Stabilising Soho

Compensation grouting works on Crossrail’s Tottenham Court Road and Bond Street stations
Compensation grouting for the construction of Crossrail’s Bond Street and Tottenham Court Road stations is due to finish in May, marking the end of a logistically-complex and technically challenging three-and-a-half year project to protect buildings above and around the route. Max Soudain, a technical writer for the joint venture, and former engineering geologist reports

**The job in numbers**

- **Contract value**: GBP 40M (USD 63M)
- **Number of grout shafts**: 13
- **Total length of tubes-a-manchette**: 50km
- **Maximum TAM length**: 90m
- **Treatment area**: 63,500m²
- **Total volume of grout injected**: 3.5M litres.
VIEWERS OF the first episode of the BBC’s 2014 documentary on Crossrail, The Fifteen Billion Pound Railway, may recall the sight of GBP 1M of vintage Rolls Royces, Aston Martins and other classic cars being squeezed past (and in fact over) a grout shaft to reach the auction rooms of Bonhams in New Bond Street.

For the team using the shaft tucked behind the Bonhams’ building, access is a daily challenge, however.

All plant, equipment and materials needed to carry out compensation grouting works for this section of Crossrail have to be brought in through a narrow arch to the shaft site, and stacked above, in a vertical compound built on scaffolding platforms.

This is just one of 13 shafts being used by KBR (a joint venture of geotechnical contractors Keller and BAM Ritchies) to protect buildings above and around the new Bond Street and Tottenham Court Road stations on this 2km stretch of the route. Almost every shaft is down a narrow alley, hidden behind a façade or up against a building, in one of the most prestigious postcodes in London.

“Logistics have certainly been a significant challenge,” confirms KBR Contract Manager David Bradley. “We have some very close neighbours and highly sensitive buildings, so we have had to take a collaborative approach, managing stakeholder relationships very carefully, and keeping a close eye on the details.”

CONTRACT

KBR was awarded the GBP 40M settlement mitigation contract in January 2011 by main contractor BFK, itself a joint venture of BAM Nuttall, Ferrovial and Kier. KBR covers two of BFK’s Crossrail packages: C100, the Western Running Tunnels, and C410, Bond Street and Tottenham Court Road Stations.

KBR’s remit is to protect buildings from damage through ground movements caused by the excavation of the station boxes and the tunnels and to enable safe construction of the underground structures.

The running tunnels are built using Herrenknecht TBMs. The larger diameter platform tunnels were formed by the TBM tunnel, which was then enlarged using conventional excavators and sprayed concrete lining (SCL). SCL is also being used for the cross passages and links to the nearby London Underground stations.

Most of KBR’s work involves compensation grouting (although it has also carried out some permeation grouting – see box).

To achieve complete coverage, grout injections are carried out using an array of tube-a-manchette (TAM) pipes radiating out from the approximately 25m deep, 4.5m diameter shafts dotted around the area. TAMs, drilled at a depth of around 13m, are between 5m and 92m long.

Along with the five shafts at Bond Street, there are seven at Tottenham Court Road and one at the Fisher Street ventilation shaft near Holborn Station, just to the west of this section.

“The shaft locations were decided before we finalised the treatment design,” Bradley says. “This meant that some of the areas requiring treatment were some distance from the shafts and a few of the TAMs are longer than usual.”
GETTING STARTED
Drilling of the 50km of TAMS started in November 2011. By February 2012, KBR had begun pretreating the ground to raise ground levels by 5mm and to compensate for settlement caused by installing the TAMS. Drilling continued until April 2013, with pretreatment complete that June.

"Most of our work involves "concurrent" grouting over the tunnels as they are excavated, with typically one grout pass carried out for every 2m tunnel advance," Bradley says.

"The aim is to inject grout to lift the ground in front of the tunnel face, let it settle slightly as the excavation passes and then inject to lift it back up again. Pretreatment is crucial as it "activates" the ground, making it immediately responsive to subsequent grout injections."

While the overall volume loss of the tunnelling, and therefore the settlement, is minimised by using TBMs in the running tunnels and the platform tunnels, there is still a need for compensation grouting, Bradley adds.

"It is best to control all the movements within the station..."
footprint [with grouting] because it minimises the number of cycles of lifting and settlement of the buildings above, reducing the risk of damage.

**GROUTING DOMAIN**

Grouting is concentrated in a 2m thick layer of London Clay, about 2m beneath its boundary with the River Terrace Gravels and 4.5m above the tunnel crown. Grout injections are carried out in advance of, rather than directly above, the tunnel face to prevent instability and, in the case of the SCL tunnels, to stop additional stress being placed on the fresh concrete, Bradley says.

Grouting operations are 24/7 and to date, KBR has carried out more than 1,300 passes. Before each shift, a review meeting is held to check the planned grout injections for that shift and to examine ground and building movements, which are being monitored continually through a network of sensors and surveying equipment.

Monitoring is being carried out by a joint venture of Getec and ITMSOil.

Grout designs are sent to the grouting modules on site, specifying volumes, pressures and injection points. The TAMS have rubber sleeved ports every 0.5m to allow grout to flow into the surrounding ground, with injections performed via a packer which is pushed to a predetermined distance along the TAM by hand and inflated.

The packer seals off the rest of the TAM and grout can then be injected precisely where it is needed.

About 40 to 100 litres of the 2N to 3N cement bentonite grout is used for each injection, pumped at between 25 and 40bar. Larger volumes, of up to 150 litres, have been pumped where a steep settlement profile is expected (typically located directly above the tunnel) or where the ground is less responsive. Engineers are on hand throughout grouting to ensure the ground reacts as predicted and can adjust injection schedules if need be.

“We have injected about 3.5M litres of grout over the three years of the project, which sounds a lot but it should be remembered this is for 2km of tunnels. In fact, this is a precision project. With a wide range of buildings, foundation types and underground structures, it is about injecting the correct volume of grout, in the correct place, at the correct time,” Bradley says.

“The key is not to use high volumes of grout in every injection but to use multiple passes and lower volumes to move buildings slowly and evenly. What we are trying to avoid is differential movement, which causes the most damage.”

This is particularly important when dealing with a number of sensitive structures along the route, including the House of St Barnabas in Soho Square. This beautiful Grade 1 listed house has ornate cornicing and plasterwork, which could be damaged by excessive and rapid movements.

As well as historic structures, KBR had to cope with ground movements caused by new buildings.

Part of the reason for the very restricted position of the shaft next to Bonhams was the fact that the auction house built a new GBP 30M extension to its headquarters (with a basement), just 500mm away from the shaft wall – during grouting works.

“It was certainly a challenge to keep settlement within limits during this time,” Bradley says. “Bonhams’ work involved demolition, basement excavation and then construction, which obviously involved unloading and reloading of the ground. There has also been additional grouting to ensure the new building is not exposed to detrimental movements.”
This grouting, or ‘jacking’, mitigates medium to long term settlement and is carried out for up to 12 weeks after the tunnel has passed, based upon on-going monitoring of ground and building movement.

**CONSIDERATION GROUTING**

While grouting is carried out at any time of day or night, all work is undertaken with due consideration to the neighbours.

“We are working closely with the local community to notify residents and businesses when grouting work is happening. With up to 90 operatives and engineers on site at any one time, things can get noisy,” Bradley says.

“We make every effort to minimise disturbance. If it is possible, we will do it. Plant and vehicles are not operated at night, deliveries are restricted to the day and all equipment is super-silenced and housed in soundproofed timber sheds or containers.

“Mayfair and Soho have some of the most valuable properties and exclusive businesses in the world – the last thing they want is construction sites right outside their front door.

Fortunately, everyone is aware of Crossrail’s long term benefits and understands that we need to work together to get the job done.”

Any inconvenience experienced by the local community, due to grouting works at any rate, will soon be over, with tunnels at Tottenham Court Road finished and approximately 90 per cent complete at Bond Street as Tunnelling and Tunneling goes to press.

Grouting at Bond Street was finished in this year, with KBR continuing to monitor movements up until July. By then, the shafts are due to have been backfilled and covered over, leaving little evidence of the past three years’ activities.

**FINAL THOUGHTS**

For the KBR team, there will be an immense sense of satisfaction on leaving site. “While the project has been technically challenging, and logistically highly complex; good planning, monitoring and having the right procedures in place meant we were prepared for any eventuality,” Bradley says.

“We have done a fantastic job here. We have not delayed tunnelling at any point and have controlled the settlement of some very sensitive buildings. That is something we are very proud of and the client is extremely pleased about.”

**Permeation grouting**

While compensation grouting was underway, KBR was called in by BFK to help construction of a ventilation tunnel which was due to pass close to the London Clay/River Terrace Gravel interface.

“BFK were concerned that if the boundary was breached, it could cause water and material to enter the excavation, which would endanger the tunnellers and the tunnel construction. With work due to start in a matter of weeks, we had to react quickly,” says KBR contract manager David Bradley.

“After ruling out a number of options, we decided that permeation grouting of the gravels to create an impermeable barrier above the tunnel was the most appropriate solution.”

To ensure the solution was viable, KBR developed a 3D BIM model of the shaft, the tunnel section and the grout injection boreholes. The theoretical grout spreads were then added, to demonstrate the ground would be fully treated.

“The grout shafts were partly backfilled to bring the base high enough to allow injection boreholes to be drilled at a shallow angle from above the water table,” Bradley explains. “We had to be very precise when drilling to ensure the bores were in the correct place – there was no room for error.” Drilling and grouting took 10 weeks.

“The target permeabilities were challenging but permeability testing after we had finished showed treatment was successful. To be absolutely sure, the tunnelling team drove a controlled bore up through the tunnel crown and into the treated area. The water return was absolutely minimal and gave extra confidence that tunnelling could safely continue,” Bradley says.

**Right: Aerial view of one of the 13 shafts required for grouting this 2km section of Crossrail**