot.gov*
Lead Agency Project ID:	**Other Project ID (i.e., contract #):**	**Project Start Date:**
Original Project End Date:	**Current Project End Date:**	**Number of Extensions:**

Project schedule status:

☒ On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date

Project Description:

The Federal Highway Administration established an Inter-Agency Agreement (IAA) with the Department of Energy's (DOE) Argonne National Laboratory (ANL) Transportation Analysis Research Computing Center (TRACC) to get access and support for High Performance Computational Fluid Dynamics (CFD) modeling for highway hydraulics research conducted at the Turner-Fairbank Highway Research Center (TFHRC) Hydraulics Laboratory. TRACC was established in October 2006 to serve as a high-performance computing center for use by U.S. Department of Transportation (USDOT) research teams, including those from Argonne and their university partners. The objective of this cooperative project is to:

- Provide research and analysis for a variety of highway hydraulics projects managed or coordinated by State DOTs.
- Provide and maintain a high-performance Computational Fluid Dynamics (CFD) computing environment for application to highway hydraulics infrastructure and related projects.
- Support and seek to broaden the use of CFD among State Department of Transportation employees.

The work includes:

- Computational Mechanics Research on a Variety of Projects: The TRACC scientific staff in the computational mechanics focus area will perform research, analysis, and parametric computations as required for projects managed or coordinated by State DOTs.
- Computational Mechanics Research Support: The TRACC support team consisting of highly qualified engineers in the CFD focus areas will provide guidance to users of CFD software on an as needed or periodic basis determined by the State DOTs.
- Computing Support: The TRACC team will use the TRACC clusters for work done on projects; The TRACC system administrator will maintain the clusters and work closely with the Argonne system administrator's community; The TRACC system administrator will also install the latest versions of the STAR-CCM+ and OpenFOAM CFD software and other software that may be required for accomplishing projects.

Progress this Quarter:

(Includes meetings, work plan status, contract status, significant progress, etc.)

1: Computational Mechanics Research on a Variety of Projects

1.1: Computational Study of Hydraulic Performance of Ohio DOT Catch Basin CB6 and Barrier Inlet

To handle higher volumes of traffic, modern roads are being built and old roads are being expanded with more lanes giving a larger rainfall collection area. In addition, more frequent and extreme rain events can overwhelm existing drainage systems and new systems need to be designed to handle the higher rates of runoff. State Departments of Transportation are developing new designs of drainage structures including more accurate estimates of efficiency under a variety of conditions. They are also assessing old designs to determine if they can drain higher flow rates of water from the roads.

Three-dimensional computational fluid dynamics (CFD) analysis can determine flow and efficiency through drains with complex geometry and catch basins at field scale over a broad range of conditions. Ohio DOT approached Argonne researchers to continue the evaluation of their drainage structures. In the previous phase of the study, inlet types CB3 and CB3A were evaluated with the use of computational fluid dynamics on a high-performance computing cluster, and in the current phase, the flow capacity of catch basin CB6 and a barrier inlet is analyzed.

The test case matrix includes varying cross-slopes and longitudinal slopes of the road surface, shoulder/gutter width, as well as a range of flow rates. On-grade and sump conditions are analyzed in the study. Six-inch-high curbing with a maximum water depth of 5 inches is used for the on-grade scenario. The computational analysis yields the hydraulic efficiency of the inlets, the split of the flow rate between front, side, and backflow of the grate, as well as the bypass flow with a 2-foot composite gutter at 8.33% and a pavement cross slope at 1.6% and with a 4-foot gutter at 4.0% and a pavement cross slope at 1.6% for the following spreads: 2', 4', 6', 8' and 10'. The roadway longitudinal profile grades of 0.25%, 0.50%, 1%, 3%, 5%, 8% are considered. In the sump condition, the hydraulic capacity of flow relative to the depth of ponding over the grate is modeled with water depth of flow varying from 1 in (0.025 m) to 18 in (0.457 m) above the center of the grate. Figure 1 presents a plan view of the catch basin CB6.

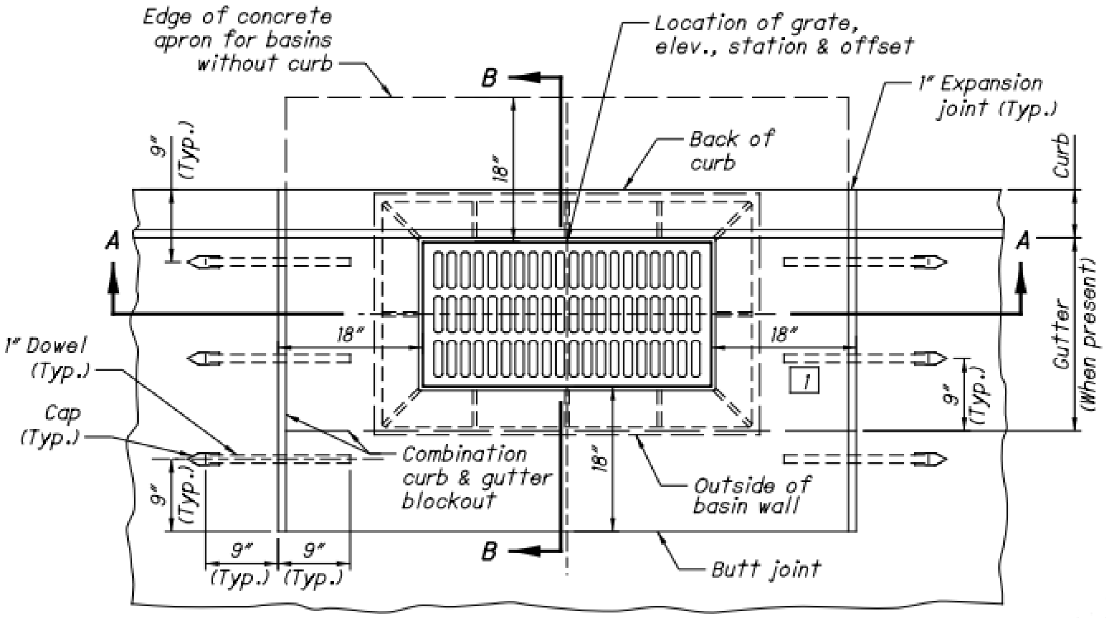
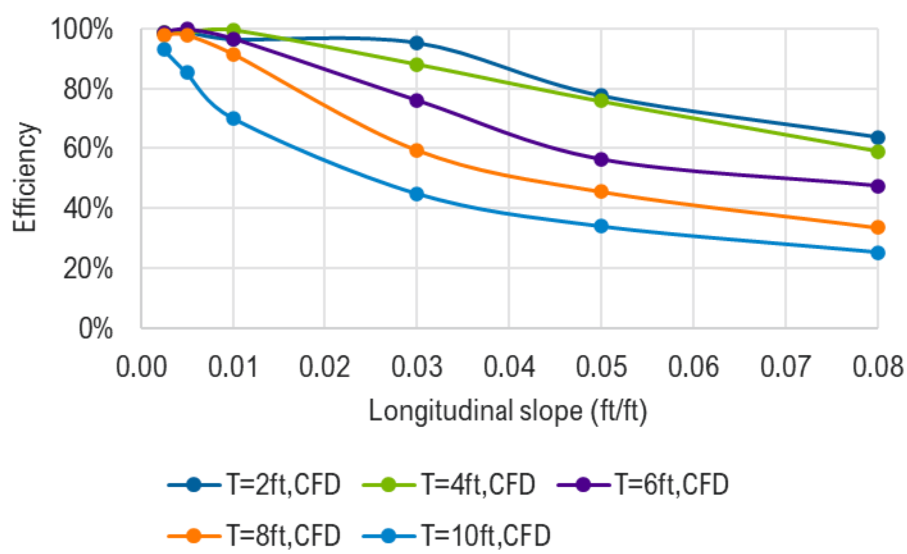


Figure 1: Catch basin CB6 plan view.

The analysis of the hydraulic efficiency of the catch basin CB-6 in on-grade locations was performed. The geometry of the computational model used in the analysis was built in Simcenter STAR-CCM+ 2022.1. The domain covers a section of a road upstream and downstream of the catch basin, the grate inlet and the catch basin underneath. Simulations are initialized with the computational domain filled with air. An inlet boundary is defined upstream of the catch basin with velocity distribution obtained in a separate simulation that represents a fully developed velocity profile. The side, top and downstream surfaces are outlets with reference pressure equal to the atmospheric pressure. The computations continued until a steady state was reached.

Figure 1 presents plots of the hydraulic efficiency, as a ratio of the intercepted to total flow, versus (a) longitudinal slope and (b) upstream flow spread. The efficiency drops from 100% to 25% with increasing slope and spread. It is lower compared to the previously analyzed CB-3A [2], for the same conditions, due to the lack of a curb inlet, different shape of the bars which have a rectangular cross section instead of curved-vane, and smaller open area of the grate. An analysis of the splash-over velocity for the grate is underway.

(a)



(b)

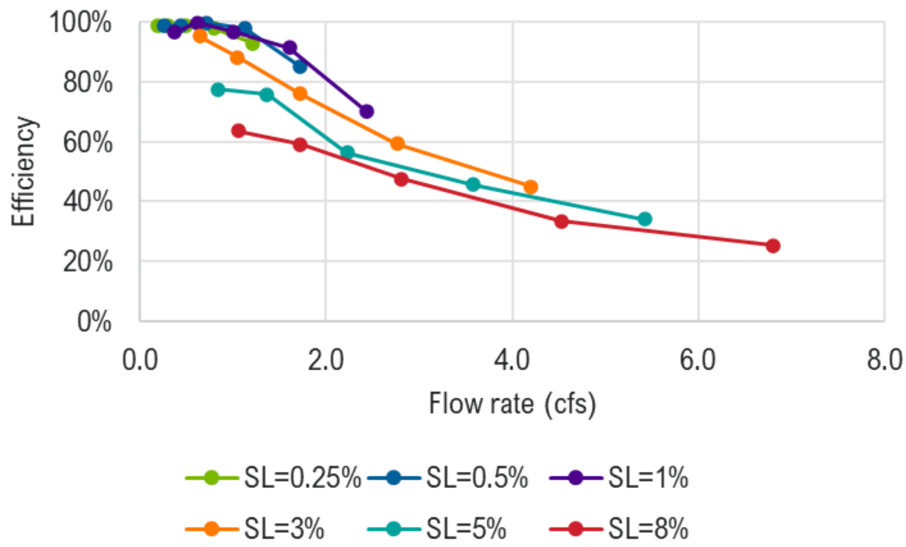
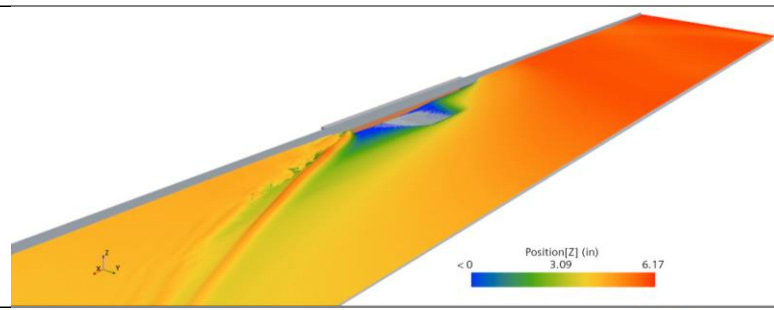
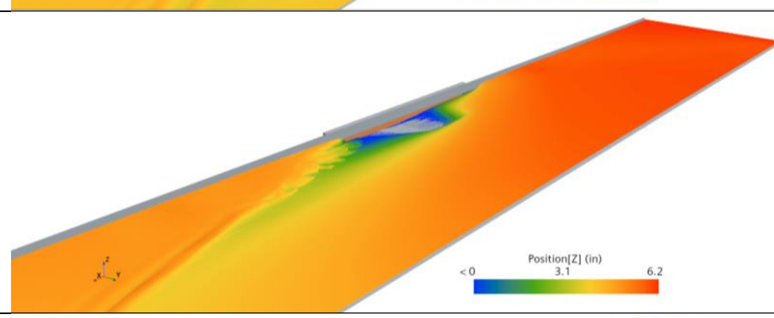
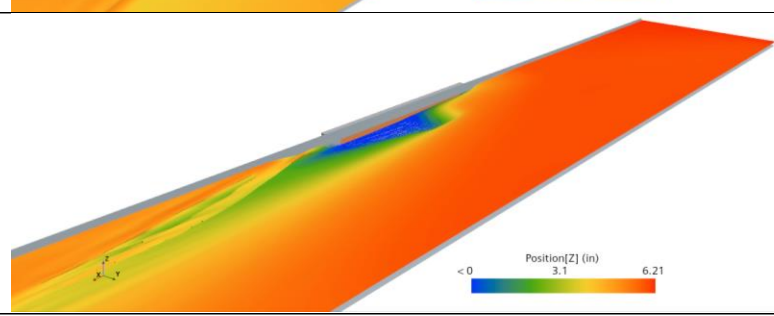


Figure 1. Plots of the hydraulic efficiency, as a ratio of the intercepted to total flow, versus (a) longitudinal slope and (b) upstream flow spread.

The barrier inlet was evaluated for an on-grade location with varying grade SL from 0.5 to 8%, and water depth at curb 6 inches. Figure 2 shows the flow patterns over the inlet changing from weir regime to orifice regime with increasing slope. Figure 3 shows the dependence of the intercepted flow percentage on SL.

SL	
0.5%	
1%	
3%	

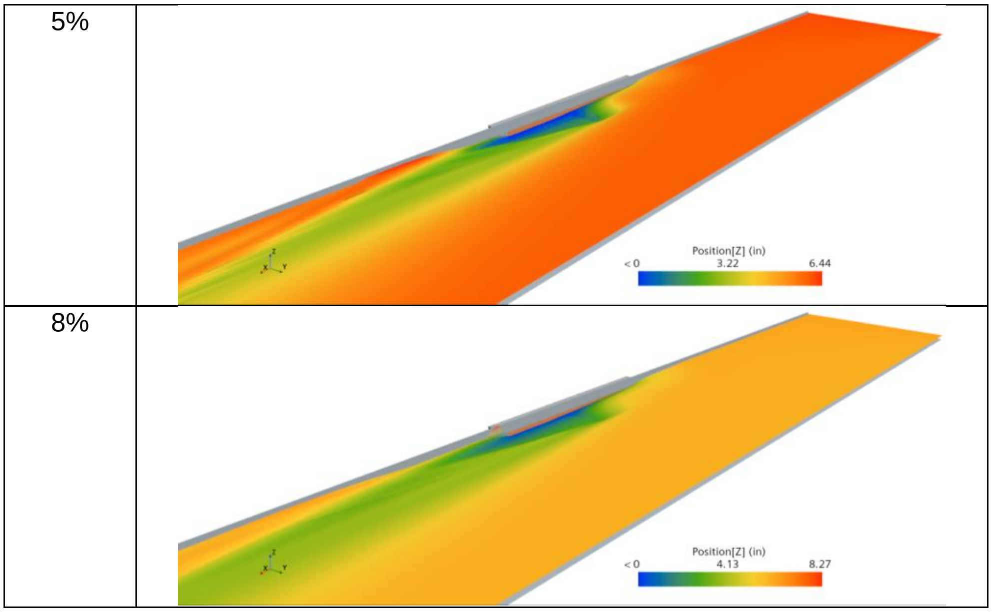


Figure 2: Perspective view of the flow over the inlet for varying longitudinal slope.

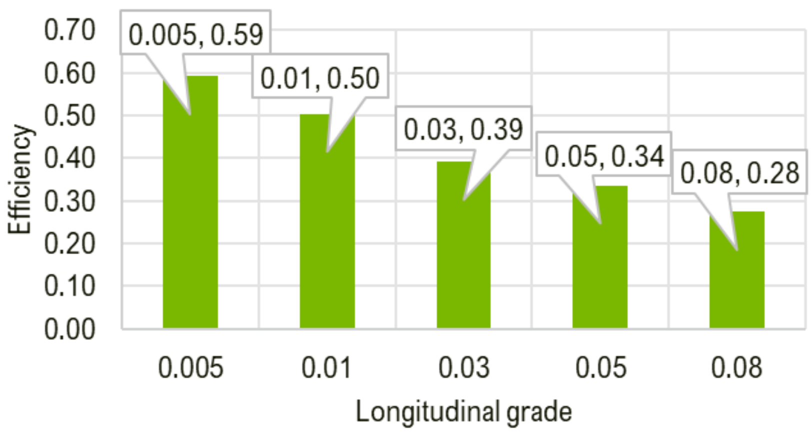


Figure 3: Hydraulic efficiency of the inlet in the analyzed cases.

[1] Sitek, M.A. and S.A. Lottes. "Computational Analysis of Water Film Thickness During Rain Events for Assessing Hydroplaning Risk Part 2: Rough Road Surfaces.", Argonne National Laboratory, ANL-20/37, July 2020.
[2] M.A. Sitek, S.A. Lottes, J. Syar, Computational Analysis of Hydraulic Capacity of Ohio DOT Catch Basins On-Grade and in Sag Locations, ANL-21/20, April 2021

Anticipated work next quarter:

1: Computational Mechanics Research on a Variety of Projects

- hydraulic analysis of catch basins on grade and in sump
- analysis of water film thickness on pavements (hydroplaning water film thickness and speed)

2: Computational Mechanics Research Support

This work will continue.

Task 3: Computing Support

This work will continue.

Circumstance affecting project or budget.

(Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.