NHERI Lehigh EF Laboratory Demonstration

Multi-directional Nonlinear Real-time Hybrid Simulations of a Tall Building With Damped Outriggers Subjected to Multi-Natural Hazards

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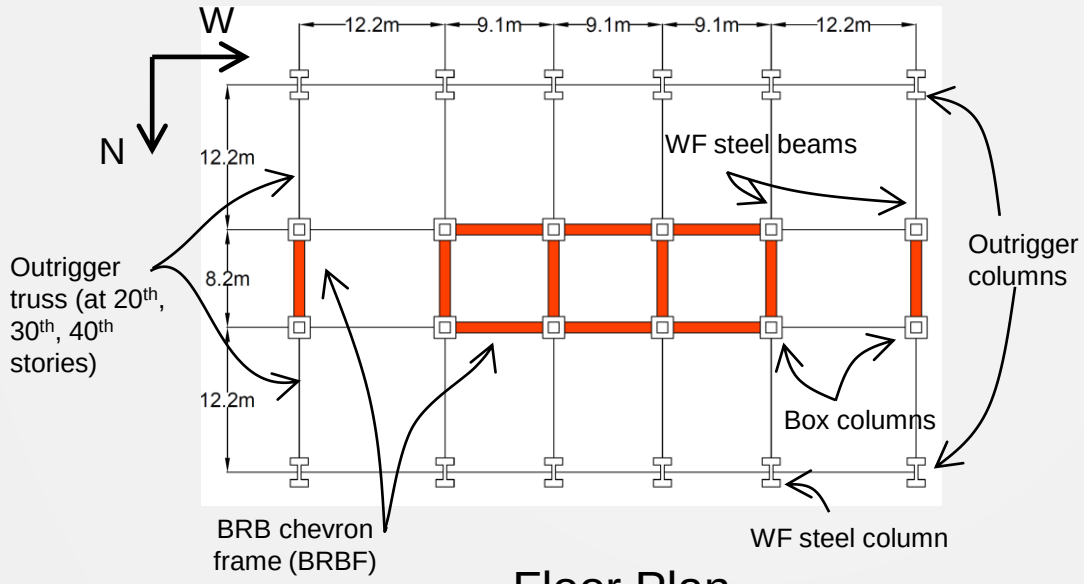
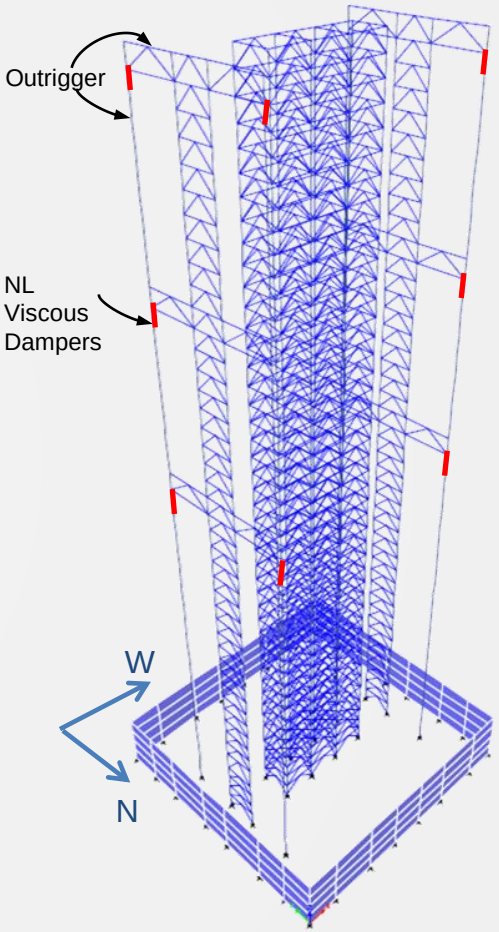
Tall Building Subject to Multi-hazards

- 40-story (+4 basement) BRBF building in Los Angeles designed by SGH[(1)] for PEER Tall Building Initiative case studies – BRBFs with Outriggers
- Objectives of study
  - Improve performance using nonlinear fluid viscous dampers with outriggers
  - Assess performance of structure under multi-hazards using RTHS.



Floor Plan



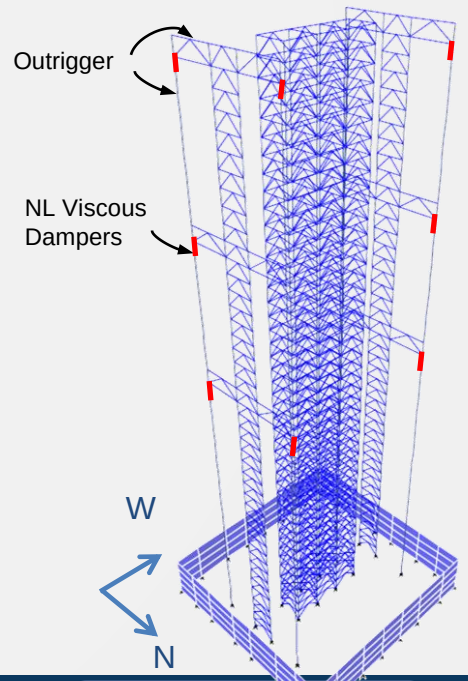
(1) Moehle et al., PEER 2011/05

Al-Subaihawi, S., Kolay, C., Thomas Marullo, Ricles, J. M. and S. E. Quiel, "Assessment of Wind-Induced Vibration Mitigation in a Tall Building with Damped Outriggers Using Real-time Hybrid Simulations," *Engineering Structures*, 205, https://doi.org/10.1016/j.engstruct.2019.110044, 2020.

Kolay, C., Al-Subaihawi, S., Thomas Marullo, Ricles, J. M. and S. E. Quiel, "Multi-Hazard Real-Time Hybrid Simulation of a Tall Building with Damped Outriggers," *International Journal of Lifecycle Performance Engineering*, Vol. 4, Nos. 1/2/3, pp.103–132, https://doi.org/10.1504/IJLCPE.2020.10893, 2020.

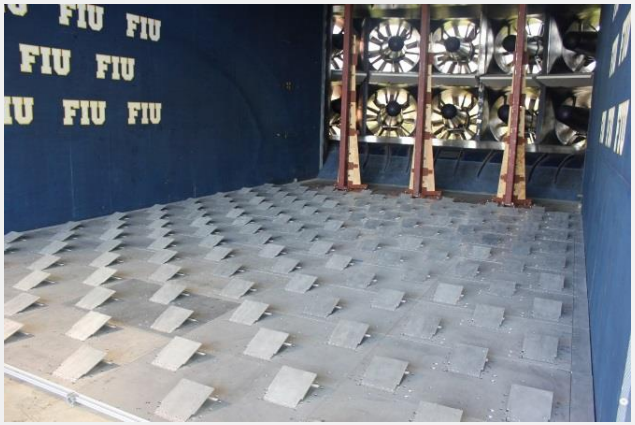
Multi-Hazard 3-D Nonlinear RTHS of Tall Building – EQ & Wind

- Bidirectional EQ ground motions
  - 1989 Loma Prieta EQ – Saratoga Aloha Ave Station scaled to MCE (2500 year return period) hazard level
- Bidirectional wind loading
  - Wind speed of 110 mph, 700 MRI
  - Exposure B



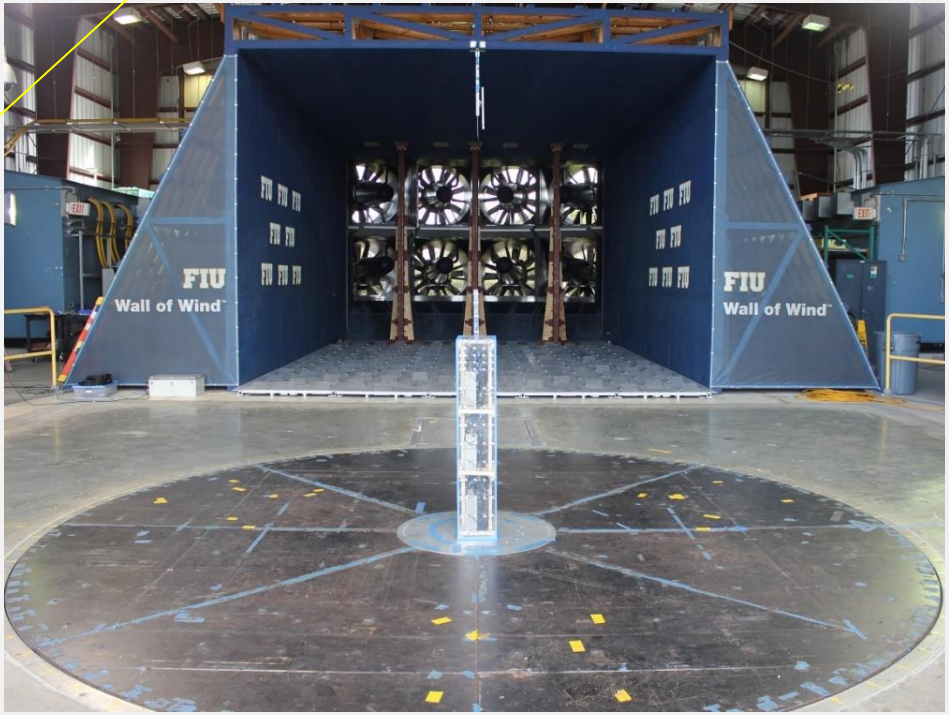
Wind Loading
Aerodynamic Wind Testing @ FIU WOW

- Aerodynamic wind testing at the NHERI FIU WOW to obtain wind pressure time histories distributed on the building.

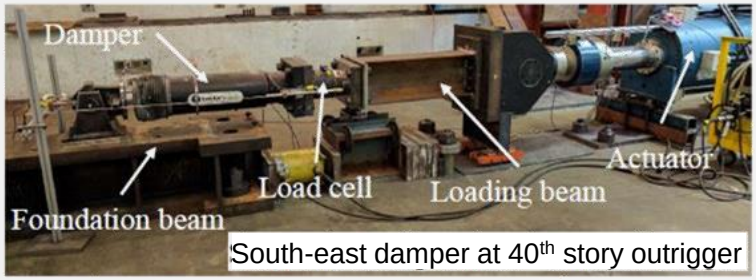


Courtesy: Amal Elawady
and Arindam Chowdhury, FIU

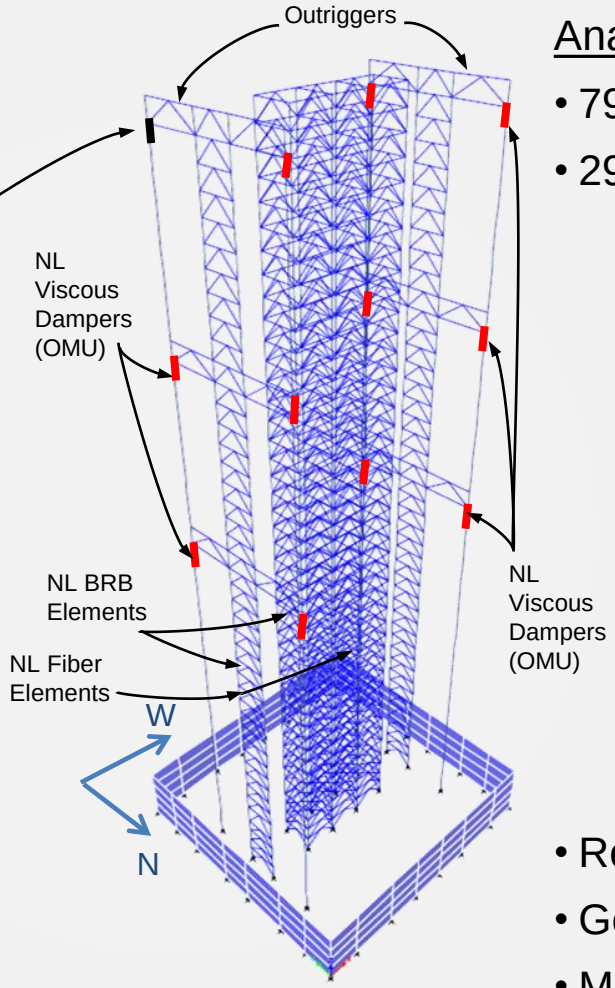
336 total number of
pressure taps



RTHS Substructures: Tall Building Subjected to Multi-Natural Hazards



Experimental Substructure – NL Fluid Viscous Damper



Analytical Substructure

Analytical Sub. Key features:

- 7902 DOF
- 2974 Elements
  - 2411 Nonlinear Explicit Force-based fiber elements
  - 11 Nonlinear Explicit Maxwell Elements(1,2) with real-time on-line model updating (dampers placed in each outrigger at 20th, 30th, & 40th floors)
  - 552 Nonlinear truss elements
- Reduced Order Modeling
- Geometric nonlinearities
- Mass
- Inherent damping of building

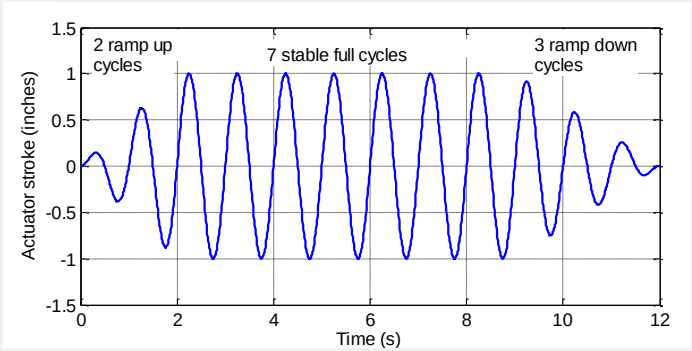
(1) Al-Subaihawi, S. (2022). *Real-time Hybrid Simulation of Complex Structural Systems Subject to Multi-Hazards*. PhD Dissertation, CEE Dept., Lehigh University.

(2) Al-Subaihawi, S., Ricles, J., and S. Quiel. "Online Explicit Model Updating of Nonlinear Viscous Damper for Real Time Hybrid Simulation," *Earthquake Engineering and Soil Dynamics*, Vol. 154, https://doi.org/10.1016/j.soildyn.2021.107108, 2022.

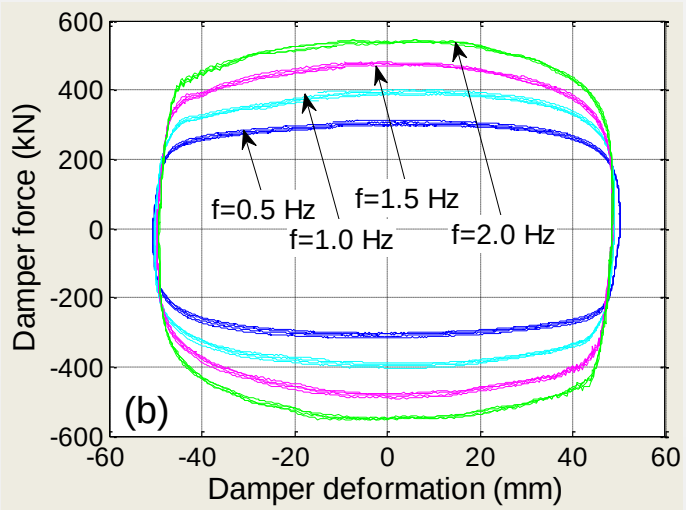
Full-Scale Nonlinear Viscous Dampers

Characterization testing

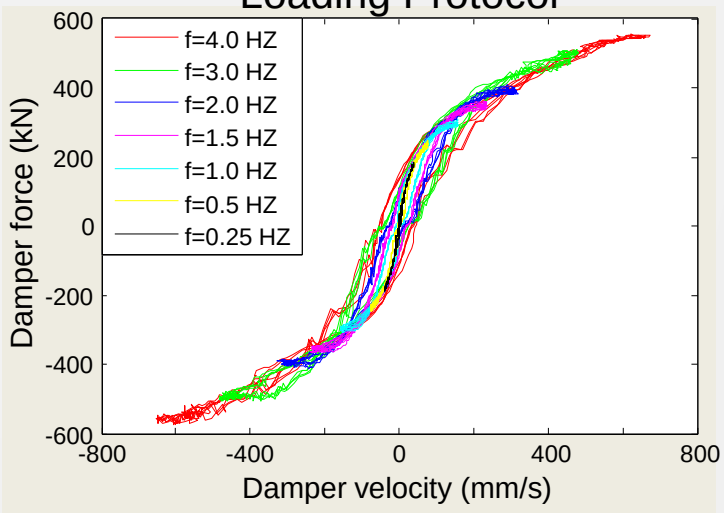
Damper testbed



Loading Protocol



Damper force - deformation



Damper force - velocity