ETH zürich

Band 252 02/19

Influence of smear and compaction zones on the performance of stone columns in lacustrine clay

Jean Nicolas François-Xavier Gautray

IGT
Institut für Geotechnik

vdf

Influence of smear and compaction zones on the performance of stone columns in lacustrine clay

Jean Nicolas François-Xavier Gautray

Veröffentlichungen des Instituts für Geotechnik (IGT) der ETH Zürich
Band 252, Februar 2019

IGT

vdf Hochschulverlag AG an der ETH Zürich

ETH-Dissertation Nr. 22107

ISBN: 978-3-7281-3797-5 (Printversion)
ISBN: 978-3-7281-3798-2 (E-Book)
DOI-Nr.: 10.3218/3798-2

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

À et grâce à mon père

Foreword

Construction on soft soils is always accompanied by the risk of significant, time-dependent settlement and bearing capacity failure. As technical knowledge has advanced, optimised ground improvement has offered significant economic advantages in reducing net settlement and resisting failure by installation of more flexible and cost-effective stone columns or sand compaction piles in the ground, rather than more rigid inclusions, such as steel or concrete piles. The stiffness and strength of the subsoil around the columns is greater, and the consolidation time is reduced through shorter (radial) drainage paths.

More sophisticated, time-dependent analysis of the settlement response and assessment of the bearing capacity of the improved ground under vertical loading from stiff footings is essential. Prediction of post-construction settlements must be made to guarantee the serviceability limit state of the footing in the long-term. This research has investigated the system response in terms of load transfer from the footing into the stone columns, combined with consideration of the micromechanical effects in the smear and compaction zones around the columnar inclusion, as well as the resistance to failure of the stone column itself through shear, bending, barrelling, punching or spreading.

Physical and numerical modelling has been conducted on a soil-footing system, initially as a single unit cell and subsequently as an entire group of stone columns, beginning with installation of the stone columns through to loading by a rigid footing. The interaction between the various elements, the stress concentration in the stone columns and the transfer of load within the stiffer stone inclusions and the surrounding soft soil have been presented and discussed. A unique focus of this work has been the identification of various forms of failure in embankments, underlying soil and columns, as well as the load transfer through arching within an embankment over soft soil and onto stiffer inclusions.

Physical modelling was conducted in the well-established ETH Zurich Geotechnical Drum Centrifuge, combining existing geotechnical techniques with micromechanical analyses (using mercury porosimetry and environmental scanning electron microscopy) into the alignment of particles, the change in porosity and density of the clay immediately adjacent to the column. An electrical impedance needle was developed and commissioned to investigate whether changes in impedance in the smear and compaction zone around the stone columns could be determined through re-alignment of the clay minerals in the former or changes in void ratio in the latter. Although the findings in this research were mainly limited to the compaction zone, realignment of the clay minerals seemed to extend from the shear zone into the compaction zone. This novel information should impact on future design.

Both axisymmetric (single column) and innovative three-dimensional finite element analysis (five stone column group) were carried out, including a wished-in-place approach with reduced stiffness in the smear zone. The load-settlement behaviour of composite foundations using stone columns in soft clays was well predicted. This has revealed some interesting interactions and added further insight into the mechanisms derived from the physical modelling and experimental techniques. For example, it became clear that the stress concentration reduced so much with depth that the stone column dimensions could be optimised in terms of reduced diameter and/or length for this particular case of load bearing capacity.

Dr. sc. ETH Zürich Jean Gautray has made a valuable scientific contribution to the understanding of the zones formed around a stone column during installation and the load capacity of stone columns beneath a footing, which has wide application in practice.

Prof. Dr. Dr. h.c. mult. Sarah M. Springman CBE FREng
ETH Zurich
Institute for Geotechnical Engineering

Acknowledgements

Many people in my personal and professional environment have helped me over numerous years to become the person I am today, to reach my goals and to achieve this work.

A very special thanks goes of course to my deceased father François Gautray, who was my dad, my best friend and my confident for twenty six years and whose heart decided to let go last fall. He always put me back on track when troubles appeared, gave me everything he could so I got to achieve my goals and not a single word of this thesis would have been written without his help. His inspiration, his advice and his personality shall accompany and help me forever.

My stepmother Catherine Rodier could find the words to teach me how to write properly, to help me learn foreign languages and to bear me when I was a rather complicated kid. She helped me to become a grown-up and has been a true mother at my side at any time for the past seventeen years.

Julia Selberherr has been bringing me sunshine and warmth, this even in the darkest and coldest moments. She has helped me to find new perspectives, has enlightened my world with her smile, and will hopefully continue to do so. My thanks also go to her family, who welcomed me with open arms and offered me a second home.

A requirement for the conduction of a PhD thesis is of course not only a favourable personal situation but also an adequate professional environment.

This is why I would like to thank my supervisor Prof. Dr. Sarah Springman for taking the decision to give me a position in her group and for giving me the opportunity to conduct this research. The benefits from this position over the past four years will surely be helpful in the future.

Dr. Jan Laue was supportive in his role as a co-supervisor by being available and excited about new ideas and suggestions.

The assistance of my second co-supervisor, Prof. Dr. Helmut Schweiger, was decisive in the conduction of the numerical modelling. His availableness during my stays in Graz, Austria, was remarkable and his advice of great value. The help from his assistants Dr. Franz Tschuchnigg and Dr. Bert Schädlich was also very deeply appreciated.

Dr. Michael Plötze was always very helpful and his expertise in the domain of clay mineralogy and of Mercury Intrusion Porosimetry was much esteemed. The expertise of Gabriela Peschke was also of great help in order to obtain high quality Environmental Scanning Electron Microscopy results.

A central part of this work is the modelling of boundary value problems under enhanced gravity using the geotechnical drum centrifuge at the ETH Zürich. Such modelling activities are unthinkable without a highly competent technical staff.

Markus Iten provided his expertise for the management of the geotechnical centrifuge and his good mood, even when having to pop up at 4 o’clock in the morning. None of the tests would have been possible without him.

The help of Heinz Buschor and Andreas Kieper was also absolutely essential for the production of the new centrifuge tools coming out of Dr Jan Laue’s and/or of my imagination. Their ability to deliver very high quality products within short time periods was crucial and always deeply appreciated.

Modern techniques always involve more complicated technologies which make the help of an electrical engineering technician of immense value. Ernst Bleiker was always available to help me out with the numerous electrical issues I had during the conduction of my thesis, and his ability to think “out of the box” to find imaginative and effective solutions in order to solve complicated problems within very tight time periods was of invaluable support.

My thanks also go to Dr. Pierre Mayor for his valuable support and good advice.

Eventually, I would like to thank Ralf Herzog, Dr. André Arnold, Frank Fischli, and Dr. Ferney Morales for their good company and nice conversations over the past years, and the other members of the Institute for Geotechnical Engineering, whom I worked with, for their help with professional matters.

Contents

List of figures