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Back-analysis of a basement with a raft foundation in overconsolidated stiff clay

Back-analyse d'un sous-sol avec un radier en argile raide surconsolidée

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ABSTRACT

This paper presents details on the construction of a deep basement where a raft foundation was used. A detailed three dimensional back-analysis has been carried out using the BRICK updated soil parameters. The results show that the 'most probable' parameters match reality reasonably well, providing confidence in their description of the actual soil-structure interaction. The field measurements show that the control movements were excellent during construction and fall within the low bound values of historical data presented in the literature for similar conditions.

RÉSUMÉ

Cet article présente des détails sur la construction d'un sous-sol profond où un radier a été utilisé. A trois pas en arrière détaillée dimensions-analyse a été effectuée en utilisant les paramètres BRICK sols mis à jour. Les résultats montrent que les paramètres «plus probable» correspondent à la réalité assez bien, donner confiance dans leur description de l'interaction sol-structure réelle. Les mesures sur le terrain montrent que les mouvements de contrôle ont été excellents pendant la construction et à l'automne dans les valeurs limite basse de données historiques présentées dans la littérature pour des conditions similaires.

Keywords: Deep basement, soil-structure interaction, numerical analysis, raft, settlement, monitoring, instrumentation

1 INTRODUCTION

The paper presents the case study of a deep excavation in the city of London where the main objective is the validation of the 'most probable' BRICK parameters in a three dimensional numerical analysis.

2 SITE DESCRIPTION

The existing ground level around the site rises from approximately +14.0mOD to +15.5mOD in the north/south direction.

The new development consisted in the construction of a basement using a secant pile wall with a depth between 10m and 11.5m to a formation level of +4.0mOD.

The built raft was 1.5m deep. The site was occupied by two existing buildings. Both had a one level basement at approximately +11.0mOD and +10.5mOD. These buildings were demolished for the new development, and the basements backfilled to create a platform for piling.

Figure 1 shows a site plan. At the east side, a London Underground line runs through a formerly open cut almost parallel to the new basement wall. In the south side, an existing subway

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passes beneath St Botolph Street and Houndsditch. At the south west corner this is less than 1m away from the proposed wall. In order to avoid all the complexities introduced by these structures, the north west corner was selected as an object of study in this paper. The area is marked by a dashed line in Figure 1. The dash and dotted line represents the line of the proposed wall approximately, which covers an area of 90m x 55m approximately in plan.

Table 1. Soil stratigraphy and geotechnical parameters

Soil Type	Elevation top of strata (mOD)	Unit weight (kN/m3)	E', (MPa)	ν	φ', (deg)	Ko
Made Ground	+15.5 to +14.5	18	1.0	0.2	25	0.58
Terrace deposits	+10.2	20	3.5	0.2	35	0.43
London Clay	+4.2	20	BRICK	-	-	-
Harwich Formation	-27.5	20	150	0.2	39	0.37
Thanet Sand	-45	20	150	0.2	39	0.37

3 GROUND & POREWATER CONDITIONS

The ground investigation comprised the following: (i) Three boreholes drilled by cable percussive methods to an average depth of 45m below ground level; (ii) four observation pits to a maximum depth of 2.1m to investigate areas of potential contamination; (iii) six horizontal concrete cores to investigate existing basement walls; (iv) six vertical cores to investigate the existing basement structure; (v) four inclined cores and one vertical core drilled using a Beretta T41 track mounted rotary rig to investigate the geometry and composition of the LUL reclined wall and to prove the top of the London Clay in the northern boundary of the site; (vi) nine trial pits to locate utility services within the surrounding pavements; (vii) installation of two vibrating wire piezometers and one standpipe in the boreholes.

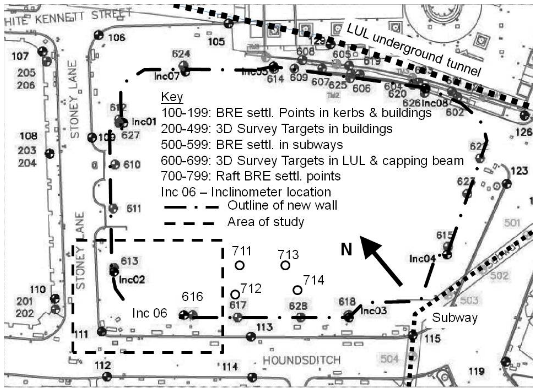

Figure 1. Site map and location of instruments

From the investigation above, the initial soil stratigraphy and parameters were derived as shown in Table 1. The derivation of these parameters is outside the scope of this paper.

The BRICK soil model was used to model the behaviour of London clay. This model was firstly introduced by Simpson [1], later reviewed by Pillai [2] and lastly finalised in a 3D version developed by Brian Simpson, which has been recently developed by Ellison et al [3]. This model is a non-linear elasto-plastic model, which is strain based. The model generates the Ko profile based on the stress history assumed for the site. Details are given by Simpson [1] and Ellison [3].

A hydrostatic profile from level +8mOD was taken for the model before demolition of existing buildings began.

The installed piezometers showed an underdrained profile at the London Clay, with a slope of approximately 20% of the hydrostatic full profile. The porewater pressures followed a hydrostatic profile for the deposits below the London Clay.

4 CONSTRUCTION SEQUENCE

Table 2 shows the construction sequence based on 'as built' records focusing in the north west corner. Stages 1 to 4 cover the site history and the construction of the existing buildings. Stages 5 to 15 cover the works carried out for the construction of the new development up to the end of September 2008. The numerical analysis was carried out for this work up to Stage 12.

Table 2. Modelled and actual construction sequence

Stage	Description
1	Initialisation.
2	Wish in place gravity wall, old building wall on the perimeter of the excavation zone and old building ground floor slab. (Undr.).
3	Installation of existing basement slab at 10.2mOD, application of the spread load of previous building. (Undr.).
4	Apply new pwp profile (Dr.).
5	Demolition of existing building (Undr.).
6	Backfill materials into existing basement (Undr.).
7	Wish in place new secant wall (Undr.).
8	05/03/08 – Wish in place king posts and props to existing retaining wall. Excavation of north side to +11.8moD. (Undr.).
9	23/04/08 – Wish in place first row of corner props. Further excavation to +7.9mOD. (Undr.).
10	21/05/08 – Construction of access ramp in north side of the site. (Undr.).
11	26/06/08 – Wish in place second row of props in corner. All site reduced to level +7.9mOD except access ramp in north side. (Undr.).
12	28/07/08 – Excavation to formation level (+4.0mOD approx.), removal of access ramp. Foundations for tower cranes being built. (Undr.).
13	03/09/08 – Tower cranes in place. North core starts to be built. Wish in place raking props at minipiles. Raft cast. (Undr.).
14	16/09/08 – Further progress on raft construction up to half way into minipiles location in west wall. (Undr.).
15	29/09/08 – Access ramp reduced even further. Removal of first corner prop in NW corner. (Undr.).

It is important to highlight that less than 10 days went by between excavation to formation level and casting of the raft in the north west corner of the site.

The temporary works consisted of 660mm diameter circular hollow sections (CHS) corner props mounted on 305x305x118 universal columns (UC) king posts and tie beams, and 152x152x30 UC raking props connected to waling beams in the minipiles areas as shown in Figure 2. Details of the above sections in the UK can be found in the SCI Blue Book [4].

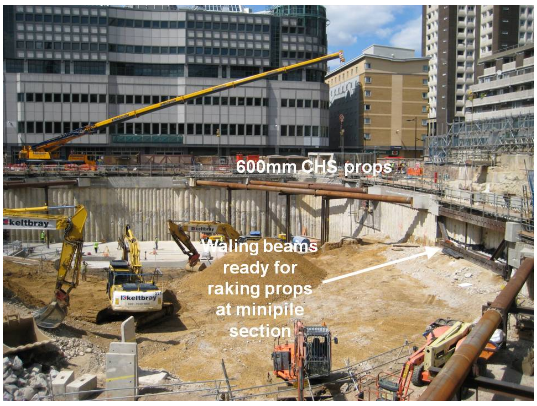

Figure 2. Propping system on 21/07/08 in the north-east corner.

5 MONITORING

A comprehensive monitoring scheme was implemented on site, which consisted of: (i) 37 No. precise levelling studs on surrounding pavements, subways, footpaths and structures for measurement of vertical displacement; ii) 14 No. reflective survey targets on adjacent buildings façades for measurement of horizontal and vertical displacement; iii) 4 No. tiltmeters and 4 No. reflective survey targets for an adjacent underground tunnel retaining wall to measure horizontal and vertical displacement; iv) 8 No. inclinometers installed within the new secant pile wall for measurement of wall deflection profiles; and v) 8 No. reflective survey targets on the secant pile wall capping beam to measure wall deflection. Figure 1 shows the location of the instrumentation.

It was assumed that the inclinometers were fixed at the bottom and therefore, no further correction was needed.

The results of horizontal movement at inclinometer 6 are shown in Figure 4. The inclinometer was installed on 22/04/08 and baselined on 25/04/08. This means that at the time of installation, the excavation had already reached the +7.9mOD level approximately.

Figure 5 shows the variations of the readings in target no 616, immediately adjacent to the inclinometer and attached to the capping beam. It must be noted that in some cases there is a difference of 3 days between the modelled day and available data. This may account for some of the differences in the results. By comparison, it also shows that the assumption of fixed bottom of the inclinometer was reasonable.

Figure 6 shows the vertical movement of the raft after construction. The baseline readings were taken on 05/11/08, when the ground floor basement slab had been installed at this location. It shows that the maximum level difference is 3.5mm up to 06/02/09. It is clear that the load of the building was outweighing any potential heave caused at the base from pore water dissipation, if happening at all. Figure 3 shows the construction site activities from Stage 13 when the formation level was reached until 04/02/09, when the last reading of the slab settlement points was taken.

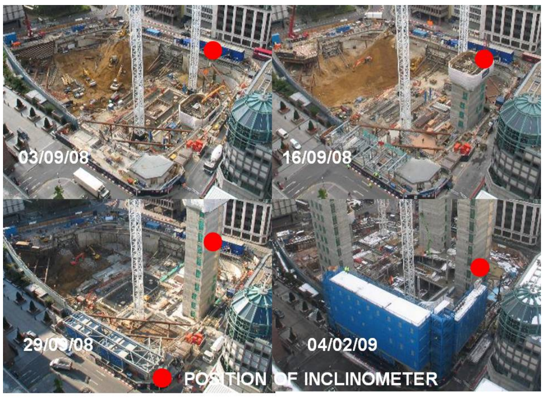

Figure 3. Inclinometer readings.

The vertical movement values behind the wall both measured and calculated were also very small to make any meaningful comparison.

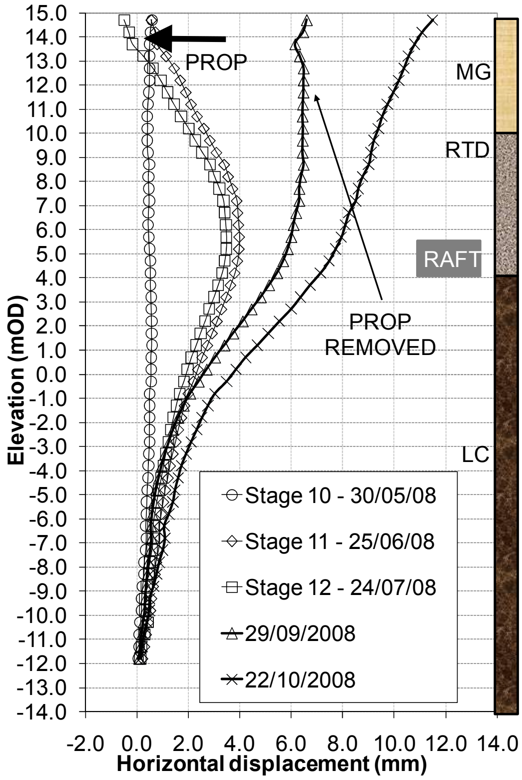

Figure 4. Inclinometer readings.

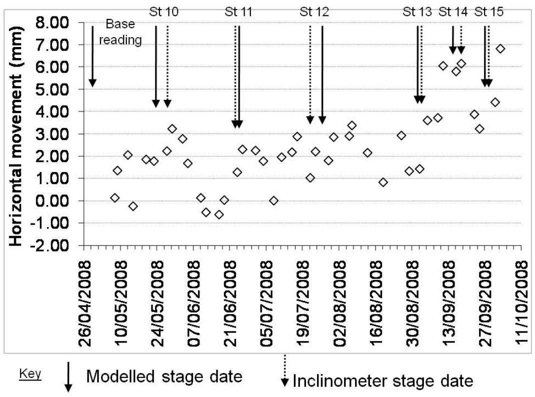

Figure 5. Horizontal displacement of target at same location of the inclinometer. Positive displacement indicates movement towards the excavation.

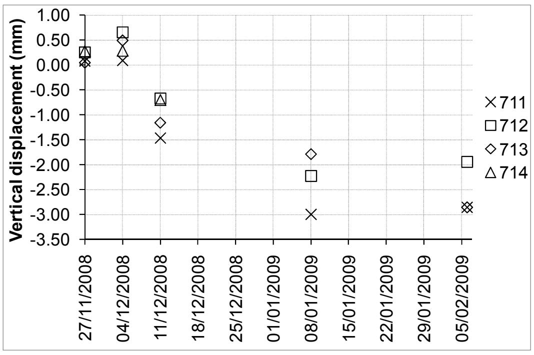

Figure 6. Raft vertical displacement. Negative movement indicates settlement.

6 FINITE ELEMENT MODEL

A computer programme called LS-DYNA was used to undertake the analysis, and Hypermesh was used to create the 3D mesh.

All soil elements, were modelled using solid elements; the retaining walls, capping beams, slabs and other walls were modelled as shell elements; and the waling beams, temporary props, temporary works beams and king posts were modelled using beam elements. It consists of 629,770 nodes, 607,634 solid elements, 41,286 shell elements and 269 beam elements.

The bottom of the mesh was placed five times the retained height below the excavation level, and the sides about four times the retained height away from the nearest point to the wall.

Two sets of parameters were used for BRICK (see Table 3); 'Characteristic' from Simpson[1] and 'Most probable' from SCOUT [5]. A definition of these terms can be found in Gaba et al [6].

Table 3. BRICK parameters

Parameter	Characteristic	Most probable
λ	0.1	0.1
κ	0.02	0.02
ι	0.0019	0.00175
ν	0.2	0.2
μ	1.3	1.3
β^G,β^φ	4.0	4.0

G_t / G_{max} (strain %)	String lengths Characteristic	Most probable
0.92	3.04E-05	3.00E-05
0.75	6.08E-05	7.5E-05
0.53	1.01E-04	1.5E-04
0.29	1.21E-04	4.0E-04
0.13	8.20E-04	7.5E-04
0.075	1.71E-03	1.5E-03
0.044	3.52E-03	2.5E-03
0.017	9.69E-03	7.5E-03
0.0035	2.22E-02	2.0E-02
0	6.46E-02	6.0E-02

KEY: Gmax is the maximum shear modulus, Gt is the shear modules, λ is the slope of the isotropic normal compression line and κ is the slope of the isotropic swelling line in εvol – ln p' space, ι is a parameter controlling elastic stiffness, ν is the Poisson's ratio, μ controls string length due to changes in orientation in the π-plane, β^G,β^φ control the amount of initial stiffness and strength gain from overconsolidation respectively.

7 RESULTS AND DISCUSSION

Figure 7 shows a comparison between the results obtained in the back-analysis and the inclinometer readings. It can be observed that the agreement between the 'most probable' parameters and the field measurements is reasonable, whereas the 'characteristic' over predict the movements as expected. A similar application with similar results was presented for a different basement with different construction conditions by Fuentes et al [7].

Figure 4 also shows that the top of the retaining wall moves significantly inwards as the temporary propping at capping beam level is removed. The movements that occur after the excavation reaches the formation level with time are evident in the figure. The origins of these movements are very difficult to decipher. Some attribute it to soil creep and/or relaxation of the soil as pointed by Roscoe and Twine [8].

The inclinometer covered only the last 4m of excavation. For this excavation phase, the observed ratio between maximum lateral displacement of the wall and the retained height, is 0.12%. This value is at the low end of those presented by Long [9] for walls with h > 0.6H and Stiff Soil at excavation level, where h is defined as the depth of the overlying deposits over the stiff clay, and H is the retained height.

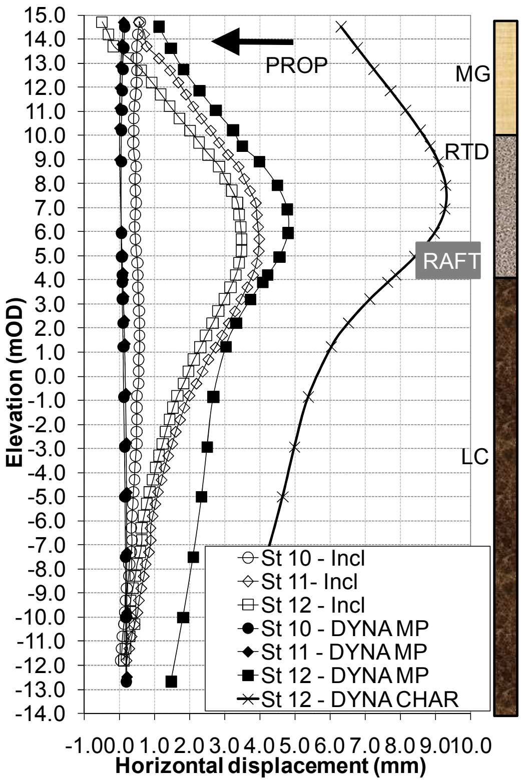

Figure 7. Inclinometer and FE results comparison - 25/04/08.

The lack of previous monitoring data hinders the interpretation and back-analysis, and once more highlights the importance of adequate monitoring.

8 CONCLUSIONS

This case study presents a successful application of the BRICK's 'most probable' parameters to a basement construction. It provides confidence in their application to first: understand general behaviour of soil-structure interaction, and for potential application in the Observational Method. At the same time, the 'characteristic' parameters prove to be an effective set to be used at design stage when some degree of conservatism is required.

The readings from the raft show that the settlement due to building construction overweighs any potential heave caused from dissipation of porewater pressures in the stiff clay.

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