Probabilistic Functional Recovery Assessment of RC Wall Buildings with Force-Limiting Connections

Sena Mursel

Lehigh University

sem419@lehigh.edu

Georgios Tsampras

University of California San Diego

gtsampras@ucsd.edu

C. Franco Mayorga

University of California San Diego

cfmayorg@ucsd.edu

Paolo Bocchini

Lehigh University

paolo.bocchini@lehigh.edu

Post-earthquake building performance is increasingly judged not only by life safety, but by how quickly and reliably a facility can regain functionality. Recent earthquakes have repeatedly shown that buildings can remain structurally stable yet experience prolonged downtime due to nonstructural damage, system outages, and recovery impediments. Force-Limiting Connections (FLCs) have been proposed as a resilience-focused technology to control force transfer and damage concentration, but their influence on functional recovery outcomes and especially on the variability and tail risk of recovery has not been comprehensively quantified within a probabilistic framework.

This study proposes a probabilistic functional recovery assessment framework and applies it to a reinforced-concrete building system with conventional rigid-elastic (RE) connections and an alternative configuration incorporating force-limiting connections (FLCs). The framework combines nonlinear time-history structural analyses to capture global response measures under suites of earthquake records across multiple hazard levels with a surrogate mapping that translates global shaking intensity measures

and building attributes into the floor-level intensity measures required for component fragility assessment. These demands are then propagated through a PBEE-based recovery engine that simulates component damage, repair actions, sequencing and interdependencies, workforce allocation constraints, and impeding factors. The result is an ensemble of building-level functionality trajectories representing the stochastic evolution of usable occupancy over time. Building performance is evaluated using distribution-aware recovery metrics, including percentile recovery curves, probabilistic functionality curves, downtime exceedance relationships for target functionality thresholds, variability-based measures that capture predictability, and decompositions that attribute delays to administrative impediments versus physical repairs.

Results indicate that FLC-equipped systems exhibit improved functional recovery performance relative to conventional configurations, not only by accelerating typical recovery trajectories but also by narrowing the spread of outcomes and reducing the likelihood of prolonged downtime. The probabilistic metrics reveal differences that are not apparent from mean recovery curves alone, highlighting the importance of characterizing tail behavior and recovery reliability when comparing alternative designs. In addition, downtime decomposition suggests that as physical repair demands are reduced through improved seismic response, non-technical impediments can become dominant constraints on timely recovery. Overall, the proposed framework provides a transparent, decision-oriented basis for evaluating building systems against functional recovery objectives, enabling design comparisons that explicitly account for uncertainty, variability, and recovery bottlenecks.