Field Measurements of the Variability of Pore-Water Pressure Generation in Christchurch, NZ and Port of Longview, WA Soils Based on Shaking Trials with T-Rex

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In-Situ “Liquefaction Testing”

- Develop a test method that can be used to directly evaluate the liquefaction resistance of soils in situ.
- Specifically by measuring:
  1. pore water pressure generation, and
  2. nonlinear shear modulus behavior in native soil deposits as a function of induced cyclic shear strain and number of loading cycles.
- Not intended to be a “routine” test.
Generalized Field Set-Up: T-Rex Shaking of an Embedded Array of Sensors

Static Loading

Dynamic Shaking

0.6 m

2.3 m

1.2 m

Instrumented Zone

Not to scale
Creating the Array of Embedded Sensors: Pushing Geophones and Pore-Pressure Transducers with T-Rex
Generalized Arrangement of Sensors

(a) Cross Section

T-Rex Base Plate 2.3 m

In-line Shaking Direction

2-D Geophone

Pore-Pressure Transducer

(b) Instrumentation

~ 0.60 m

0.50 m

0.50 m

0.25 m

0.25 m

0.75 m

0.6 m

0.6 m

0.6 m
Pre-Shaking Characterization of Soil: Direct-Push Crosshole Seismic Testing to Determine $V_p$ and $V_S$

Vertical Impacts (Seismic Source and Timing Trigger)

Digital Recorder/Analyzer

3-D Geophone Receiver

Source #1 (S1)

Source #2 (S2)

$V_S^*$ is stress-corrected for T-Rex

$V_p^+$ (m/s) for testing at Site 6 in NZ
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
Results of Field Tests: $\gamma$ - time and $r_u$ - time
Results of Field Tests: $\gamma$ - time and $r_u$ - time

Legend
- 2-D Geophone
- Pore Pressure Transducer
Results of Field Tests: $\gamma$ - time and $r_u$ - time

- Pore Pressure Ratio (%)
  - $N = 30, r_u = 6.4\%$
  - $r_u = 27.2\%$
  - Continues to increase
  - 6-NS-1, 0.60 m

- Shear Strain (%)
  - $N = 30, \gamma = 0.6\%, CSR = 0.44$
  - 6-NS-1, 0.60 m

Legend:
- 2-D Geophone
- Pore Pressure Transducer

Dynamic Shaking

Not to scale
Field $r_u - \log \gamma$ Relationships of Saturated, Loose Sand with Few Fines (SP): Good Comparison with Predicted Behavior

6-NS-1, 2.85 m
FC $\leq$ 5 %
$V_P = 1,728$ m/s
($Sr = 100 \%$)
$V_S^* = 156$ m/s
Soil Type: SP
Dr $\sim$ 45 %

Site 6, NZ

$\gamma_t^{PP}$
Lab G-log $\gamma$ Relationship and Correction Due to Pore-Water Pressure Generation

Resonant Column Testing

Shaking with T-Rex in the Field, NZ

Note: 1. Points were extrapolated to $\gamma = 0.3\%$. 

S6 (2.0 m) Looser (Avg Dr-40%) : $\sigma_0' = 28$ kPa

$\frac{G}{G_{\text{max}}} = \log \gamma$ 

($r_u = 0$)

$r_u - \log \gamma$ 

(N = 30 cycles)

Shear Modulus, G, MPa

Excess Pore Pressure Ratio, $r_u$, %

Shear Strain, $\gamma$, %
Shear Stress vs. Shear Strain at $\sigma_o' = 28$ kPa (Represents In Situ Condition)
Shear Stress vs. Shear Strain at $\sigma_o' = 28$ kPa (Represents In Situ Condition)

- $G/G_{max} = 0.63$ where $r_u = 0.1$
- $G/G_{max} = 0.34$
- $G/G_{max} = 0.26$
- $G/G_{max} = 0.23$
- $G/G_{max} = 0.29$
- $G/G_{max} = 0.16$
- $G/G_{max} = 0.09$

Shear Stress, kPa vs. Shear Strain, %
T-Rex Shaking at the Port of Longview, WA
Pre-Shaking Characterization of Soil: Direct-Push Crosshole Seismic Testing to Determine $V_p$ and $V_s$ at the Port of Longview, WA
Characterization of OSU-5: Embedded Array of Sensors in Depth Range of 2.8 to 3.6 m at the Port of Longview, WA
Comparison of: (1) Field G - log $\gamma$, (2) Field $r_u$ - log $\gamma$, and (3) Lab G - log $\gamma$ Relationships and Pre-Shaking Crosshole $G_{max}$ (from $V_s$) at Site OSU-5; Port of Longview, WA

OSU-5, Depth = 2.8m ~ 3.6m  
$I_c = 1.96$, $FC = 5\%$ ~ 35\%, $V_s = 119$ m/s

Pre-Shaking Crosshole  
Field G - log $\gamma$  
* Lab G - log $\gamma$  
Field $r_u$ - log $\gamma$  
Hardening  
* Silty Sand from OSU-8
Conclusions

1. Controlled, in-situ “liquefaction testing” involves large electro–hydraulic shakers (T-Rex and Rattler) to statically and dynamically load instrumented portions of the soil.

2. The generalized field test method is quite laborious, time consuming and still evolving. The method is not designed for routine testing; rather, for testing these hard-to-sample soils for which we have few field parametric studies.
Conclusions

3. Field studies of the effects of various parameters on the pore-pressure generation ($r_u - \log \gamma$) and shear-modulus nonlinearity ($G - \log \gamma$ and $G/G_{\text{max}} - \log \gamma$) of liquefiable soils are in their early stages. Parameters being studied include:

a. number of cycles of loading, $N$,
b. degree of saturation ($S_r$ of 95 to 100 %),
c. prediction of $S_r$ using $V_p$,
d. nonplastic fines content, and
e. plasticity of fines.
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