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St John’s Wood Square advanced modelling and monitoring back-analysis

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ABSTRACT: Constructing the basement for the St John’s Wood Square development offered a unique opportunity to demonstrate the potential for digital and technical innovation through combining advanced 3D finite element modelling with extensive monitoring data. St John’s Wood Square occupies 2.2 hectares on the former St John’s Wood Square Barracks site in London, delivering a luxurious residential scheme comprising apartments and townhouses over one of the largest basements under construction in the UK (130m x 160m, single to triple storey). The development is adjacent to highly sensitive assets, including Transport for London St John’s Wood Station structures and tunnels, water and gas buried services, high value residential properties directly bordering the site and the 200-year-old Grade 2 listed Riding School barracks building. Robert Bird Group (RBG) developed a viable construction proposal to enable the 156,000m^3 excavation to proceed within the stringent movement requirements imposed by third parties. RBG undertook advanced 3D finite element modelling of all proposed construction sequences to confirm predicted movements and impact on the existing sensitive structures. As the construction progressed on site, extensive monitoring data were recorded, and a purpose-built tool was created by RBG as a digital innovation to streamline extraction, processing and visualisation of data. Concurrently, three stages of back-analysis were delivered by integrating 3D numerical modelling with real-time data from the comprehensive suite of monitoring instruments to validate the original predictions. This robust approach de-risked the project, avoided additional construction costs and programme delays, and effectively managed third-party interfaces throughout construction, demonstrating a significant advancement in the industry standard approach to ground movement predictions. The combination of advanced numerical modelling and monitoring back-analysis using a data-driven approach, unlocked the construction of this large basement without adversely impacting the existing sensitive structures, offering significant value engineering and sustainability opportunities.

KEYWORDS: Complex basement, numerical modelling, monitoring, back-analysis, digital innovation.

1 INTRODUCTION

St John’s Wood Square (SJWS) is a super prime residential development in the heart of London, UK. The development features one of the UK’s largest basements currently under construction, adjacent to sensitive assets located both above and below the ground.

During the design phase, Robert Bird Group (RBG) completed advanced 3D finite element (FE) modelling of 100+ construction stages, to accurately predict movements and impacts on the existing assets. This enabled the 156,000m^3 excavation to proceed within the stringent movement requirements set by third parties.

As construction progressed, several key sequence changes were introduced, posing a risk of increased ground movements and potential adverse impact on third-party assets. Leveraging monitoring data from over 2,500 instrument points, RBG developed a purpose-built tool to streamline data extraction, processing, and visualisation. Concurrently, three stages of back-analysis were conducted by integrating the Plaxis 3D FE modelling with real-time data, providing a more accurate validation of movement predictions and a better understanding of the ongoing impact on the third-party assets.

This approach de-risked the project, increased construction efficiency by avoiding additional costs and programme delays, effectively managed the third-party interfaces by safeguarding the integrity of their assets throughout construction, whilst introducing sustainability opportunities.

This paper outlines the basement design and details of the advanced finite element modelling undertaken; it describes the steps of the monitoring back-analysis and observational method approach and presents a summary comparison of movement predictions versus real-time monitoring data.

2 PROJECT DESCRIPTION

2.1 *The Site*

The SJWS site is situated in St John’s Wood, in the City of Westminster, Central London. The site covers an area of 2.2 hectares on the former St John’s Wood Square Barracks. Relatively flat and highly constrained by existing assets, the site is bounded by streets along its eastern and western perimeter; water and gas utilities run underneath these streets, including the historic King’s Scholars’ Pond Sewer (KSPS). The southern and northern perimeters of the site back onto private residential buildings and mews. Transport for London (TfL) Jubilee Line tunnels and station structures are located underneath the site.

The SJWS development is designed to become a residential destination that includes private and affordable accommodation split into apartments, townhouses and penthouses, ranging in height from 3 to 7 storeys, setting a new precedent for residential developments in the London’s super prime market. The development comprises a general single-level basement (7m deep), with a triple-level basement (12m deep) in the eastern section of the site, accommodating car parking, stores and plant areas. The basement footprint measures approximately 130m x 160m in plan, representing a total area of approximately 20,800m^2, making SJWS basement one of the largest basements currently under construction in the UK.

The site was originally occupied by the buildings of St John’s Wood Square Barracks, including residential accommodation, stables, amenity blocks, office and workshops. The north-western part of the site comprised a strip of terraced shops with flats. All existing buildings have been demolished during the enabling works phase of the project, except for the Grade II listed Riding School, which is being refurbished into a swimming pool with leisure facilities and social function areas. The completely different configurations between former and new buildings did not provide opportunities for reusing any of the existing foundations or retaining structures, except for the masonry perimeter walls of the Riding School that are being retained.

Figure 1 and Figure 2 show a 3D model of the SJWS development, and a detailed plan including the site boundary (annotated in red) and all major site constraints.

Site works started in spring 2022. As of this writing, substructure works are complete, whilst superstructure works are ongoing. Full completion is planned in 2028.

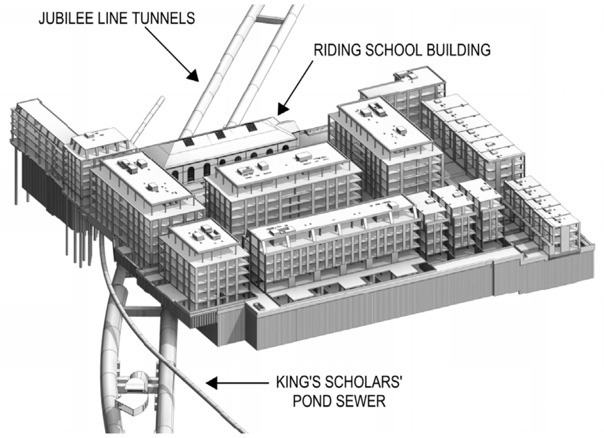

Figure 1. 3D Model of SJWS development.

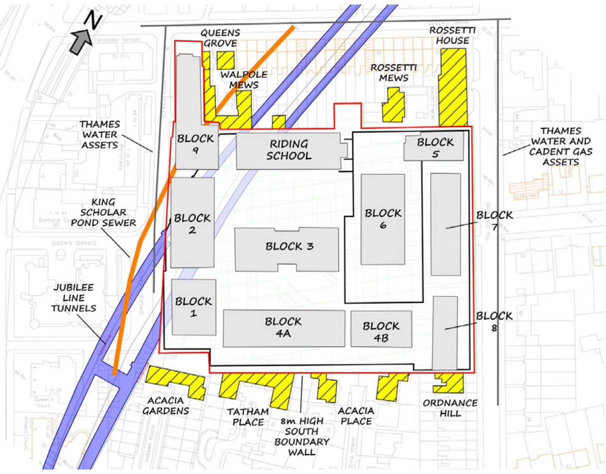

Figure 2. SJWS block plan and major site constraints.

2.2 *Ground conditions*

A site-specific Ground Investigation (GI) was carried out in 2013 and 2014, including pressuremeter tests, oedometer tests, and advanced consolidated undrained triaxial tests with bender elements. The sunk boreholes revealed Made Ground overlying the London Clay. The boreholes were not deep enough to explore the strata below. From historical BGS boreholes, however, it was understood that the London Clay overlies the Lambeth Group, Thanet Sands and Chalk Formation. The simplified stratigraphical model is presented in Table 1.

Table 1. Idealised ground model (existing ground level at +50mOD).

Stratum	Level at top (mOD)	General description
Made Ground	+50	Gravel with brick and concrete and pockets of clay and sand
London Clay	+48	Weathered to unweathered firm to very stiff Clay
Lambeth Group	-33	Very stiff Clay with Sand and Gravel
Thanet Sand	-48	Very dense fine-grained Sand
Chalk	-56	Extremely weak to moderately weak Limestone

Descriptions for Lambeth Group, Thanet Sand and Chalk are not site specific and are based on common knowledge of these materials.

Compared to the typical geology in London, the SJWS site is unusual as the London Clay consists of the full formation thickness, including the uppermost units which are typically eroded. This means that the stratum is more overconsolidated than in other parts of London, with a higher lateral earth pressure coefficient, adding complexity to the design of the basement retaining system.

The FE modelling adopted the linear elastic perfectly plastic Mohr-Coulomb constitutive model for Made Ground, Lambeth Group and Thanet Sands. The non-linear hardening constitutive model with small strain-stiffness (HSS) has been adopted for the London Clay, to capture the soil stiffness decay behaviour with strain levels. This is essential for assessing small deformation behaviours associated to wall deflections and settlements. However, unloading/reloading behaviours are simplified with potential over- or under-predictions of larger strain behaviours (such as heave movements), especially when modelling overconsolidated clays and deep/large excavations.

The characteristic geotechnical parameters for the FE modelling were derived by calibrating the GI testing results with SoilTest in Plaxis, as outlined in Table 2 and Table 3.

Table 2. Characteristic geotechnical design parameters.

Stratum	Friction angle $\phi'(°)$	Effective cohesion c' (kPa)	Effective Young Modulus E' (MPa)	Lateral earth pressure k0 (-)
Made Ground	30	-	10	0.5
London Clay	25	5	HSS	2.0
Lambeth Group	27	20	150	1.0
Thanet Sand	40	-	250	1.0

Table 3. London Clay HSS parameters.

Secant modulus, $E'_{50,ref}$	0.8 * 600 * cu
Oedometer modulus, $E_{oed,ref}$	0.8 * $E'_{50,ref}$
Unloading/reloading modulus, $E'_{u,ref}$	3 * $E'_{50,ref}$
Power, m	1
Small strain shear modulus, G_0	86MPa
Strain level at 70% G_0, $\gamma_{0.7}$	0.01%

Undrained shear strength $c_u = 50 + 5z$ (z depth from top of stratum).

Although the input parameters of the London Clay are defined in terms of effective stress, an undrained behaviour was used during construction followed by consolidation to capture both the short-term and the long-term soil conditions. For the consolidation of the London Clay, a distinction between the horizontal and vertical permeability was made based on the GI factual information, with the vertical permeability three orders of magnitude lower than the horizontal permeability.

During the site investigation works, the water pressures measured at various depths showed a large scatter but indicated a typical hydrostatic profile from the top of the London Clay.

2.3 *Outline of existing third-party assets*

The design and construction of the SJWS basement have faced significant challenges due to the presence of numerous sensitive third-party assets located within the SJWS basement area of influence, as summarised in Table 4.

Table 4. Simplified list of both below and above the ground assets.

Owner	General description
Thames Water	King's Scholar's Pond Sewer (KSPS) – 2000mm diameter, 7.8m deep, concrete lining
Thames Water	11No. sewers – 255mm to 2250mm size, 2.4m to 4.1m deep, brick/vitrified clay/cast iron
Thames Water	9No. water mains – 76.2mm to 304.8mm diameter, 07m to 1.7m deep, cast iron and HPPE
Cadent Gas	652.8mm diameter, 0.5m to 1.0m deep, cast iron
Transport for London	Jubilee Line station escalator, platform and running tunnels – 3810mm to 6930mm diameter, cast iron lining, ground level to 15m deep
Party Wall	34No. private buildings – 2 to 4 storeys, with/without basement, brick

3 BASEMENT DESIGN

3.1 *Construction sequencing*

The adoption of conventional temporary works approaches presented significant programme and technical issues:

- The large basement width meant that flying props would have not sufficiently restrained ground movements. The quantity of temporary steel would have driven up costs and compromised the project sustainability objectives.
- Perimeter berms would have delayed construction access alongside the secant wall, prohibitively extending the construction programme.
- The size and many steps and holes in the ground floor slab would have greatly complicated its use for a full top-down construction, also extending the programme.

Therefore, the project required bespoke temporary retaining solutions along each side of the basement perimeter.

The temporary perimeter retaining system was formed by 750mm and 900mm diameter secant and contiguous pile walls. A partial top-down solution was implemented to retain the northern boundary and to enable the excavation of the deeper internal 3-level basement under Block 6 (Figure 2). A trench system with two levels of horizontal props was integrated along the western boundary. A unique system of barrettes was introduced by the substructure contractor along the eastern and southern boundaries. Unreinforced barrettes extending below the basement formation level were constructed perpendicular to the perimeter walls, with triangulated steel frames plunged into the barrette's concrete. The raking props integrated into the frame were then exposed and jacked during excavation.

The excavation of the one level basement inside the Riding School building was retained using a ground level top-down slab and two levels of horizontal steel props.

The foundations within the basement perimeter comprise a reinforced concrete raft ranging between 900mm and 1100mm thick. Only the Block 9 structure, which is located outside the basement in the north-west corner of site (Figure 2), is founded on bearing piles.

3.2 *Advanced finite element numerical modelling*

Delivering advanced Plaxis 3D finite element modelling was critical to managing the complexity of the construction sequencing and to ensuring compliance with the stringent criteria set by the asset owners.

RBG modelled the full basement construction across 100+ stages to accurately simulate the progression of site works and to capture in detail the three-dimensional effects on adjacent assets. Given the size and complexity of the 3D FE model, challenges were inevitable. Therefore, a robust validation was initially completed with the aid of simplified 3D tools, Plaxis 2D and 'slices' of Plaxis 3D modelling, and by comparing results with established literature references. Ensuring coherence and confidence in the outputs at every stage, while remaining aligned with programme constraints, was essential.

The Plaxis 3D model incorporated both temporary and permanent works, including demolition, staged excavation, application of the new development structural loads, and long-term ground consolidation. The Jubilee Line tunnels, the KSPS and the Cadent gas main have been specifically modelled as plate and beam elements to remove part of the conservatism that is introduced during greenfield modelling. A reduction of the element flexural stiffness due to potential joint movement was adopted when relevant; specific calculations of bolt stress and lining stress were also undertaken for the Jubilee Line tunnels.

The boundary conditions were set at a lateral and vertical distance of >10 times the general excavation depth.

Figure 3 shows an intermediate construction stage in the Plaxis 3D model. Figure 4 shows plate and beam elements as per the final stage of the modelling.

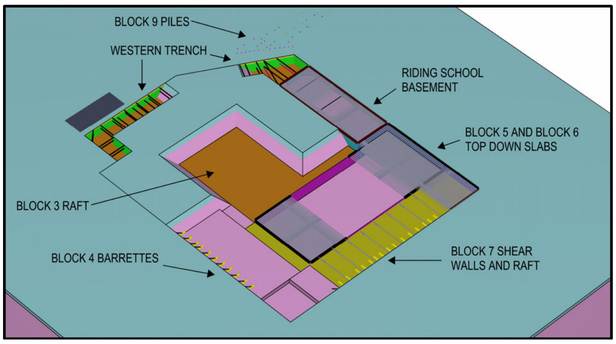

Figure 3. Intermediate construction stage in Plaxis 3D FE model.

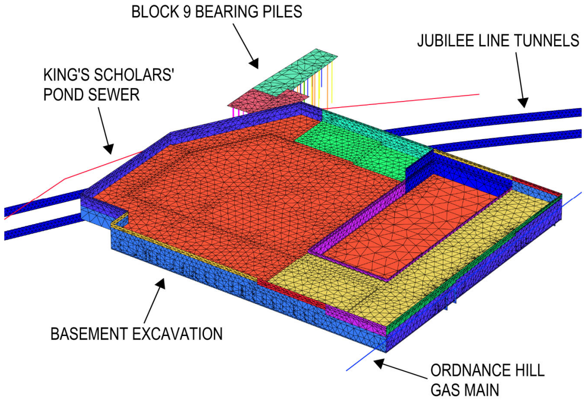

Figure 4. Mesh of plate elements in the Plaxis 3D model (final stage).

4 MONITORING

4.1 *Monitoring system*

Reflecting the complexity of the SJWS basement construction, an extensive monitoring system has been implemented to deliver design verification and asset protection, consisting of:

- 115No. precise levelling studs on the kerbs of the streets surrounding the site (manual).
- 158No. 3D prisms and retro reflective targets on the neighbouring buildings and structures (manual).
- 42No. tilt meters and BRE sockets on the Riding School (manual and automated).
- 19No. inclinometers within the basement secant and contiguous walls (manual and automated).
- 57No. 3D prisms on the perimeter wall capping beams (manual).
- 565No. 3D prisms within the Jubilee Line escalator shaft and tunnels (automated).
- 48No. Bassett Convergence System (BCS) and 6No. electrolevel beams with 363No. sensors within the Jubilee Line tunnels (automated).

4.2 *Monitoring Interpretation*

Traditionally, interpreting monitoring data involves manual downloading, processing, and plotting; a repetitive, time-intensive, and error-prone process, which could delay interpretation and hinder timely decision-making. For a project of SJWS's scale, with 300,000 monitoring data points recorded every week (45 million to date), the traditional approach to handling monitoring interpretation was simply unsustainable.

To address the challenge, RBG developed GeoMotion, a fully automated workflow designed to enhance interpretation efficiency. Implemented in Python, GeoMotion directly integrates with the monitoring contractor's data management platforms, automates and streamlines data extraction, significantly reducing processing time from hours to minutes. The tool enables robust data storage, filtering and visualisation, with the capability to generate hundreds of graphs within minutes. Beyond accelerating data handling, GeoMotion improves quality assurance and accuracy.

On the SJWS project, the development of GeoMotion facilitated effective monitoring interpretation by automating traditionally manual and repetitive tasks, cutting engineering time by more than 80%. This allowed RBG engineering team to access timely insights with minimal effort, focusing on critical analysis and decision-making, ultimately contributing to better project outcomes.

5 BACK-ANALYSIS

5.1 *Limits of standard practice*

Ground movement and asset impact assessments are typically conducted during the design phase to establish acceptable behaviours, followed by monitoring throughout construction to check that the actual behaviours are within acceptable limits. Planned contingency actions should be put in place if the limits are likely to be exceeded. However, conventional approaches often fall short: monitoring data may be insufficient to manage complex interfaces, and real-time validation is rarely performed to confirm actual construction impacts. Standard practice often relies on predefined trigger levels and periodic reporting, which may not capture dynamic site conditions or evolving risks. This disconnect can lead to technical, programme, and cost risks if the actual impact exceeds third-party tolerances.

5.2 *Principles of the Observational Method*

The Observational Method (OM) is permitted by the Eurocode (BS EN 1997, specifically in Clause 2.7), although the standard provides limited guidance on implementation. CIRIA C760 (Gaba et al. 2017), however, includes a dedicated section on the OM, highlighting its potential to deliver significant programme and cost efficiencies, particularly in scenarios involving difficult or highly uncertain geotechnical behaviours. The OM enables safe construction through a rigorous risk management framework. By integrating planned and robust monitoring with (near) real-time back-analysis, the OM allows the designer to refine and adapt the design of any structure during construction. This feedback loop supports informed decision-making and contingency planning, ensuring that design modifications are based on reliable observational data.

Figure 5 illustrates some of the OM potential advantages; sustainability benefits could also be achieved through leaner engineering solutions and adaptive design strategies.

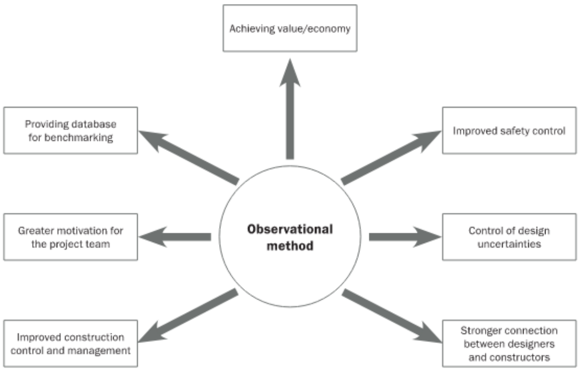

Figure 5. Illustration of potential advantages by using the OM (Nicholson et al. 1999).

CIRIA 760 (Gaba et al. 2017) divides the OM approaches in two categories:

- 'Ab initio' (from the start), where the use of OM is planned from the start of the project.
- 'Ipso tempore' (in the moment), where the performance and design of the retaining system is re-assessed during construction.

5.3 *SJWS back-analysis methodology*

Given the unique complexity of the SJWS construction sequencing, a standard approach to monitor the impact on third-party assets, would have not been sufficient to safeguard the project success. Instead, the RBG team implemented a data-driven, real-time monitoring and back-analysis framework, integrating advanced Plaxis 3D FE modelling with the implementation of the GeoMotion tool. This approach enabled continuous validation of design assumptions and proactive management of third-party interfaces, aligning with best practices in the field of geotechnical engineering. SJWS back-analysis showcases a successful application of the 'Ipso tempore' OM, adopted after the walls were installed.

The back-analysis has been conducted in stages, allowing the project team to proactively assess and manage residual risks as the construction continued. Each phase focused on a specific construction timeframe, integrating the following key steps:

1. Review final designs and as-builts, and construction sequencing adopted on site in that period, to identify key changes from what was originally modelled in Plaxis 3D.
2. Revise Plaxis 3D to incorporate the identified changes.
3. Where results did not closely match the monitoring data, calibrate Plaxis 3D FE modelling assumptions to obtain a closer correlation with on-site monitoring data.
4. Model remaining construction stages within the new calibrated assumptions to obtain accurate and more realistic predictions of the cumulative (end of construction) impact on high-risk assets.
5. Provide key conclusions from the back-analysis process to identify any residual risks to future construction works and third-party interfaces.
6. Confirm the requirement for changes to the remaining site activities or for implementation of contingency plans.

The back-analysis focussed on reviewing the monitoring data from selected inclinometers (most accurate and reliable instrumentation) in the areas where the key bulk excavation activities occurred, to compare real-time field measurements with Plaxis 3D predicted retaining wall deflections. Inclinometers D07 & D08, D10 to D12, D14 to D16, and D19 and D20 have been integrated in the back-analysis. The location of these inclinometers is shown in Figure 6.

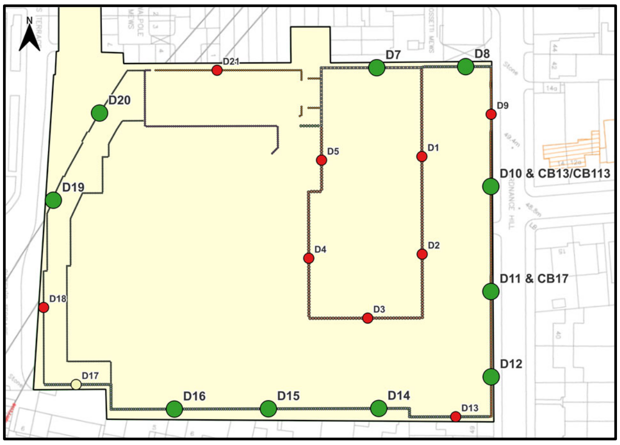

Figure 6. Outline location of inclinometers.

6 MONITORING DATA VERSUS PREDICTIONS

6.1 *Outline of the back-analysis results*

A comparative analysis between Plaxis 3D predictions and real-time inclinometer data is outlined in this section, at key phases of the basement excavation (completed on site) and in the long-term conditions, following completion of the superstructure works (currently ongoing, therefore monitoring data are not yet available). For each inclinometer, the comparison in the long-term conditions includes both the original design predictions, undertaken before the works started on site, and the updated outputs from the latest back-analysis.

Predictions are presented as 'local', which are calculated assuming no movement at the wall toe for direct comparison with the inclinometer data, and as 'global', showing full predicted wall deflection including toe movements, for a direct understanding of the impact on the third-party assets.

As expected, given the complexity of the SJWS basement construction, alignment between predicted and measured wall movements varies across instruments. These variations underscore the importance of iterative back-analysis and real-time validation in refining geotechnical models and effectively managing third-party asset risks.

6.2 *Northern perimeter wall inclinometers D07 & D08*

The same back-analysis outcome was concluded for both instruments:

- Post-substructure completion, predictions align closely with the most recent inclinometer data (1-3mm deviation).
- Under long-term conditions, back-analysis shows global movements up to 15mm above original predictions.
- The increase is due to revised bulk excavation sequencing in front of the wall, and updated spring stiffness assumptions for the top-down slabs.

Figure 7 shows the results for inclinometer D07 (end of substructure works and post consolidation), as a representative example of the comparative analysis for the northern wall.

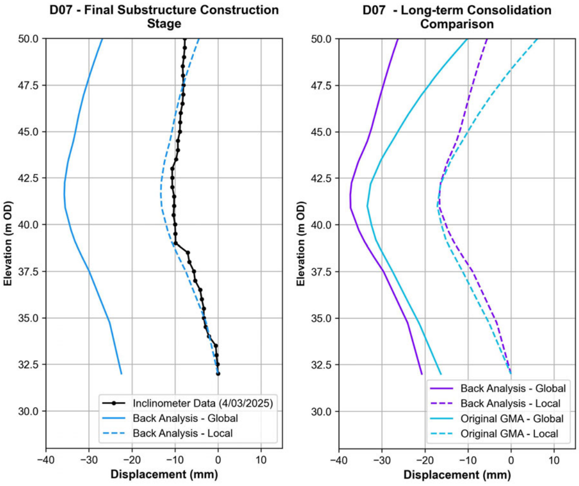

Figure 7. D07 back-analysis graphs (post-substructure & long-term).

6.3 *Eastern perimeter wall inclinometers D10 to D12*

The same back-analysis outcome was concluded for inclinometers D10 and D11:

- During interim bulk excavation, predictions aligned very well with the monitoring data.
- Post-substructure completion, monitoring data is higher than predictions, up to 9mm. This discrepancy may be due to Plaxis limitations in modelling localised excavations and intermediate consolidation stages.
- Under long-term conditions, back-analysis shows global movements up to 6mm above the original predictions. This was anticipated as several changes were introduced to the basement excavation sequencing in this area.

Figure 8 shows the results for inclinometer D10 (end of substructure works and post consolidation), as the most onerous example of the comparative analysis for the eastern wall.

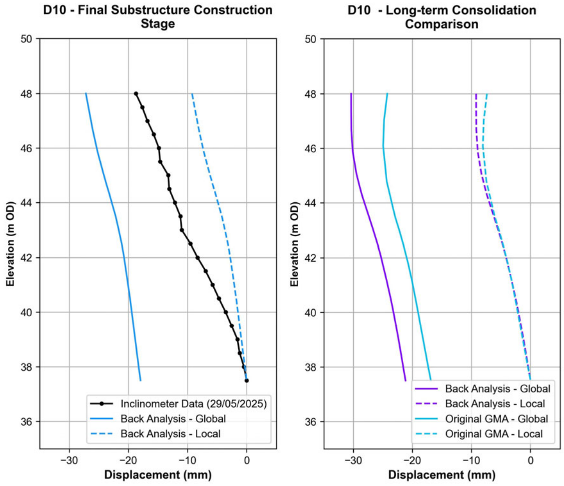

Figure 8. D10 back-analysis graphs (post-substructure & long-term).

On the contrary, a consistent close alignment is obtained when comparing both original and back-analysis predictions with the monitoring data at D12.

6.4 *Southern perimeter wall inclinometers D14 to D16*

The same back-analysis outcome was concluded for inclinometers D14 to D16:

- Post-substructure completion, predictions align with the monitoring data (2-5mm deviation).
- Under long-term conditions, back-analysis movements align with the original predictions (2-3mm deviation).
- The better comparison between the original predictions and the back-analysis predictions for the southern wall compared to the northern and the eastern walls, is attributed to the fact that only minor changes in the construction sequencing were introduced at this location.

Figure 9 shows the results for inclinometer D14 (end of substructure works and post consolidation), as a representative example of the comparative analysis for the southern wall.

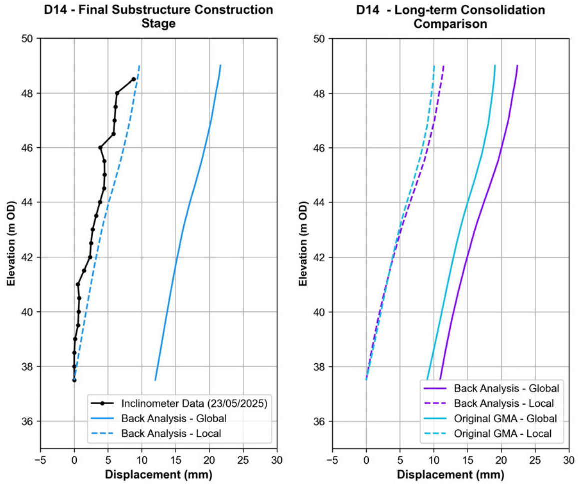

Figure 9. D14 back-analysis graphs (post-substructure & long-term).

6.5 *Western perimeter wall inclinometers D19 & D20*

The same back-analysis outcome was concluded for inclinometers D19 and D20:

- Post-substructure completion, predictions align very well with the most recent inclinometer data.
- Under long-term conditions, back-analysis movements align with the original predictions (1-3mm deviation).

Figure 10 shows the results for inclinometer D19 (end of substructure works and post consolidation), as a representative example of the comparative analysis for the western wall.

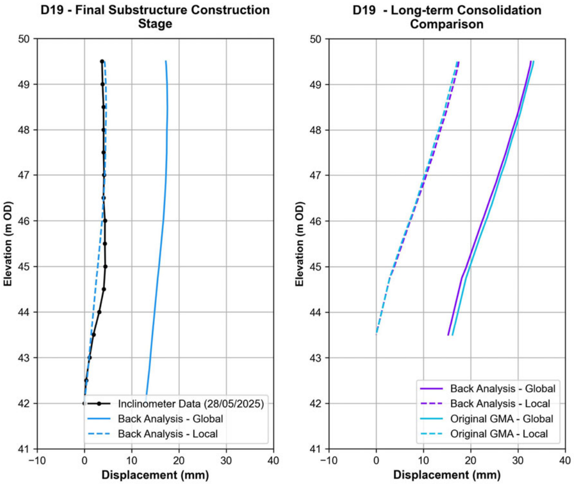

Figure 10. D19 back-analysis graphs (post-substructure & long-term).

7 BACK-ANALYSIS LESSONS LEARNED

The SJWS integration of advanced Plaxis 3D FE modelling and monitoring back-analysis enabled continuous refinement of the soil-structure assumptions, and a well-informed understanding of the impact on third-party assets when changes to design or sequencing occurred during construction.

An outline of key lessons learned from the integrated process, to beneficially inform future projects, includes:

- For basement excavations spanning extended durations, incorporating intermediate consolidation stages is critical to accurately replicate true behaviours. However, defining input assumptions remains challenging, particularly when complex staged construction sequences area adopted.
- Large basement excavations induce 'local' movements (i.e. wall deflections) and 'global' movements (a wider effect due to significant soil mass removal). While the 'local' response was effectively captured by the wall inclinometers, global movements could not be reliably monitored. Constructing isolated deeper piles to install inclinometers anchored at much greater depths, would have enhanced the understanding of global behaviours and supported a more robust back-analysis. No space was available to install inclinometers within boreholes between the perimeter walls and the tight site boundaries.
- Refinement of the calibration of HSS parameters is recommended to reduce conservatisms with the FE predictions. The SJWS back-analysis highlighted how the adopted unloading/reloading modulus conservatively generated excessive heave when compared with the measured vertical movements of roads, neighbouring buildings, and the Jubilee Line tunnels. These data could have also been integrated in the back-analysis process.
- Achieving a balance between conservative and realistic predictions remains a key geotechnical challenge, requiring careful calibration and validation.

8 SUSTAINABILITY

Sustainability opportunities have been introduced throughout the project life cycle, with the following being the key benefits.

Perimeter pile walls were designed to their minimum length required for retention and to reduce settlements, as the basement raft alone satisfies the ultimate checks against failure. This leaner design compared to the original scheme with piles also satisfying ultimate checks, reduced the embodied carbon by 193tC02e (Orr et al. 2020), which represents 15% savings. The total pile concrete volume was reduced by over 1,000m^3.

The substructure contractor's innovative use of barrettes with integrated steel A-frames accelerated the programme by over two months, enabling concurrent superstructure works, and streamlining site logistics for clear and safer working areas. Post-substructure completion, steel frames were removed and recycled. Compared to a traditional bottom-up scheme with raking props, the embodied carbon was reduced by 975tCO2e.

The implementation of the back-analysis and observational method approach enabled leaner engineering solutions, avoiding overly conservative temporary works. Contingency measures were prepared, but never required. This strategy optimised time and material use ensured safe construction and indirectly improved overall project sustainability.

9 CONCLUSIONS

The integration of advanced 3D finite element modelling and monitoring back-analysis using a data-driven approach, enabled more accurate predictions of ground movements, which unlocked the construction of the St John's Wood Square (SJWS) basement, one of the largest under construction in the UK, without adversely impacting the existing third-party assets.

The digital innovation tool specifically developed by Robert Bird Group (RBG), facilitated effective handling of the extensive monitoring dataset, reducing engineering time by more than >80%, improving quality assurance, and enabling the successful implementation of the observational method.

The SJWS project stands as a successful case history to demonstrate the value of adopting the observational method (OM) to complex basement constructions. The implementation of 'Ipso tempore' OM provided enhanced control over the site activities and deeper insight into their impact on existing sensitive third-party assets. This ultimately translated into more effective risk management and maximised project value across programme, cost, and sustainability, through more informed decision-making. As all critical stages were back-analysed, 'Ab initio' OM would have likely delivered similar savings.

10 ACKNOWLEDGEMENTS

The developer St John's Wood Square, the substructure contractor McGee and the main contractor Multiplex. Close collaboration among project partners has been essential to address the complexity of constructing a large basement in urban areas, ensuring seamless integration of expertise.

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