# Liquefaction Experiments and Analysis Projects (LEAP)

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# What is LEAP?

- LEAP is an international collaboration to advance the state-of-the-art in analysis of liquefaction and its effects on civil infrastructure through:
  - high quality laboratory experiments
  - numerical simulations using state-of-the-art modeling techniques,
  - in-depth analysis of the experimental and numerical simulation results,
  - systematic documentation, archiving, and timely dissemination of the research results that can be used for the assessment, calibration, and validation of future constitutive models and numerical modeling techniques.

# Why a new validation project?

- In the past 25 years significant improvements have been achieved in centrifuge modeling: better shakers, in-flight measurements of soil properties, new sensor technologies, and new visualization techniques.

- A number of major new developments have also emerged in the fields of constitutive and numerical modeling. Several public domain and commercial software packages are available to conduct fully-coupled effective stress-based simulations using advanced constitutive models for soils.

- It is time to validate the tools that are available today and to generate high quality data that are needed for new modeling techniques that are being developed.

# Initial Stages of the LEAP development

- The idea of a collaborative research with aim of validation of constitutive and numerical modeling techniques used in analysis of liquefaction and its effects through centrifuge experiments was discussed among three US investigators (Kutter, Manzari, Zeghal) in a US NSF grantee conference in Boston in July 2011.
- The US team reached out to a few leading researchers around the world to discuss the initiation of an international collaboration. Professors Iai (KyU), Madabhushi (CU), Chen (ZJU) and Lee (NCU) along with their colleagues joined the US team to form the initial core of the research collaboration.

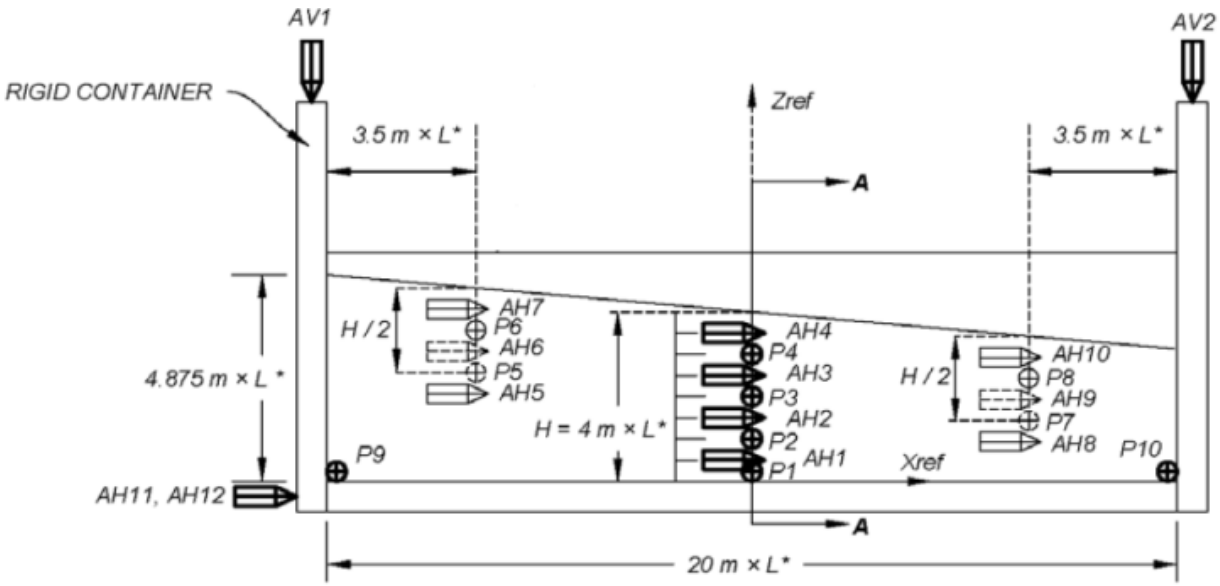
# VELACS-II workshop and LEAP-2014 session at 4th GEDMAR in Kyoto

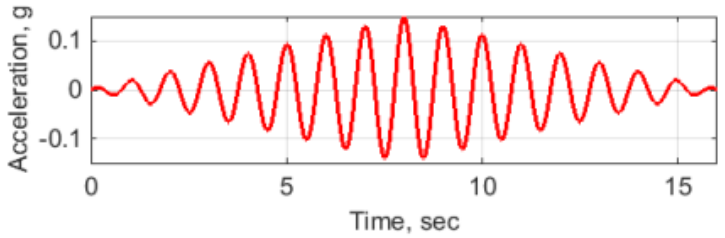
- In fall 2012, Professor Iai received a research grant to study the lateral spreading of Toyoura sand at Kyoto University. A number of Japanese and US researchers participated in a blind prediction exercise to simulate the results of the KyU tests.
- The first international workshop was held in January 2013 at KyU to discuss the experimental and numerical simulation results at the Kyoto workshop.
- Following the workshop, a number of participants met to discuss future collaborations and the acronym LEAP was coined by Prof. Ichii to capture the essence of the project.
- A subsequent LEAP session was held during the 4th GEDMAR conference in September 2014.

# US Planning Project (PLEAP or LEAP-2015):

- In August 2013, the US team received a research grant from the US NSF to conduct a **P**reliminary **LEAP** (**PLEAP**) and demonstrate the feasibility of an international collaboration aiming at validation of numerical modeling techniques using high quality laboratory tests on liquefiable soils.
- The initial core of LEAP collaborators (Cambridge Univ., George Washington Univ., Kyoto Univ., Rensselaer, UC Davis, and Zhejiang Univ.) selected Ottawa F-65 as the main soil for testing.
- Researchers at GWU performed a large number of laboratory tests to characterize the physical and mechanical properties of Ottawa F-65 sand
- The participating centrifuge teams conducted a preliminary set of tests to investigate the earthquake-induced lateral spreading of a mildly sloping ground.
- Five numerical simulation teams (Kyoto Univ., Univ. of Washington, Virginia Tech, California Division of Safety of Dams, and a practicing engineer) predicted the PLEAP centrifuge test results in a blind prediction exercise.

# PLEAP Centrifuge Experiment

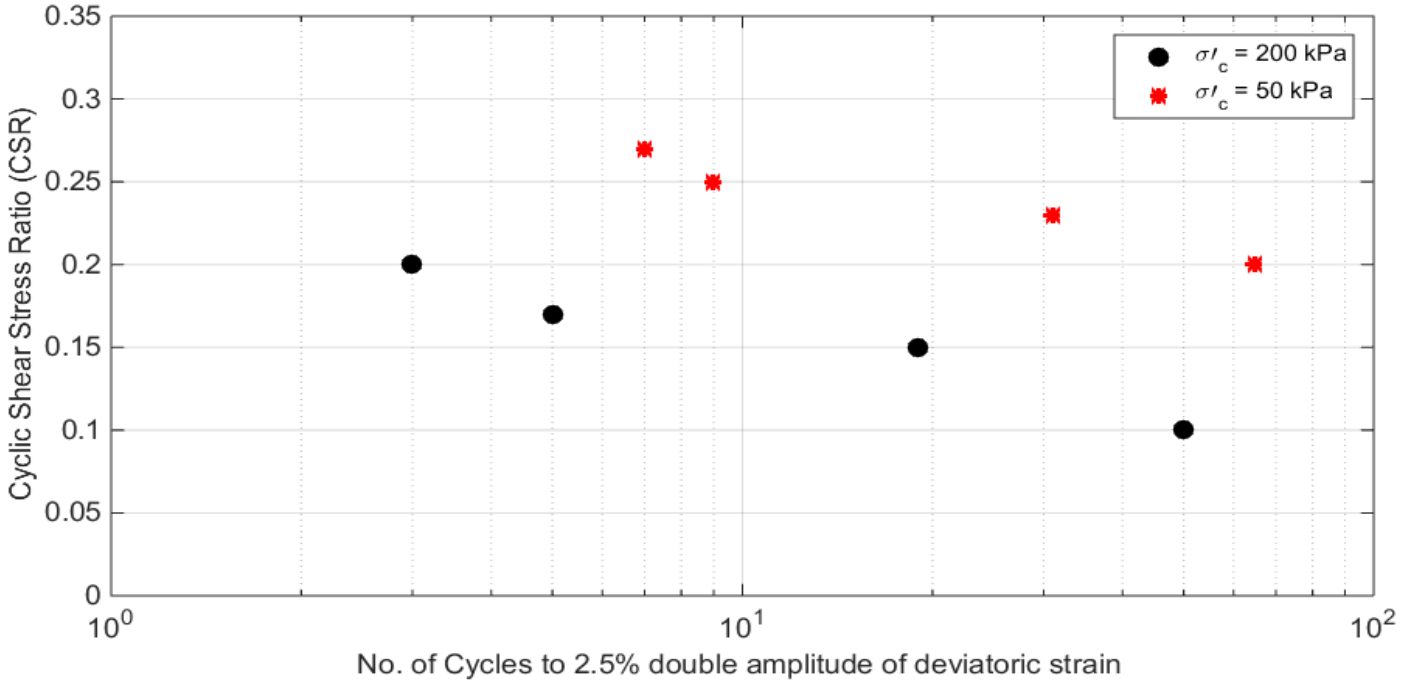



**1 Hz, Tapered Sine Wave**

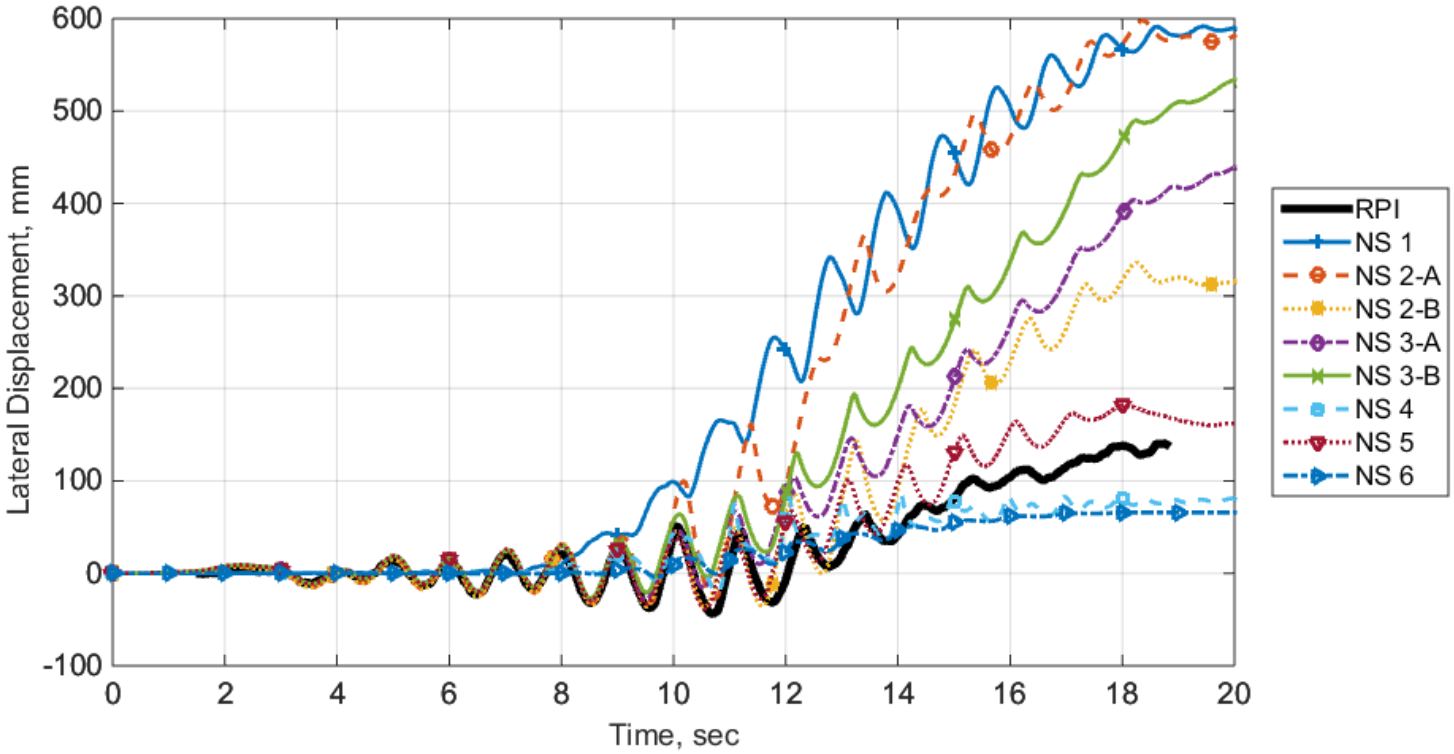
**Kutter et al. (2017)**

# Example of Element Tests conducted for PLEAP:




Cyclic undrained traixial tests conducted on Ottawa F-65 sand with an average initial density of 1658 kg/m$^3$ (Vasko, 2015).

# PLEAP Type-B Simulations :
# A sample comparison of numerical simulations with measured lateral displacement




Manzari et al. (2017)

# LEAP-GWU-2015 Workshop in Washington DC

# Documentation of LEAP-2015 project

- Special issue of JSDEE on LEAP-2015 project, SDEE, Sept. 2018:
  - Contains 16 papers discussing various aspects of the project

- Documentation of the soil characterization and laboratory element tests on Design-Safe:
  - Vasko, Andrew; ElGhoraiby, Mohamed; Manzari, Majid, (2018-10-12), "LEAP-GWU-2015 Laboratory Tests" , DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2TH7Q

# LEAP-2017: Repeatability, Variability, and Sensitivity

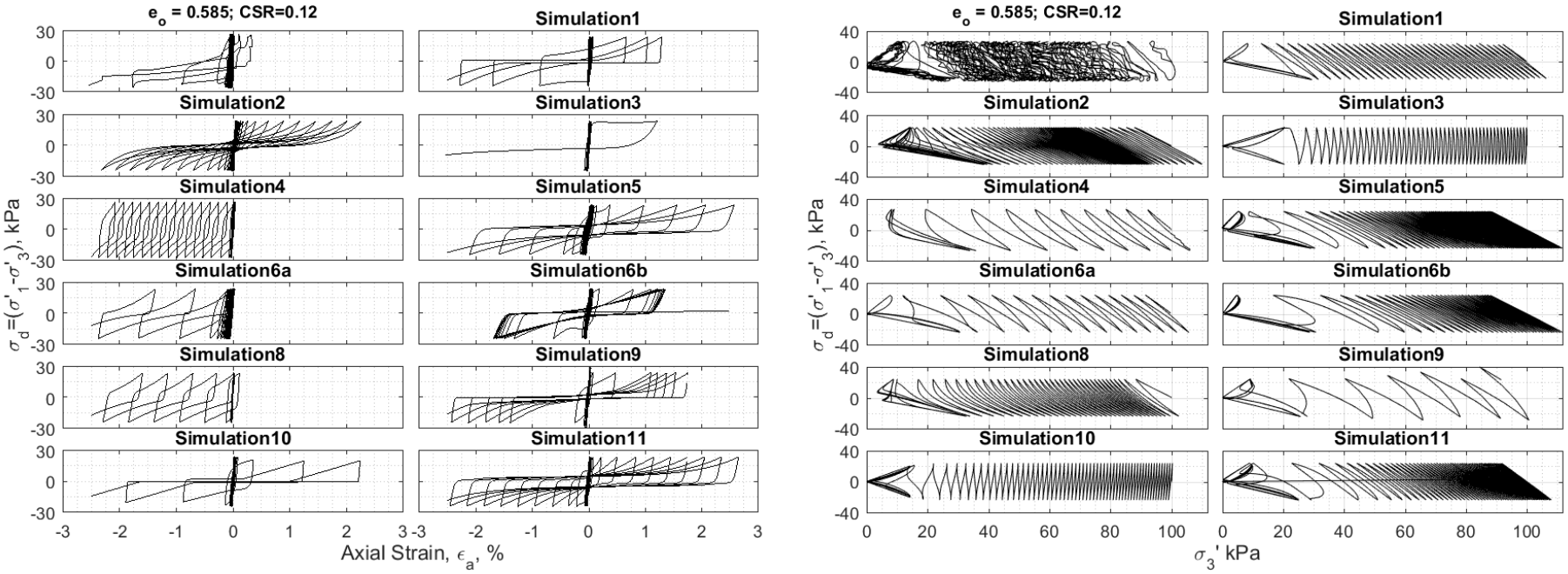
- The main goal of this project was to addresses the repeatability, variability, and sensitivity of centrifuge tests in modeling lateral spreading of mildly sloping liquefiable soils.
- A large number of additional soil characterization and laboratory element tests (cyclic stress-controlled on three different densities) were conducted to further characterize Ottawa F-65 sand.
- Over 24 centrifuge tests were conducted at 9 different centrifuge facilities around the world.
- 11 simulation teams submitted simulations of the element tests and type-B simulations of 9 selected centrifuge tests

# New features of LEAP-2017 project

- For the first time, sufficient number of experiments were conducted on the same test configuration to define the test-to-test and facility-facility variability of the centrifuge test data.

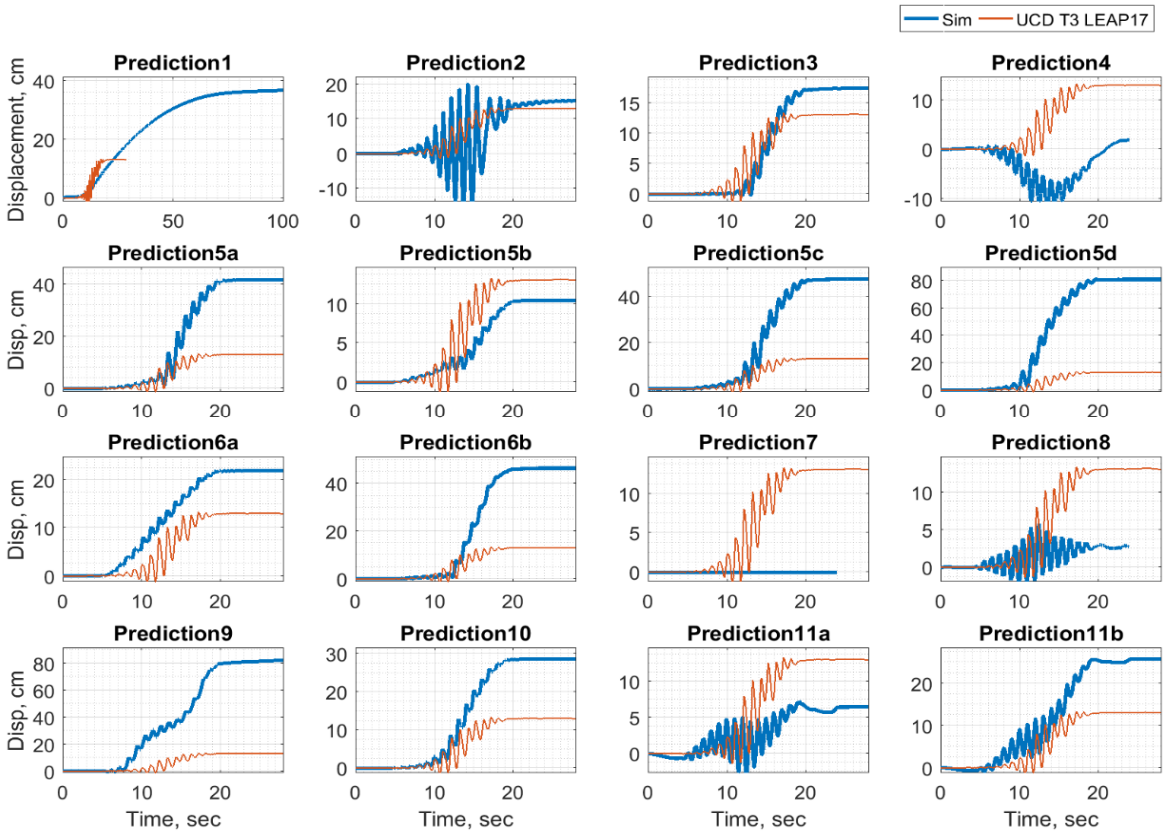
- The relatively large number of centrifuge tests allowed for defining a response surface and enabled an assessment of the sensitivity and variability of the tests.

# A sample comparison of the simulation of a cyclic triaxial test by various constitutive models




cyclic stress-controlled test on Ottawa F65 sand for $\rho_d$=1,666 kg/m$^3$, (e= 0.585, Dr~71.5%), $p'_0$=100 kPa, CSR=0.12.

# Sample comparison of Type-B simulations with centrifuge test results (UCD-3 test)



# Documentation of LEAP-2017 project

- The results of all the 24 centrifuge tests have been archived on DesignSafe:
  - Kutter et al. (2018-10-08), "LEAP-UCD-2017 Experiments (Liquefaction Experiments and Analysis Projects)", DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2N10S

- Details of the soil characterization and element tests have also been documented on DesignSafe:
  - El Ghoraiby et al. (2018-10-15), "LEAP-2017 GWU Laboratory Tests", DesignSafe-CI [publisher], Dataset, doi:10.17603/DS2210X.

- Proceedings of LEAP-UCD-2017 workshop will be published soon.

# LEAP-UCD-2017 workshop at Davis

# Concluding remarks

- Through an ongoing collaborative effort among researchers, LEAP projects have promoted in-depth analysis and thorough assessment of the predictive capabilities and limitations of the constitutive models and numerical simulation techniques that are currently available for analysis of soil liquefaction and its effects.
- The proceedings of the workshops at Kyoto University (VELACS-II, 2013, GEDMAR, 2014), GWU (2015), UC Davis (2017) projects have produced valuable literature on seismic response of mildly sloping liquefiable grounds.
- The LEAP-Asia-2019 workshop is a great opportunity to further extend these accomplishments.
- The next LEAP workshop (LEAP-RPI-2020) will be held at RPI.