Webinaire « Doctorants en géotechnique »

Clouage des sols : comportement sous sollicitation sismique de l'interface sol-clou

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Who are We?

RRO Test deals with applied research issues identified in particular during expertise on real projects or works.

**Scope of Action:**
- Observation and monitoring of sites and geotechnical structures in full scale.
- Behavior, dimensioning, and design of geotechnical structures.

**Methods of Research:**
- Experimental testing (scale 1:1 or on site as possible).
- Analytical (calculations).
- Numerical approaches (CESAR-LCPC, OPTUM CE...).

**On-going Research:**
- Ground-frame friction for the foundations of the bolt and nail type.
- Seismic behavior of ground reinforcements by nailing.
- Behavior, design and dimensioning of the structures for protection against rockfall,
- Vulnerability of civil engineering structures required by a hard impact at moderate speed.
- Behavior and diagnosis of masonry works.
- High-precision instrumentation for monitoring works and sites by optical fiber.
Soil Nailed Walls:

- Soil retaining structures where soil is reinforced by sealed grouted steel bars.

**Economically:**
- Reduced cost
- Rapid construction
- Easy implementation

**Performance:**
- Remarkable seismic performance.
Stability of Soil Nailed Walls:

- Stability of soil-nailed walls
- Acceleration direction
- Failure of soil-nailed walls by pull out of nails

Context
Objectives of research
Test Setup
Results
Challenges & Perspective
Stability of Soil Nailed Walls: local behavior

Illustration of soil-nail interface friction

Displacement between soil and nail

Friction ($\tau_x$)

Stability
Seismic Behavior: limits of design methods

- Simplifying the Complexity of seismic load
- Ignoring Flexibility
- Not accounting to non-linear behavior of soil-nail interface

Non homogenous distribution of acceleration

Under estimation of resistance

Over estimation of inertial forces

Over design of the full structure, with high rigidity

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Seismic Behavior: limits of design methods

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The Interface Behavior: static problem

At equilibrium:

\[ T(x) - T(x + \Delta x) - \pi \tau_x D = 0 \]

And according to Hook's law:

\[ \sigma = E\varepsilon \]

\[ \frac{d T_x}{S} = E \frac{d u}{d x} \]

The equations add up to form a 2nd order deferential equation:

\[ ES \frac{d^2 U}{dx^2} - \pi \tau_x D = 0 \]

\[ \frac{d^2 U}{dx^2} = \frac{\pi \tau_x D}{ES} \]
In dynamic problem:

At equilibrium acceleration shall be considered:

\[ ES \frac{d^2 u(x,t)}{dx^2} - \pi \tau_x D = \rho S \frac{d^2 u(x,t)}{dt^2} \]

Where:
- \( S \): surface area of the nail section
- \( E \): young modulus of the steel
- \( D \): diameter of cross section

The main problem is that interface friction \( \tau_x \) in case of dynamic loading is unknown.

Identifying parameters influencing \( \tau_x \):
- Frequency
- Amplitude
- Confining pressure
- Soil properties
Aim of the Study:

- Understanding local interface behavior
- Identifying the parameters on which friction at interface depends

Through dynamic pull-out tests.
The Dynamic pull-out device:

Operating Mode:
- Impose static tension load in two different configurations: incremental loading pullout tests (steps configuration) or during a linear increase of the tensile force (slope configuration).
- Superimposition of vibrational pulses centered around the static load with an amplitude at percentage of the static load (1-50% of the static tension).

<table>
<thead>
<tr>
<th>Static Load</th>
<th>Dynamic pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Duration</td>
</tr>
<tr>
<td>Magnitude</td>
<td>Frequency</td>
</tr>
<tr>
<td></td>
<td>amplitude</td>
</tr>
</tbody>
</table>

Hydraulic pump
Hydraulic accumulator
Controlled solenoid valve
Programable automate (PLC)

The dynamic pull-out device
Experimental Setup: connections and monitoring

Connection of optical fiber along the steel bar:

- Double optical fiber connected along the two flat sides of the steel bar
- Displacement and load sensors connected at the head of the nail

Employed setup connections:

- Metallic tube
- Steel bar
- Actuator
- Optic fiber
- Sand

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## Test Protocol:

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Static load</th>
<th>Dynamic load (pulse)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pressure (bar)</td>
<td>Duration (sec/step)</td>
</tr>
<tr>
<td>Test 0</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
<tr>
<td>Test 1-5%</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
<tr>
<td>Test 2-5%</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
<tr>
<td>Test 3-5%</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
<tr>
<td>Test 4-5%</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
<tr>
<td>Test 5-5%</td>
<td>10-100-140-213</td>
<td>30</td>
</tr>
</tbody>
</table>

The duration of the pulse is **5 sec** (manual timer is used).
Measured Strains: top vs bottom fiber

Test 3-5% Top fiber

Test 3-5% Bottom fiber

Test 3-5% average of fibers
Evaluation of Interface friction coefficient $\tau$:

$\cdot$ Tau($\tau$) is computed from the linear fit of strains at relative step and relative frequency, according to:

$$\tau = \frac{EA \frac{d\varepsilon}{dx}}{D\pi \frac{d\varepsilon}{dx}}$$

Where $\frac{d\varepsilon}{dx}$ is the slope of the linear fit.
Increasing the Friction at interface: How?

The following equation allows us to see the factors influencing the friction force ($F$) occurring at the interface:

$$F \approx \sigma \tan(\varphi) \frac{\pi d^2}{4}$$

- Increasing the dimension of the inclusion
- Increasing the restricted dilatancy through increasing the interface's roughness
- Increasing the confinement
- Gluing sand particles to the grout
- Larger tube fit sand and vibrating needle
- Membrane with fluid pressure calculations of preliminary values to choose tube dimensions
- Splitted bolted tube with fluid pressure leakage of fluids and loss of pressure to be carefully managed
Increasing the Interface roughness:

**Grouting of the nail:**

- **Sticking Sand particles to grout done in PVC (aid of glue).**

  - **W/C=0.45**
Increasing the Soil confinement:

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Increasing soil confinement

Pressure application by fluid flow through an elastic membrane.

Adjustable compressible tube

Strengthen particles bond with the inclusion

Increasing friction at interface

Membrane
Metallic Tube
Sand
Nail
Thank you for your attention

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Measured Strains: at different frequencies

Average strains at static test 10

\[ y = 18.6989x + 1039.2015 \]

Average strains at peaks Test 1-5%

\[ y = 13.0060x + 1061.4007 \]

Average strains at peaks Test 2-5%

\[ y = 14.4656x + 1062.3474 \]

Average strains at peaks Test 3-5%

\[ y = 14.3270x + 1093.9147 \]

Average strains at peaks Test 4-5%

\[ y = 19.4030x + 1039.9561 \]

Average strains at peaks Test 5-5%

\[ y = 19.4030x + 1039.9561 \]
Friction model proposed by FRANK and ZHAO: