Seismic Soil-Structure Interaction Analysis of the Kealakaha Stream Bridge on Parallel Computers

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Introduction

The Hawaii Department of Transportation is planning on constructing a new bridge on the Mamalahoa Highway over the Kealakaha stream, Island of Hawaii. The three-span prestressed concrete bridge depicted in Fig. 1 will be designed to withstand the anticipated seismic activity, which is particularly important because of the very high seismic activity in the Island of Hawaii. In the UH Civil and Environmental Engineering Department, there is an ongoing research project on soil-structure interaction modeling of the Kealakaha Bridge. The research team was faced with a computational model that is beyond the capability of a single-CPU machine as the model contains an extensive soil region in the vicinity of the bridge to accurately represent the seismic response of the bridge-soil system. The main objective of the current study is to develop a parallel computational framework for large-scale seismic soil-structure interaction analysis that can be used on commonly available clusters.
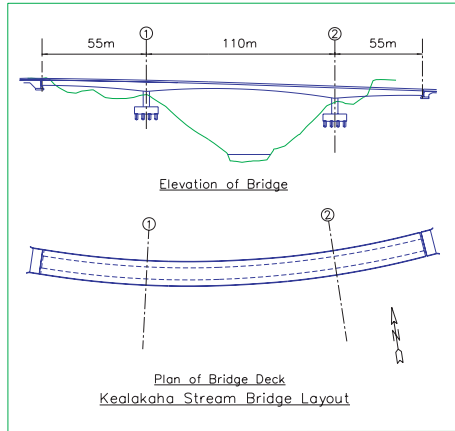

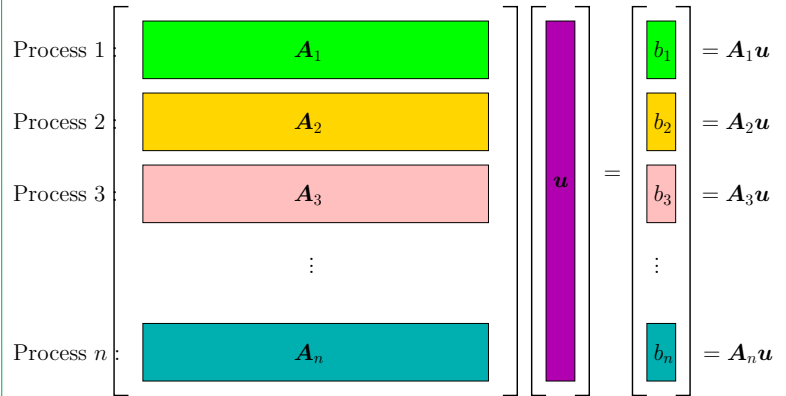Figure 1. Layout of the Kealakaha Stream Bridge

Figure 2. Compressed sparse row format for parallel matrix-vector multiplication

Parallel Computational Framework

We used the central difference method to solve the time-dependent equations of motion thus avoiding solving linear equations. The classical viscous absorbing boundary condition (ABC) was used to approximately simulate the unbounded extent of the soil region. It was recognized that matrix-vector multiplication is the most intensive part of the computation, and so our effort was concentrated on this aspect of implementation in parallelizing the code. We partition a matrix-vector multiplication $\boldsymbol{Au} = \boldsymbol{b}$ as depicted in Fig. 2. Since matrices are

sparse, the compressed sparse row format is used where process i contains only the non-zero entries of $\boldsymbol{A}_i$. In the MPI-based computational procedure, first $\boldsymbol{u}$ is broadcast and $\boldsymbol{A}_i\boldsymbol{u} \equiv \boldsymbol{b}_i$ is computed on each slave process. Then the result is sent to the master process, where $\boldsymbol{b}$ is obtained by assembling the results from all processes. The Squall system at MHPCC was used for computations.

Computational Model and Numerical Results

In the computational model shown in Fig. 3, the soil consists of three layers and a relatively large buffer region denoted as the scattered field was used to help the viscous ABC absorb outgoing waves. 5376 solid and 56 frame finite elements were used to discretize the model. To satisfy the stability criterion, $\Delta t = 2 \times 10^{-5}$ s was used, which necessitated undergoing 1.5 million time steps for the response analysis due to a 30 second-long earthquake recorded at the Pahala station on the Island of Hawaii. It took about 4 hours and 30 minutes on the Squall using 16 processors. Fig. 4. displays the displacement amplitude contour on the soil region at a few different time instants. Propagation of waves from the interior to the outer edge of the domain is clearly seen.
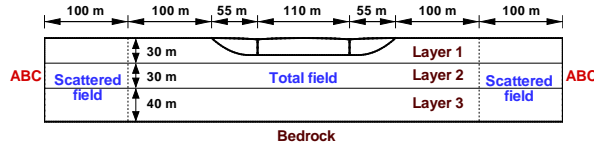

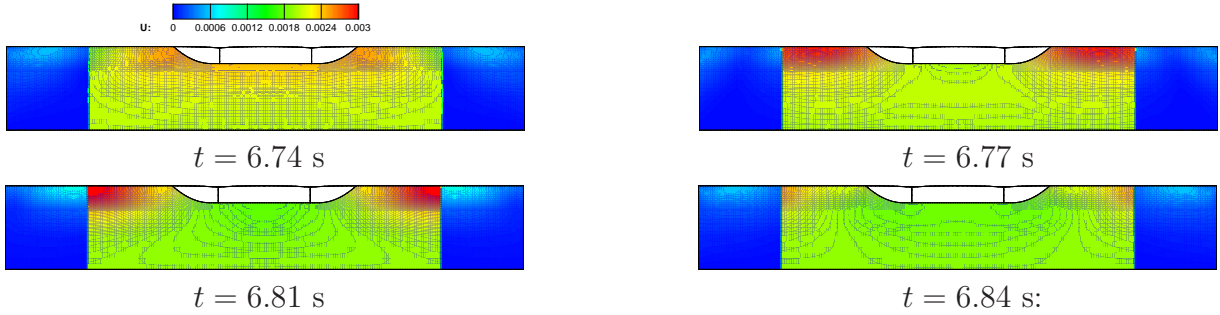Figure 3. Computational model of the bridge-soil system

$t = 6.74$ s

$t = 6.77$ s

$t = 6.81$ s

$t = 6.84$ s:

Figure 4. Displacement amplitude contour

Conclusions

In this work we have established a computational framework for large-scale soil-structure interaction analysis. In the future, we would like to consider a 3D model of the bridge-soil system using a more efficient parallel implementation.

Acknowledgments