International Research (Project No.: 30W-04)

Project name: Tuned Hybrid Systems for Resilient Seismic Building Performance
同調ハイブリッド構造システムによるレジリエントな耐震性能の実現
Principal Investigator: Larry Fahnestock
Affiliation: University of Illinois at Urbana-Champaign
Name of DPRI collaborative researcher: Masahiro Kurata
Research period: June 1, 2018 ~ May 31, 2020
Research location: Kyoto University, Hokkaido University, University of Illinois at Urbana-Champaign, Lehigh University, Oregon State University
Number of participants in the collaborative research: 10 total (DPRI staff: 1, non-DPRI staff: 9)

- Collaborators: (6 total) Masahiro Kurata, Taichiro Okazaki, Larry Fahnestock, James Ricles, Richard Sause, Barbara Simpson
- Number of graduate students: 4 total (Master students: 2, Doctor students: 2)
- Participation role of graduate students: preliminary structural analysis, design and experimental planning

Anticipated impact for research and education

This fundamental intellectual and practical impact of this research will be a novel building structural system with enhanced seismic resilience. This system is intended to reduce structural and non-structural damage by controlling drift and acceleration response so that buildings will remain functional even after a large earthquake. The international engagement of faculty and graduate students from multiple U.S. and Japanese universities and research labs is providing unique opportunities for innovation, technical exchange and education of students.

Research report

(1) Purpose

This funding supported the initiation of a major international collaborative research program between three U.S. universities, two Japanese universities and two major research labs (E-Defense and the ATLSS Center). The team is developing a novel tuned hybrid steel frame-spine lateral-force-resisting system with force-limiting connections to control multi-modal seismic response and protect a building from damaging lateral drift and accelerations, providing resilient structural and non-structural building performance. This economical seismic-resilient system will be particularly valuable for essential facilities, such as hospitals, where damage to buildings and contents, and occupant injuries, must be prevented. Full-scale 3D testing will provide fundamental system-level response data and support advancements in computational modeling.

The DPRI grant provided seed funding for collaborative planning and preliminary studies in support of a major proposal to the U.S. National Science Foundation. This 3-year project “Collaborative Research: Frame-Spine System with Force-Limiting Connections for Low-Damage Seismic Resilient Buildings” was funded starting August 1, 2019. The cumulative funding for this project between the University of Illinois at Urbana-Champaign, Lehigh University and Oregon State University is $1,324,056. The DPRI funding largely supported travel for the U.S. researchers to visit Japan for collaboration meetings, and even though the DPRI funding is concluding, the U.S.-Japan team will continue to work closely over the next few years as the joint project progresses.

(2) Summary of research progress

Significant collaboration and technical exchange have occurred over the duration of this DPRI-funded project. In particular, the following in-person meetings have been essential working sessions for the international team:

- Collaboration meetings, November 27-28, 2018, E-Defense and DPRI (travel funded by this DPRI grant).

- Collaboration meetings, February 7-8, 2019, E-Defense as part of the NHERI/E-Defense 2nd Joint Research Planning Meeting (travel of U.S. participants funded by the U.S. National Science Foundation).
- Collaboration meetings, September 18-19, 2019, Osaka (travel funded by this DPRI grant).
- Collaboration meetings, December 4-6, 2019, E-Defense and Kobe as part of the NHERI/E-Defense 3rd Joint Research Planning Meeting (travel of U.S. participants partially funded by DPRI and the U.S. National Science Foundation).

During the time period of the grant, the team has been working extensively on experimental planning for the tests to be conducted at E-Defense. These tests will be conducted in partnership with the Japanese project, Enhancement of Resilience for Tokyo Metropolitan Area, funded by NIED and the Ministry of Education, Culture, Sports, Science and Technology (MEXT). A steel and protective systems team (led by Kurata) is focusing on Holistic Assessment of Seismic Damage in Medical Facilities, including shake table tests of two (linked) full-scale steel special moment-resisting frame buildings (one base isolated) at E-Defense. Investigation of the new frame-spine system is directly integrated with this steel and protective systems team. The objective for study of the new frame-spine system is to provide fundamental system-level response data and support advancements in computational modeling.

Numerical simulations and parametric studies have been conducted to evaluate potential input ground motions, predict structural response and design the test structure and fixtures. The 3-story base-isolated special moment-resisting frame building from the Tokyo Metropolitan project will be used as the base building for the present project. Simulations by the team demonstrated that the 3-story building did not possess the appropriate dynamic properties, so a new 4th story has been designed and will be added to the top of the building. Spine elements and force-limiting connections (FLC) have been designed, and prototype FLC tests have been conducted at the ATLSS Center. Clevis base connection details for attaching the building and spines to the E-Defense shake table have been designed and a lifting system has been designed for moving the building in the E-Defense lab.

(3) Summary of research findings

Although the research project is in progress and full conclusions and outcomes are to be determined in the future, the accomplishments to date include:

- Linear and nonlinear static and dynamic response evaluation of 3-story and 4-story moment frame buildings with and without spines to determine target structural properties suitable for full-scale shake table testing.
- Nonlinear dynamic response evaluation of test building to determine favorable input ground motions for testing at E-Defense.
- Design of a new added story for the test building at E-Defense.
- Design of new base fixture details for the test building at E-Defense.
- Design of a lifting system for moving the test building at E-Defense.
- Design and full-scale testing of force-limiting connection prototypes at the ATLSS Center.

(4) Publications of research findings

The research project is currently intensively planning for full-scale shake table testing at the E-Defense lab in December 2020, so the team has not been at a stage for focusing on publications. On behalf of the team, a presentation about the project was given by the PI at the NHERI/E-Defense 3rd Joint Research Planning Meeting in December 2019. A paper about preliminary numerical simulations related to the project was submitted for presentation at the 17th World Conference on Earthquake Engineering, but this event has been postponed until 2021 and a decision has not been rendered yet.