

# Parallel large-eddy simulation of scour around an abutment in a channel with a floodplain: A Stanford-Singapore Partnership proposal

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## 1 Overview

This project aims to synthesize laboratory-scale studies with a parallel large-eddy simulation sediment transport solver to gain a fundamental understanding of the mechanisms that govern clear-water scour around an abutment in a channel with a floodplain. In particular, we hope to answer how the interaction of the main channel flow with the floodplain affects the equilibrium scour depth. The study will involve implementation of existing sediment transport models and numerical techniques into a parallel Navier-Stokes solver in order to obtain high-resolution computations of the velocity, sediment, and shear stress distributions around different abutment and channel configurations and compare the results to laboratory-scale data.

The project will involve one Ph.D. student from NTU who will spend half of the project time working with the simulation code at Stanford University under Professor Fringer, who specializes in parallel computations, and the rest of the time performing production runs and analyzing and verifying simulation data at NTU under Professor Lim, who specializes in laboratory-scale scouring experiments.

## 2 Brief background for proposed work

Sediment at the bed of a body of water does not erode as long as the shear stress imposed by the overlying flow is lower than some critical value. When an obstruction is added to the bed, such as a bridge pier or an abutment, the flowfield adjusts to accommodate it and elevates the shear stress around the obstruction, leading to erosion. For a fixed set of flow conditions, erosion, or scouring, continues until the shear stress falls and reduces the Shields parameter below its critical value, resulting in an equilibrium condition. An understanding of this equilibrium condition is crucial to the design of water-bound structures in order to determine the depth at which the structural foundation must be built beneath the bed.

Professor Lim has performed a host of laboratory experiments to determine the equilibrium clear-water scour depth for idealized abutments [1, 2] as well as abutments in floodplains [3]. For the latter, three experiments were performed in a laboratory-scale idealized floodplain using an Acoustic Doppler Velocimeter to obtain the velocity distribution around an abutment in the floodplain. Velocity distributions were obtained in a plane perpendicular to the flow direction in order to determine a time-history of the velocity field over the course of the development of the scour hole. It was found that the velocity fields varied substantially over the course of the development of the scour hole. Based on his results, we propose to perform high-resolution numerical simulations to obtain three-dimensional velocity fields around an abutment using the following numerical tools.

## 3 Numerical tools

### 3.1 Large-eddy simulation codes

The Environmental Fluid Mechanics Laboratory (EFML) at Stanford University has considerable experience with direct numerical and large-eddy simulations of laboratory-scale environmental flows. Our simulations employ the method developed by Zang *et al.* [4], in which the Boussinesq equations of motion are solved on a curvilinear coordinate non-staggered grid. The equations are discretized in time using a fractional step approximate projection method and the pressure field is solved using the multigrid method. Members of the EFML have used this method along with a large-eddy simulation for subgrid and subfilter scale motions [5] to study a host of three-dimensional flows. Calhoun *et al.* [6] studied turbulent stratified flow over a wavy bed, while Ding *et al.* [7] studied the internal wave motions induced by a three-dimensional hill, and Fringer and Street [8] studied the fundamental physics of breaking interfacial waves. Zedler and Street [9] implemented the code to study sediment transport over ripples. Under an ONR grant, they are currently implementing the immersed boundary method (IBM) of Tseng and Ferziger [10] in order to study erosion rates around mines. The IBM method is ideally suited to studying erosion problems because it provides for a seamless method to implement moving boundaries into a complex LES code, such as that of Zang *et al.* [4]. Instead of moving the actual grid, the IBM method moves the boundary and effectively adds forcing terms to the Navier-Stokes equations so as to satisfy the time-varying boundary conditions.

### 3.2 Parallel computation

The Environmental Fluid Mechanics Laboratory also has extensive experience with parallel flow solvers and parallel computing. Fringer *et al.* [11] are in the process of developing a parallel coastal ocean model to simulate internal wave dynamics in Monterey Bay, California, and Mamala Bay, Hawaii. This model employs parallel unstructured adaptive grids to solve the nonhydrostatic Boussinesq equations with a large-eddy simulation for the resolved motions. Cui and Street [12] adapted the large-eddy simulation solver of Zang *et al.* [4] to simulate laboratory-scale rotating stratified flows using MPI, the message passing interface, on parallel computers. That code was 41% faster than the next comparable code on the

NASA IBM SP-2 [13]. We have the ability to use the code on-site in our laboratory with the use of our Beowulf parallel computing cluster at the Peter A. McCuen Environmental Computing Center. Currently, the cluster consists of 40 Compaq/Alpha 667 MHz CPUs with a total of 24 Gb of RAM and a 2 Gigabit Myrinet interconnect. The cluster is currently capable of performing simulations with  $256^3$  computation cells, and we are constantly updating and expanding it to accommodate improved architectures and programming methodologies.

## 4 Proposed Work

Zedler and Street [9] are in the process of implementing an IBM module into the code of Cui [12], and they are likely to be finished by mid-2004. Since their sediment modules do not employ varying grain size distributions or the effects of cohesive sediments, a natural avenue for code development is to implement cohesive and grain size distribution modules into the parallel code.

Once these modules are implemented, the focus of the work would be to first simulate the already existing experiments of Lim and Nugroho [3] to develop three-dimensional flowfields to add to the findings for scour around an abutment in a floodplain. These initial simulations would serve as verification of the performance of the simulation code. Subsequent simulations would then involve studies of other parameters, such as floodplain geometry, that would otherwise be too difficult to perform in the laboratory.

### 4.1 Timeline of proposed work

The work would involve one Ph.D. student who would work towards the completion of his or her doctoral dissertation at Nanyang Technological University in Singapore, under the direction of Professor Lim as the student's principal advisor, and Professor Oliver Fringer, the student's co-advisor.

- Year one: Stanford University
  - Learn how to use and implement the parallel solver.
  - Run simulations of laboratory-scale scour problems to verify the implementation.
  - Begin implementation of cohesive and grain-size models.
- Year two: Nanyang Technological University
  - Run simulations of laboratory-scale scour problems to study the effects of a pre-determined parameter space. Compare to laboratory-scale simulations.
  - Continue cohesive and grain-size model implementation.
- Year three: Nanyang Technological University
  - Complete implementation of cohesive and grain-size models.
  - Run simulations of laboratory-scale problems to verify new implementations.
  - Write up dissertation.

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