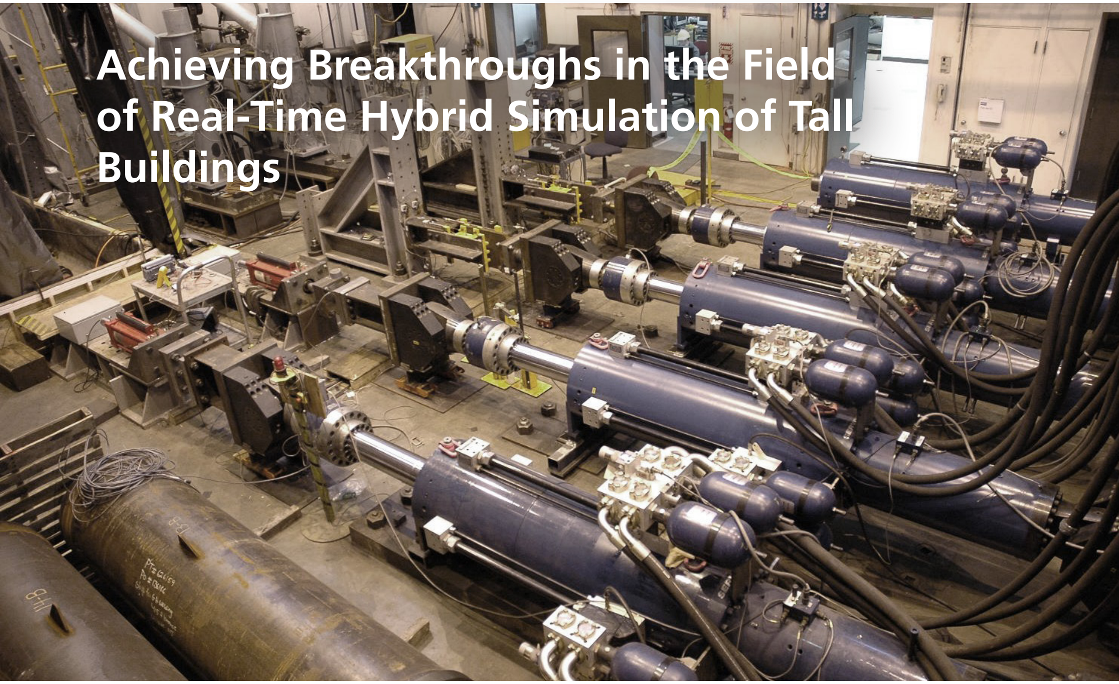
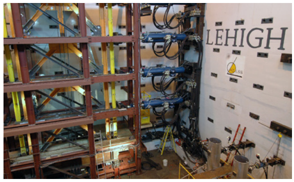
Lehigh University



Achieving Breakthroughs in the Field of Real-Time Hybrid Simulation of Tall Buildings

speedgoat
real-time simulation and testing

In collaboration with Servotest, Natural Hazards Engineering Research Infrastructure (NHERI) Experimental Facility (EF) at Lehigh University has developed a MATLAB® and Simulink® based algorithm and deployed it to Speedgoat hardware to perform real-time hybrid simulations of tall buildings excited by wind or seismic forces.



Funded by NSF, the NHERI Lehigh EF is a world-class, open-access facility that enables researchers to address fundamental research questions linked to the challenge of community resilience.

The facility's experimental resources provide means to conduct research mitigating the impact of natural hazards, including earthquakes and wind on structures.

Lehigh University is one of the top facilities in the world for performing large-scale multi-directional real-time hybrid simulations, combining physical experiments with computer-based simulations for evaluating the performance of large-scale components and systems.

That one may create the desired link between physical experiments and computer-based simulations, Thomas Marullo, NHERI Lehigh research scientist at Lehigh with

Speedgoat and Servotest Systems at NHERI Lehigh RTMD Experimental Facility

Servotest designed the Integrated Control and Pulsar Digital Control System around SCRAMNet to establish flexible outer loop control which is essential for the implementation of cutting-edge real-time hybrid simulation algorithms using Simulink Real-time Target systems.

Real-Time Hybrid Simulation with HybridFEM-MH

In a real-time hybrid simulation, structural systems are divided into experimental (physical) and analytical (numerical) substructures. The physical substructure describes all components that cannot be modeled numerically with the desired accuracy, while the numerical substructure entails all remaining non-physical components of the entire system.

The dynamic response of the complete hybrid system is simulated by integrating the equations of motion in real-time using a direct integration algorithm. Explicit integration algorithms with unconditional stability and controllable numerical damping are preferred. There are two main factors for this: they do not necessitate iteration to satisfy equilibrium, and the numerical damping can eliminate any spurious participation of high-frequency modes.

To integrate the equations of motion requires knowledge of the analytical and experimental substructures' restoring forces at the end of each time step of a simulation. The restoring forces of the analytical substructure are obtained numerically from a state determination process, while those of the experimental substructure are measured physically, all in real-time. In order to obtain the solution for these time steps correctly, the NHERI Lehigh team required a deterministic real-time computation environment.

Over the last ten years, they have developed algorithms and implemented them into the program HybridFEM-MH[1], facilitating nonlinear structural Finite Element Analysis (FEA) in the Simulink® environment. These computations are performed using the Simulink Real-Time software in Speedgoat real-time hardware.

Project Development and Future Endeavors

In combination with Servotest's hydraulic actuators and Pulsar digital control system, which facilitates real-time links to Lehigh's MATLAB/Simulink development through Speedgoat hardware, the team was able to accelerate the development and implementation of its real-time computational capabilities and real-time adaptive control of servo-hydraulic actuators and advanced damping systems.

In 2012, the team reached the limits of their real-time numerical modeling to create analytical substructures and to integrate the equations of motion in real-time, and therefore purchased a second Performance real-time target machine. This enabled the NHERI Lehigh EF to implement parallel processing between target machines.

In order to pursue highly complex 3D real-time hybrid simulations involving both earthquakes and wind hazards, the NHERI Lehigh EF invested in another Performance real-time target machine with the latest multi-core

CPU technology. The team then went on to perform numerous 3D real-time hybrid simulations of a 40-story tall building outfitted with nonlinear fluid viscous dampers, leveraging the capabilities of the Speedgoat hardware.

In addition, they expanded the capabilities of the NHERI Lehigh EF by creating the Lehigh Real-time Cyber-Physical Structural Systems Laboratory, a reduced laboratory with MTS 244 servo-hydraulic actuators, along with Tolomatic RSA electric actuators that is dedicated to conducting cyber-physical, structure-related systems research.

With the success of the Servotest digital control system, Lehigh purchased a second system to control both the MTS and Tolomatic actuators, creating a combination of simultaneous hydraulic and electric actuator control.

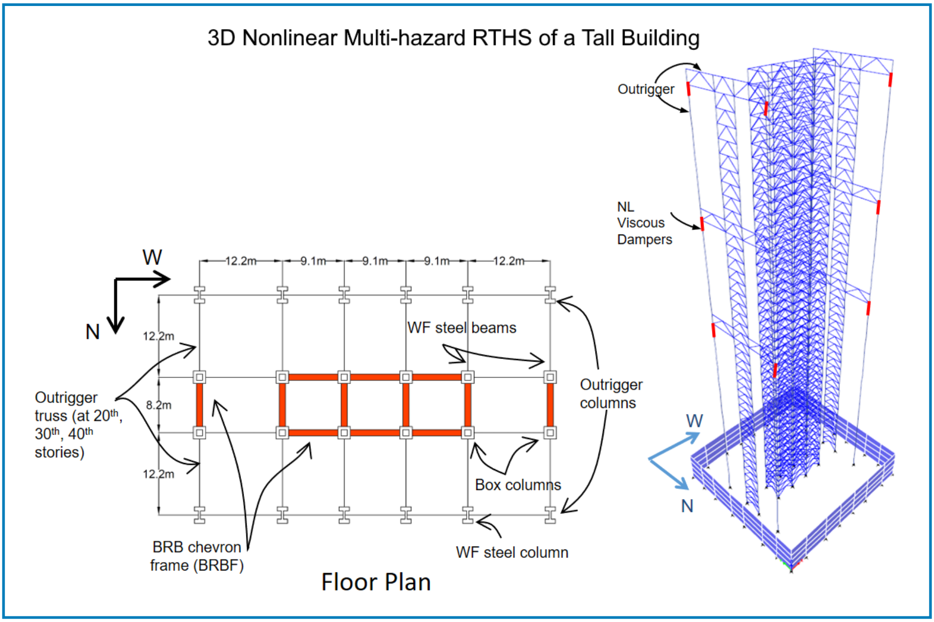
Even though the field of real-time hybrid simulation is still in its infancy, this project marks a breakthrough for the field by combining established understandings of physical systems through real-time nonlinear FEA with direct sensor feedback and command outputs to physical components.

> "Solutions from Speedgoat have been pivotal towards the success of complex real-time hybrid simulations at the NHERI Lehigh Experimental Facility."

Thomas M. Marullo, NHERI Lehigh Research Scientist at Lehigh University

The NHERI Lehigh EF team, lead by Dr. Liang Cao, NHERI Lehigh research scientist, and their colleagues at Servotest plan to take this workflow further by expanding the cyber-physical capabilities of the facility with a shake table and large capacity soil-structure interaction test infrastructure.

Leveraging machine learning with online model updating algorithms implemented into Simulink, the NHERI Lehigh EF plans to expand its numerical modeling capabilities of real-time FEA to facilitate simulations of much larger and more complex systems and their components.



[1]Kolay, C., Marullo, T. and J. Ricles, "HybridFEM-MH: A Program for Nonlinear Dynamic Analysis and Real-Time Hybrid Simulation of Civil Infrastructure Systems Subject to Multi-Hazards," ATLSS Report No. 18-06, ATLSS Engineering Research Center, Lehigh University, Bethlehem, PA, 2018.

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