Long-term basement heave in over-consolidated clay

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When a basement is excavated, the permanent removal of soil overburden leads to a reduction in vertical effective stress, causing the remaining soil to swell. At locations with over-consolidated clays, such as London Clay and Cambridge Gault, these movements often continue for many years after the end of construction, generating additional heave movements and swell pressures in a phenomenon known as "long-term heave". Since very few construction projects have the resources to monitor a substructure's movement beyond structural completion, there is a dearth of physical data to calibrate the methods of design.

In this research, a series of geotechnical centrifuge tests were performed to investigate the heave behaviour of rectangular basements underlain by over-consolidated clay. The construction sequence, basement slab stiffness, and embedment conditions at formation level were varied between tests, to investigate the influence of these factors on the magnitude of heave displacements and swell pressures. The experimental results were corroborated with a case study where engineers monitored the gradual heave of a vacant basement in London for 21 years, and with finite element simulations of the same basement prototypes where the over-consolidated clay was represented by the small-strain hardening soil model.

The results of these investigations showed that the prediction of high swell pressures is a *self-fulfilling prophecy* that should be avoided in design. The assumption of high swell pressures leads to the specification of stiff and heavy slabs, which constrain vertical movements and attract high swell pressures from the clay. In contrast, a flexible slab permits drastic relaxations of swell pressures regardless of over-site development loads, albeit at the expense of allowing higher heave displacements. It would be preferable to specify an allowable heave displacement based on serviceability requirements, and design a slab that provides the appropriate flexibility to accommodate the specified displacement and the expected swell pressures.

This thesis proposes improvements to two semi-analytical methods of heave prediction, namely the relaxation ratio method and the relative stiffness method. It is hoped that future research will generate further data to refine the parameters used in these design methods, producing leaner designs of basement structures that will satisfy the growing demand for urban underground space.

Keywords: basements, centrifuge modelling, clay, consolidation, soil-structure interaction