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Numerical study of ground movements induced by traditional foundation underpinning

Etude numérique des mouvements de terrain induits par les fondations traditionnelles en sous-œuvre

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ABSTRACT: Traditional concrete underpinning is a commonly adopted technique for the construction of basements beneath or beside existing buildings, in congested urban settings. The successful implementation of underpinning schemes places a significant reliance on suitable construction means and methods to limit impacts on neighbouring assets. Case study data regarding the ground movements induced by construction of underpins are very limited. This presents a challenge when assessing the potential impact of underpinning works on nearby existing structures and assets, with practitioners frequently adopting inappropriate empirical relationships based on other construction activities. This paper presents the results of a series of finite element soil-structure interaction analyses, assessing ground movements arising from underpinning of an idealised strip footing foundation. The impact of underpin depth on induced ground movements has been investigated, simulating an idealised construction sequence and considering two typical ground models. Proposed charts of normalised ground movements are presented for use in practice.

RÉSUMÉ: La sous-construction traditionnelle en béton est une technique couramment adoptée pour la construction de sous-sols sous ou à côté de bâtiments existants, dans des contextes urbains encombrés. La mise en œuvre réussie des projets de sous-construction repose dans une large mesure sur des moyens et des méthodes de construction appropriés pour limiter les impacts sur les actifs voisins. Les données des études de cas concernant les mouvements de terrain induits par la construction des fondations sont très limitées. Cela présente un défi lors de l'évaluation de l'impact potentiel des travaux de soutien sur les structures et les actifs existants à proximité, les practiciens adoptant fréquemment des relations empiriques inappropriées basées sur d'autres activités de construction. Cet article présente les résultats d'une série d'analyses d'interaction sol-structure par éléments finis, évaluant les mouvements du sol résultant de la reprise en sous-œuvre d'une fondation à semelle filante idéalisée. L'impact de la profondeur du sous-sol sur les mouvements de sol induits a été étudié, en simulant une séquence de construction idéalisée et en considérant deux modèles de sol typiques. Des graphiques proposés de mouvements du sol normalisés sont présentés pour une utilisation pratique.

Keywords: Underpinning; ground movement; numerical modelling.

1 INTRODUCTION

As part of many projects, especially those in congested urban areas, designers are required to demonstrate that ground movements induced by a new development will not have an unacceptable impact on existing adjacent assets.

Where structures are founded on shallow footings and located close to proposed excavations, traditional mass concrete underpinning is frequently used to reduce the impact of construction activities on these structures or to avoid loss of usable basement space which would result from using embedded retaining walls.

Traditional underpin construction involves local excavations beneath the live foundations of the structure, carried out following a hit-and-miss sequence. Construction of these underpins is frequently undertaken with relatively limited/low stiffness excavation support and therefore has the potential to induce ground movements in the nearby area.

The availability of case study data for ground movements induced by underpin construction is extremely limited. Geotechnical engineers therefore typically make use of other existing empirical relationships to determine likely ground movements. Ground movement relationships put forward in CIRIA C760 (Gaba et al., 2017) for installation of piled or diaphragm walls are commonly used in UK practice. The construction methodologies are clearly very different and ground movement predictions made using this type of methods should be viewed with appropriate caution.

This paper presents the findings of a series of parametric numerical simulations, to provide practitioners with normalised ground movement charts, in the style of CIRIA C760. These may be used in the early stages of design to provide an indication of the impact of underpinning activities.

2 METHODOLOGY

2.1 Structure and underpinning procedure

A parametric study has been carried out using the commercially available software program Plaxis 3D (Bentley Systems, 2023).

This study examined the development of ground movements during underpinning of a 10m long strip footing, 1m wide, founded 1m below ground surface level, as indicatively shown in Figure 1. This footing is sufficiently long in relation to the underpin depth, so that relatively uniform ground movements, broadly representative of plane strain conditions, are expected to occur along most of its length.

A 5-stage underpinning sequence has been simulated, based on proposals made in Underpinning: Good practice guidance (2023), as schematically reproduced in Figure 2. These underpins are 1m wide. Underpins of depth (H) varying between 1.5m and 2.5m have been examined, to allow the resulting ground movements to be normalised, in a similar fashion to the CIRIA C760 ground movement curves.

A load of 100kN/m has been applied to the footing throughout the underpinning sequence, to represent the building load. The footing itself has been placed at the edge of the finite element mesh (thereby restraining the footing from moving horizontally) in order to model the restraint provided by the superstructure and any form of temporary propping which may be installed along the footing, and prevent rigid body rotation of the footing.

2.2 Ground model

Two idealised ground profiles have been examined as part of this study.

Firstly, a ground profile consisting entirely of stiff clay has been considered.

Secondly, a ground profile consisting entirely of dense gravel has been considered. Since the underpins are cut vertically in each case, a nominal cohesion has been assumed in the gravel to prevent excavation collapse in the temporary condition.

The standard Hardening Soil Model available in Plaxis 3D has been used for the gravel, while the version including the small strain stiffness feature has been used for the clay. The input parameters for both materials are summarised in Table 1. The adopted clay parameters are based on the work by Pillai et al. (2023) to simulate the behaviour of London Clay. The gravel parameters are based on the authors' previous experience with dense River Terrace Gravels in the London area.

For the purpose of the outline assessment undertaken, a groundwater level lower than the underpin depth has been assumed, therefore ignoring the impact of any potential dewatering works.

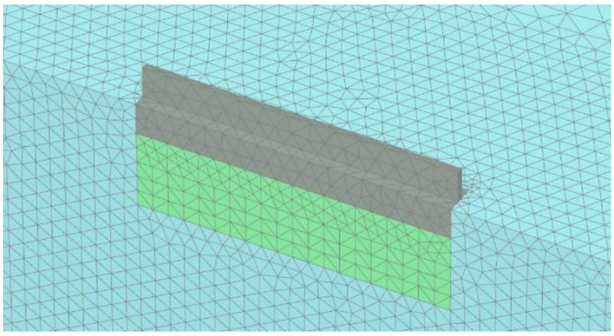

Figure 1. View of finite element mesh (Initial Phase).

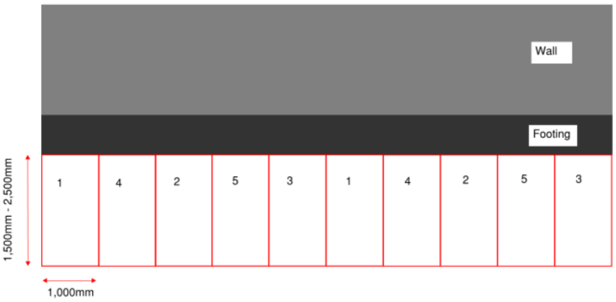

Figure 2. Underpinning sequence – vertical cross-section along wall (numbers refer to installation order/sequence).

Table 1. Material parameters.

Parameter	Stiff Clay	Dense Gravel
c' (kPa)	5	5
ϕ' (deg)	24	34
E_{50}^{ref} (MPa)	11.75	100
E_{oed}^{ref} (MPa)	9.4	100
E_{ur}^{ref} (MPa)	23.5	300
m (-)	0.8	0.5
p_{ref} (kPa)	100	100
G_0^{ref} (MPa)	57.13	-
$\gamma_{0.7}$ (-)	0.096×10^{-3}	-
K_0	1.0	0.44

3 RESULTS

The zone of influence of the underpinning operations and the maximum ground movement immediately adjacent to the footing are observed to be generally uniform along the footing. Results have been extracted at a representative cross-section perpendicular to the footing.

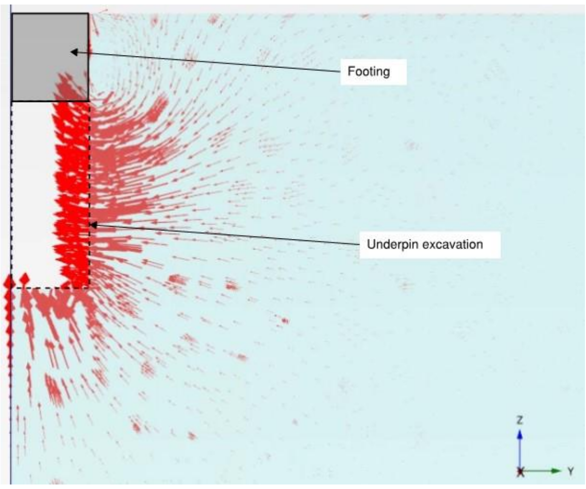

Figure 3 Exaggerated vectors of ground movement during excavation of 2.5m deep underpin in stiff clay.

The predicted soil displacement field is relatively localised (refer to Figure 3), with horizontal movements of the excavation face leading to vertical movements at ground level in the soil above, immediately adjacent to the footing.

Horizontal movements at ground surface are restrained by the presence of the footing, and initiall increase slightly moving away from it, before decreasing.

Ground movements were observed to be proportional to the depth of the underpin (H).

In the case of the underpins in stiff clay, a maximum ground surface settlement (u_z) of 7mm and maximum horizontal movement at ground level (u_y) of 1mm were observed for a 2.5m deep underpin.

In the case of the underpins in dense gravel, a maximum ground surface settlement (u_z) of 5mm and maximum horizontal movement at ground level (u_y) of 1mm were observed for a 2.5m deep underpin.

Ground movement results at ground surface for the two ground models have been normalised by distance from the footing (d) and are presented in Figure 4 to Figure 7.

4 CONCLUSIONS

This paper presents the results of a series of three-dimensional finite element analyses of traditional underpin construction.

Two idealised ground models have been considered, comprising stiff clay and dense gravel, respectively. The analyses have been carried out in a parametric fashion, varying the underpin depth from 1.5m to 2.5m.

The predicted ground movements have been normalised by the depth of the underpins to allow practitioners to apply the results to their own projects. The normalised ground movement profiles are relatively consistent for the various underpin excavation depths adopted in the study.

Results indicate a relatively localised ground movement field in proximity of the footing, rapidly dissipating when moving away from the it. The designer should consider the impact of this on any nearby assets being assessed.

The results presented represent a greenfield condition and practitioners should exercise their own judgement in applying these curves to the assessment of neighbouring structures.

Further research is required, considering a wider range of ground conditions, potentially considering the effect of dewatering and including deeper underpinning schemes, e.g. multi-level underpinning.

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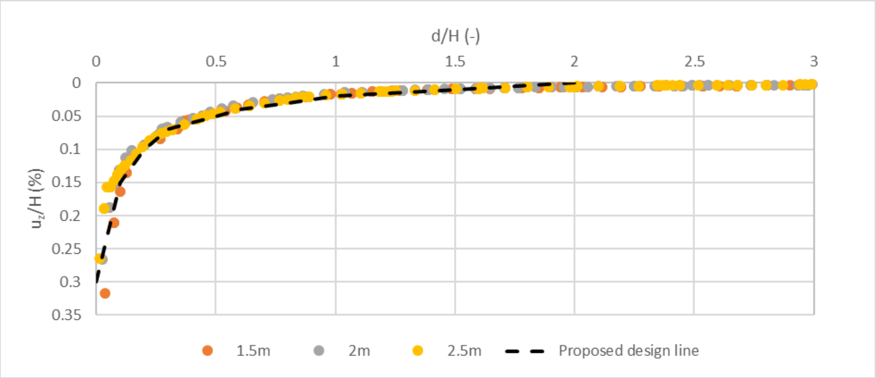

Figure 4. Normalised settlements at ground level in stiff clay for various depths of underpin, with suggested design curve.

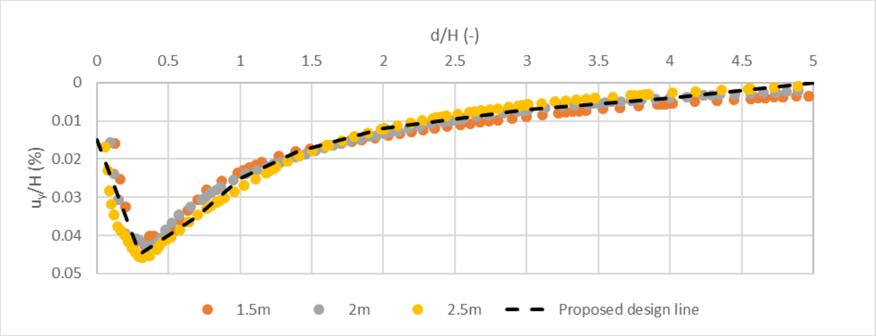

Figure 5. Normalised horizontal movements at ground level in stiff clay for various depths of underpin, with suggested design curve.

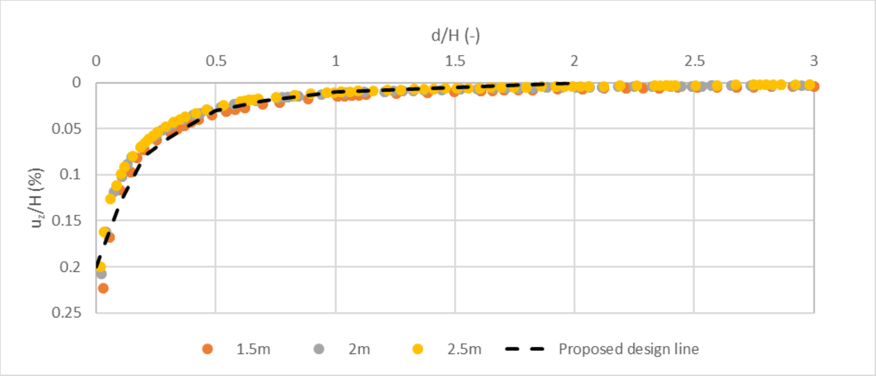

Figure 6. Normalised settlements at ground level in dense gravel for various depths of underpin, with suggested design curve.

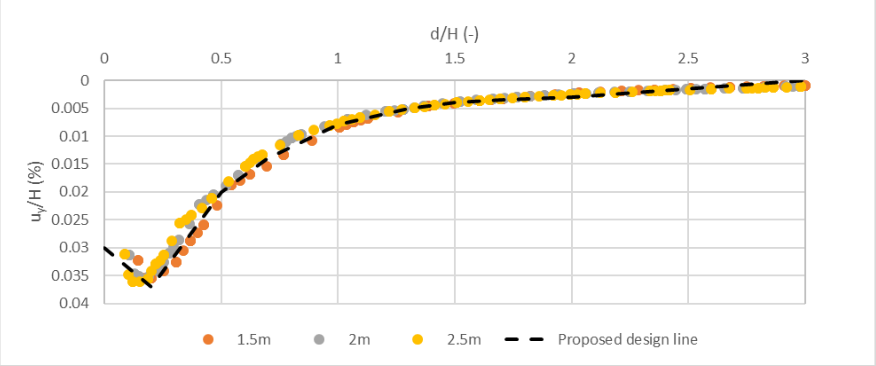

Figure 7. Normalised horizontal movements at ground level in dense gravel for various depths of underpin, with suggested design curve.