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

Jean Nicolas François-Xavier Gautray

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*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



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

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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.

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