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

Quarter 4, October – November 2023

prepared by
M. Sitek, S. Lottes, H. Ley

Nuclear Science & Engineering Division, Argonne National Laboratory

January 2024

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. CFD Modeling of Infiltration from Ditches into Roadway Embankments

Road ditches are built along roadways to prevent accumulation of rain on the pavement. They intercept rainwater from the pavement as well as from the adjacent land. Water can move freely in a ditch away from the road surface, thus making the road safer for the vehicular traffic. South Carolina DOT expressed interest in studying infiltration of water from ditches into roadway embankments. As part of the current design criteria, it is recommended that the road sub-grades be one foot above the design high-water level to protect the pavement from water infiltrating soil and subgrade under the road from the ditches. The distance between the water surface and bottom of the subbase is referred to as "freeboard". This requirement is put in place to reduce the risk of pavement damage. With changes in roadway design standards, larger shoulders and flatter cross-slopes have moved ditches further out. The additional embankment width may warrant a smaller freeboard without risking negative effects to the subbase. Computational fluid dynamics (CFD) modeling was selected as a method of testing how water infiltrates from the ditch into the embankment and how far the percolating water can travel into the embankment, with the goal to assess if the freeboard and horizontal distance between the road and the ditch can be reduced. A typical cross section through a road, embankment and ditch is showed in Figure 1. Main elements of the design, such as travel lanes and shoulder were marked in the figure, along with the freeboard as defined earlier.

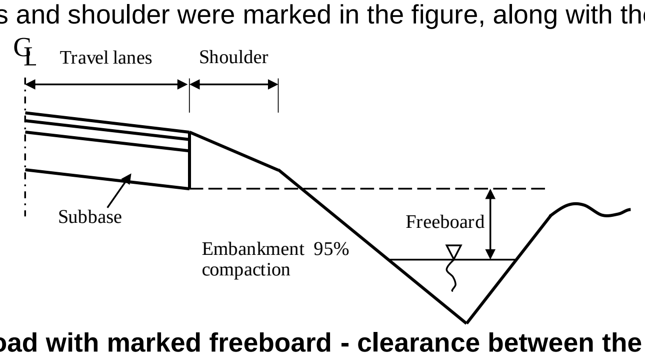

Figure 1. Typical section of a road with marked freeboard - clearance between the water free surface and bottom of the road subbase.

Road ditches are drainage elements with an almost constant cross-section and a longitudinal grade. In a case of rain events, which uniformly fill up the ditch, it can be assumed that the geometry and flow conditions are the same in each cross-section. Moreover, water infiltration and movement in soil is mostly parallel to the cross-section. Therefore, it was decided to represent a thin section of a full-size ditch with elements: (1) soil extending up to the subbase on one side and beyond the ditch on the other, (2) soil extending downwards by a distance that exceeds the extent of the percolating waterfront; and (3) a volume of air above it, big enough to capture the free water surface in the ditch.

An Eulerian Multiphase model with two phases: water and air, and Volume of Fluid approach to compute the interface between the two phases are selected for modeling the open channel flow. The unsteady Reynolds-Averaged Navier-Stokes solver is used with a two-layer realizable k-epsilon turbulence model to solve for the flow field. The water migration through the soil is solved for with the use of a porous media model that is characterized by porosity and viscous and inertial resistance; the latter two depending on the particle size and porosity of the soil. In this study it is assumed that the soil particles are uniform in size and shape. The front and back surface of the model are a free-slip (symmetry) boundaries, and all of the side surfaces are pressure outlet boundaries that allow for the air and water phases to leave the computational domain.

The analysis accounts for a set of parameters, such as: the size of soil particles, soil porosity, moisture, as well as the distance from the water surface in the ditch to the bottom of the subbase. The shoulder width is 4 ft, with slope 12.5:1; and the embankment and ditch slopes are 4:1.

Figures 2, 3 and 4 illustrate examples of how the water infiltration changes over time (from an hour to 18 hours) , porosity (40% vs 5%), and water table close to the bottom of the ditch. The color contour plots show the volume fraction of water, and the velocity vectors show the direction of the water and air movement in the soil volume.

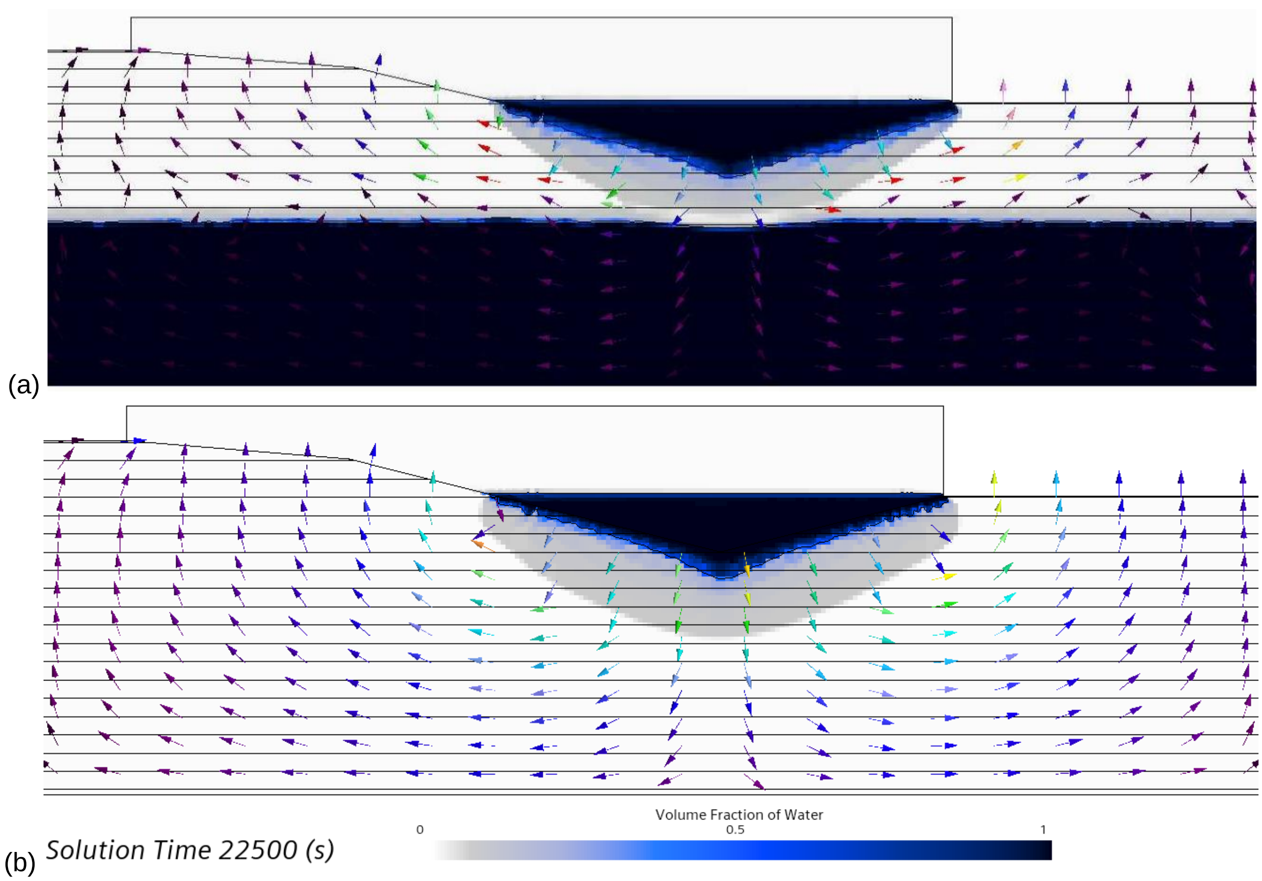

Figure 2. Water extent after 6.25 hours of simulated time in the model (a) with underground water table close to the ditch bottom and (b) with no water table in its vicinity. Initial moisture content in the ground is zero.

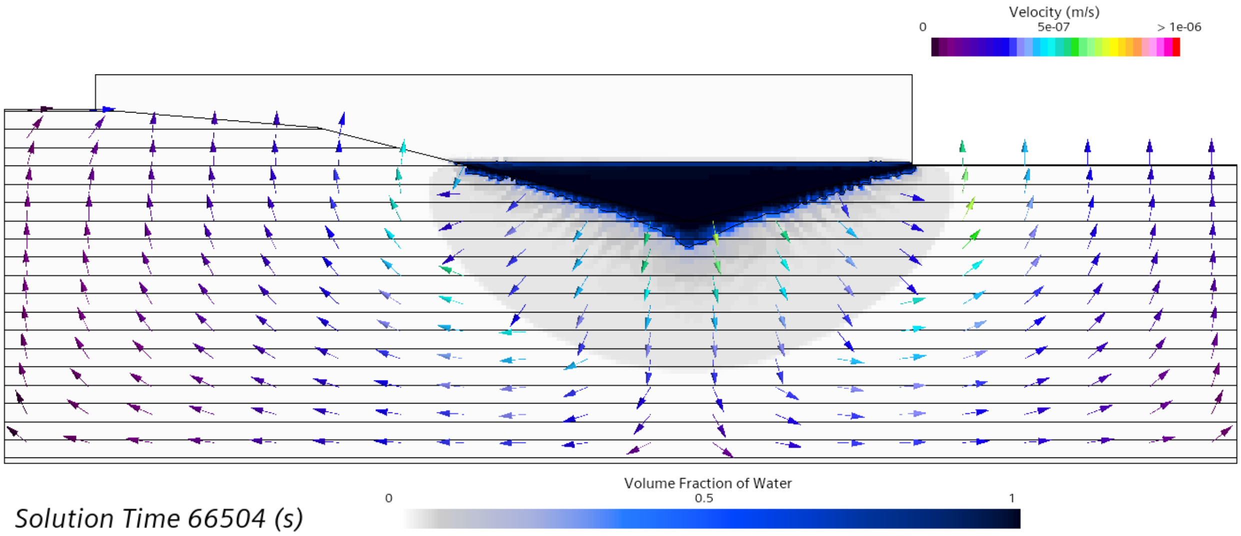

Figure 3. Water extent at ~18.5 hours of simulated time in the model without the water table.

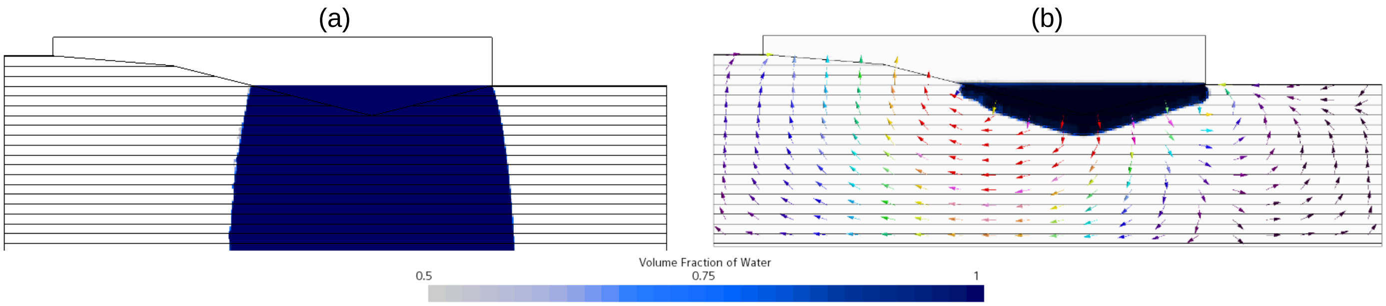

Figure 4. Water extent at 1 hour of simulated time in the model with (a) 40% porosity, and (b) 5% porosity.

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.