NUMERICAL ANALYSIS OF GEOTHERMAL ENERGY PILES IN SAND

RAJNI RUPAL

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI-110016, INDIA

DECEMBER 2014

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by

RAJNI RUPAL

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Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

NEW DELHI-110016, INDIA

DECEMBER 2014

ਭਾਗਾਂ ਵਿੱਚ ਟੁਰਨਾ ਹੈ ਲਿਖਿਆ, ਕਿਧਰੇ ਕੋਈ ਆਰਾਮ ਨਹੀਂ ਚਾਹੁੰਦੇ
ਜਿਸ ਤੋਂ ਅੱਗੇ ਰਾਹ ਹੀ ਮੁੱਕਜੇ, ਐਸਾ ਕੋਈ ਮੁਕਾਮ ਨਹੀਂ ਚਾਹੁੰਦੇ
ਮੰਜਲਾਂ ਨੇ 'ਰਾਹੀ' ਪੈਰਾਂ ਵੱਲ ਆਉਣਗੀਆਂ, ਇਕੋ ਹੀ ਪਲਾਂਘ ਅਸੀਂ ਪਰਬਤਾਂ ਨੂੰ ਲੰਘਣਾ

Dedicated

to

my father

Prof. Pritam Singh Rahi

CERTIFICATE

This is to certify that the thesis entitled, "**NUMERICAL ANALYSIS OF GEOTHERMAL ENERGY PILES IN SAND**" being submitted by **Mrs. Rajni Rupal** to the Indian Institute of Technology Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by her. She worked under my supervision for the submission of thesis, which to my knowledge has reached the requisite standard as demonstrated by international publications in journals.

Further, the contents of her research work, in full or in parts, have not been submitted to any other institute or university for the award of degree or diploma to the best of my knowledge and belief.

Date:

Place:

Dr. Tanusree Chakraborty
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology (IIT) Delhi
Hauz Khas, New Delhi-110 016
India

ACKNOWLEDGEMENTS

The journey which has led to the completion of this thesis would not have been possible without the relentless guidance and expert advices given to me by my advisor, Dr. Tanusree Chakraborty. Dr. Tanusree Chakraborty has truly made a difference in my life. She has contributed in many ways to the success of this study and made it an unforgettable experience of my life. Her guidance made me to overcome the hurdles, successfully and I learnt a lot. I would like to express my sincere gratitude and great appreciation to her for providing me an opportunity to work in an emerging research area of geothermal energy piles. I would also like to thank her for her persistent help and thought provoking reviews of my work during the course of the study. This often led me to return to and place greater emphasis on understanding underlying scientific principles. Without her immense scientific and moral support, the completion of my research would have been extremely difficult. This work would never have been progressed without my supervisor's great patience, enthusiastic encouragement and confidence in me. I could not have imagined having a better advisor and mentor for my Ph.D. study. It was through her persistence, understanding and kindness that I completed my Ph.D. study. She has always been there when I needed her brilliant technical expertise. I doubt that I will ever be able to convey my appreciation fully, but I owe her my eternal gratitude.

Besides my advisor, I would like to extend my sincere gratitude to the research committee members, Prof. B. Bhattacharjee, Prof. Puneet Mahajan and Dr. Bappaditya Manna for their thoughtful comments and advices that helped me to progress my work in the right direction. I also thank Prof. K. G. Sharma for teaching me finite element methods in geotechnical engineering and Prof. K. K. Gupta for providing me an insightful knowledge of the engineering behavior of the soils. I must acknowledge Prof. G. V. Ramana for enlightening me with the first glance of research and invaluable suggestions. It is an honor for me to extend thanks to Dr. Vasant Matsagar and Prof. G. S. Benipal for giving me warm encouragement and best suggestions. My sincere gratitude is extended to Prof. Manoj Datta, Head, Department of Civil Engineering and Prof. A. K. Jain, former Head, Department of Civil Engineering for providing excellent academic environment and computational facilities. I am particularly grateful to Dr. Dipanjan Basu whose constructive comments and suggestions have made enormous contribution to my Ph.D. study.

Thanks also goes out to my fellow researchers, Dr. M. D. Goel, Dr. Sandip Kumar Saha, Mr. Pravin Jagtap, Mr. Rohit Tiwari and Ms. Arundhuti Banerjee.

I recognize that this research would not have been possible without the financial assistance from Department of Science and Technology, Govt. of India, New Delhi, India. I express my gratitude to the Department of Science and Technology.

Most especially; to my loved ones.........

I would like to thank my loved ones, who have supported me throughout entire study, both by keeping me harmonious and helping me putting pieces together.Words alone cannot express my heartfelt gratitude to my mother, brother and sisters for their immense encouragement and love during the study. Their encouragement when the times got rough are much appreciated and duly noted. My husband, Sarbjeet Singh deserves my deepest appreciation for his outmatched patience and for his magnificent moral backup until I completed my work. Words fall short to express my love and gratitude to our kids, Karan and Asmaira who waited patiently till the research work accomplished. I am profoundly grateful to them for the unforgettable sacrifices they made for me. They were always there cheering me up and stood by me through the good times and the bad. I highly appreciate the unconditional support and love of our kids that made me to fulfil my long wished ambition. I am sincerely indebted to God for all His blessings throughout my entire life.

Rajni Rupal

ABSTRACT

The geothermal energy piles have been adopted as a sustainable solution for heating and cooling of buildings in addition to carrying its structural load. In spite of the growing recognition of the benefits of geothermal energy piles, there is a clear need to understand the load transfer mechanism of energy piles under thermo-mechanical loading and the resulting soil-structure interaction. Also, the effect of long-term cyclic heat flow in and out of the geothermal energy piles on the load carrying capacity of these piles and cyclic changes in soil stress-strain response are not well understood. In current geotechnical practice, the design of the geothermal energy piles depends profoundly on empirical equations and uses very high values of factor of safety with respect to the thermal effects which is truly uneconomical. Thus, there is need for improved scientific knowledge of the temperature effects on the soil surrounding the pile and the load carrying capacity of the pile. Due to the temperature changes on the pile and soil, contraction or expansion of piles may take place. Consequently, shear strain develops in the surrounding soil which affects the shaft capacity of piles. Also, base capacity of end bearing piles increase or decrease due to the operation of geothermal energy piles. Moreover, during the life time of the energy piles, the piles are subjected to a number of heating-cooling cycles which causes slow cyclic loading of the surrounding soil leading to strain softening of the soil, thus causing reduction in the shaft capacity of the piles. No comprehensive studies have been performed in the literature to analyze the effect of cyclic temperature change on piles in sand.

In order to bridge the knowledge gap, the investigation of the thermal and thermo-mechanical behavior of geothermal energy piles is carried out in the present work. The analyses are performed for single geothermal energy pile under only thermal loading, single cycle of thermo-mechanical loading and cyclic thermo-mechanical loading. Analyses are also performed for pile groups for different combinations of thermal and non-thermal piles in the group. The associated pile-soil interaction and the load-displacement response of piles are investigated for different mechanical and thermal load magnitudes and different pile boundary conditions. The pile end conditions and soil relative density are key parameters in deciding the thermal and thermo-mechanical response of geothermal energy piles. The geothermal energy piles under thermal loading exhibit axial and radial strains due to thermal expansion of the pile. The thermal loading on the piles also results in generation of negative shear stress and increase in the lateral earth pressure coefficient in soil. When the piles are subjected to single cycle of thermo-mechanical loading, additional stresses and strains are induced in the pile and soil due to combined mechanical and thermal loading. The piles exhibit higher axial stresses under thermo-mechanical loading as compared to that under only mechanical loading. The limit unit shaft resistance and shaft friction coefficient remain almost unaffected by the thermal loading of the pile. When subjected to multiple cycles of thermal loading, pile base displacement and axial stress gradually decrease due to thermal uplift of the pile under repeated thermal cycles. In the case of pile group analysis, differential settlement at the pile base occurs for the groups containing both thermal and non-thermal piles. In order to summarize, analyses are also performed for a range of soil relative densities, pile lengths and diameters under punching load on pile and allowable loads. It is observed that the allowable load on piles are not affected by thermal loading on the pile, however, drag load is exhibited in this process which should be taken into consideration for the design of geothermal energy piles.

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