Long Term Performance of Energy Piles

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Project Background

Energy piles are deep foundations that are embedded with circulation tubes for heat exchange operations. Due to the changes in seasonal energy demands of the building, sustainability of energy piles mainly depends on the seasonal load balance. The soil around the energy pile can be gradually heated up or cooled down as a result of unbalanced thermal loads. The long term thermo-mechanical performance of the energy piles is closely related to maintaining ground temperature as progressively changing temperatures indicate loss of heat exchange efficiency. Therefore, investigations are performed to relate different climatic conditions to seasonal energy demand profiles and long term thermo-mechanical behavior of energy piles.

Figure 1: Actual and Equivalent Ground Thermal Loads

Figure 2: Temperature Contours after 30 Years of Operation

Figure 1 shows the equivalent half sine waves created for a hot climatic location. Unbalanced thermal load amplitudes and episodes create gradual temperature changes in the pile and surrounding soil. For such a climatic region, soil temperatures are expected to increase with the operation of energy piles. Figure 2 represents the ground temperature contours after 30 years of operation of energy pile. Gradual increase in the soil temperature results in drop of heat exchange efficiency. For a cold climatic location, however, opposite will occur; soil temperatures decrease, again resulting in a loss of heat exchange efficiency.
Project Objectives
The principal objectives of this research are listed below:

1. To develop representative energy demand profiles for different climatic regions to relate the typical meteorological year climatic data to long term ground thermal loads.
2. To investigate the long term thermo-mechanical behavior of energy piles under different representative energy demand profiles therefore, identify the changes in temperatures in the piles and the surrounding soil; and estimate the displacements and stresses on the pile to address the long term performance.

Research Plan and Progress
The research plan tasks are listed below along with my progress (in italics) to date:

1. Developing hourly design thermal loads for different typical climatic conditions for a medium-size office building. Building thermal loads for numerous cities around the world are estimated by solving heat balance equations using the program HVACLoadExplorer following the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Design Procedure. Components of the building, lightning, equipment usage and occupancy were taken into account to estimate the design thermal loads. I have already finished this part of my research and have analyzed 100+ climatic locations to estimate building thermal loads.
2. Selection of ground coupled heat pump (GCHP) to estimate the hourly ground thermal loads for any location. Bin method was used to relate the ground thermal loads to ambient temperatures. I have completed this part of my research and considering typical meteorological climatic data for 100+ cities, estimated hourly ground thermal loads.
3. Developing annual equivalent half-sine waves to represent the balanced or unbalanced thermal loads for the locations selected. Durations and amplitudes of the sine waves are evaluated by performing change point analyses and equivalent area concept to define the seasonal changes from heating to cooling and from cooling to heating for a typical climatic year.
4. Estimating the total required borefield for any selected location. Based on borehole sizing equations proposed in ASHRAE Handbook, loop lengths were calculated by using simple algebraic correlations to obtain effective ground thermal resistances. I have finished this part of my research by estimating the loop lengths of all selected climatic regions.
5. Determining long term temperature changes in the energy piles and surrounding soil due to the thermal loads for different climatic regions. I have done this part of my research for all of the locations. Finite element model was used to estimate the gradual changes in the temperatures for the lifetime of the structure.
6. Analyzing long term thermo-mechanical behavior of the energy piles by considering pile-soil interaction with changing temperatures due to thermal loads. I have started this part by determining 30 year changes in temperatures and displacements for several locations. Finite element model is being used to calculate thermally-induced settlements and stresses. This way, thermo-mechanical performance of energy piles is going to be analyzed for different climatic regions.
7. A conference paper was submitted and presented at GeoFrontiers, 2017. A journal paper is in its final stages.

Conference Papers:
- Long Term Performance of Heat Exchanger Boreholes in Different Climatic Conditions. Olgun, G., Geyin, M., Ozudogru, T. (Submitted to Geotechnical Frontiers, presented on 15/03/2017)

In the next period of my research, I plan to finish analyzing long term thermo-mechanical performance of the energy piles.