International Research (Project No.: 2019W-03)

Project name: **Seismic Soil-Foundation-Structure Interaction in Unsaturated Soils**
Principal Investigator: Majid Ghayoomi
Affiliation: University of New Hampshire
Name of DPRI collaborative researcher: Ryosuke Uzuoka
Research period: June 1, 2019 ~ March 31, 2021
Research location: Disaster Prevention Research Institute and University of New Hampshire
Number of participants in the collaborative research: 4 (DPRI staff: 2 ,non-DPRI staff: 2)
- Number of graduate students: 1 (Master students: N/A, Doctor students: 1)
- Participation role of graduate students [Performing the experiments including centrifuge tests, running the data analyses, and writing papers and publications]

Anticipated impact for research and education

Soil-Foundation-Structure Interaction (SFSI) evaluates the collective seismic response of a system containing the superstructure, foundation, and surrounding soil given the earthquake motion at the ground surface. For SFSI analysis, regardless of the approach, surrounding soil plays a critical role, as it impacts both the site response and the motion transferred to the foundation. The behavior of unsaturated soil is complex and differs from dry and saturated soil deposits, because inter-particle suction stresses increase the effective stress and change the dynamic characteristics of soils. Despite the proven significant effects of degree of saturation on dynamic soil properties, current practice relies on procedures that do not directly include partially saturated soil conditions at system level; especially considering the seasonal and climatic-driven fluctuation of water table. Consequently, this uncertainty would be extremely critical in improving SFSI analysis procedures. The research and education initiatives in this project will advance the state of the art in design and performance assessment of both rocking foundations and column-yielding systems, especially under fluctuating water levels.

Research report

(1) Purpose

The project aims to study the effects of unsaturated soils and fluctuation of ground water level on seismic response of soil-foundation-structure systems.

(2) Summary of research progress

In this research, thus far, two series of centrifuge experiments have been performed. In the first set, the performance of a slender single-degree-of-freedom rocking shallow foundation embedded in sandy silt with varying groundwater table conditions was investigated. The tests included six successful target tests (dry, saturated, and partly saturated) out of ten trials and calibration tests. In partly saturated tests, water level was lowered from the soil surface by adjusting the drainage valves at the bottom of the laminar container and monitoring the pore pressure profile. Results from these tests were interpreted through the far-field response of the soil layer, kinematic and inertial effects, settlements, rocking effects at the footing level, soil stiffness and damping properties, and lateral earth pressure.

Given the complex nature of soil-foundation-structure interaction systems and to better understand the contrast in yielding soil-foundation versus yielding structure, the second set of centrifuge experiments was to investigate the performance of a more conventionally designed structure placed on variably saturated soil conditions. The same sample preparation and testing protocol were followed except with a different structural system. The system encapsulated structural fuses at the column base connections to isolate and guide the weak plastic sections. Results from these experiments were analyzed by examining the soil-foundation-structure parameters in comparison with the first set in addition to structural drift and bending moment and strains.

Due to COVID19-related travel restrictions the team could not complete the proposed project. Thus, the project will carry-over another year to test soil-foundation-structure response in clayey soils to better clarify the role of water retention the

extent of the SSI response.

(3) Summary of research findings

The data suggested that as the depth of the groundwater level increased the free-field soil and foundation settlements both decreased, regardless of input motion intensity. Also, by increasing the depth of the water level, the cumulative residual rotations decreased in rocking foundations and the seismic demand increased. Therefore, the importance of considering water table fluctuation in rocking isolated designs is important while lowering the water table elevation may reduce the foundation deformations when compared to both fully saturated and dry conditions but increase the demand on structure. Greater flexural drifts often resulted in higher recorded bending strains at the base of the columns in the instrumented structural fuse locations. This study highlighted the potential trade-offs of founding a structure on soil with variable water table depths. Shallow water table elevations give rise to greater deformations, in terms of settlements and rotations, and associated nonlinearity at the soil-foundation interface. Meanwhile greater water table depths lead to greater deformations, in terms of flexural drifts and bending strains, and associated nonlinearity in above-ground superstructure locations.

(4) Publications of research findings

The following publications are either prepared or under preparation as a result of this research:

Journal Papers:

- Turner, M.M., Ghayoomi, M., Ueda, K., Uzuoka, R. “Performance of Rocking Foundations on Unsaturated Soil Layer with Variable Groundwater Levels”, Geotechnique, Accepted and In-Press.
- Turner, M.M., Ghayoomi, M., Ueda, K., Uzuoka, R. “Soil-Foundation-Structure Interaction of Inelastic Structural Systems on Unsaturated Soil Layers”, ASCE Journal of Geotechnical and Geoenvironmental engineering, In preparation, to be submitted by 31/May/2021.

Conference Papers:

- Turner, M.M., Ghayoomi, M., Ueda, K., Uzuoka, R. “Centrifuge Modeling of Rocking Shallow Foundation on Variably Saturated Ground”, 20th International Conference on Soil Mechanics and Geotechnical Engineering, May 1-6, 2022, Sydney, Australia, Abstract Accepted, Paper draft due 1/Jun/2021.
- Turner, M.M., Ghayoomi, M., Ueda, K., Uzuoka, R. “Centrifuge Modeling of Seismic Response of Inelastic Structure Embedded in Unsaturated Soil”, Geocongress 2022, March 20-23, Charlotte, North Carolina, USA, Abstract Accepted, Paper draft due 11/Jun/2021.