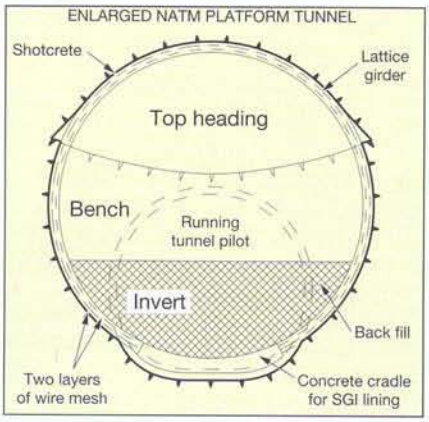
London Bridge Station

Contract 104

Station work at London Bridge by Costain/Taylor Woodrow involves excavation and construction of the new JLE station complex as well as a new south bound platform tunnel to ease congestion on the existing Northern Line station.

Access to the underground works started in early 1994 with the excavation of the 11.35 m i.d. x 33 m deep temporary access shaft at the main Redcross Way construction site. After sinking the top 10 m of the shaft as a caisson through the upper water bearing strata, it was taken to full depth through the London Clay using NATM. NATM was then to continue for all the underground works except for the two step plate junctions around the existing running tunnels at each end of the new south bound station platform tunnel for the Northern Line which were always intended to be excavated using traditional hand-mining and SGI lining methods.

When the Heathrow collapse stopped NATM work on JLE in October 1994, a great deal had been accomplished using the method at London Bridge. All the large development works at the bottom of the main access shaft, and some 300 m of running tunnel work had been completed and 25% of the 115 m-long platform Northern Line platform tunnel had been excavated using a full face, top heading, bench and invert sequence. The vertical side wall drift method had also been used for excavation of the start of the step plate junction at the south end of the Northern Line tunnel and for the larger diameter chambers at the bottom of the working shaft.



Pilot redesign to avoid the vertical walls of the side drift method on Contract 104.

With NATM comprising most of the work at London Bridge, many of the changes imposed at London Bridge are required not only to meet revised design specifications but also to mitigate the anticipated delays waiting for HSE clearances.

In addition to ordering a hand mining shield for possible traditional excavation of the station platform tunnels and ordering large quantities of SGI segmental linings, Costain/Taylor Woodrow was forced also to immediately convert the station platform works on the Northern Line to hand mining methods to keep this time-critical part of the contract in progress. Hand work picked up with construction of a 3.66 m diameter SGI-lined pilot through the remaining station platform tunnel area which is now being enlarged to the 6.5 m i.d. platform tunnel size.

NATM restarted at London Bridge with the advance of the 5.3 m diameter shotcrete-lined running tunnels under the revised design criteria and the continuation of these through the station platform areas as pilots. The NATM running tunnels at London Bridge will be lined with *in-situ* concrete but time does not allow for an *in-situ* lining for the larger platform or concourse tunnels, given that the platform tunnels must be fully lined

MBT CONTRIBUTION TO JLE

MBT International, part of the Master Builders Technologies conglomerate, has taken a clean sweep on shotcreting technologies required on JLE. Despite fierce competition from various Continental and local suppliers, MBT is supplying the shotcreting machines and the various shotcreting additives to both Costain/Taylor Woodrow on London Bridge (Contract 104) and to Balfour Beatty/Amec on Waterloo (Contract 102).

The shotcreting equipment on both contracts is based on MBT's Meyco Suprema wet shotcreting pumps which include an accurate, pre-programmable dosing unit to feed liquid accelerator into the mix at the nozzle. Balfour Beatty/Amec, which started its NATM work at Waterloo using wet mix shotcrete, geared up in March 1994 with four Suprema machines and hand-held nozzle operation. Costain/Taylor Woodrow started NATM work at London Bridge in January 1994 using dry mix and a variety of dry mix machines. In July 1995 it switched to wet mix shotcreting using three Meyco Supremas. Subsequently, Costain/Taylor Woodrow has purchased two Meyco Robojet 041 remote-controlled shotcreting nozzle booms and has mounted these on two Boart tracked carriers. These Meyco Robojet nozzle booms have an extended reach of up to about 12 m high and, in addition to taking the nozzle operator out from underneath the shotcrete rebound area, the Robojets allow for better nozzle control to ensure a more accurate, uniform application of shotcrete layers.

Admixtures supplied by MBT start with its Delvocrete Stabiliser, a hydration control admixture which will suspend the cement curing reaction and extend the life of the wet mix shotcrete for up to four hours or more, depending on the dose. To this Balfour Beatty/Amec is adding Rheobuild 3520 which is a liquid thixotrope and pumping agent which is added at the batching plant, and is introducing the liquid Delvocrete S-51 sodium aluminate accelerator at the nozzle to achieve the early strength specifications of the shotcrete.

On Contract 104, Costain/Taylor Woodrow chose to use the powerful Rheobuild 2000 PF water reducing liquid additive at the batching plant with the Delvocrete S-51 sodium aluminate liquid accelerator at the nozzle to benefit from the higher earlier strengths this combination offers while retaining correct pumpability characteristics. Test and quality control panels produced with this shotcrete mix have recorded early strength laboratory readings of 25 N/mm² after 24 h. This complies with JLE's 28-day compressive strength specification in just one day.

"Representatives on both contracts have said they are very pleased with the wet mix results," said Mr Martin Annett, senior manager, MBT International. "The Meyco pumps are operating at outputs of between 8-12 m³/h and rebound on Contract 104 is reduced, it is reported, from 30%+ with the dry mix to between 5-10% with the wet mix. This is expected to reduce further to 3-5% when using the Meyco Robojet nozzle booms. These benefits not only increase productivity and safety in application, but also contribute to significantly to reduced operating costs," said Mr Annett.

In the thorough review of JLE's NATM work following the collapse at Heathrow, no cracks or signs of shotcrete deficiencies were recorded in the existing shotcrete support shells at Waterloo or London Bridge. In fact, shotcrete which had been standing at Waterloo for many months before the HSE review, is now testing to compressive strengths of 50 N/mm² after 1 year. "The actual performance of the shotcrete mix specification remains unchanged in the NATM revisions," said Mr Annett. "But the HSE revisions demand an increased thickness of shotcrete and more wire mesh and lattice girder reinforcement to meet the extra loads now required to be considered in the design. Despite the consequences of the Heathrow collapse, wet shotcrete as a support element will continue to be used in the UK and there are already applications here where shotcrete is being accepted as both the initial and permanent final lining of underground structures. The design and structural advantages of the technique cannot be denied."

Above left: SGI lining erected within the shotcrete shell from off the travelling gantry.

Above right: Enlargement of the pilot to station platform tunnel size.

Right: Traditional SGI lined hand mining in the Northern Line platform tunnel.

with their final lining before enlargement of the adjacent concourse tunnel can begin. To mitigate against the potential delay, Costain/Taylor Woodrow, as part of its agreed recovery programme with JLE, is erecting an SGI segmental lining inside the NATM shotcrete shells of the enlarged platform and concourse tunnels and grouting up the 100 mm annular gap.

This combination of shotcrete and SGI segments placed the running tunnel pilot in the invert of the large tunnel cross section and led to the inclusion of a concrete slab, some 500 mm thick, in the invert, to form a cradle on which the final SGI lining is erected. The shotcrete and immediate support elements of the enlargement are keyed into either side of the slab which, being cast as part of the pilot excavation sequence, avoids the need to rework the vulnerable invert area during the enlargement works.

Enlargement of the pilots follows a similar sequence to the smaller running tunnel excavation, comprising a top heading, bench and invert on 1 m rounds and demolition of the pilot above the slab. The pilot tunnels, which are built to the same design specification as the running tunnels, are required to stand for about 6 months before the ITC Schaeff excavator and ATM 70 roadheader employed by Costain/ Taylor Woodrow use all their power to breakout the strong shotcrete walls which are reinforced with a layer of wire mesh and a lattice girder on maximum 1 m centres.

The SGI lining is being erected from a travelling gantry which progresses concurrently some metres behind the advancing enlargement works. The temporary roadway backfill is excavated in 5 m-wide sections to expose the concrete cradle slab and a bridge structure in the gantry spans the ring-building work area to allow the muck hauling vehicles to pass from the advancing enlargement works back to the muck bunker at the bottom of the Redcross Way access shaft.

Excavated material from all underground areas in London Bridge as well as from the JLE Contract 103 shield drive running tunnels to Waterloo, which are being advancing under subcontract from London Bridge (see page 17), is lifted through the Redcross Way shaft. At peak, some 3,000 m^3 of material

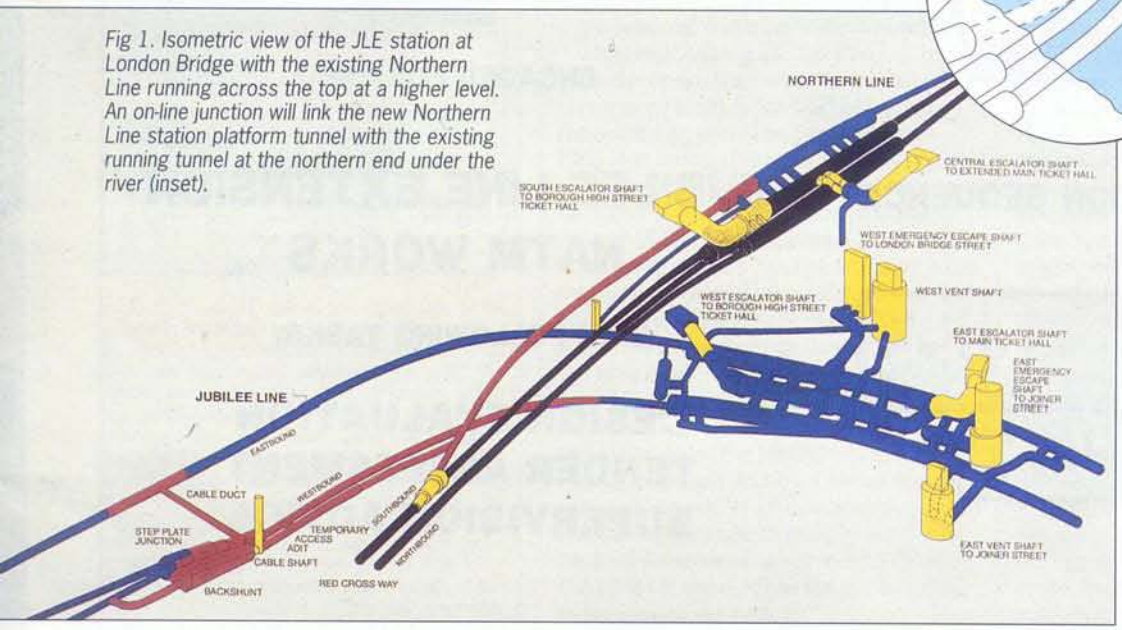


Fig 1. Isometric view of the JLE station at London Bridge with the existing Northern Line running across the top at a higher level. An on-line junction will link the new Northern Line station platform tunnel with the existing running tunnel at the northern end under the river (inset).

(unbulked) is lifted out of this shaft per week in the 18 m^3 shaft hopper. It is then stockpiled on the site for later transport by truck away for disposal.

NORTHERN LINE JUNCTION

One of the trickiest operations yet to be tackled on the contract is the north end step plate junction of the new south bound station platform tunnel for the Northern Line. This junction lies directly under the Thames about 20 m from the foundations of the adjacent London Bridge crossing and under a limited 5 m clay cover which has been disturbed over the years by old piling operations and perhaps the existence of old timber piers of earlier London Bridge structures.

"Originally, this junction was planned as a large hand-mined, SGI-lined excavation stepping down from a maximum diameter of 10 m to 5.75 m around the existing running tunnel," explained Mr Bob Ibell, project manager for Costain/Taylor Woodrow. "It was to be excavated under compressed air and without interrupting on-going Northern Line services. However, we recognised that we could take no chances with this challenging task and following further investigation, JLE has decided instead to suspend services in the southbound route of the Northern Line and we will execute an on-line junction. To start, the existing running

Covered excavation of the ticket hall beneath Borough High Street.

tunnel through the junction area will be filled with a foam concrete mix between two bulkheads. This will support the rings of the existing tunnel as they are encircled by the new works and will protect the railway against the possibility of any inrush from the waterbearing Thames Gravels above," said Mr Ibell.

The north junction work is programmed to start in the summer of 1996 and is expected to take four months to complete. Once completed, the Northern Line southbound trains will be diverted to the new platform tunnel via the new step plate junction and the existing platform tunnel will become a central concourse.

SURFACE WORKS

In addition to the labyrinth of underground works, Contract 104 involves extensive cut-and-cover surface works and many shafts of various diameters for ventilation and emergency escape as well as several inclined shafts of up to 10 m diameter for new escalator wells. All this work is going on either near or directly underneath the arched foundations of the London Bridge railway station which is believed to be one of the largest brick-built structures in the world. The shafts have been sunk by underpinning through treated zones of the upper waterbearing strata and some taken to depth through London Clay using NATM.

Walls of contiguous piles supported a covered excavation operation to build a new subsurface ticket hall beneath Borough High Street and extensive arrays of compensation grouting, as well as flat jack supports, have provided the protection required to control and limit surface settlement beneath the many sensitive buildings in the area (see page 11).

As this maze of heavy civil engineering work continues beneath and around them, the throngs of people who pass through this busy city terminal each day are guided and protected through the works by temporary walkways, hoardings and canopies erected as part of a concentrated effort to minimise disruption and guarantee public safety throughout the contract period.