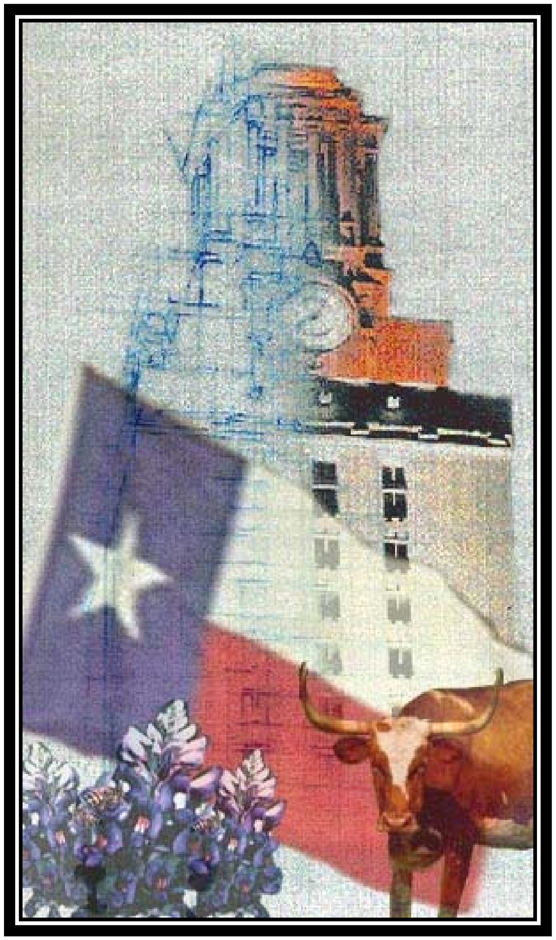
Recent Developments in Characterizing Liquefiable Sandy Soils in the Field and Laboratory



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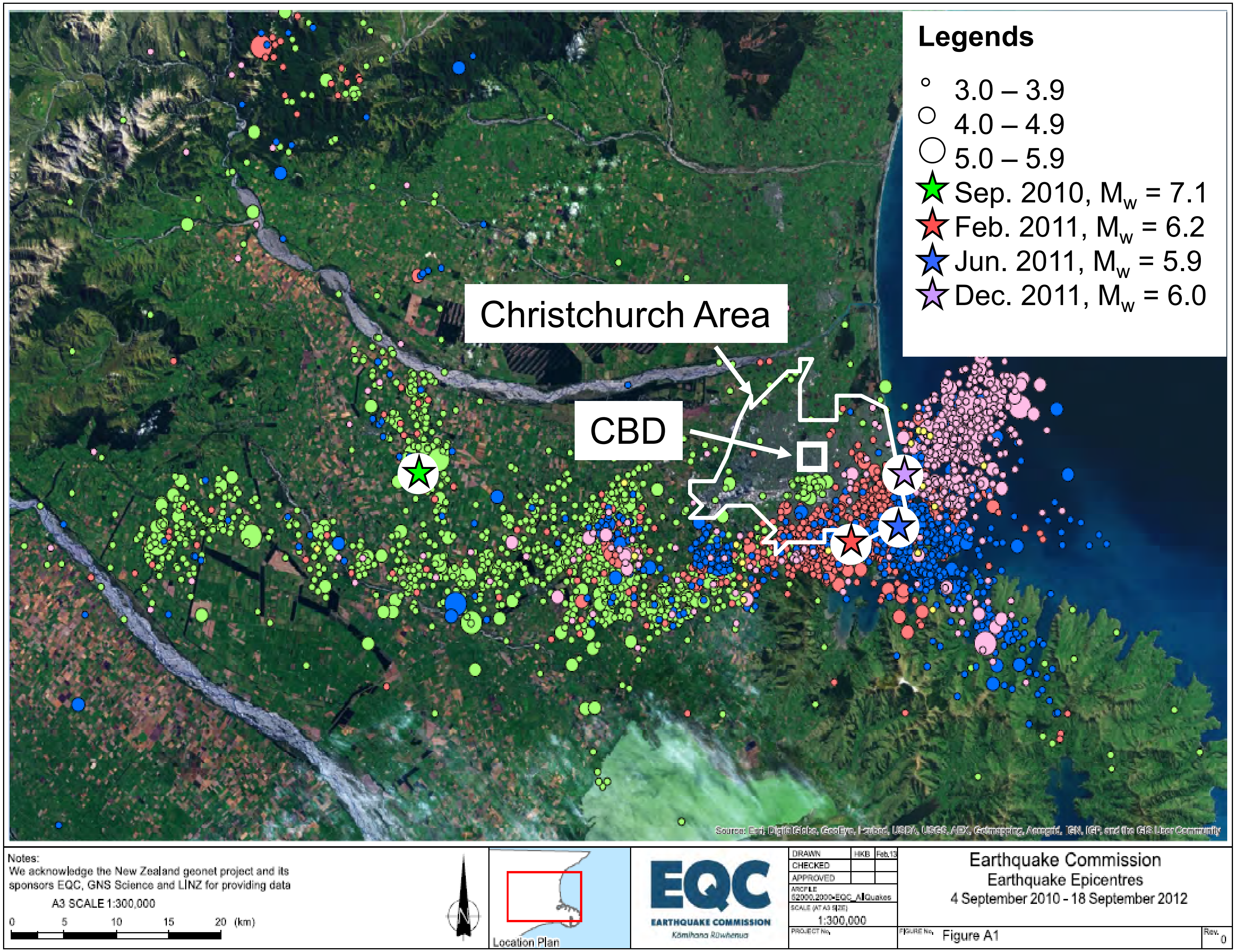
GeoVirginia 2018
Williamsburg, VA
April 9-11, 2018

Outline

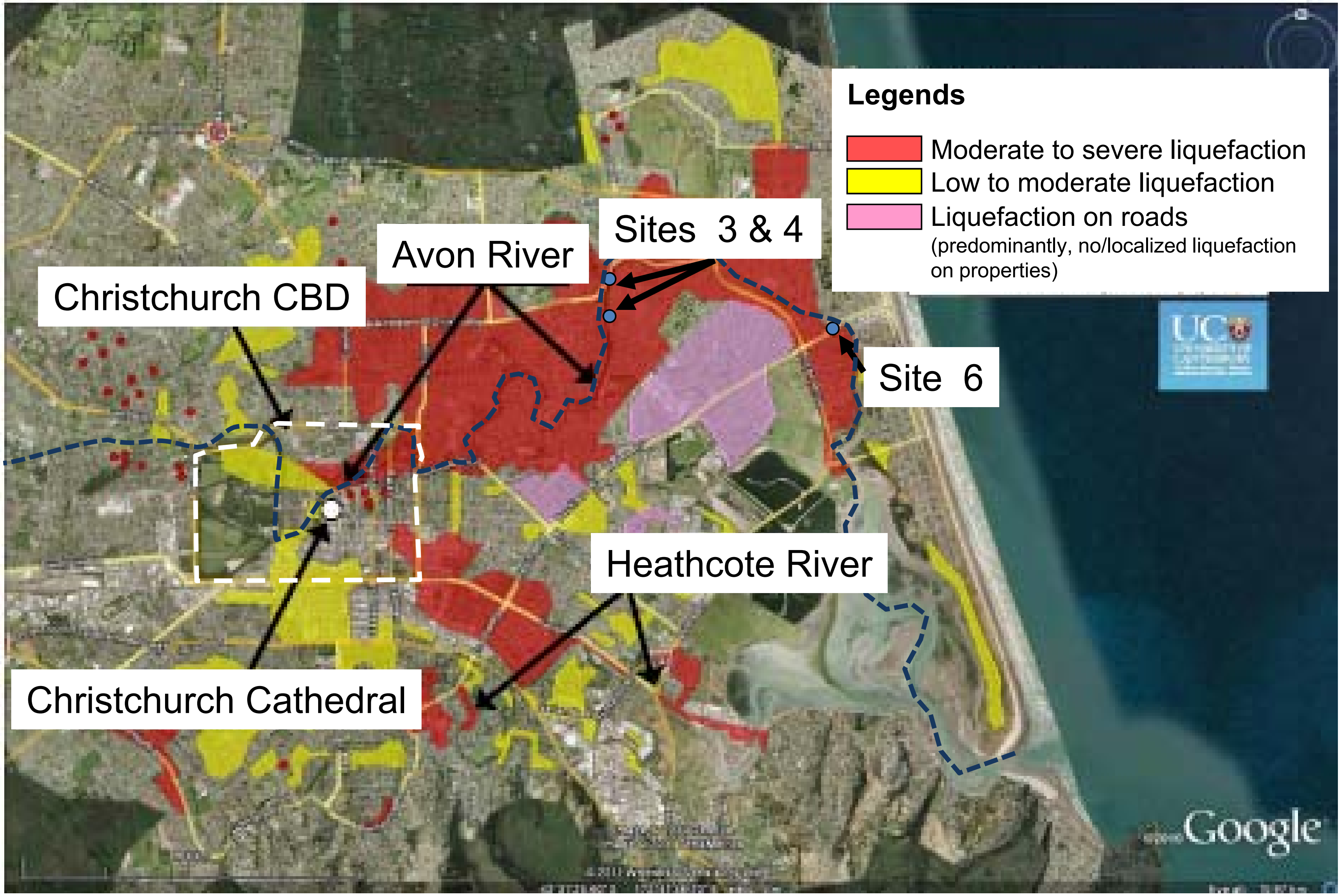
1. Present results from recent (2013) in-situ liquefaction testing in Christchurch, NZ with T-Rex in terms of r_u – Log γ at given N's.
2. Investigate the dynamic response of the sand skeleton using the combined field and extrapolated r_u – Log γ relationship (N = 30 cycles) with the effective-stress, G – Log γ relationship determined from dynamic laboratory testing of the actual soil.
3. Briefly present the $\tau - \gamma$ curves determined from the G – Log γ relationships with and without pore water pressure.
4. Very briefly introduce improvements in:
   - modeling (G/G_{max} – Log γ) of sands (SP, SW and SM),
   - combined dynamic and cyclic laboratory testing, and
   - next-generation field liquefaction testing.
5. Conclusions
6. Acknowledgments

2010-2011 Canterbury Earthquake Sequence



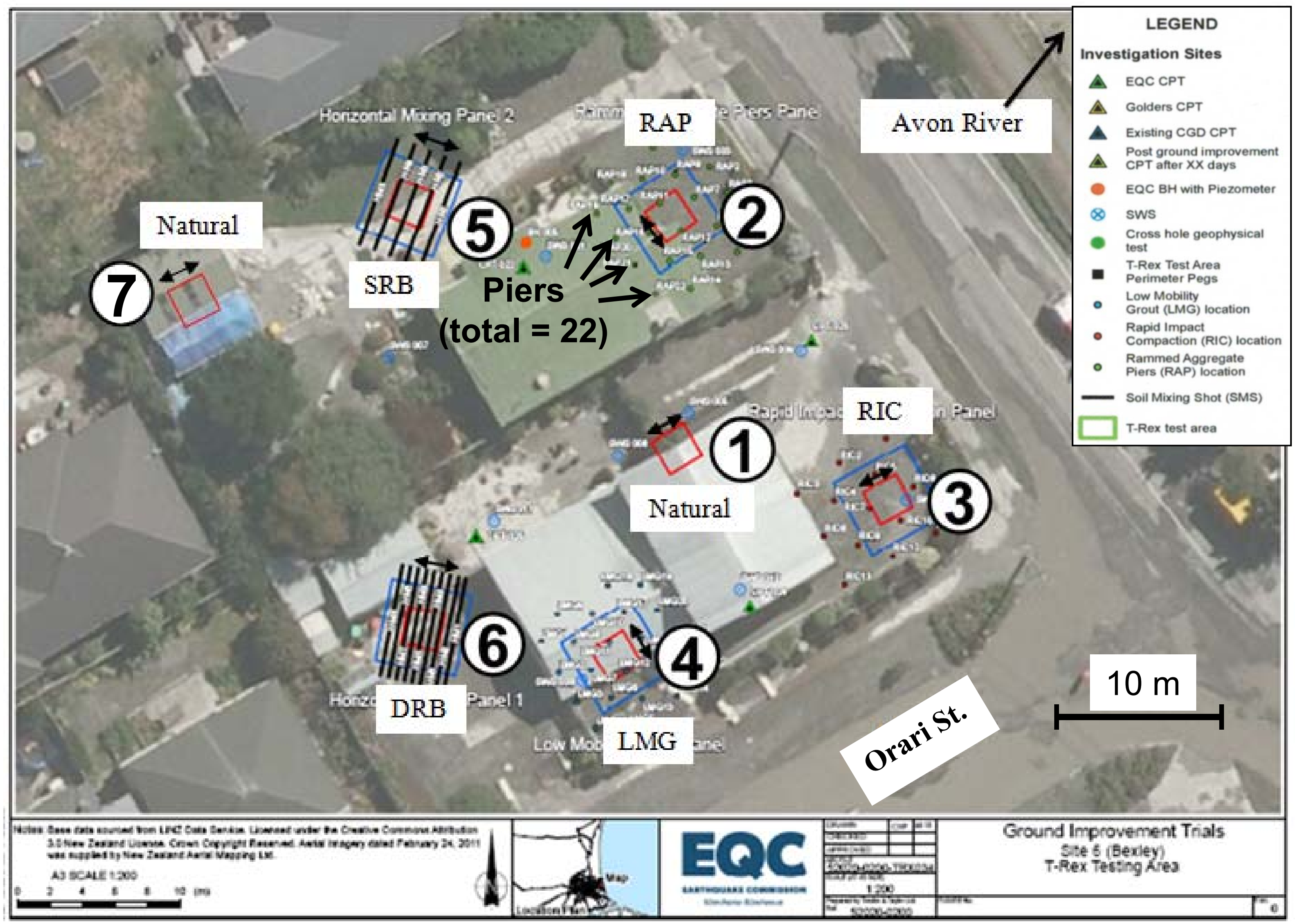
Severe Liquefaction in Suburbs

1. Example: Field Shaking Tests at Site 6 and Associated Dynamic and Cyclic Laboratory Tests

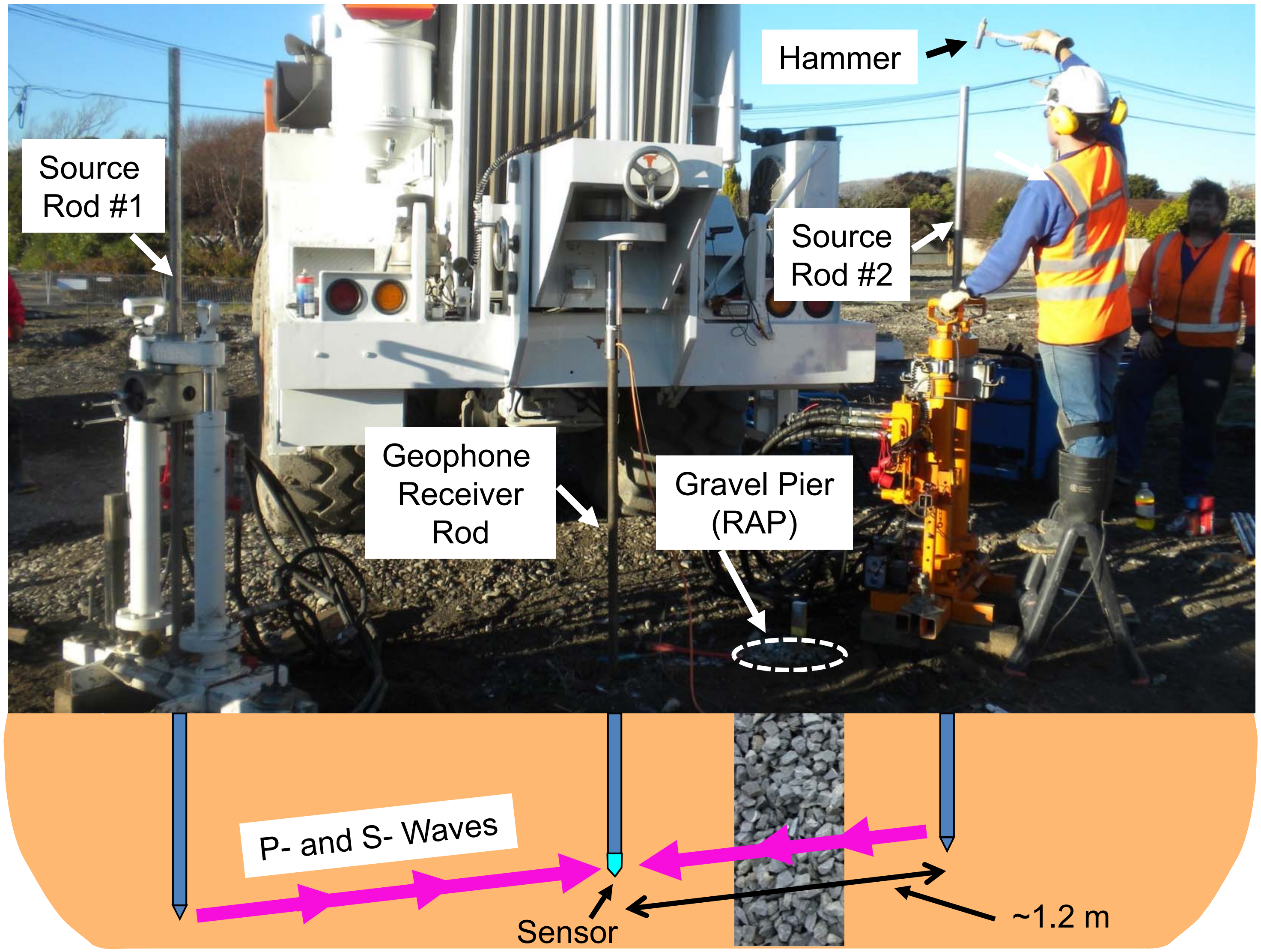


Plan View of Site 6 with Natural Soil Test Panel

(Ariel Photograph Before Homes Removed)

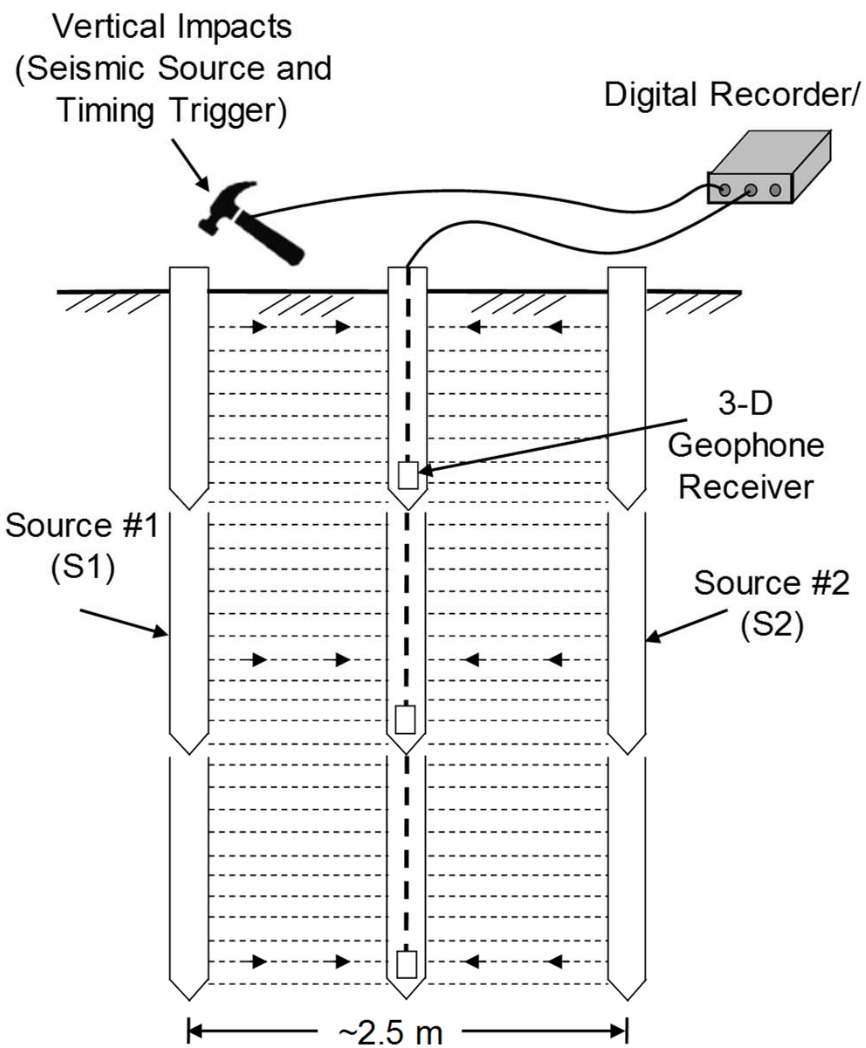


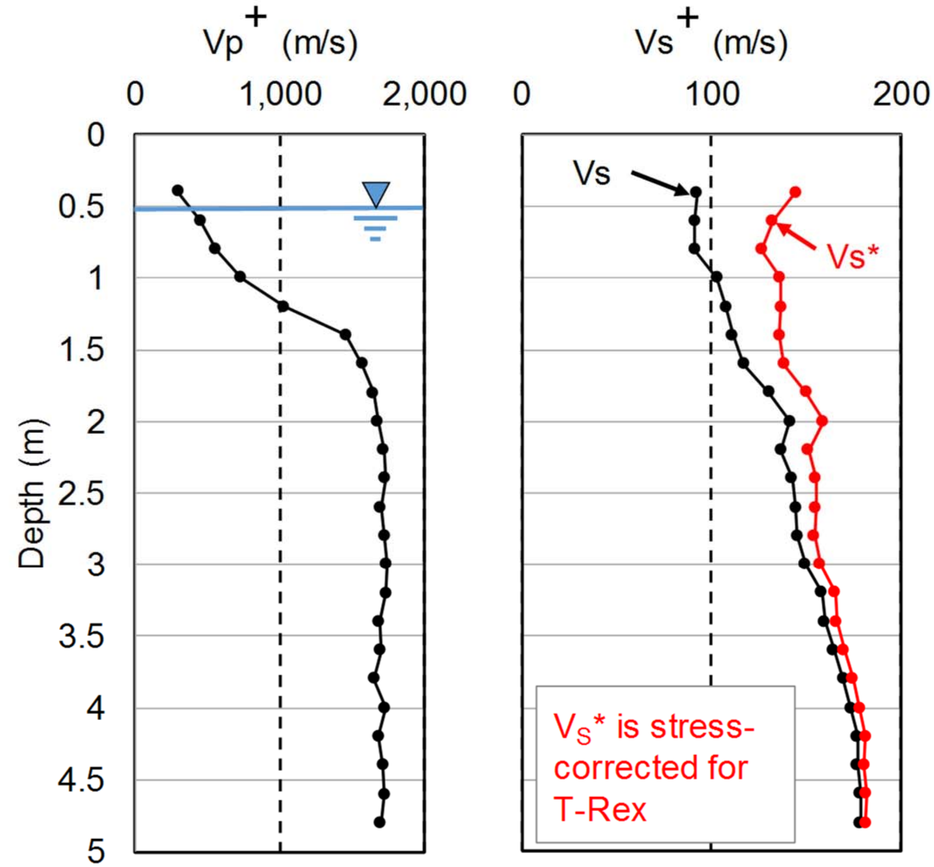
Pre-Shaking Crosshole Testing in Progress to Characterize Soil



Note: General arrangement used as the field verification procedure.

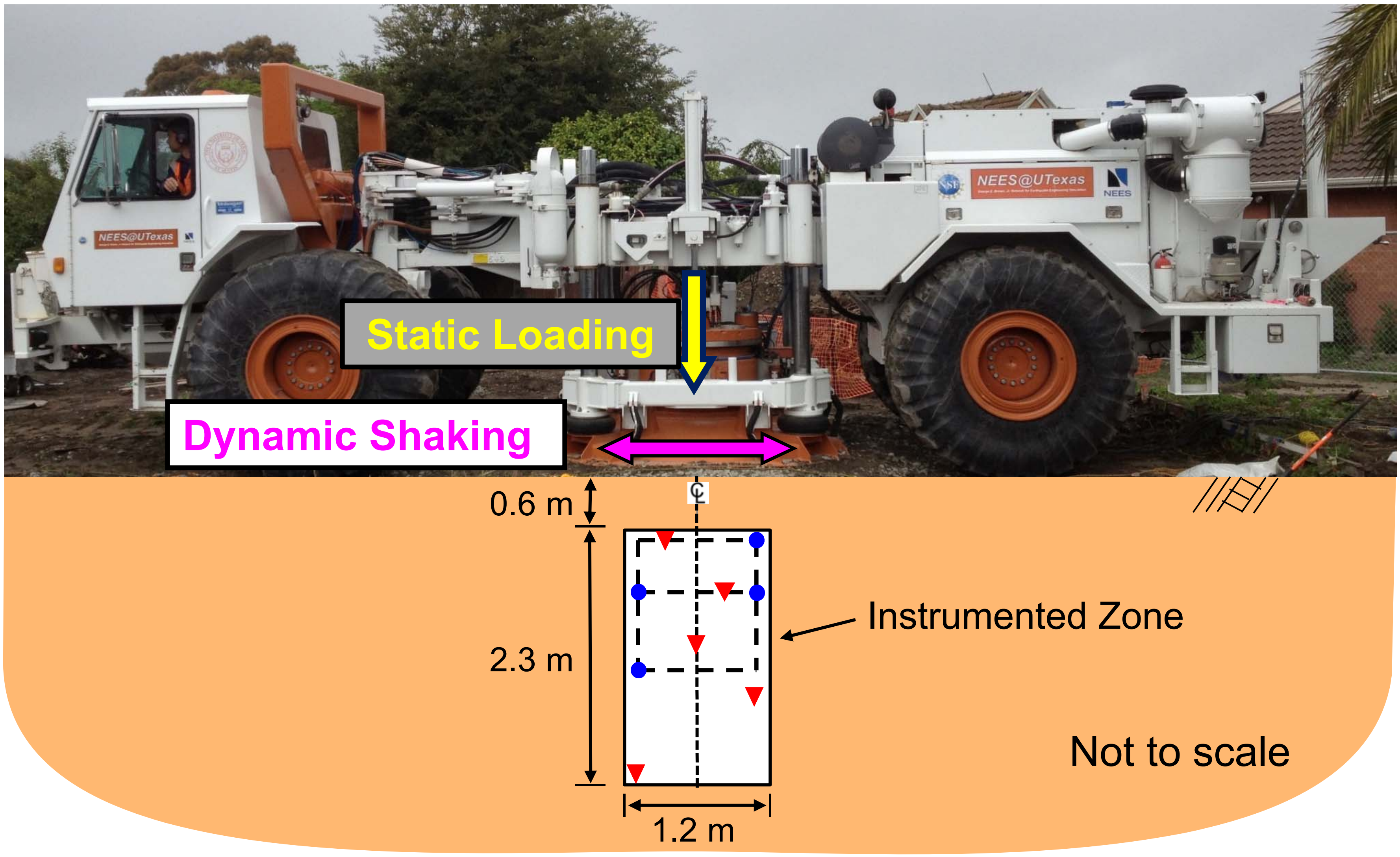
Pre-Shaking Characterization of Soil: Direct-Push Crosshole Seismic Testing to Determine V_P and V_S



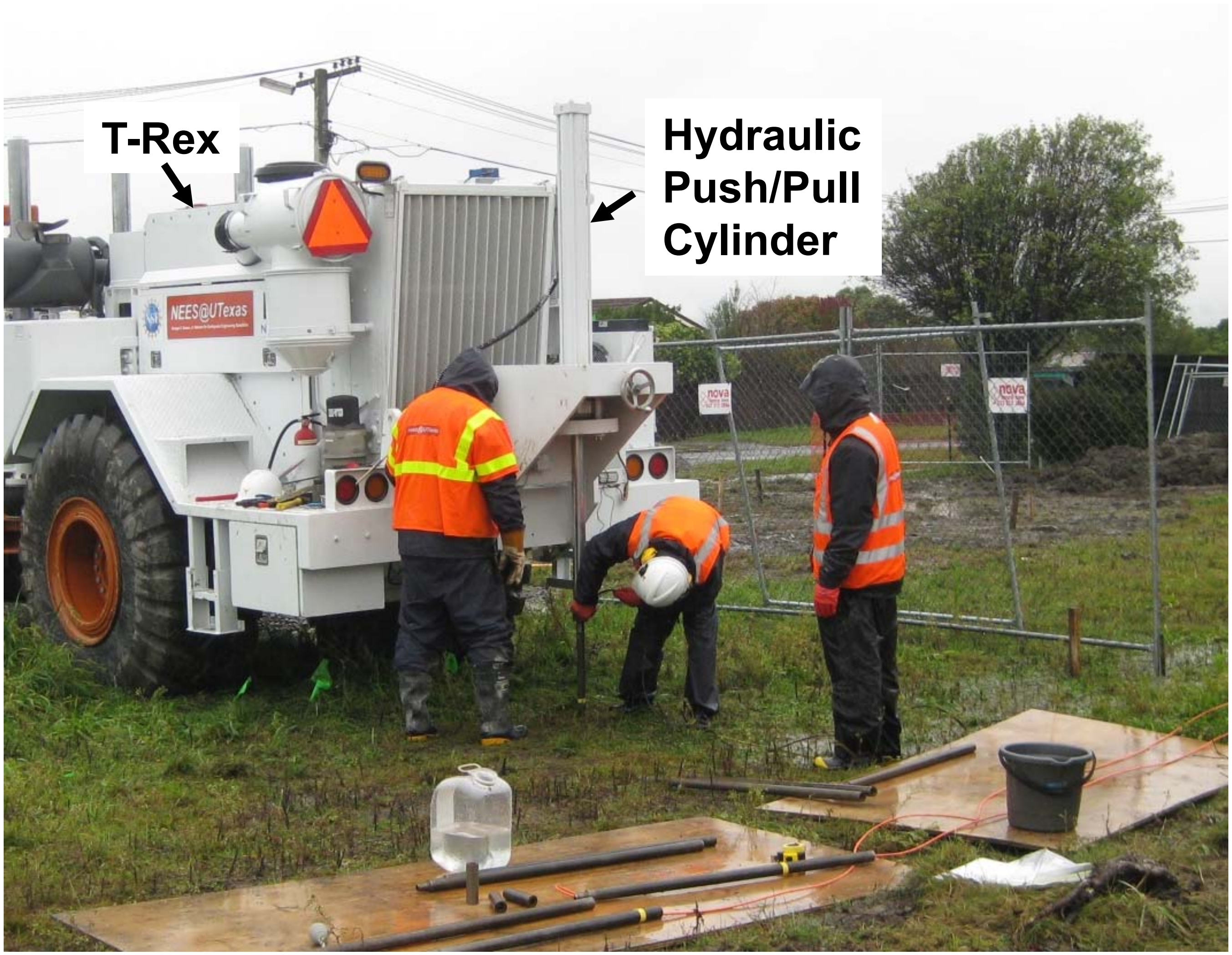


+ for testing at Site 6 in NZ

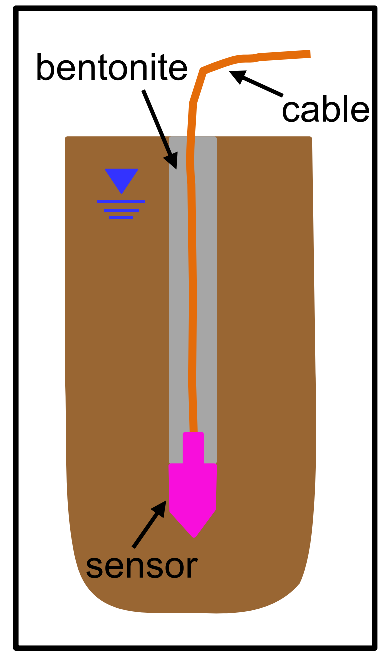
Generalized Field Set-Up: T-Rex Shaking of an Embedded Array of Sensors



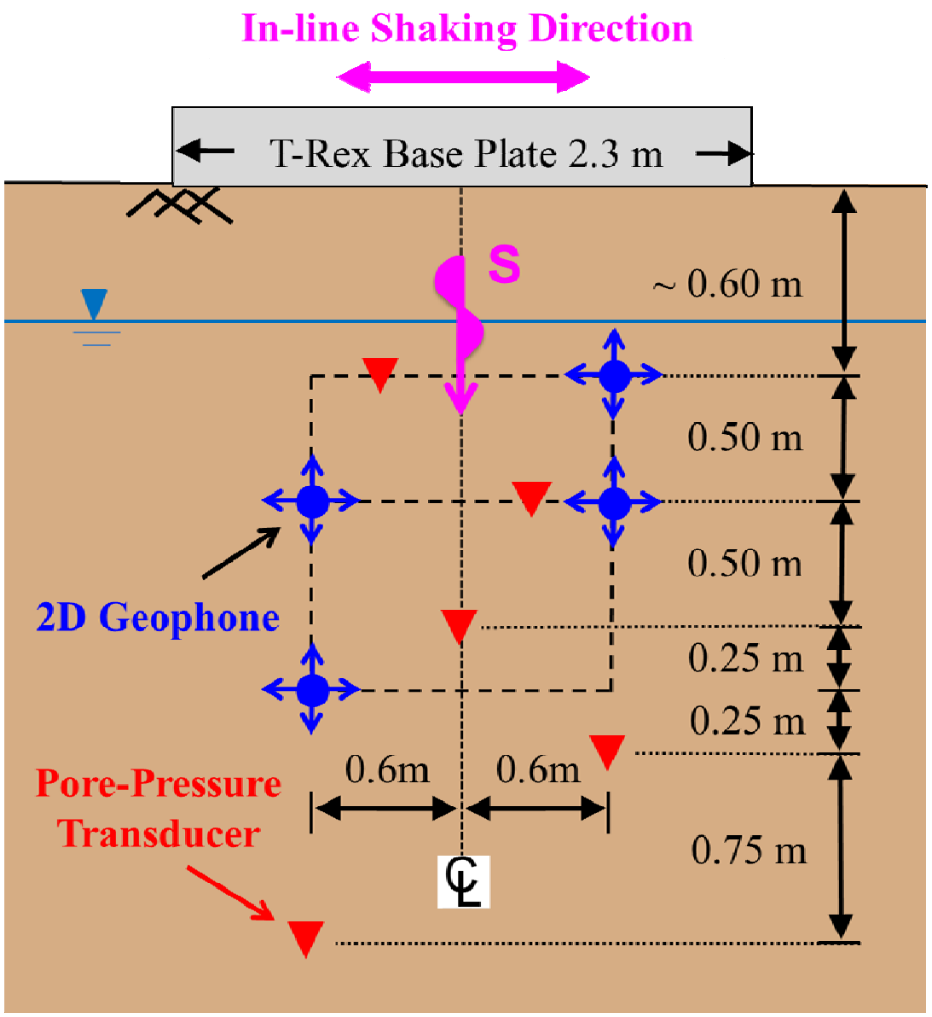
Creating the Embedded Array of Sensors: Pushing Geophones and Pore-Pressure Transducers with T-Rex



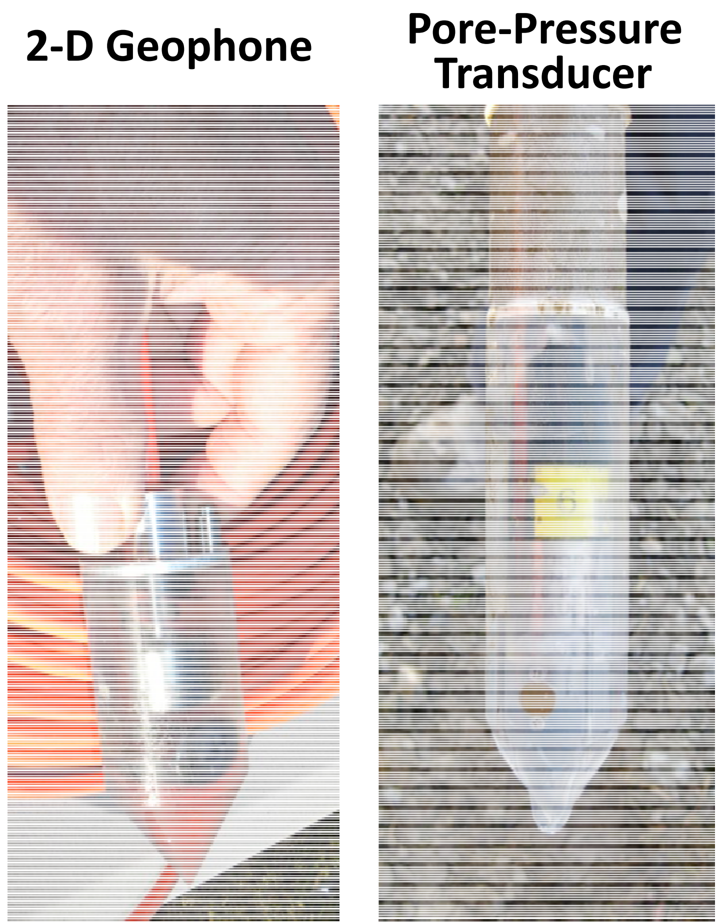
Sensor Installation



Generalized Arrangement of Sensors to Evaluate r_u versus Time (N) and γ versus Time (N)

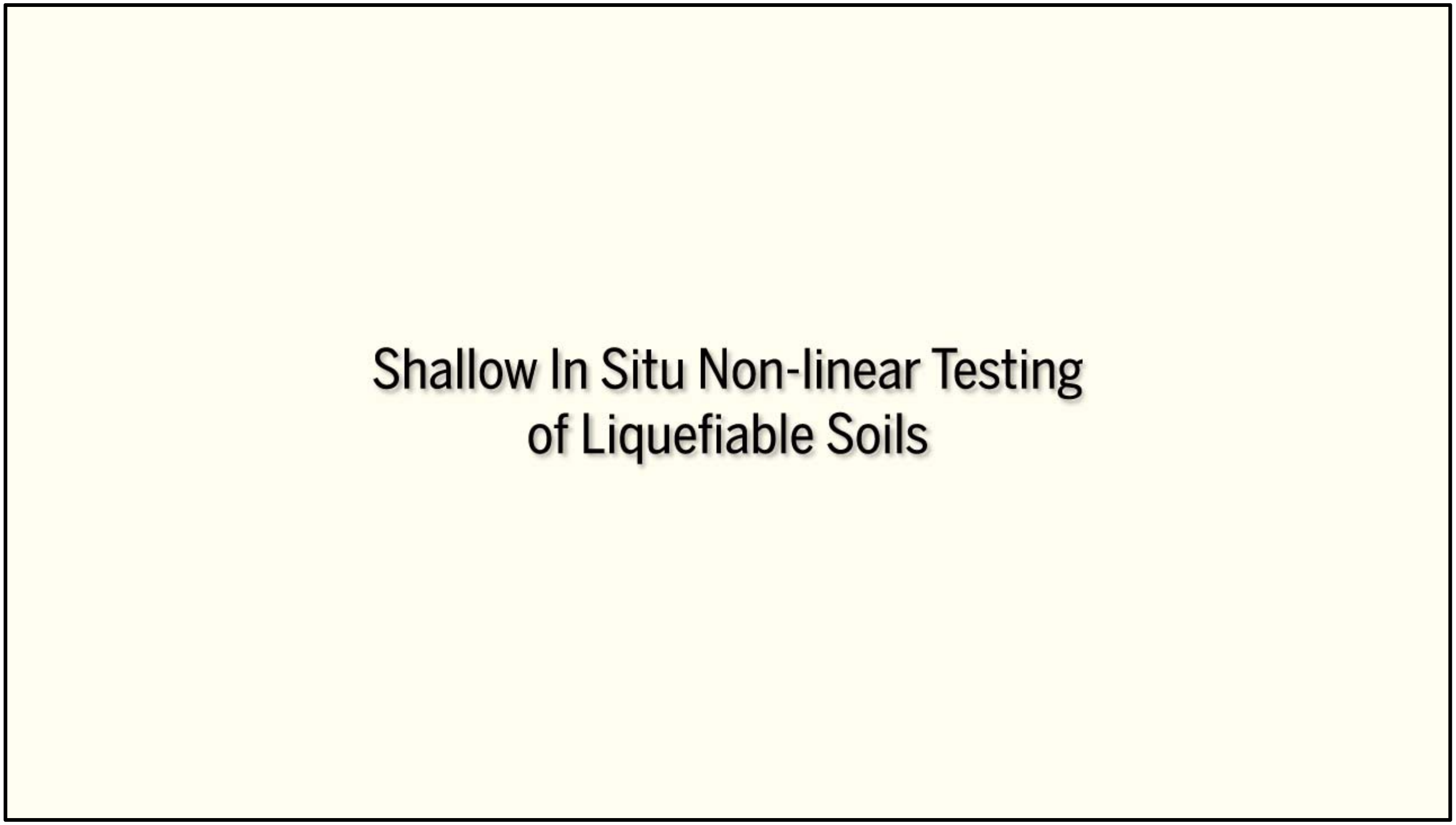


(a) Cross Section



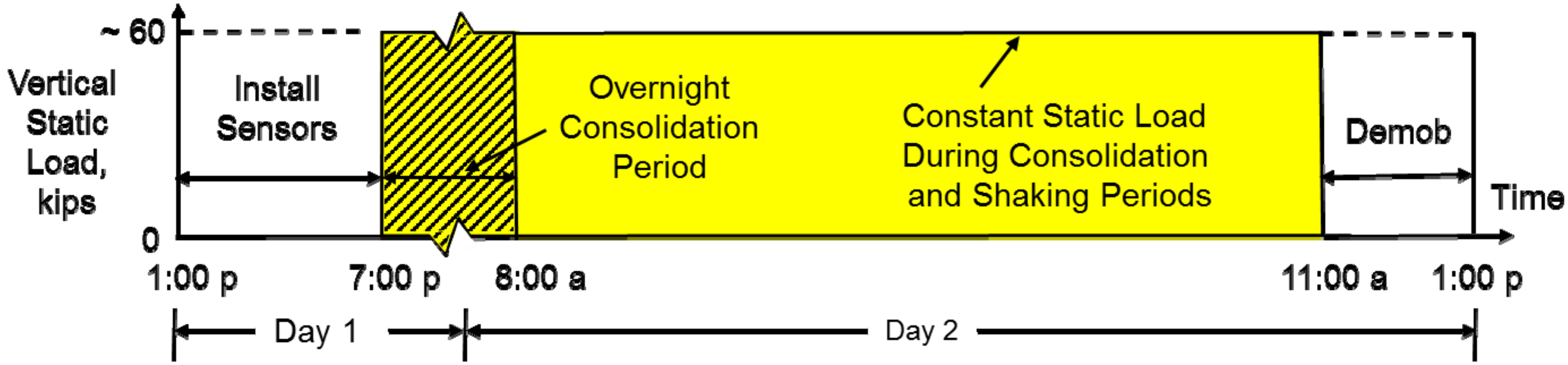
(b) Instrumentation

In Situ Non-Linear Testing of Liquefiable Soils

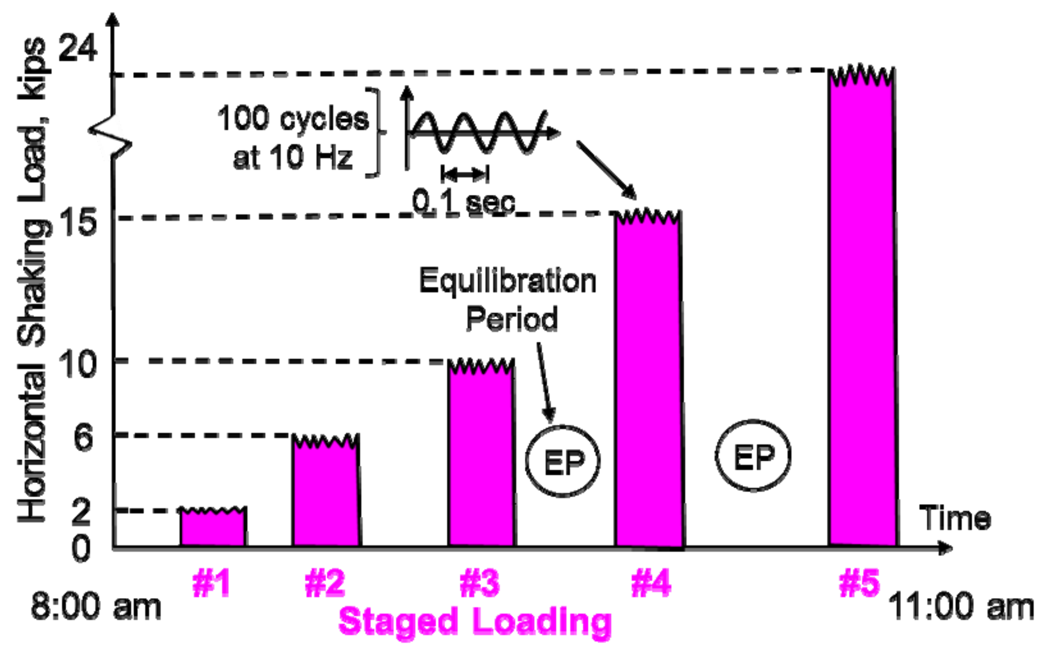


24-hr Process of Sensor Installation and Staged Loading with T-Rex at the Natural Soil Test Panel

(a) Install Sensors, Vertical Static Loading, and Demobilization



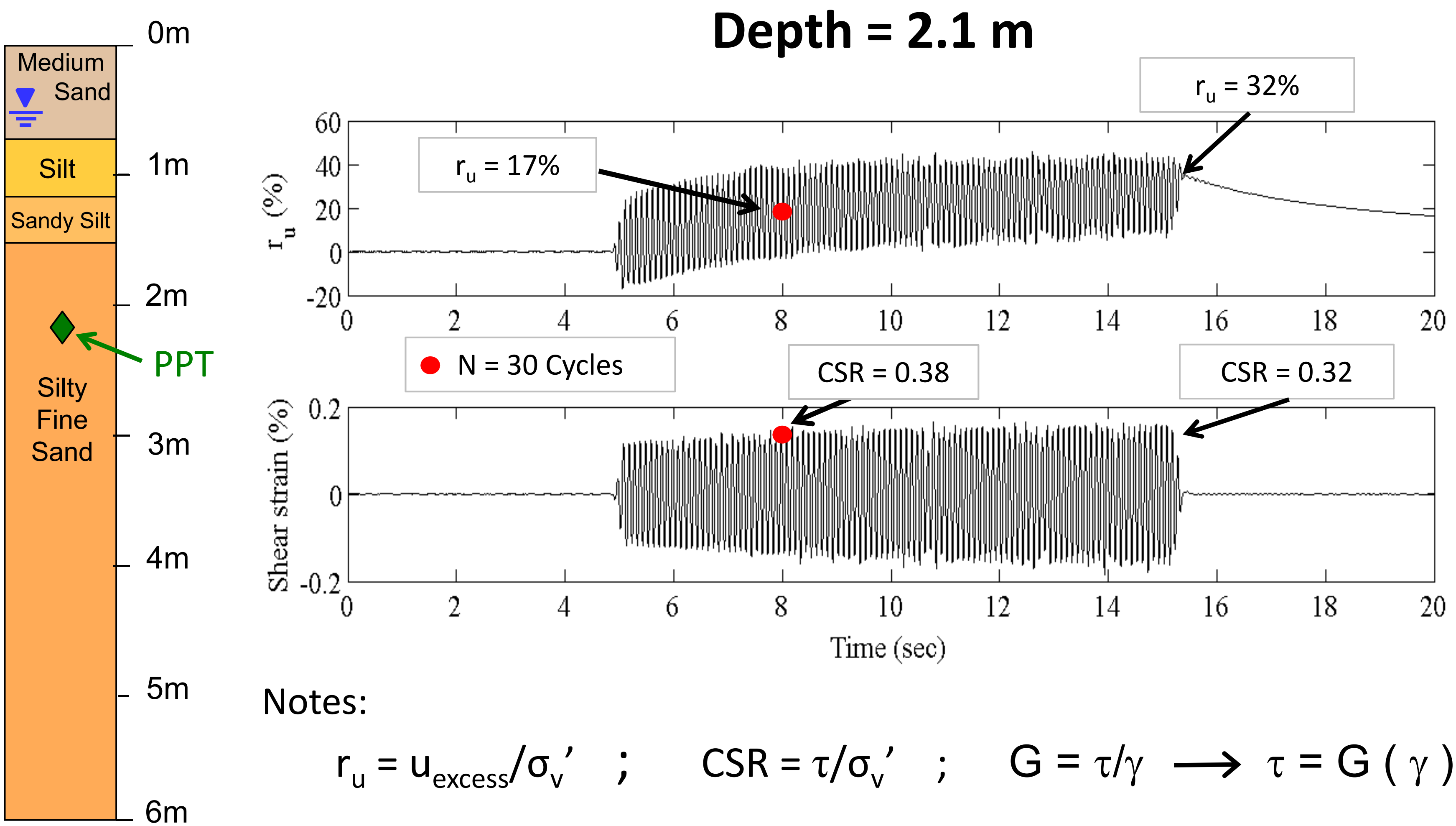
(b) Staged, Horizontal Shaking with T-Rex



Natural Soil Test Panel at Site 6:

Stage 5 - Pore Water Pressure Ratio, r_u, versus Time

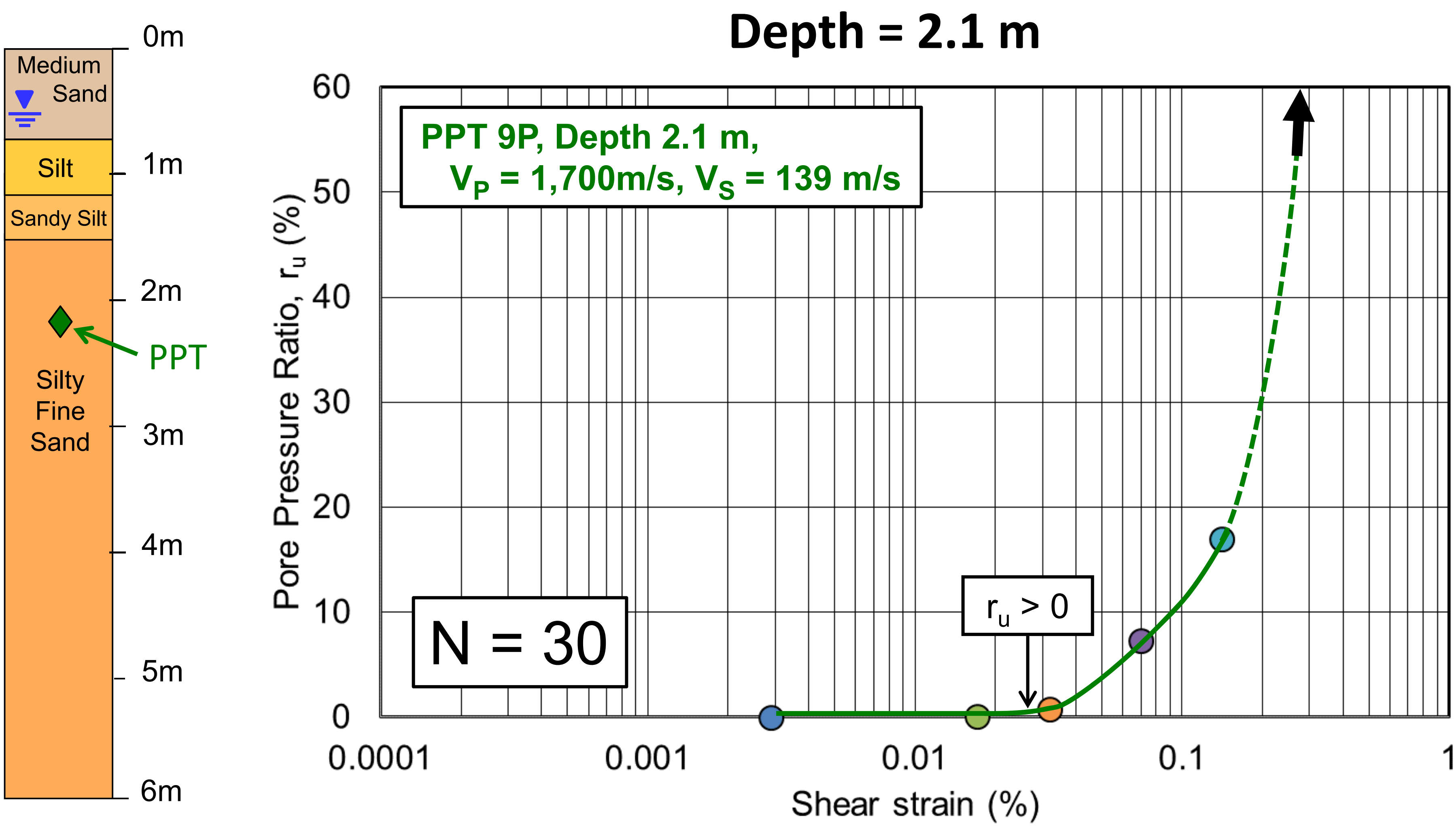
Shaking: 100 cycles at 10 Hz; Stage 5; Peak Horizontal Force ~ 91 kN (20,500 lbs)



Notes:

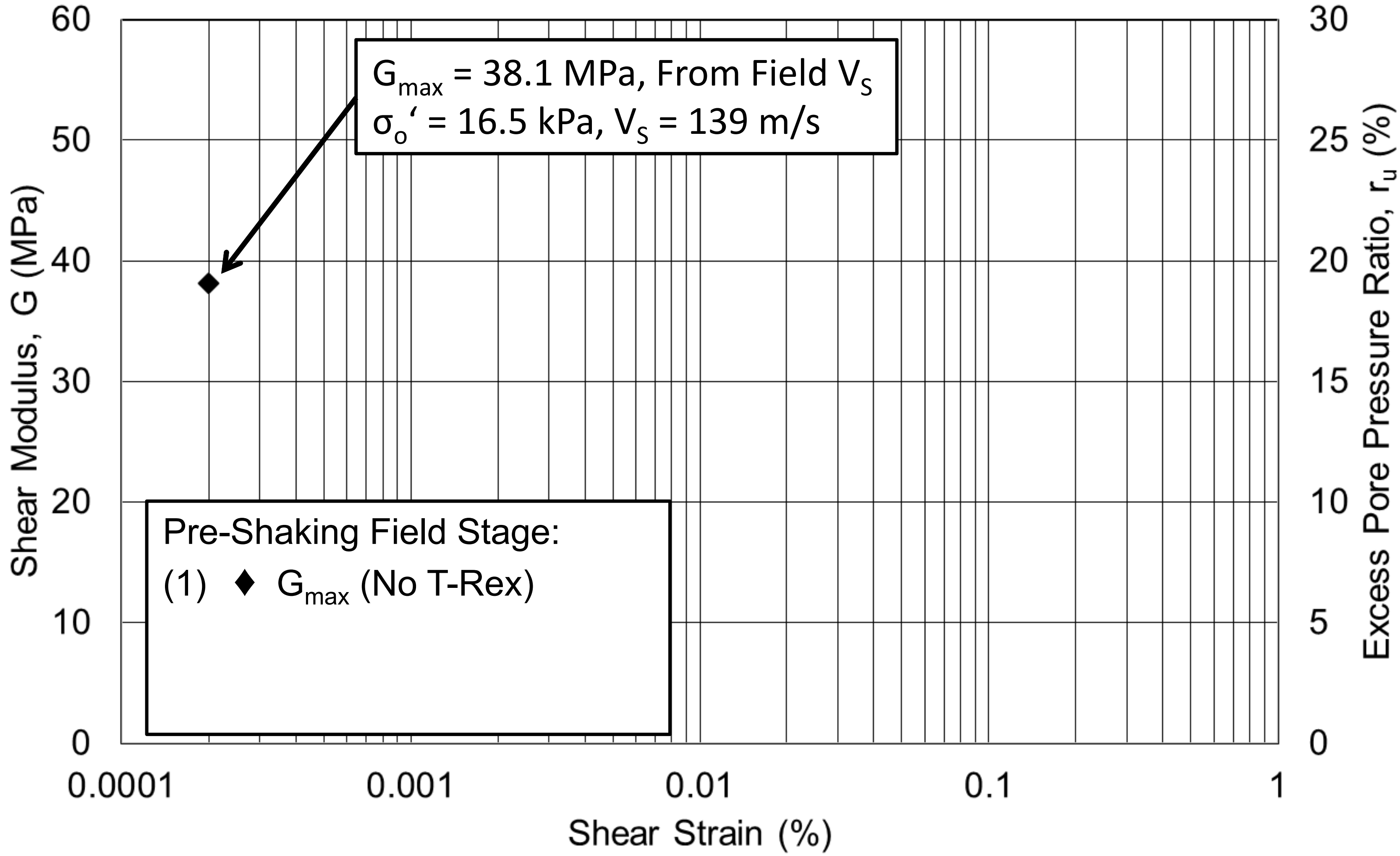
$r_u = u_{excess}/\sigma_v'$; $CSR = \tau/\sigma_v'$; $G = \tau/\gamma \longrightarrow \tau = G(\gamma)$

Stage Testing at Natural Soil Test Panel, Site 6:
r_u versus Log γ after 30 Cycles of Shaking at Each γ

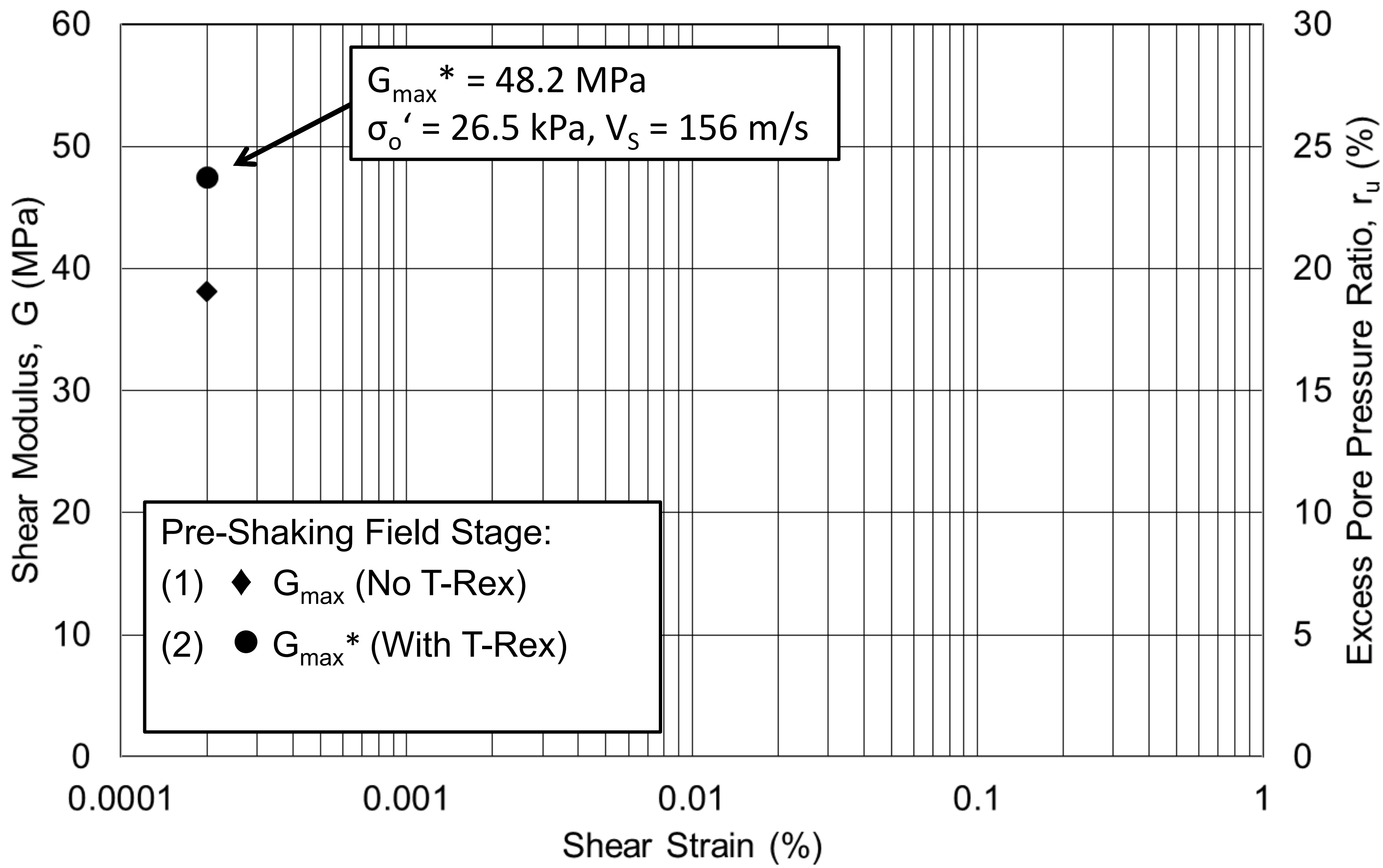


Shaking Stages: Stage 1; Stage 2; Stage 3; Stage 4; Stage 5

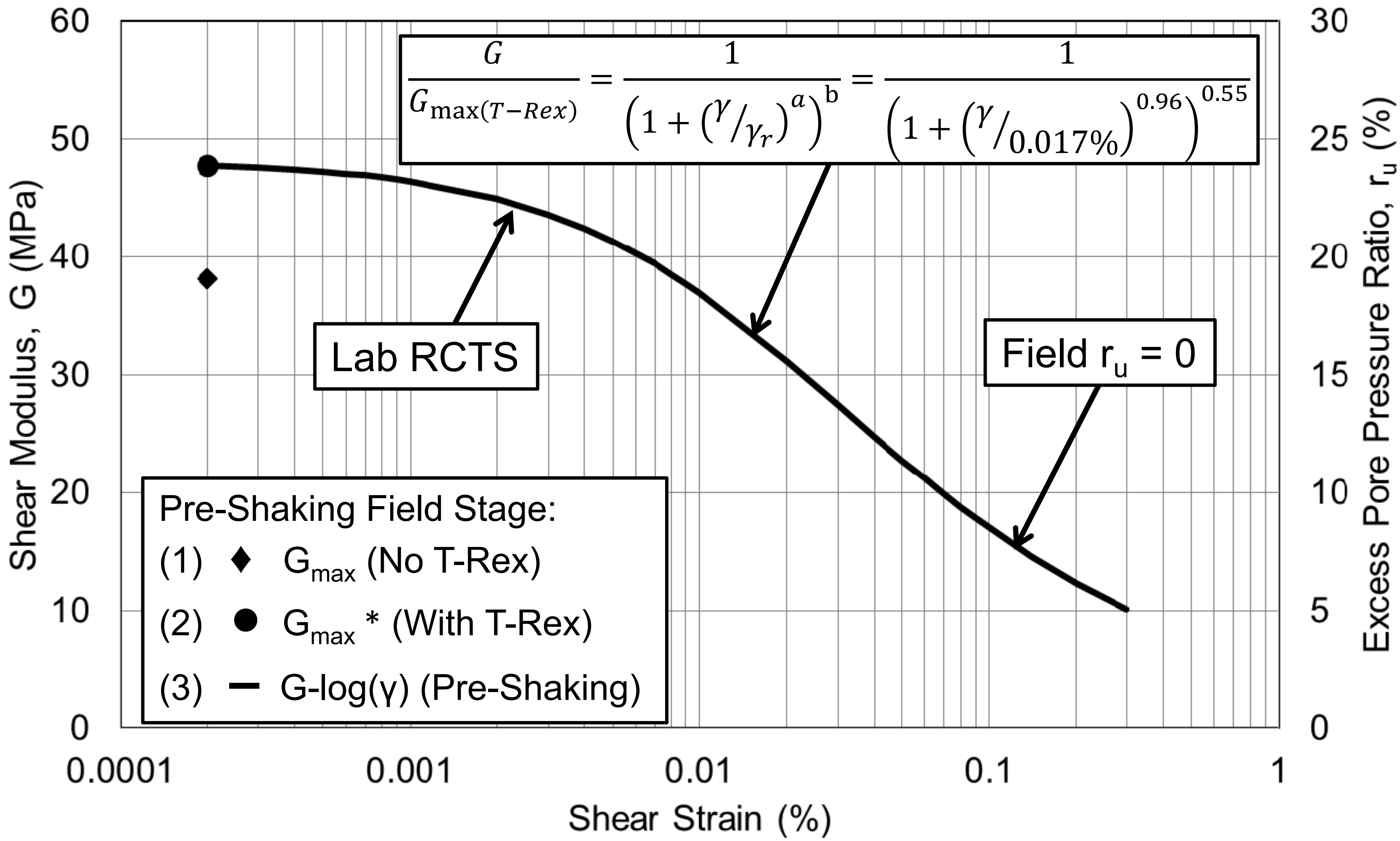
2a. Modeling the Loading of the Natural Soil Test Panel <u>Before</u> T-Rex Shaking: Depth 2.1 m



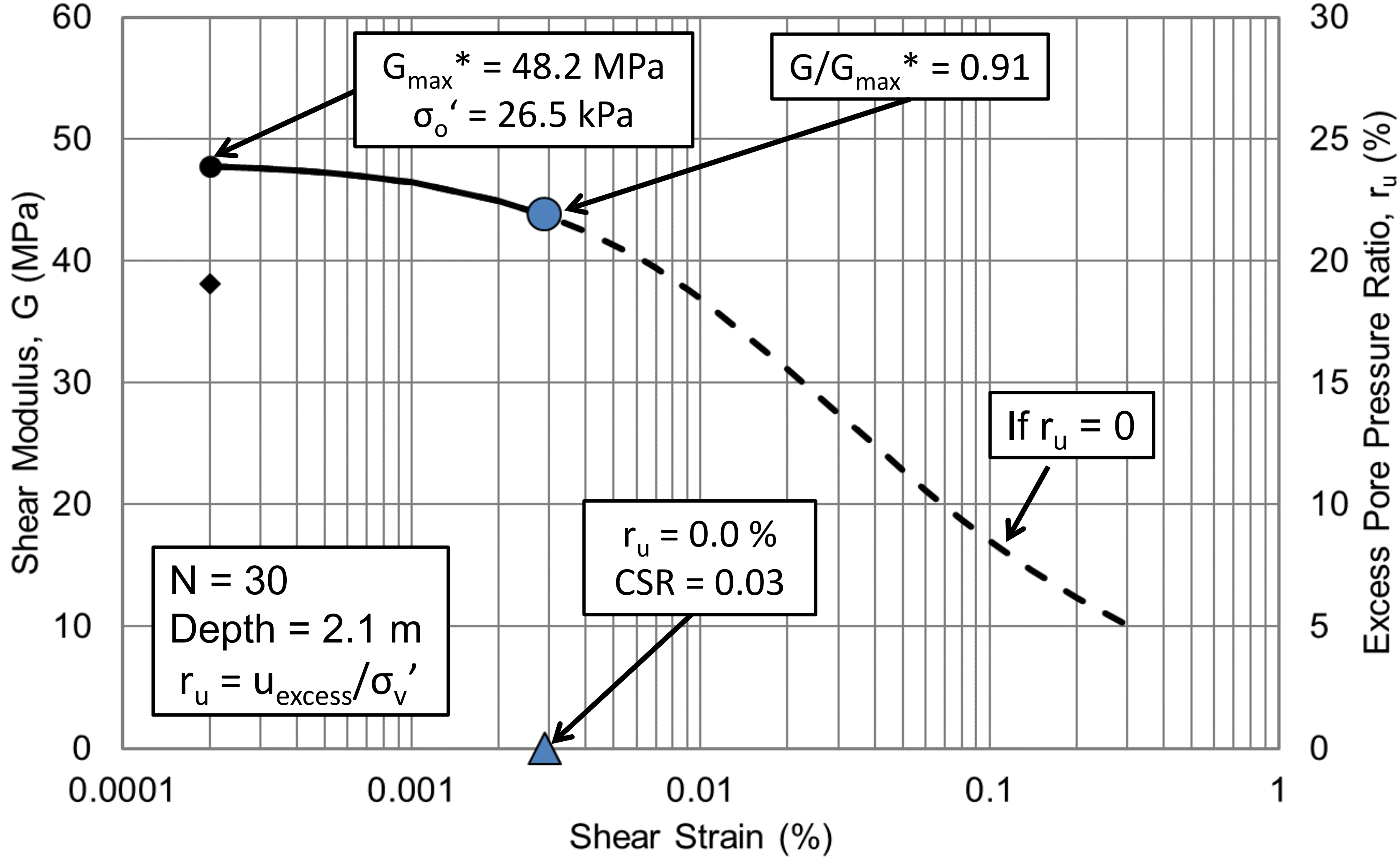
Modeling the Loading of the Natural Soil Test Panel <u>Before</u> T-Rex Shaking: Depth 2.1 m



Modeling the Loading of the Natural Soil Test Panel <u>Before</u> T-Rex Shaking: Depth 2.1 m

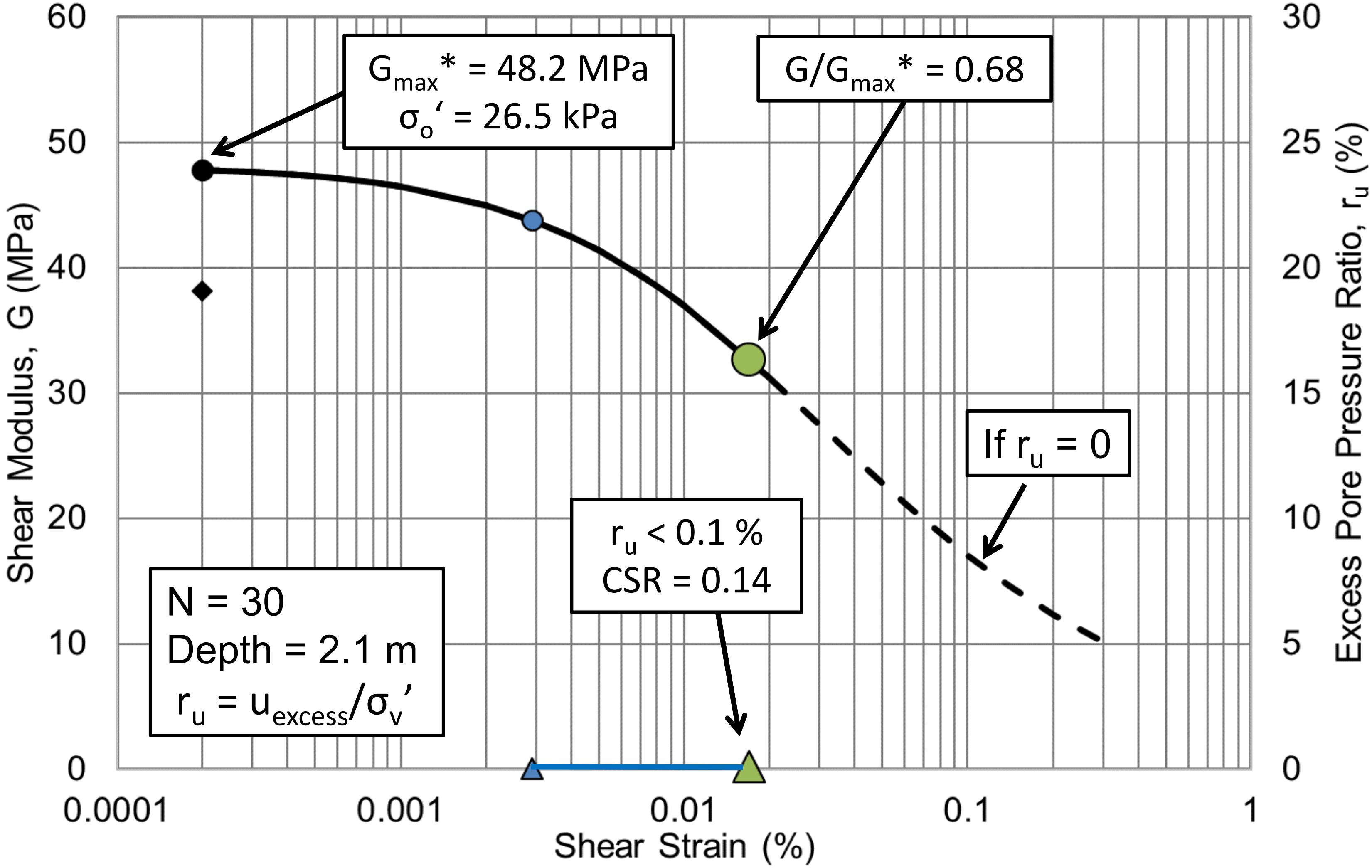


2b. Modeling the Loading of the Natural Soil Test Panel During T-Rex Shaking: with Measured Values of r_u



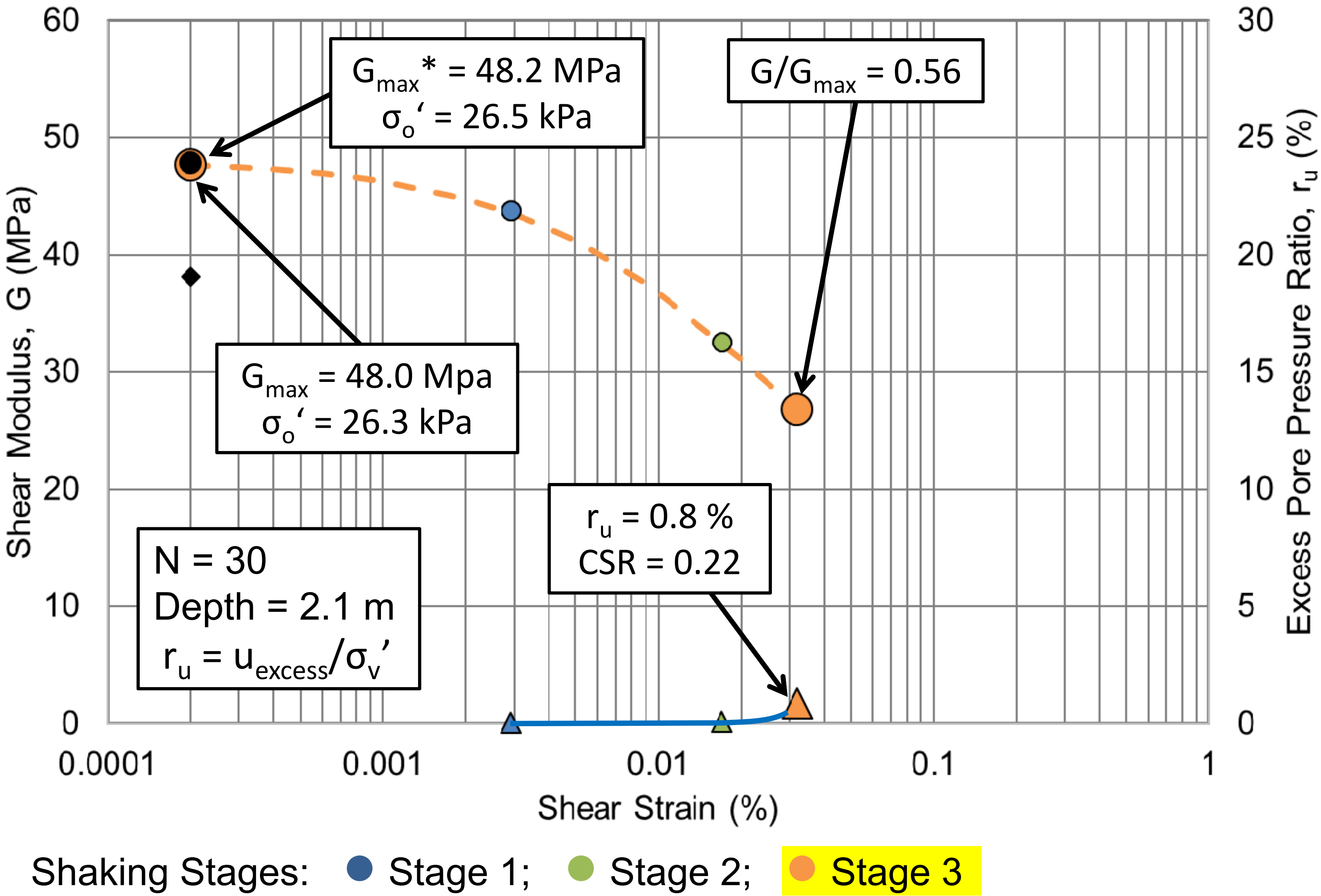
Shaking Stages: Stage 1

Modeling the Loading of the Natural Soil Test Panel During T-Rex Shaking: with Measured Values of r_u

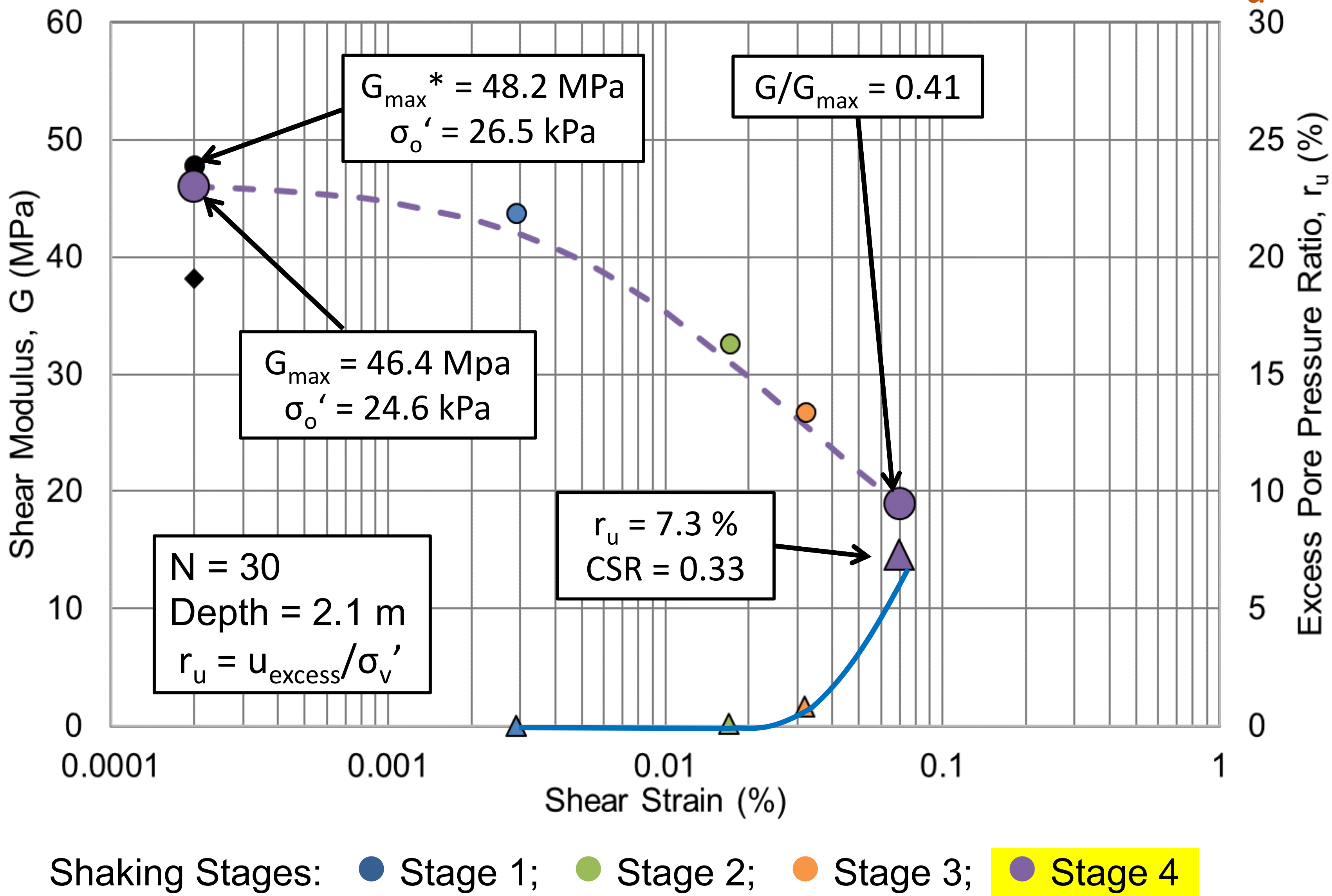


Shaking Stages: Stage 1; Stage 2

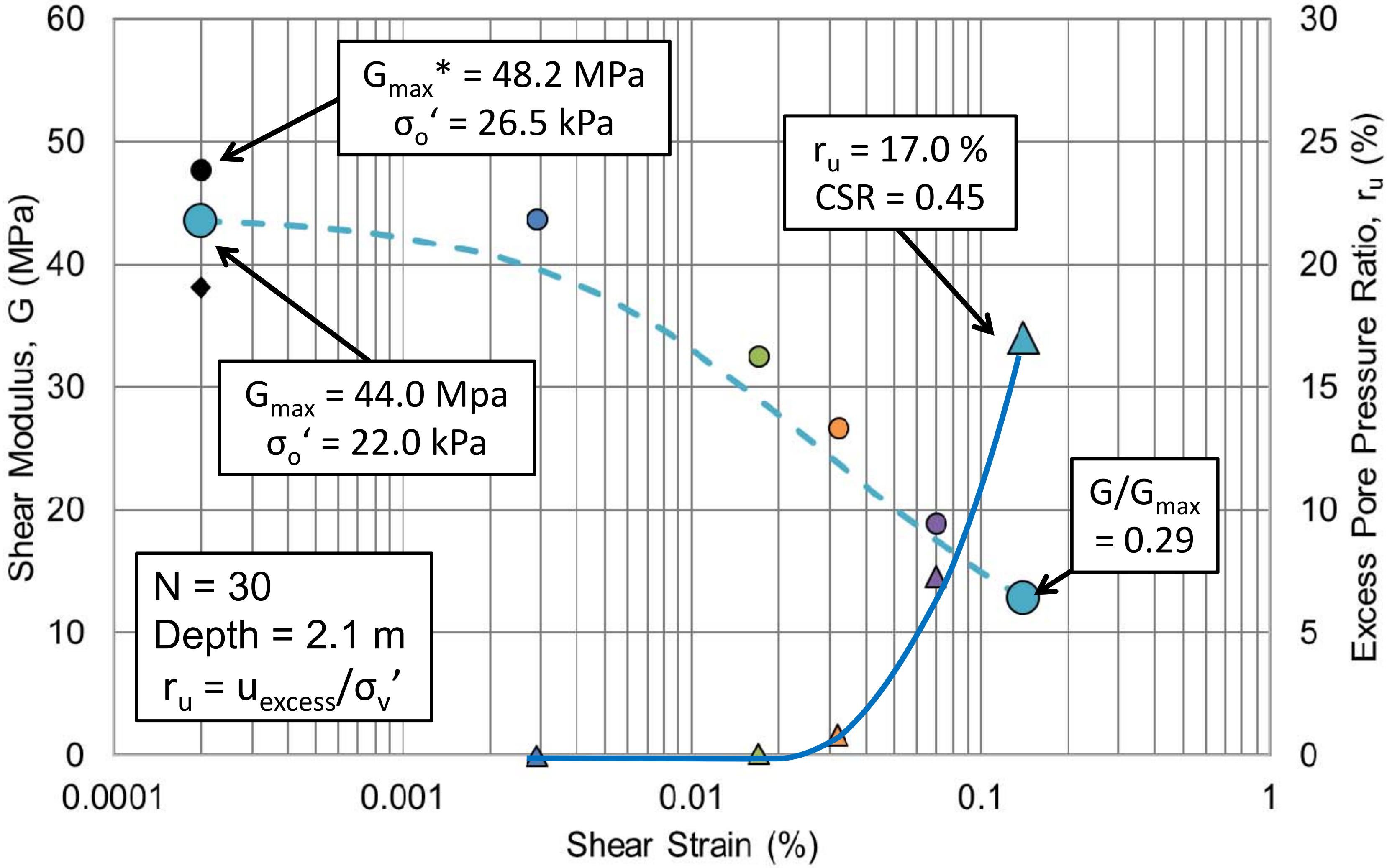
Modeling the Loading of the Natural Soil Test Panel During T-Rex Shaking: with Measured Values of r_u



Modeling the Loading of the Natural Soil Test Panel During T-Rex Shaking: with Measured Values of r_u

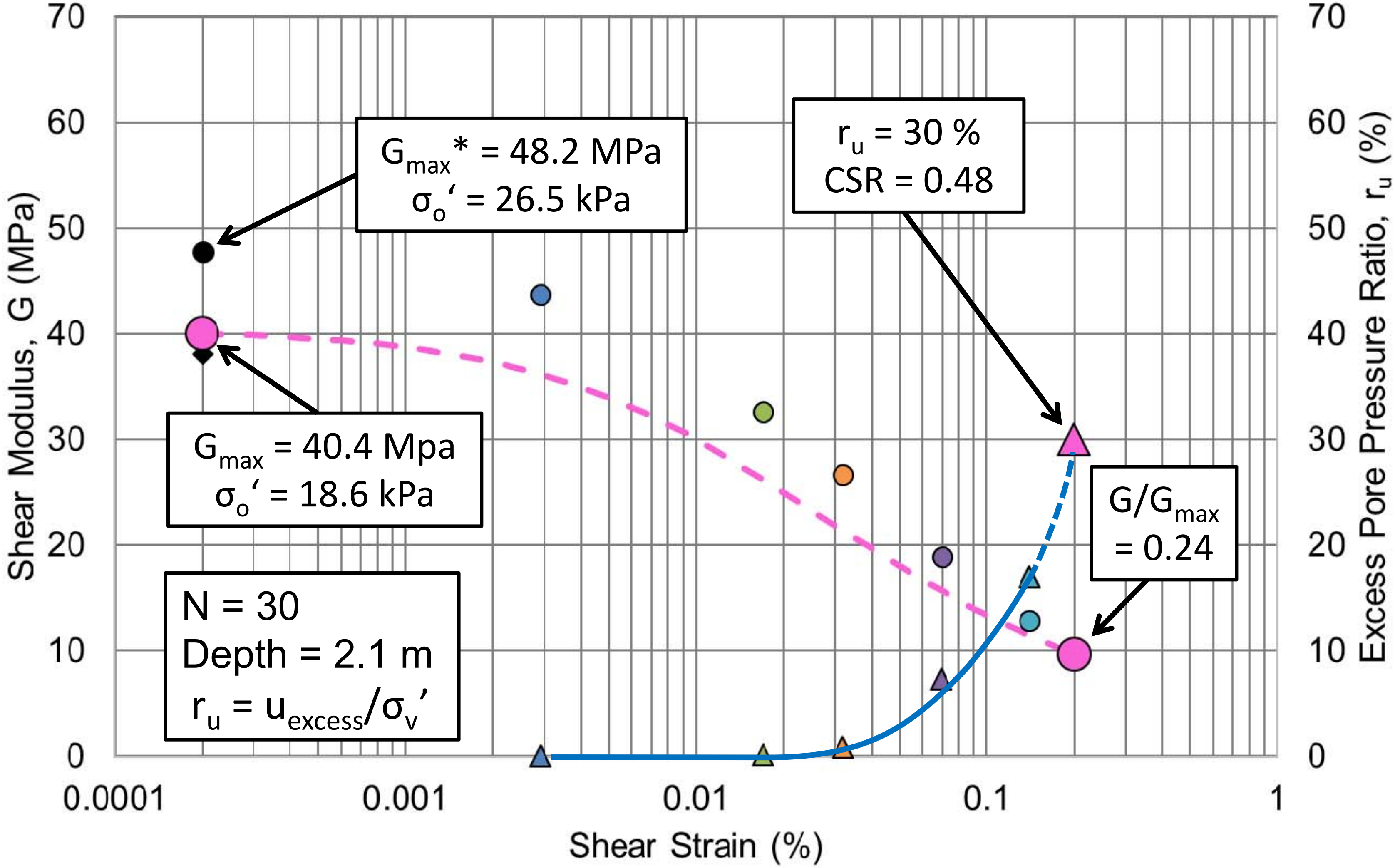


Modeling the Loading of the Natural Soil Test Panel During T-Rex Shaking: with Measured Values of r_u



Shaking Stages: Stage 1; Stage 2; Stage 3; Stage ;4 Stage 5

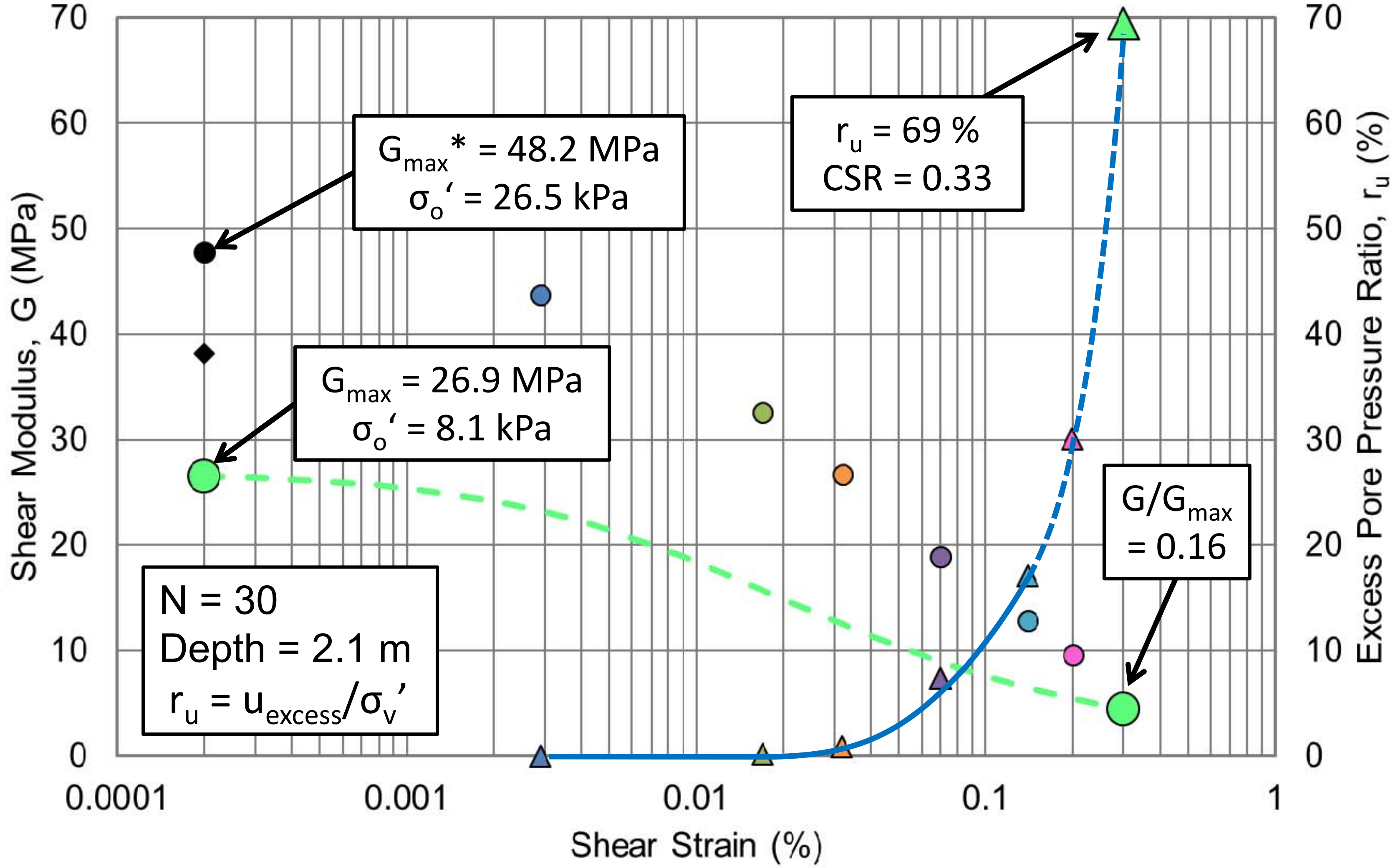
2c. Predicting the Response of the Natural Soil Test Panel at High Levels of Shaking: with Estimated Values of r_u



Shaking Stages: Stage 1; Stage 2; Stage 3; Stage 4; Stage 5

Predicted Shaking Results: Stage 6

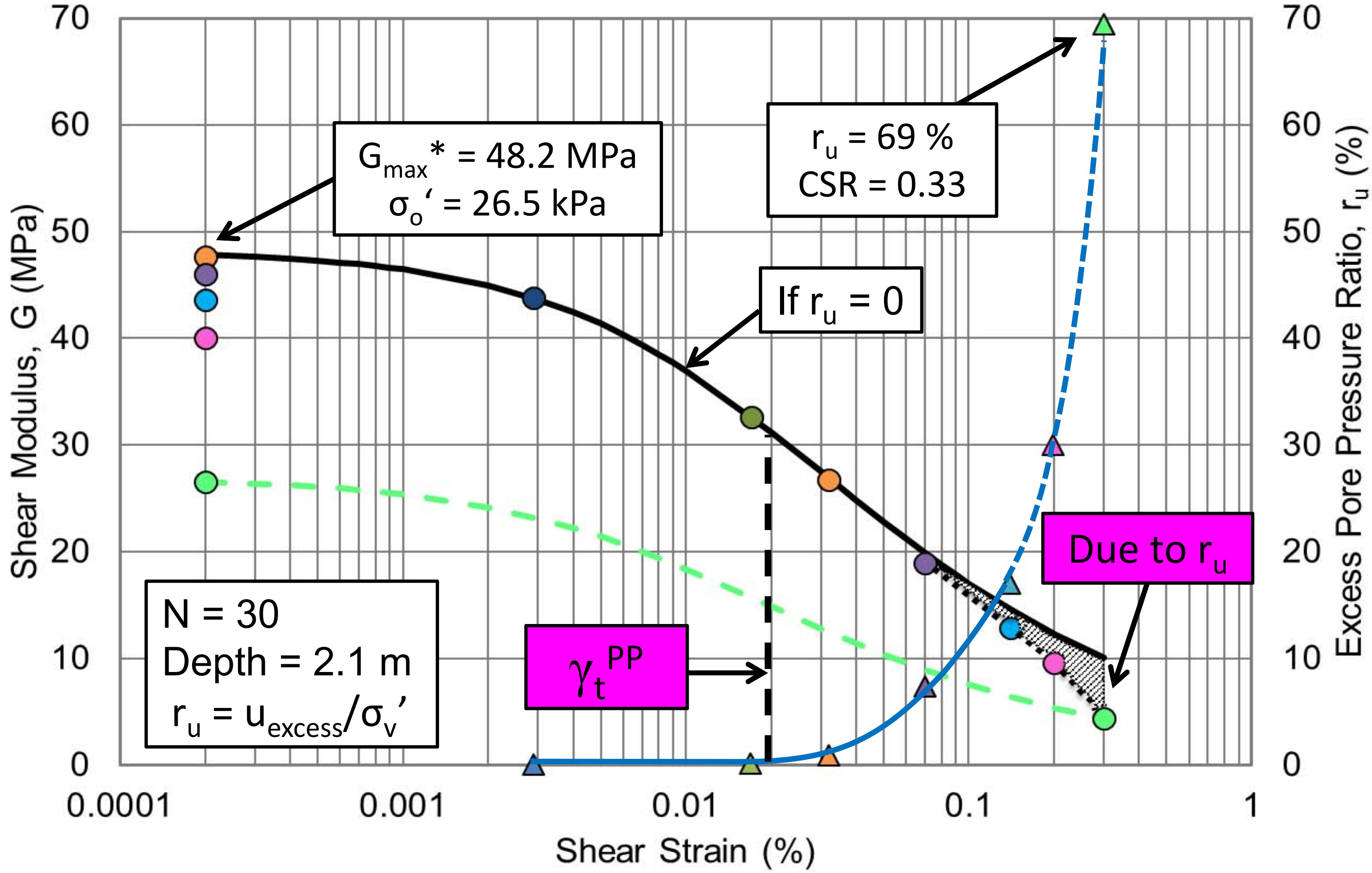
Predicting the Response of the Natural Soil Test Panel at High Levels of Shaking: with Estimated Values of r_u



Shaking Stages: Stage 1; Stage 2; Stage 3; Stage 4; Stage 5

Predicted Shaking Results: Stage 6; Stage 7 (G/G_{max}* = 0.09)

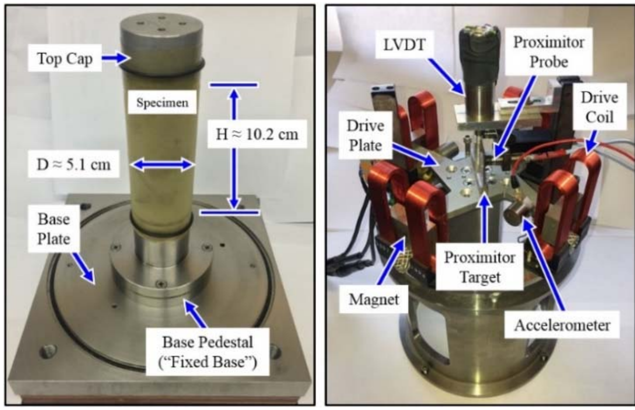
2d. Comparing the Response of the Natural Soil Test Panel at High Levels of Shaking: with and without r_u



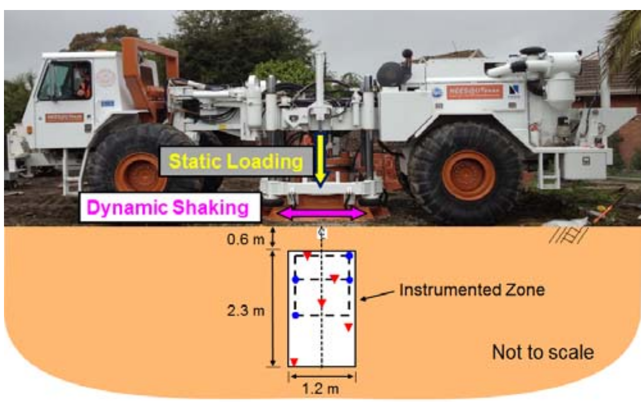
Shaking Stages: Stage 1; Stage 2; Stage 3; Stage 4; Stage 5

Predicted Shaking Results: Stage 6; Stage 7

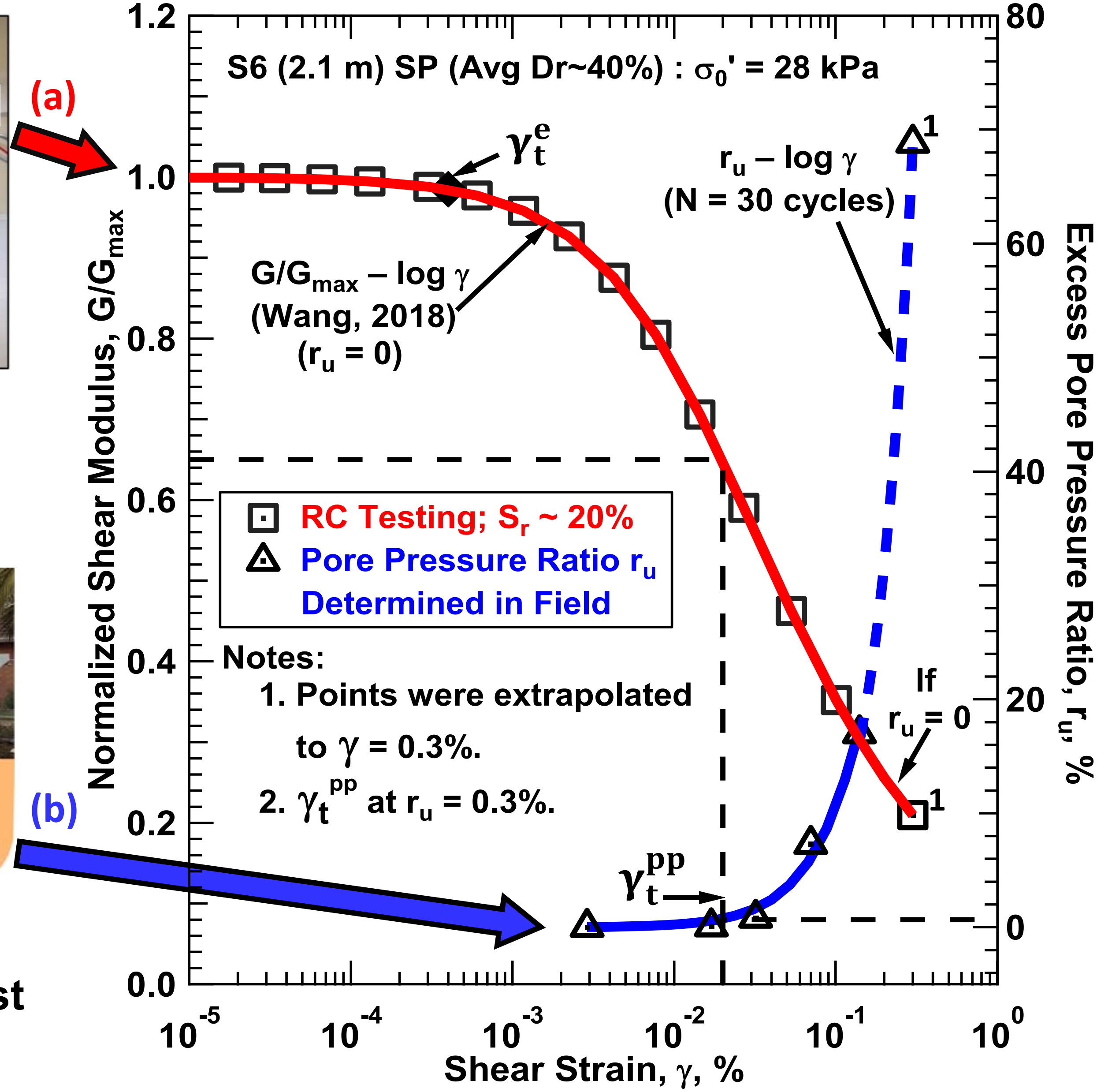
3. Combining the Laboratory G/G_{max} – Log γ Data (a) and the In-Situ r_u – Log γ Data (b)



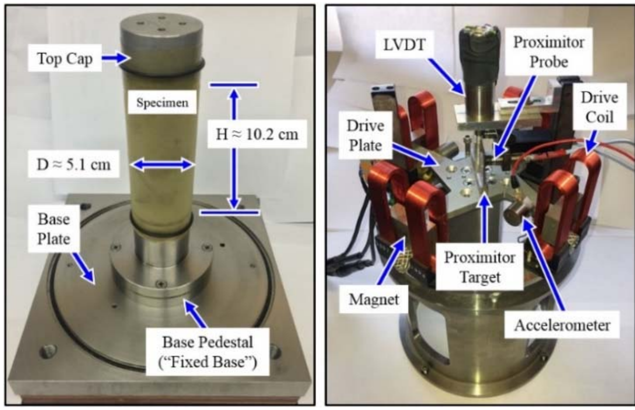
Laboratory RC Test



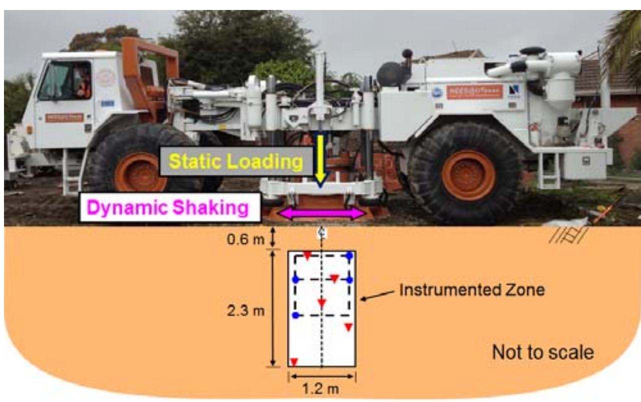
In-Situ T-Rex Shaking Test



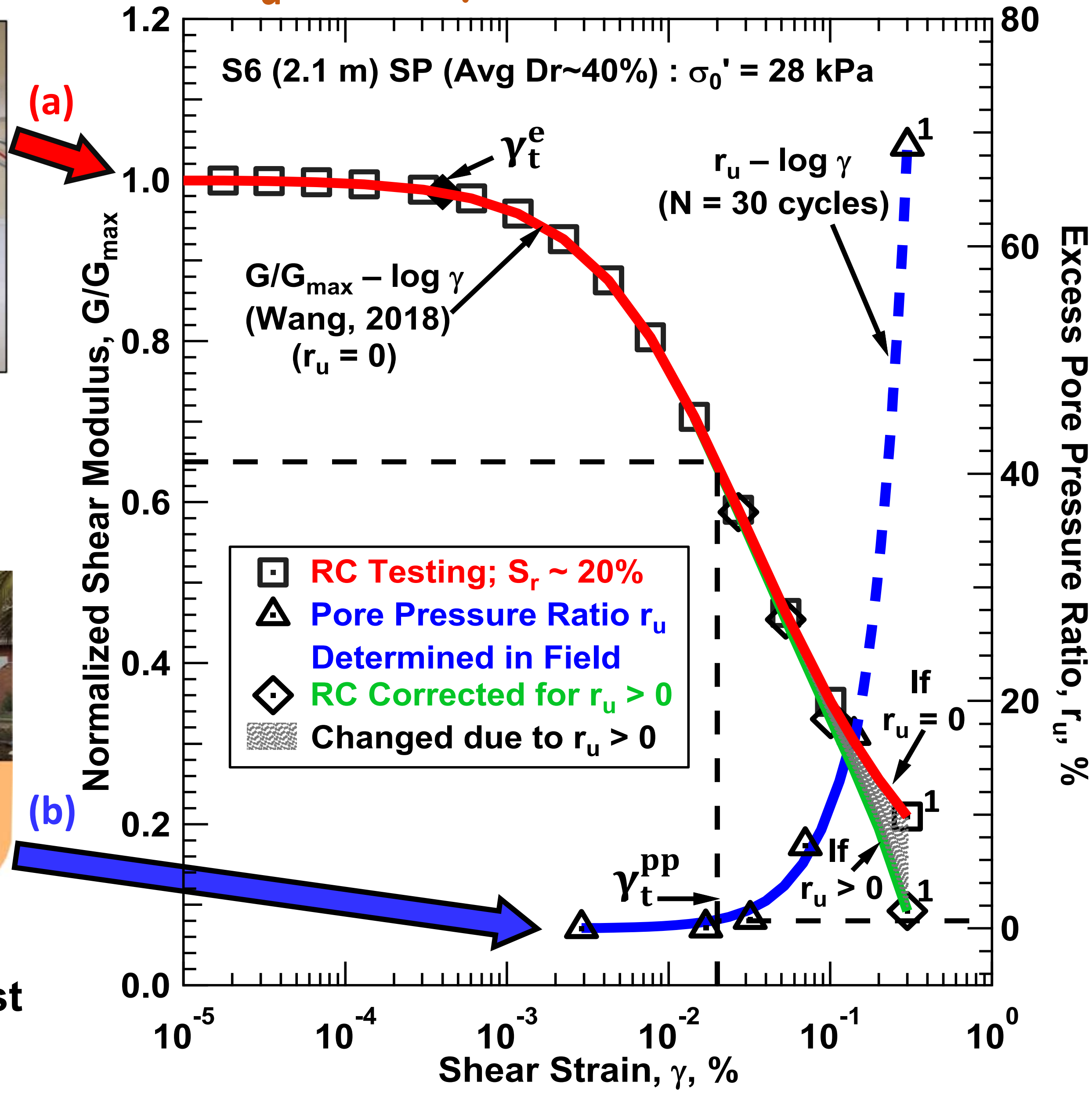
Combining the Laboratory G/G_{max} – Log γ Data (a) and the In-Situ r_u – Log γ Data (b)



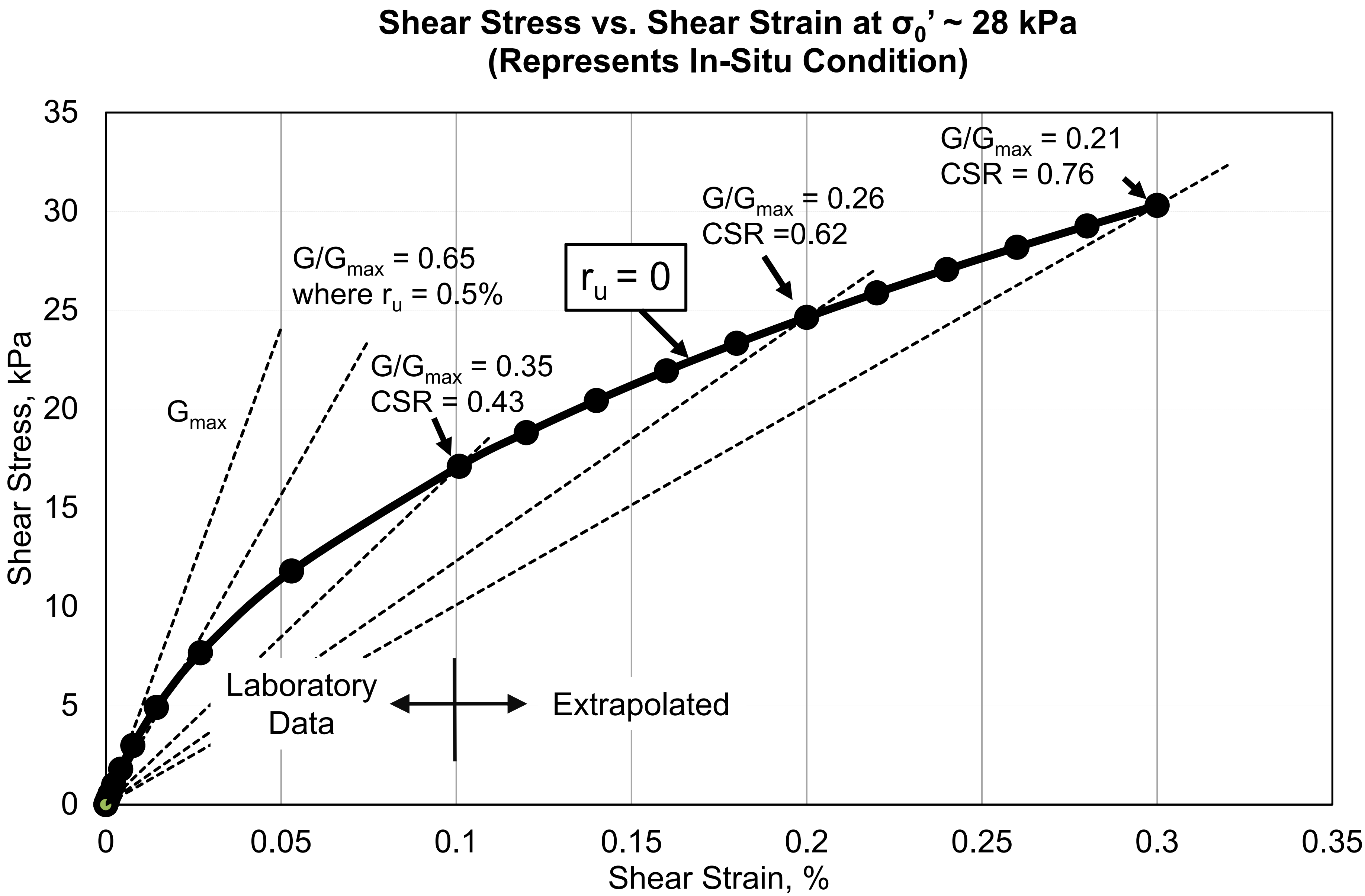
Laboratory RC Test



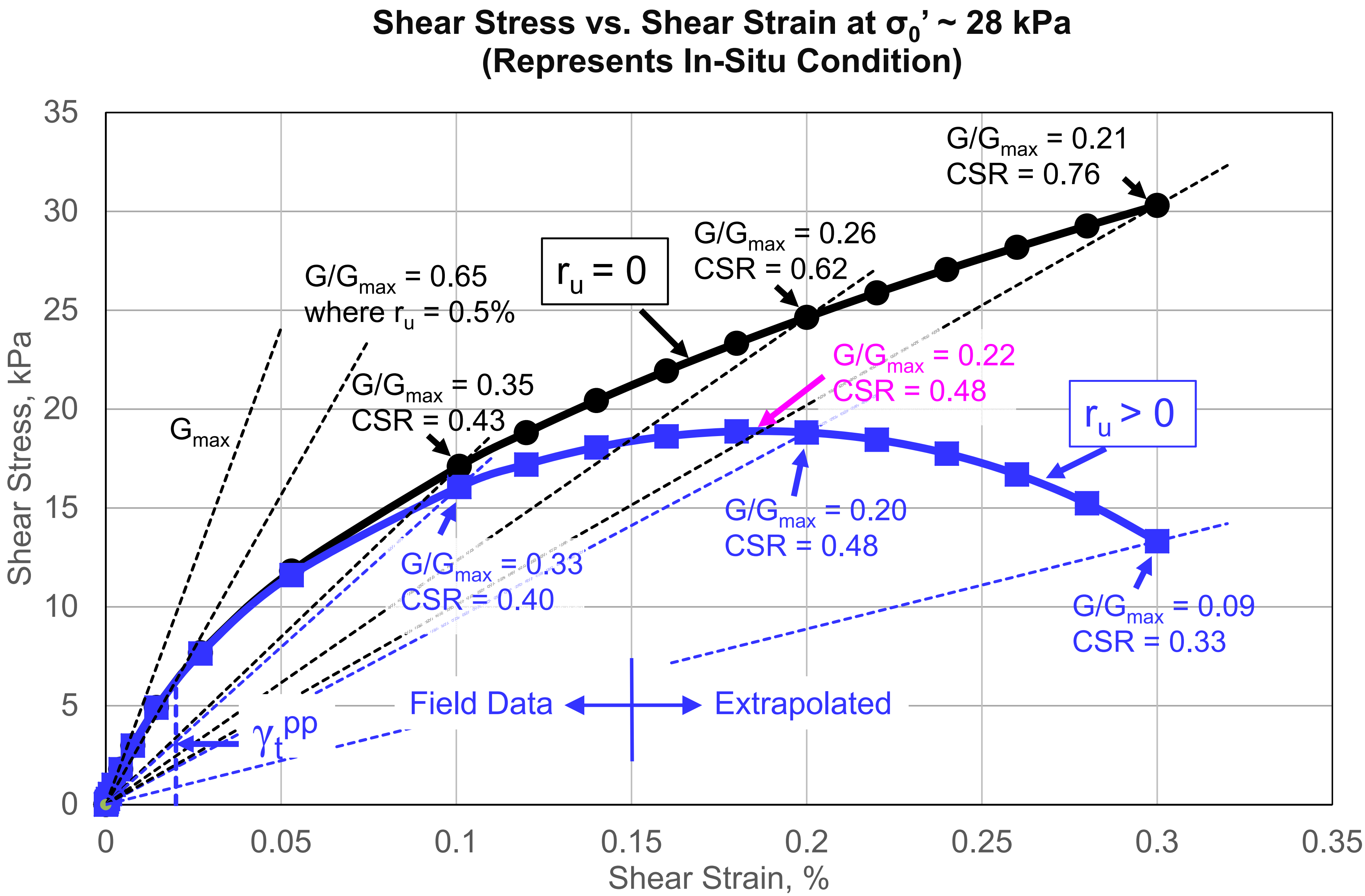
In-Situ T-Rex Shaking Test



Creating the $\tau - \gamma$ Curve for $r_u = 0$ from the Laboratory G/G_{max} – Log γ Data and the In-Situ G_{max}*



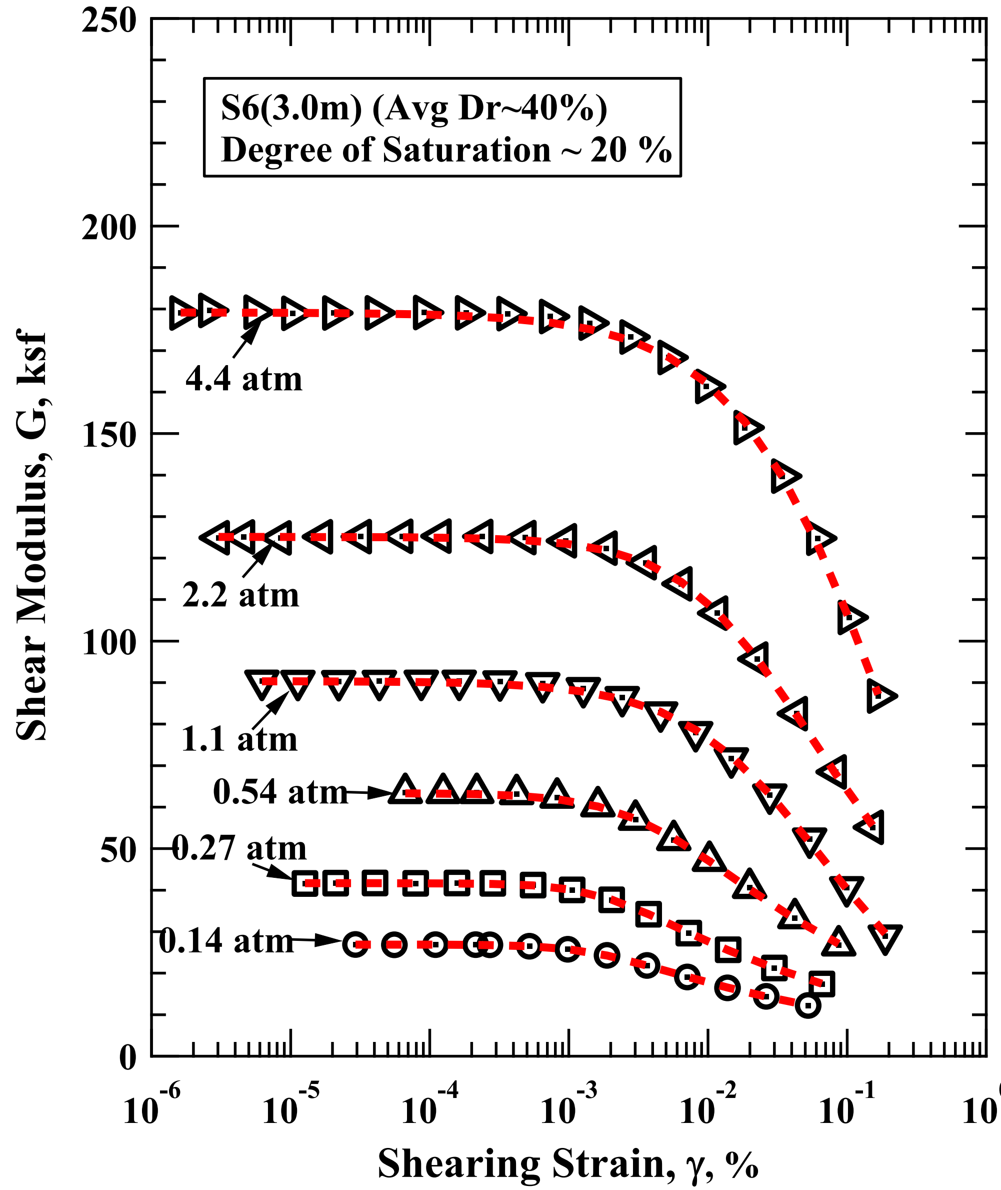
Creating the τ – γ Curve for $r_u > 0$ from the Laboratory G/G_{max} – Log γ Data and the In-Situ G_{max}*



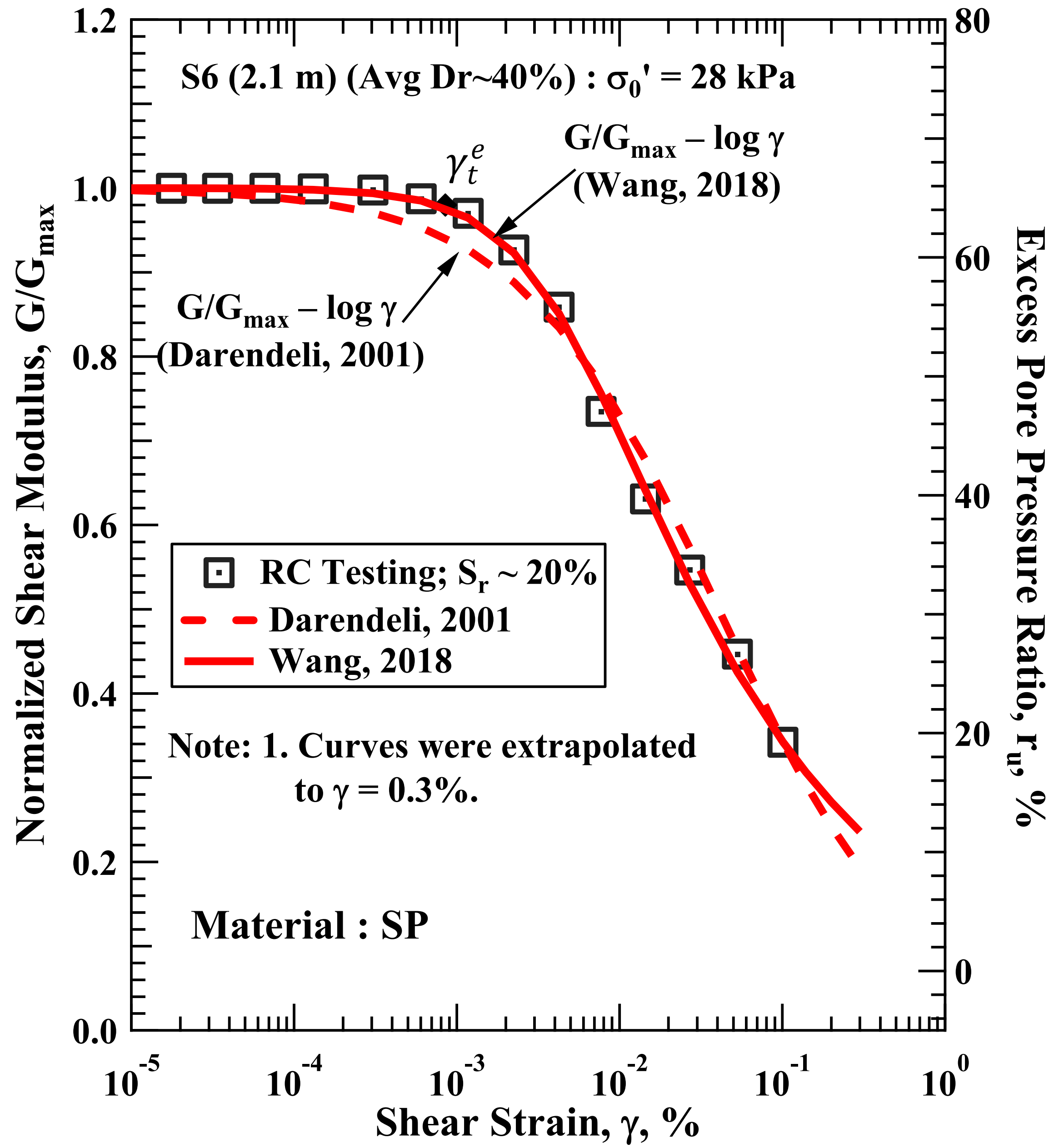
4a. Improved Laboratory Testing and Modeling Using Combined Dynamic Resonant Column (RC) and Cyclic Torsional Shear (TS) Equipment

RC Testing:

1. More Data from Non-Plastic Sandy Soils.
2. Wide Range in Effective Confining Pressures, σ_0'= 0.14 to 14 atm.
3. Wide Range in Strains, $\gamma \sim 10^{-5}$ % to 0.3 % or more.
4. Model for the G- Log γ Relationship is: $G = G_{max} (1/(1 + (\gamma/\gamma_r)^a)^b)$



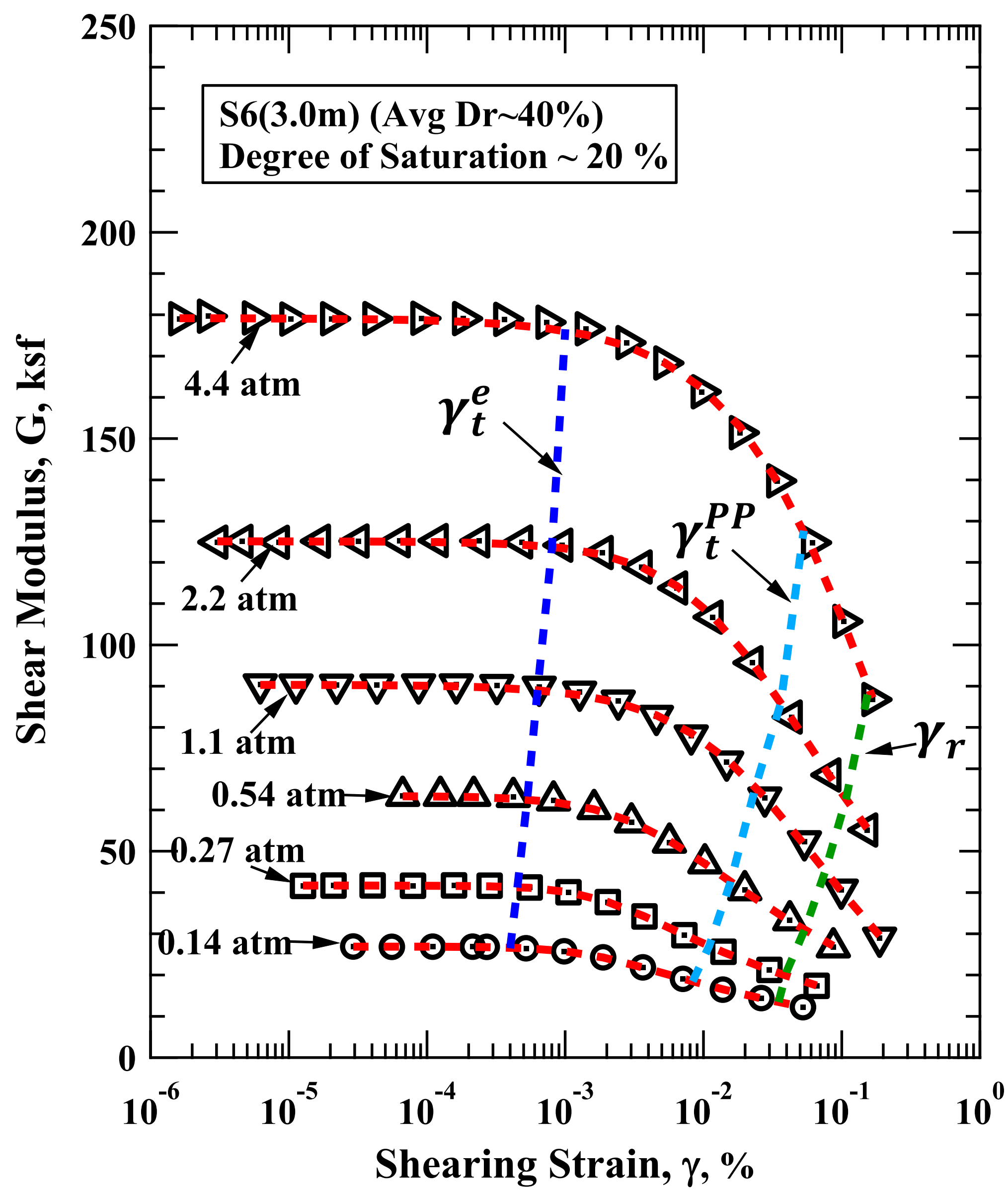
More Effective Constitutive Model for Sands (SP, SW, and SM)



Improved Laboratory Testing and Modeling Using Combined Dynamic Resonant Column (RC) and Cyclic Torsional Shear (TS) Equipment

TS Testing:

1. Testing Hollow Specimens.
2. Evaluating Effects of S_r and N.
3. Determining γ_t^{PP} (Threshold for Pore Pressure Generation).
4. Model for the G – Log γ Relationship is
   $G = G_{max} (1/(1 + (\gamma/\gamma_r)^a)^b)$



Pore Water Pressure Generation Data from Laboratory TS Test (0.54 atm, Strain = 0.05%, N = 30 cycles)