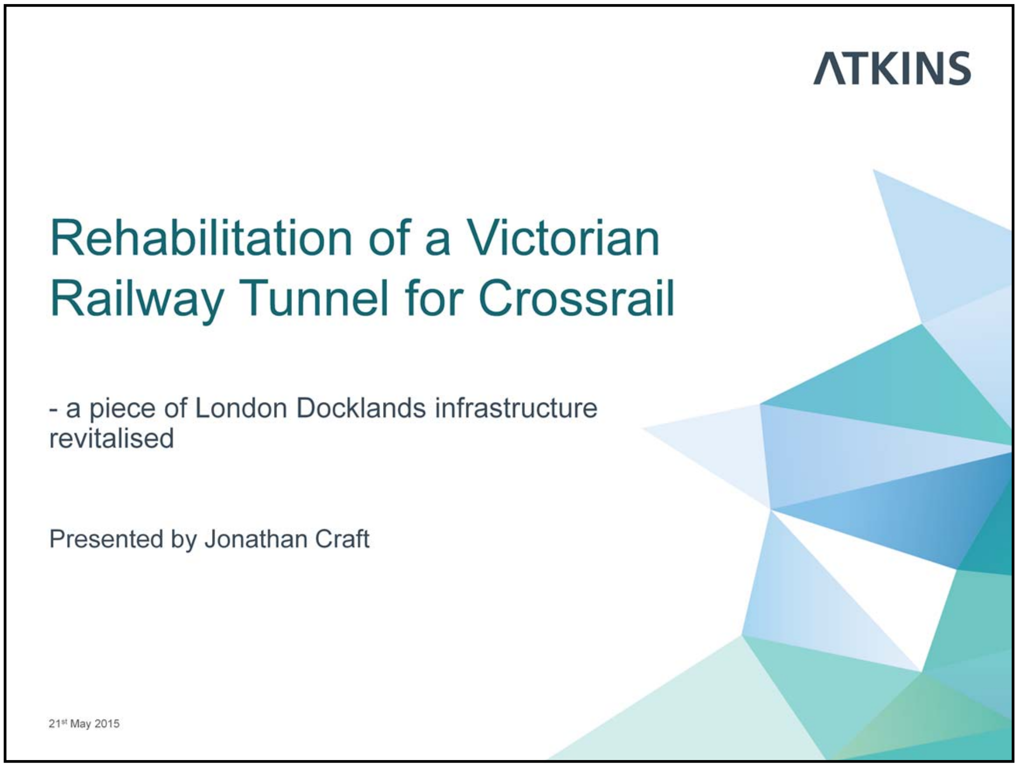
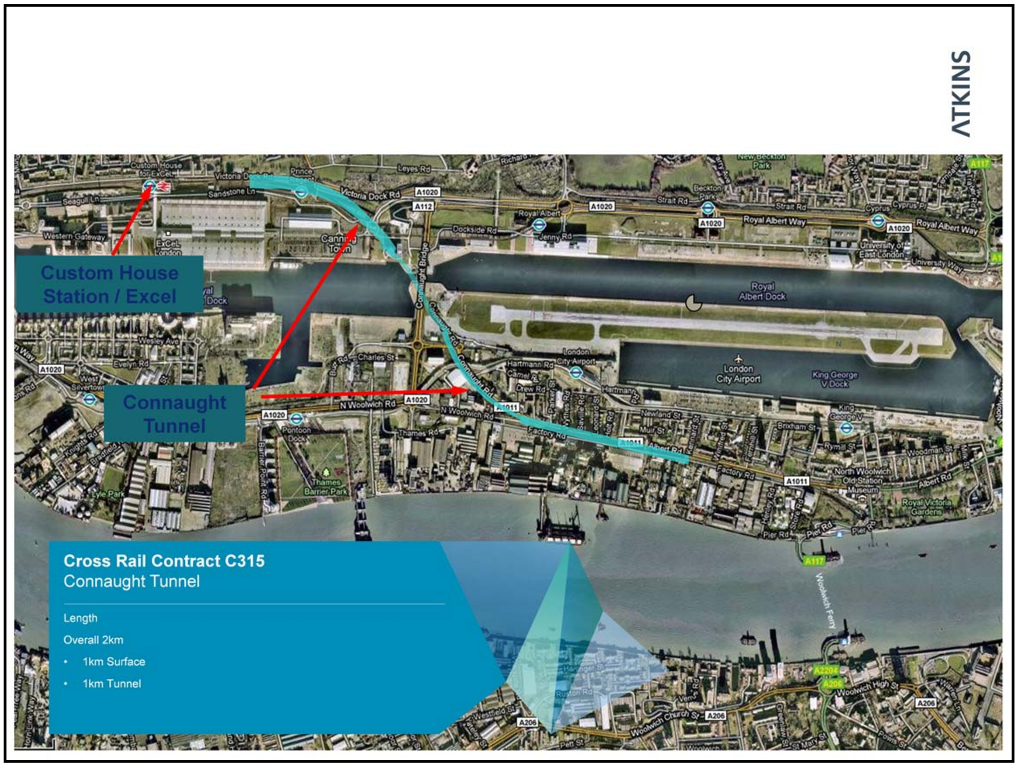


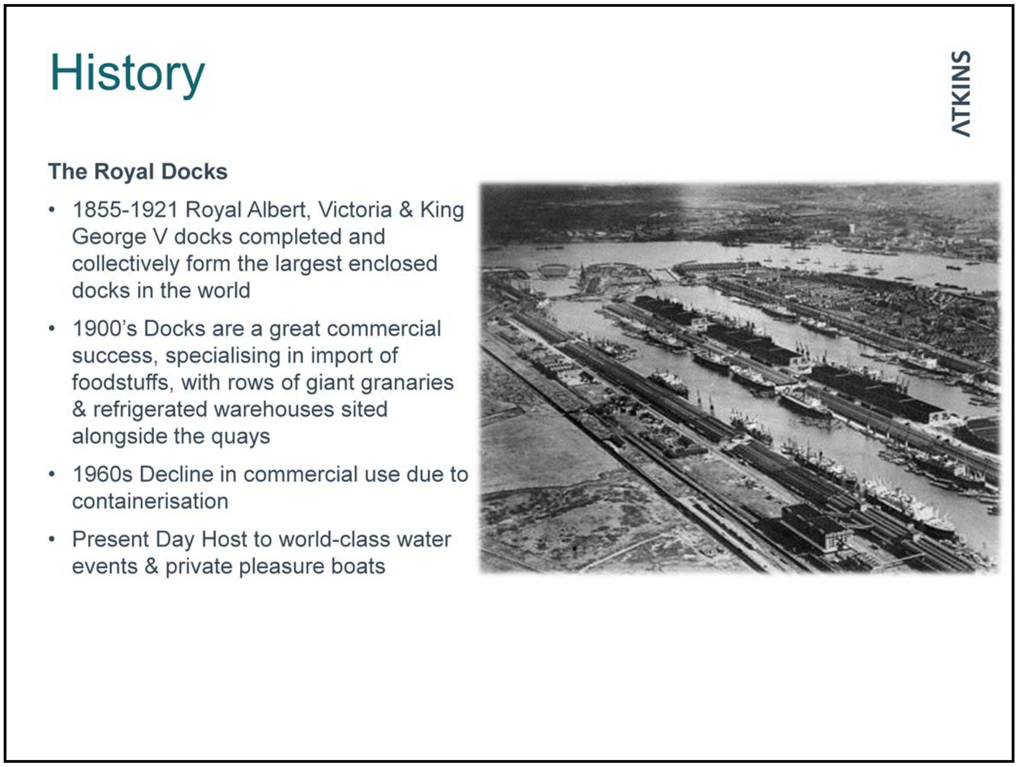
GOOD AFTERNOON LADIES AND GENTLEMEN!

This presentation is a snapshot of a paper written by myself and my Arup colleague David Wilde which will appear in Volume 2 of the ICE Crossrail compendium to be published later this year (Volume 1 is already available), and I propose to start by outlining a little of the history of this very important part of London's Docklands before going on to examine just some of the many technical – both design and construction – challenges that we and our contractors had to overcome on this fascinating project.

Connaught Tunnel is a Victorian brick-arch cut-and-cover structure designed by Sir Alexander Meadows Rendel (son of the founder of the eponymous firm of consulting engineers) and built in the 1870's during the creation of London's Royal Docks.



The tunnel is located to the north of the Thames Barrier and west of London City Airport. It is approximately 1km in length and passes beneath the Dock Passage between the Royal Victoria and Albert Docks. The tunnel was built to carry trains between Canning Town and the docks transporting passengers and freight to and fro.



However, the original pre-1850 plan had been to take the railway across the docks on a swing bridge but this was discounted because it was thought that frequent opening of the bridge to let ships pass through would interfere too much with train services.

To solve this conundrum, a tunnel was mooted and in 1878 the Connaught Tunnel opened to steam trains on the North London Line (the western approach ramp can be seen on the right of the slide).

History

The Route & Railway

Ancient Times

The track route was part of the Roman Road network, itself built over prehistoric pathways

1800's

North London Line steam trains begin carrying passengers & freight

With the construction of the Royal Docks, the plan for a rail swing-bridge was dismissed as it was thought that frequent openings of the bridge for ships would interfere with train services

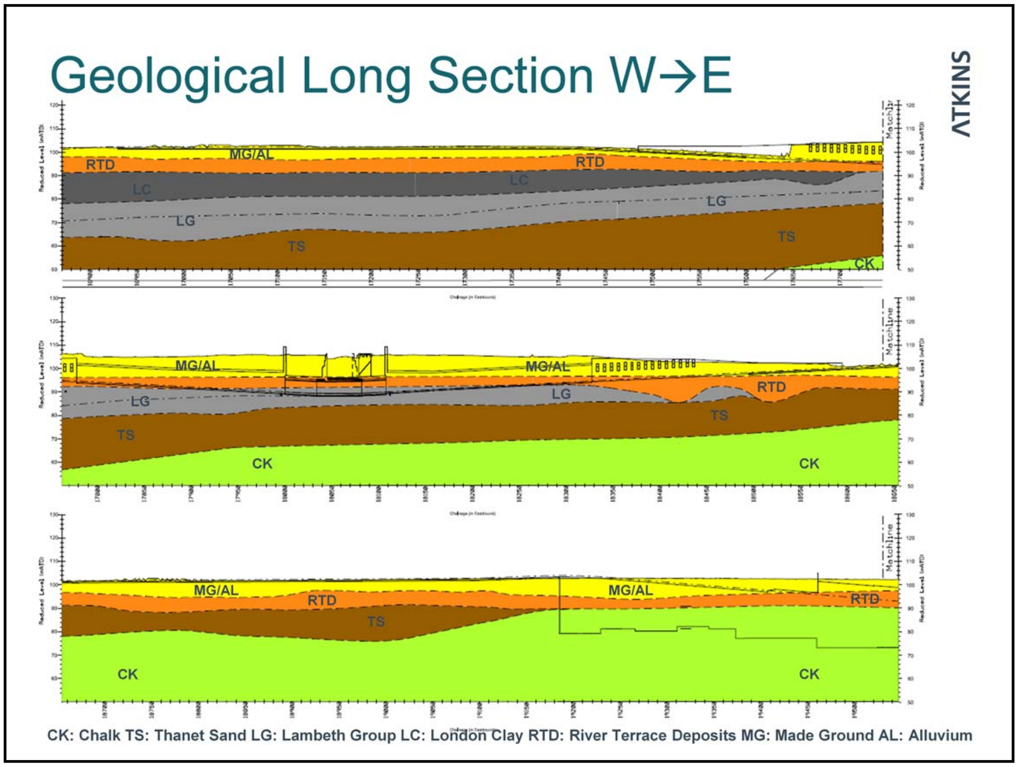
1878

To solve this, a cut & cover tunnel was built – it is called the *Connaught Tunnel*

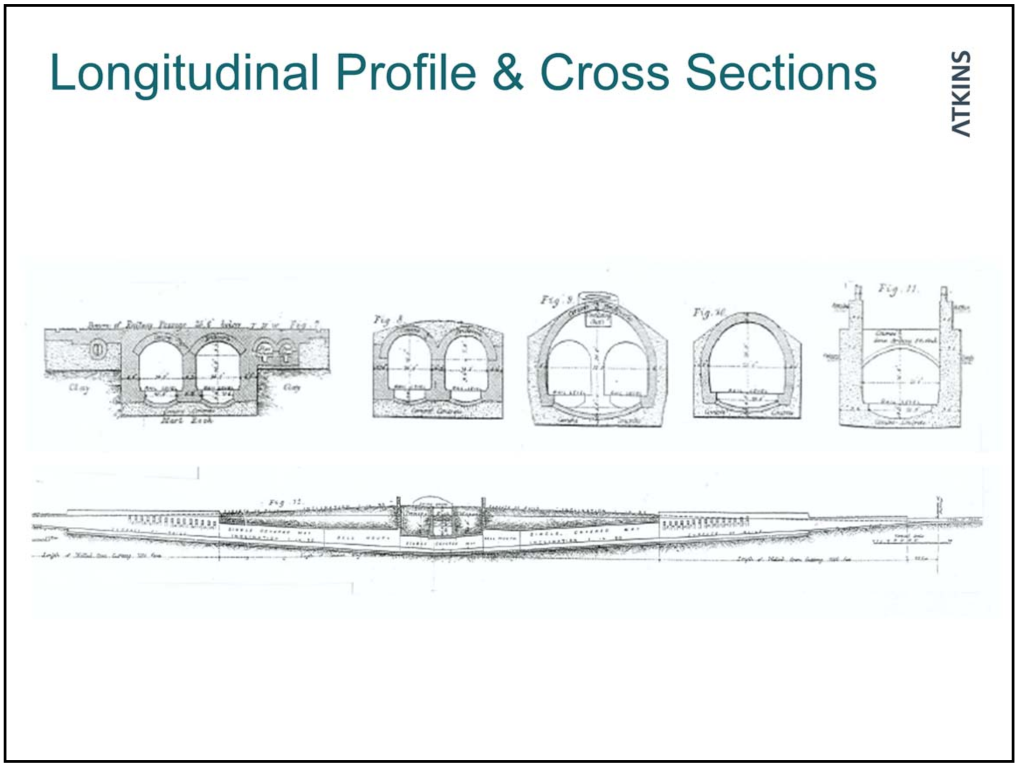
Looking east toward Connaught Road Station.
Beckton branch diverges left & North Woolwich diverges right.
The later deviation leading to Connaught Tunnel is shown on the extreme right.

Now as an aside it is perhaps interesting to note that this is the only section of the entire 43km long underground route for Crossrail that is not located in brand spanking new precast concrete lined tunnels fashioned by state-of-the-art tunnel boring machines as featured on the recent BBC2 documentaries which I'm sure many of you will have seen.

But as you might imagine, the choice to re-use existing infrastructure – albeit 150 years old – rather than bore two new tunnels from Woolwich to Custom House, was governed more by hard-nosed economics than sentiment!

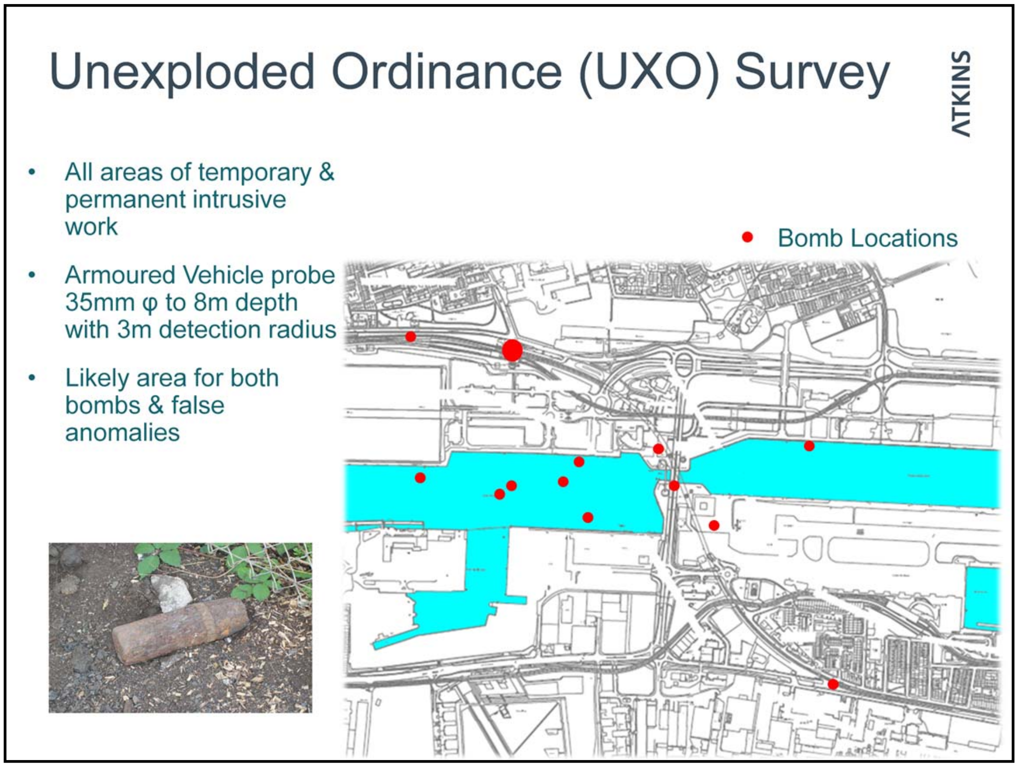


Based on extensive site investigation programmes the ground conditions obtaining at Connaught are as shown on this long section and comprise Made Ground/Alluvium/ River Terrace Deposits/ London Clay/ Lambeth Group/ Thanet Sands/ Chalk but the strata of direct influence on the tunnel – as can be seen on the section - are the River Terrace Deposits and Lambeth Group deposits.



The structure was built in five major sections (as shown on this copy of an original drawing):

- West Approach Ramp
- West Single Arch (twin track) Tunnel
- Central Twin Arch (single track) Tunnels
- East Single Arch (twin track) Tunnel
- East Approach Ramp



In addition to the conventional borehole programme of ground investigation, a UXO (unexploded ordinance) survey was carried out because – as you might imagine – this area of London was subjected to sustained campaigns of heavy bombing during the 2nd World War………..

This one did explode!

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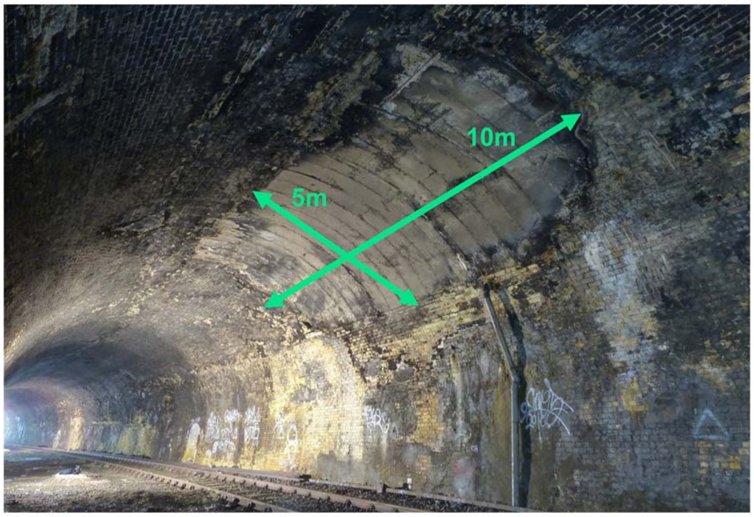
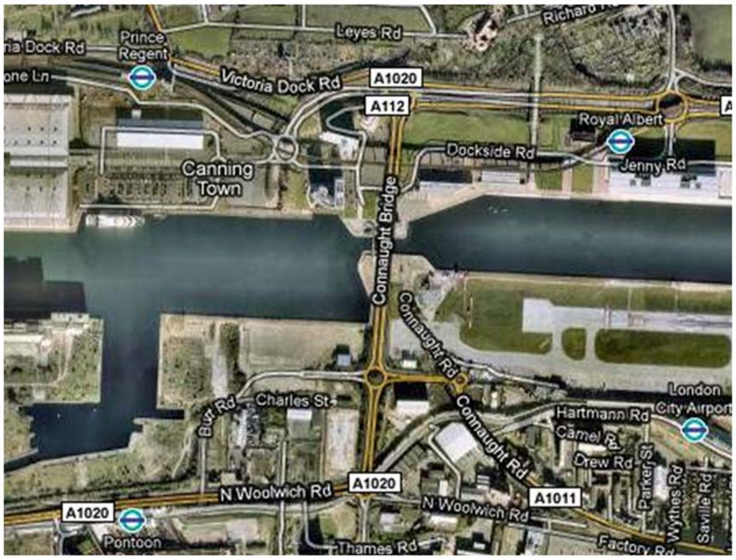


…………but apart from this one, no other direct hit to the railway was recorded. The slide shows the contemporary repair - which remarkably has withstood the test of time – but additional reinforcement and sprayed concrete has since been applied (as well as grouting of the brickwork) consistent with the 120 year design life of Crossrail infrastructure.

Dock Passage Crossing



The tunnel alignment passes beneath the Dock Passage on an S-curve like so (*)

Dock Passage Crossing

The section immediately beneath the water channel had to be deepened – in around 1935 – because of concerns that deep ship hulls might scrape the top of the tunnel!

Tunnel Under Dock Passage

Cast Steel Lining

1935

Concerns about deep ship hulls colliding/scraping the top of the tunnel led to a lowering of the dock floor and installation of cast iron rings

To cater for this deepening, the tunnel was reinforced with a cast steel lining.

Marine Survey – Multibeam Results

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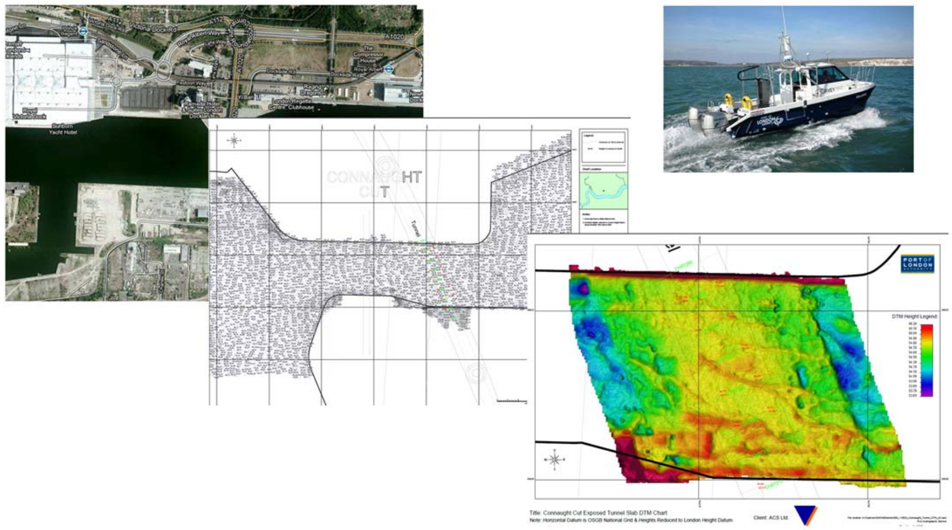
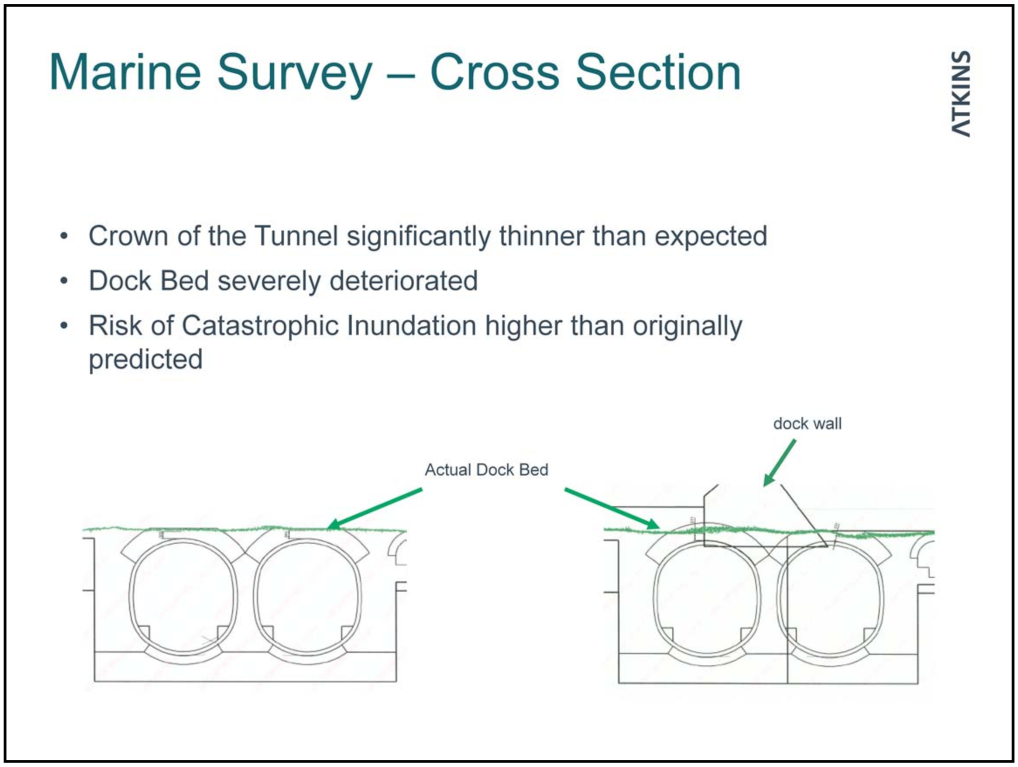
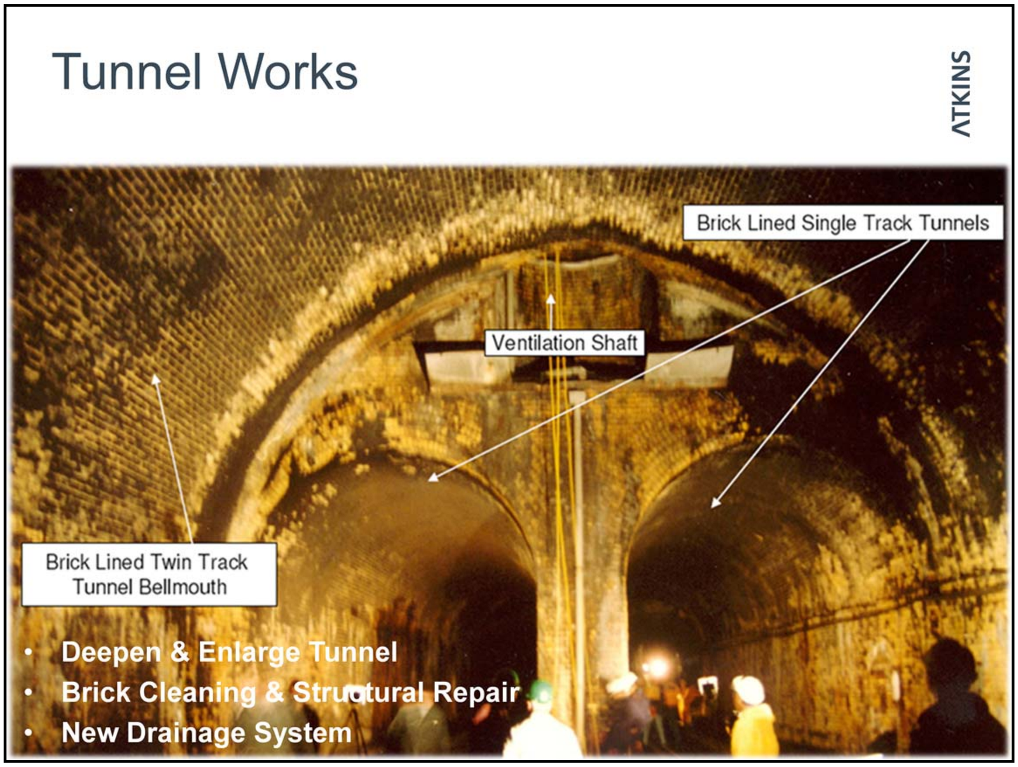


Given the potentially fragile condition of the tunnel crown, it was felt that additional precautionary measures such as a marine survey needed to be carried out before any new works for Crossrail could be carried out here.



This marine survey (by sonar and divers) revealed that the condition of the brickwork crown was extremely poor and its thickness (200~300mm) insufficient to permit works including the removal of the cast steel lining within the tunnel to be carried out in a safe manner (of which more later).



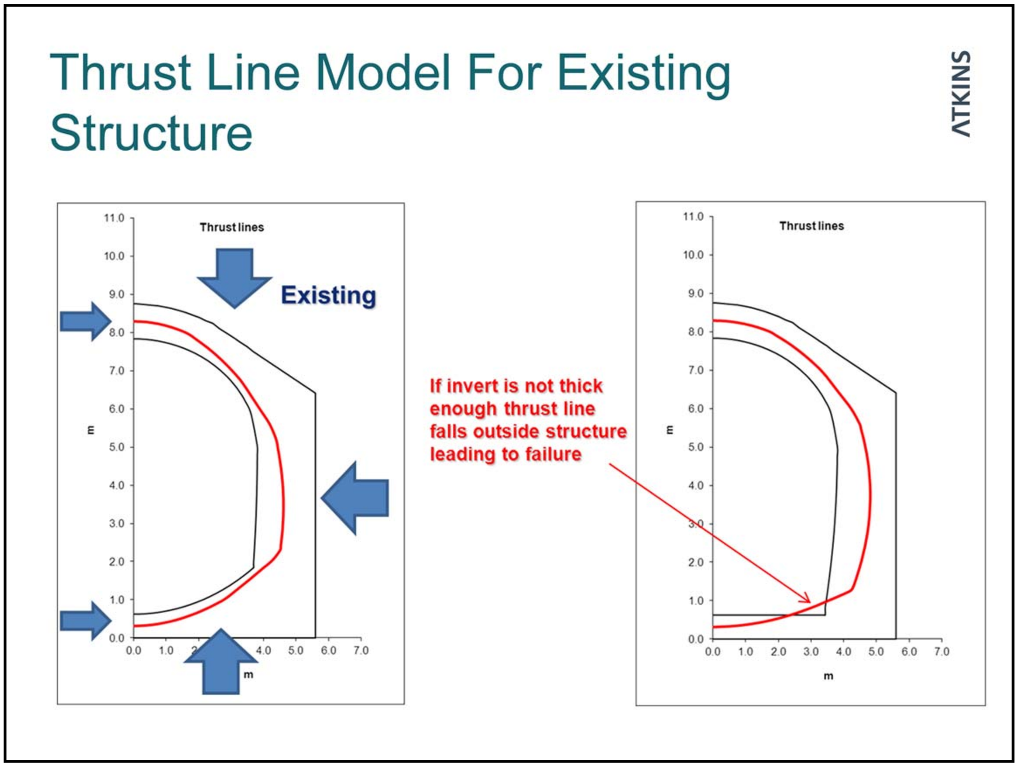
As we have already seen the Tunnel Works comprise 3 principal sections:

- West Single Twin-track Brick-lined Tunnel
- Central Twin Single-tracked Tunnel
- East Single Twin-track Brick-lined Tunnel

To accommodate the new train envelope and the over-head line equipment, it was necessary to lower the invert of the East and West Single Tunnels and for most of the length of these two sections this was achieved by grinding out the existing brickwork and underlying mass concrete.

The brickwork is amazingly robust having a minimum compressive strength of 16MPa which after applying various load factors gave a working capacity of 3.2MPa (the equivalent value for the mass concrete is 10.3MPa).

Admire the astonishing brickwork after saw-cutting 1.0~1.2m



The analysis of the existing structure was based on the use of a pole and ray force diagram which is an iterative process to establish viable thrust lines throughout the tunnel structure (*).

Based on this analysis it was determined that a re-profiled invert would have had insufficient capacity approaching the Bellmouth sections both East and West.

As a result 40 m and 70m respectively of the West and East Twin-track Tunnel inverts had to be replaced………………

As may be seen on the next 3 slides….

Invert Replacement

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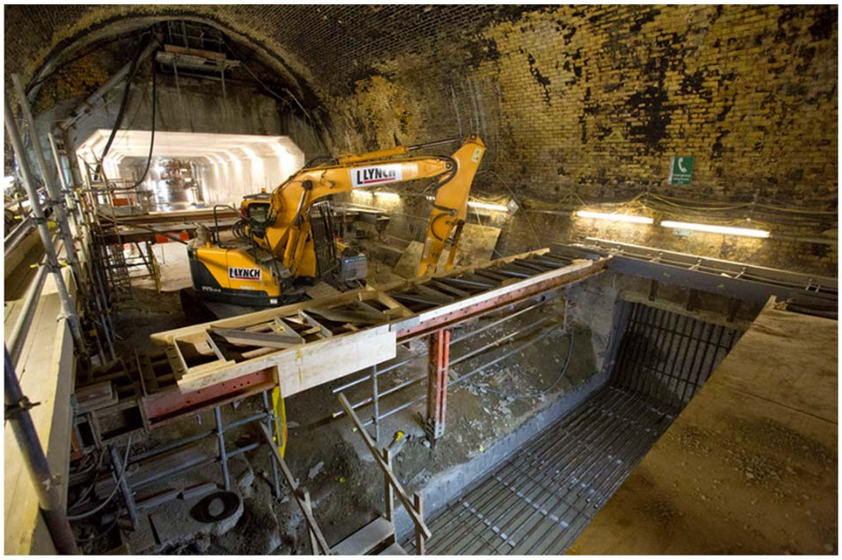

Invert Replacement

Invert Replacement

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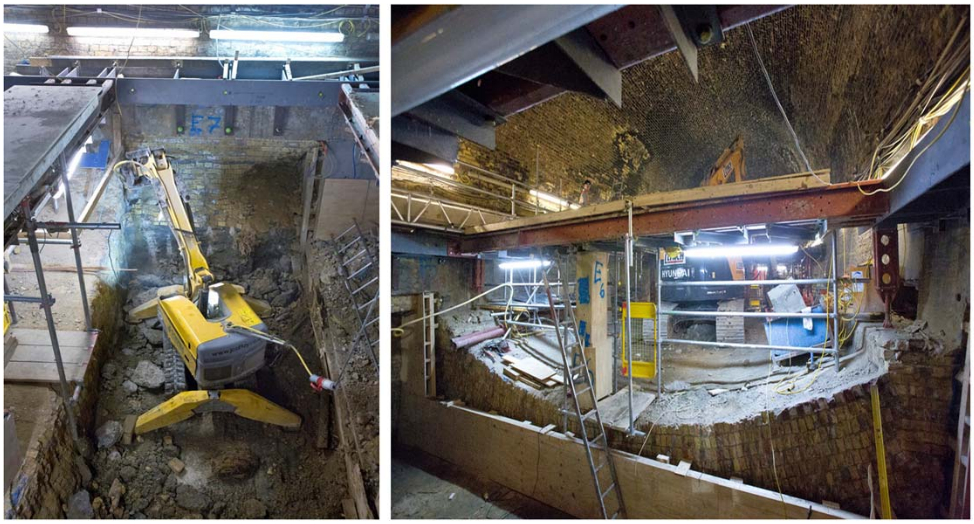
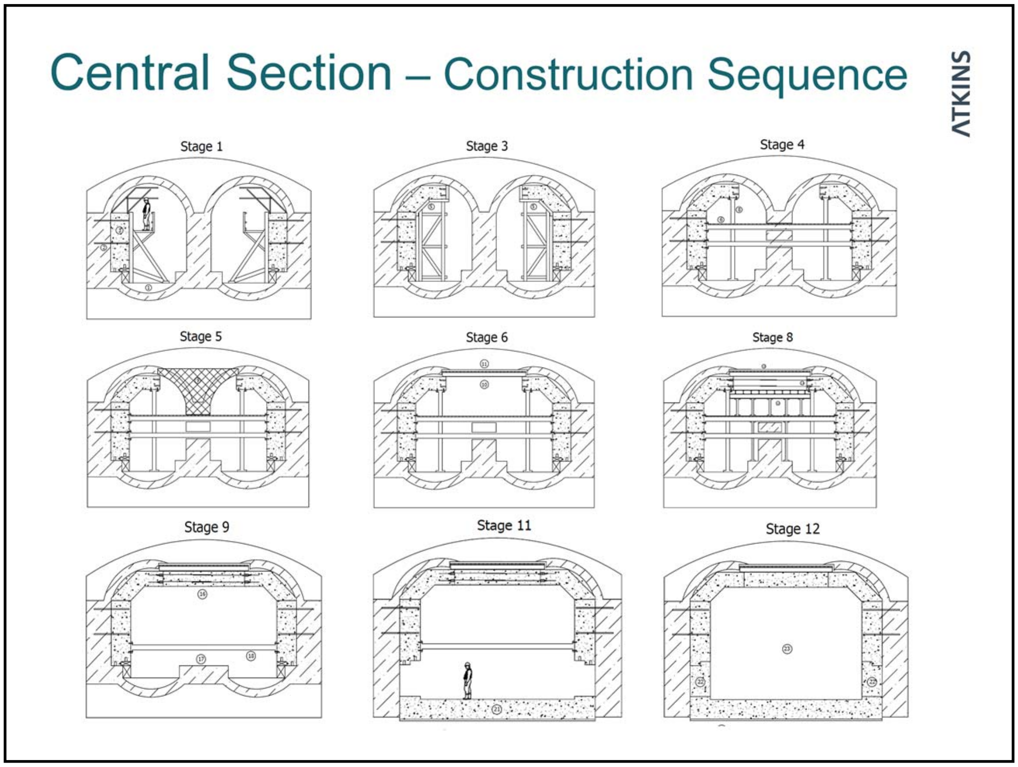
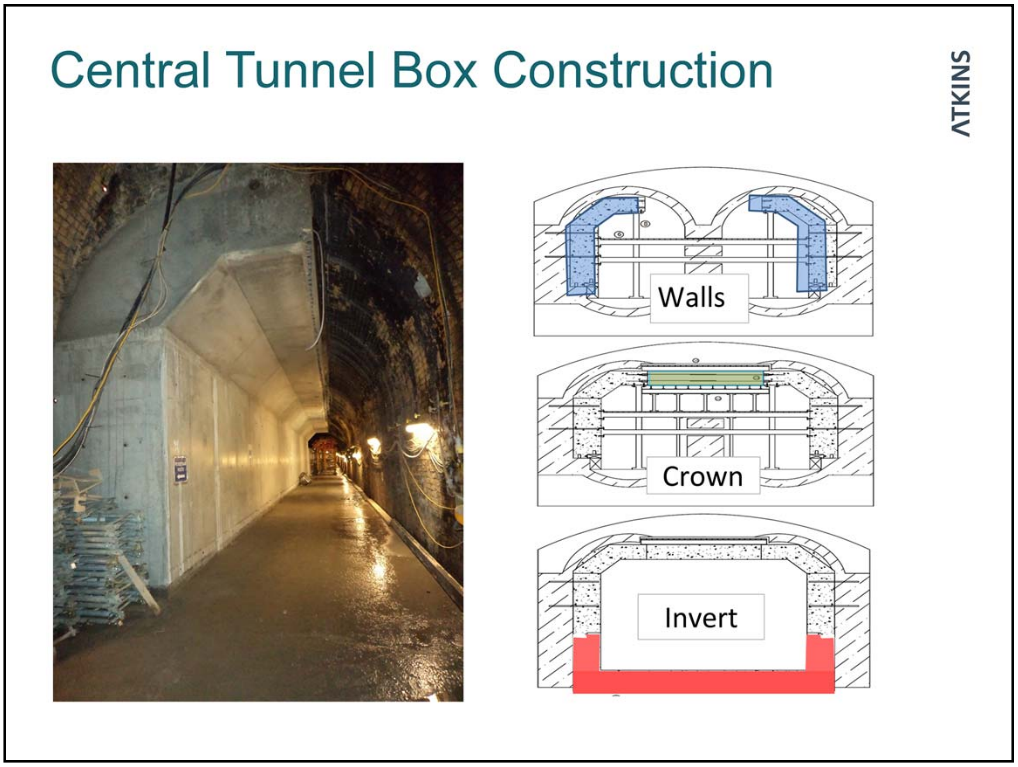


This invert replacement was carried out in bays of only 2.5m which was a challenge to the teams of subcontractors deployed by Taylor Woodrow / Vinci Construction as may be seen here.



The Central Section was an even more complicated affair as before any new construction could be started, the existing cast steel lining had to be removed piecemeal.

Thereafter the construction sequence comprised fully 12 stages as shown here.



After casting the side walls within the single track tunnels, the central load-bearing wall was cored and props were installed spanning between the newly cast concrete sections.

Central Tunnel Box Construction

The brickwork crown was then broken out piecemeal and the new concrete crown section constructed using poling bars to support the brickwork above which was extremely laborious and its success was in no small measure due to the skill of the miners employed by Joseph Gallagher and Sons.

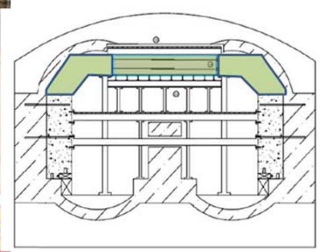
Then, the new invert was constructed in 4.3m bays on a hit-and-miss basis, and finally the lower side wall sections were completed.

Cofferdam - Within Dock Passage

As already mentioned, the existing ultra-thin brickwork crown to the Central Twin Tunnel section where it crosses the Dock Passage, necessitated a more radical approach, namely a pair of steel sheet-piled cofferdams at either end of the Dock Passage as proposed by the Contractor in order to be able to remove the water and to break out the crown from the top.

However, before the Dock Passage could be dewatered all forms of aquatic life trapped between the cofferdams had to be netted and transferred to open water in the adjacent docks (from memory about 200 fish were successfully re-homed in this way).

Central Tunnel Box Construction

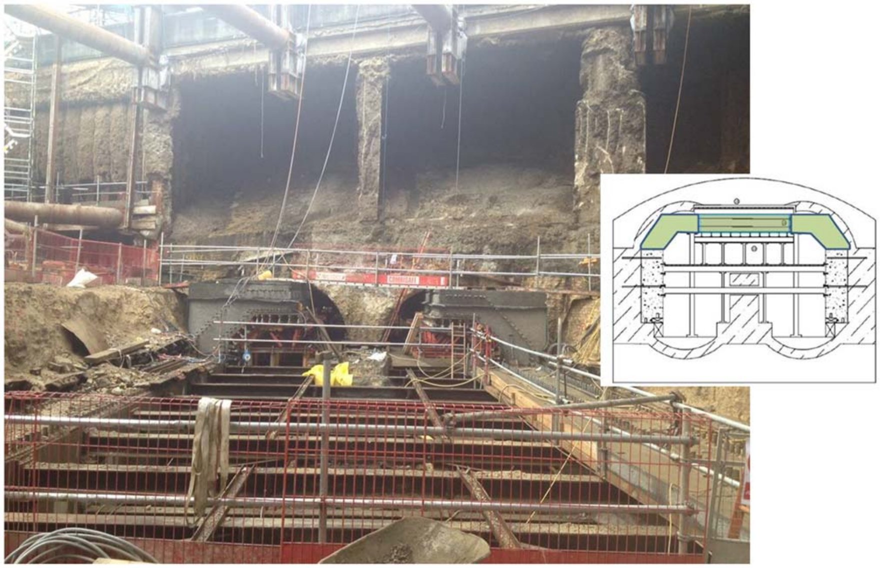


- Splay reinforcement (part of crown construction)

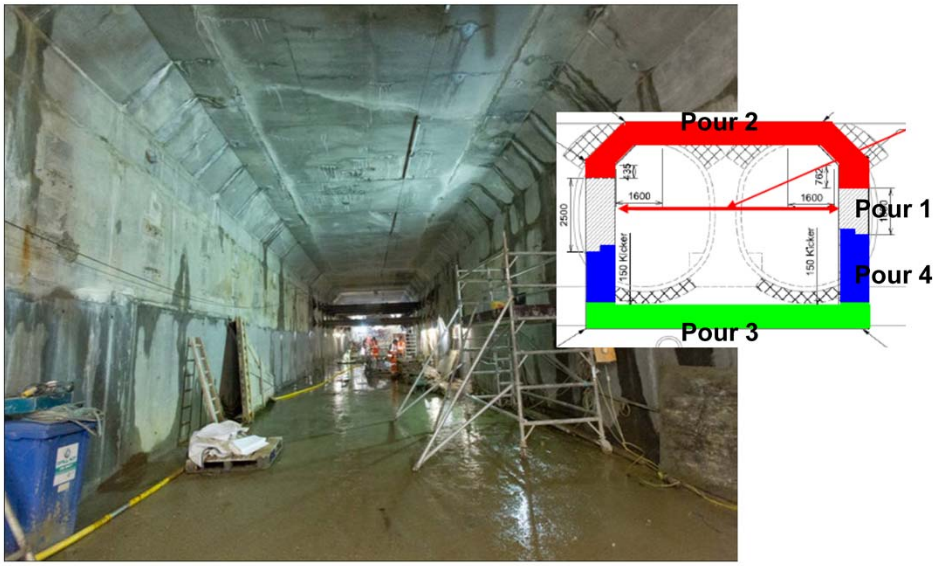
The side walls having already been constructed inside the tunnels, it was then possible to build up the shoulders and crown of the new tunnel more conventionally.

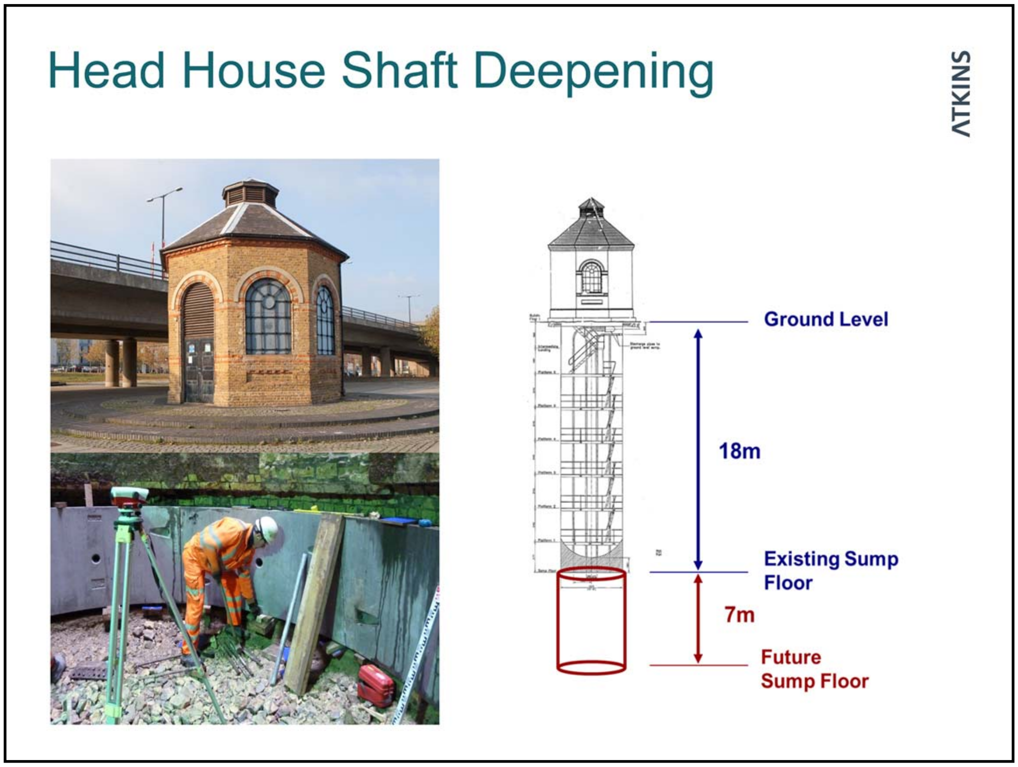
Once the new roof was in place and sealed against the existing dock-wall structures, the cofferdam was re-flooded and the sheet-pile cofferdams removed, just in time for the Boat Show at the Exel Centre.

Central Tunnel Box Construction



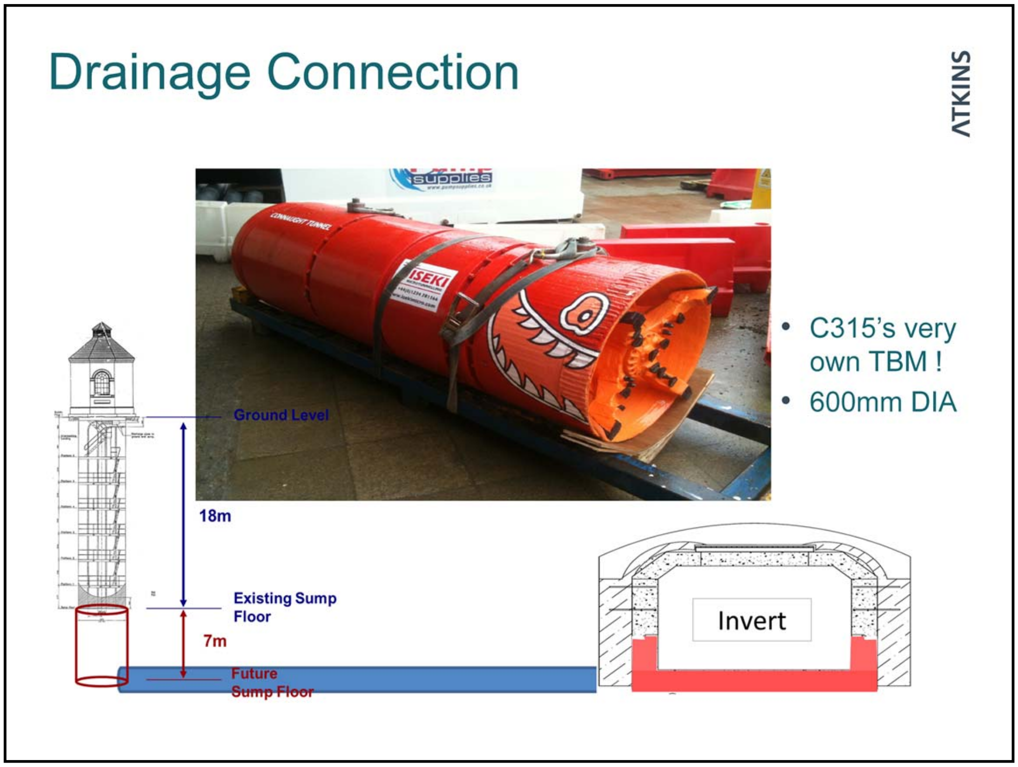
Central Box Completed





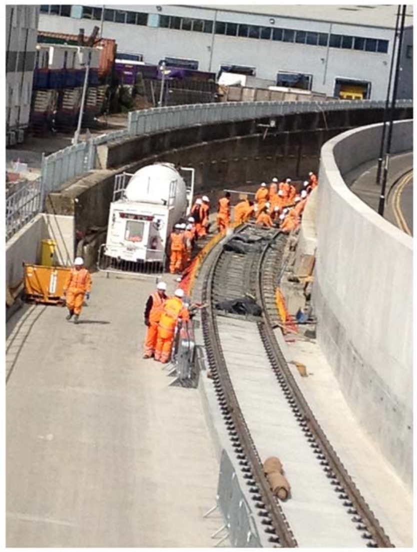
In order to provide adequate sump capacity for the tunnel drainage system, the existing Head House Shaft had to be deepened by 7m; this was done by conventional underpinning methods.

The brick head-house structure was carefully dismantled and stored to be re-erected at a new site.



The drainage connection adit to the new nadir sump in the tunnel was constructed using our very own TBM!

Connaught Tunnel Comes Full Circle



The very first underground section of the new railway for Crossrail - which will connect to the North Kent Line at Abbey Wood – is now under construction in this revitalised piece of Victorian infrastructure that is The Connaught Tunnel!

Acknowledgements:

This presentation is based on a paper of the same title co-authored by Jonathan Craft (Atkins) and David Wilde (Arup) who are grateful to Crossrail Ltd for their permission to publish.

My thanks are also owed to our colleagues in the Crossrail Team and to the Geological Society of London for inviting me to present this story.