Thermo-mechanical analysis of single energy piles

Introduction

Consider an energy pile of 20 m in length and 0.8 m in diameter that is a part of the square group of energy piles reported in Figure 1. Assume that the energy pile is socketed in a saturated sand deposit and that a 12 × 12 m rigid slab (resting on the ground) made of reinforced concrete connects all the energy piles. The sand and the pile proprieties are reported in Table 1 and Table 2, respectively.

Evaluate the bearing capacity of the energy pile assuming it as a non-displacement pile, by using a long-term analysis approach (i.e., in terms of effective stresses), and considering the Hansen's method (Hansen 1970) for the evaluation of the base contribution of capacity.

By using the software Thermo-Pile (Knellwolf et al. 2011) and referring to the relations proposed by Frank et al. (1991) for piles in coarse-grained soils, evaluate the vertical stresses and displacements developed in the considered energy pile, assumed to be a single isolated element, in five different cases:

- CASE 1: pile free at the head subjected to a vertical load of $P = 500$ kN and to a temperature change of $\Delta T = 0$ °C.
- CASE 2: pile free at the head subjected to a vertical load of $P = 0$ kN and to a temperature change of $\Delta T = 10$°C.
- CASE (1+2): pile assumed to be characterised by the effects induced by the loads considered in CASE 1 and CASE 2 through an elastic superposition principle.
- CASE 3: pile free at the head subjected to a vertical load of $P = 500$ kN and to a temperature change of $\Delta T = 10$ °C.
- CASE 4: pile restrained at the head by the presence of the slab and subjected to a vertical load of $P = 500$ kN and to a temperature change of $\Delta T = 10$ °C. Assume that the slab stiffness can be estimated through the following equation, with reference to a rigid rectangular plate resting vertically loaded on an isotropic elastic half-space (Gorbunov-Posadov and Serebrjanyi 1961):

$$K_{slab} = \frac{E_{soil}\sqrt{B_{slab}L_{slab}}}{(1 - v_{soil}{}^2)\rho_0}$$

where E_{soil} is the Young's modulus of the soil, B_{slab} and L_{slab} are the dimensions of the slab, v_{soil} is the Poisson's ratio of the soil, and ρ_0 is a displacement coefficient. Consider that the displacement coefficient can be evaluated as a function of the ratio $\chi = L_{slab}/B_{slab}$ using Figure 2.

For each case, plot the evolutions along the length of the energy pile (discretised in 200 elements in Thermo-Pile) of the vertical stress, shear stress and vertical displacement induced by the applied mechanical and/or thermal loads. Compare and discuss the differences between the obtained results through a short resume for each case, with a particular focus on the reason why CASE (1+2) and CASE 3 differ. Compare as well in each case the obtained results with the thermo-mechanical schemes discussed during the course. To which extent are these charts representative of the actual behaviour of energy piles?

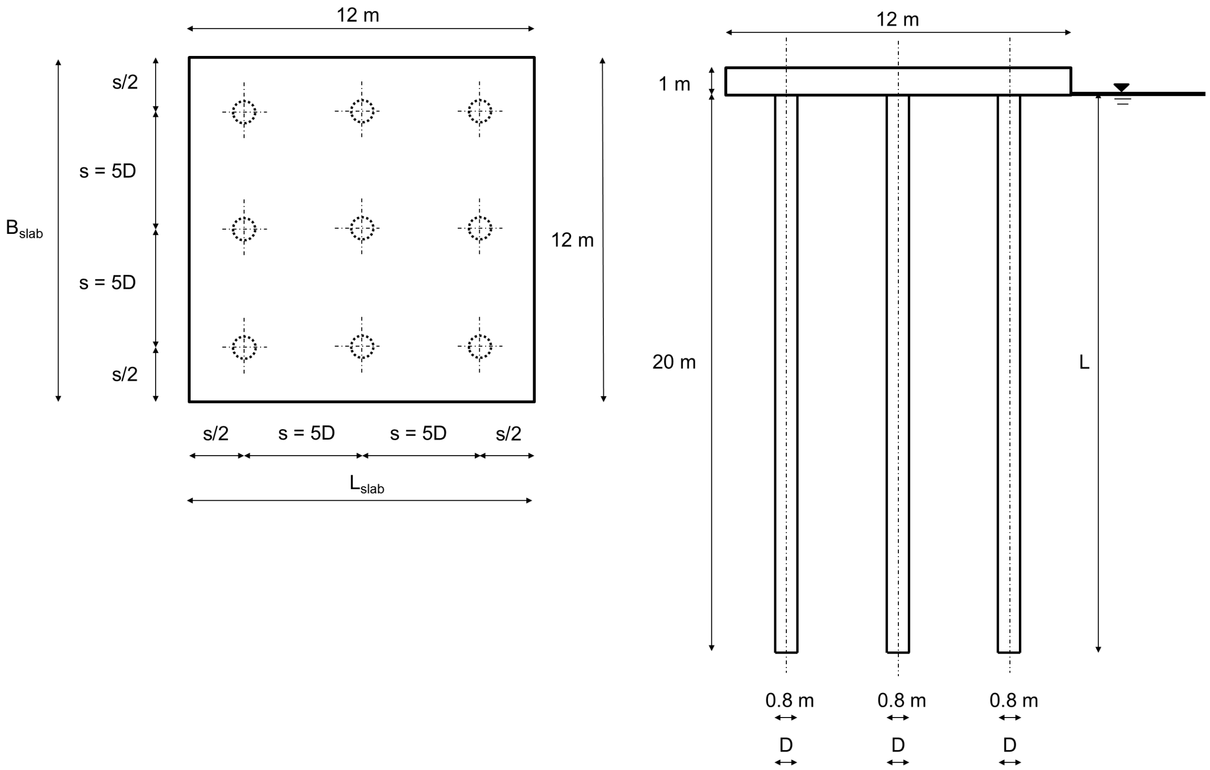

Figure 1. The problem.

Table 1. Sand properties.

	γ_{soil}	c'	φ'_{cv}	φ'	E_{soil}	ν_{soil}	α_r
	[kN/m^3]	[kPa]	[°]	[°]	[MPa]	[-]	[-]
Sand	19	20	31	38	78	0.3	0.33

Table 2. Pile properties.

	$\gamma_{concrete}$	E_{EP}	ν_{EP}	α_{EP}
	[kN/m^3]	[MPa]	[-]	[με/°C]
Pile	25	30000	0.25	10

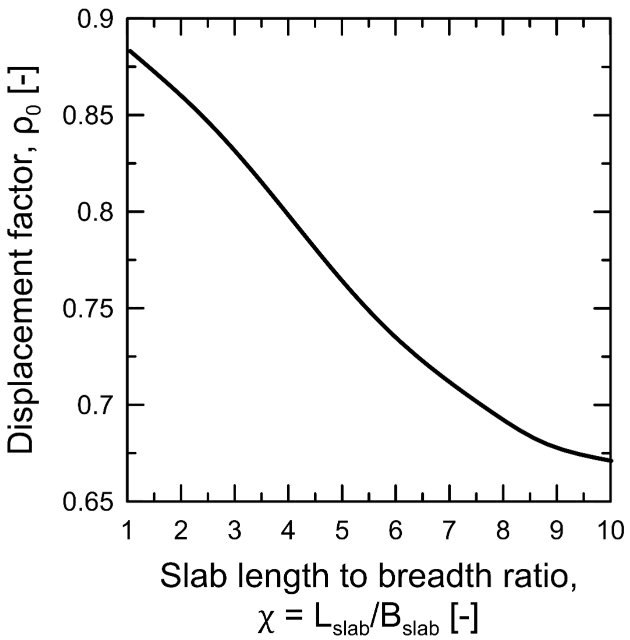

Figure 2. Displacement coefficient of a rigid rectangular plate resting on an isotropic elastic half-space (Gorbunov-Posadov and Serebrjanyi 1961).

References

Frank, R., Kalteziotis, N., Bustamante, M., Christoulas, S., and Zervogiannis, H. 1991. Evaluation of performance of two piles using pressuremeter method. Journal of Geotechnical Engineering **117**(5): 695-713.

Gorbunov-Posadov, M.I., and Serebrjanyi, R.V. 1961. Design of structures on elastic foundation. *In* 5th International conference on Soil Mechanics and Foundation Engineering. pp. 643-648.

Hansen, J.B. 1970. A revised and extended formula for bearing capacity. Danish Geotechnical Institute Bulletin **28**: 5-11.

Knellwolf, C., Peron, H., and Laloui, L. 2011. Geotechnical analysis of heat exchanger piles. Journal of Geotechnical and Geoenvironmental Engineering **137**(10): 890-902.