Seismic Behavior, Analysis and Design of Complex Wall Systems

A *Small-Group* Research Project Funded through the NSF NEES Research Program

The Research Team

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  - Graduate and Undergraduate Researchers
- University of Illinois
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- External Advisory Panel
  - Ron Klemencic and John Hooper, Magnusson Klemencic Associates
  - Andrew Taylor, KPFF Consulting Engineers
  - Neil Hawkins, Professor Emeritus, University of Illinois

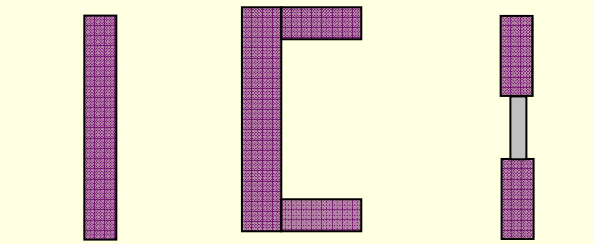
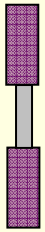
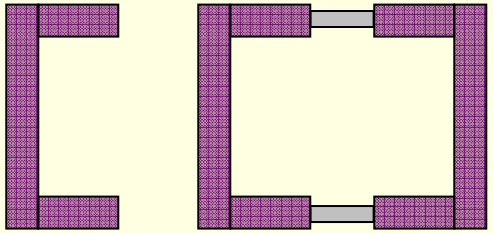
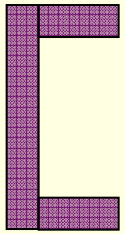
Project Basics

- Research Objectives:
  - Improve understanding of the seismic behavior of complex reinforced concrete walls including soil-structure interaction and develop tools to enable performance-based seismic design of these components.
- Project Scope:
  - Experimental investigation of slender walls with complex configurations using the UIUC MUST-SIM NEES facility.
  - Development of numerical models and modeling recommendations to enable simulation of the seismic response of buildings with walls, including foundation flexibility.
  - Development of damage-prediction models and performance-based design recommendations
- Project Funding and Duration: $1.5 million over 4 years

Seismic Behavior of Walls

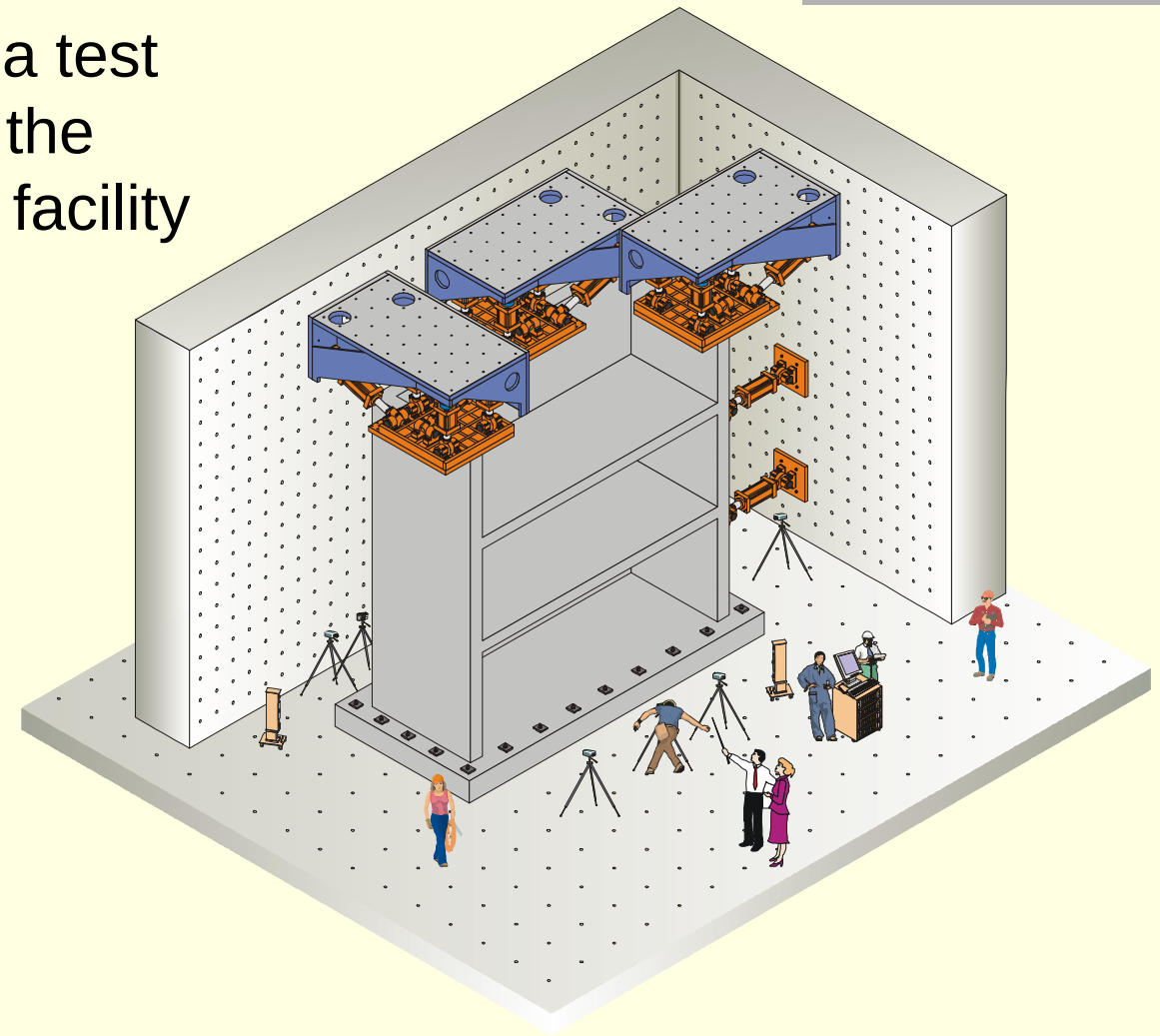
- Laboratory testing of wall sub-assemblages to generate data to support development of
  - Numerical models for use by practicing engineers to predict load and deformation demands on walls with realistic foundation boundary conditions,
  - Numerical models for behavior of structural concrete,
  - Performance-prediction models for use in design.
- Experimental testing to be conducted using the UIUC NEES facility. This facility enables
  - Testing of wall sub-assemblages with realistic configurations at moderate scales (~1/3)
  - Simulation of the load distribution that develops in the critical region at the base of the wall in buildings of moderate height.
  - Testing of representative foundation boundary conditions.
  - High-resolution measurement of the specimen displacement and strain fields.

Experimental Test Program

	Moment Gradient	SSI Boundary Conditions	Load History
Unidirectional Loading	 Planar (2) Flanged Coupled		
Bidirectional Loading	 Core-Wall System		

Laboratory Test Specimens

- Depiction of a test specimen in the UIUC NEES facility



Analysis of Wall Systems

- Develop recommendations for the use of simple, elastic, effective-stiffness models for performance-based design of walls.
- Develop recommendations for the use of simplified nonlinear models for performance-based design.
- Develop sophisticated nonlinear continuum models that can be used for design of special structures as well as to investigate the impact of design parameters and load history on performance.
- Develop nonlinear macroscopic models for use in simulating pile and spread-footing foundations.

Performance-Based Design Tools

- Quantify the uncertainty with which the simplified simulation models predict wall demand.
- Identify repair-specific performance states for slender wall systems.
- Develop probabilistic models linking structural performance with predicted demand.

	PS One	PS Two	PS Three	PS Four
Damage	Hairline cracking	Cracking and minimal spalling	Substantial spalling	On-set of bar buckling
Representative Damage Pattern				
Repair	No repair	Epoxy inject cracks and patch concrete	Remove and recast concrete	Replace concrete and reinforcement

Integration of Analysis and Laboratory Experimentation

- Simulation to support design of the experimental test program:
  - Analyze two prototype buildings using standard analysis software and procedures to determine appropriate moment gradients and drift histories for the laboratory test specimens.
  - Analyze a range of foundation conditions for the prototype buildings to determine the foundation stiffness to be simulated in the laboratory.
  - Use state-of-the-art, nonlinear continuum models to finalize specimen design details and improve the likelihood that the desired failure mechanisms are simulated in the laboratory.
  - Use state-of-the-art nonlinear continuum models to determine the preferred layout for instrumentation.

Integration of Analysis and Laboratory Experimentation

- Using experimental data to develop and advance numerical models:
  - Instrumentation at the UIUC NEES facility enables measurement of the displacement of the specimen with relatively high-resolution over an extended region.
  - The tests are scheduled so that data from the first planar wall tests can be used to calibrate and validate models that will be used to finalize design of the wall specimens with more complex configurations.

Integration of Analysis and Design

- Perform parameter studies using numerical models to extend experimental data.
  - High-resolution, nonlinear simulation of wall behavior.
  - Simulation of nonlinear foundation response for both pile and spread-footing foundations.
  - Investigation of soil-structure interaction and the impact of this on wall performance.

Outreach to the Profession

- External advisory panel comprising primarily consulting engineers.
- Initial questionnaire has been distributed to practicing engineers across the United States to identify typical design parameters as well as issues of concern to structural engineers.
- Interactive website is in development that will enable practitioners to
  - Access research results of interest.
    - Results of the questionnaire
    - Simulation and performance-based design tools
  - Sign-up to receive e-mail announcement of project activities and new project deliverables.

Education and Community Outreach

- Exhibits for UW and UIUC Engineering Open Houses
  - Attended by members of the community including K-12 students.
  - For year one:
    - Small-scale models of the test specimens will be constructed for use in conjunction with a small-scale shake table at UW.
    - 1/5-scale models of the test specimens will be constructed for use with the small-scale model of the UIUC facility that includes a reaction structure, LBCB, instrumentation and data-acquisition system.
  - In subsequent years:
    - Exhibits will feature video of the experiments and results of numerical simulation

Education and Community Outreach

- Educational modules for use in undergraduate and graduate design classes that will include
  - Summary of research results.
  - Lecture materials, homework assignments and analysis projects to emphasize modeling techniques for use in design as well as application of performance-based design tools.
- Interactive website to disseminate research results to earthquake engineering educators and students.