Thesis Title: Robust Hybrid Simulation with Improved Fidelity: Theory, Methodology and Implementation

Abstract: Civil engineers of today have been charged with the task of providing resilient and sustainable infrastructure designs, and to use those for establishing resilient communities. To achieve this mission, improved designs, new materials, and efficient retrofit strategies are being introduced around the world. Before many of these techniques are used in the real world, experiments will be needed to demonstrate their performance. Efficient methods are needed to evaluate the performance of those innovations through high fidelity experimentation. Hybrid simulation is an integrated, numerical-experimental method that combines the benefits of simulation with component-level experiments. In hybrid simulation, the structural components which are difficult to model are constructed physically (named the experimental substructure) while the rest of the structure is computationally modeled in a simulation (named the numerical substructure). During hybrid simulation, the boundary condition information between the numerical substructure and experimental substructure is exchanged at each numerical substructure integration step. In this dissertation, robust solutions to the challenges associated with this powerful numerical-experimental method are considered.

The objective of this dissertation is to advance the state of the art in hybrid simulation. First, a robust platform for real time hybrid simulation is developed that considers the complex interactions between various components of the physical-computational system. The platform includes: 1) a robust integrated actuator control algorithm for accurate boundary condition synchronization between numerical and experimental substructures under random noise, and 2) a modified Runge Kutta integration algorithm to improve the accuracy of the numerical integration with computation delay due to the sequential loading. Next, to improve the fidelity of hybrid simulations that contain numerical elements that are similar to the physical specimen, online system identification is integrated into hybrid simulation. Hybrid simulation with model updating is demonstrated numerically and experimentally, and different classes of structural models are investigated. The improvement in hybrid simulation fidelity is illustrated through the model updating performance as well as a global assessment by comparing to the shake table test results.