Tottenham Court Road Station Upgrade: London

Hydraulic Grab on 875 Base Machine

In December 2009, BAUER Keller JV were awarded the contract to perform the foundation works at the Tottenham Court Road Station Upgrade project for London Underground. The success of the £250m project is reliant upon achieving significant feats of engineering, many of which involve some of the most technically challenging operations currently being undertaken in Europe.

BAUER's challenge commenced in March 2010 when the majority of the project team arrived on site. From the 15th floor of the Centre Point Building, we had an incredible view of London and its sights but it also brought home the difficulties that we would be facing over the coming months: very limited space on site considering the size of machinery required to build some of the most complex piles, significant traffic congestion and generally a logistical nightmare due to the one way systems in the area and ongoing enabling works for Crossrail.

The Joint Venture between Bauer Technologies and Keller allowed both parties to concentrate on their strengths with BAUER carrying out rotary piling and diaphragm wall works and Keller taking care of CFA piling and mini-piling works. The works comprised approximately 590m of retaining walls, 7nr large diameter complex rotary piles and 11nr plunge columns and was split into the following areas and techniques:

- **Northern Line Escalator Box (NLEB): Secant wall**
- **Oversite Development (OSD) piles: 7nr large diameter rotary complex piles**
- **Falconberg Court (FBC): Secant wall**
- **Goslett Yard Box (GYB): Diaphragm wall (D-wall) and 11nr plunge columns**
- **Oxford Street Entrance and Ticket Hall (OSE/TH): Secant and contiguous wall and mini piles**
- **The Decline: Secant wall (connection between Goslett Yard Box and the Ticket Hall)**

Secant Pile Walls

After months of planning, preparation and paperwork, the construction

phase commenced in April 2010, with the installation of the first secondary pile on the Northern Line Escalator Box. All secondaries consisted of 600mm CFA piles, whereas all primary piles were constructed using 1180mm segmental casing and 1050mm tools. In total, 90m of hard soft secant wall were successfully constructed on time and to budget. Three large diameter rotary OSD piles were situated on the western side within the secant wall. The OSD piles were an extremely challenging part of this project.

OSD Piles

The OSD piles consisted of 7nr complex large diameter rotary piles of varying lengths, diameters and degrees of difficulties. The largest casing diameter used was 2.43m and the largest bored diameter was 2.03m. The deepest pile was installed to a length of 64m under bentonite into the chalk. Four of the 7 OSD piles were constructed using a slip coated liner with bitumen coating, to a depth of about 30m below ground level to eliminate the load transfer between the new Northern Line Escalator Box and these piles. The remaining three piles required even greater protection, as they were installed very close to the running Northern Line tunnels.

As part of the oversite development agreement, these piles had to be permanently cased to well past the axis of the tunnels, i.e. to 35m depth. These three piles also contained the bitumen coated liners. BAUER's BG40 rig (the most powerful in the worldwide market) was used to construct the OSD piles.

BG40 Piling Rig

The drilling tool only just fitted over the permanent casing, with barely 2 inches to spare. An oscillator was used on the OSD piles adjacent to the Northern Line tunnels to assist with the installation of the permanent casing. Unlike the other OSD piles, the casings had to be pushed into the ground 1m at a time and then drilled (again just 1m at a time).

The oscillator used was BAUER's BV2000, the biggest oscillator that can be attached to a piling rig, capable of exerting 2780kNm torque (compared to 390kNm torque from the BG40). In addition to the logistical difficulties associated with the site location, one of the 3 permanently cased piles (CP05) is unique due to the proximity of the future escalator box construction. The top half of the pile is D-shaped, with the flat section of the pile aligned parallel to the box structure, whilst the bottom half is a traditional circular pile.

The design of the pile was governed by the proximity of the Northern Line Tunnel and the Escalator Box structure. The box at this location is 36m deep requiring the D-shape to extend over the same depth.

Directly beneath Charing Cross Road run the North and Southbound Northern Line London Underground tunnels. Our piling works required strictly controlled working periods, granted by concessions from London Underground. Our piling activities were just over 1m away from the tunnel wall. At critical depths of drilling, works could only be undertaken during engineering hours.

In order to comply with the strict tolerances dictated by the specification, the BAUER rope inclinometer equipment known as a 'Seil Neig' was used.

By combining:

- **large diameter rotary bored piles**
- **permanent casings installed by oscillator**
- **bitumen coating to reduce skin friction**

Specially designed D-Cage

(which are all processes that BAUER have performed in various locations around the World) these piles were without doubt special. However, combine this with a very tight site in the close vicinity of live running tunnels and working so closely to the general public, plus the fact that part of the pile is not round but D-shaped, it certainly became one of the most complicated foundations ever built. After nearly 4 months of intensive design of all temporary features such as lifting points, trapping off points and beams, centre of gravity etc., the OSD piles were constructed successfully. The successful delivery required an incredible amount of planning, foresight, understanding of each element in the process and teamwork between the owner, main contractor, designer and specialist contractor.

Following on from the OSD piles we moved on to the next phase of the works on Falconberg Court. A combination of hard soft and hard firm secant pile wall was built, totalling approximately 135m of retaining wall in this section. This work was completed in January 2011.

Diaphragm Walling

During November 2010, the installation of the D-wall commenced. With a total depth of 41m, the 1m wide 152m long retaining structure enabled installation of the Crossrail ticket hall. Geothermal loops were also installed to ensure that any future developments above ground comply with current environmental requirements.

After installation of the OSD piles and secant walls, the BAUER Keller JV at TCR faced a new challenge of constructing a 44m deep diaphragm wall box and 11nr plunged columns. The box formed a four storey basement for future escalators and lifts. The plunged columns will enable the top down construction of the box. Work on the diaphragm wall commenced in November 2011 and was completed in April 2011 Work on the plunge columns ran from June to July.

The 1m thick diaphragm wall was generally built in single bite panels of 3.2m length (apart from corners) in order to reduce ground movements in the surrounding area. BAUER's new HS875 was the base machine for a hydraulic grab, equipped with a rotator to ensure optimal performance on a limited access site and to optimize the achievable verticality tolerance. Each panel was excavated using the grab to its final depth under bentonite.

After installation of pre-cast stop ends over the entire depth of the panel, heavily reinforced cages had to be installed.

The reinforcement cages consisted mainly of 50mm bars as closely spaced as possible without restricting the concrete flow, often in double layers, which meant that the cages had to be connected on site using a combination of splices and couplers to build up a cage of the entire length of 44m.

This kind of cage requires an incredible fixing accuracy to ensure that the part cages can be connected again on site. In order to guarantee this, the skeleton of the cages were made in the steel yard in one piece, before being taken apart for transporting. Positional couplers for slab connections were also installed within the cage, making it very complex to assemble in the steel yard and then to accurately install on site. Due to limited space being available on site all cage deliveries had to be accurately scheduled for a 'just in time' delivery, just before they were required on site.

The site works operated late into the night with night-time work having to be carried out quietly (due to Section 61) and with careful co-ordination with the Local Council. Noise restrictions also applied by day.

Plunged Columns

Following the successful completion of the diaphragm wall and the demobilisation of all associated gear, BAUER's brand new BG40 was mobilized to site to install the 11nr plunged columns into large

Plunge column works

diameter 48.5m deep piles, which would facilitate the top down construction of the box, which in turn will reduce ground movements and noise emissions during the follow on construction works.

The plunged columns installed at Tottenham Court Road were by far the heaviest and longest the industry has seen for quite some time. A mixture of 600 x 600 and 700 x 700 columns up to 33m long had to be installed. The columns were fabricated by the only steel contractor who stood out as one of the few who was able to commit to manufacturing these columns to a 1 in 1000 fabrication tolerance. The size and weight of the individual column in combination with a permissible verticality tolerance of only 1 in 400 (which is inclusive of the 1 in 1000 fabrication tolerance), 10mm positional tolerance at ground level and 5mm level tolerance make the installation of these columns incredibly challenging.

In order to comply with the specification and install all the columns within the permissible tolerances, a new bespoke plunged column frame was designed and engineered. This frame is 23m long, equipped with laser guides and for the first time in UK history, bears on 'naked' soil rather than a steel casing, clamping the frame in place.

The piles were constructed in a traditional rotary bored manner, a pile cage installed and then concreted. The concrete was designed to maintain its workability for an extended period to ensure that the column could be plunged easily. Obviously, once the pile is concreted, the clock starts ticking.

Without the commitment of everyone involved, the installation of the plunge column would not be possible, as many preparatory steps have to be undertaken before the column is installed in its design position: removal of bentonite, lifting of the plunge column frame from the 'rathole' (an empty bore), installation of the frame in the pile, 'manoeuvring' the frame into the correct position and securing it there, lifting the already assembled column from another 'rathole', cleaning the column and finally plunging the column 7m into the pile. Without the construction of two 'ratholes', the installation of the columns would not have been possible, due to the limited space available on site and the time frame in which the concrete stays workable, i.e. plungeable.

From the now completed plunged column works, data collected confirms that all columns were installed well within the permissible tolerances, which turns this new frame into a confidence inspiring piece of engineering, meticulously planned for the job in hand, turning the plunging of columns into a controlled activity, reliably achieving outstandingly good tolerances.

Client:	London Underground Ltd
Main Contractor:	Vinci Bam Nuttall
Piling Contractor:	BAUER/Keller JV
Contract Period:	April 2010 to September 2011
Scope of Works:	- Secant Pile Walls 10,000m^2 - 2.4m diameter 68m deep OSD piles 7 nr - Diaphragm Walls 6,437m^2
Turnover:	£17 million
Equipment:	Diaphragm Wall Grab BG40 + BG28 Piling Rigs