

MICROPILE WALL - AN OPTION TO DEVELOP ENERGY BARRIERS

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ABSTRACT

Micropiles used in underground walls can be seen as hybrid structures functioning partly as vertically loaded piles, partly as lateral capacity of the retaining wall, or even a heating/cooling insulation barrier when geothermal energy has to be controlled under the building. This paper discusses the Case Kupittaa in Turku as a preliminary study of an energy pile foundation for heating and cooling purposes of a new building. Case Kupittaa is one of the first studies concerning the efficiency of a vertical insulation barrier surrounding an energy pile foundation. A 2D model was created with and without the vertical insulation barrier to compare the results and to see if the insulation barrier reduces energy loss through the building basement and maximizes the energy storage below the building. In both models, a ten year transient analysis was carried out. The insulation improves thermal balance in the first few meters below the ground surface reducing thermal losses through the building. Ground temperature differences with and without the insulation barrier is between 1.5-3.5°C depending on the depth. With the insulation barrier, temperature differences between the inner and outer part of the insulation barrier decrease with depth.

BACKGROUND

The market share of micropiles and other steel piles is remarkably high in the Nordic countries, partly due to innovations and active research during the past decades. Drilled micropile walls extend the use of drilled piles to sites where

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conventional piling has previously not been seen as an option. The drilled pile walls can be installed in very demanding soil conditions and boulders or dense soils are not obstacles to embedment. Drilled pile walls can be constructed under basements or in any conditions where micropiles are available as a foundation method.

The C pile is an example of Finnish micropile innovation to drill an open section as a structural body of a drilled pile. Open section drilling can be done using an eccentric drilling bit, and the eccentric part of the machinery can be removed from the pile body through the open side of the steel section.

Two variations of drilled pile walls have been introduced recently in the Nordic countries based on either drilled steel pipe piles (RD piles) or an application of open section drilling utilizing C and CT profiles (Lehtonen 2013, Lehtonen et al 2014). Using open section drilling, a drilled pile wall can be implemented starting with embedding of an open C section (Fig. 1), and the wall can be extended using CT profiles. The first C profile provides open access to the next element. The T part of the CT profile penetrates to the previous C section creating a locking structure, and the C part of the CT profile provides access to the next element. Use of grout flushing improves structural capacity and water tightness of the wall. Grout can be used as insulation material, too.

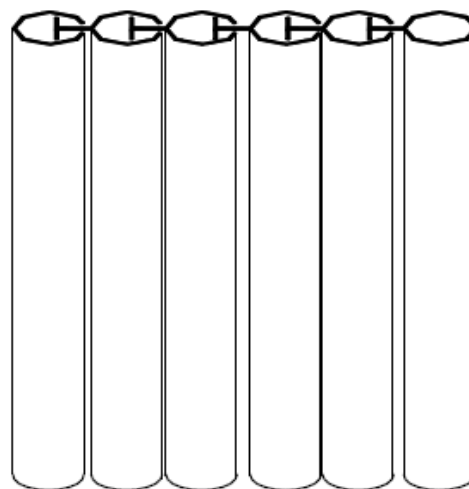


Figure 2. A wall constructed using C and CT micropiles. The first element is a drilled C pile (on left) and the following elements are type of CT profiles.

HEAT INSULATING GROUT

Concrete is traditionally a mixture of a binder (cement), filler (course and fine aggregate) and water. Nowadays additives and admixtures are used commonly. In regular concrete, the aggregate consists of: sand, gravel and stone. Concrete has high weight (density) and high thermal conductivity (λ).

Normal thermal conductivity of concrete, which we use in building design, varies from 1.2 to 1.7 W/(mK) when the dry density of concrete is from 2000 to 2300 kg/m³. In mortars, plasters and grouts, the maximum size of aggregate is much smaller. The density is somewhat lower, as is the conductivity, ranging from 0.9 to 1.2 according to Finnish building regulations. (Ministry of Environment, 2003)

Thermal conductivity depends on the density of grout, on the conductivity of both cement paste and aggregate and on the moisture content of the grout. The lighter the grout., the lower the conductivity. The dryer the grout, the lower the thermal conductivity. The amount of cement paste increases as the size of aggregate gets finer. Cement paste is the part of the grout that gets wet.

The best known ways to reduce the thermal conductivity of concrete are to increase the air content in cement paste or to use different kinds of light aggregates. When the cement paste has air cells uniformly distributed in the mix, we call the product aerated, cellular, foamed or gas concrete. It is produced by using air-entraining agents, carbon ash, aluminium waste or zeolite powders to create air.

About 70% of concrete is aggregate, so the change of aggregate is a very effective way to lower the density. General types of lightweight aggregates are aggregates which are prepared as expanding, calcining or sintering products such as blast furnace slag, clay, diatomite, fly ash, shale or slate. They can also be prepared by processing natural materials, such as pumice, scoria or tuff (ASTM, 2013). The most common lightweight concrete with low thermal conductivity is LECA (light expanded clay aggregate) concrete. The density of light-weight concretes and grouts varies from 600 to 1600 kg/m³.

Table 1. Some test results of lightweight concretes (Hansson, 2010) and a plaster

Material	Density kg/m ³	Thermal Conductivity W/mK	Compressive strength MPa
Aerated Concrete	215-365	0,065-0,103	0,69-1,69
Leca Concrete	300-500	0,11	0,09-0,55
Foamconcrete	300-1600	0,8	0,5-10
Multipurpose insulation plaster	315	0,06	2,5

The last product in Table 1, the multi-purpose insulation plaster Thermoplast, produced by Say Yeni Nesil Yapi Ürünledi LTD, Istanbul, Turkey, was tested in the concrete laboratory of Turku University of Applied Sciences. It was also sprayed (as shotcrete) to one half of a cold garage wall as insulation, but only the workability was studied in the garage. According to information in the bag approximately 98% of the plaster contains inorganic substances. Foamed, recycled glass is used as aggregate. Maximum aggregate size is only about 2 mm. The laboratory test results were consistent with the product information. (Thermoplast, 2014)

From these figures of thermal conductivity we notice that plaster can have very low thermal conductivity, better than many traditional insulation materials.

Grouting of piles sets the terms and conditions for the grout used. Most lightweight products are likely too light for the grouting methods used. The pressure has to be very high to push lightweight products to the bottom of the pile and to fill it completely. The consistency has to be suitable for the machine used. A suitable density could be between 600-1000 kg/m³ and the thermal conductivity about 0.1-0.2.

The compressive strength should be at least 25 N/mm² according to EN 14199, 2001. If this is required it is difficult to get low thermal conductivity. Strength and density unfortunately correlate together. For workability, a mixture with 30-40% of normal sand and the rest lightweight aggregate, (such as foamed glass) could be suitable. The strength and the thermal conductivity has to be tested.

CASE STUDY IN AALTO UNIVERSITY

Case Kupittaa in Turku is a preliminary study of an energy pile foundation for heating and cooling purposes of a new building for the Turku University of Applied Sciences. In addition this is one of the first times studying the efficiency of a vertical insulation barrier surrounding an energy pile foundation (Cervera, 2013). In this study a simplified 2D model simulating an energy pile foundation and a vertical insulation barrier of 5m depth and 200mm thick was carried out with SoilVision/Heat v2.4.10. The objectives of this case were to study the ground thermal behaviour and response to an energy pile foundation in long term analysis, define the ground energy storage capacity for heating and cooling purposes and evaluate the efficiency of a vertical insulation barrier surrounding the pile foundation in order to reduce the thermal loss through the building basement.

Model Geometry and Characteristics

The final design of the building for the Turku University of Applied Sciences is still not finalised. Due to this, a simplified 2D model was carried out to get preliminary information about the energy pile foundation and the efficiency of the insulation barrier. The 2D symmetric model simplifies the geometry of the building and the pile foundation (Fig. 2).

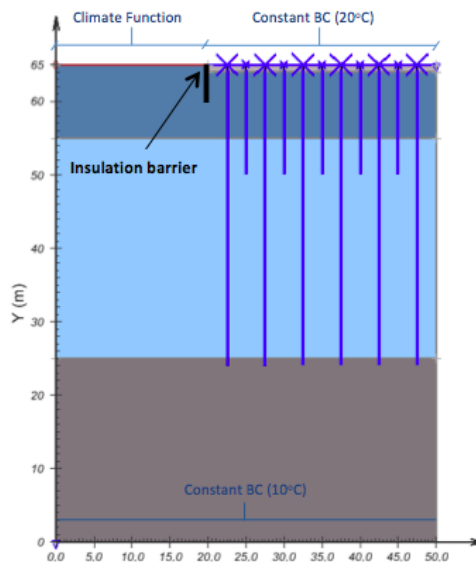


Figure 2. Schematic of the model geometry, ground layers and boundary conditions applied in the 2D model.

In this model, a non-insulated concrete slab of 800mm represents the building floor. Two different types of piles with identical diameter of 200mm are considered. Long piles reach the bedrock (40m length) and work as a foundation and as a heat exchanger extracting energy from the ground throughout the year. Short piles (15m length) work only during summer time injecting solar energy collected into the ground to compensate the asymmetric energy extraction due to climatic conditions in Turku, Finland. The distance between long piles is five meters, otherwise short piles are placed between two long-piles only in one direction. The thermal conductivity of the vertical insulation barrier is 0.046 W/mK with a thickness of 200mm up to a depth of 5m.

The ground profile was divided into three different soil layers: a silty-clay layer from the ground level to 10m in depth, a granular material (Calcio-fluvial sand and gravel) at 10-40m in depth, and the bedrock (Granodiorite) at the depth of 40m. As this is only a preliminary study, there was little data available regarding the thermal properties of the ground, and most of the parameters were obtained from literature (Andersland et al., 1994; Sundberg, 1988). Table 2 summarizes the thermal properties of the ground and other construction materials.

Table 2. Thermal properties of the ground and construction materials

Material		Thermal Conductivity	Heat capacity	Vol. Water Content
		W/mK	kJ/m ³ K	m ³ /m ³
Ground Layers				
Clay	Unfrozen	1,22	2400	0,55
	Frozen	1,74	2000	0,55
Granular	Unfrozen	1,97	2800	0,35
	Frozen	3,01	2000	0,35
Bedrock	Unfrozen	2,89	1980	0,05
	Frozen	3,36	-	0,05
Construction Materials				
Concrete	Unfrozen	1,63	2150	0,1
	Frozen	1,75	2000	0,1
XPS	Unfrozen	0,046	45	0,01
	Frozen	0,046	45	0,01

The initial conditions were established with two different constant temperature boundary conditions. The first of them was applied in the ground surface with the annual average temperature in Turku (+5.6°C). Another constant temperature boundary condition was applied at 65m depth. The temperature at this point was +10°C. This temperature was considered because of the ground water temperature measurements done in situ at 20m in depth.

Boundary conditions applied:

During the transient analysis, several boundary conditions were applied in the modelling. Some of these boundary conditions were constant throughout the entire analysis. The temperature inside the building was considered constant in the analysis. It was represented as constant temperature boundary condition at +20°C applied in the upper part of the concrete slab. Ground temperature at the depth of 65m was also considered constant with a temperature of +10°C.

On the other hand, in the transient analysis, there were other time-dependent boundary conditions such as the climate function or the energy function. The climate function represents the monthly average air temperature in Turku, Finland for the last 30 years (FMI, 2012). It was applied in the ground surface which is not in contact with the building, and it was repeated annually during the transient analysis (Fig. 3).

The energy function represents the boundary condition of the energy piles working as heat exchangers for cooling and heating purposes during the analysis. It was created based on previous studies done in Finland relating the energy that can be extracted or injected into the soil depending on the thermal

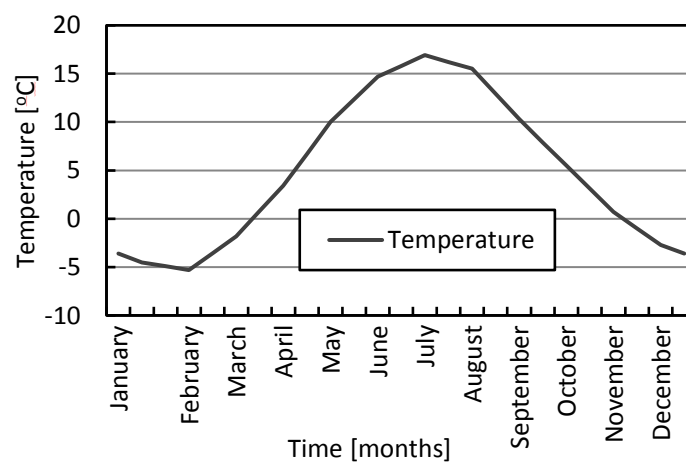


Figure 3. Turku cyclic climate function based on average air temperatures (FMI, 2012)

conductivity (Nyholm, 2011). The energy piles are extracting or injecting heat into the ground depending on the seasonal operation and building requirements. The maximum value of heat extracted during winter by the long piles is 23 W/m, while the maximum value of heat injected during the summer was 32 W/m. The short piles work only during the summer time and the maximum value of heat injected was 25 W/m.

Results of the efficiency of the vertical insulation barrier:

On a big scale, the results did not show major differences between the ground temperature of the insulated and the non-insulated models. This could be explained because of the shallow depth and thickness of the insulation barrier compared with the entire model. Despite of this, ground temperature results were examined in points placed close to the insulation barrier at different depths in order to better understand the effect of the vertical insulation barrier. In the insulated model, ground temperature was evaluated in the inner and the outer part of the insulation barrier during the entire transient analysis. Modelling results showed that the temperature differences between the inner and the outer part of the insulation decreased with depth (Fig. 4). In the long-term analysis, ground temperature differences between the inner and the outer part of the insulation increased gradually. The temperature difference increases faster with depth, even though the temperature difference is lower. Modelling results were compared with and without the insulation barrier. Figure 5 shows the ground temperature difference in the same points with and without the insulation barrier by depth. As can be seen in the figure,

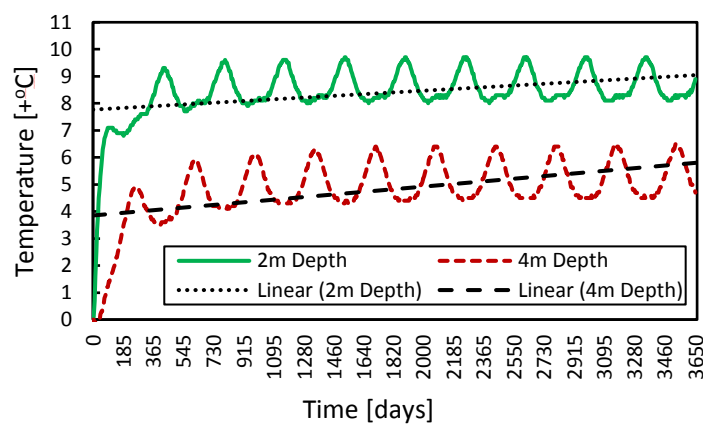


Figure 4. Ground temperature differences between the inner and the outer part of the vertical insulation barrier by depth

temperature difference varies between 1.5°C and 3.5°C depending on depth. Ground heat storage capacity is related to temperature difference and the heat capacity of the soil. Thus, considering the heat capacity of the ground and the temperature difference between the insulated and the non-insulated model, the thermal losses through the building floor were reduced by 1.0-2.3kWh per cubic meter. The effect of the insulation barrier reduces with distance and temperature differences with or without insulation barrier at 10m from it were negligible.

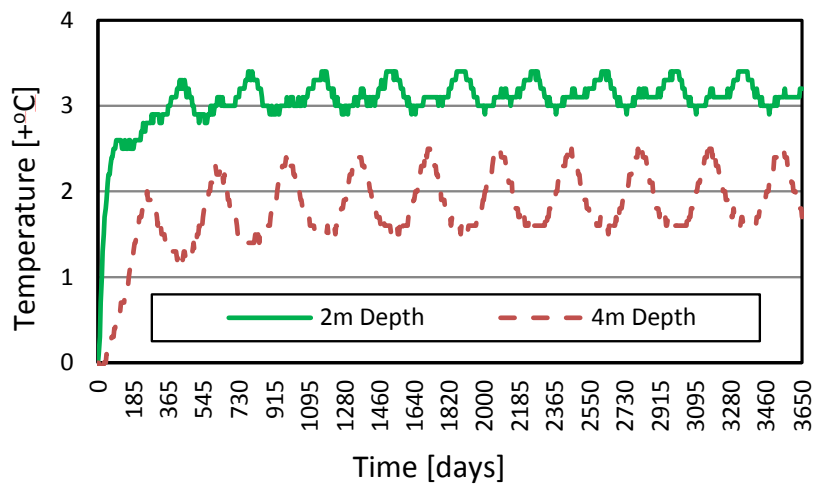


Figure 5. Ground temperature differences in points placed close to the vertical barrier in the insulated and non-insulated model by depth

CONCLUSIONS

Numerical modelling represents a powerful tool in engineering design saving time and sources. The main purpose of this paper was to study ground thermal response to energy pile foundations and contribute to the improvement of the knowledge of ground thermal behaviour. In the case studied, mechanical properties of the piles as well as the hydrological ground conditions were not considered. Both can affect the reliability of the results obtained. Further analysis and modelling should be done in order to determine the effect of hydrological and mechanical conditions to energy pile foundations. Multi-physical finite element modelling must be done to evaluate the structural consequences and geotechnical risks related to energy foundations under cyclic thermal loading, especially if it produces any change in the effective stresses in the soil.

For energy pile foundations, there is some evidence that suggests typical values for the amount of energy that can be extracted from the soil. However, these typical values are related to soil properties and ground temperatures. In Finland, due to the climatic conditions, ground temperatures are relatively low and it means that the capacity of extracting heat from the soil is lower than in warmer countries where ground temperatures are higher.

The energy function created for the evaluation of the ground thermal behaviour was adapted to the ground conditions in Finland and it is repeated cyclically every year. Short piles were planned to pump heat to the ground collected by solar panels in order to keep the thermal balance. The total estimated amount of energy pumped during the summer time by the short piles is 2.216MWh, less than the energy needed to keep ground thermal balance. Moreover, the energy pumped during the summer time is heating the area a few meters below the building because of the short length of the piles. This situation means that high temperatures are reached on the ground (more than $+30^{\circ}\text{C}$) between the building and 20m below it. Meanwhile, between 35 to 40m depth, ground temperature is lower and remains almost constant with values around $+5$ to $+7^{\circ}\text{C}$ yearly. This high temperature differences between the top and the bottom of the piles may produce differences in the behaviour of the pile due to thermal stresses. In addition, the heat carrier fluid inside the piles, which was not modelled, can be affected by the different temperatures and modify the total amount of heat extracted. According to the results it would be better to distribute the collected solar energy between the short and long piles in order to solve this high temperature difference between the top and the bottom of the energy pile foundation.

Concerning the efficiency of the vertical insulation barrier surrounding the pile foundations, the insulation improves thermal balance in the first few meters below the ground surface reducing thermal losses through the building. Ground temperature differences with and without the insulation barrier is between 1.5 - 3.5°C depending on the depth. With the insulation barrier, temperature differences between the inner and outer part of the insulation barrier decrease with depth. The temperature difference between the insulation is around 5 - 10°C , having maximum values in points close to the surface. Otherwise, the effect of the insulation barrier decreases with the

distance and it only affects the piles located close to building borders. Ground temperature effects of the underground insulation barrier reduce with higher distances from barrier. The effects are practically negligible in points located more than 10-15m from the insulation.

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