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THERMO - ACTIVATED PILE FOUNDATION

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1. INTRODUCTION

Thermo-active pile foundation makes use of geothermal energy to cool or heat buildings. It is an innovative technology that contributes to environmental protection by reducing carbon dioxide emissions and reduces building energy and maintenance long-term costs.

The GSHPA (Ground Source Heat Pump Association) provides the standards for designers and installers of ground source systems to maintain a high level of installation quality. The document contains regulatory and government agency requirements, contractual responsibilities, design methods and compliance and other information that is helpful in designing and using of ground source heat pumps.

Ground Source Heat Pump system (GSHP) contains closed tube in earth-contact concrete elements through which a heat carrier is pumped to exchange energy from the building to the ground. The heat carrier fluid is water with antifreeze or a saline solution. This system is known as 'primary circuit'. The 'secondary circuit' is a fluid-based building heating network in the floors or walls of the structure. Primary and secondary circuits are connected via a heat pump. It takes advantage from the fact that under the certain depth, soil temperature remains constant throughout the whole year.

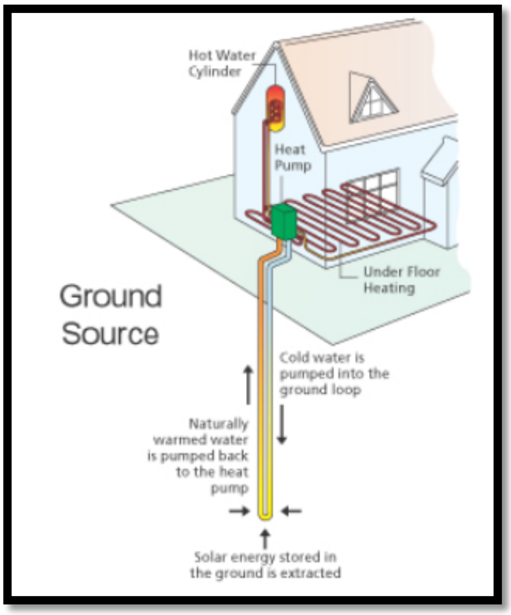

Figure 1. Scheme of GSHP system.

2. PROBLEM STATEMENT

This work aims to understand the mechanical and thermal behavior of thermo-active pile foundation. The system contains concrete pile and steel inner tube. Dimensions of elements are given in the following picture:

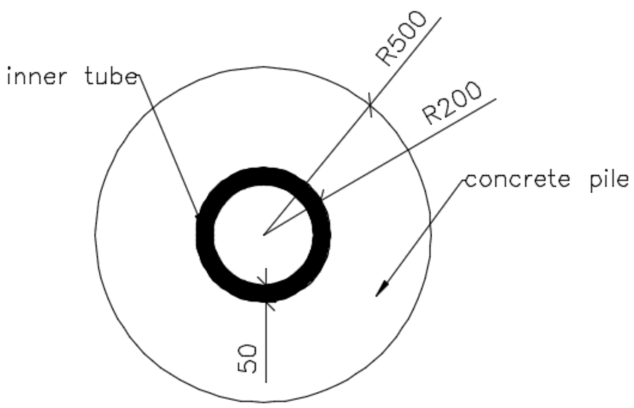

Figure 2. Dimensions of elements.

The system consists of two materials, steel and concrete. The outer pile is surrounded by soil. The mechanical and thermal properties are indicated in Table 1.

Material	Young's modulus (MPa)	Density (Kg/m^3)	Poisson's ratio	Thermal expansion coefficient (°C^{-1})	Thermal conductivity (W/m K)	Friction angle
Concrete	27000	2500	0.2	1.0e-5	2	-
Steel	210000	7800	0.3	1.2e-5	50	-
Ground	-	2000	-	-	-	30

Table 1. Material properties.

The following aspects were investigated:

- analysis of the stress state of the concrete and steel pipe due to ground pressure and a vertical load
- analysis of the increase of stresses in the concrete due to flow of water inside the pipe
- analysis of the maximum increase in water temperature that the steel pipe and the concrete can withstand
- analysis of the stress state after using a new type of concrete whose properties vary with temperature

3. METHODOLOGY

In order to achieve work goals, thermal and mechanical numerical analysis were performed. A study of a thermo-active pile foundation was carried out using the software Abaqus. For the purpose of the practice, the calculations were carried out on a 3D model.

3.1 Geometry and materials

First, a computational model was created. It is made of two parts. One part is a concrete tube with an external radius of 0.5 m and an inner radius of 0.2 m. Second part is a steel tube with an external radius of 0.2 m and an inner radius of 0.15 m. Both parts are 1.0 m long. On both the concrete and steel part, at the height of 0,5m, calculation points were created to read the stress state. This height corresponds to 20.0 m of the real pile depth. The materials with properties given in point 2 were assigned to each part.

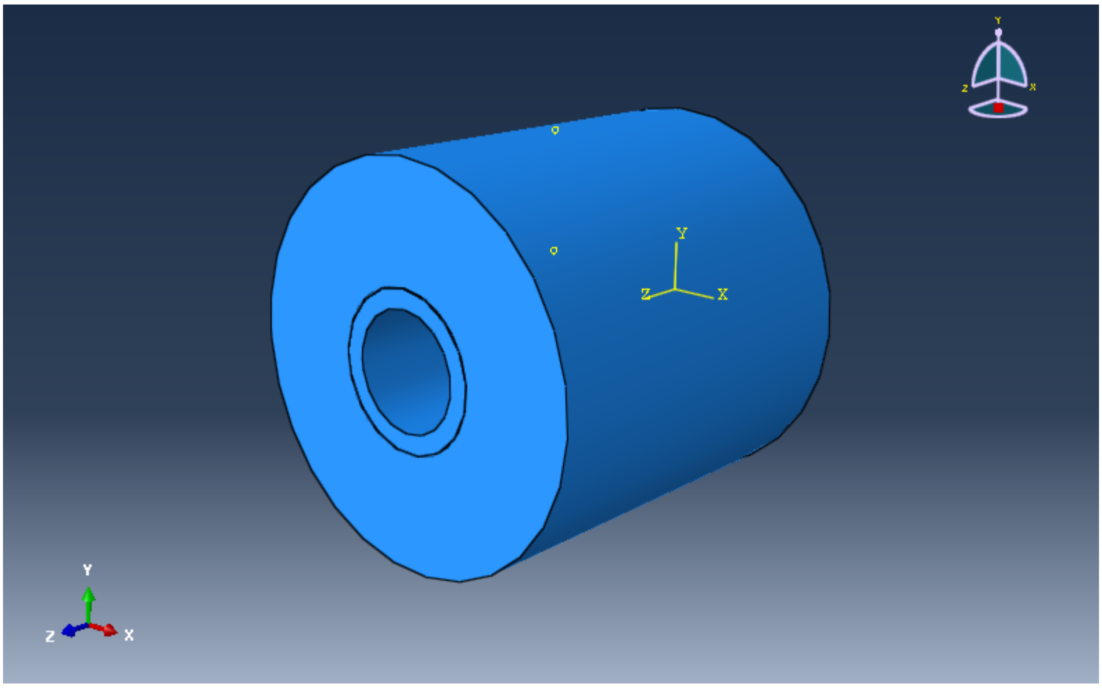

Figure 3. Model geometry.

3.2 Loads

The different forces affecting the thermopiles are described in the following subtopics. The forces are added to the model as loads, in this case as pressure loads on a surface. To deal with the different forces we used averaged values. There are four different types of forces. The first one is the Self-weight of the different materials. The self-weight is caused by the density of the material and the gravity. We considered the self-weight as fixed value for the upper surface of the model, because the dimensions of the pile above our out grabbed piece are much smaller in comparison with the 19.5 m of pile above our model. In reality, the self-weight would change over the height as a ramp function. The same assumptions we used for the hydrostatic pressure and the ground or soil pressure. We used a constant pressure over the profile and not a ramp function because of the small dimensions.

3.2.1 Self-weight

Concrete pile: $2500 \frac{kg}{m^3} * 9{,}81 \frac{N}{kg} * 19{,}5\ m = 478238\ \frac{N}{m^2}$

Steel tube: : $7800 \frac{kg}{m^3} * 9{,}81 \frac{N}{kg} * 19{,}5\ m = 1492101\ \frac{N}{m^2}$

3.2.2 Vertical load

V = 300 kN

$$\frac{300000\ N}{\pi * (0{,}5m^2 - 0{,}2m^2)} = 454959 \frac{N}{m^2}$$

3.2.3 Ground pressure

At the depth of 20,5 m:

$K_o = 1 - \sin 30^o = 0{,}5$

$$2000\ \frac{kg}{m^3} * 9{,}81 \frac{N}{kg} * 20{,}5m * 0{,}5 = 201105 \frac{N}{m^2}$$

3.2.4 Hydrostatic pressure

At the depth of 20,5 m:

$$1000\ \frac{kg}{m^3} * 9{,}81 \frac{N}{kg} * 20{,}5m = 201105 \frac{N}{m^2}$$

3.2.5 Temperature

Concrete pile: 30°C

Steel tube: 50°C

3.3 Boundary conditions

As boundary conditions displacement fixations are used. For solving a Partial Differential Equation, it is necessary to set the degree of freedom to the correct level. Because auf the Pressure on top of the thermo-pile, the whole model is expected to expand in radial direction. So, there is no radial fixation, expressed by the free value for the U1, U2 coordinates at the bottom (Figure 4.). For the U3 coordinate the displacement is set to zero, to fulfill the needed boundary conditions and prevent the model of the pile to move in direction of the pressure.

At the surface of the pile there is a free displacement because the material is expected to be compressed in z-axis direction and also have a displacement in radial direction, caused by the different implemented pressures. There is no rotational displacement expected, caused by the uniform pressure over all circumference.

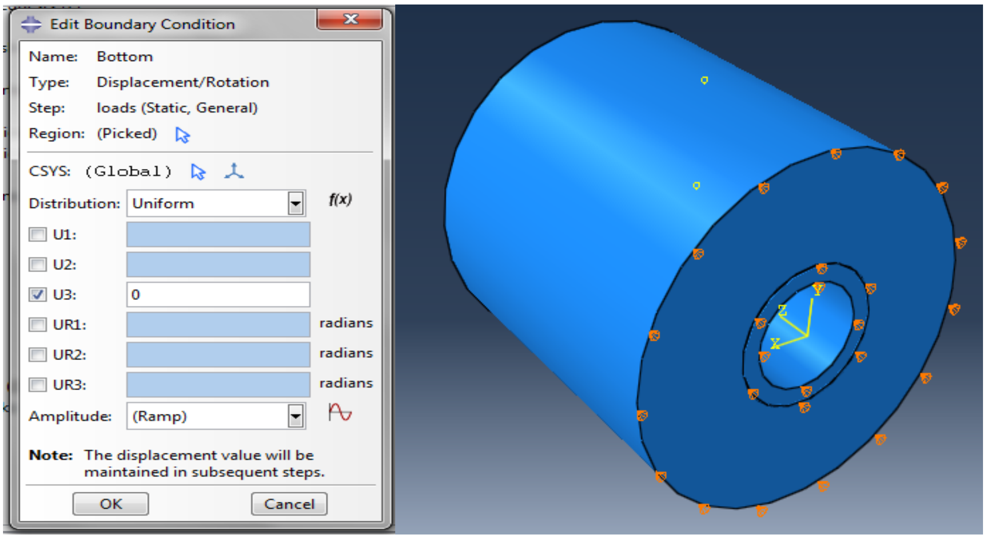

Figure 4. Boundary Conditions at the bottom

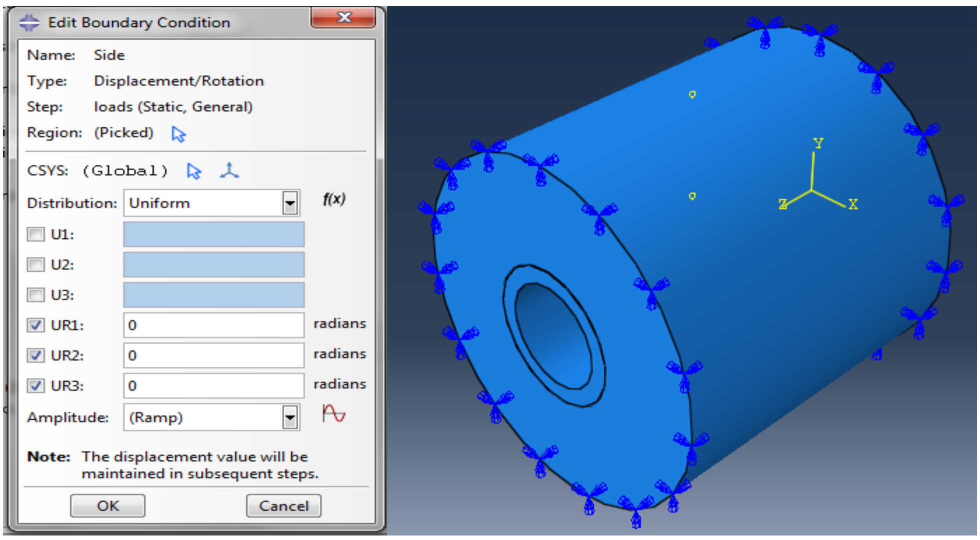

Figure 5. Boundary Conditions at the bottom

3.4 Mesh

To calculate the physical properties of the model it has to be discretized. For this discretization finite elements are used in form of a hexagonal mesh with a hex-dominated sweep mesh technique to obtain a good mesh quality for a cylindrical element. For this geometry, its recommended to use an o-grid to refine the meshing for smaller radius but the student version of Abaqus limits the possibilities of the meshing quality by an upper limit of nodes of 1000. For this reason, the mesh of the model is of a low quality.

In addition to that there are to different parts in the model: The steel tube and the concrete. The mesh is unique for each part and therefore not connected. In Figure 6 gaps between the two parts are to observe and also angular geometry instead of a circular or cylindrical geometry. In an ideal mesh the distribution of the elements would be uniformed to prevent calculation errors. With the few elements and the not fitting linking between the parts the geometry is not well represented and errors in the calculation are expected.

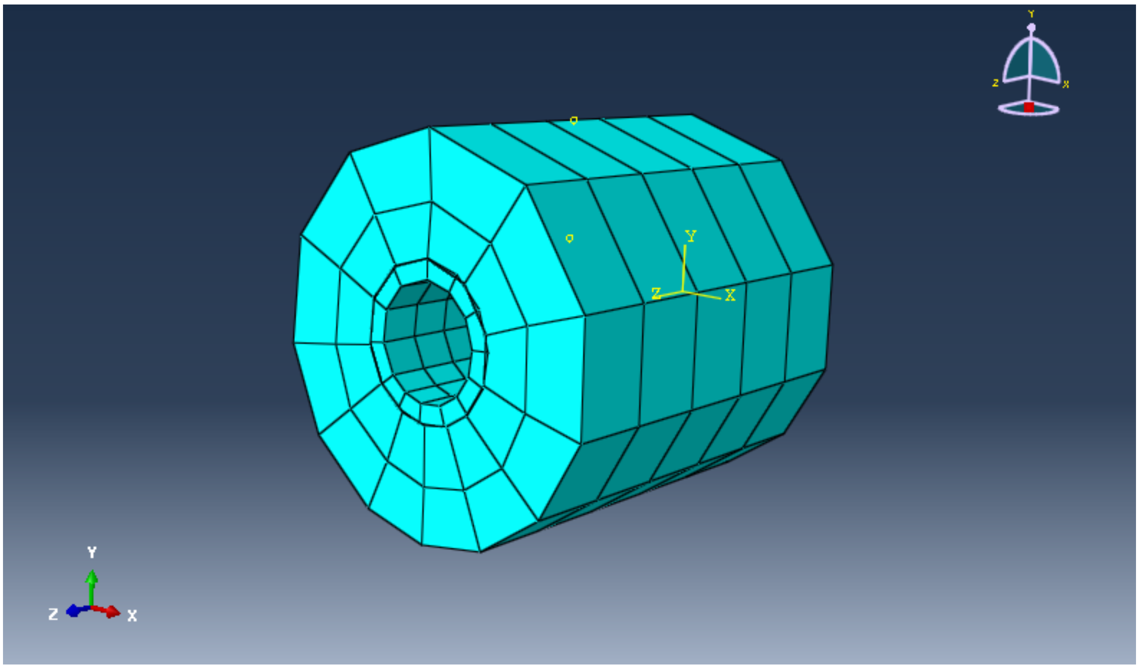

Figure 6. Mesh of the model

4. RESULTS AND DISCUSSION

4.1 Analysis of the stress state of the concrete and steel pipe due to ground pressure and a vertical load

Steel: 2,12 * 10^8 N

Concrete: 4,48 * 10^7 N

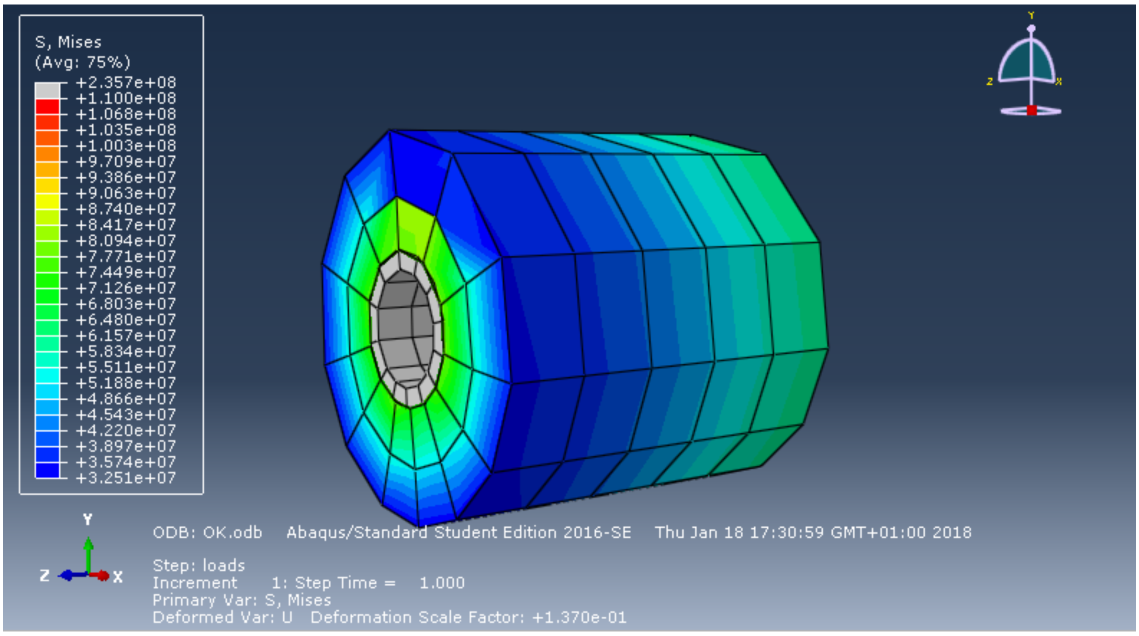

Figure X. Stress state.

The stress state is higher for the steel pipe because the elasticity of steel is of higher value as the properties of concrete.

It is also to observe that the Stresses in the concrete are higher in the with smaller radius. We presume that with the higher self-weight of the steel and the hydrostatic pressure from the inside of the pipe, the steel expands more than the concrete and therefore provokes a pressure against the inner surface of the concrete cylinder.

The increasing of the S. Mises over the z-axis could be provoked by the Force load on the top of the concrete.

4.2 Analysis of the increase of stresses in the concrete due to flow of water inside the pipe

no values for 20,0m because its not uniform

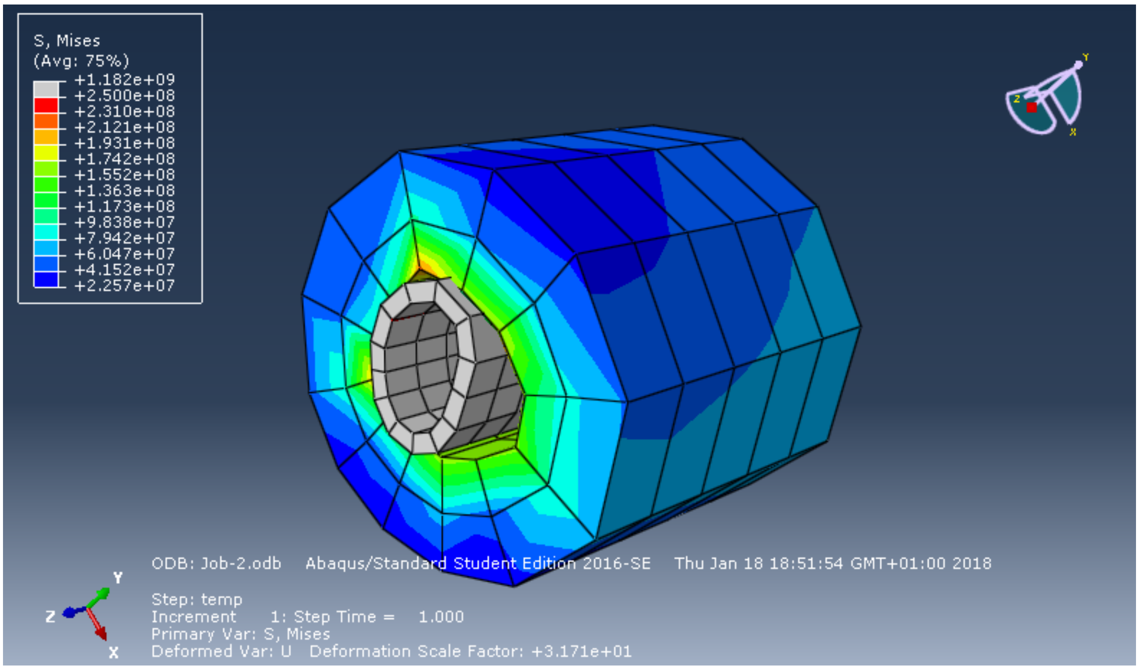

Figure X. Stress state.

This simulation occurs to be not to evaluate because of huge errors in the calculations. The deformation of the steel pipe is different to the deformation of the concrete pile. We changed various boundary conditions and modeling properties but we came to no result. The expectation is that the stresses will increase caused by the thermo- stresses.

4.3 Analysis of the maximum increase in water temperature that the steel pipe and the concrete can withstand

For the engineering point of view is very important to specify the limits of a construction. For this reason, it is important to get an approximate impression what are the limit values for the water temperature. With higher temperature, the stresses will increase. To determine the maximum temperature without exceed the maximum stresses an iteration of the temperature difference in the simulation is the best opportunity. In our model, we weren't able to apply those method because of our problem with temperature modelling.

4.4 Analysis of the stress state after using a new type of concrete whose properties vary with temperature.

To analyze the new stress, state the concrete properties have been changed:

	Young's Modulus	Poisson's Ratio	Temp
1	27000000000	0.2	15
2	35000000000	0.2	25
3	50000000000	0.2	35
4	70000000000	0.2	45
5	100000000000	0.2	55

Figure X. The new concrete properties.

Nothing has changed in our model, which is not what we expected. The reason must be a wrong presumption in our model.

5. CONCLUSIONS AND ERROR ANALYSIS

As a conclusion it is to say, that our model seems to have some basic errors which cause malfunctions during the simulations, especially in the model with temperature.

The main reasons for those errors are an insufficient mesh quality for the problem at hand and a to high simplification with averaged values. Furthermore, it is probable that we made wrong assumptions during our calculations caused by a lack of knowledge of the simulation program Abaqus.

For optimized results, it would be better to create the whole model in a two dimensional space to reduce the needed operational power. With a size-reduced model our calculation would be appropriate in the student version of Abaqus.

But we learned to deal with the basic possibilities of Abaqus and managed to make an approximate simulation to forecast physical behavior.

6. REFERENCES

1. GSHPA, 2012. Thermal Pile - Design, Installation and Material Standards, Great Britain

2. Assunção Freitas R. M., 2014. Thermal and Thermal-Mechanical Analysis of Thermo-Active Pile Foundations. MSc Thesis, Instituto Superior Tecnico Lisboa, Portugal

7. APPENDIX

How the work is divided among the group members:

Paulina

- writing the main parts report

Henrik

- oral presentation
- writing parts of the report

Paulina&Henrik

- numerical analysis in Abaqus