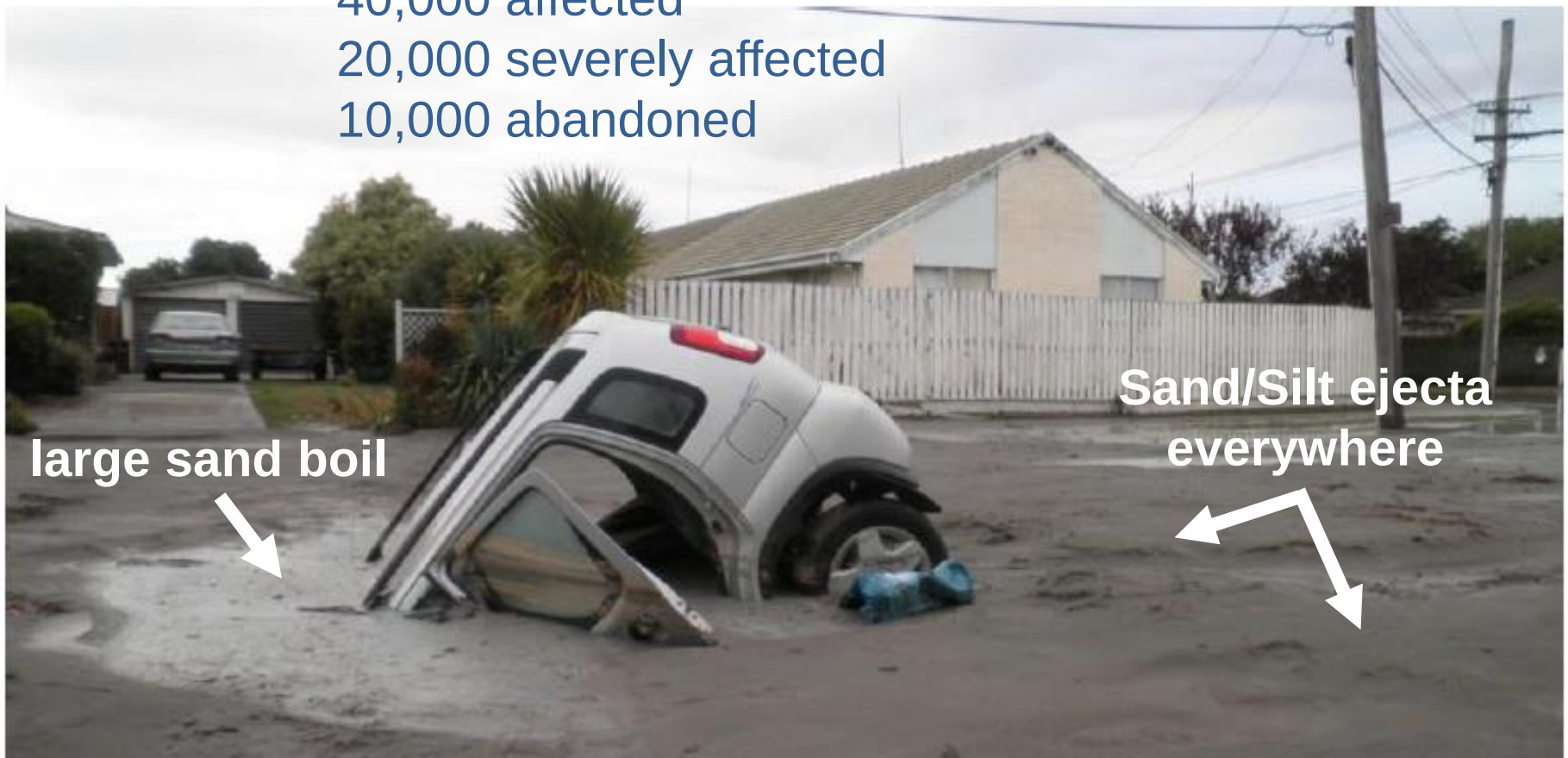
Effectiveness of Inhibiting Liquefaction Triggering by Shallow Ground Improvement Methods: Field Shaking Trials with T-Rex at One Area in Christchurch, NZ

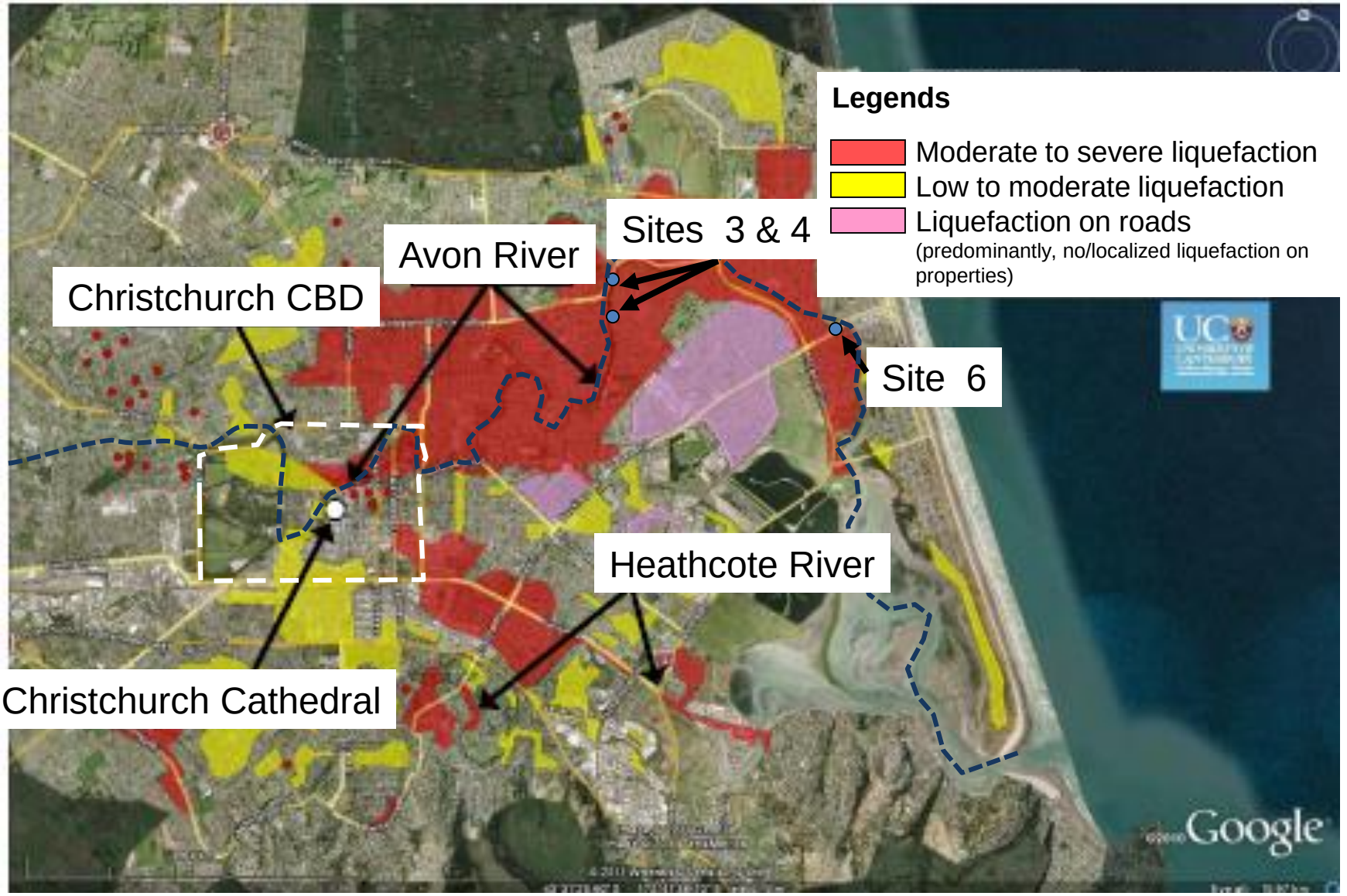
T-Rex and the NEES@UTexas Team Preparing to Begin Testing

Summary of Effects: 22 Feb. 2011 EQ., M_w 6.2

- 185 fatalities
- CBD gone: 2,400 buildings demolished (out of 3,000)
- Total economic loss approx. 40 billion NZ dollars; 20% of New Zealand's GDP
- Liquefaction effects on residential properties:
  - 40,000 affected
  - 20,000 severely affected
  - 10,000 abandoned

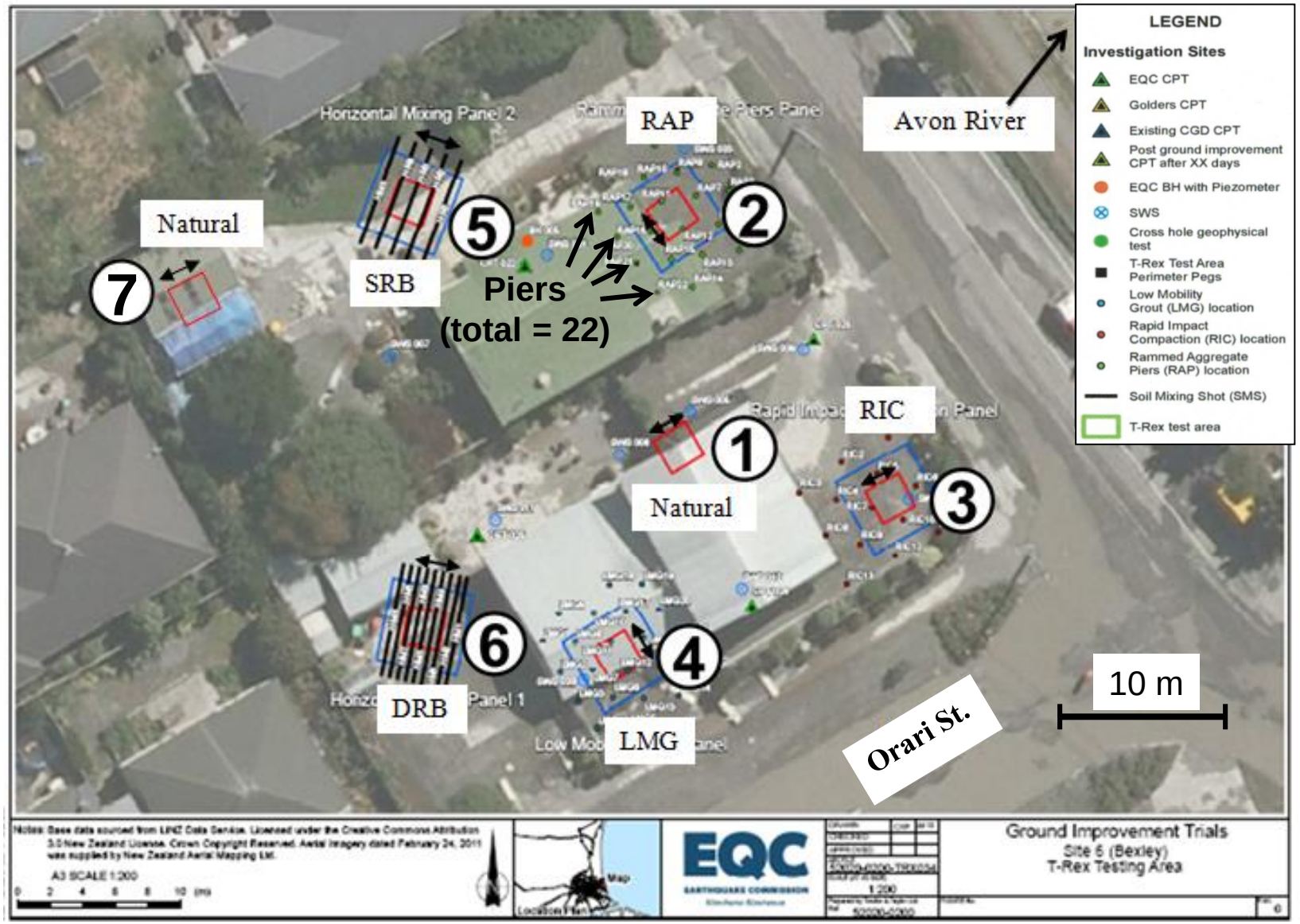


Approach: Field Shaking and Blasting Tests; Three Test Locations: Sites 3, 4 and 6

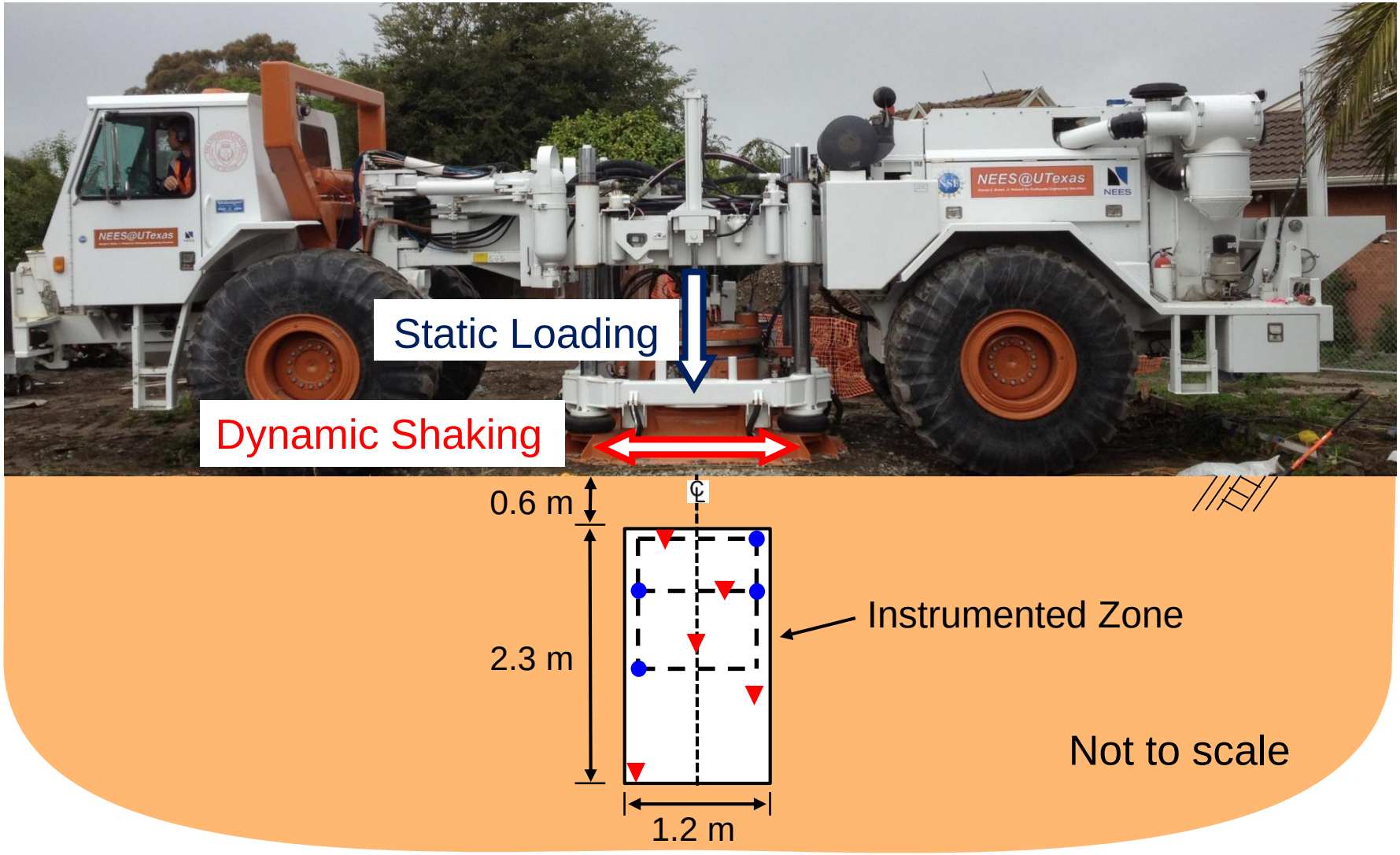


Field Trials: Plan View of Site 6 with Seven Test Panels

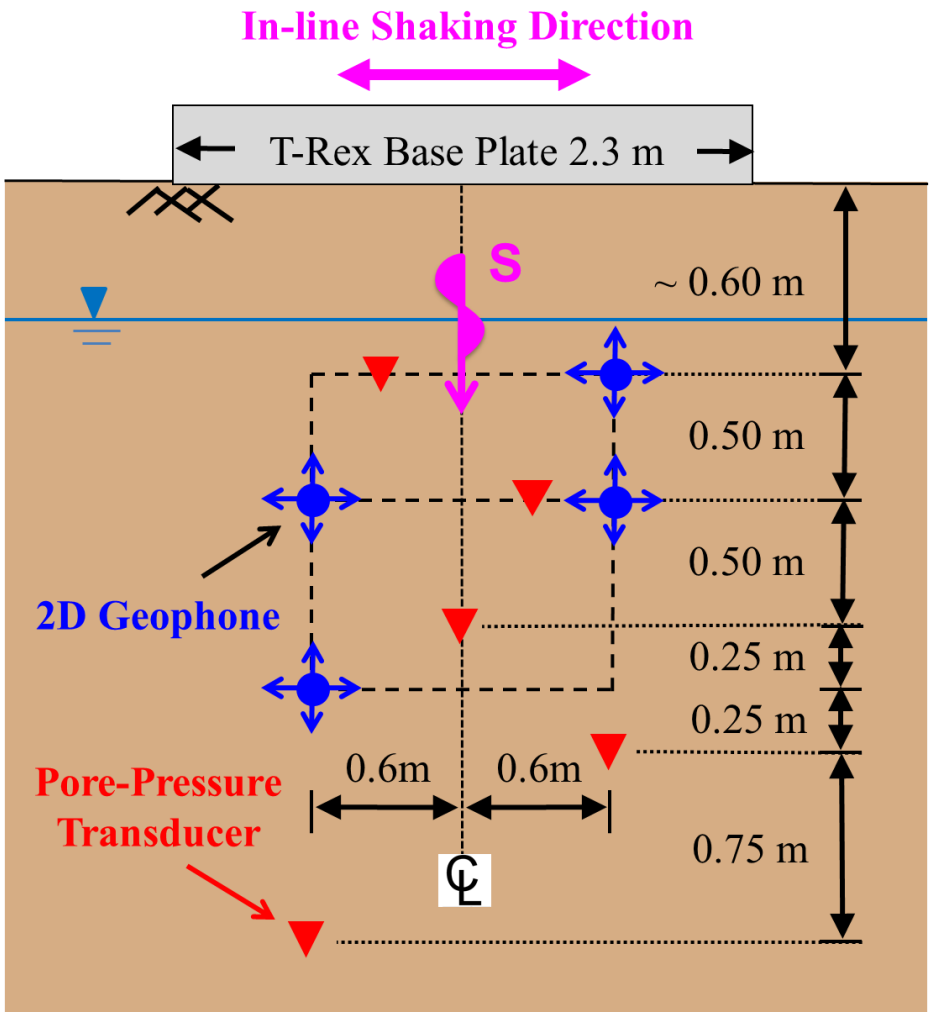
(Ariel Photograph Before Homes Removed.)



T-Rex Shaking of Each Test Panel: Location of Embedded Sensors



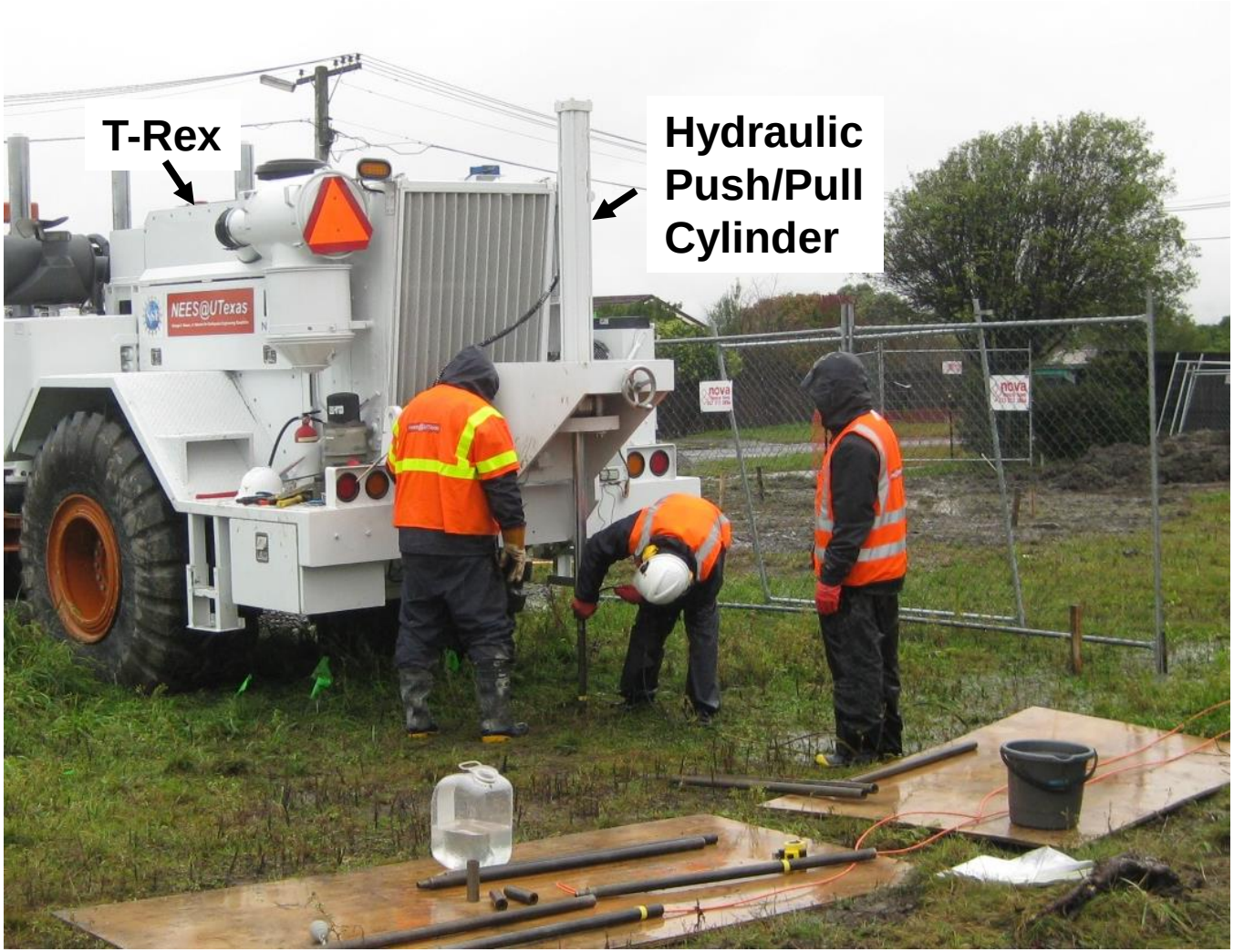
Generalized Arrangement of Sensors at the Natural Soil and RIC Test Panels at Site 6



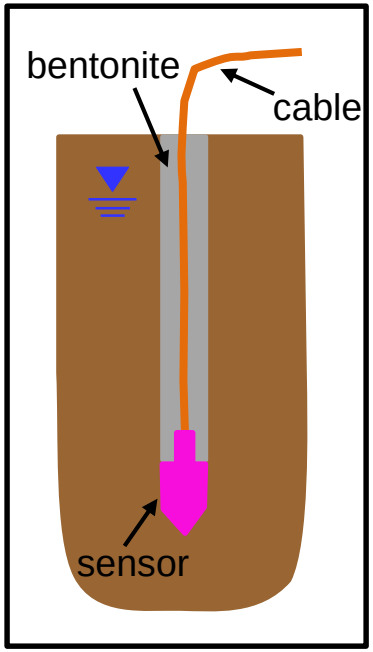
(a) Cross Section

(b) Instrumentation

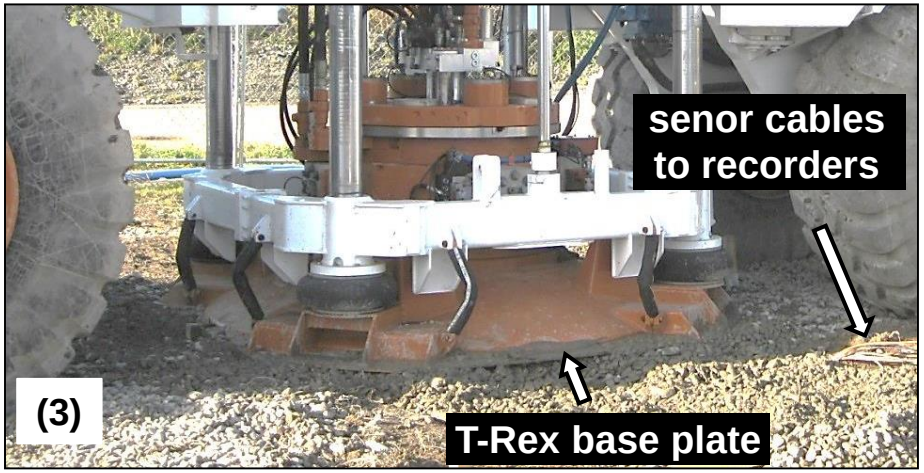
Pushing Geophones and Pore-Pressure Transducers with T-Rex



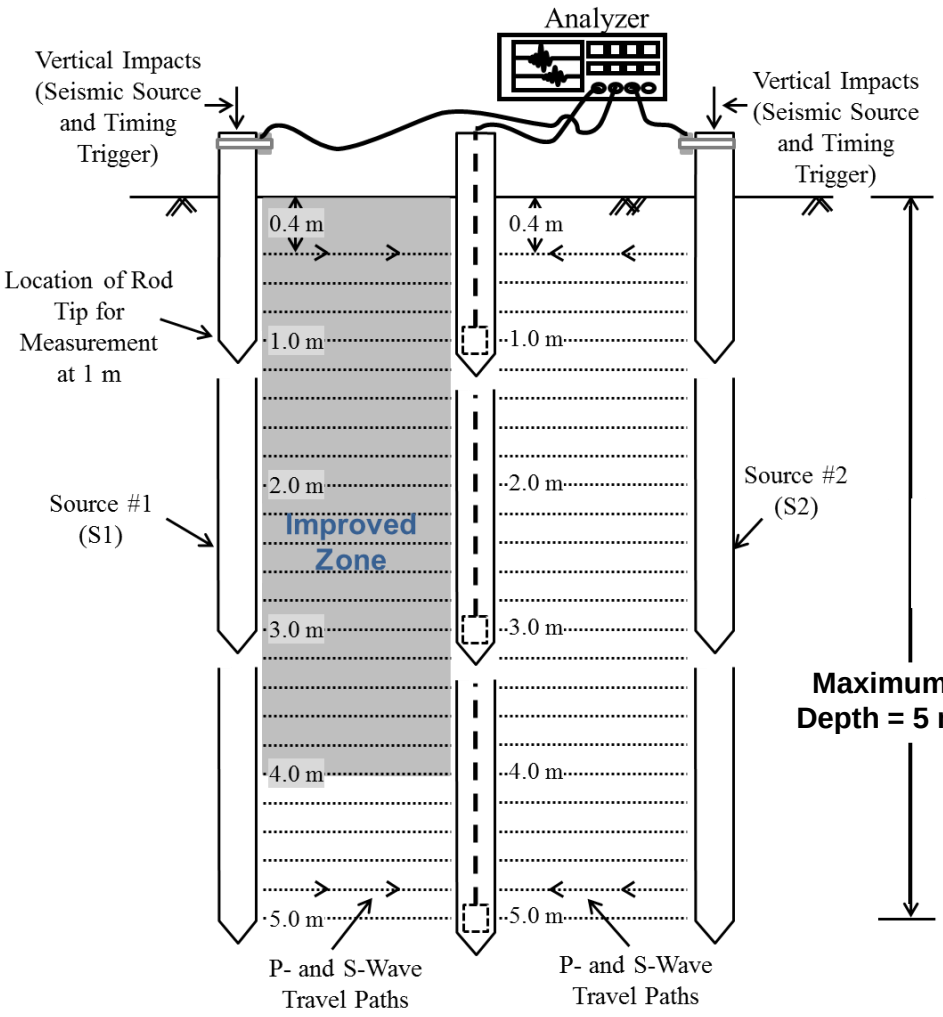
Sensor Installation

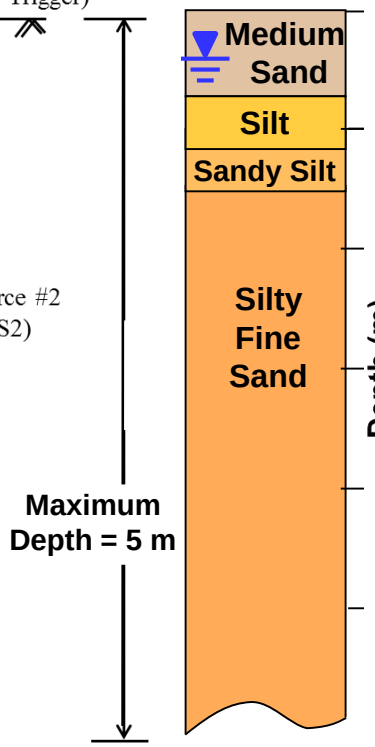


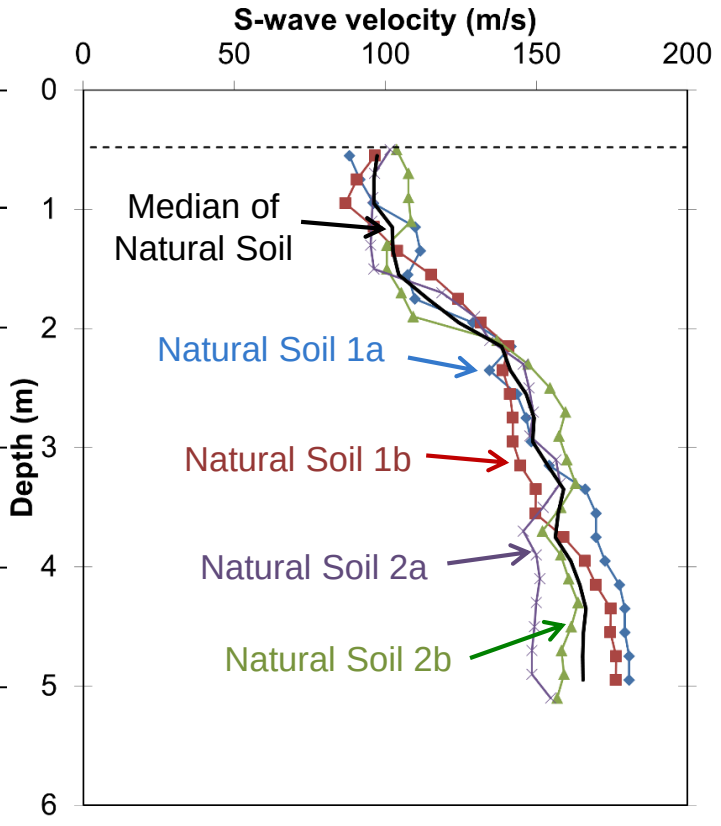
Preparing for T-Rex Shaking: (1) Burying Sensor Cables in Native Soil, (2) Placing Gravel Pad, (3) Load with T-Rex Overnight and (4) T-Rex Shaking and Recording



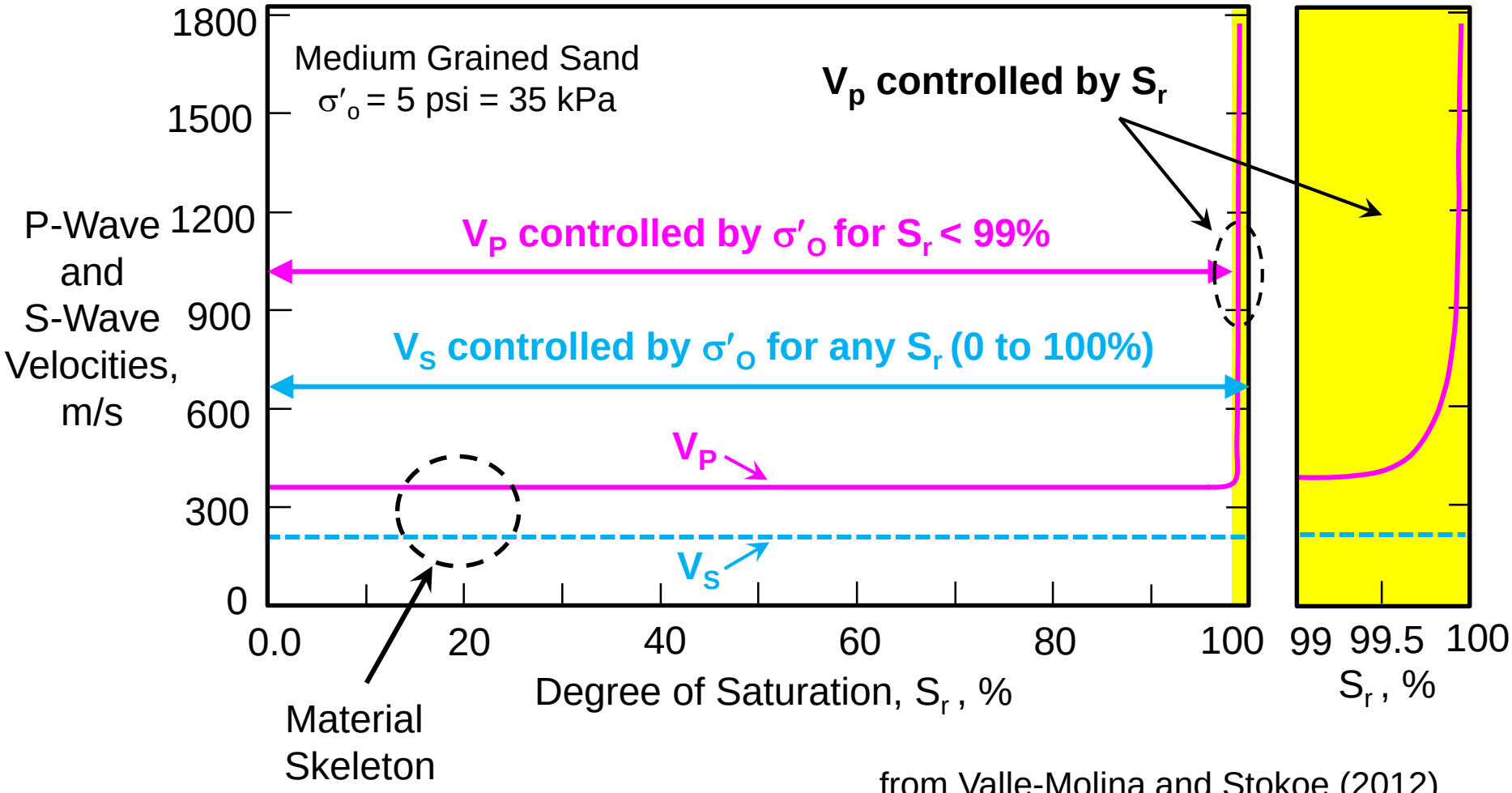
Crosshole Testing : S-Wave Velocities at Natural Soil Test Panels for Reference Profile





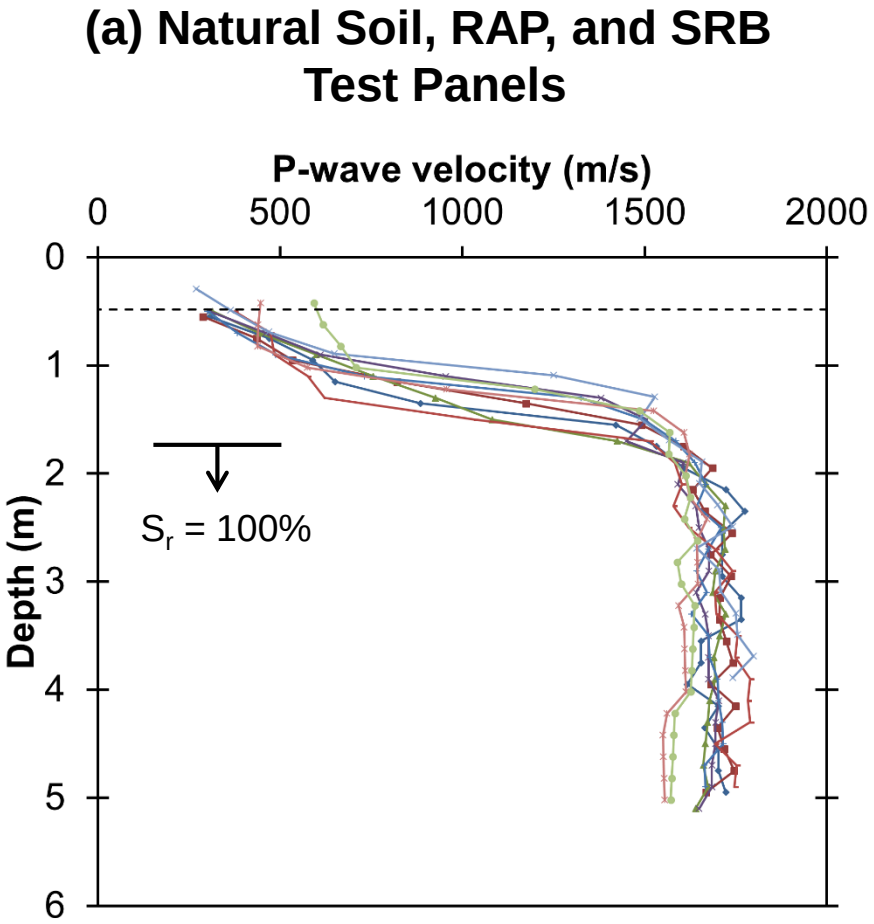


Effect of Degree of Saturation (S_r) on P- and S- Wave Velocities

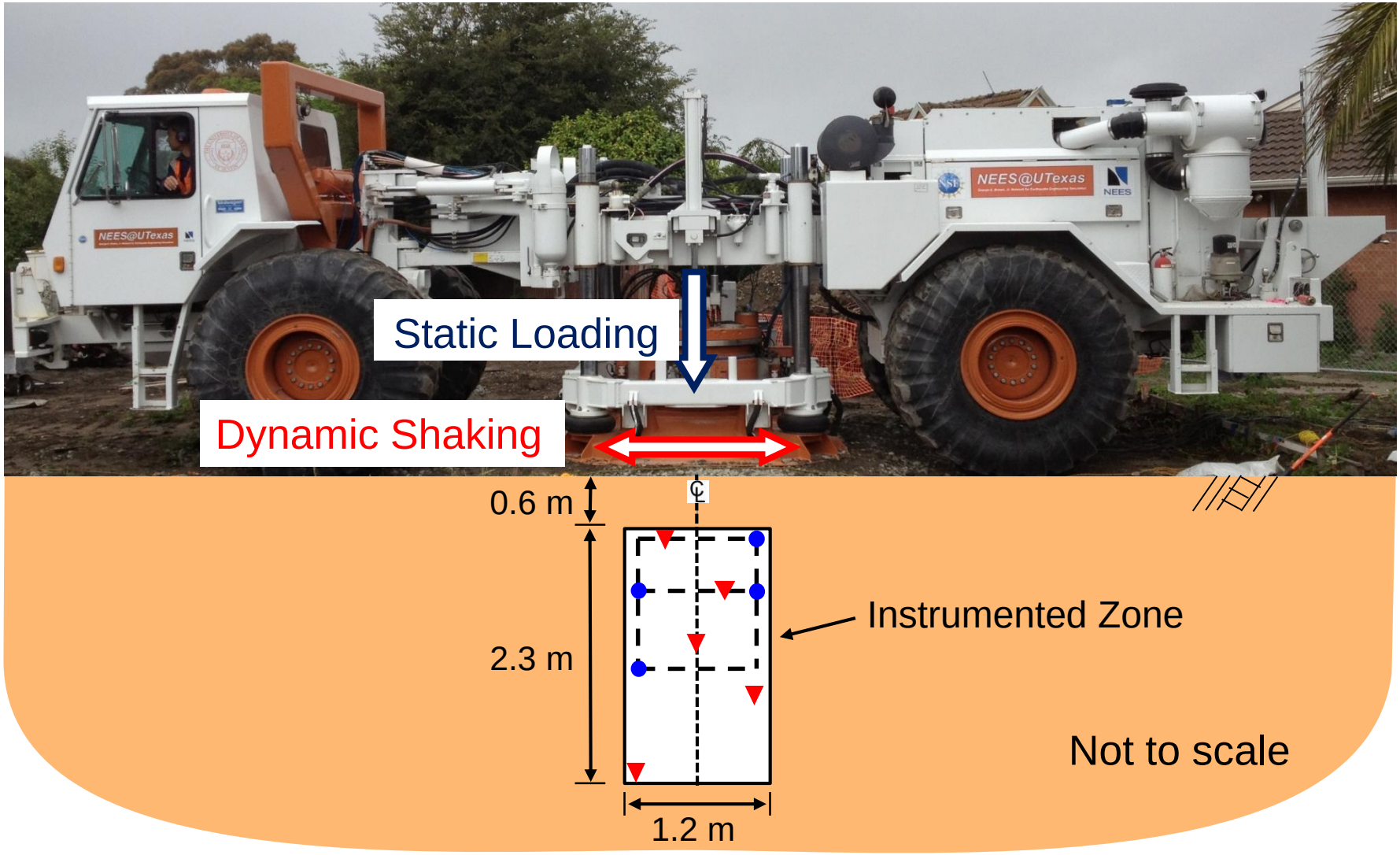


from Valle-Molina and Stokoe (2012)

P-Wave Velocity Profiles at Site 6: To Determine Where Soil is Saturated

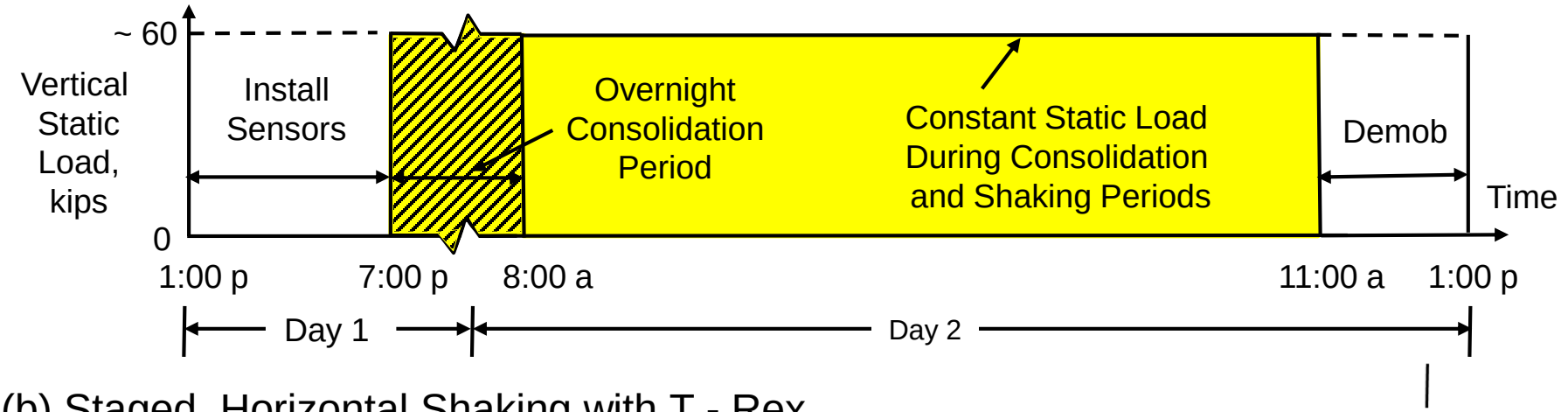


T-Rex Shaking of Each Test Panel: Location of Embedded Sensors

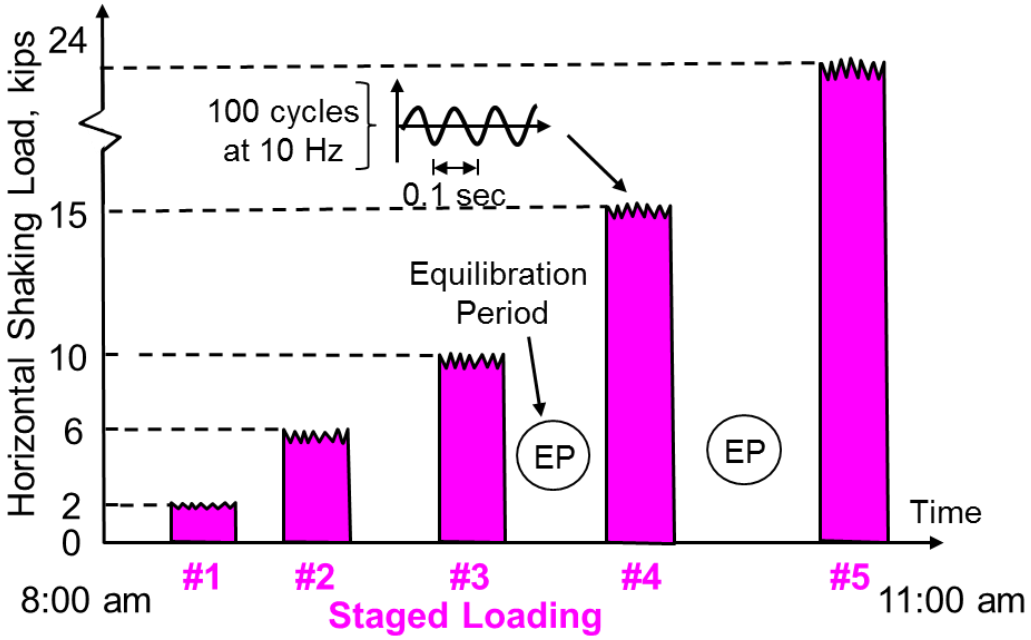


24-hr Process of Sensor Installation and Staged Loading with T-Rex at Each Test Panel

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



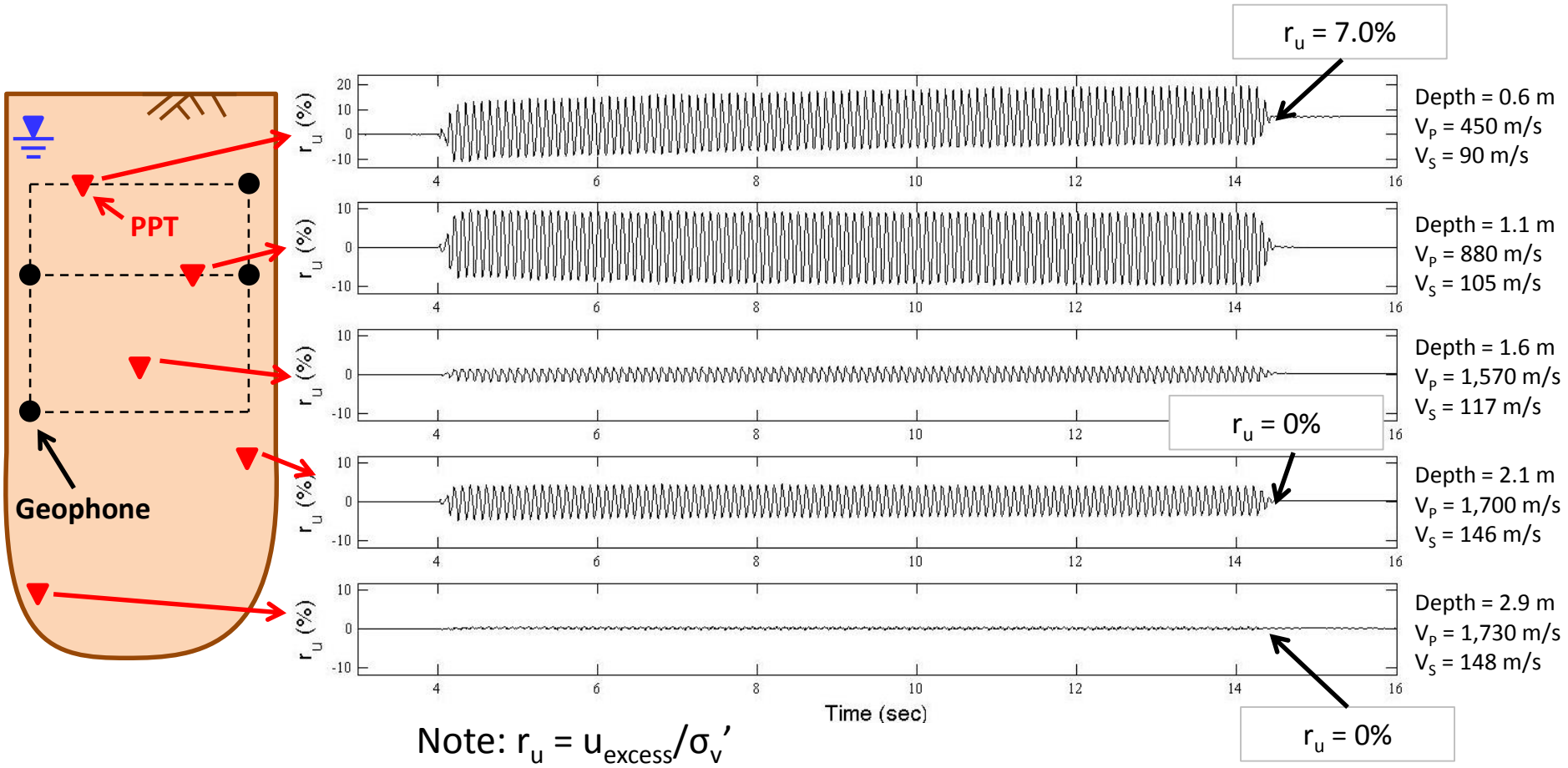
(b) Staged, Horizontal Shaking with T - Rex



Natural Soil Test Panel at Site 6:

Stage 2 - Pore Water Pressure Ratio, r_u, Versus Time

Shaking: 100 cycles at 10 Hz; Stage 2; Peak horizontal force ~ 28 kN (6,300 lbs)

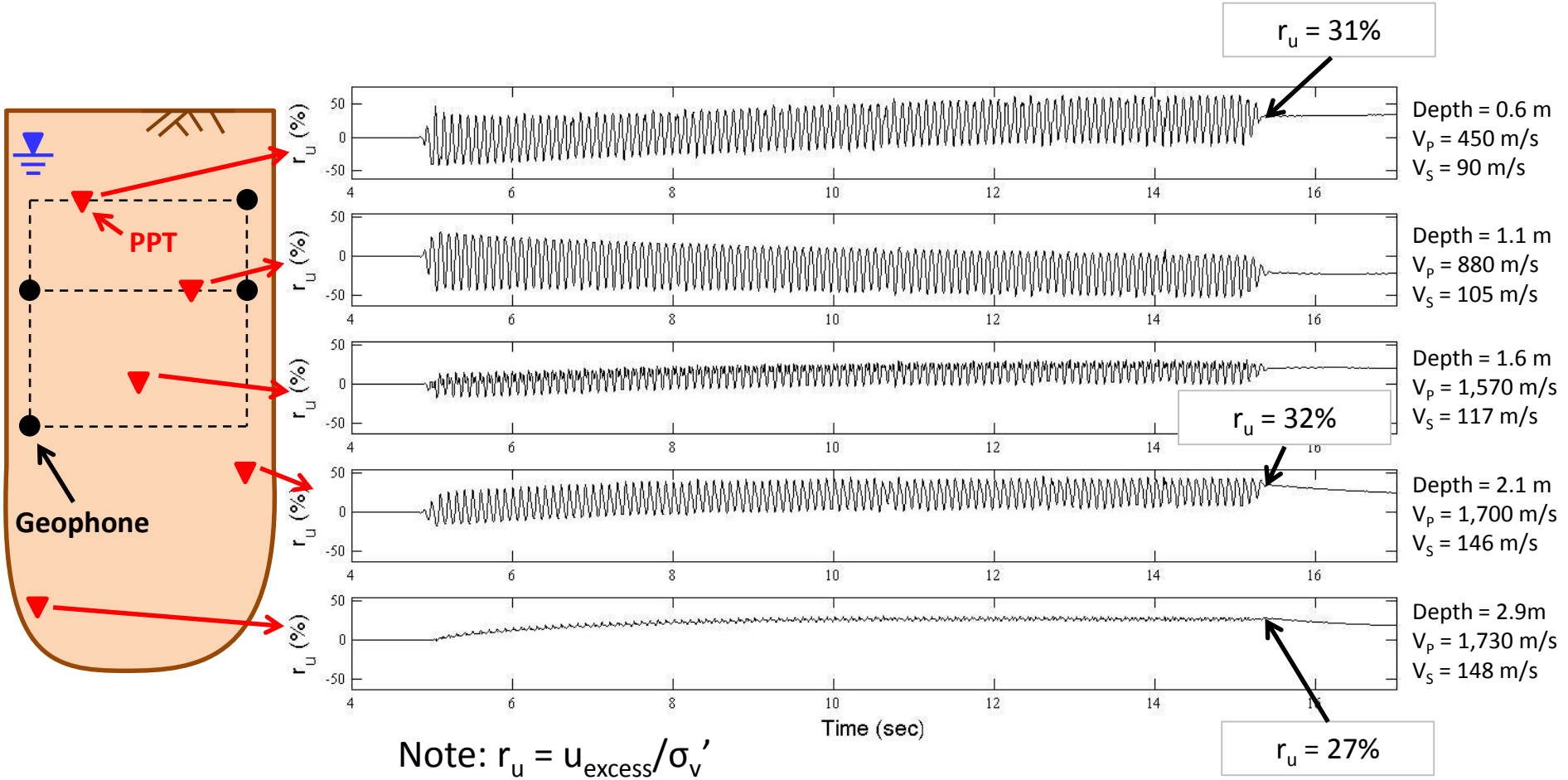


Note: $r_u = u_{excess}/\sigma_v'$

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 ~ 91.2 kN (20,500 lbs)

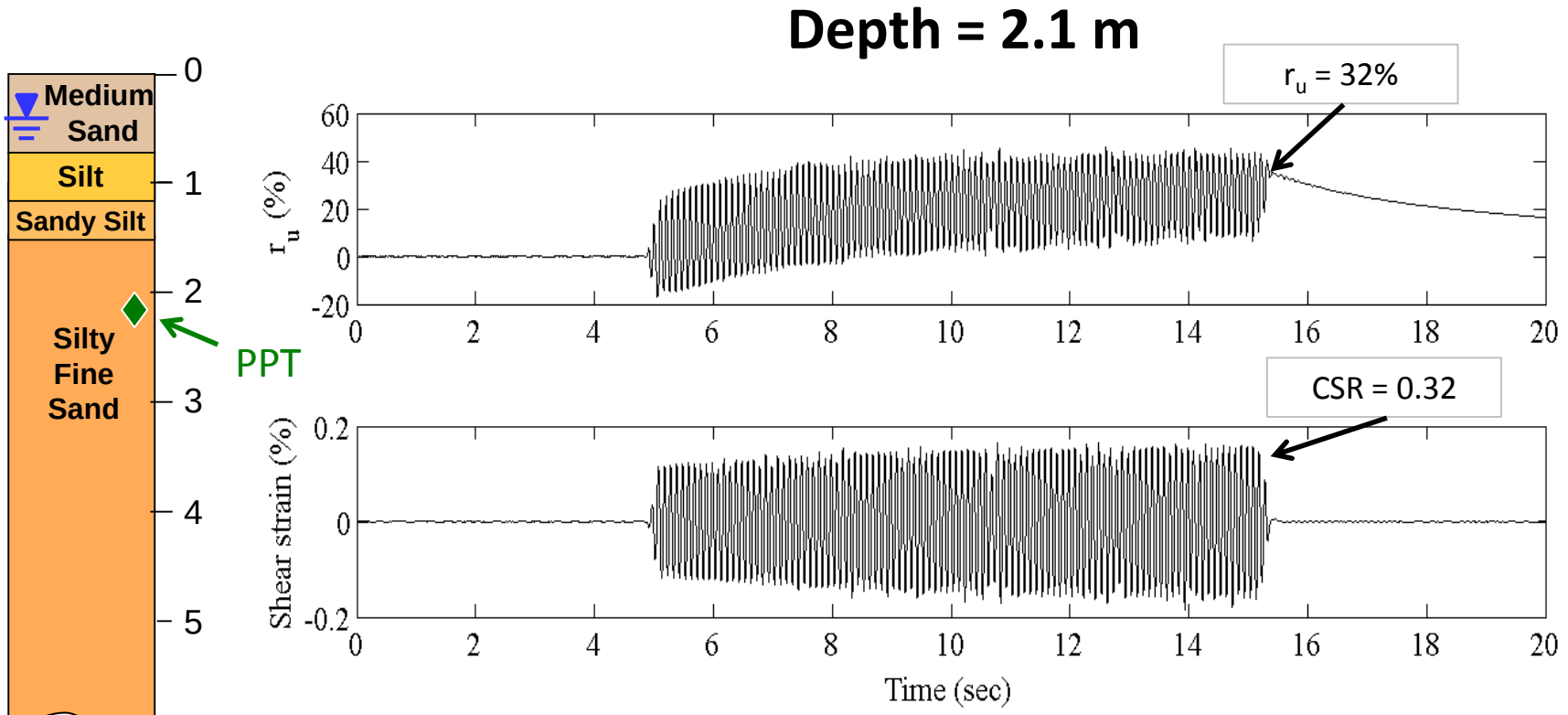


Note: $r_u = u_{excess}/\sigma_v'$

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)

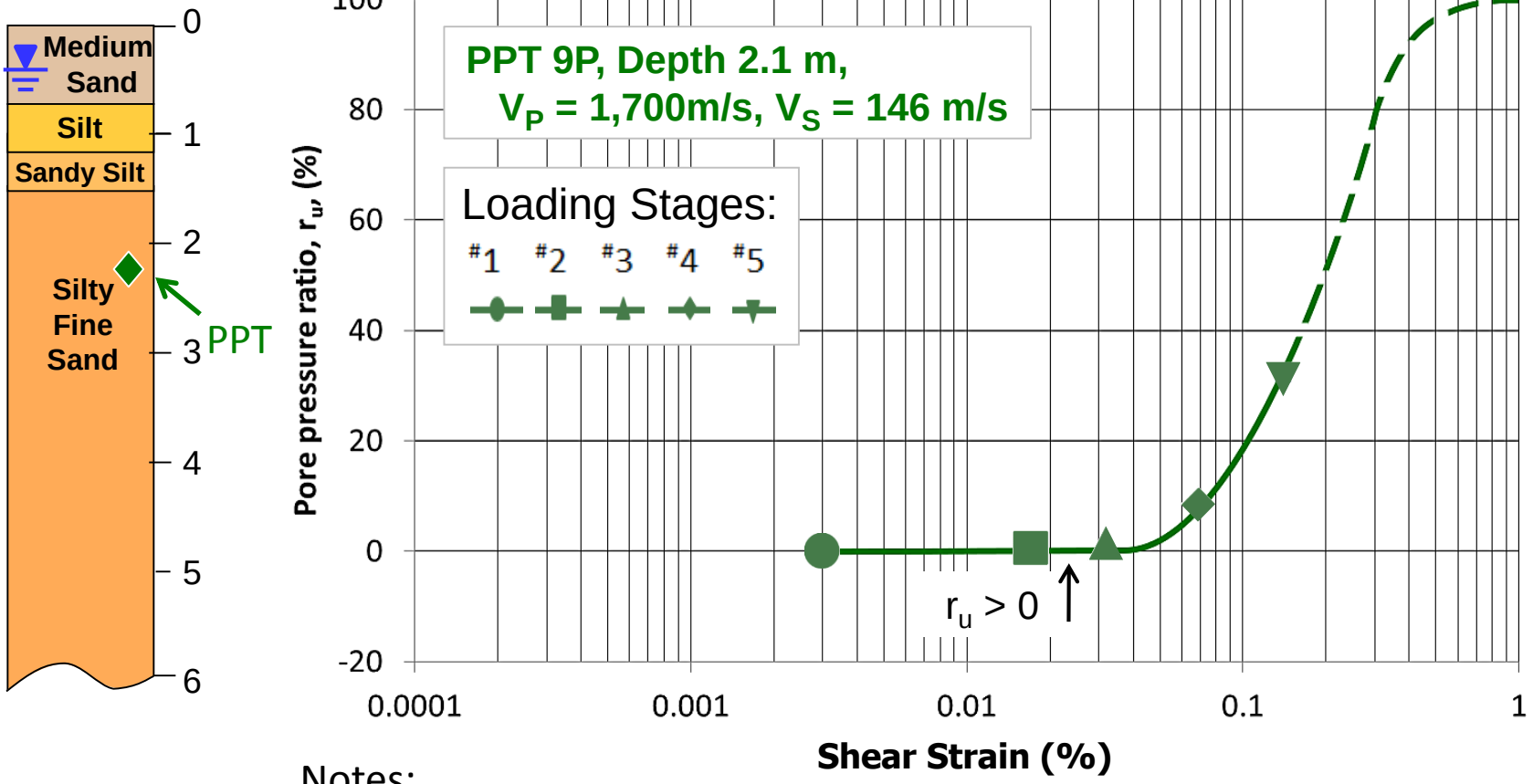


Notes:

$r_u = u_{excess}/\sigma_v'$ CSR = τ/σ_v' $G = \tau/\gamma \rightarrow \tau = G(\gamma)$

Stage Testing at Natural Soil Test Panel, Site 6: r_u versus Log γ after 100 Cycles of Shaking at Each γ

Depth = 2.1 m

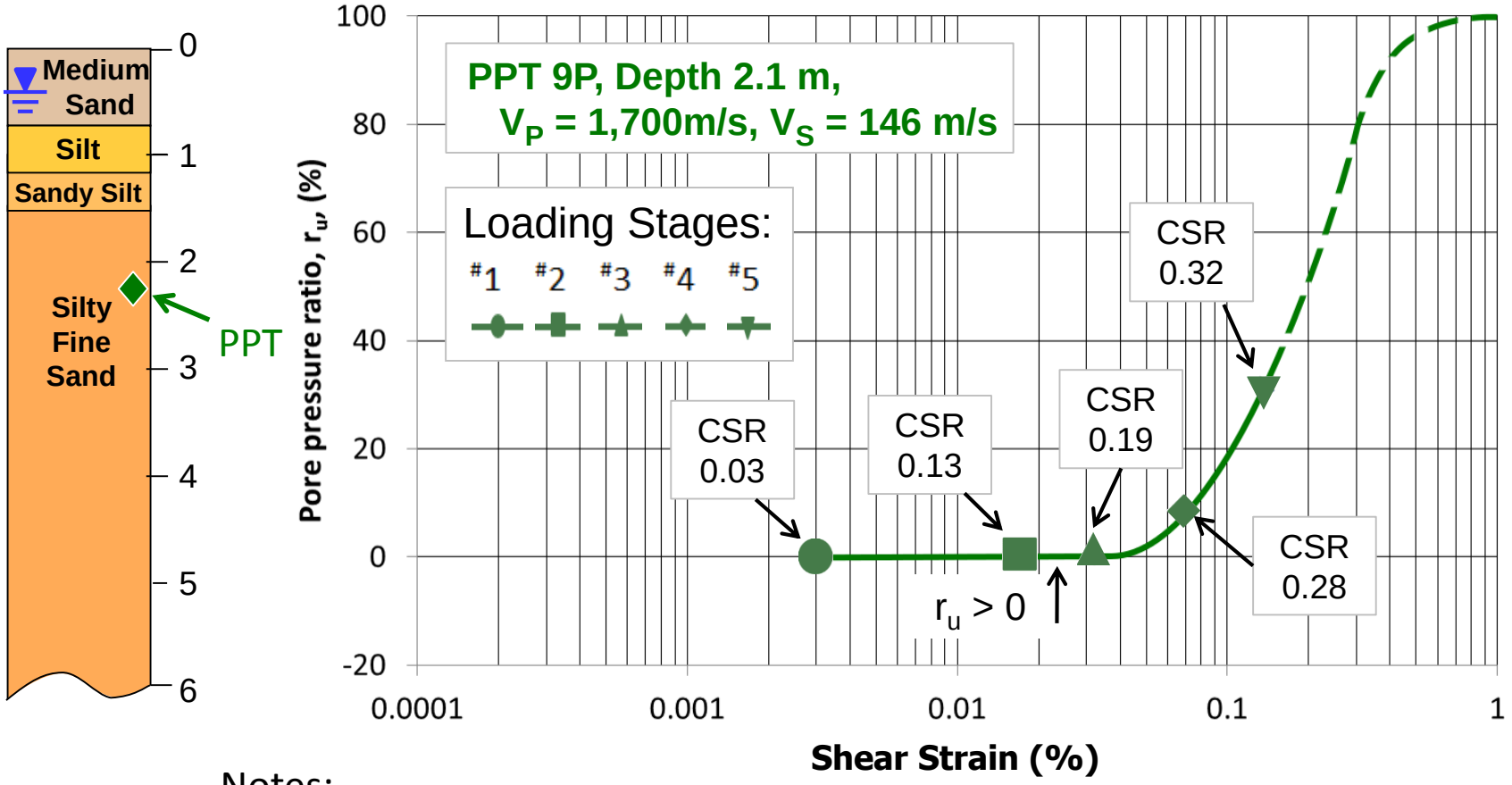


Notes:

$r_u = u_{excess}/\sigma_v'$

Stage Testing at Natural Soil Test Panel, Site 6: r_u versus Log γ after 100 Cycles of Shaking at Each γ

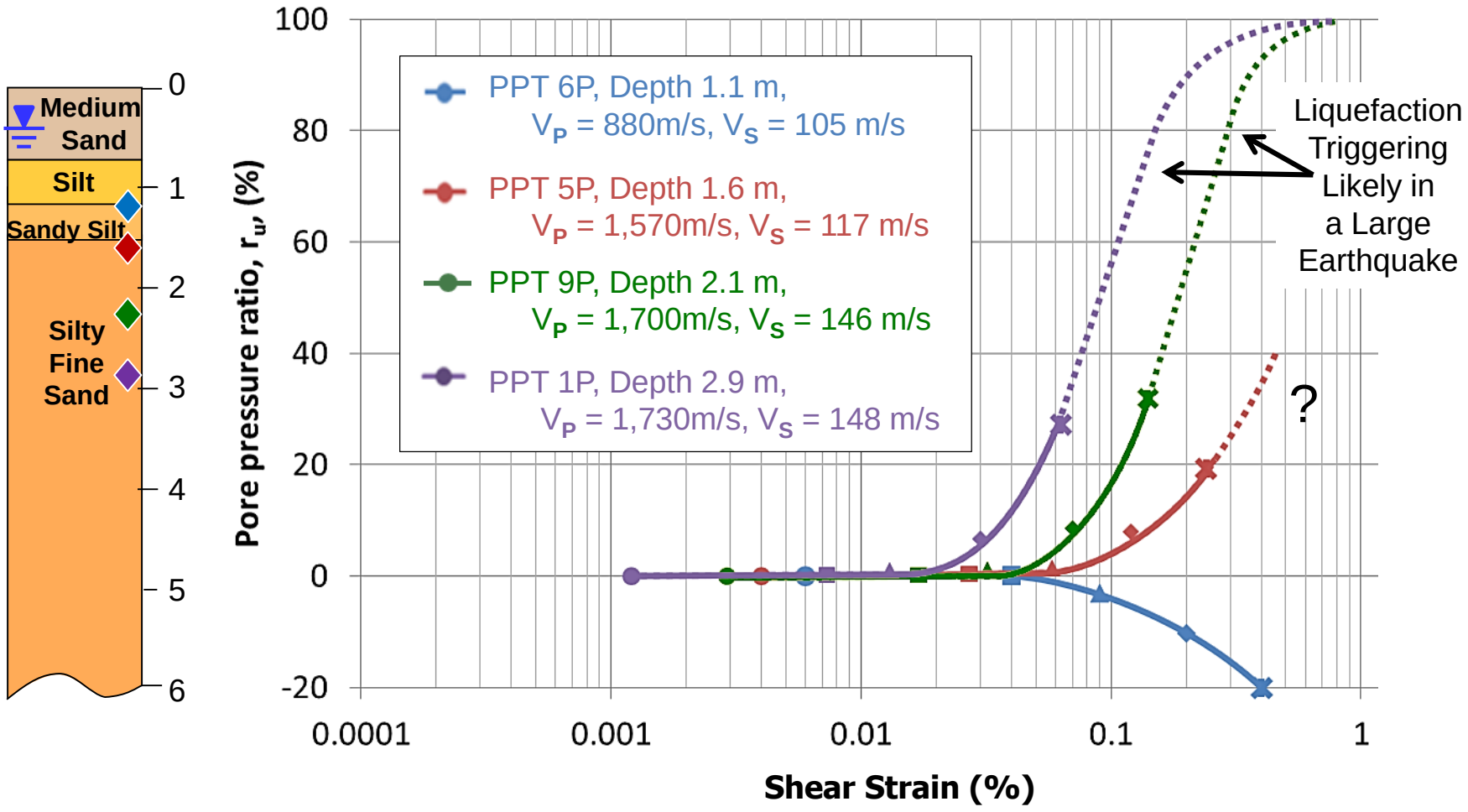
Depth = 2.1 m



Notes:

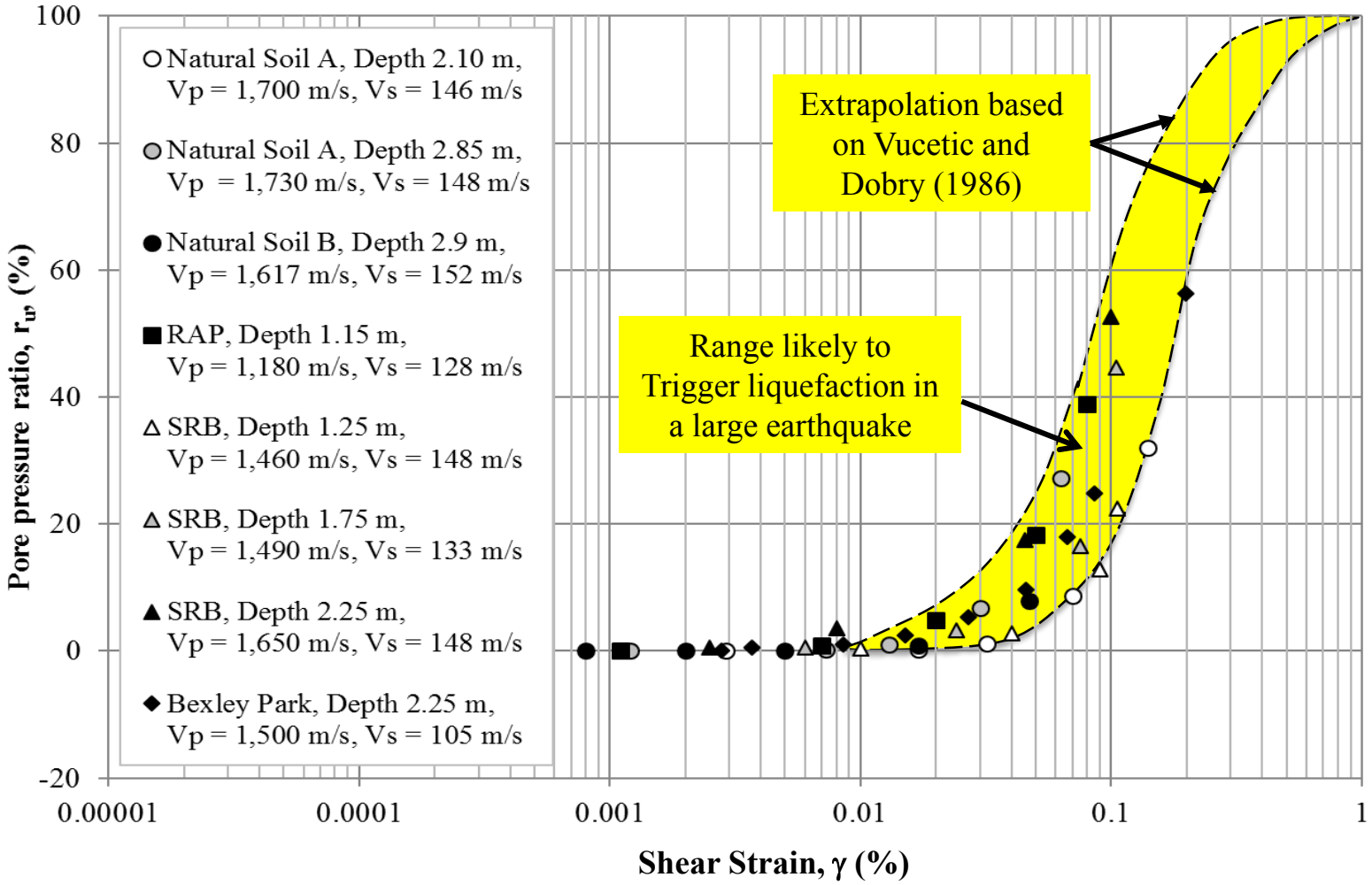
$r_u = u_{excess}/\sigma_v'$; $CSR = \tau/\sigma_v'$; $G = \tau/\gamma \longrightarrow \tau = G(\gamma)$

Stage Testing at Natural Soil Test Panel, Site 6: r_u Versus Log g after 100 Cycles of Shaking at Each γ

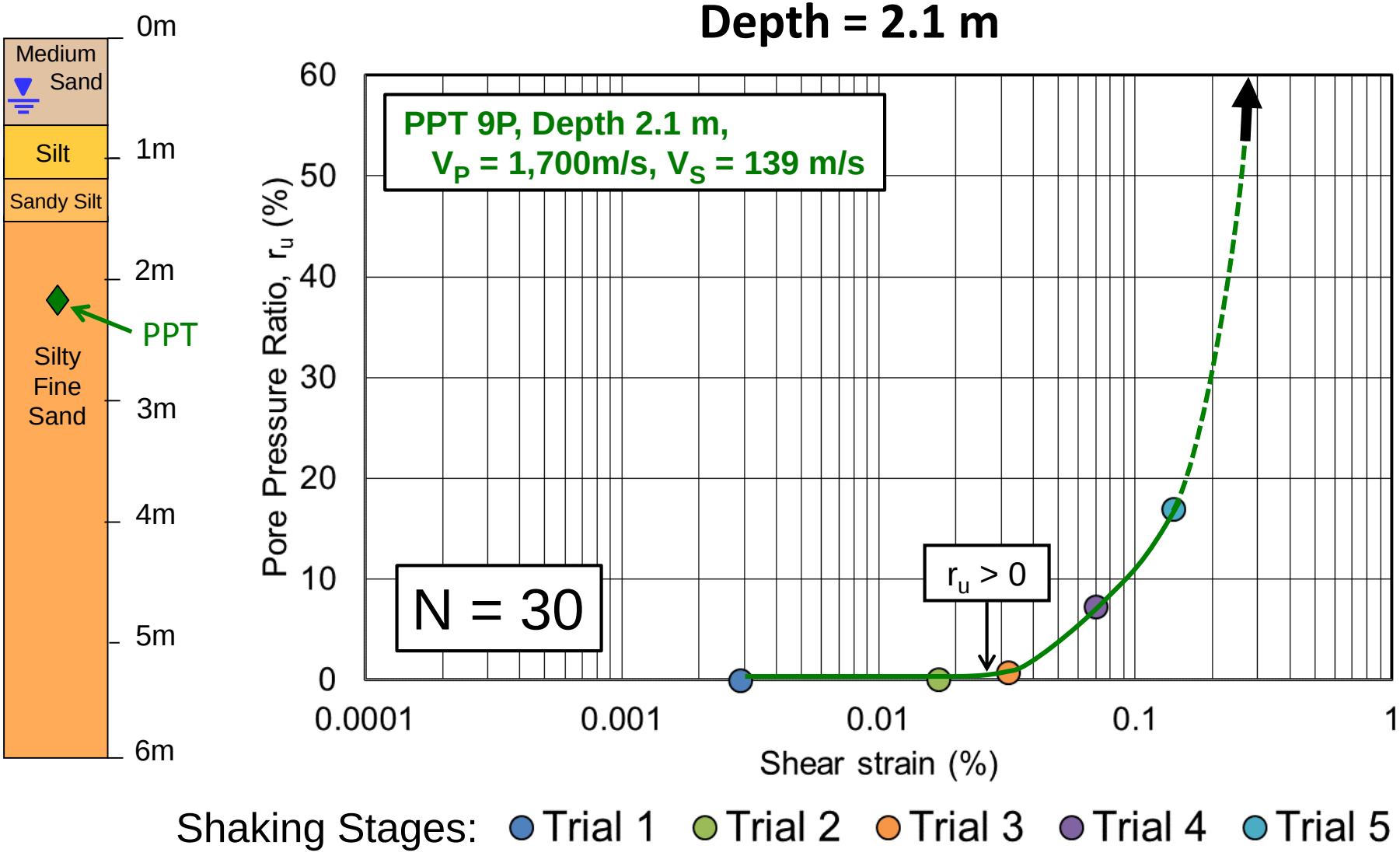


Evaluation of T-Rex Shaking Tests at Site 6

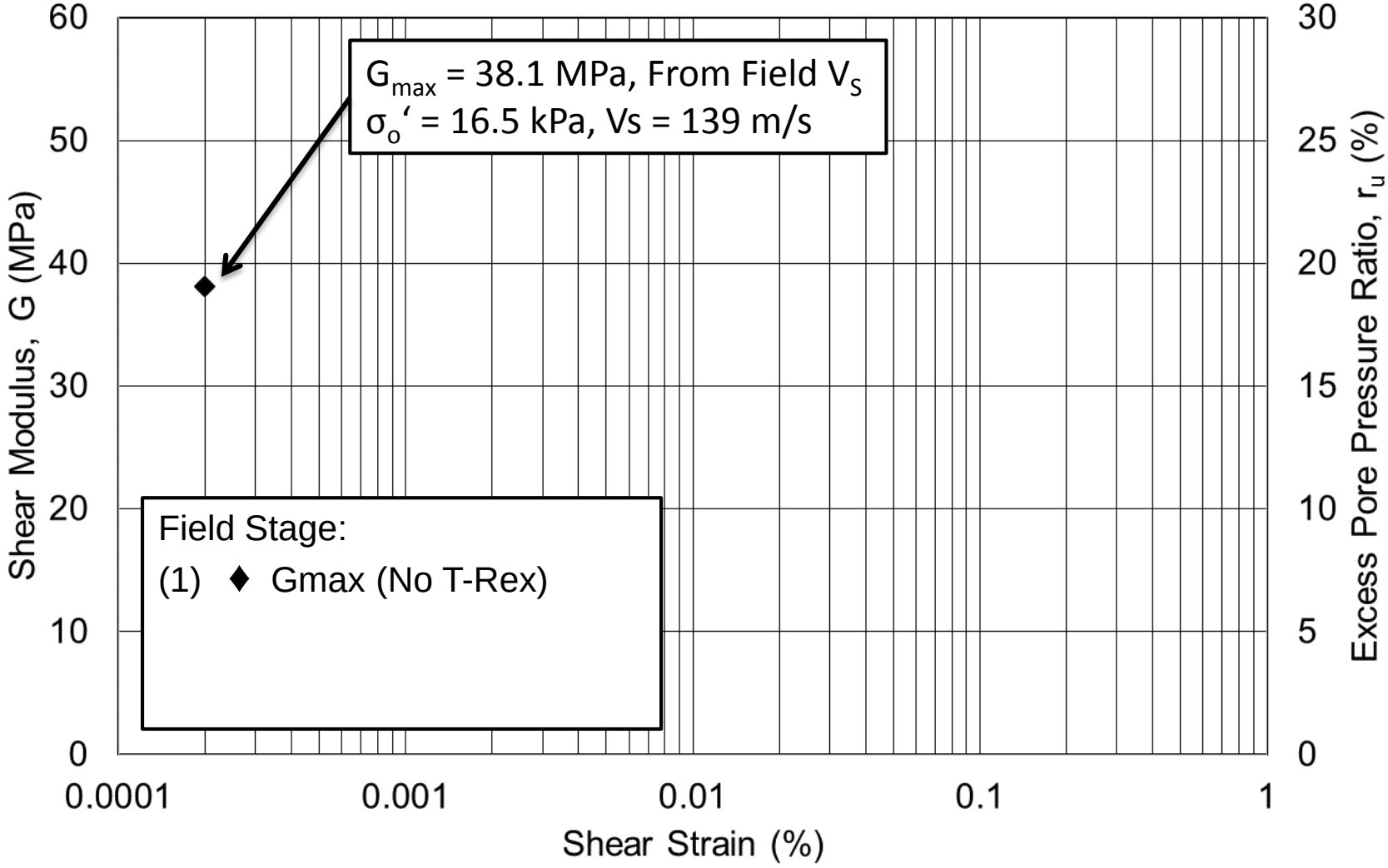
Reference r_u - Log γ Liquefaction Triggering Relationships
100 Cycles of Shaking at Each γ



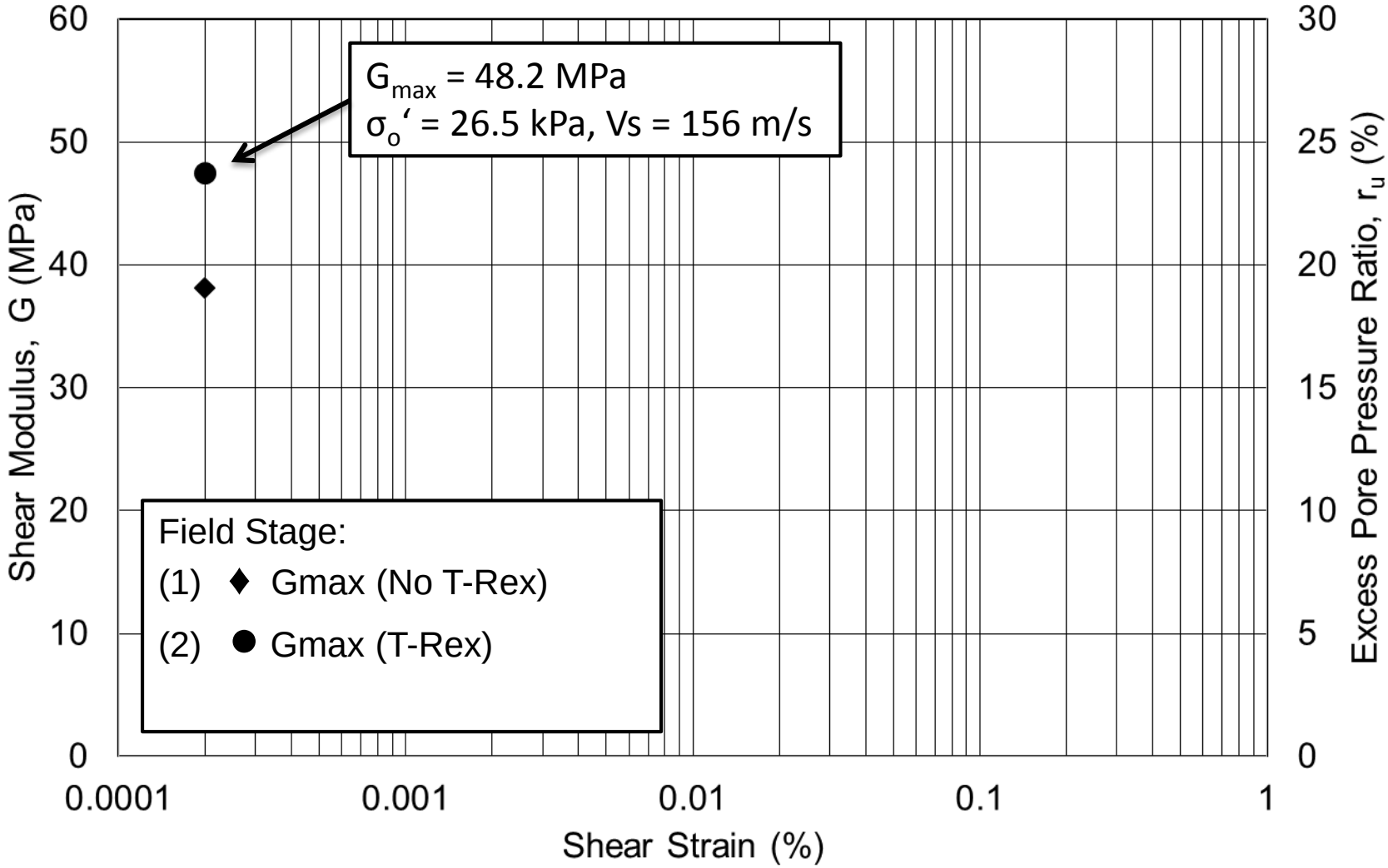
Stage Testing at Natural Soil Test Panel, Site 6: r_u versus Log γ after 30 Cycles of Shaking at Each γ



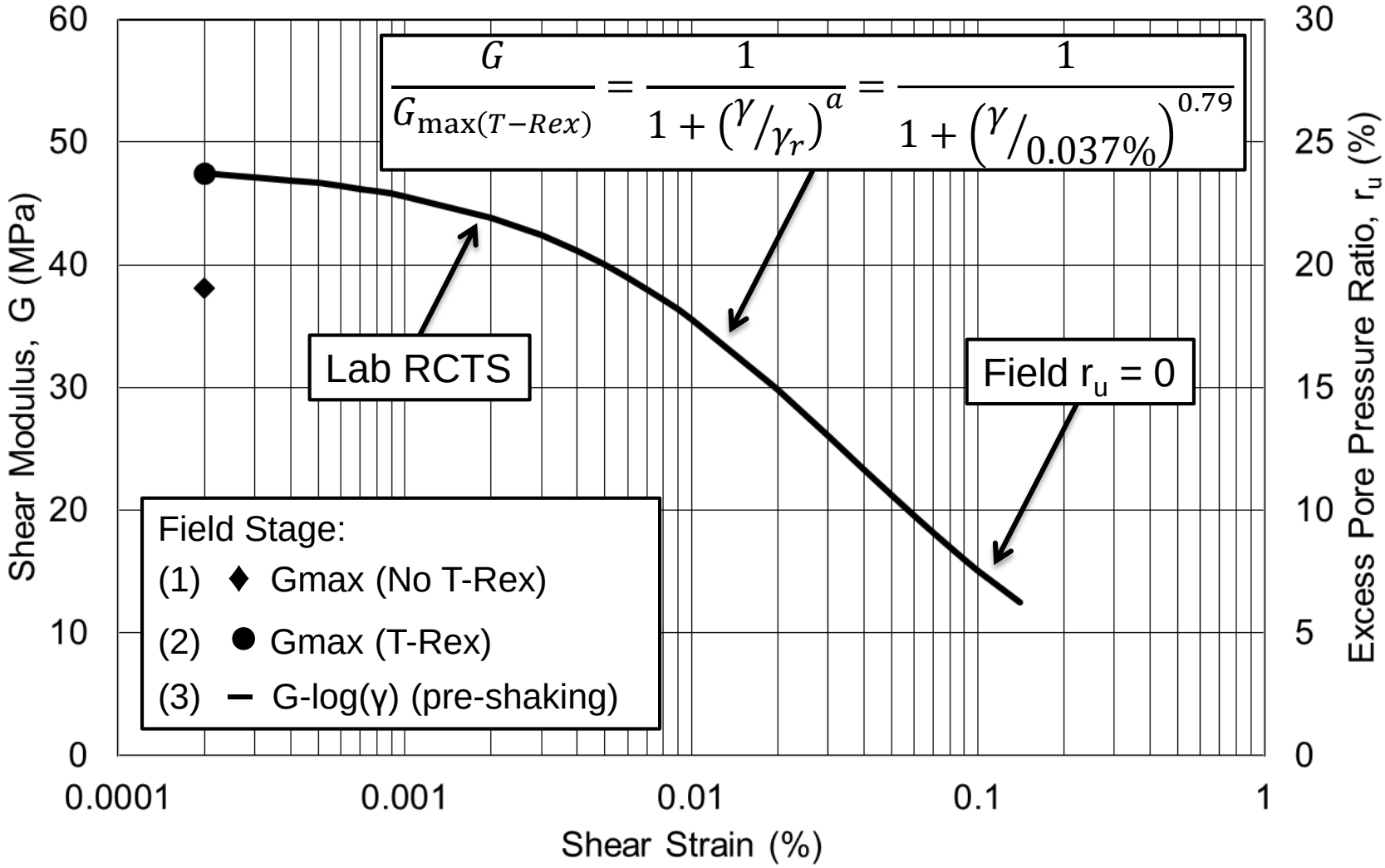
Modeling the Loading of the Natural Soil Test Panel: Before T-Rex Shaking; Depth 2.1 m



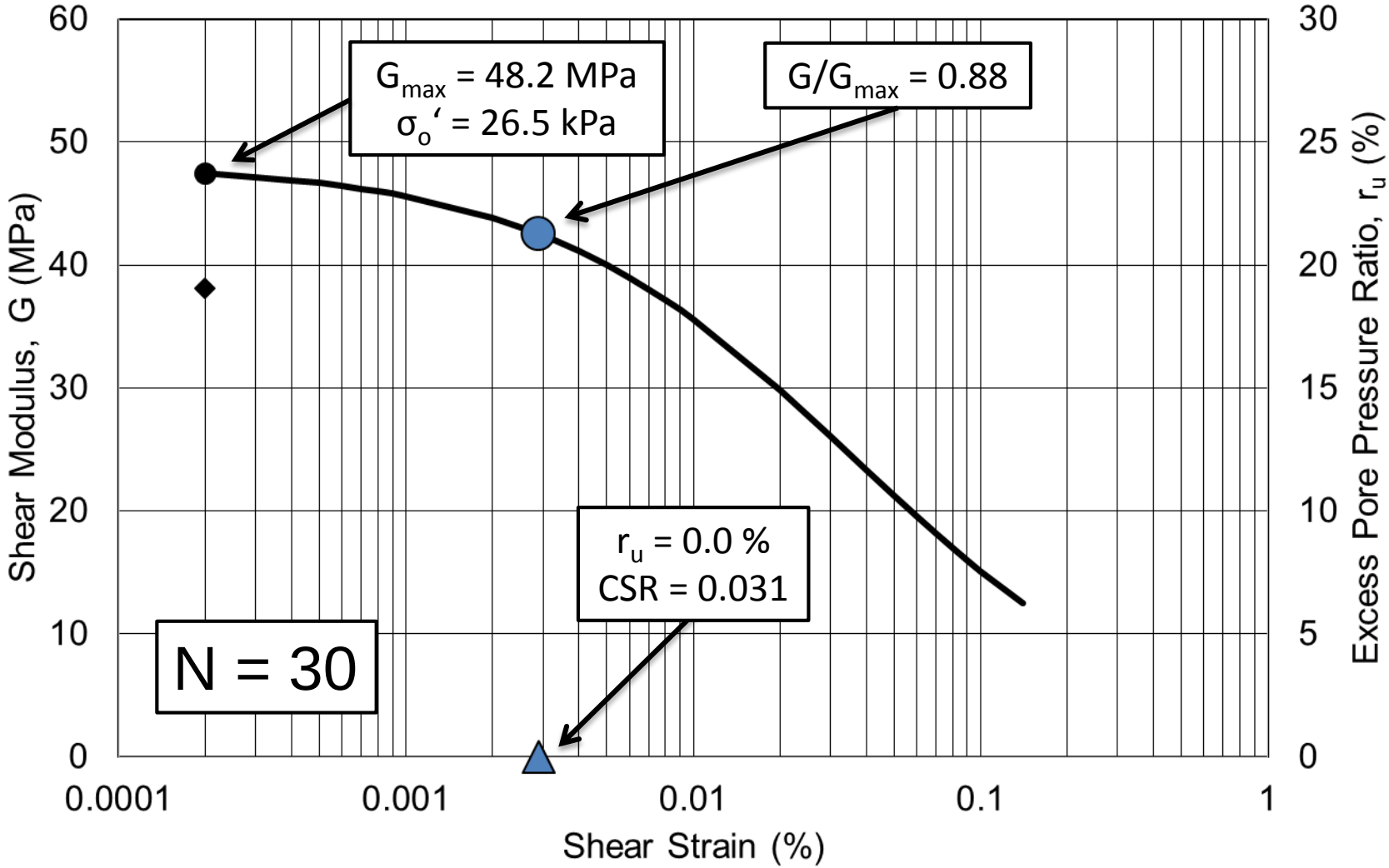
Modeling the Loading of the Natural Soil Test Panel: Before T-Rex Shaking; Depth 2.1 m



Modeling the Loading of the Natural Soil Test Panel: Before T-Rex Shaking; Depth 2.1 m

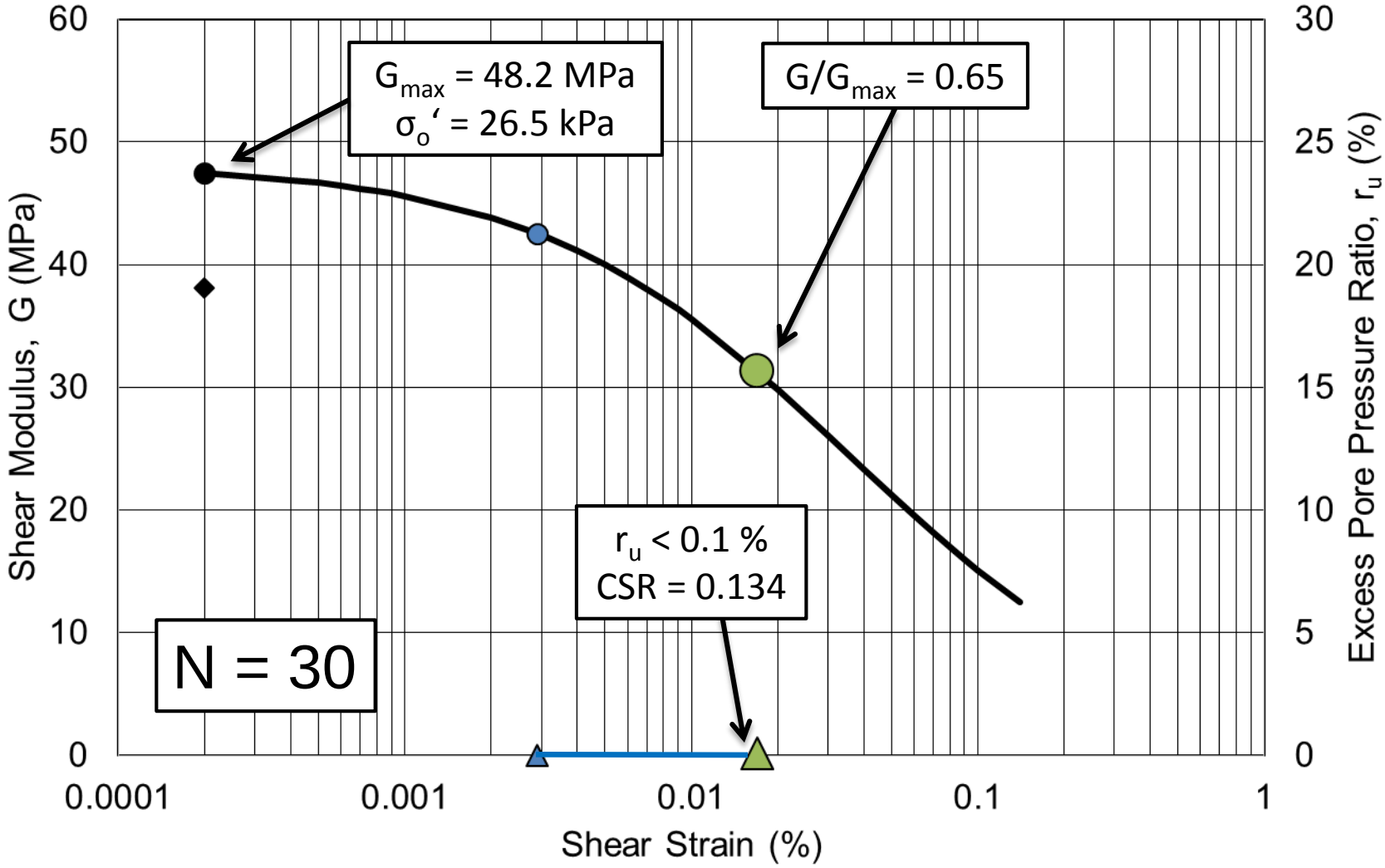


Modeling the Loading of the Natural Soil Test Panel: During T-Rex Shaking; Depth = 2.1 m



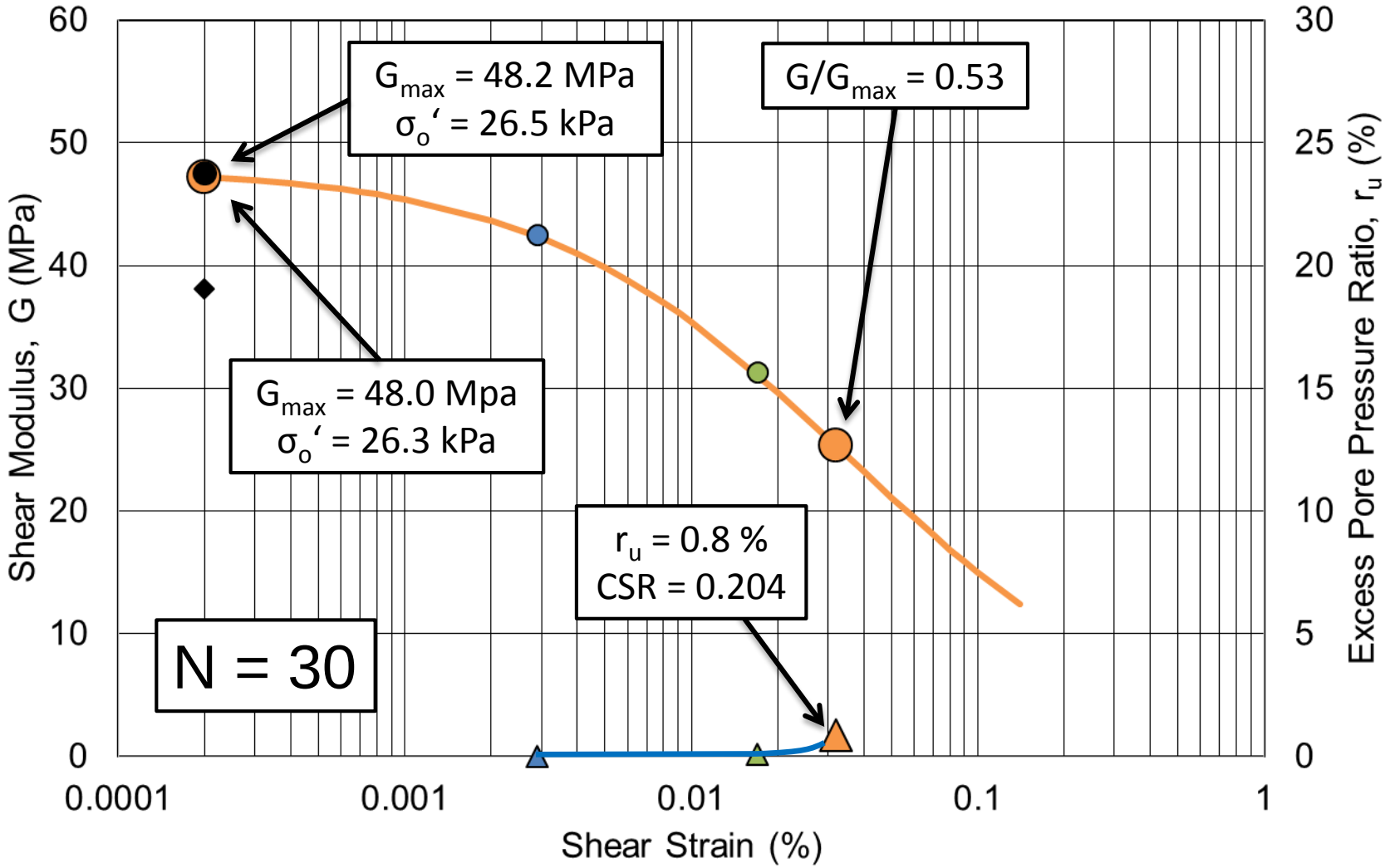
Shaking Stages: ● Trial 1

Modeling the Loading of the Natural Soil Test Panel: During T-Rex Shaking; Depth = 2.1 m

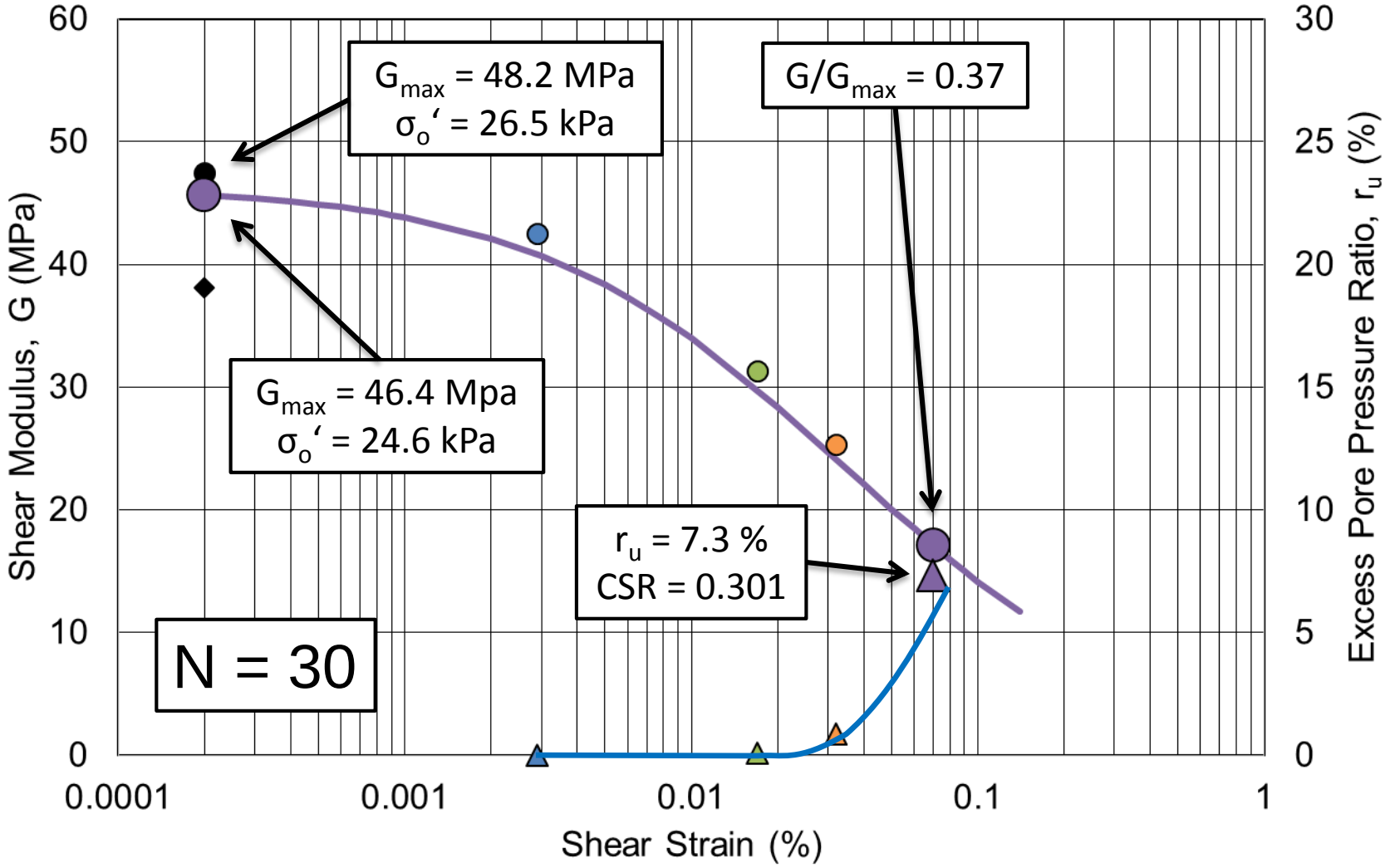


Shaking Stages: ● Trial 1 ● Trial 2

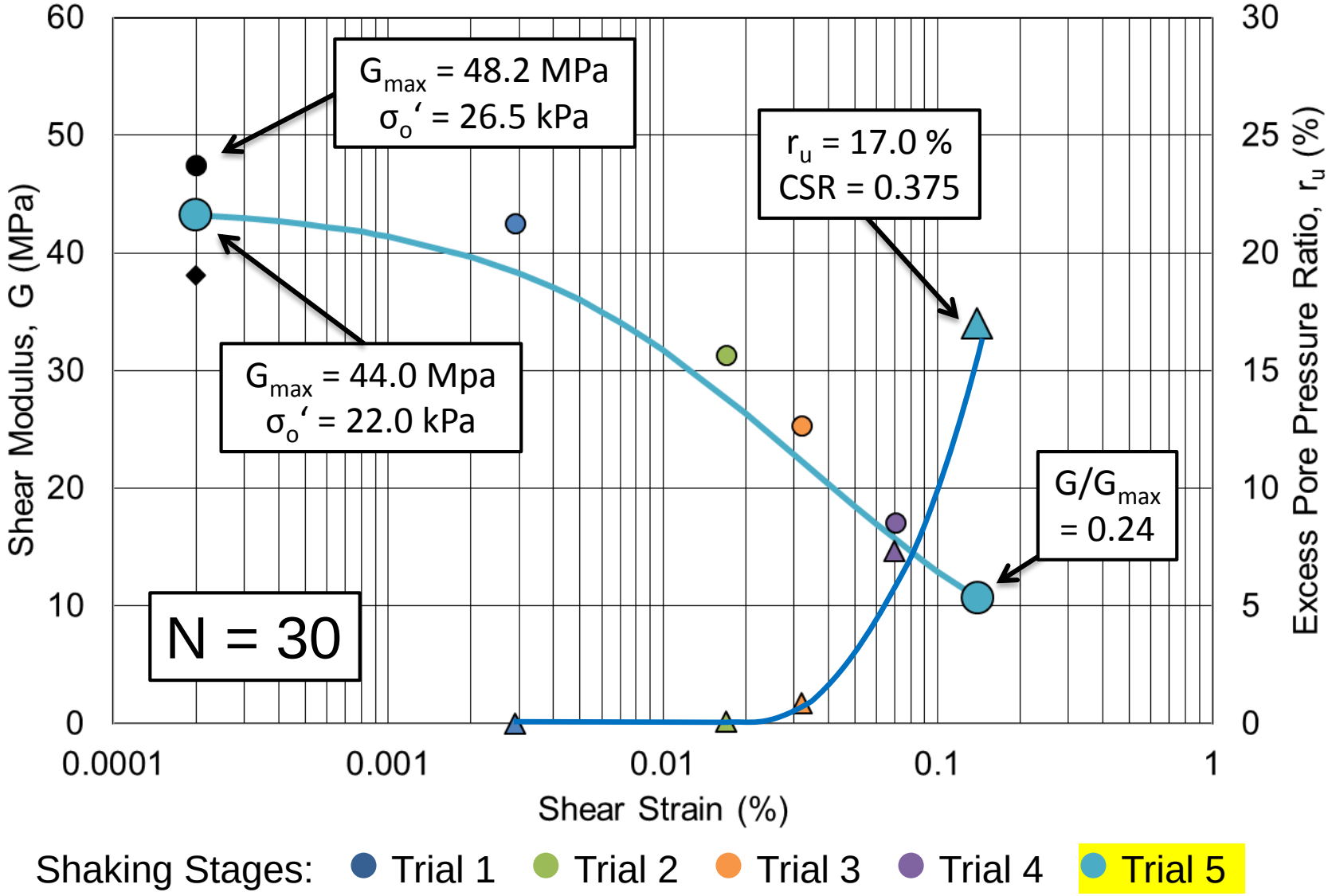
Modeling the Loading of the Natural Soil Test Panel: During T-Rex Shaking; Depth = 2.1 m



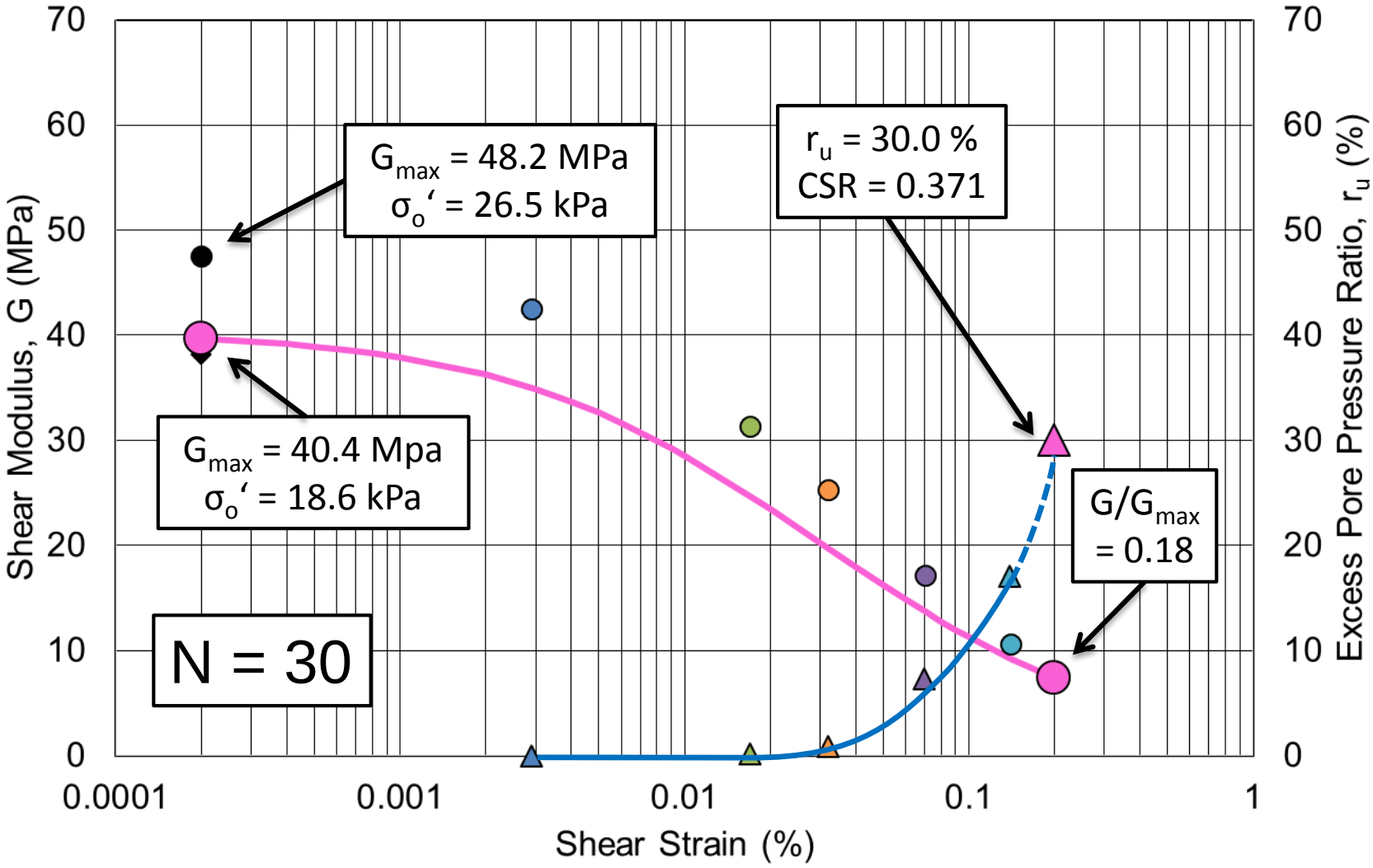
Modeling the Loading of the Natural Soil Test Panel: During T-Rex Shaking; Depth = 2.1 m



Modeling the Loading of the Natural Soil Test Panel: During T-Rex Shaking; Depth = 2.1 m



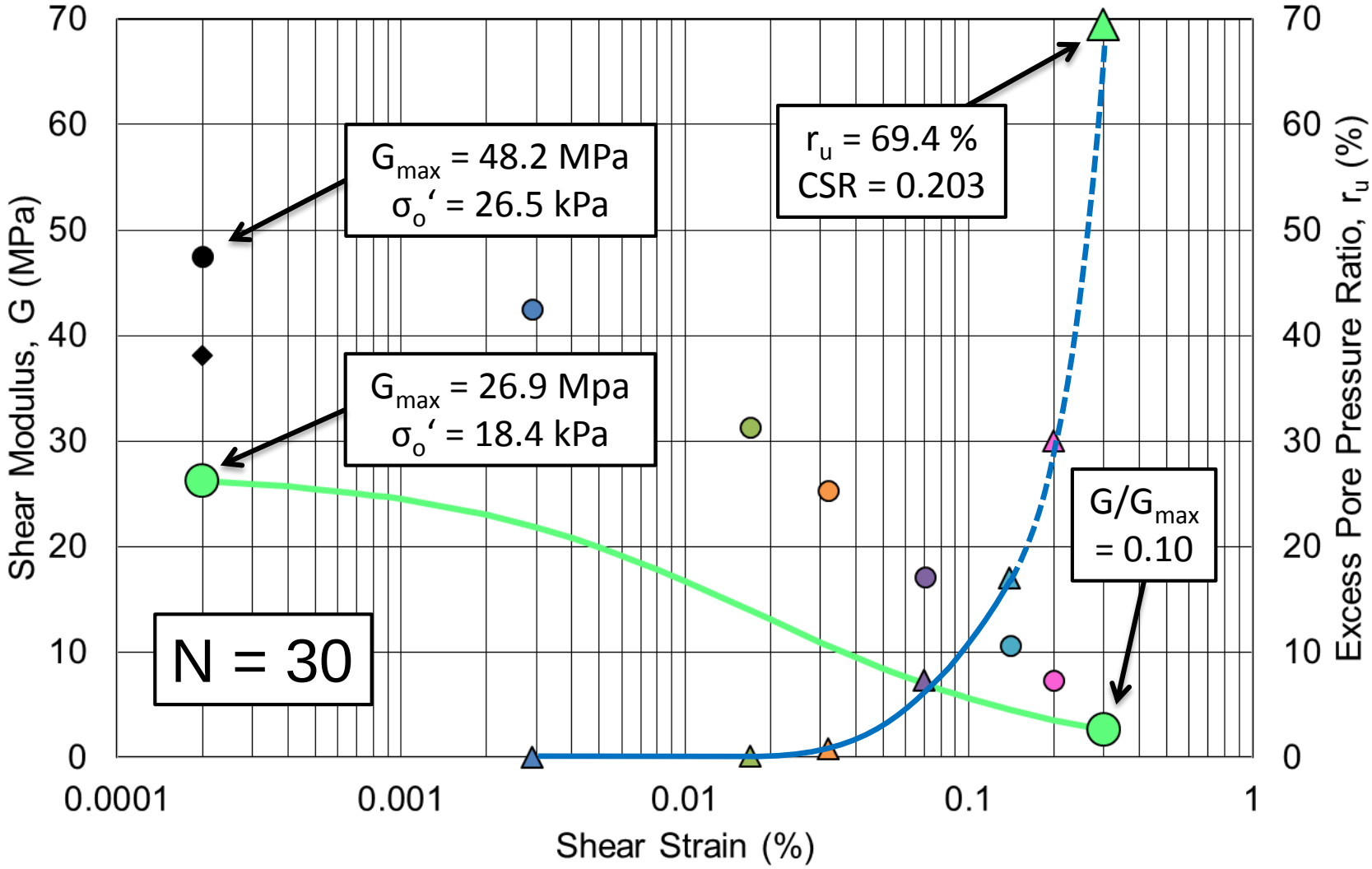
Modeling the Loading of the Natural Soil Test Panel: Predicting High-Level T-Rex Shaking; Depth = 2.1 m



Shaking Stages: Trial 1 Trial 2 Trial 3 Trial 4 Trial 5

Predicted Shaking Results: Trial 6

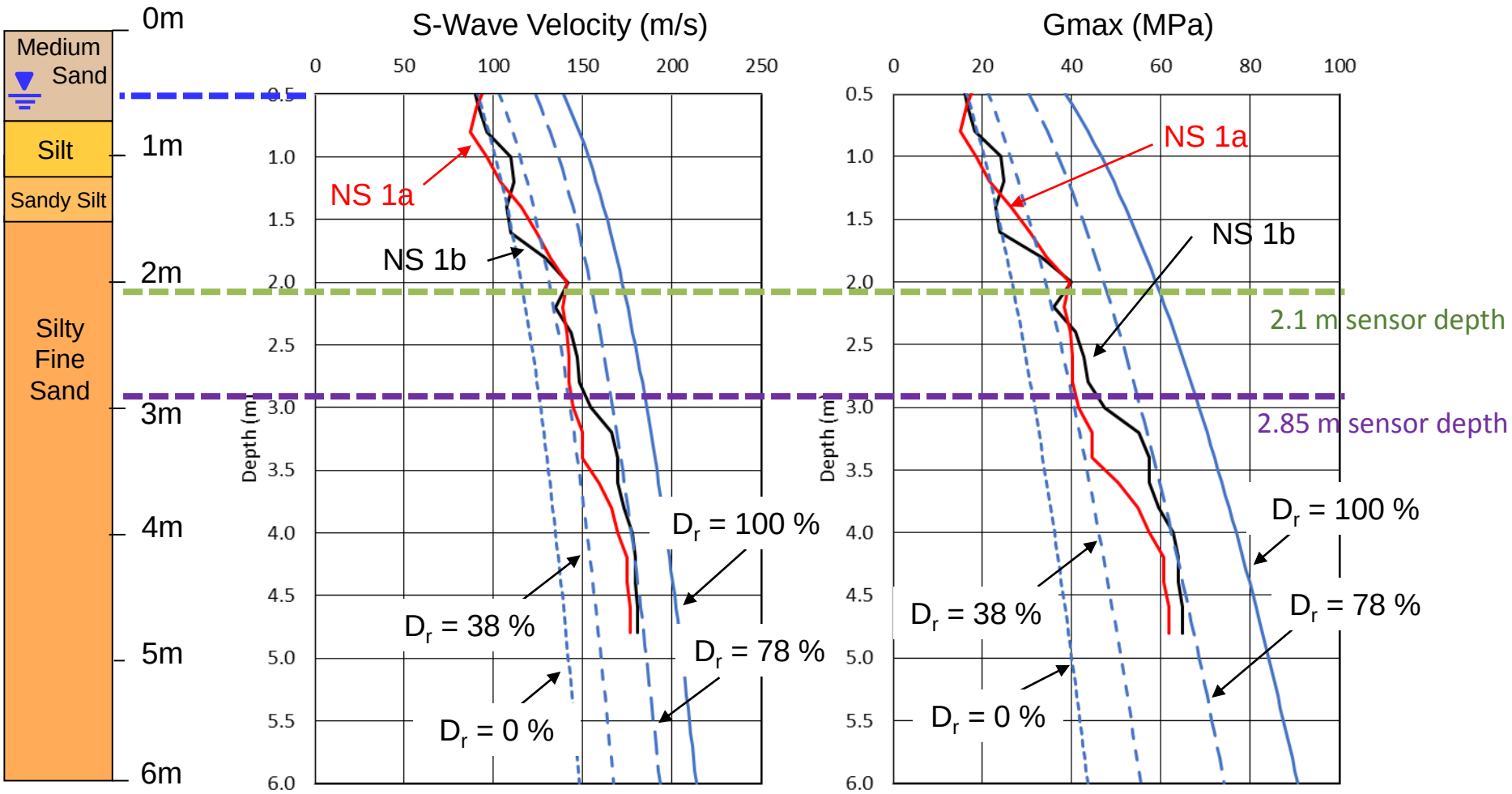
Modeling the Loading of the Natural Soil Test Panel: Predicting High-Level T-Rex Shaking; Depth = 2.1 m



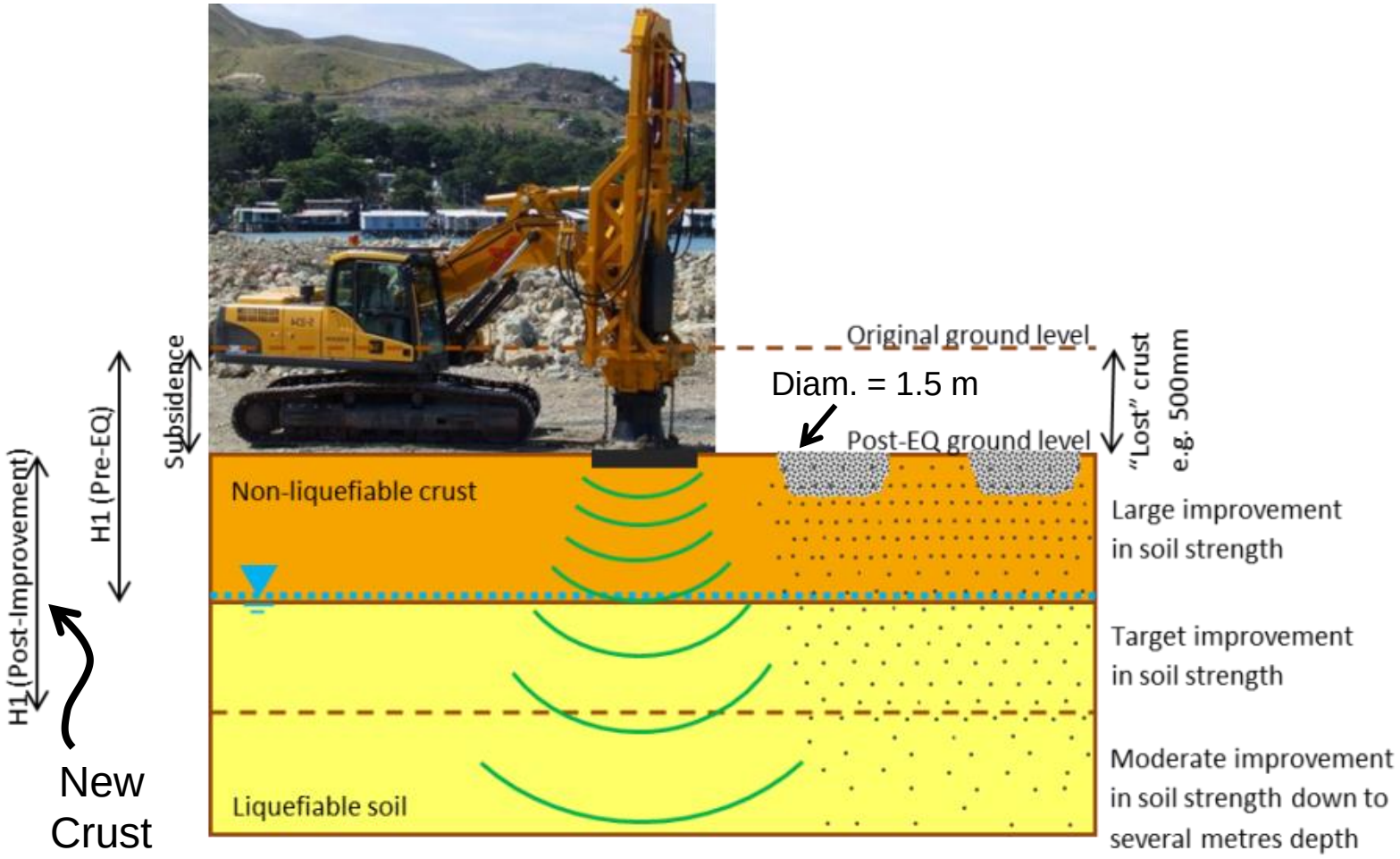
Shaking Stages: Trial 1 Trial 2 Trial 3 Trial 4 Trial 5

Predicted Shaking Results: Trial 6 Trial 7

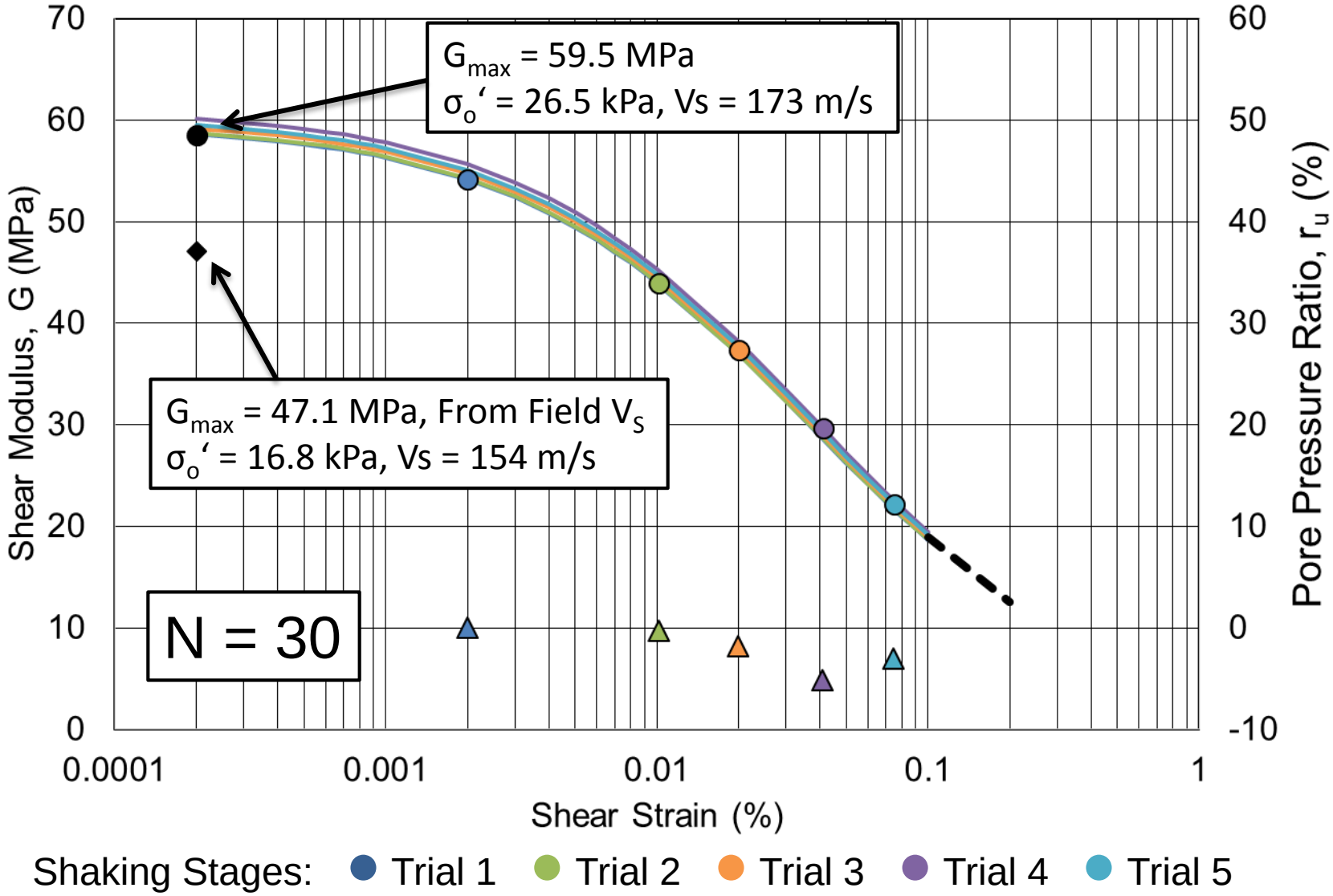
Variation in V_S and G_{max} with Depth and Estimated D_r at the Natural Soil Test Panel



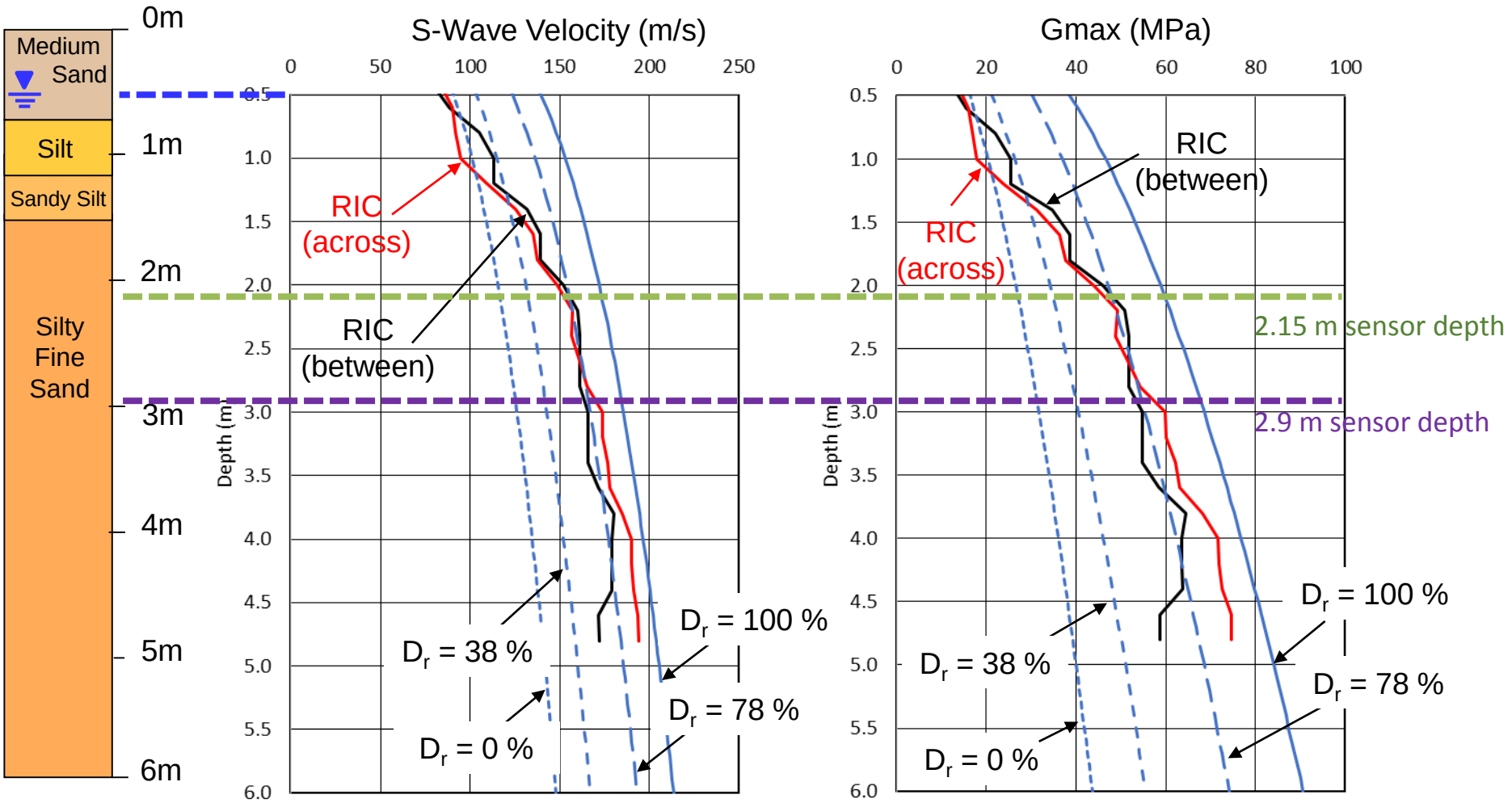
Ground Improvement Method No. 1: Rapid Impact Compaction (RIC)



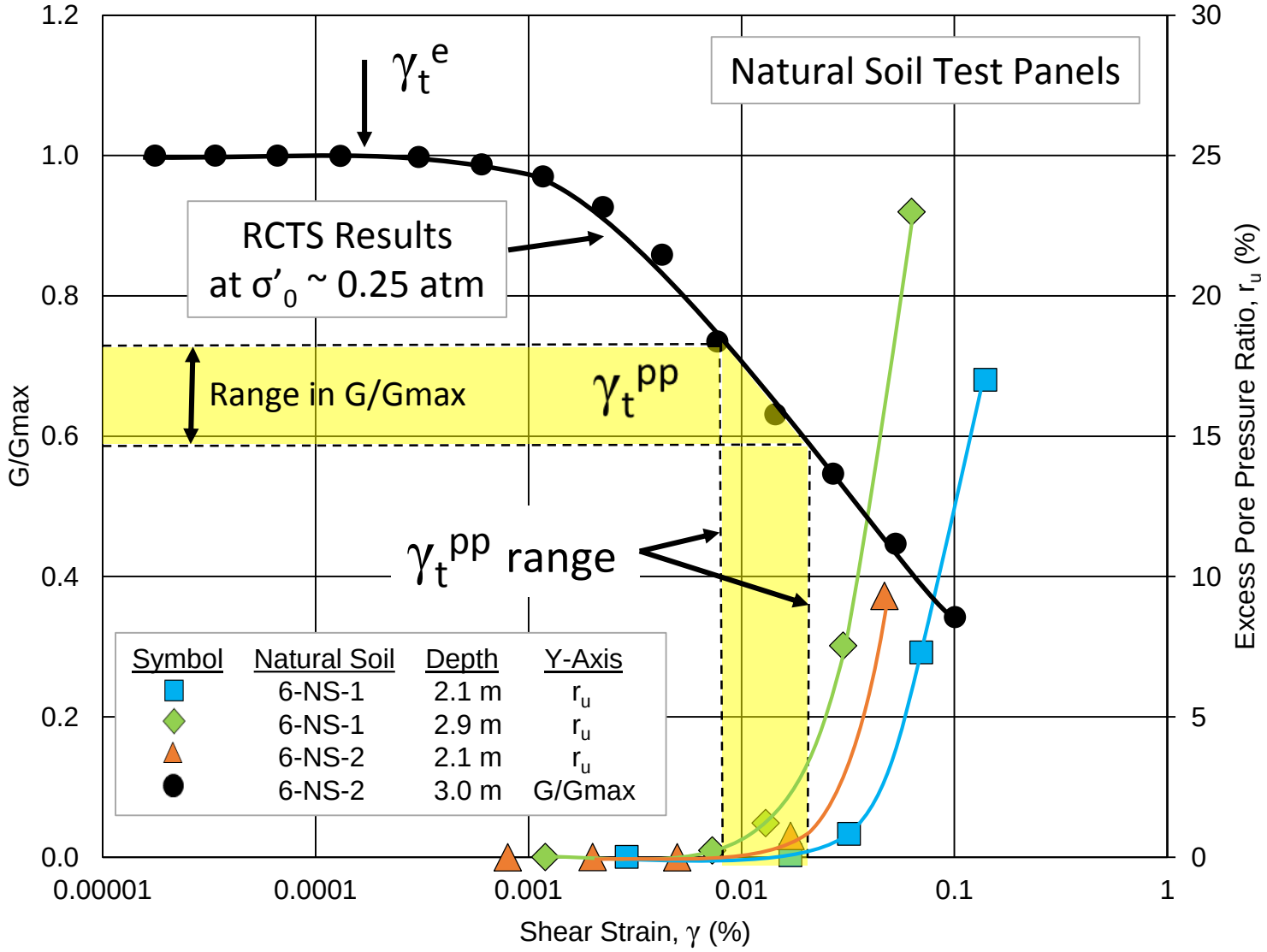
Modeling the Loading of the RIC Panel: During T-Rex Shaking; Depth = 2.1 m

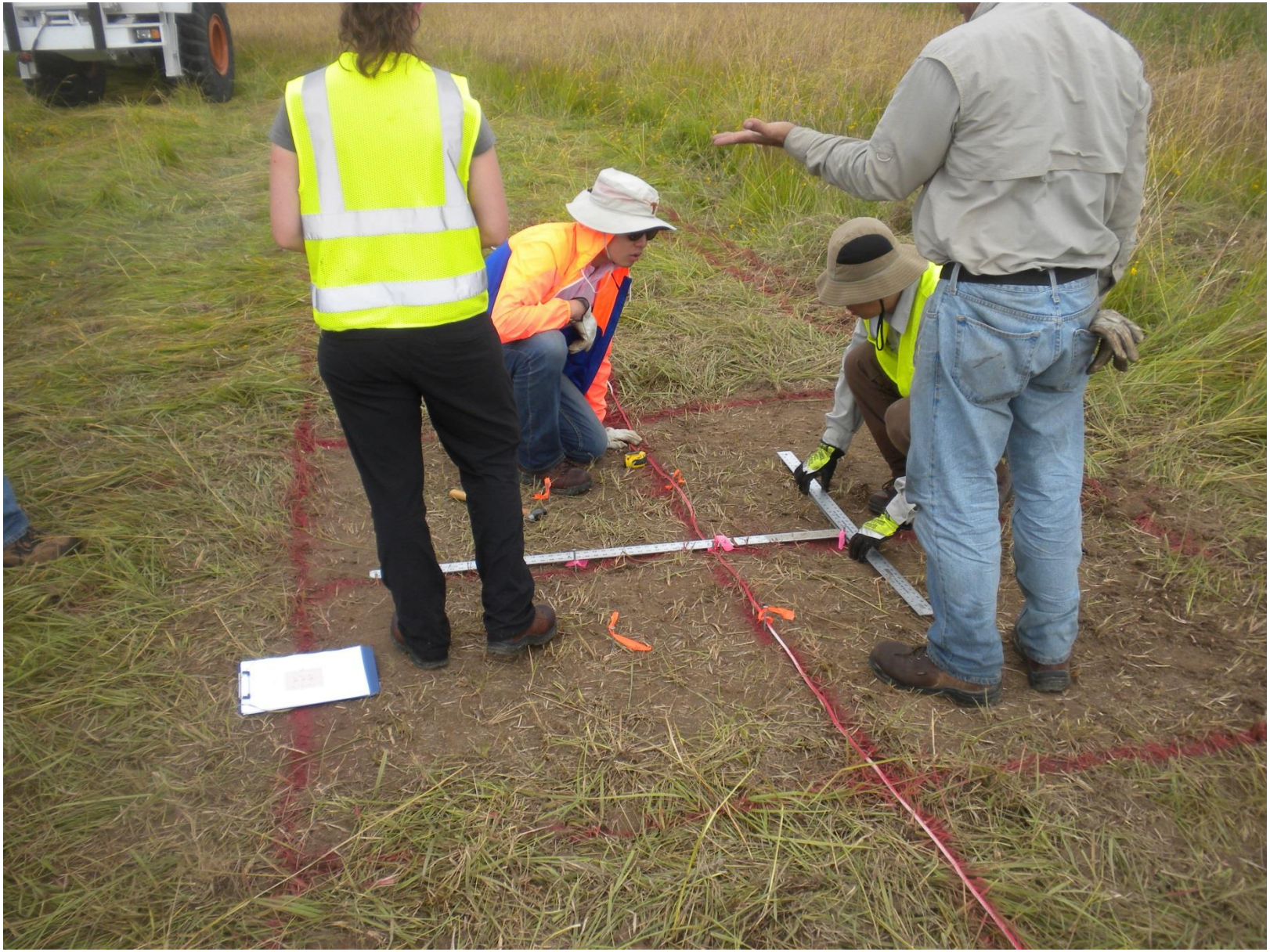


Variation in V_S and G_{max} with Depth and Estimated D_r at the RIC Test Panel



Relationship Between G/Gmax-log γ Curve and The Threshold Strain for Pore Pressure Generation, γ_t^{pp}



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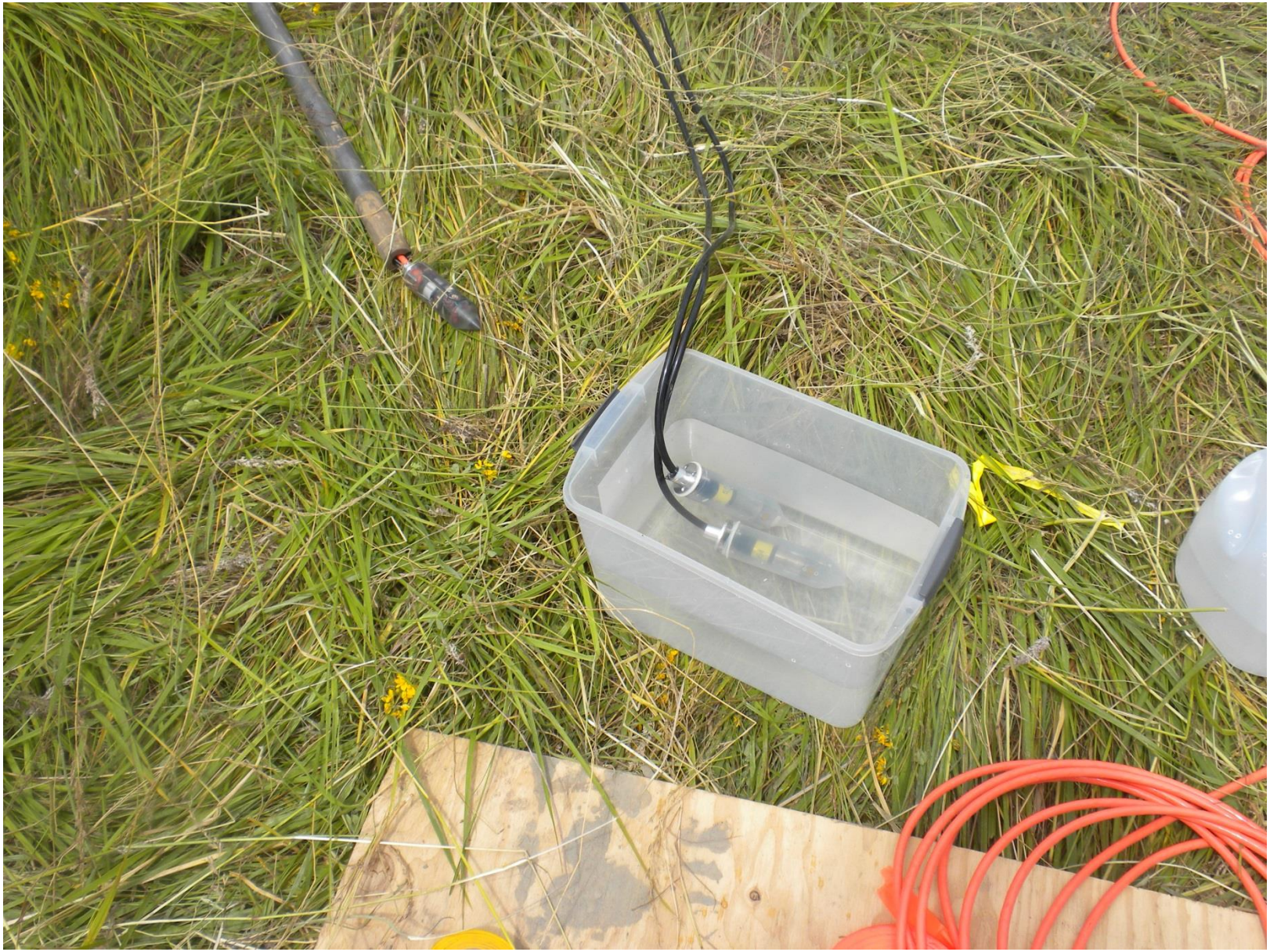

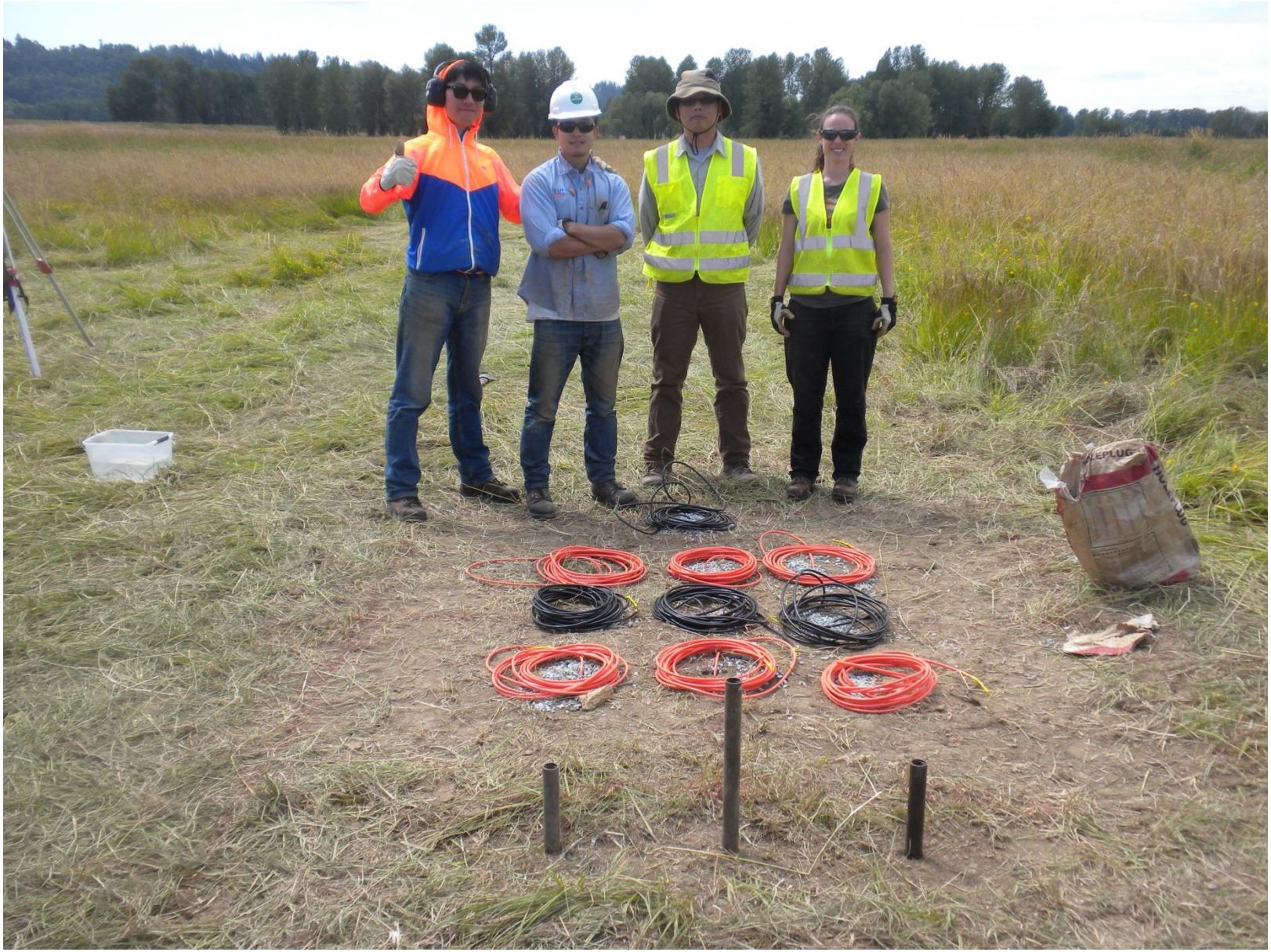


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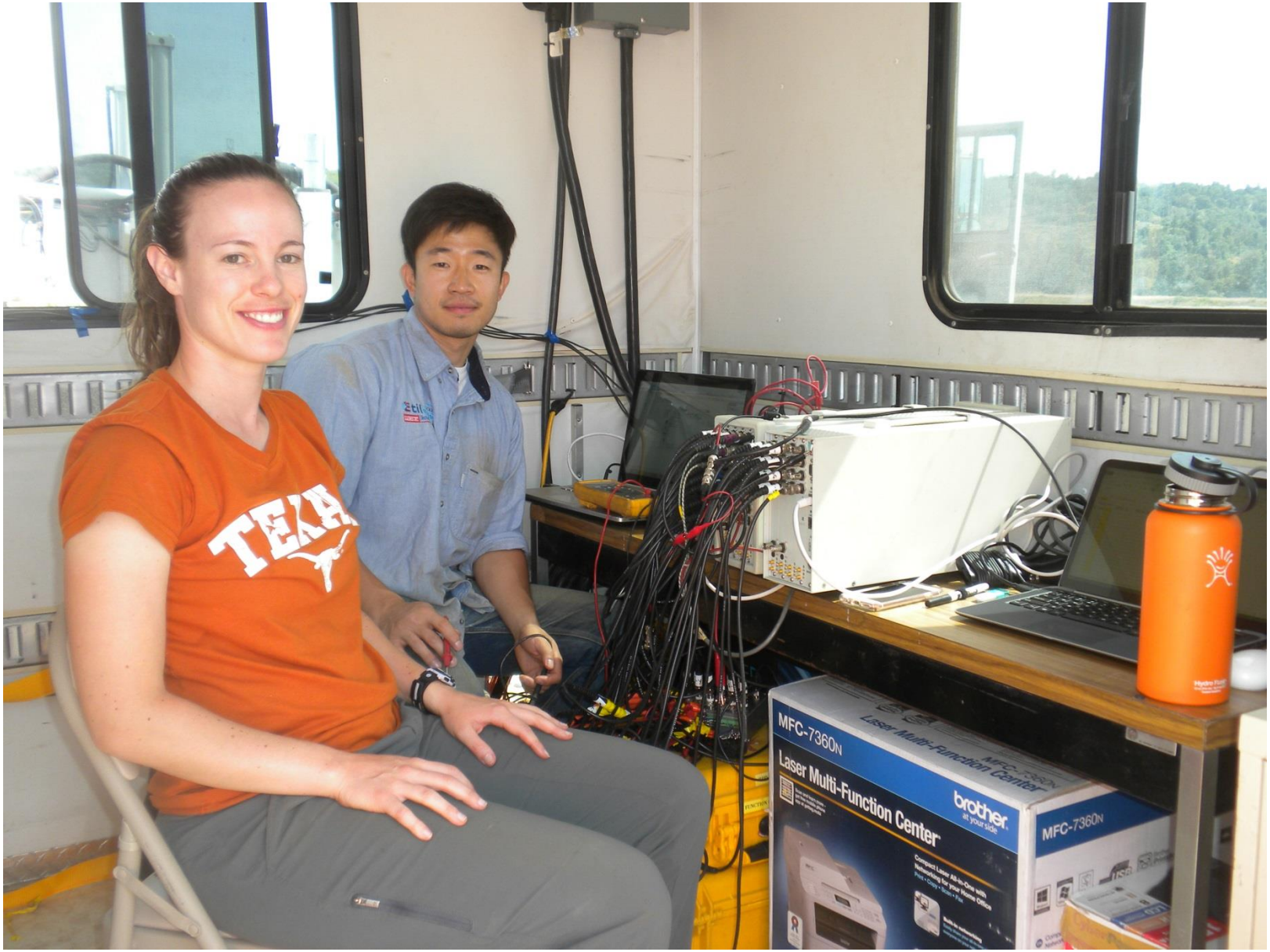
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