Liverpool Central Tunnel High-Level Neck Repairs

By Andy Dunlop and David Thomas

Liverpool's High-Level Neck tunnel (HLN) cannot lay claim to being the city's most famous cavern, but it can justifiably be labeled as being one of the most unusual and challenging tunnels on the entire UK rail network.

To start with, there is just the sheer scale of the structure. Not in length. There are many more that can out-do HLN in yardage terms. However, there are few that can challenge it on its soaring 49 ft (15 m) height from track level to tunnel crown (Fig. 1).

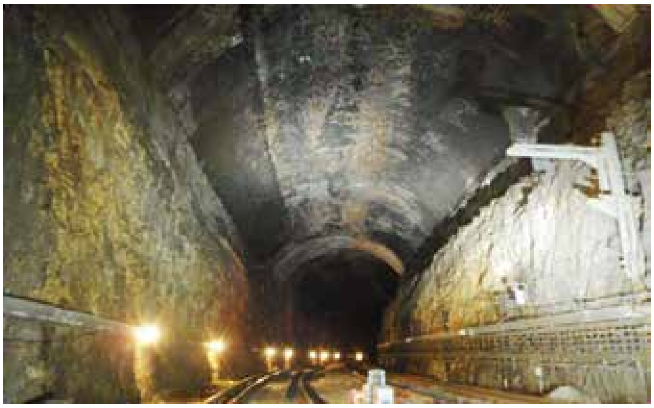

Fig. 1: Not your typical tunnel!

This extraordinary height is a quirk of the tunnel's long history and change in use over the years. Originally opened in 1892 as a tunnel of "normal" proportions serving Liverpool Central station, the structure became redundant in 1966 when Beeching closed the overland station. The Beeching cuts were a reduction of route network and restructuring of the railways in Great Britain, according to a plan outlined in two reports—*The Reshaping of British Railways* (1963) and *The Development of the Major Railway Trunk Routes* (1965), written by Dr. Richard Beeching.

The tunnel was given a new lease of life with the arrival of the Merseyrail network, and this is the stage in its life where HLN evolved into the cavern that it is today.

The invert of the tunnel was lowered to connect with low-level platforms at the new Merseyrail Central Station.

While spectacular to the casual observer, the height of HLN means access is extremely difficult and maintenance and repair of the structure without causing massive disruption to network operations is an ongoing headache. In short, it is a structure that no Asset Manager would choose to have on their patch.

Previous repairs in 2010, involving brickwork repairs and fiber-reinforced dry-mix shotcrete, had been carried

BACKGROUND

- 820 ft (250 m) long tunnel dating back to the late 1800s.
- The tunnel is unusually proportioned—being 33 ft (10 m) wide and 49 ft (15 m) high—possibly the tallest on the UK network.
- A key piece of infrastructure on the Merseyrail network, one of the most heavily used UK railway networks outside London.
- Historically, maintenance and renewal interventions have been extremely difficult and inefficient.
- Inspections showed that the tunnel brickwork lining had severely deteriorated.
- There was a significant risk of failure of the brickwork that would result in severe and potential lengthy disruption to the Merseyrail network.

STATS

- New concrete lining required for a 541 ft (165 m) section of the tunnel.
- 120-year design life required with minimal future maintenance liability.
- Construction of intricate crash/deck working platform allowed works to be undertaken safely without disruption to running of trains beneath.
- Innovation: refinement of RAM Arch system for permanent works use and fabrication of bespoke installation machine.
- 994 yd^3 (760 m^3) of specialized concrete applied by tracked robotic machine.
- 990 RAM Arch reinforcement panels installed.
- 32,000 safe hours worked.

out during nighttime work. This was costly and had numerous issues, including access, manual handling, dust, productivity, confined spaced working, and logistics issues.

Following a Network Rail inspection in 2015, it was evident that the remaining brickwork in the tunnel soffit had been found to be worse than feared. Effectively, the mortar had degraded to a point where it was nothing more than a thin crust, much of the brickwork was hollow, and most of it needed repointing.

It was immediately obvious that using conventional methods to repoint such a huge area would be prohibitive in terms of both cost and time, and we had to come up with an alternative repair solution.

ACCESS HELD THE KEY

One of the biggest challenges faced in 2010 was getting materials, equipment, tools, and men to the workface. Everything had to be brought in by road rail vehicles (RRVs) from more than a mile (1.6 km) up the line, but this route was only available for a few hours each night.

Further research revealed that hidden away in Network Rail's maintenance depot was the old portal entrance to the earlier high-level tunnel entrance (Fig. 2). It wasn't ideal as this portal has an immediate sheer drop to track level and its location in the city center had its own logistical challenges with access too tight for large vehicles.

It was agreed with Network Rail that the old portal could be used to access the tunnel.

A NEW WORKING PLATFORM

With access identified, the next challenge was developing a platform that would create a safe working environment and give better productivity. We certainly weren't going back to the 2010 situation of using a birdcage scaffold that gave us limited working windows.

We came up with a design that would establish a crash deck and working platform high above the railway running along a 540 ft (165 m) section of the tunnel (Fig. 3). The design of the deck meant we could separate the repair work from the trains running beneath, and ticking all the boxes required for creating a safe working environment, eliminating disruption to traffic, and giving huge potential efficiencies.

This was no normal scaffold crash deck. The deck would need to be robust enough to cope with the weight of a robotic concrete sprayer, the thrust from a specialist lifting boom used to install reinforcement mesh to the tunnel, accumulations of concrete rebound from spraying, and any possible fall outs during spraying concrete (Fig. 4).

The best demonstration of the challenge that the deck posed is the fact that three successive specialist scaffolding companies all refused to quote for the work.

RETHINKING RAM ARCH

With the access sorted, our minds turned to the design and methodology of the actual work required to repair the structure.

Fig. 2: The original disused portal is just visible in the background to the left of the train. This was the key to the success of the project

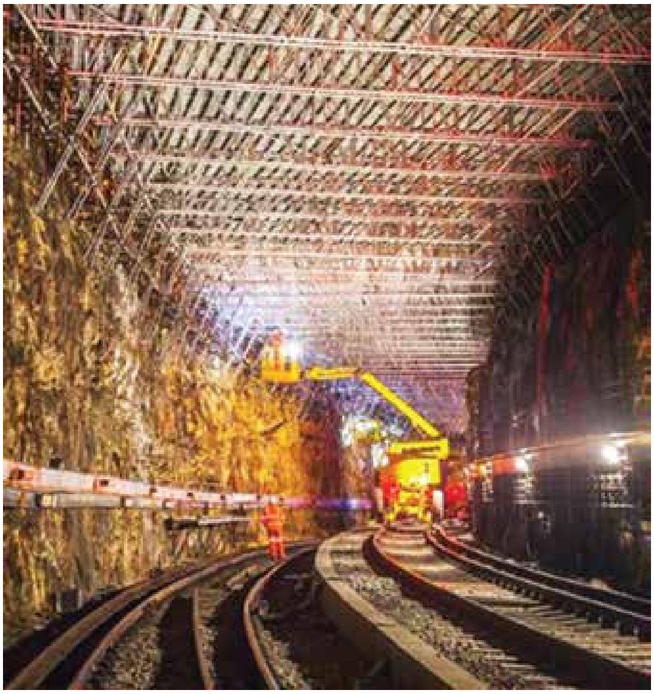

Fig. 3: The access deck from track level

Fig. 4: A fully segregated working platform is created with trains running below

This boiled down to pinning a mesh to the tunnel crown brickwork and then spraying this with a new concrete lining. But, as ever, nothing in HLN is ever that simple.

We had to develop a solution with the designers, COWI (formerly Donaldsons), that met the performance requirements of Network Rail but with several restrictions on the solution, including:

- 120-year design life requirement;
- No L-pins—these would usually be used in similar circumstances to secure steel mesh to the tunnel lining, but the scale of works required at HLN made their use too expensive and slow. Initial calculations showed it would take 12 men 3 months to install the 12,000 L-pins that would be required;
- High-quality mesh;
- No steel fibers; and
- Concrete applied at a thickness suitable to provide Network Rail with a structural layer, enabling them to forget about the brickwork beneath.

The solution to this challenge lay in an innovative technique previously adopted by AMCO for works in other tunnels on the network.

Fig. 5: 990 RAM Arch reinforcement units installed. Bespoke arch lifting machine shown to the left

Fig. 6: Reed B20HP

Known as RAM Arch, the system provides reinforcement panels to support loose and unstable brickwork in tunnels. The use of the RAM Arch panels allowed us to reduce the thickness of concrete from the original 12 in. (300 mm) design down to 10 in. (250 mm) while still providing the required structural layer and 120-year design life.

The next challenge was installing the RAM Arch. In normal circumstances, it is installed by a bespoke arch lifting attachment fitted to an RRV. It was not possible to use an RRV as the RAM Arch would need to be installed directly from the scaffold deck, not from the track below.

We designed and fabricated a mini arch lifter that could be used on the scaffold. The design of the mini lifter had to account for the constraints of working on the scaffold working platform so it had to be as light as possible (with limited thrust so as not to exert too much force down into the scaffold), maneuverable, and easy to use (Fig. 5).

All that had to be done now was to find the best way of getting 1000 yd^3 (760 m^3) of specialized sprayed concrete to the worksite and applying it in a carefully controlled manner.

Our specialized supply chain partner, Gunform International, proposed to design the concrete mixture (Specification C40/50) and use their tracked robotic arm to traverse the scaffold deck and apply the concrete that would be pumped 525 ft (160 m) from the portal.

With the design signed off, all we needed to do was:

- Create an access via the old high-level portal and build our way into the tunnel;
- Build a 540 ft (165 m) long robust working platform 33 ft (10 m) above the track;
- Design and build a new bespoke mini RAM Arch installer;
- Use a robotic sprayer to accurately apply the new concrete lining; and
- Complete the works with trains running below.

Following completion of the scaffold deck constructed during nighttime possessions, we set about installing the RAM Arch. To enable the RAM Arch to be erected, we had to create a base for it to spring off by saw-cutting a 12 in. (300 mm) ledge into the tunnel sandstone and install an array of rock bolts and a ventilation system.

After many weeks of pre-construction trials, concrete testing, and preparatory works, Gunform tracked the robotic arm to the far end of the decking and the first batch of concrete from CEMEX began to pump the 540 ft (165 m) using a REED B20HP pump complete with integrated dosing system (Fig. 6). Everything went perfectly to plan.

The following 6 weeks were a carefully choreographed ballet of concrete production line perfection. Working daytime shifts (8:00 a.m. to 5:00 p.m.) with trains running below, concrete was delivered to the portal from 8:30 a.m. each morning. Each delivery provided enough concrete for approximately 1 hour of spraying (Fig. 7). At the end of each hour, a team of AMCO operatives would descend onto the deck to bag up and remove all rebound material, and half an hour later, the process would begin again.

As the spraying progressed back towards the portal, we could start dismantling the scaffold deck behind it during nighttime possessions to ensure a rapid demobilization at the end of the project.

The scheme developed and delivered by AMCO in collaboration with Network Rail and specialist suppliers from COWI (design), Crossway (scaffolding), Gunform (robotic concrete spraying), and CEMEX (concrete supply) delivered a robust, long-term repair solution that ensures safe and reliable use of the tunnel for generations to come (Fig. 8).

RESULTS

- Zero accidents;
- Zero train delays;
- On-time delivery;
- Within budget;
- $16.8 M USD (£12m) cost saving against comparable previous works undertaken in the tunnel;
- Collaborative joint team approach between AMCO, Network Rail, and specialist supply chain;
- Widespread acclaim from Network Rail; and
- Solution with a 120-year design life that removes a significant risk of failure from the infrastructure and provides a maintenance free result for generations to come.

Fig. 7: Robot sprayer at work. Remember there are trains running beneath this!

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2017 OUTSTANDING UNDERGROUND PROJECT

Project Name
Liverpool Central Tunnel High Level Neck Repairs

Project Location
Liverpool, UK

Shotcrete Contractor
Gunform International Ltd.

General Contractor
AMCO Rail

Architect/Engineer
AMCO Rail and COWI (formerly Donaldsons)

Material Supplier/Manufacturer
Cement Concrete (CEMEX), Ram Arch (ISS), and BASF*

Equipment Manufacturer
REED Shotcrete Equipment* and MEYCO

Project Owner
AMCO Rail and Network Rail

*Corporate Member of the American Shotcrete Association

Fig. 8: Job done!