

Crossrail Shaft C501 - Moorgate, London



'A real postage stamp' is how Bauer Technologies described the work at Crossrail's Moorgate shaft, the deepest shaft on Crossrail. The site, 40x35m, was tightly constrained by sensitive buildings and infrastructure. At 60m deep the shaft is a key part of London's new Crossrail Liverpool Street Station which will connect the existing Moorgate Underground station with Liverpool Street's main line and Underground Stations.

The diaphragm walls were far from straightforward with complex connections and designs to contend with as well as the logistics of getting materials onto site. A major hurdle was how to remove numerous large diameter piles in accordance with London's strict noise and vibration regulations.

Pile removal commenced in late February 2012 using a revolutionary new Annulus Cutter system developed by Bauer Technologies. Piles had to be

removed without excessive vibration or noise as the site is in a densely built up area of London City Centre and is close to sub surface underground lines. Incremental destruction of piles can be a noisy process and the limitations imposed in central London would not have allowed the 900mm piles to have been removed without causing nuisance to the surrounding neighbours. We elected to adopt a method of de-bonding the piles from their surrounding soils and later disassembling them above ground for transport off-site.

The real challenge was to find a method that could reliably remove the soil from around the piles. We considered many methods of loosening, liquefying or isolating the soils before lifting the piles from the ground and eventually settled on a novel process. The Bauer method involves first drilling a threaded bar down the full length of the pile and

grouting it into position.

A large diameter segmental casing is then installed eccentrically over the pile, using a powerful BG40 drilling rig, adapted to increase its torque capacity for casing installation by 50%. Once the casing is sealed into the London Clay stratum, an open hole of around 900mm is drilled alongside the pile and also within the segmental casing. This is termed the relief hole.

Bauer Technologies annulus cutter, is then attached to the drilling rig and lowered over the pile. Using the rig to rotate the device, the annulus cutter incrementally removes the soil from around the full periphery of the pile, with the soil cuttings falling to the bottom of the relief hole. In a series of increments, the soil is first cut from around the pile, then removed from the relief hole until the tool has passed over the full elevation of the pile.



Bauer recognised early in the development stage of the tool that completely removing the soil from around the pile would destabilise it. In order to deal with this difficulty Bauer designed an elaborate system of load bearing beams to maintain tension in the centrally grouted bar - and thus the pile during the entire soil removal process. Once the soil is removed to the toe of the pile, hydraulic jacks within the head works can be used to raise the pile slightly from the ground, to establish its known weight, before a 280t crane ultimately lifts the pile through a working platform, where it is cut apart into sections between 2m and 11m long. Scope was increased further when we were asked to develop an aggressive destructive pile removal system, to deal with the removal of

additional piles that were significantly larger in diameter than expected. Using a mixture of the two systems, Bauer removed 25 No. 34m deep piles with a maximum diameter of 1350mm, including the removal of two existing piles with permanent steel liners.

After removing the last of the existing piles Bauer installed three 2.4m diameter Over Site Development (OSD) piles to a depth of 58m. The piles were unusual in that the top 37m required a slip-coated steel liner to prevent damage to a new tunnel that will eventually thread between the piles. To ensure the tight installation tolerances could be achieved, Bauer pre-drilled the liner boreholes with a 2.8m digging bucket and used a Seilnig (Bauer rope inclinometer) to accurately locate the toe of the liner 37m down.

Diaphragm wall installation commenced in January 2013. Using the new Bauer MC64 and a 3.2m x 1.2m grab, Bauer installed D-wall panels to 53m and barrettes with king posts to 60m. The Moorgate site itself presented many challenges, as the working footprint sits in a basement that is bound on all sides by either listed buildings, sewers or London Underground running tunnels. There is restricted storage outside the basement so moving from one D-wall panel to the next required intricate planning as every piece of plant had to be moved if the position of one had to be changed.

The project was logistically very challenging, Bauer used a 3D model of the site to correctly sequence the movements of equipment and construction materials.

The reinforcement cages for the diaphragm walls had to be brought into the site at night with road closures in place from midnight to 5am two to three times a week. The larger ones had to be walked from the Old Street roundabout with someone on foot operating the rear steer on the low loader from behind.

The cages were up to 18.98m long and 2.6m wide, which may not sound too large, however four sections had to be connected to create the 53m long cages used for most of the panels on the project. The cages weighed up to 60t each and there were two basic designs of reinforcing cages with over 6000 couplings needed for the project in reality no two were the same. Bauer used the highest level of reinforcement allowed under European Standards meaning that concrete flow was a concern so a high flow C35/45 mix that would stay 'live' for 5 hours was used.

The biggest challenge was 'panel five' which was located on the north east corner of the diaphragm wall. Panel five was the largest panel on the wall and called for three bites to excavate it and three tremmies fed by three different concrete pumps to deliver the 500m³ of concrete over a period of 16 hours to form the finished panel. The panel was not only large in profile but also very deep at 60m which took it close to the Hammersmith and City Line. The proximity of other infrastructure also impacted on the approach to the work. The Northern Line Underground tunnels follow the line of Moorgate road immediately to the east of the site and the Hammersmith & City line runs along the northern boundary. Moorgate Road also contains a major brick built sewer



and to the south are some listed buildings that were underpinned ahead of the shaft work. To the west is Moorgate Tube Station. Bauer had to close Moorgate Road for several days at the end of April in order to complete the work on panel five. The road was used to store the cages and a spare concrete boom pump in case one of the others on site failed.

Innovations - In addition to the annulus cutter pile removal operation, Bauer innovated further with the diaphragm walling works. Bauer had to lift the cages together vertically as they inserted them. Three cages could be laid down on top of the covered walkway above

the entrance to Moorgate Station and Bauer also created a dummy panel in the south east part of the site where we could store two connected cages vertically in the ground. The dummy panel was an 18m long steel structure that had been inserted into a diaphragm wall panel excavation to allow up to two cages to be installed vertically. The outer face of the steel structure was covered in Visqueen with grease between the layers before it was grouted into position. The Visqueen and grease along with the collapsible mechanism within the panel meant that we were able to extract the structure at the end of the work.

Barrettes - Through the centre of the shaft were two lines of barrettes that were formed in eight sections to depths of 60m below ground level. The bottom 20m of the construction is a conventional barrette but the upper 40m was formed by king posts that were encased in a lean mix concrete that could be broken out during the excavation.

The king posts extend past the base slab to be used to support a platform for the crane that main contractor BNK would then use to carry out the bulk dig of the shaft. The normal method of constructing a barrette with a king post would be to plunge the column through the concrete, however with a 40m long king post this approach would not give us enough control. Therefore it was decided to put the column in as part of the cage but this was not a simple solution. The king post columns were split into three sections so Bauer developed a new system to trap off the column while the next section of the king post was bolted in place.

Although the column sections were lighter than the barrette cages at 15t compared to 21t, there were less points to connect to for lifting so it made the columns difficult to handle. Bauer also



had to use 128 bolts to connect each section of the column before lowering the next section. The king post columns are 356mm by 406mm by 340mm UC sections and weigh in at 340kg/m. To ensure concrete flowed evenly around the column during construction, Bauer used two tremmie pipes, one on either side, which were fitted into temporary steel guides bolted onto the king posts.

Dealing with difficult ground conditions

The geology has also made the work complicated as once Bauer got 51m below ground level, they were digging into the Thanet Sands which are very dense and difficult to excavate. Bauer had to adapt the grab to excavate the sand and also deal with issues related to desanding the bentonite after excavating these panels.

Client:

Crossrail

Principal Contractor:

Bam Nuttall/Kier JV

Piling Contractor:

BAUER Technologies Limited

Contract Period:

February 2012 - August 2013

Bauer's Scope of Works:

- 3No 2.4m diameter, 60m deep, slip coated piles to support future over site development
- Construction of a 6165m² diaphragm wall to a depth of 53m
- Construction of 8 barrettes to a depth of 60m
- Construction of 1714m² of D-wall strutting walls to a depth of 42m
- Geothermal loops installed within the diaphragm wall panels
- Works all undertaken within extremely tight working spaces