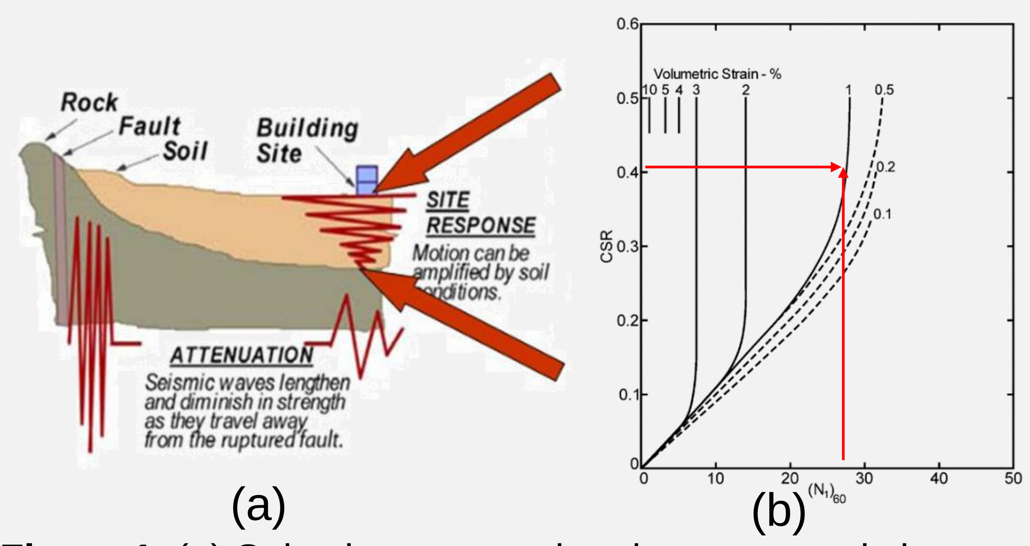
SEISMIC COMPRESSION OF UNSATURATED SANDS

Principal Investigator: John S. McCartney, Ph.D., P.E., F. ASCE
Student Investigator: Wenyong Rong, S.M. ASCE
University of California San Diego

UC San Diego
Structural Engineering
JACOBS SCHOOL OF ENGINEERING

Introduction

Seismic compression is defined as the accrual of contractive volumetric strains in soils during earthquake shaking and has been recognized as a major cause of seismically-induced damage to civil infrastructure (Stewart et al. 2004). The state-of-the-practice method used to predict contractive volumetric strains of soil layers during earthquake shaking involves use of a chart developed by Tokimatsu and Seed (1987), which was developed based solely on test results on saturated and dry quartz sands from Silver and Seed (1971).



(a) (b)

Figure 1. (a) Seismic compression due to upward shear waves in earthquake events; (b) Empirical approach to estimate seismic compression of soil layers (Tokimatsu and Seed, 1987)

Motivation and Objectives

Compacted backfill soil layers in transportation systems (i.e. retaining walls and slopes, embankments and bridge abutments) are designed with the intention of remaining in unsaturated conditions by provision of adequate drainage. Even small backfill settlements can have a negative impact on the functionality of transportation systems and can lead to high repair costs. Therefore, in earthquake-prone areas, it is critical to understand the mechanisms of seismic compression of unsaturated soils. Specifically, the objectives of this study are summarized as below,

1. Develop a cyclic simple shear test device with a suction-saturation system that can provide independent measurements of both fluid phases in controlled drainage
2. Perform drained and undrained cyclic shearing tests to understand the effect of suction in seismic compression
3. Create experimental data for unsaturated soil model calibration and develop new model based on the experiments

Development of Test Device

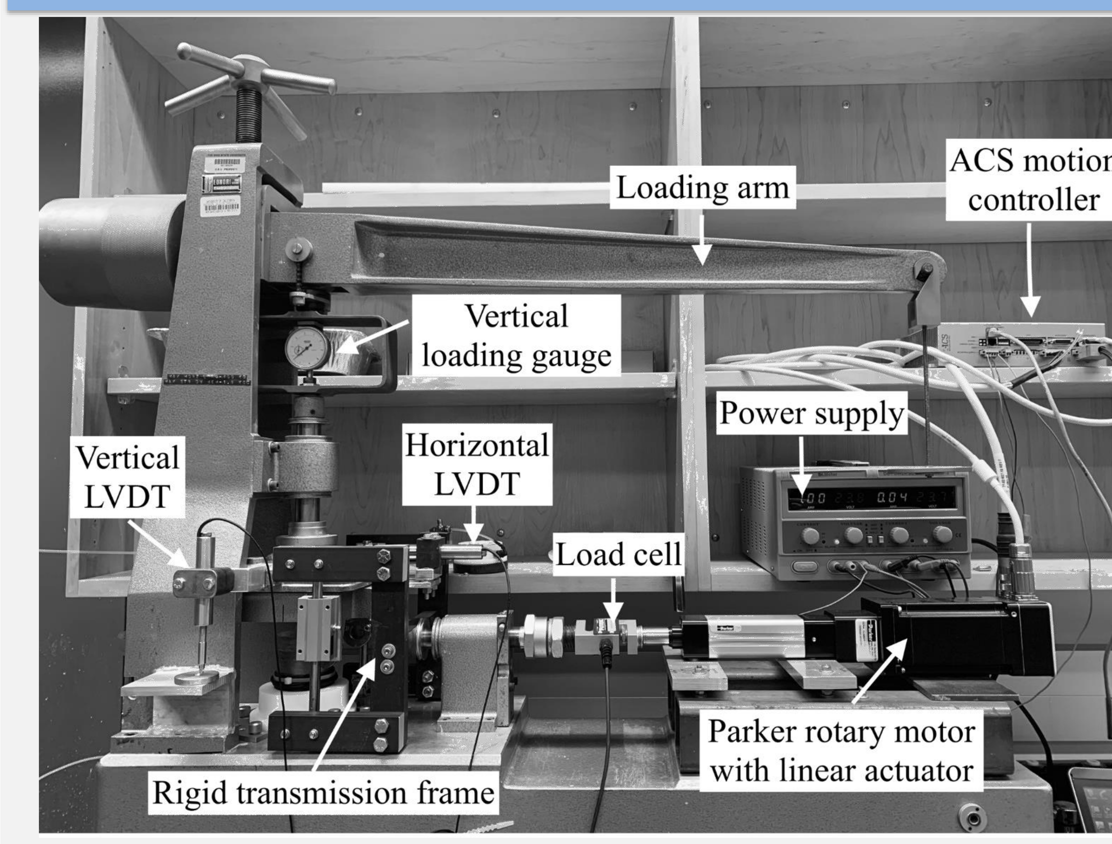


Figure 2. Overall view of the NGI-type simple shear test device with updated cyclic motor and transducers

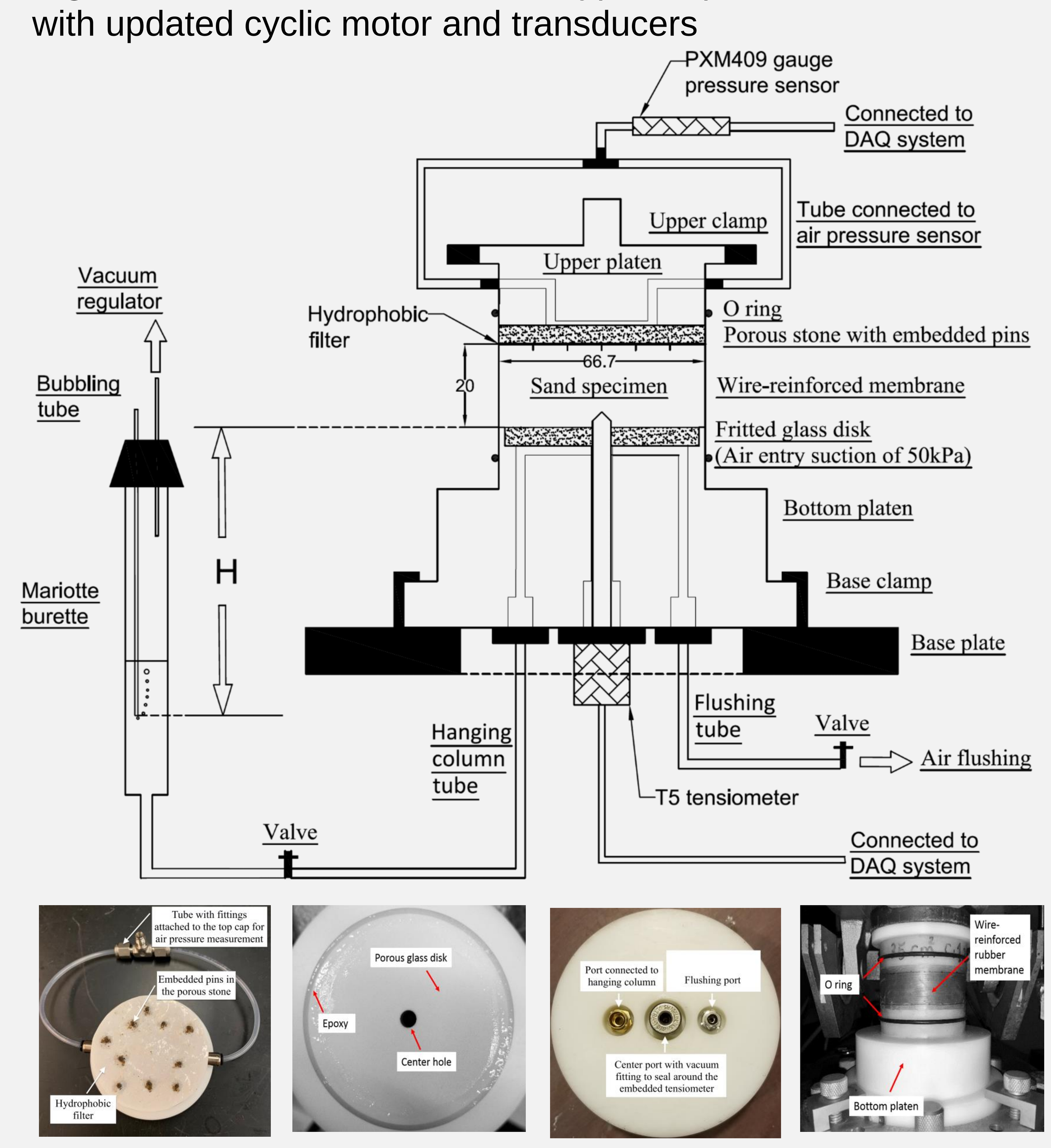
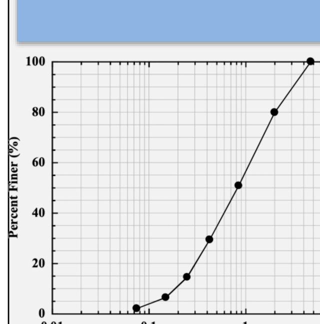


Figure 3. Design of the specimen housing for unsaturated sand with a suction-saturation control (detailed view of the components at the bottom)

Material Properties and Testing Program



Parameter	Value
van Genuchten SWRC parameter, α_{vG} (kPa^{-1})	0.70
van Genuchten SWRC parameter, N_{vG}	2.10
Residual volumetric water content, θ_r	0.00
Volumetric water content at zero suction on drying path, $\theta_{0,drying}$	0.38
Volumetric water content at zero suction on wetting path, $\theta_{0,wetting}$	0.20
Hydraulic conductivity of saturated soil, k_{sat} (m/s)	1.5×10^{-7}

Figure 4. Particle size distribution curve along with the sand properties

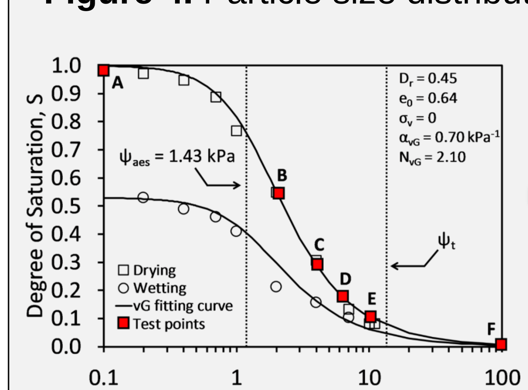


Figure 5. SWRCs

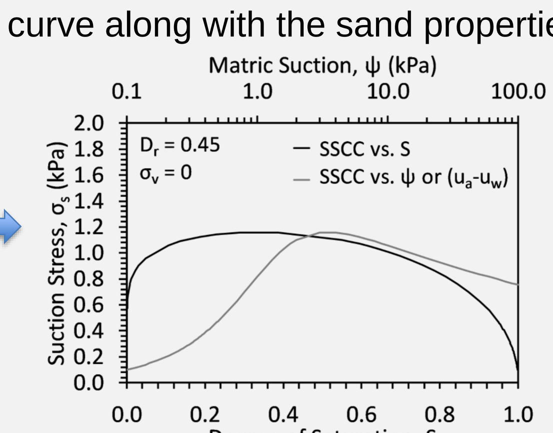


Figure 6. SSCC

Effective stress (Lu et al. 2010)

$$\sigma' = (\sigma - u_a) + \left[\frac{u_a - u_w}{\left(1 + [\alpha_{vg}(u_a - u_w)]^{N_{vg}}\right)^{1-\frac{1}{N_{vg}}}}\right]$$

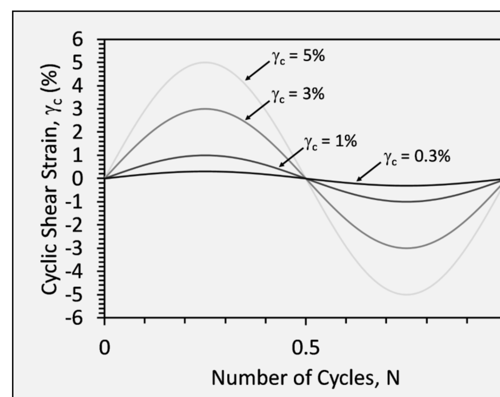


Figure 7. Applied constant shear strains of different amplitudes in one cycle

Test Results

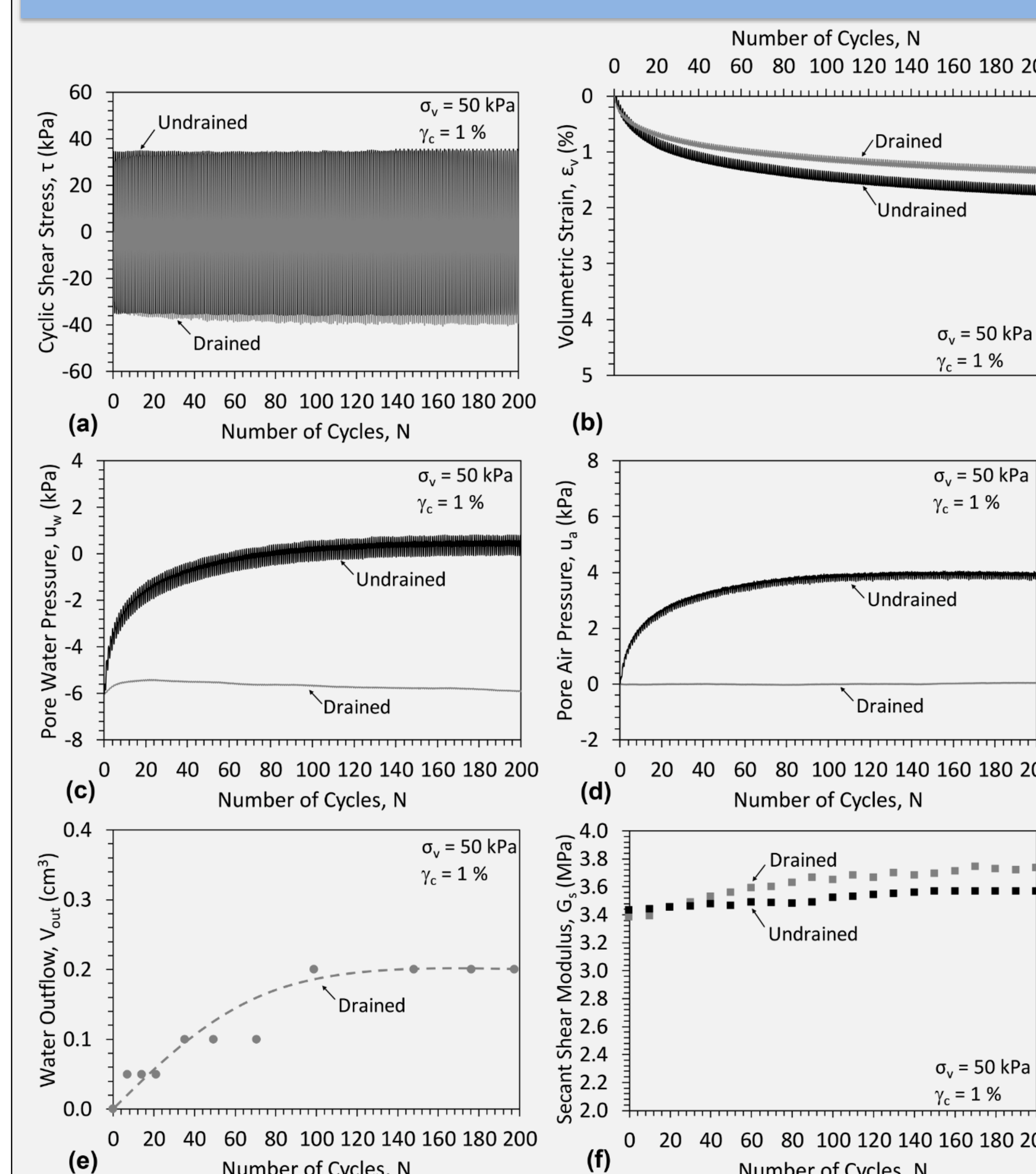


Figure 8. Test results on unsaturated sand specimens with the matric suction of 6 kPa in drained and undrained conditions

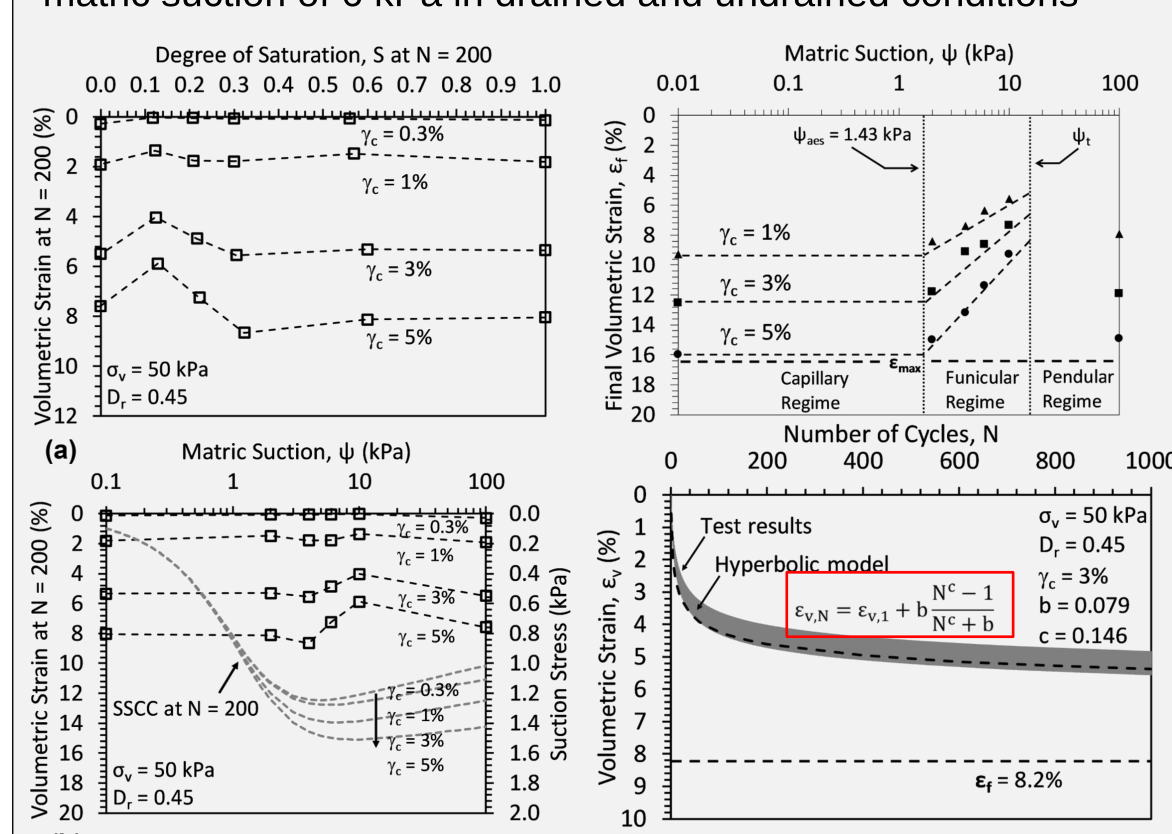


Figure 9. A simplified model to predict the stabilized seismic compression of unsaturated sand based on the test results in drained condition (Rong and McCartney 2020, manuscript accepted for publication)

Conclusions

1. The results in drained and undrained tests emphasizes the importance of considering hydro-mechanical coupling in estimating seismic compression of unsaturated soils
2. In the funicular regime, the stabilized volumetric strain was observed to have a log-linear relationship with suction assuming drained conditions

Acknowledgements

The authors would like to acknowledge partial financial support provided by the Department of Transportation in California (Caltrans) Project 65A0556 and from the University of California San Diego Academic Senate Grant A050757.

Reference

1. Lu, N., Godt, J.W., and Wu, D.T. (2010). “A closed form equation for effective stress in unsaturated soil.” Water Resources Research, 46(5), 55-65.
2. Silver, M.L., and Seed, H.B. (1971). “Deformation characteristics of sands under cyclic loading.” Journal of Soil Mechanics and Foundations Division, 97(8), 1081-1098.
3. Stewart, J.P., Smith, P.M., Whang, D.H., and Bray, J.D. (2004). “Seismic compression of two compacted earth fills shaken by the 1994 Northridge earthquake.” Journal of Geotechnical and Geoenvironmental Engineering, 130(5), 461-476.
4. Tokimatsu, K., and Seed, H.B. (1987). “Evaluation of settlements in sands due to earthquake shaking.” Journal of Geotechnical Engineering, 113(8), 861-878.