

Experimental study of heat and mass transfer in moist saline sand under axial freezing

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Abstract. The article involves the study of the freezing process of medium-grained sand saturated with aqueous NaCl solutions of various concentrations (0–104 g/l). The purpose of the study is to determine the influence of NaCl concentration on heat and mass transfer processes. Freezing was initiated from one end of the sample; the temperature field was recorded by eight thermocouples, while the moisture distribution was determined by weighing followed by drying. The results confirmed a linear decrease in the freezing point of pore water with increasing NaCl concentration, down to -7°C . It was found that in all tests, moisture redistribution occurred with its accumulation near the freezing front. In non-saline samples this effect was most pronounced, which can be attributed to the combined influence of thermodiffusion and phase pressure differences at the water–ice interface. With increasing salinity, this effect weakened, and the contrast in moisture content between frozen and unfrozen zones decreased. The obtained time-space distributions of temperature and moisture provide a basis for parameterizing mathematical models of heat and mass transfer in frozen media, as well as serve as a starting point for further studies of freezing processes in saline soils.

Keywords:

artificial ground freezing, saline sand, NaCl, heat and mass transfer, phase transition, moisture distribution

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References

1. Balobaev V.T., Baulin V.V., Garagulya L.S., et al. **1999.** *Fundamentals of geocryology*. Ch. 5. *Engineering geocryology*. Moscow: MGU, 526 p. (In Russ.).
2. Chen Q.M., Ghimire B., Su L.B., Liu Y. **2024.** Micro-scale investigations on the mechanical properties of expansive soil subjected to freeze-thaw cycles. *Cold Regions Science and Technology*, 219, Article 104128. doi:10.1016/j.coldregions.2024.104128

3. Lai Y., You Z., Zhang J. **2021**. Constitutive models and salt migration mechanisms of saline frozen soil and the-state-of-the-practice countermeasures in cold regions. *Sciences in Cold and Arid Regions*, 13(1): 1–17. doi:10.3724/SP.J.1226.2021.00001
4. Li K.Q., Yin Z.Y., Zhang N., Liu Y. **2023**. A data-driven method to model stress–strain behaviour of frozen soil considering uncertainty. *Cold Regions Science and Technology*, 213, Article 103906. doi:10.1016/j.coldregions.2023.103906
5. Li S., Zhang M., Pei W., Lai Y. **2018**. Experimental and numerical simulations on heat-water-mechanics interaction mechanism in a freezing soil. *Applied Thermal Engineering*, 132: 209–220. doi:10.1016/j.applthermaleng.2017.12.061
6. Vyalov S.S., Gmoshinsky V.G., Gorodetskiy S.E., et al. **1962**. [Strength and creep of frozen soils and calculations of ice-soil retaining structures]. Moscow: Academy of Sciences of the USSR Press, 254 p. (In Russ.).
7. Zhou M.B. **2025**. Structure model and design of iced cylindrical shell for large-diameter ground freezing shaft sinking. In: *Tunnelling into a sustainable future – methods and technologies*. CRC Press, p. 1930–1937.
8. Zhou X. et al. **2022**. Comprehensive review of artificial ground freezing applications to urban tunnel and underground space engineering in China in the last 20 years. *Journal of Cold Regions Engineering*, 36(3), Article 04022002. doi:10.1061/(ASCE)CR.1943-5495.0000273
9. Kostina A., Zhelnin M., Plekhov O., Pantelev L., Levin L. **2018**. Creep behavior of ice-soil retaining structure during shaft sinking. *Procedia Structural Integrity*, 13: 1273–1278. doi:10.1016/j.prostr.2018.12.260
10. Trupak N.G. **1974**. [Freezing of soils in underground construction]. Moscow: Nedra, 280 p. (In Russ.).
11. Pilecki Z. et al. **2025**. Temperature anomaly as an indicator of groundwater flow prior to the shaft sinking with the use of artificial ground freezing. *Engineering Geology*, 347, Article 107916. doi:10.1016/j.enggeo.2025.107916
12. Semin M. et al. **2024**. Enhancing efficiency in the control of artificial ground freezing for shaft construction: A case study of the Darasinsky potash mine. *Cleaner Engineering and Technology*, 18, Article 100710. doi:10.1016/j.clet.2023.100710
13. Phillips M. et al. **2021**. Use of artificial ground freezing in construction of cross passages under Suez Canal. *Geomechanics and Tunneling*, 14(3): 298–307. doi:10.1002/geot.202000045
14. Olkhovikov Y.P. **1984**. [Support of capital workings in potash and salt mines]. Moscow: Nedra, 238 p. (In Russ.).
15. Qin B. et al. **2022**. Research on influences of groundwater salinity and flow velocity on artificial frozen wall. *Transportation Geotechnics*, 34, Article 100739. doi:10.1016/j.trgeo.2022.100739
16. Tounsi H. et al. **2024**. Thermo-hydro-mechanical modeling of brine migration in a heated borehole test in bedded salt. *Rock Mechanics and Rock Engineering*, 57(8): 5505–5518. doi:10.1007/s00603-023-03632-5
17. Bublik S. et al. **2023**. Experimental and theoretical study of the influence of saline soils on frozen wall formation. *Applied Sciences*, 13(18), Article 10016. doi:10.3390/app131810016
18. Semin M. et al. **2024**. Influence of soil salinity on the bearing capacity of the frozen wall. *Fracture and Structural Integrity*, 18(69): 106–114. doi:10.3221/IGF-ESIS.69.08
19. Semin M.A., Levin L.Yu., Bublik S.A., Brovka G.P. **2025**. Effect of salinity on moisture migration in artificially frozen ground. *Journal of Mining Science*, 61(2): 267–277. doi:10.1134/S1062739125020115
20. Fan W.H., Yang P. **2019**. Ground temperature characteristics during artificial freezing around a subway cross passage. *Transportation Geotechnics*, 20, Article 100250. doi:10.1016/j.trgeo.2019.100250
21. Fan W.H., Yang P., Yang Z.H. **2019**. Impact of freeze-thaw on the physical properties and compressibility of saturated clay. *Cold Regions Science and Technology*, 168, Article 102873. doi:10.1016/j.coldregions.2019.102873
22. Wen Z., Ma W., Feng W.J., et al. **2011**. Experimental study on unfrozen water content and soil matric potential of Qinghai-Tibetan silty clay. *Environmental Earth Sciences*, 66: 1467–1476. doi:10.1007/s12665-011-1386-0
23. Stähli M., Stadler D. **1997**. Measurement of water and solute dynamics in freezing soil columns with time domain reflectometry. *Journal of Hydrology*, 195: 352–369.
24. Watanabe K., Muto Y., Mizoguchi M. **2001**. Water and solute distribution near an ice lens in a glass-powder medium saturated with sodium chloride solution under unidirectional freezing. *Crystal Growth & Design*, 1(3): 207–211. doi:10.1021/cg005535i
25. Rui D.H., Guo C., Lu M., et al. **2019**. Experimental study on water and salt migrations in clay under freezing effect. *Journal of Glaciology Geocryology*, 41(1): 109–115. doi:10.3390/app14198970
26. Xu X.Z., Wang J.C., Zhang L.X., et al. **1995**. *Mechanisms of frost heave and soil expansion of soils*. Beijing: Science Press. (In Chinese). (Google Scholar)
27. Bing H., He P. **2008**. Experimental study of water and salt redistribution of clay soil in an opening system with constant temperature. *Environmental Geology*, 55: 717–721. doi:10.1007/s00254-007-1023-0
28. Bing H., He P., Zhang Y. **2015**. Cyclic freeze-thaw as a mechanism for water and salt migration in soil. *Environmental Earth Sciences*, 74: 675–681. doi:10.1007/s12665-015-4072-9
29. Xiao Z.A., Lai Y.M., You Z.M. **2017**. Water and salt migration and deformation mechanism of sodium chloride soil during unidirectional freezing process. *Chinese Journal of Rock Mechanics and Engineering*, 39(11): 1992–2001. doi:10.11779/CJGE201711006
30. Xiao Z., Hou Z., Zhu L., Dong X. **2021**. Experimental investigation of the influence of salt on the phase transition temperature in saline soil. *Cold Regions Science and Technology*, 183, Article 103229. doi:10.1016/j.coldregions.2021.103229
31. Cheverev V.G., Brushkov A.V., Polovkov S.A., Pokrovskaia E.A., Safronov E.V. **2021**. Analysis of concepts on the mechanism of cryogenic water migration in freezing soils. *Earth's Cryosphere*, 25(5): 3–12. (In Russ.). doi:10.15372/KZ20210501
32. Pavlov M.V., Karpov D.F. **2023**. Solution of heat and mass transfer boundary problem using the method of sources for soil radiant heating conditions. *Prirodobustroystvo*, 4: 15–20. (In Russ.). <https://doi.org/10.26897/1997-6011-2023-4-15-20>
33. Lucas T. et al. **2001**. Freezing of a porous medium in contact with a concentrated aqueous freezant: numerical modelling of coupled heat and mass transport. *International Journal of Heat and Mass Transfer*, 44(11): 2093–2106. doi:10.1016/S0017-9310(00)00238-6
34. Xiao Z. et al. **2024**. Study on the multi-field-coupling model of saline frozen soil considering ice and salt crystallization. *Computers and Geotechnics*, 169, Article 106209. doi:10.1016/j.compgeo.2024.106209