HEATHROW EXPRESS NATM TRIAL TUNNEL

At a total cost of about £235 million, London is to have a new high speed rail link between Paddington terminal in central London and the capital's principal international airport at Heathrow. Under the scheme, dedicated rolling stock will provide a 16-minute non-stop rail service between central London and the passenger terminals at Heathrow, cutting the present journey time by public transport by nearly three quarters.

Promoted by BAA plc, the owner and operator of Heathrow Airport, the 25km route follows the main Paddington/South Wales line out of London before turning south into 5.5km of twin tunnels running under the M4 motorway and on to an underground station serving Terminals 1, 2 and 3 of Heathrow's Central Terminal Area. From here, a 2km long single tunnel, accommodating services in both directions, will continue to an underground terminus station beneath Terminal 4. Provision is made for a further underground station at the proposed Terminal 5. If built, the single line section will be doubled to a dedicated running tunnel in both directions.

STATIONS

Given the necessary size of the underground stations, both for ventilation requirements and to accommodate expected passenger volumes, it became obvious that providing such spaces by cut-and-cover in the middle of the world's busiest airport could cause unacceptable disruption. From the project's earliest development stages, it was evident therefore that the stations would have to be constructed in bored tunnel.

As is usually the case, the layout of the underground stations is a complex network of passageways and shafts defined principally by the access points from the terminals. At Heathrow's central area, for example, this has resulted in a long central concourse tunnel, a large number of cross passages connections, two escalator tunnels, two lift shaft areas and a significant volume of tunnelling for the necessary ventilation. Although less complex in its access requirements, the Terminal 4 station also demands a significant number of underground areas. Perhaps more importantly, both stations include a number of relatively large span openings.

Tunnelling for the stations will be in London Clay, a homogeneous, relatively impermeable over-consolidated blue clay which has proved to be highly suitable for underground excavation. It is primarily London Clay which allowed early and extensive development of London's underground system.

Two side headings in the Type 1 excavation sequence at the Heathrow trial tunnel.

At Heathrow, the 8km of 5.6m internal diameter running tunnels are expected to be excavated using traditional open faced tunnelling shields with rings of expanded precast concrete segments providing the permanent lining.

Initial planning for the stations was also based on the use of traditional segmental lining methods. However, the special demands of a modern rail system like the Heathrow Express mean that they would be time consuming and expensive to build with the modular approach required by segments. Building a segmental lining has been compared with running a mobile factory. The system is ideal for long tunnels of constant cross-section. The drawback is that if changes are made to the excavation sequence, production rates fall. The complex shapes and wide openings required in the Heathrow Express stations do not suit the relatively inflexible modular segment system.

Breakout of the NATM trial tunnel at the bottom of the precast concrete shaft.

NATM

The stations and step plate junctions are therefore to be excavated using the NATM. This tunnelling method has been used for the design and construction of many underground stations on metro systems particularly in Europe and more recently in the USA and Far East.

NATM is a special form of the observational tunnelling method where the ground support is modified to suit the observed movements of the

Excavation of the first sidewall drift of the Type 2 sequence.

ground. The basic difference between traditional methods and the NATM is the use of shotcrete instead of precast concrete or cast iron segments as the initial ground support. As such NATM provides several advantages over traditional methods. Perhaps the most important is immediate and consistent support of the freshly excavated ground.

In addition the system has greater flexibility to accommodate non-circular tunnels. Also, because of the longitudinal stiffness of the permanent lining, NATM will support wider openings than can generally be achieved with segments. Other associated advantages can include:

- shorter cycle times
- flexibility to set cycle advance lengths and the excavation sequence to suit the prevailing ground conditions
- rapid mobilisation using standard excavation equipment
- lower capital cost of essential equipment
- elimination of shield erection and dismantling chambers

In July 1989, Mott MacDonald was appointed lead designer for the project. In October 1989, Taylor Woodrow was engaged as BAA's Construction Manager. In view of the potential savings of the methods Taylor Woodrow invited Dr Gerhard Sauer of Austria, to examine the suitability of NATM for the underground stations at Heathrow.

A feasibility study and cost estimate for the NATM design and excavation of the Heathrow Express stations identified substantial time and cost savings over traditional methods. As a result, BAA chose the NATM for the construction of the Heathrow Express stations and the Dr G Sauer Company was retained by Mott MacDonald as specialist NATM sub-consultant.

As with any tunnelling scheme in an urban environment, one of the primary concerns at Heathrow is potential ground movement. Many of the tunnels comprising the two stations are under airport terminals, car parks or other sensitive structures. At one point the three main tunnels for the central area station pass under the London Underground Piccadilly Line. There was considerable concern about the amount of settlement likely to result from the construction of the stations when using the NATM in London Clay. The overburden between the station and the surface is typically about 18m.

Although NATM has a 15 year track record of tunnelling in soft ground, particularly in southern Germany and Japan, its use in the UK had been extremely limited. To date the only significant'soft ground' tunnels using the method in the UK are the Castle Hill section of the Channel Tunnel in 1988, and the Roundhill Tunnel on the A20 in 1991, but most of this ground was substantially stiffer than London Clay.

Back analysis of data from previous NATM projects in soft ground together with extensive finite element analysis suggested that acceptable settlements could be achieved. But, in view of the sensitivity of this application, it was decided to carry out a trial of the method in the London Clay to provide confidence in the settlements predicted by analysis.

OBJECTIVES

The location for the trial was chosen on the south side of the airport where a shaft is required for ventilation and emergency escape on the main tunnel drive. The trial is being driven from this shaft along the line of the main tunnel but at the size of a station platform tunnel, about 9m wide x 8m high.

A secondary, but by no means unimportant objective of the trial, is to confirm the viability and therefore the economics of the construction method as used in soft ground, thereby allowing the contractors tendering for the main stations to price the work realistically despite the lack of experience in London Clay.

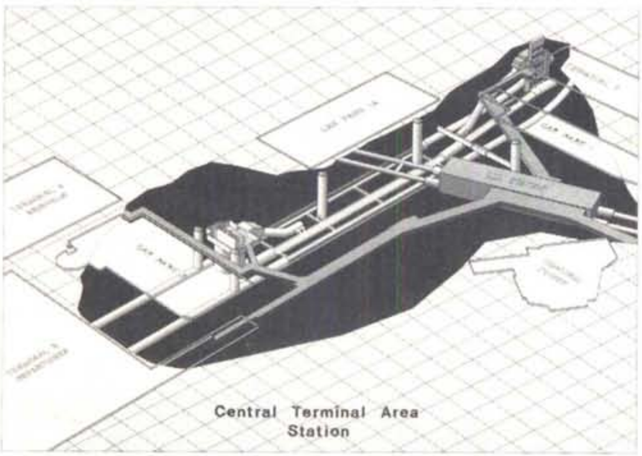
The trial tunnel therefore was specifically designed to:

- demonstrate that NATM excavation of the stations can be undertaken without causing ground movements that could lead to structural damage to ground level buildings and other underground installations.
- enable tenderers for the NATM station works to inspect an exposed face of London Clay.
- provide information to designers and tenderers about the properties and behaviour of London Clay when excavated.
- observe ground movements above and around the trial tunnel.
- use data gathered from the trial tunnel to predict ground movement in the main station areas.
- establish works procedures that reduce ground movements for application in critical areas of the main station works.

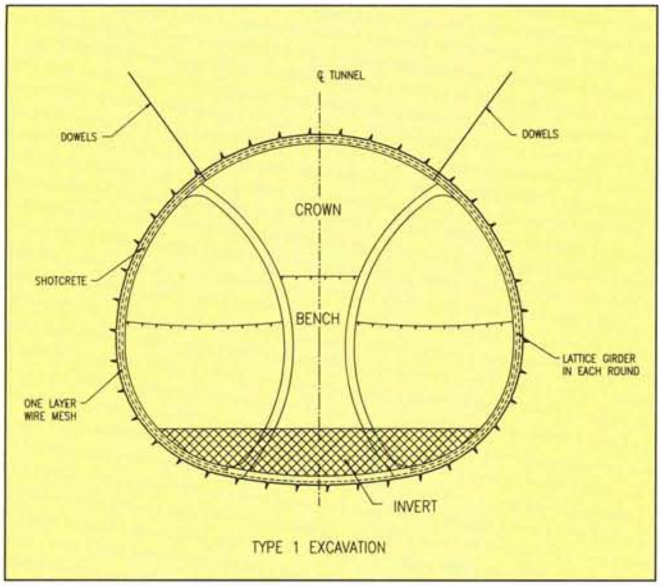
By its very nature, NATM allows a large number of construction sequences for any particular tunnel. The object of the trial is to establish the range of settlements that might be expected using various excavation sequences. It was therefore decided to drive 100m of trial tunnel and test three different sequences each over a length of at least 30m. Like the project's actual stations, the trial tunnel is being constructed at about 20m below ground level. A length of 30m for each station is required to ensure that the surface movements due to one section have only a small effect on the adjacent trial lengths.

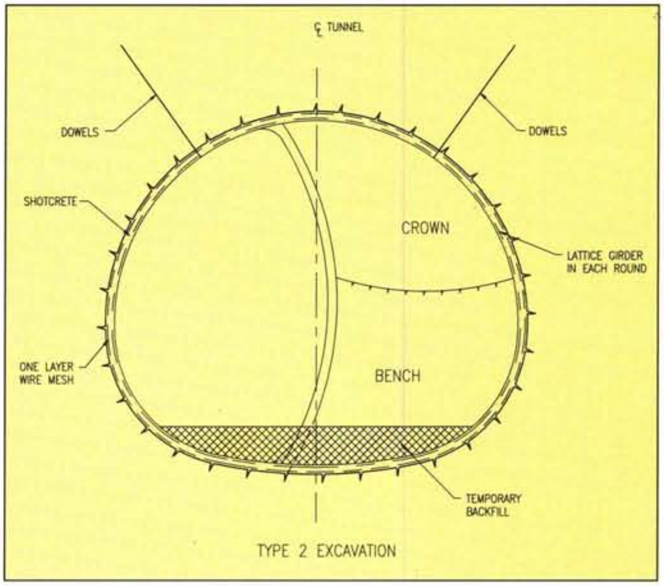
With this limited number of variations, it was decided to maintain the same construction specifications for shotcrete thickness, mesh and lattice girder spacing throughout the trial tunnel and change only the excavation sequence. Analysis of previous tunnels has shown that the sequence, and particularly the time at which the shotcrete ring is completed, is one of the main influences on settlement above the excavation.

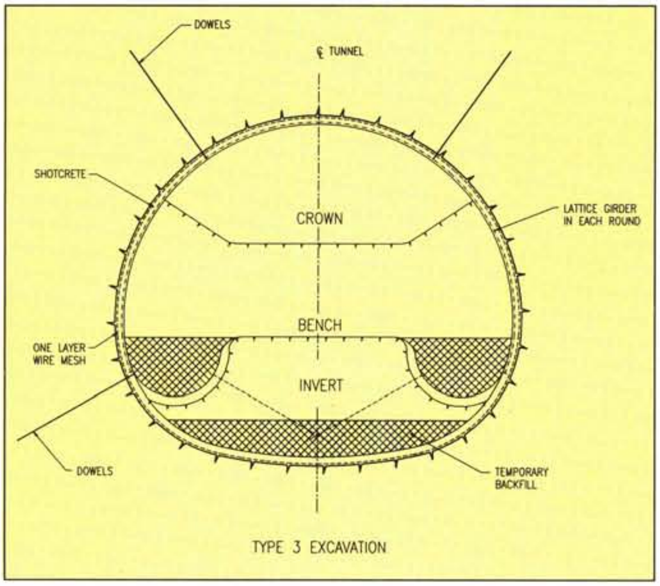
Three different sequences were chosen therefore, to represent the range that might be



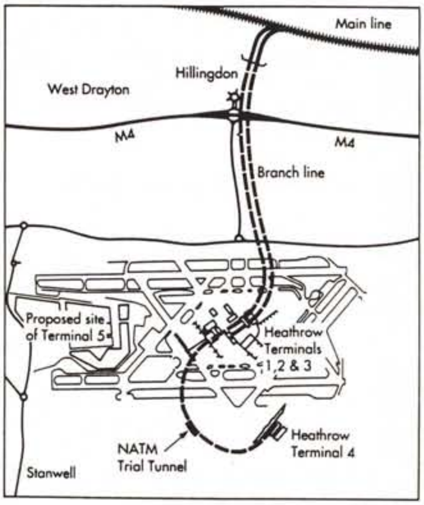
Artists impression of the layout of the central termimal area station, Heathrow.







Above left & right – Type 1 and 2 excavations. Left– Type 3 excavations. Below– Plan of the Heathrow-Paddington express rail link route.



used in the Heathrow Express station works. The first and most conservative consists of two side headings followed at some distance by removal of the central core. The second is to excavate one side of the tunnel and then enlarge it to full size. The third is a top heading and bench sequence with the base of the heading supported on inverted concrete arches into the bench to limit the settlement caused by the walls of the heading pushing into the bench. Within each of these sequences, the individual rings of shotcrete are closed as quickly as possible. This, together with limiting each round to 1m cycles and a relatively thick 250mm shell of shotcrete, is designed to limit settlement.

TRIAL CONTRACT

The trial tunnel proposal was adopted by BAA and in January 1992, the Kier/Lilley/Kunz joint venture was awarded the trial contract with a tender price of about £1.2 million. Work on site started in February 1992 and is expected to be completed by June.

The 10.65m internal diameter x 25m deep access shaft was sunk using conventional caisson and under-pinning methods and is lined with bolted precast concrete segments. At the bottom, each of two tunnel eyes were constructed using shot-crete. The trial tunnel is driven out of one eye and the second will be used to start the running tunnel drive to the Central Terminal area. Excavation of the trial tunnel starts with Type 1, the sequence designed to provide the greatest degree of control over ground movement and settlement.

The ability of NATM to control settlement and residual ground movement is monitored by a series of in-situ measuring devices which are logged at frequent and regular intervals. Interpretation of the collected data warns of potential problems and provides information upon which modification of the excavation and support sequence can be made.

The tunnel is monitored by a significant amount of instrumentation. As well as conventional convergence measurements within the tunnel, shotcrete and soil stress cells are installed in each construction sequence together with a number of load cells on special dowels. These instruments are being monitored by a team from Mott MacDonald/Sauer to provide a record of the behaviour of the tunnel as it is constructed.

A second and equally significant array of instrumentation has been installed from ground level. TRRL are monitoring a large number of settlement pins, as well as extensometers, inclinometers, stress cells and piezometers which they have installed in boreholes adjacent to the line of the tunnel. Measurement of ground movement both at the surface and near the tunnel will allow analytical models to be produced to assist in the prediction of settlement above the main station complexes.

The Kier/Lilley/Kunz joint venture is using a Liebherr 902 excavator for tunnel advance. Once transported to the shaft by Volvo loader, muck is lifted to the surface in a 2 m skip.

Work is progressing 24 h/day, 7 days/week. This is necessary since the ability of the NATM concept to control excessive ground movement depends largely on a continuous working cycle which avoids long delays between the various operations. Supervision is carried out by Taylor Woodrow with design support on site from Mott MacDonald and Dr Sauer Company.

When complete the tunnel will provide an important database of information for a technique which is likely to be used in a number of the tunnelling projects proposed for London over the next few years.

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