ENERGY GEOSTRUCTURES – TRAINING EXAM

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Instructions

The questions include multiple choice questions and open questions covering theoretical and applied problems that have been treated during the course.

Exam questions

1. The stress unit of the metric system is:
   a. Gram, g
   b. Newton, N
   c. Pascal, Pa
   d. None of the above

2. The strain unit is:
   a. Meter, m
   b. Newton, N
   c. Pascal, Pa
   d. None of the above

3. What are the two fundamental roles of energy geostructures? What is the main difference between energy and conventional geostructures?

4. In general, shallow geothermal systems can be exploited:
   a. To produce heat and electrical power
   b. To produce power
   c. To produce heat
   d. None of the above

5. List and describe the purpose of the possible applications of energy piles.

6. When an energy geostructure is cooled as a consequence of its geothermal operation, the building is:
   a. Cooled
   b. Heated
   c. Heated and cooled
   d. None of the above

7. The purpose of using a heat pump to heat a building environment through energy geostructures is:
   a. To enhance the heat input that can be extracted from the soil
   b. To diminish the heat input that can be extracted from the soil

8. The typical range of power for a heat extraction with heat pump application is
   a. 50-100 W/m
   b. 40-60 W/m
   c. 20-40 W/m

9. What are three of the typical aspects that need to be considered for the holistic, integrated, energy, geotechnical and structural design of energy geostructures?

10. Which are the typical conditions or aspects that involve a stress variation in a body as a consequence of an applied temperature change?

11. Which are the two terms that govern the mathematical expression of the strain of a body subjected to a thermal load under free expansion conditions?

12. The unit measure of the linear thermal expansion coefficient is:
   a. °C
   b. m/°C
   c. °C/m
   d. 1/°C

13. Considering a bar subjected to a temperature change in a completely restrained case:
   a. The thermally induced stress is zero
   b. The thermally induced displacement is zero
   c. None of the above

14. Consider a steel bar that is free to deform and subjected to a uniform temperature change. Is this bar characterised by a stress variation as a consequence of the applied temperature change?

15. How is the degree of freedom DOF of an energy pile mathematically defined? Specify the meaning of the terms involved in its definition.

16. Write the mathematical expression of the thermally induced stress in an energy pile, with reference to a Young's modulus E, the observed strain ε_o^{th} and the free strain ε_f^{th}. Consider compressive stresses and contractive strains to be positive.

17. Calculate the deformation of a steel bar characterised by a linear thermal expansion coefficient of $\alpha = 12$ $\mu\varepsilon/°\text{C}$ and subjected to a temperature change of $\Delta T = 20$ °C under free expansion conditions. Refer to one-dimensional conditions. Consider compressive stresses and contractive strains to be positive.

18. Calculate the absolute value of thermally induced displacement of a steel bar of 20 m in length characterised by a linear thermal expansion coefficient of $\alpha = 12$ $\mu\varepsilon/°\text{C}$ and subjected to a temperature change of $\Delta T = 20$ °C, assuming that the deformation of the bar is completely restrained at one end.

19. Calculate the stress that is generated in a completely restrained steel bar characterised by a linear thermal expansion coefficient of $\alpha = 12$ $\mu\varepsilon/°\text{C}$ and Young's modulus of $E = 210$ GPa, subjected to a temperature change of $\Delta T = 20$ °C. Refer to one-dimensional conditions. Consider compressive stresses and contractive strains to be positive.

20. What is the null point of an energy pile?

21. The presence of the null point in energy piles subjected to thermal loads involves that:
    a. Energy pile equilibrium cannot be solved via closed form solutions
    b. Energy pile equilibrium can be solved via closed form solutions
    c. None of the above

22. The discussed thermo-mechanical schemes for energy piles are developed under the fundamental hypothesis of:
    a. (Thermo-)elastic conditions
    b. (Thermo-)plastic conditions
    c. Anisotropic conditions
    d. None of the above

23. Can the superposition principle be employed to investigate the effects of the interactions caused by both mechanical and thermal loads among energy piles?

24. With reference to a thermo-elastic framework, sketch the vertical stress and vertical displacement variations caused by the application of a mechanical load at the head of an energy pile that is characterised by no head and base restraints (i.e., fully floating pile). Consider compressive stresses and downward displacements to be positive.

25. With reference to a thermo-elastic framework, sketch the vertical stress and vertical displacement variations caused by the application of a positive temperature change (heating thermal load) along an energy pile that is characterised by no head and base restraints (i.e., fully floating pile). Consider compressive stresses and downward displacements to be positive.

26. With reference to a thermo-elastic framework, sketch the vertical stress and vertical displacement variations caused by the application of a positive temperature change (heating thermal load) along an energy pile that is characterised by no head restraint but by a strong base restraint (i.e., end-bearing pile). Consider compressive stresses and downward displacements to be positive.

27. Which are the two basic methods that can be used to install piles?

28. Write the vertical equilibrium equation that is accounted for characterising the ultimate load capacity of energy piles and specify the meaning of the involved terms.

29. Sketch the tri-linear load transfer curve *referring to energy piles* that has been proposed by Knellwolf et al. (2011), based on the work of Frank and Zhao (1982), and which describes the interaction between the pile shaft and the surrounding soil. Consider positive shear stresses developed with positive displacement values, i.e., settlements.

30. Describe the physical meaning behind each of the three branches of the tri-linear load transfer curve *referring to energy piles* that has been proposed by Knellwolf et al. (2011), based on the work of Frank and Zhao (1982), and describes the interaction between the pile shaft and the surrounding soil.

31. Describe the essential features of the load-transfer method for energy piles.

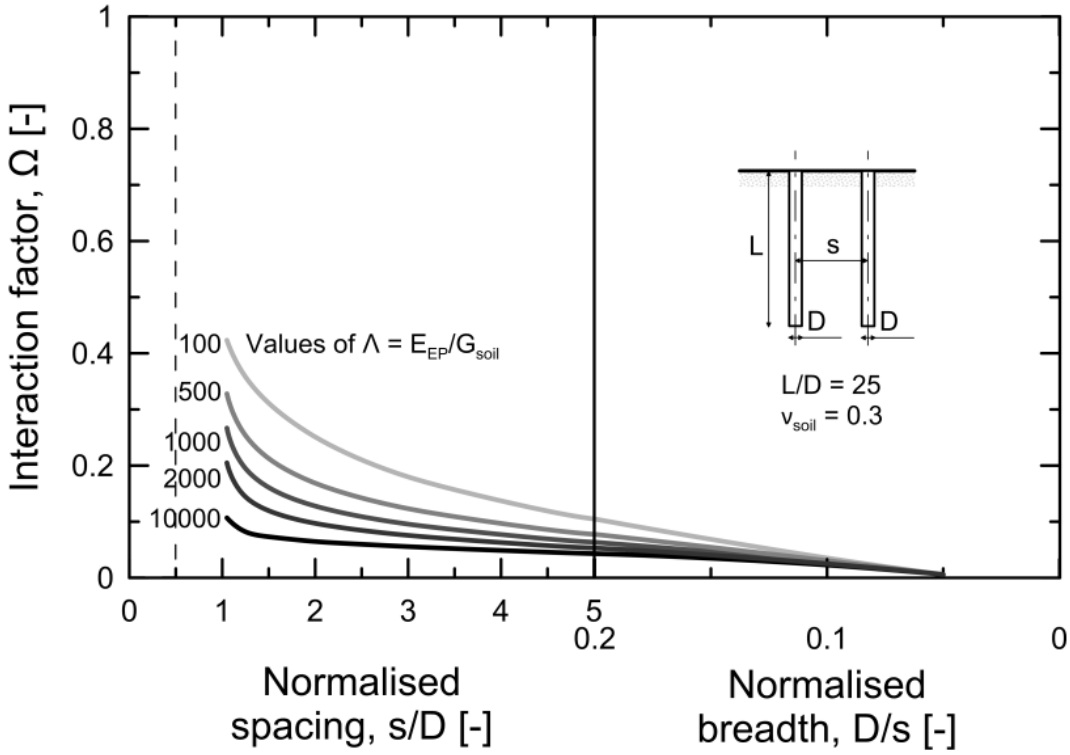
32. Which is the typical centre-to-centre spacing that distinguishes a closely spaced energy pile group from a widely spaced energy pile group, in terms of the pile diameter?

33. Which are the main effects of interactions on the behaviour of energy pile groups, in terms of deformation of the piles and stresses developed in the piles?

34. Does an analysis of an energy pile that is considered to be in a single and isolated case provide a conservative estimate of its displacement? Why?

35. How the displacement interaction factor is defined?

36. Consider a group of two identical energy piles characterised by a slenderness ratio of $L/D = 25$ that are surrounded by an isotropic, homogeneous and deep thermo-elastic soil mass. Assume that one pile in the group is subjected to a temperature change. If the piles are characterised by a Young's modulus of $E_{EP} = 30$ GPa and the soil by a Young's modulus of $E_{soil} = 78$ MPa and a Poisson's ratio of $\nu_{soil} = 0.3$, which is the value of interaction factor between the two piles for a normalised spacing of $s/D = 3$? Consider the following interaction factor chart to answer to this question.



37. Consider a group of two identical energy piles that are surrounded by an isotropic, homogeneous and deep thermo-elastic soil mass. Assume that both piles in the group are subjected to the same temperature change. Write the expression for the vertical displacement of each pile of the group w_k by considering that the vertical displacement of the piles in the single isolated case subjected to the same temperature change reads w_i and the interaction factor between the piles in the group is Ω.

38. Consider a square group of four identical energy piles subject to a $\Delta T = 15\,°C$. Assume that the vertical displacement per unit temperature change of the single isolated energy pile is $w_i = 0.122\, mm/°C$. The interaction factors for the two characteristic centre-to-centre distances between the piles are $\Omega_{s1} = 0.063$ and $\Omega_{s2} = 0.045$. Which is the value of the average vertical head displacement of the group?

39. Which is the basic concept behind the equivalent pier method?

40. The equivalent pier method can be applied for aspect ratios of the group and for normalised spacing between the piles of
    a. AR < 4 and s/D ≤ 5
    b. AR > 4 and s/D ≤ 5
    c. AR ≤ 4 and s/D >5
    d. AR > 4 and s/D > 5

41. List the quantity/quantities that can be derived through the application of the equivalent pier method:

42. What are the two typical aspects that govern the mechanical behaviour of the energy walls

43. To increase the thermal potential of energy walls it is better to install the pipes
    a. Next to the ground
    b. It depends
    c. Next to the airside
    d. None of the above

44. List the two fundamental modes of heat transfer for energy walls

45. Discuss the advantages and disadvantages of the current available design recommendations and standards for energy geostructures?

46. Eurocodes are
    a. Prescriptive standards
    b. Performance-based design recommendations
    c. Performance-based design standards
    d. Prescriptive recommendations

47. In the Eurocodes thermal actions applied to energy geostructures will be classified as
    a. Permanent actions
    b. Variable actions
    c. The choice is left to the designer
    d. A combination of the three

48. Which are the main considerations that can be concluded for the analysis and design of energy geostructures at ULS and SLS

49. The driving cause of heat transfer by conduction is generally considered to be:
    a. The motion of a fluid
    b. An invisible motion of the particles that constitute a medium
    c. Waves of the electromagnetic field propagating at the speed of light

50. Write the mathematical expression of Fourier's law and define the involved terms.

51. Heat transfer by convection can be free (i.e., natural) or forced. Provide a description of these two processes, highlighting the crucial differences between them.

52. Which is the fundamental parameter that allows understanding if convection plays a major role in the heat transfer in soils? To which law is this parameter related? Write the considered law. Define the different terms involved.

53. Is it reasonable to foresee thermal energy storage through energy geostructures for a site that is characterised by significant groundwater flow? Why?

54. Consider an energy pile located below a very large raft of a building and operating as geothermal heat exchanger. Assume that a very thick thermal insulation layer is placed at the uppermost surface of the slab, so that no influence of the ambient conditions is experienced in the subsurface. Consider that the soil is saturated and that no groundwater flow occurs. Which is/are the main mode/s of heat transfer occurring in the soil?

55. Write the simplified Fourier heat conduction equation and define the parameters involved in this expression. Neglect any conversion of mechanical energy into heat. Consider a body characterised by arbitrary thermal conditions on its surfaces, internal volumetric heat generation as well as constant thermal conductivity.

56. What is the unit measure of thermal conductivity?
    a. W/°C
    b. °C/W
    c. °C/m
    d. W/(m °C)

57. Which is the mathematical expression of the thermal diffusivity? Define all of the parameters that are included in this expression.

58. Calculate the effective thermal conductivity, λ, of a dry sand at the temperature level of 15 °C characterised by a porosity $n = 0.42$ and a value of thermal conductivity of solid particles $\lambda_s = 0.41$ W/(m °C). Repeat the calculation for the same sand assuming it is fully saturated with water. Comment on the results and on the impact of the different values of λ on the heat exchange characterising an adjacent energy pile.

59. Soils of large thermal diffusivity respond:
    a. Quickly to changes in their thermal environment
    b. Slowly to changes in their thermal environment
    c. Irrespectively of the changes of their thermal environment
    d. Depending on the thermal conductivity

60. List at least three of the five boundary conditions that are used in the mathematical theory of heat transfer as idealisations for any portion of the bounding surface of a considered medium.

61. Under steady conditions, the heat transfer occurring within energy geostructures can be modelled with:
    a. A time-dependent approach
    b. A time-independent approach
    c. None of the above

62. The concept of thermal resistance can be used:
    a. To characterise heat transfer as a purely resistance process
    b. To characterise electrical current flow as a purely resistance process
    c. To characterise groundwater flow as a purely resistance process

63. Which are the three fundamental heat transfer processes that are considered in the definition of the time-independent part of the thermal resistance?

64. Explain the concept of thermal resistance in reference of the time-dependent modelling of heat transfer.

65. Provide the mathematical formulation of the infinite cylindrical surface source model of a geothermal heat exchanger with a constant heat flux around its surface at $r=R$ equal to $\dot{q}_l$, initially at a temperature $T=T_0$

66. List four mathematical models that can be used to describe the time-dependent heat transfer around energy geostructures. Which heat transfer mode is accounted for in these models?

67. An advantage of a laboratory test is to be performed
    a. In the natural state of soil
    b. In a controlled environment
    c. None of the above

68. The estimation of the thermal potential allows to have a good estimate of the actual performance of energy geostructures
    a. True
    b. False

69. The thermal properties of interest are
    a. The initial temperature
    b. The thermal conductivity
    c. The volumetric heat capacity

70. The needle probe method allows to consider
    a. Steady state and transient condition
    b. Steady state condition
    c. Transient condition

71. The potential anysotropy condition in site of the soil can be better taken into account with
    a. The needle probe method
    b. The divided bar method

72. The TRT allow to define the following parameters
    a. The time-independent resistance
    b. The effective thermal conductivity
    c. The time-dependent resistance
    d. Undisturbed ground temperature

73. It is suggested to perform TRT test
    a. For borehole
    b. For energy pile
    c. For borehole and energy pile
    d. For energy pile and walls

74. Thermal loading is usually associated with
    a. Undrained conditions
    b. Drained conditions
    c. Both of them

75. The volumetric soil behavior is usually assessed experimentally through
    a. Oedometric test
    b. Triaxial test
    c. Direct shear test
    d. Oedometric test and triaxial test

76. Pre-consolidation pressure is temperature dependent
    a. True
    b. Faulse

77. For the temperature levels characterising energy geostructure applications a thermo-plastic behaviour upon a heating-cooling cycle is typical of soil
    a. In NC conditions
    b. In highly OC conditions
    c. In slightly OC conditions

78. In the thermo-elasticity framework thermal load can induce
    a. Change in shape
    b. Rigid body motion
    c. Change in volume
    d. A combination of the three

79. Describe the essential features of the behaviour of fine-grained soils to one heating-cooling cycle depending on the consolidation state.

80. The angle of shear strength of soils under constant volume conditions markedly varies with temperature:
    a. True
    b. False