ICONHIC2022
3rd International Conference on Natural Hazards & Infrastructure
5-7 July 2022, Athens, Greece

Effect of soil relative density on a liquefiable sand deposit supported by a sheet-pile quay wall

Evangelia, Korre, PhD
ETH Zurich

Tarek, Abdoun, Thomas Iovino Chair Professor, M. ASCE, Mourad, Zeghal, Professor
Rensselaer Polytechnic Institute

1 INTRODUCTION & SCOPE OF WORK

Sheet-pile walls are retaining structures commonly found in waterfront areas. The high water table and the type of soil materials in such areas, increase the risk of seismically triggered liquefaction, which may lead to large deformations of the backfill and the retaining structure (e.g., *Yamaguchi et al., 2012*). One of the main factors affecting the dynamic response of such systems is the soil relative density (*De Alba et al., 1976*). As part of the experimental campaign of the Liquefaction Experiment and Analysis Project in 2020 (LEAP-2020), three centrifuge models were developed and tested at the geotechnical centrifuge facility of the Center for Earthquake Engineering Simulation (CEES) in Rensselaer Polytechnic Institute (RPI). All models refer to the same prototype problem of a rigid floating sheet-pile quay wall supporting a liquefiable deposit of varying relative density. The target of the ongoing international collaboration of the LEAP is to establish consistent protocols for validation and verification of the numerical tools, based on databanks of reliable experimental data, for different liquefaction hazards. Even though usually such retaining structures are flexible and supported by tiebacks, a more "simplified" approach of the problem at hand was adopted, in order to facilitate a straightforward and consistent numerical simulation of the experimental models.

2 METHODOLOGY

Figure 1 illustrates the adopted experimental layout of the centrifuge models. The examined prototype problem refers to a 3-m excavation below the water table supported by a rigid floating sheet-pile quay wall. In all models the soil deposit consisted of clean Ottawa F-65 sand with a very dense ($D_r \approx 90\%$) bottom layer of 1-m thickness. The relative density of the upper layers varied, corresponding to loose ($D_r \approx 55\%$), medium-dense ($D_r \approx 65\%$) and dense ($D_r \approx 75\%$) sand deposits. Consistency in repeatability was ensured fashion by means of air dry pluviation, maintaining consistent velocity and drop-height during sand raining. The sheet-pile wall was made of aluminum and was designed to behave as a rigid body during testing having a thickness of $0.109\,m$ in prototype scale. Accelerometers and pore pressure transducers (PPTs) were embedded in designated locations in the backfill and excavated deposit. The backfill settlements as well as the sheet-pile lateral displacements were monitored by means of Linear Variable Displacements Transducers (LVDTs).

After construction the centrifuge model was mounted on the centrifuge basket and was prepared for saturation as described in *Korre et al., 2020*. The achieved viscosity of the methylcellulose solution (viscous fluid) utilized for saturation was $23\ cP$, in accordance with the centrifuge similitude laws (*Garnier et al., 2007*). The testing sequence included in-flight CPT measurement in the backfill before the destructive shaking for all tested models. The CPT results confirmed (with minimal discrepancy) the uniformity of the achieved relative density in the backfill deposit for all tested models, while the recorded tip resistance was consistent with the achieved relative density. The destructive input motion was a synthetic tapered sinusoidal acceleration time history, consisting of five strong cycles of maximum acceleration $0.15g$ (Figure 2). All models were tested at $23g$ gravitational field. All dimensions provided henceforth are in prototype scale.

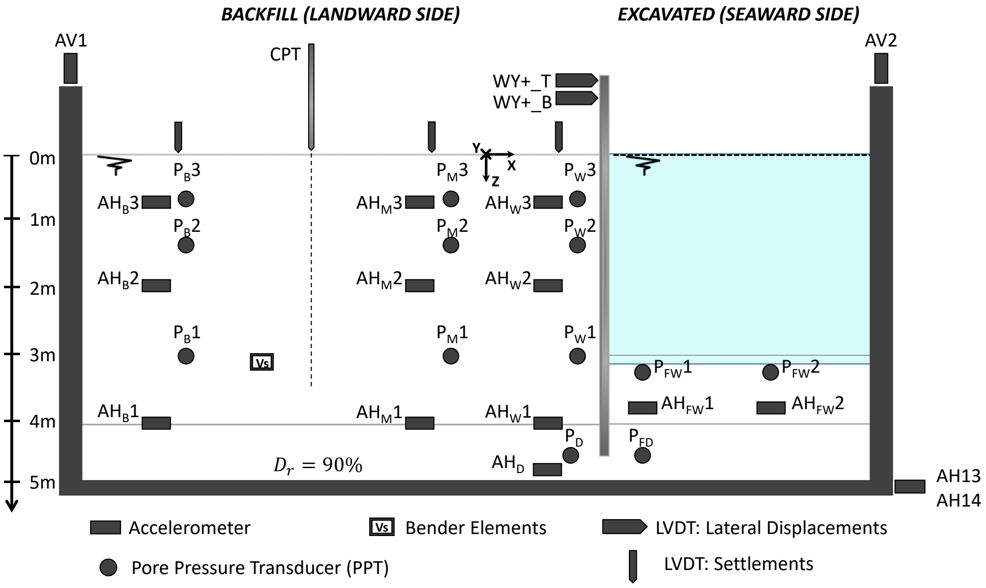

Figure 1. *Experimental layout adopted for the conducted experiments.*

3 RESEARCH OUTCOMES

The input acceleration is reproduced with high fidelity in all tests, both in terms of amplitude and frequency content (Figure 2). The comparison of the acceleration and excess pore water pressure ratio (R_u) response is depicted in Figure 2 for locations W3 (adjacent to the wall) and B3 (further away from the wall), both located within 1 m depth of the backfill. Starting with location B3 (AHB3 and PB3), soil liquefaction is observed in the loose model, as revealed by the significant de-amplification of the acceleration amplitude and the increased R_u values ($R_u \approx 1$) after $t \approx 8.5\ s$. The response is similar in the medium-dense and dense models, with fully liquefied conditions being however observed after $t \approx 12.5\ s$. In the latter, large negative acceleration peaks and excess pore water pressure negative peaks are clearly depicted, associated with dilation spikes due to the seawards rotation of the sheet-pile wall. This effect is also present in the loose model, being however more pronounced in the medium-dense and dense models.

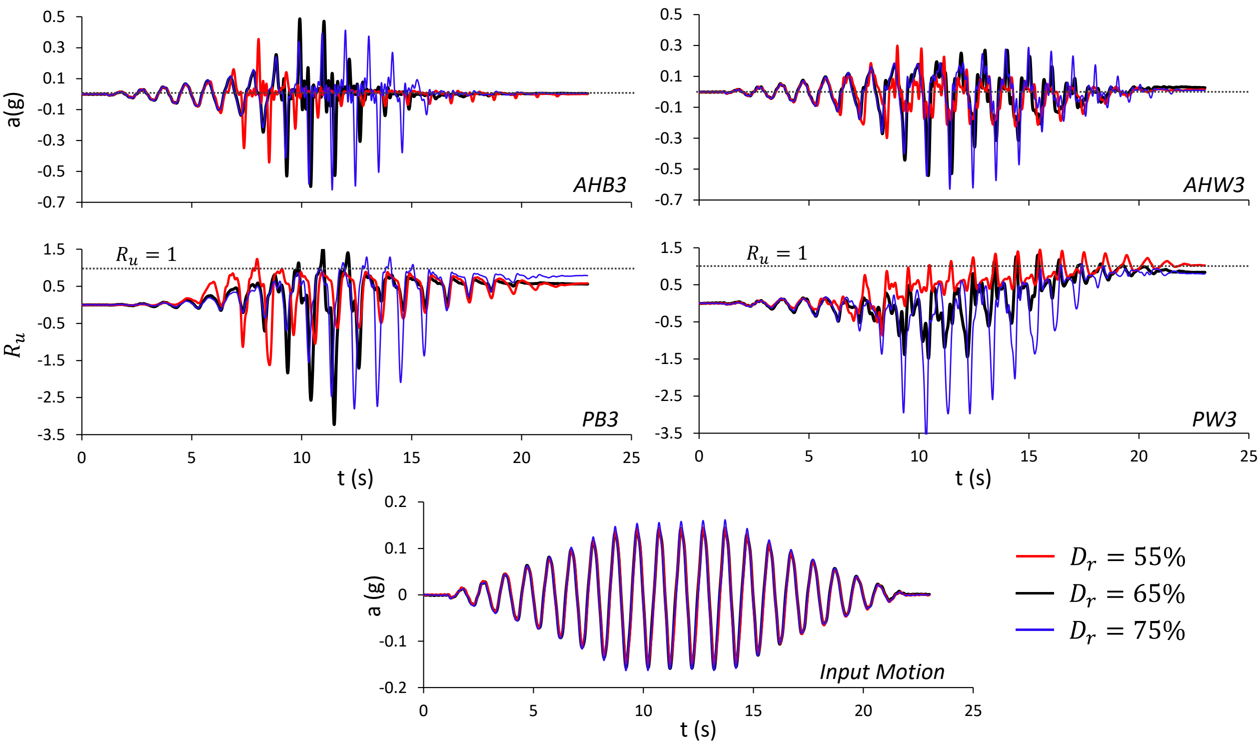

Figure 2. *Comparison of the short-term response in terms of accelerations and excess pore water pressure ratio (R_u) for the conducted experiments.*

Moving on to location W3 (AHW3 and PW3), all models exhibit strong dilative peaks in the acceleration time history response throughout the entire seismic shaking. Regarding R_u response, the dense model exhibits negative excess pore water pressure peaks of significantly higher amplitude compared to the loose and medium-dense models. The response in location W3 is clearly driven by soil-structure-interaction effects, being pronounced due to close proximity to the sheet-pile wall. The observed small discrepancies in the response between the two locations may be attributed to localized variations of soil properties in the vicinity of the sheet-pile wall.

Moreover, Figure 3 illustrates the comparison of the sheet-pile wall residual rotations for all conducted experiments. The rotation with respect to the y axis (θ_y) corresponds to the in-plane (seawards/landwards) rotation of the wall, whereas the rotation relative to the z axis (θ_z) is employed to quantify the assumption of plane-strain conditions. The accumulated seaward rotation of the wall at the end of the test was $\theta_y \approx 12°$ for the loose model, $\theta_y \approx 6.3°$ for the medium-dense model (about half) and $\theta_y \approx 6.2°$ for the dense model. Finally, the rotation θ_z did not exceed 0.6° in all tests, thus confirming practically plane-strain conditions. This pronounced reduction of the sheet-pile wall residual rotation in the medium-dense and dense models is attributed to the overall stronger dilative soil response.

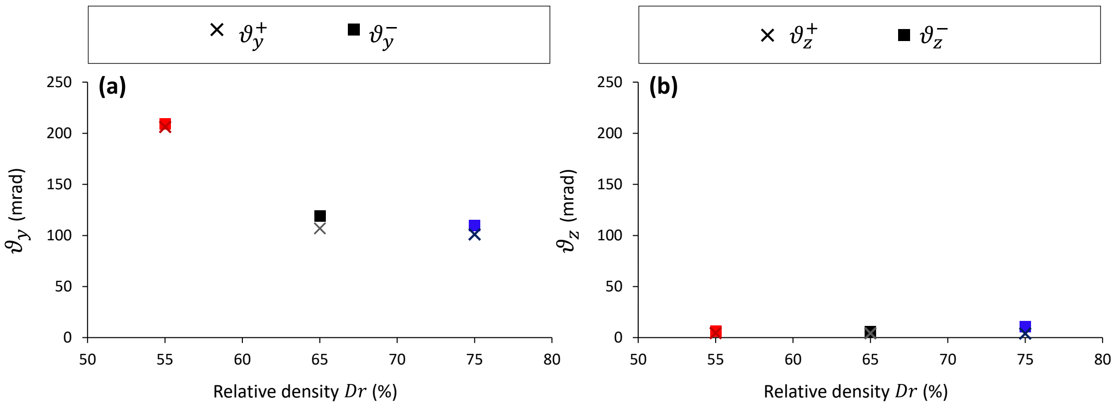

Figure 3. *Comparison of the residual ϑ_y and ϑ_z rotations of the sheet-pile during the conducted experiments.*

Overall, the conducted experimental campaign confirmed the crucial double role of soil relative density and soil dilation in the dynamic response of the examined system. Firstly, in the less dilative loose model, fully liquefied conditions ($R_u \approx 1$) occur earlier, resulting in larger accumulation of sheet-pile wall displacements and rotations. On the contrary, the strong dilative field generated in the medium dense and dense models is beneficial to the system response, since the backfill liquefied $\approx 4\,s$ later and thus accumulating smaller deformations. Secondly, soil dilation in the vicinity of the sheet-pile wall leads to unloading of the wall, as a result of local instantaneous soil re-stiffening (results not shown herein).

REFERENCES

De Alba, P., Chan, C. K., & Seed, H. B. (1976). *Determination of soil liquefaction characteristics by large-scale laboratory tests*. Shannon & Wilson.

Garnier, J., Gaudin, C., Springman, S. M., Culligan, P. J., Goodings, D., Konig, D., Kutter, B., Phillips, R., Randolph, M. F., & Thorel, L. (2007). Catalogue of scaling laws and similitude questions in geotechnical centrifuge modelling. *International Journal of Physical Modelling in Geotechnics*, *7*(3), 01–23. https://doi.org/10.1680/ijpmg.2007.070301

Korre, E., Abdoun, T., & Zeghal, M. (2020). Liquefaction of a sloping deposit: LEAP-2017 centrifuge tests at Rensselaer Polytechnic Institute. *Soil Dynamics and Earthquake Engineering*, *134*, 106152. https://doi.org/10.1016/j.soildyn.2020.106152

Yamaguchi, A., Mori, T., Kazama, M., & Yoshida, N. (2012). Liquefaction in Tohoku district during the 2011 off the Pacific Coast of Tohoku Earthquake. *Soils and Foundations*, *52*(5), 811–829. https://doi.org/10.1016/j.sandf.2012.11.005