St Giles Circus: meeting the challenges of building above the Elizabeth line

Clive Fussell
MEng, CEng, MIStructE
Director, Engenuiti, London, UK

NOTATION

BIM	**Building Information Modelling**
NLEB	**Northern line Escalator Box**
OLE	**overhead line equipment**
OSD	**oversite development**
RC	**reinforced concrete**

Introduction

The St Giles Circus project involves the £150M redevelopment of a central London site adjacent to Tottenham Court Road Station (Figure 1). The structural and civil engineering design was undertaken by Engenuiti, with geotechnical advice from Donaldson Associates. The development includes leisure, retail, commercial, residential accommodation and a boutique hotel. Above ground, the building incorporates an immersive multimedia urban gallery hung from two-storey steel trusses cantilevered over Tottenham Court Road Station. Below ground, a 2000-person basement venue for live music and events is being built 6m above the eastbound Elizabeth line tunnel, adjacent to the London Underground Northern line platform tunnels and above the inclined cut-and-cover concrete box housing the escalators that provide public access to the Northern line.

There have been significant engineering challenges with the construction of the deep basement over the Elizabeth line and limiting the movement and deformation of the tunnel. A scheme was designed and approved to build the basement above in sections, using deep piles and tunnelled 'adit' beams to create 50m deep piled 'staples' to hold the tunnel down.

Collaboration with Arup brought to the table previous experience of excavating down to the Elizabeth line tunnel to form the Paddington Station box. The St Giles scheme was calibrated against the significant monitoring data collected by Arup from the Paddington Station project, leading to a revised construction scheme which was quicker, safer and provided a £7M saving. Through collaboration, knowledge sharing and innovative design of the foundations and basement, the team has maximised the value brought to the client within this constrained site.

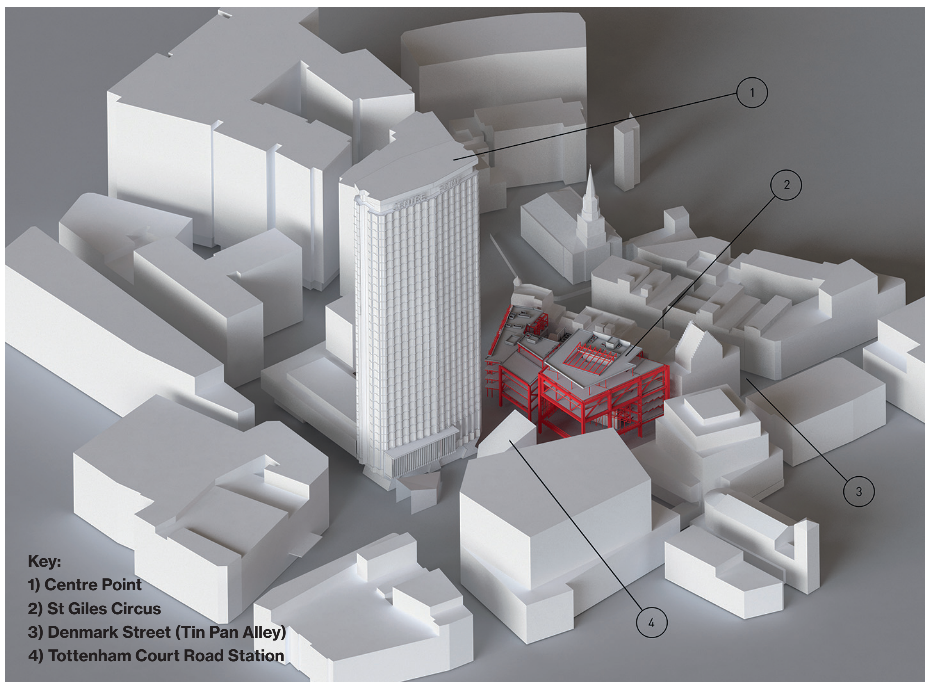


Figure 1
St Giles Circus development adjacent to Tottenham Court Road Station and Centre Point

From an early stage, the client brief for the development was quite clear: maximise the size of the basement to maximise the value of the site; and provide a flexible basement performance space with a large clear height that can be used for music events, product launches, music rehearsals and club nights.

Site constraints

The St Giles Circus site is in the London Borough of Camden and is bounded by Charing Cross Road to the west, the former Andrew Borde Street and the Centre Point development to the north, St Giles High Street to the east and Denmark Street to the south. The site lies in a Conservation Area and contains a significant number of listed buildings, particularly on the Denmark Street frontage. Denmark Street is known as 'Tin Pan Alley' through its long association with the British music industry, particularly in the 1960s and 1970s, and retains a significant number of independent guitar and music shops.

A key requirement of the project brief was to maintain the character of Denmark Street and keep the independent shops trading

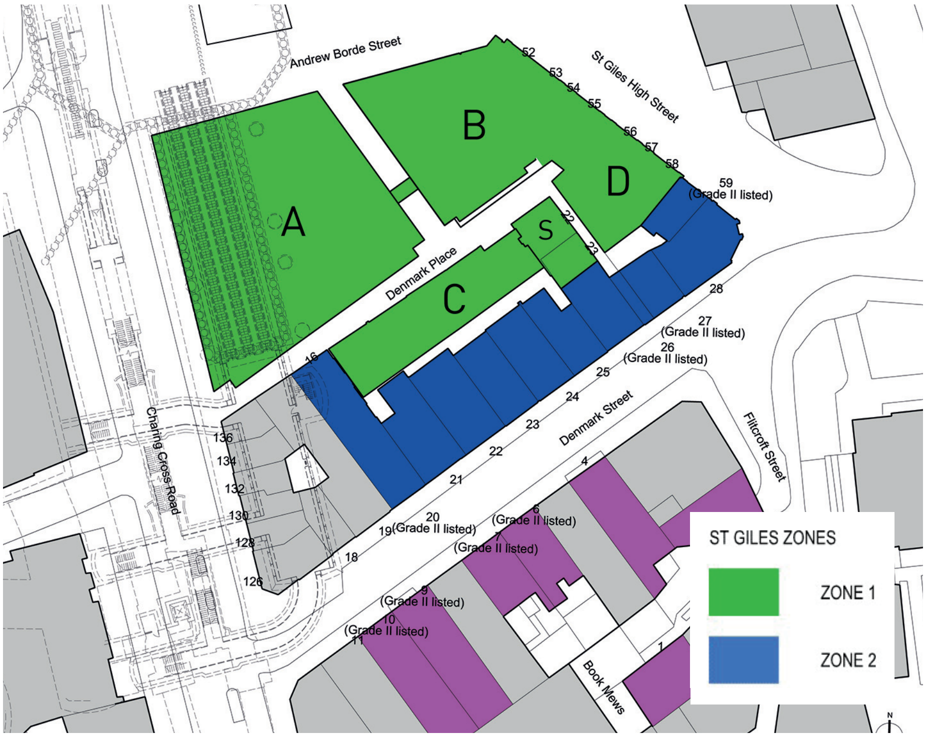


Figure 2
Site plan with listed buildings and extent of Zone 1 and Zone 2

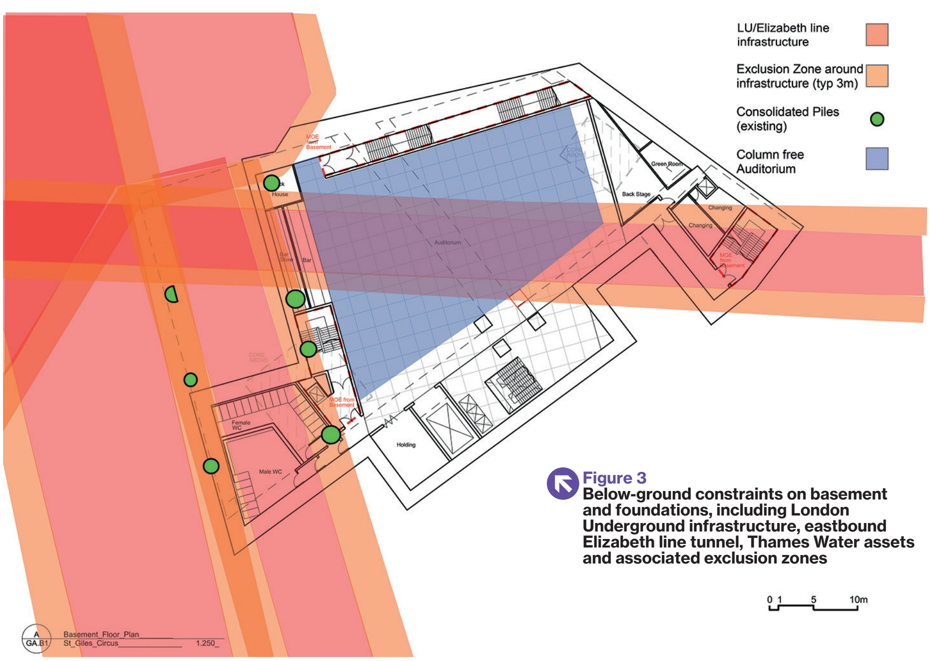


Figure 3
Below-ground constraints on basement and foundations, including London Underground infrastructure, eastbound Elizabeth line tunnel, Thames Water assets and associated exclusion zones

before, during and after the development. For this reason, the development was split into two parts – the new buildings and basement construction in the north and west of the site, known as 'Zone 1'; and the retained and refurbished buildings on Denmark Street and St Giles High Street, known as 'Zone 2'. Figure 2 identifies the site plan, the listed buildings and the extents of Zones 1 and 2.

The footprint of the new development was constrained by the street plan and the existing buildings at ground level, but the size and depth of the new basement – submitted for planning in 2012 – was informed by the underground infrastructure, both existing and proposed.

The site lies immediately to the southeast of Tottenham Court Road underground station, with the Northern line station platforms running under Charing Cross Road immediately to the west of the site. The eastbound Elizabeth line tunnel was due to pass under the site in 2013. As part of the first phase of the Tottenham Court Road Station upgrade works constructed between 2010 and January 2015, a new ticket hall was built adjacent to the site with an escalator connection (known as the Northern line Escalator Box or NLEB) to the Northern line platforms passing under the site. A 2010 Development Agreement between the client and London Underground allowed the latter to lease part of the site during the upgrade works to Tottenham Court Road Station, demolish the buildings over the footprint of the NLEB, divert Charing Cross Road across the site to improve the construction sequencing of the new ticket hall at Tottenham Court Road Station, and construct the NLEB as a cut-and-cover tunnel as opposed to the originally proposed sprayed concrete-lined tunnel.

As part of the Development Agreement, seven deep piles designed by the author while at BuroHappold, were installed around the proposed NLEB to support a future oversite development (OSD). The seven piles – known as the 'Consolidated Piles' after the client – were designed to be at least 1.0m clear from the proposed eastbound Elizabeth line tunnel, and isolated from the NLEB so that the NLEB and the adjacent Northern line London Underground infrastructure did not rely on the piles, and the piles did not rely on the Elizabeth line or London Underground infrastructure. This was important, as any future OSD would require an independent foundation structure if the client was to retain the freehold for the land above the NLEB. The design and construction of the Consolidated Piles, in particular of the 'D-pile', was detailed in the construction press at the time[1,2].

Figure 3 identifies the underground constraints on the site, including the Northern line platform tunnels, the NLEB, the eastbound Elizabeth line tunnel and the Victorian sewers of the surrounding roads. The Consolidated Piles were installed by Bauer in 2010, with the NLEB temporary works secant piled wall, as part of the Vinci BAM Nuttall upgrade works to Tottenham Court Road Station.

Development of planning application

Engenuiti was appointed in 2011 by Consolidated Developments to prepare structural and civil engineering designs

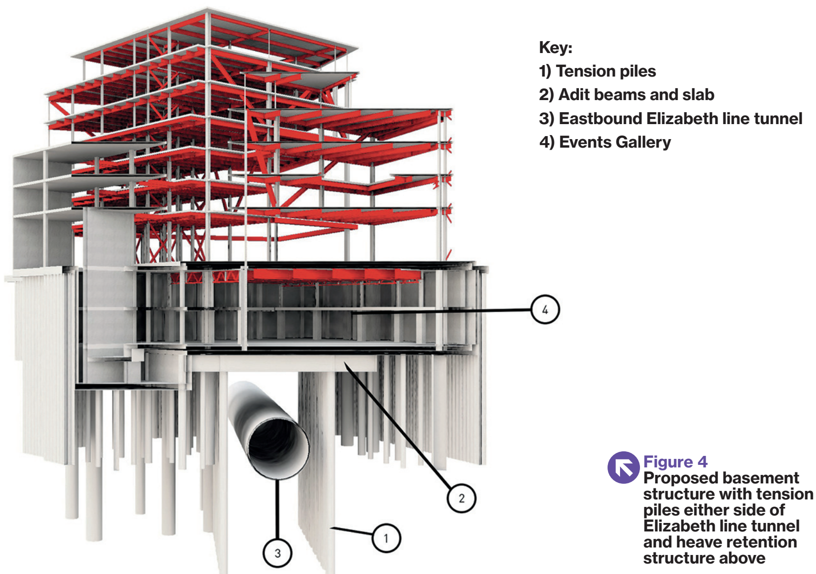


Figure 4 Proposed basement structure with tension piles either side of Elizabeth line tunnel and heave retention structure above

and technical submissions in support of a planning application for the St Giles Circus development. With the client's brief for as large a basement as possible, it was clear that this could have a significant interface with the eastbound Elizabeth line tunnel that was due to be constructed under the site. The depth of the basement would be limited by the Development Agreement with Crossrail Ltd which required 6.0m clearance between the tunnel crown and any basement or foundation structure above. This would limit the depth of the basement above the Elizabeth line tunnel to approx. 11m.

Removal of almost two-thirds of the overburden above the proposed tunnel would result in significant heave of the tunnel. Early liaison with Crossrail's Third Party Development Manager confirmed that the movement limits for the tunnel would be tight to control track distortion, opening up of the joints in the segmental concrete tunnel lining and, in particular, 'egging' or 'squatting' of the tunnel which, if excessive, had potential to exceed the kinematic allowances between the rolling stock and the overhead line equipment (OLE) for the Elizabeth line. Details of the constraints were provided by the guidance in Crossrail's 'Information for Developers Pack'[3]. Engenuiti engaged Donaldson Associates (now part of COWI) to provide additional geotechnical services, including ground movement modelling, to the design team. Early two-dimensional (2D) analysis showed that simply removing the overburden above the tunnel could result in 40mm of heave at the tunnel crown and 20mm of egging of the tunnel, significantly beyond the 10mm limit identified in the Crossrail guidance.

In order to control the predicted movements, the team developed a heave retention system to effectively 'staple' the tunnel down. This would use a combination of deep tension piles either side of the tunnel to resist the heave, and a system of beams and slabs between the tension piles to transfer the heave forces to the tension piles. This arrangement is shown in Figure 4.

The heave retention system was modelled in Plaxis[4] and results compared with a simple hand calculation assuming uniform skin friction on the tension pile, axial pile stiffness based on a cracked pile section (i.e. tension reinforcement only) and bending theory for the beams and slabs to transfer a heave load equivalent to the weight of overburden removed. Both systems showed that the predicted heave movements could be more than halved by the proposed retention system, depending on the parameters such as pile depth and diameter, amount of tension reinforcement, spacing between the piles and stiffness of the beams and slab. So, the movement criteria could be met in theory, but could the system be constructed without having to remove the overburden first to construct the retention slab?

A 'brain storming' workshop was held with Hilary Skinner and Vicky Potts from Donaldson Associates in early 2012. Hilary recalled a technique used during the construction of the Westminster Station upgrade as part of the Jubilee line works. The District and Circle lines needed to remain operational during construction of the new station box below, but there was very limited headroom available to construct a new transfer structure to support the lines above the box. A series of headings supported by timber props ('timber headings') were tunnelled under the District and Circle lines in a hit-and-miss arrangement to enable the insertion of a new transfer structure below the operational railway. By using a similar technique at St Giles Circus to construct the heave retention slab above the Elizabeth line tunnel, it would be possible to insert the slab while maintaining the overburden above.

It was agreed that the tension piles could be installed from ground level and form a cut-off wall either side of the tunnel. This would isolate the area above the Elizabeth line tunnel, allowing the basement construction to be split into three distinct areas: north of the tunnel, south of the tunnel and above the tunnel. The basement areas north and south of the tunnel could then be excavated in advance of the area above the tunnel.

A system of horizontal props and waling beams would be used around the perimeter of each basement to control lateral deflection of the wall and the Elizabeth line tunnel. Timber headings or 'adits' would then be advanced from the formation level through coordinated soft spots in the tension piled wall, reinforcement would be placed in the adits and concrete cast to form 'adit beams' anchored to the tension piles that would be capable of limiting the heave that would result from excavating the overburden above the adit beams. Figure 5 shows the proposed construction sequence and arrangement of the adit beams.

A key consideration in the design of the adit beams was the access requirements for the miners that would advance the timber headings; advice was taken from Joseph Gallagher Ltd who specialise in this type of work, often for London Underground. An adit beam size of 1200mm wide × 1800mm high was decided upon, with a concrete blinded base to minimise any softening of the base during construction.

During Stage 2, a parametric study considered the effect of varying the span and spacing of the adit beams along the tunnel. It was found that the tunnel was more sensitive to the span of the adit beams than the spacing, as the effect of the span was not only influenced by the deflection of the adit beams, but also the interaction between the tension piles and the tunnel: the shorter the distance between the tunnel and the tension piles, the more restraint that the tension piles would provide to the tunnel. The results of the analysis were regularly discussed with Crossrail, as constructing the piles closer to the tunnel presented its own risks of movement or ground failure during pile construction.

The depth of the basement excavation, large event space in the basement and modest size of the above-ground development meant that removal of the overburden above the tunnel was much more significant than any gravity loads that could be applied by the new structure.

The Development Agreement between the client and London Underground allowed for piles to be constructed just 1.0m clear from the proposed Elizabeth line tunnel adjacent to the NLEB, as the position of the tunnel would be constrained by the NLEB, the Northern line platform tunnels and access shafts to the Northern line[5]. The Development Agreement allowed for the clearance to taper from 1.0m to 3.0m as the tunnel progressed east across the site and moved away from the constraints of the NLEB, in order to give Crossrail some flexibility in the final alignment.

As it was now clear that the Elizabeth line tunnel would be constructed before the St Giles Circus development, Crossrail imposed a limitation that the piles must be at least one pile diameter clear of the tunnels and that the detailed geotechnical site investigation must investigate the risk of sand lenses in the London clay around the tunnel, as these could cause collapse of the pile bore during construction.

A conceptual design statement was prepared for Crossrail and submitted with the planning application in December 2012. The engineering risk assessment in the statement concluded that the best balance between extent of tunnel movement, risk of pile bore collapse and cost of construction would be met by constructing piles up to 1200mm diameter under bentonite at a distance of 2.0m plus construction tolerance. An adit spacing of 3000mm was selected so that the remaining overburden could 'arch' between the adit beams in the temporary case. This incorporated 2D assessments of ground movements and their effect on the Crossrail tunnel, and preliminary structural calculations for the heave retention system. A basement impact assessment was also prepared for the planning submission to the London Borough of Camden.

With the basement only 6m above the eastbound Elizabeth line tunnel and only slightly further away from the Northern line platform tunnels at Tottenham Court Road, the acoustic performance of the basement space was also a key consideration. The main performance space or 'Events Gallery' in the basement will be used for a wide variety of functions, from musical rehearsals and performances, corporate functions and product launches, to club nights and gigs. As a result, there was a need to provide acoustic separation from train noise and vibration breaking into the Events Gallery, but also from performance noise breaking out to other spaces within the development.

From an early stage, it was agreed that a 'box-in-box' solution would be the most effective method of isolating the Events Gallery from other sources of noise and vibration. This would entail a double structure around the Events Gallery, with the outer walls, floors and roof structures supported by the building's foundations and an inner structure separated from the outer structure by an air void at least 70mm wide.

While the walls and roof structures could be completely separate, the weight of the inner box structure would need to be supported by acoustic bearings sitting on the main basement floor level. Engenuiti worked with the acoustics team at BuroHappold to develop the performance requirements of the acoustic bearings so that they would tune out the dominant vibration frequencies from the trains passing around the site, but would have a natural frequency distinct from possible sources of excitation such as footsteps and dancing. A natural frequency of approx. 9.5–11.5Hz was selected for the bearings.

As a result of feedback from the planners, there was a requirement to re-site a significant amount of building services plant that had previously been located at roof level. This resulted in a need for more basement space to house the plant. As the site footprint had already been maximised, site constraints meant that the only way to do this would be to excavate deeper either side of the Elizabeth line tunnel to form a new level of basement below the main Events Gallery, effectively forming a saddle over the Elizabeth line tunnel. This basement space would improve construction access to the proposed adit beams.

Camden's planning committee approved the St Giles Circus scheme in November 2013; the design team was then appointed to move the scheme forward in early 2014.

Collaborative approach to value engineering

The design of the heave retention structure had been developed to support the planning application in advance of the Elizabeth line tunnel construction. In the time between the submission of the planning application and the end of the Stage 4 design, the Elizabeth line tunnels had been built from Paddington

Figure 5
Proposed basement construction sequence with adit beams to restrain heave during construction

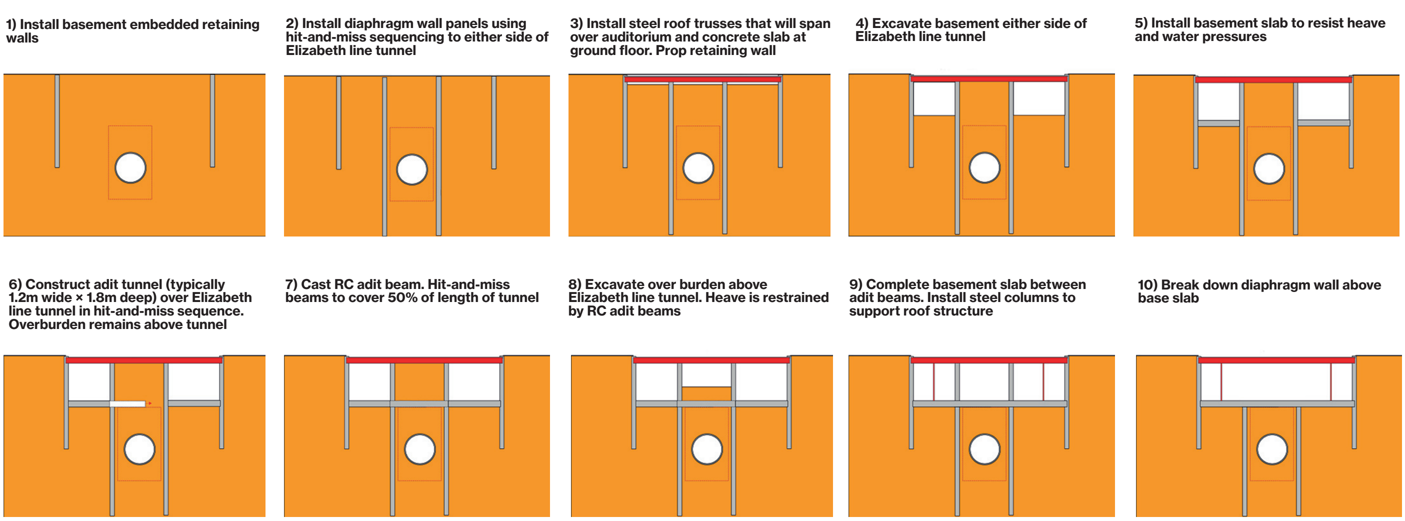


TABLE 1: COMPARISON OF PREDICTED TUNNEL MOVEMENTS

Location	Short-term movements (mm)				Long-term movements (mm)			
	Original scheme	Arup 2D feasibility	Donaldson 2D verification	Donaldson 3D verification	Original scheme	Arup 2D feasibility	Donaldson 2D verification	Donaldson 3D verification
Tunnel invert	6	14	13	10	8	22	19	14
Tunnel crown	10	24	21	19	12	36	30	25
Ovalisation	4	10	8	9	4	14	11	11
Adit slab/beam	Not available	Not available	38	39	Not available	Not available	46	47

to Stratford and the station box excavated above and around the Elizabeth line tunnel at Paddington.

In many ways, the excavation of the station box at Paddington had similarities to the proposed construction at St Giles Circus. On both sites the Elizabeth line tunnels were constructed in advance of the new basement structures; both basements would be constructed using top-down construction within embedded retaining walls (diaphragm walls at Paddington, secant piled walls at St Giles).

The tunnel crown was approximately the same depth below ground level on both sites; the tunnel construction was the same on both sites with the tunnel remaining unpropped during the excavation; both sites proposed to use tension piles to control the heave; and the geology on both sites was similar, with made ground overlying river terrace deposits, overlying the London clay through which both tunnels passed.

At Paddington, the excavation then continued to expose the tunnel crown and break out the bored tunnels to form the station box; therefore, no adit slab was required as the tunnel no longer existed.

Collaboration with Arup, the structural and geotechnical engineers for the Elizabeth line tunnel and the station box at Paddington, enabled the learning and real movement data from constructing and excavating the station box at Paddington to be used to inform the design and construction methodology for the St Giles Circus development. Results from the excavation at Paddington showed that the short-term tunnel movements for an excavation of similar depth to that proposed at St Giles Circus would be in the order of 15mm at the crown and 5mm at the invert, resulting in a net ovalisation of approx. 10mm.

Although the basement depths, tunnel depths and ground conditions at Paddington and St Giles Circus were not exactly the same, if similar movements could be shown to apply at St Giles Circus, it might be possible to amend the construction sequence to a conventional top-down methodology removing the adit beam construction, generating both cost and programme savings, and crucially removing a significant health and safety risk of excavating an extensive adit system in confined spaces.

Arup was instructed to undertake a feasibility study that post-rationalised the predicted movements of the Paddington Station box, so that confidence could be gained that the proposed analysis techniques for the St Giles Circus development would, when applied to the Paddington Station box, correlate with the actual movement recorded at Paddington. Once this had been done, Arup developed a number of value engineering options using Plaxis 2D that considered the effect of varying the stiffness of the adit slab and heave retention piles at St Giles Circus, with the aim of limiting the movement of the track slab and ovalisation of the tunnel to criteria agreed with Crossrail.

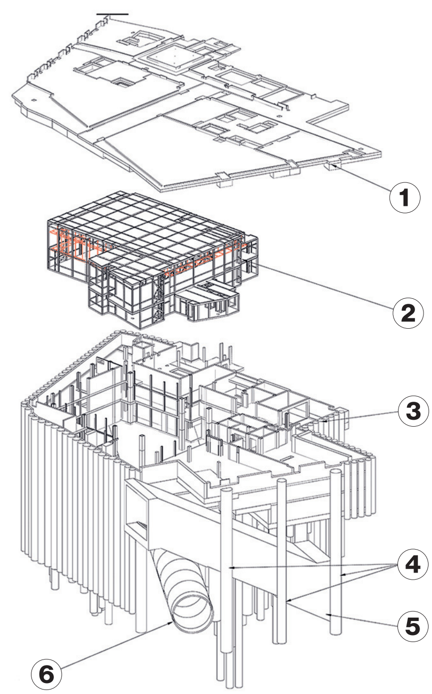
The alternative construction sequence was presented to Crossrail and agreed in principle. The 2D analysis results were then verified by Donaldson Associates using Plaxis 3D analysis[6] so that the effect of the complicated basement form on the tunnel movements could be assessed. Table 1 compares the predicted tunnel movements for the original scheme with the Arup feasibility study and the Donaldson 3D analysis.

In view of the magnitude of the predicted movements of the adit slab, the decision was taken to increase the thickness of the slab from 1.0m to 1.1m after the Arup feasibility study. This accounts for the slightly smaller movements predicted by Donaldson.

Given the close proximity of the basement development to the Elizabeth line tunnel, Crossrail required that an independent Category III check was undertaken to verify the movement and structural capacity of the tunnel. This was undertaken by A-squared Studio using the Plaxis 3D finite-element modelling package to replicate the construction sequence. Similar results were obtained to the Donaldson models.

The resulting basement arrangement is shown in Figure 6.

Figure 6
Isometric of basement arrangement showing interfaces with Elizabeth line and London Underground infrastructure



Key:
1) Ground-floor reinforced concrete slab
2) Box-in-box structure steel frame with metal deck composite concrete floor and roof slab
3) Main basement box reinforced concrete frame
4) Consolidated Piles
5) NLEB
6) Eastbound Elizabeth line tunnel

The Smithy

At the rear of the listed building at 26 Denmark Street were two smaller buildings: a three-storey Victorian warehouse known as 23 Denmark Place and a single-storey 18th century former blacksmith's forge known as the 'Smithy'. As a rare survivor of this type of building in central London, the

Smithy is of local historic significance and adds character to the area.

These buildings are located above the Elizabeth line tunnel and the original plan was to leave the buildings in place so that the basement would not encroach on the footprint of the buildings. This presented a challenge, because the proposed Elizabeth line heave retention scheme was to pass under the Smithy in order to maintain a consistent interface with the tunnel over the length of the site. During the Stage 3 design phase, ground movement analysis showed that the original arrangement would potentially result in significant damage to the existing Smithy building. Alternative options were therefore considered, assessed and presented to Crossrail (Table 2).

It was agreed that the most favourable option for both protection of the Elizabeth line tunnel and safely constructing the works was to move the Smithy. By de-coupling the Smithy from the other buildings at 26 Denmark Street, the existing structures would either be entirely supported on the new piled basement structure or on their existing spread footings, reducing the risk of differential movement between the piled basement and the existing footings adversely affecting the buildings. The building at 23 Denmark Place was considered to be of limited architectural merit in the context of St Giles, and efforts were therefore focused on finding a way to safeguard the Smithy building. As this would require the demolition of 23 Denmark Place, approval was obtained from the conservation officer at Camden Council and Historic England before progressing with the

TABLE 2: ALTERNATIVE OPTIONS CONSIDERED FOR SMITHY

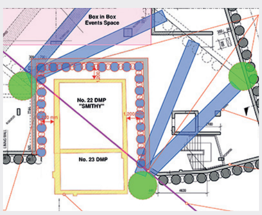
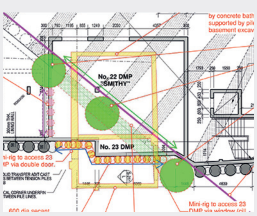
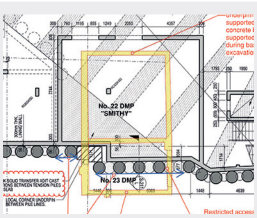
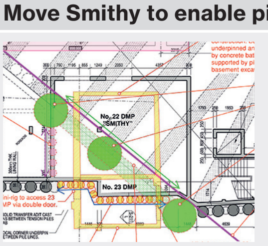
Options	Construction implications	Effect on Elizabeth line	Health and safety implications	Effect on Smithy
Piling around Smithy, no basement under				
	Simple conventional construction, but complicated by skewed adit beams	Poor as heave retention system would be incomplete around footprint of Smithy	Potential movement of Elizabeth line tunnel	Ground movement assessment showed potential for structural damage to Smithy due to both pile installation and basement excavation
Pile within Smithy footprint to maintain consistent heave retention system, either no basement under or pile within 23 Denmark Place to extend basement				
	Would require either small caisson construction or specialist piling techniques (e.g. Martello) to work in tight space of Smithy – slow and expensive. Adit beams would need to be constructed from one end	Good as heave retention system would be more consistent over site footprint	Working in tight spaces with large machinery potentially dangerous. Risk of collapse of Smithy due to impact or vibration. Small caisson construction has significant safety implications	Risk of damage to Smithy during construction works. Smithy roof likely to require temporary removal during pile/ caisson construction
Pile within 23 Denmark Place and construct 'super adit' to get similar heave retention system to rest of site. Support Smithy on piles, extend basement under Smithy				
	Would either require demolition of 23 Denmark Place or piling within the existing building. Smithy would need to sit on transfer structure. Requires additional adit construction	More consistent heave retention structure, but longer spans result in some additional movement	Working in tight spaces with large machinery potentially dangerous unless No. 23 demolished. Additional adit construction undesirable	Reduced risk of damage to Smithy as it will be supported on piles, but likely to require demolition of No. 23 either to facilitate pile access or as result of differential movement between basement and spread footings
Move Smithy to enable piling either side of Elizabeth line tunnel				
	New transfer structure required under Smithy to enable move. Large crane for move. Conventional piling and adit beam construction. Programme and logistics of move need to be carefully planned	Good as heave retention system consistent across site footprint	Conventional underpinning and large lift, but no working in confined spaces or increased risk of tunnel movement	Requires 23 Denmark Place to be dismantled, but reduced risk of damage to Smithy fabric than other options

Figure 7
Smithy move in August 2016 by H. Smith and Abbey Pynford as part of enabling works

structural option preferred by Crossrail.

Once the principle of moving the Smithy was agreed, options for the logistics of the move were developed, such as: lift with crane or slide on skate; support on concrete base slab or steel grillage. In order to minimise the programme implications of the move, it would be beneficial to undertake the first move as part of the demolition and enabling works package that was let to H. Smith. The logistics of the move were developed with input from Skanska and specialist subcontractor Abbey Pynford so that the agreed solution would have minimal impact on both the enabling works and the permanent works.

Sliding the Smithy was quickly discounted as it would require significant excavation and temporary works to move the Smithy horizontally without the need for a vertical lift, and any crane required for a vertical lift would be able to move the Smithy the short distance required to install the piles. Initially, inserting a steel grillage below the Smithy was the favoured lifting option as it would reduce the total lifting load compared to a concrete base slab, but there were concerns about the stiffness of the steel grillage and transfer of the Smithy from its current foundations onto the grillage and again from the grillage onto the permanent works.

ANDREW PARISH

Figure 8
Smithy returned to original position in October 2017 by Skanska and Mammoet

The concrete base slab could be integrated into the ground-floor permanent works, avoiding a double transfer. Abbey Pynford's assessment of the total lifting load showed that it was viable to lift the Smithy and the base slab together and (just) fit the crane on the site, so the concrete option was adopted. Figure 7 shows the Smithy move from its original location in August 2016 and Figure 8 shows the return trip by Mammoet in October 2017.

Construction methodology

As can be seen from the preceding sections, the key to the success of the St Giles Circus project was the control of ground movements and the protection of adjacent infrastructure during the basement construction phase.

Top-down construction was adopted for the basement with the ground floor and basement mezzanine slabs providing horizontal props to the retaining wall during the basement excavation. The key benefit of top-down construction was the reduced risk of ground movements adversely affecting the adjacent buildings on Denmark Street, the London Underground infrastructure and the Thames Water infrastructure. However, the constrained nature of the site and the complicated basement construction meant that top-down construction also provided more lay-down and working space at ground-floor level, improving the logistics of deliveries to the site and muck away, particularly from the Charing Cross Road entrance. Top-down construction would also release the superstructure construction earlier, which had major programme benefits as the duration of the basement excavation, construction and box-in-box installation was of similar duration to the above-ground works.

The adoption of the top-down method required significant temporary works in order to support the construction over both the Elizabeth line tunnel and the NLEB. With limited locations available on the site footprint for deep foundations, it was not possible to install a regular grillage of plunge columns. Long spans over the Events Gallery required significant permanent steel transfer beams at ground-floor level to support the structures above. These were supplemented by temporary transfer beams over the NLEB and below building D (Fig. 2) to support the ground floor until the permanent vertical support provided by the Consolidated Piles around the NLEB and the raft slab below building D could be mobilised.

Construction advice from Skanska required the load capacity of the ground-floor structure to be enhanced to a minimum of 20kPa to support the logistics of deliveries and muck away; in some areas this would need to be enhanced further to 110kPa to support mobile cranes required for the erection of the steel-framed superstructure.

The steel transfer beams and ground-floor slab below building D will be supported by the basement perimeter piled wall during excavation down to basement mezzanine level; however, the piled wall in this location lies above the Elizabeth line tunnel, with the pile toes at least 6m above the tunnel crown. Therefore, an alternative method of support is required before the basement excavation progresses below basement mezzanine level and exposes the lower part of the piled wall. Early construction of the liner walls between basement mezzanine and ground-floor level enables the lining walls to act as deep transfer beams that support the ground-floor and basement mezzanine slabs over the Elizabeth line tunnel until the main basement raft slab above the tunnel is completed. For this reason, the superstructure works for building D will not be able to commence until the main basement raft slab is completed.

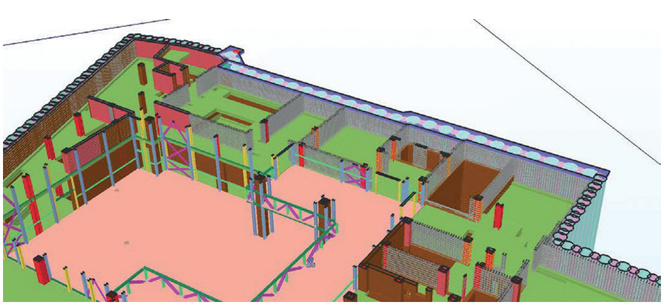


Figure 9
BIM model for production of reinforcement detailing for basement

A key hold point for the basement construction is the completion of the basement mezzanine slab and the associated horizontal propping that is required to restrain the perimeter piled wall. Until this is complete, the excavation may not progress below basement mezzanine level. The majority of the propping at this level is provided by the permanent concrete slab; however, the need to maximise the footprint of the Events Gallery in the permanent condition resulted in some pinch points where insufficient slab was available to act as a complete whaling or ring beam around the perimeter of the excavation.

In these locations, Skanska's temporary works engineers designed a system of temporary props to complete the ring beam in the temporary case. The stiffness of the steel/concrete propping system was independently assessed by both Skanska and Engenuiti, with figures agreed prior to submission to Cementation, which was responsible for the final design of the piles and piled wall. The complex form of the basement resulted in the need for 11 different retaining wall analysis models, each with either a different section or construction sequence. The upper and lower bound results from the retaining wall analysis were then fed back into the propping models to check the stiffness assumptions, deflections and stresses in the propping system.

The complexity of the basement and superstructure arrangements led Engenuiti to adopt 3D modelling for the project from the start of Stage 3 design in 2014. This was invaluable for explaining the project to Crossrail and the other stakeholders and was key to the tenderers understanding the construction sequence. Building Information Modelling (BIM) Level 2 was then adopted for the project after the appointment of Skanska as main contractor and has proved invaluable in the development and coordination of the subcontractor design information, as shown in the production of the reinforcement detailing for the basement (Figure 9).


ANDREW PARISH

Figure 11
Site photograph taken on 18 April 2018 showing progress on site

Figure 10
Model image of St Giles Circus basement and structure

Conclusions

St Giles Circus was already a complex and constrained central London site even before the infrastructure improvements associated with the Tottenham Court Road Station upgrade and Elizabeth line construction began. However, without the infrastructure capacity improvements that the Elizabeth line brings to the area, the planners would not have permitted new developments that increase the number of people working and socialising in this part of London, and the area would gradually stagnate.

By adopting a proactive and collaborative approach with the infrastructure protection team at Crossrail, it was possible to develop and agree technical solutions that maximised the potential development and value on the site, provide solutions that were mutually beneficial, and protect the heritage of the site. Continually questioning assumptions, seeking knowledge and experience in the supply chain, through precedents and through specialist consultants, was fundamental to the success of the project.

The project would not be in its current form without the knowledge of Donaldson Associates and the experiences from the construction of the Paddington Station box that Arup shared. The input of Joseph Gallagher helped to secure planning approval, Abbey Pynford facilitated the Smithy lift and Cementation fine-tuned the construction methodology of the deep bored piles and plunge columns (Figure 10). Underpinning all of this was the early involvement of the main contractor, Skanska, through a two-stage design-and-build procurement route and the continuity of the professional structural engineering team from planning through detailed design, procurement, contractor design and construction.

At the time of writing (April 2018), the project is progressing well on site (Figure 11): the plunge columns and piled foundations have been installed; the Smithy has been moved back to its original position and is supported by the temporary works steel beams; the ground-floor slab is almost complete; preparations are being made to commence the bulk dig. The next few months promise to be an interesting and exciting time.

Project team

Structural and civil engineer: Engenuiti
Client: Consolidated Developments
Architect: ORMS
Building services engineer and acoustician: BuroHappold
Project manager: GVA Second London Wall
Geotechnical engineer: Donaldson Associates (now part of COWI)
Peer review: Arup
Category III checking engineer: A2 Studio
Demolition and enabling works contractor: H Smith
Main contractor: Skanska
Piling subcontractor: Cementation
Basement and concrete subcontractor: Carey's
Steel fabricator: Severfield

REFERENCES

►1) Goldfingle G. (2010) 'In good shape', *Ground Engineering*, October, pp. 14–18

►2) Klettner A. (2010) 'Packing in the piling', *New Civil Engineer*, 4 November, pp. 22–24

►3) Crossrail (February 2008, reissued December 2016) *Information for Developers*, London: Crossrail Ltd

►4) Plaxis (2018) *Plaxis 2D* [Online] Available at: www.plaxis.com/product/plaxis-2d/ (Accessed: May 2018)

►5) BBC (2014) 'The Fifteen Billion Pound Railway. Episode 1: Urban Heart Surgery', 16 July, BBC Two

►6) Plaxis (2018) *Plaxis 3D* [Online] Available at: www.plaxis.com/product/plaxis-3d/ (Accessed: May 2018)

HAVE YOUR SAY

To comment on this article:
►email Verulam at tse@istructe.org
►tweet @IStructE #TheStructuralEngineer