**Temperature-induced mechanical behavior of energy pile**

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**Introduction**

Energy pile foundations function as structural support and also extract ground thermal via heat pump connection to serve energy to buildings. One of the main concerns of this technology is the durability of structure foundation due to the thermal solicitation.

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**Materials and Methods**

**Materials:** Kaolin and concrete

**Method:** Interface shear test

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**Case study**

In most European climate zones the seasonal ground temperatures remain relatively constant below a depth of 10 – 15 m. Values between 10°C and 15°C predominate to a depth of about 50 m. The length of energy piles design commonly longer than 10 m to utilize ground heat. Therefore three depths over 10 m are chosen as a serial test for figuring soil strength properties.

Tests are conducted according to ASTM D3080. The tests under ambient temperature, 25°C, are carried out as a calibration. The 15°C C-test is the simulation of natural ground temperature before utilizing geothermal.

Cyclic temperature 15°C and 5°C represent pile surface temperatures during operation: 10-cycle and 36-cycle cases are conducted for comparing the affect by amount of thermal cyclic loading.

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**Further study**

1. Evaluation of thermal performance of the concrete
2. Finding better pile materials or increasing heat pump efficiency
3. Establish a design manual in construction and improve facility design to strengthen the economic and environmental advantages of energy

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**Results**

Clay – Clay

<table>
<thead>
<tr>
<th>Temperature</th>
<th>φr (%)</th>
<th>cr (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C (Calibration)</td>
<td>10.0</td>
<td>16.0</td>
</tr>
<tr>
<td>15°C</td>
<td>19.7</td>
<td>15.0</td>
</tr>
<tr>
<td>15°C - 5°C - 10 cycles</td>
<td>22.4</td>
<td>6.0</td>
</tr>
<tr>
<td>15°C - 5°C - 36 cycles</td>
<td>23.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table (a) Strength parameters for Kaolin clay

Clay – Concrete

<table>
<thead>
<tr>
<th>Temperature</th>
<th>φr (%)</th>
<th>cr (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C (Calibration)</td>
<td>15.6</td>
<td>0.28</td>
</tr>
<tr>
<td>15°C</td>
<td>20.0</td>
<td>0.37</td>
</tr>
<tr>
<td>15°C - 5°C - 10 cycles</td>
<td>23.1</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Table (b) Strength parameters for the interface

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**Conclusions**

The shear strength of effective stress analysis can be described as:

\[ s = c' + δ' \sin \phi' \]

Where:

- \( s \) = shear strength
- \( c' \) = effective cohesion
- \( \delta' \) = effective stress acting on the shear surface
- \( \phi' \) = effective friction angle

Base on Table (a), the shear strength of clay subject to a temperature of down to 15°C is not different from the sample under the ambient temperature. However, cyclic temperature loading between 15°C – 5°C cases shear strength, more cycles higher strength.

Excess pore water pressure is often present along the sides of deep foundations during and immediately after construction, especially with piles in clays. However, these pressures dissipate rapidly, so hydrostatic conditions are present during the service life of the structure. If, during the service life of the structure, an additional load is placed on the foundation, little or no excess pore water pressure will be generated along the side of the foundation because there is no further compression of soil. Therefore, we may evaluate side-friction resistance using an effective stress analysis.

\[ P_f = P_{a} - W_f \]

\[ F_s = \frac{P_f}{A_s} \]

\[ P_{a} = \text{unit side – friction resistance} \]

\[ A_s = \text{unit side – friction contact area} \]

The friction resistance between the clay-concrete interface, which subjected to the cyclic thermal loading between 15°C and 5°C, is enhanced while the cycles are increasing. Therefore, the operation of thermal piles during winter, according to lab experiments, will not weaken side friction of piles.

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**Literature cited**