Experimental study of shaft resistance of energy (thermal) piles
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Material and test approach

Material and test approach (Continued)

Background
Nearly constant annual temperature of ground at shallow depth (<100 m). Figure 1 makes it well-suited for stable storage of heat energy, referred to as “shallow geothermal energy” that can be used as a heat source in winter, or a heat sink in summer. Energy piles are innovative technologies to implement shallow geothermal energy. They integrate a system of pipes within deep building foundations (conventional piles), which are generally stiff concrete cylinders having diameter of 0.5-1.5 m vertically embedded 10-30 m into the ground to support buildings (Figure 2 & 3). Conventional piles support the building through two mechanisms: friction mobilized between the pile length and the surrounding soil (shaft resistance) and the resistance provided by the mass of soil at the pile base (base resistance) (Figure 2).

Energy piles are actually conventional piles serving as heat exchanger by circulating a heat carrier fluid through the installed pipes (Figure 4) as an addition to bearing and support. This way, heat can be exchanged between the building interior and the surrounding ground for heating/cooling purposes in winters/summers. It has been reported that 85% of annual heating/cooling demand can be supplied by this technology, resulting in significant reduction in heating/cooling costs. It can also decrease the use of fossil fuels and the resultant emissions of CO2.

However, heat exchange process generates repeated cyclic thermal expansion/contraction in pile and soil associated with cyclic relative motion between them, which is thought to degrade shaft resistance and thus load carrying capacity of pile. To make up for any undesirable effect of heat exchanging on shaft resistance, energy pile’s diameter is usually designed to be twice as large as that used for conventional piles resulting in considerable additional costs. This design approach may be conservative as there isn’t sufficient evidence to claim the temperature variations during heat exchange process can negatively impact the shaft resistance.

The results of three experimental tests are presented here to explain the effect of temperature variations on shaft resistance of an energy pile. The test plan was designated for an energy pile operating in summer mode, where heat from building is injected into the ground resulting in temperature rise in both pile and soil. It is assumed that the actual ground temperature is to 24° C and the induced temperature raise in pile and soil because of energy pile operation is be to 10° C.

Material and test approach

First test - Effect of temperature on soil strength
Using a universal testing machine (Figure 5), the soil sample is subjected to all-around pressure followed by vertical pressure at two ends (deviatoric pressure), gradually increased till soil specimen collapse (Figure 6). The soil strength is proportional to the greatest deviatoric pressure measured. To examine the effect of temperature on soil strength, the largest deviatoric pressure measured at reference temperature (24° C) was compared with those measured for soil samples subjected to 34° C and 10 cycles of (24-34-24° C). The results are shown in Figure 7.

Second test - effect of temperature on shaft resistance
Under constant vertical force, the soil sample is subjected to lateral force to horizontally move relative to the concrete surface (Figure 5). The frictional resistance mobilized at soil-concrete contact during lateral movement is equal to ratio of the greatest lateral force and the contact area (100 cm2) and effectively mimics the mobilized shaft resistance of an energy pile. To examine the temperature variations effects, the measured frictional resistance at reference temperature (24° C) was compared to those measured for soil-concrete contact subjected to 34° C and 10 cycles of (24-34-24° C). The temperature of soil-concrete contact was controlled by circulating hot/cold fluid through a copper tube inserted in the concrete. The results are shown in Figure 8.

Results

Figure 7: The results indicate that heating can cause 6-8% increase in deviatoric pressure and thus soil strength (Figure 7). The results are shown in Figure 9.

Conclusions

• Temperature variations induced during energy pile operation can enhance the soil strength surrounding the pile as well as the frictional force mobilized at the contact area between pile and soil, referred to as shaft resistance.

• In addition to providing the majority of required cooling energy, energy piles presents significantly higher load-carrying capacity comparing to that presented by conventional piles. Thus, from loading capacity point of view, the smaller dimension may be selected for energy piles as compared with conventional ones.

• It makes energy pile perfectly cost efficient as they reduce both heating/cooling and construction costs. Additionally they have been found environmentally efficient as they utilize renewable energy source.

Literature cited

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