Towards the Quantitative Validation and Uncertainty Quantification of Liquefiable Geosystems

Maziar Mivehchi[1], Katerina Ziotopoulou[1]

[1]*University of California, Davis*

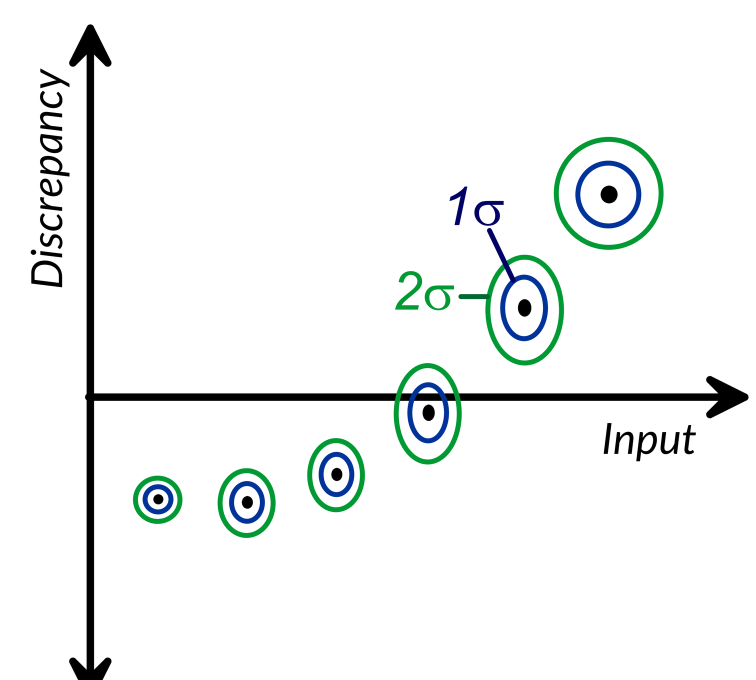
NHERI Natural Hazards Engineering Research Infrastructure

2024 NHERI Computational Symposium
February 1-2
Los Angeles, California

The first step towards **measuring the reliability** of numerical simulations for physical experiments and/or field-scale problems, is to develop a **validation metric** that can **quantify discrepancies**.

Introduction

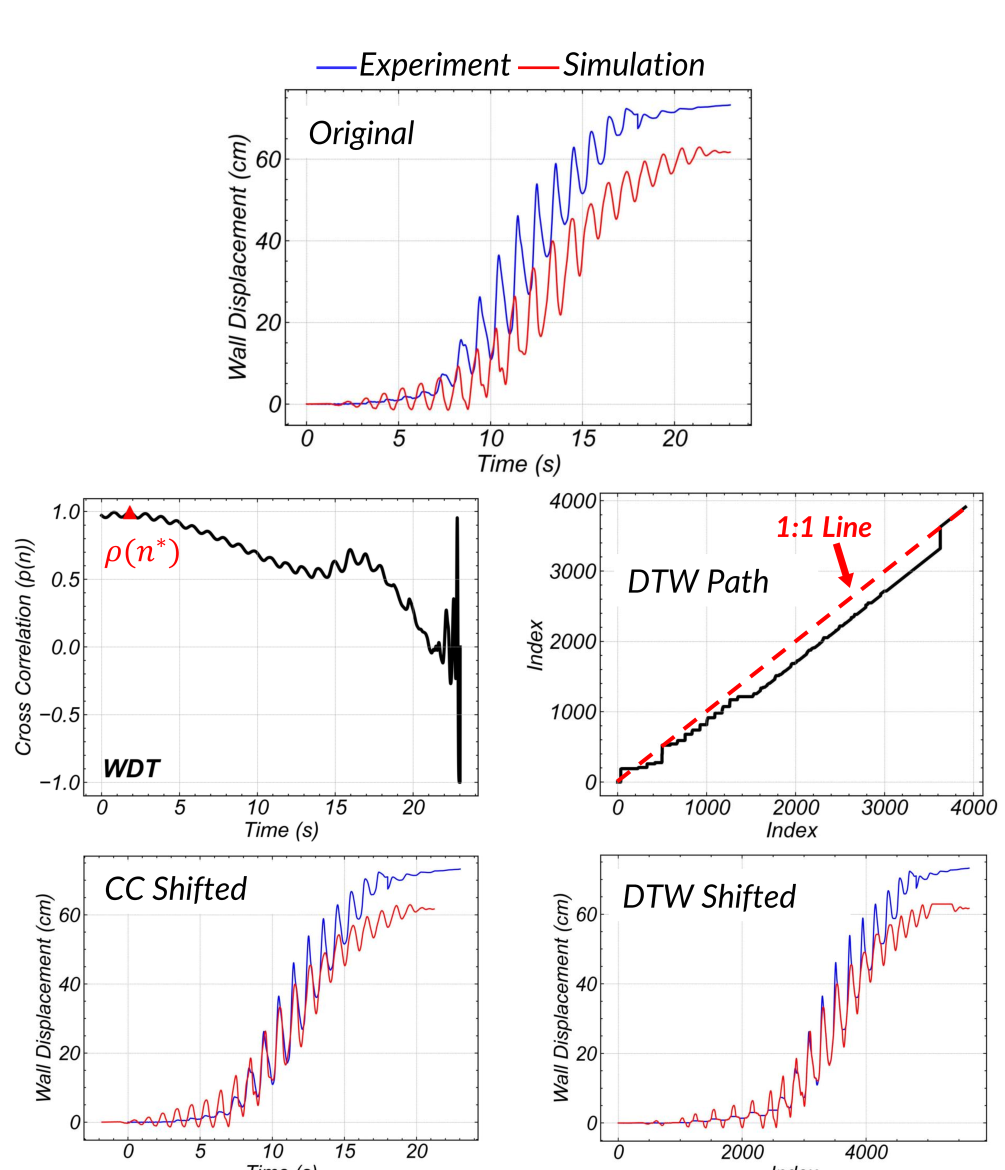
Non-linear dynamic analyses (NDAs) are widely used in geotechnical earthquake engineering, but the quality of their results depends on several factors such that assessing their reliability is challenging. Validation can assess the ability of an NDA to capture the salient mechanistic features of the response through selected metrics. The ideal metric can be used to quantify uncertainties in numerical *and* physical measurements.



Quantitative comparison between numerical and physical measurements (after Oberkampf et al. 2002)

Validation Metrics

Cross Correlation (**CC**) measures the agreement in phase between two signals. $\rho(n^*)$ is where the best major phase agreement occurs. Dynamic Time Warping (**DTW**) accounts for both major and minor phase differences and then measures the linear distance between the two. DTW path is an indicator of phase discrepancy, where a 1:1 line indicates that both signals are perfectly in phase.



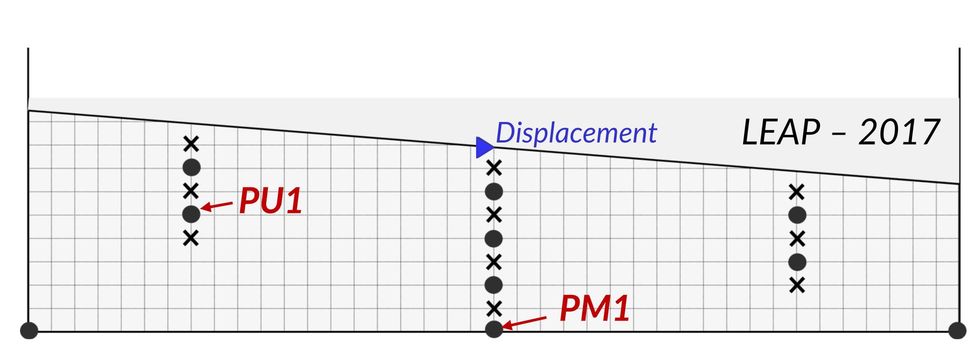
The impact of Cross Correlation and Dynamic Time Warping on the signals

Magnitude Error: $\dfrac{Distance}{Path\ index \times (\max(Exp) - \min(Exp))}$

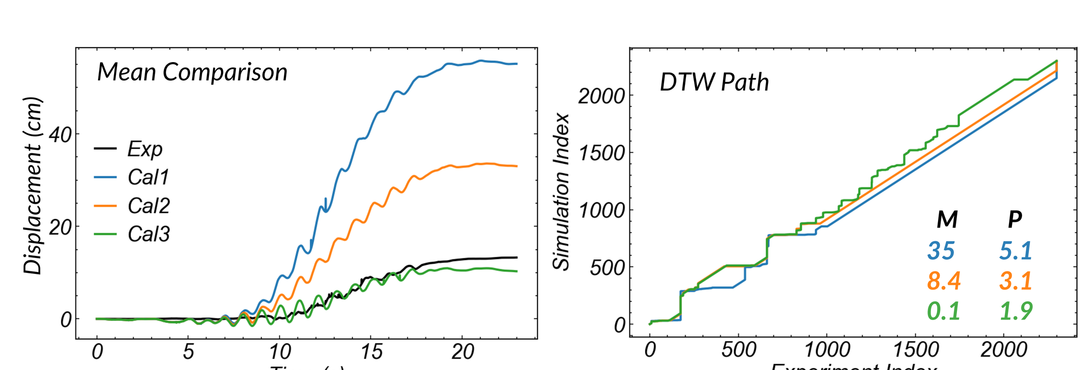
Phase Error: $\dfrac{Area\ between\ the\ path\ and\ 1{:}1\ Line}{Exp\ Index \times Sim\ Index}$

Variability Quantification

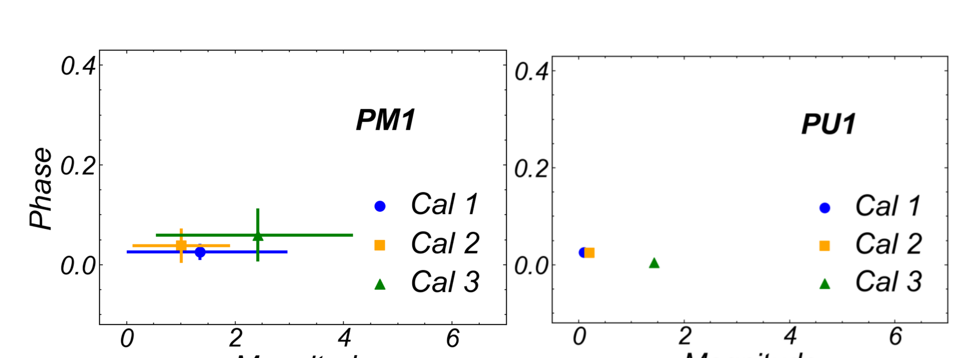
Herein, the proposed metric is a CC followed by DTW. CC is first used to detect where the best major phase agreement occurs. This information is then used as a limit for DTW to find the minimum distance path. This proposed metric is used to quantify the variability of discrepancies between numerical and physical measurements among nine different facilities in LEAP-2017 experiments.



LEAP-2017: Points show the locations for the response measurements



Quantified magnitude and phase discrepancies for a response (all facilities combined)

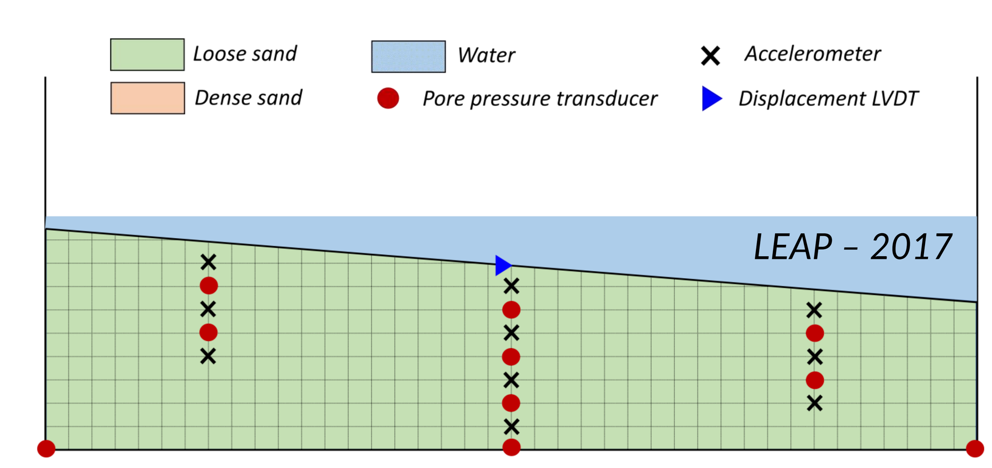


Quantification of uncertainty in numerical simulations on excess pore pressure response: PM1 has 9 experimental recording while PU1 has only one

Selected Geosystems

Simulations were performed with PM4Sand v.3.3, in FLAC v. 8.1, using three combinations of input parameter for small-strain shear modulus (G_o) and relative density (D_R).

- Cal 1: Default G_o, Designed D_R
- Cal 2: Calibrated G_o, Designed D_R
- Cal 3: Default G_o, Measured D_R



Schematic of LEAP-2017 centrifuge test with instrumentation

Conclusions

- The metric we propose is a combination of cross correlation and dynamic time warping for dynamic response validation.
- This metric can quantify and distinguish the discrepancies coming from magnitude and phase sources.
- After implementation in the LEAP-2017 project, Cal 3 was evaluated as showing the best and worst performance in displacement and excess pore pressure responses, respectively.
- This quantified comparison can be further used by modelers to inform next steps and ultimately improve the reliability of their numerical simulations.

Acknowledgements

National Science Foundation

CAREER grant CMMI-2047838