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

Quarter 2, April - June 2021

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 current 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 Fluid Dynamics Modelling of Hydraulic Capacity of Ohio DOT Drainage Structures

Highway drainage systems need to handle higher volumes of runoff during rain events than they have in the past. 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 are capable of draining higher flow rates of water from the roads.

Three-dimensional computational fluid dynamics analysis can determine flow and efficiency through drains with complex geometry and catch basins at field scale over a broad range of conditions. Argonne researchers were approached by Ohio DOT to perform an evaluation of inlet types CB3 and CB3A with the use of computational fluid dynamics on a high-performance computing cluster. These drainage structures consist of a grate and window, with the window being considered a factor of safety against grate clogging.

Geometric parameters in the test case matrix include 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. The computational analysis yields the hydraulic efficiency of the inlets, the split of the flow rate between front, side, and backflow of the grate, flow through the curb opening when present, as well as the bypass flow.

The hydraulic capacity of catch basin 3A was analyzed in on-grade conditions. Initial findings were presented in a previous quarterly report [TPF-5(446) Q1 2020]. A double catch basin CB3 is used in sump conditions. Figure 1 shows the plan view of CB3.

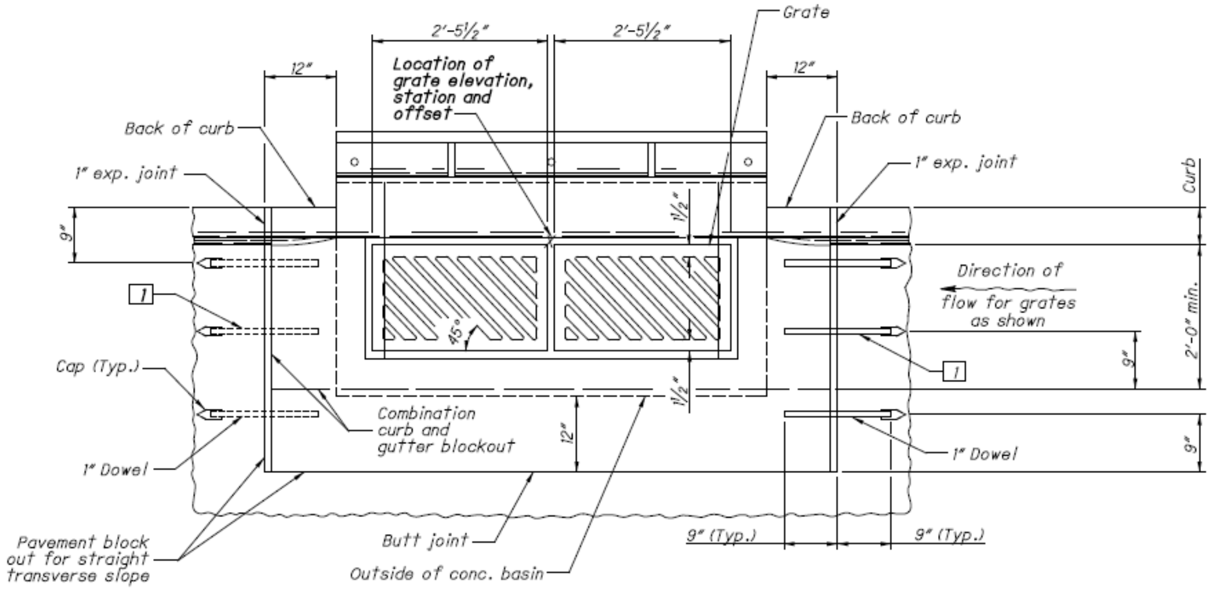

Figure 1. Plan of catch basin CB3

The geometry of the computational model used to analyze the sump condition covers a section of a road upstream of the catch basin and half of the CB3 catch basin. Being a double catch basin with a symmetric geometry, it can be assumed that the flow through the inlet is also symmetric. This assumption makes it possible to use only half of the model and therefore decrease the resources needed to complete a simulation. The height of the domain is significantly greater than the one used in the study of on-grade conditions in order to capture the orifice flow conditions that occur at higher flow depths. A perspective view of the computational domain is presented in Figure 2.

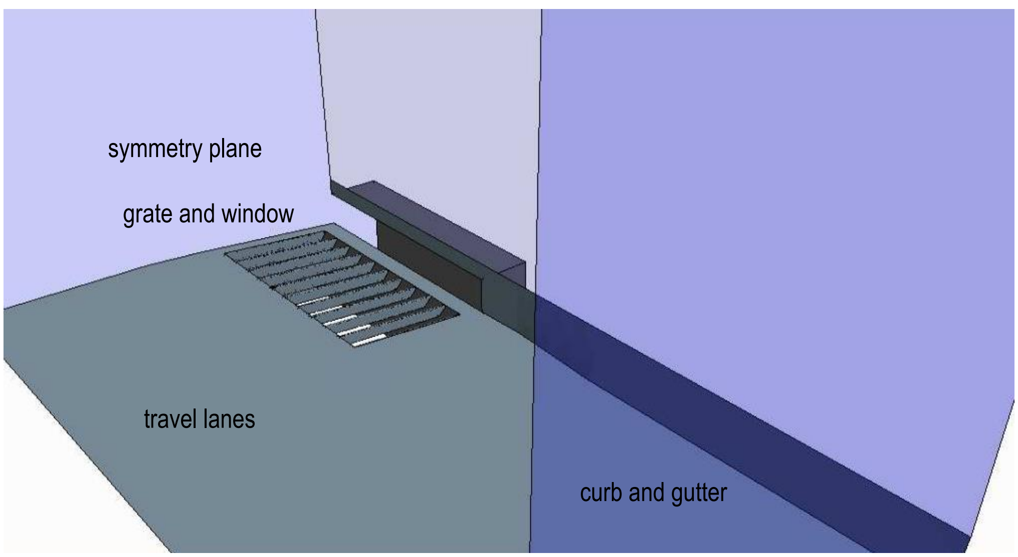

Figure 2. Perspective view of the computational model

A transient model was built, in which the domain is initially filled with water up to a depth sufficient to produce orifice flow conditions. During the simulation, the water drains through the grate and/or curb opening until all water leaves the domain. The discharge versus time and average water depth versus time data are recorded and as a final step, the data are combined to show the relationship between the discharge capacity and ponding depth.

Three scenarios are considered in the study for sump conditions:
(1) both the window and the grate contribute to the hydraulic capacity of the catch basin,
(2) the grate is unobstructed and there is no window contribution, and
(3) the window is unobstructed and there is no grate contribution.

The flow conditions over inlets in sag locations can be of one of three types: weir flow, orifice flow, and the transition between them. When water surface above the inlet is almost level and unbroken, flow is in the orifice type regime. In the weir flow regime, the inlet is partially overtopped, and the surface is broken and dips down. When the flow is in an intermediate state, and the type of the flow is not clearly identifiable, it is said to be in a transition regime.

As an example, water flow over a combination inlet is presented. Figure 3 presents snapshots in time of the water surface elevation for a model with a combination inlet when (a) grate and curb opening are in orifice flow regime, (b) curb opening starts to operate as a weir, and grate is overtopped, (c) grate and curb opening act as weirs.

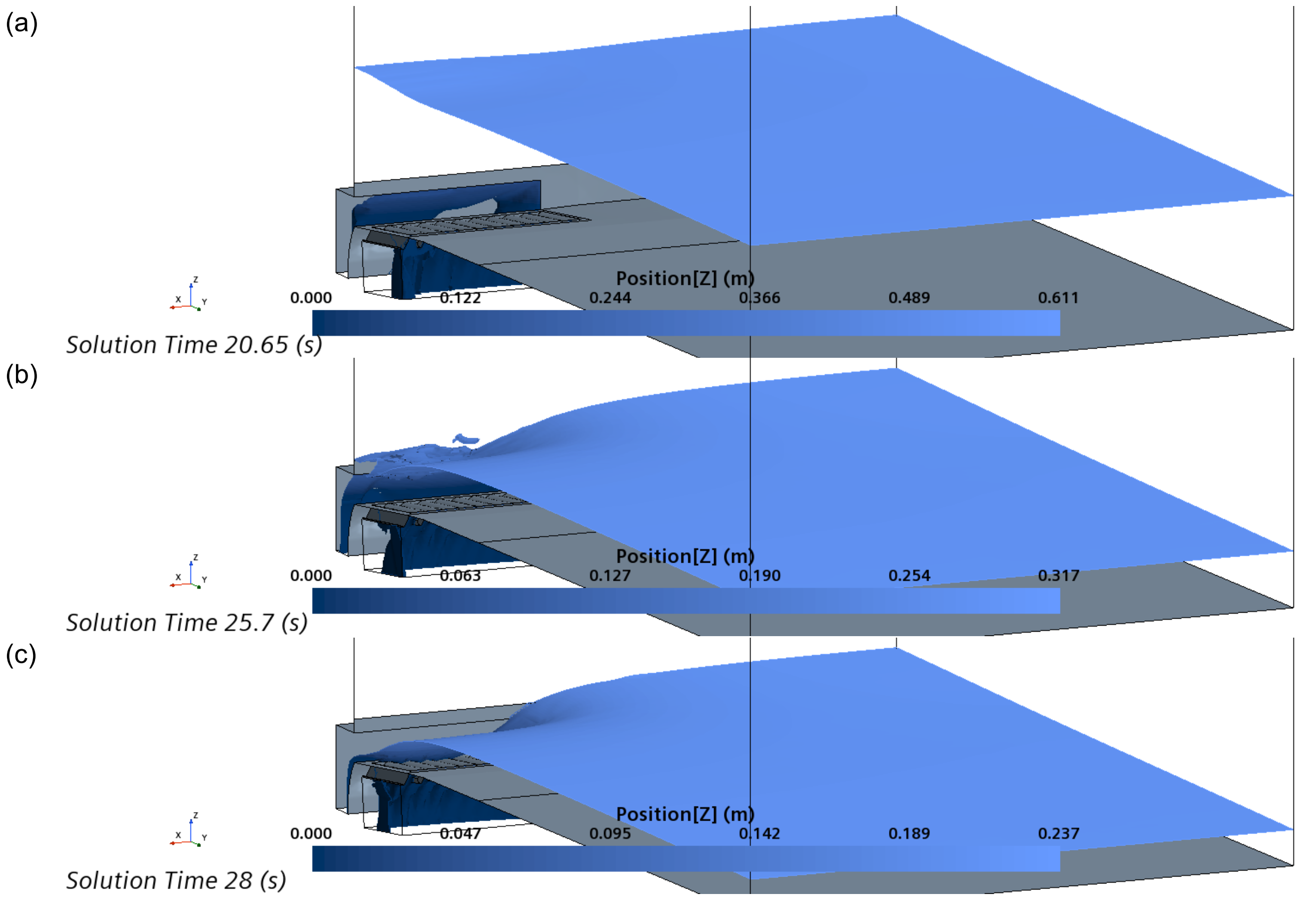

Figure 3. Water surface elevation for a model with a combination inlet, (a) orifice flow condition for both grate and window, (b) curb opening operates as a weir, grate is overtopped, (c) grate and curb opening act as weirs.

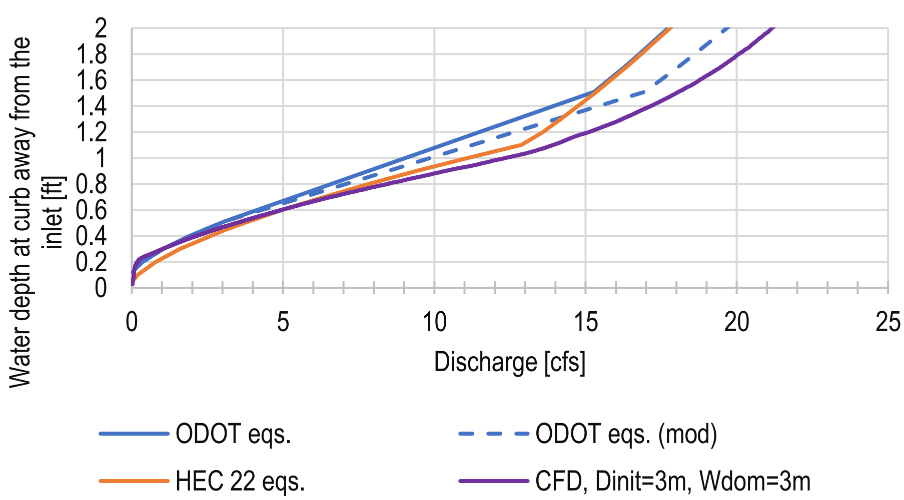

Figure 4. Combination inlet. Depth of the ponding water vs. discharge in sump conditions (Dinit – initial water depth measured from the lowest point in the gutter, Wdom – domain width from the roadside edge of grate).

Figure 4 shows a combination of plots of water depth at curb away from the inlet vs. discharge through the combination inlet obtained from CFD, ODOT equations and HEC 22 equations. If the flow is in weir flow regime, the three estimates are in good agreement. A comparison between the computational results and calculations for orifice flow, shows that for a combination inlet CFD gives greater discharge for a given water depth than the design equations. ODOT design calculations for orifice flow take a clear open area of a diagonal grate, equal to 1.45 ft^2 ("ODOT eqs." – solid blue line), which is smaller than the smallest open area of the vane grate, equal to 1.71 ft^2 ("ODOT eqs. (mod)" – dashed blue line). The modified ODOT eq. for orifice flow gives an estimate that is closer to the CFD results.

The study and CFD results indicate that the ODOT design procedure and HEC 22 procedures are adequate for more extreme events under sump conditions at sag locations. CFD results indicate that the ODOT and HEC 22 procedures are conservative by a significant margin under orifice flow condition that is likely to happen during more extreme rain events.

2: Computational Mechanics Research Support

Argonne Transportation Research and Analysis Computing Center (TRACC) computational mechanics staff ran nationwide videoconferences every other Thursday that were open to state Department of Transportation staff and university researchers supported by the Federal Highway Administration or state DOTs. The videoconferences provide a venue to discuss approaches and issues related to hydraulics modeling projects. Topics during this reporting period included, but were not limited to:

- new methodologies of scour modeling,
- approaches to modeling and mitigating hydroplaning risk,
- hydraulic analysis of catch basins.

3: Computing Support

Routine cluster maintenance including software and hardware upgrades, security patching against cyber threats, and development of custom tools to increase users' productivity. TRACC staff is currently working on upgrading the TRACC clusters to support the latest scientific and engineering software utilizing industry's best practice guidelines in Open-Source software and virtualization.

Anticipated work next quarter:

1: Computational Mechanics Research on a Variety of Projects

- development of a new methodology for riverbed scour
- hydraulic analysis of a catch basins
- analysis of water film thickness on pavements

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, scope and fiscal constraints set forth in the
agreement, along with recommended solutions to those problems).

None.