MOTT MACDONALD

Project
Waterloo Station upgrade

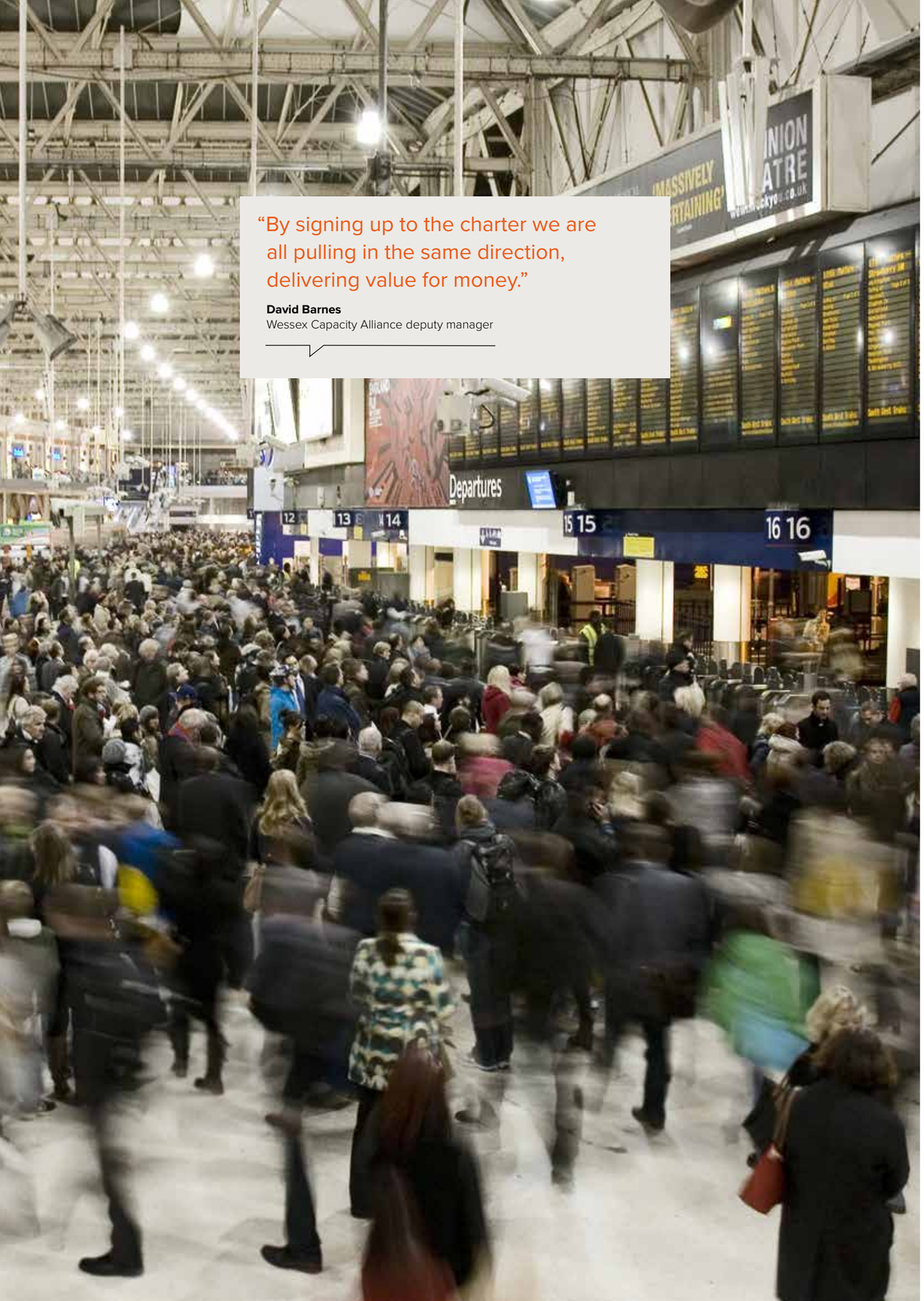
Location
London, UK

Client
Network Rail

Expertise
Rail systems, civil, structural, building services, geotechnical, environmental and fire engineering; security and ergonomic design

International rescue

Joined-up thinking and clever engineering have allowed a former international terminal to be brought back to life as part of a bigger, better Waterloo Station



> “By signing up to the charter we are all pulling in the same direction, delivering value for money.”
>
> **David Barnes**
> Wessex Capacity Alliance deputy manager

Normal service
The former Waterloo International Terminal is being brought back into use while the rest of the station remains operational

Britain’s busiest railway station, London Waterloo, is undergoing a £400M upgrade to increase capacity.

Improving the passenger experience for the 99M people who use Waterloo Station every year involves much more than the word ‘upgrade’ implies. There is major viaduct reconstruction, a new connection to London Underground, demolition of some sections of platforms and extension of others, construction of a new roof and pedestrian bridge, and a huge amount of new railway infrastructure to be installed.

Programmed around the normal working of the station and right under the public’s nose, the first nine months on site saw demolition taking place only a nibble at a time – a portion of track removed here or a new piece of infrastructure installed there – to limit disturbance.

Waterloo Station is served by the South West Mainline, the Reading and Windsor lines and suburban lines connecting London with the South and South West of England. By 2043, the number of journeys made on the route is expected to increase by 40%. Anyone using the service at peak time will be familiar with how busy trains can become. To ease congestion and create capacity for the future, Waterloo Station’s upgrade involves modifying platforms one to four to suit longer trains (from eight cars to ten) and converting the platforms of the former Waterloo International Terminal (WIT) on the west side of the station for domestic services.

Vauxhall Station will also be upgraded as part of this package of work. Alongside these station changes will be significant signalling, power and track work.

This £400M investment will be delivered by December 2018 by the Wessex Capacity Alliance, a body that was formed in January 2015 by client, designer and contracting firms. The Alliance is made up of client Network Rail, consultants Mott MacDonald and Aecom, main contractor Skanska and rail contractor Colas Rail.

The Alliance’s aim is to encourage integrated working. Savings of £65M have already been realised. An Alliance ‘charter’ states the common purpose shared by all members – “to build great infrastructure for rail users in Wessex”. Wessex Capacity Alliance deputy manager David Barnes says, “By signing up to the charter we are all pulling in the same direction, delivering value for money.”

Fast-track station modernisation

Wessex Capacity Alliance commercial project lead Tim Ryall describes the volume of work undertaken as being double that of a typical railway project over the same timeframe.

With restrictions on noise, dust, plant weight and height, demolition and construction takes place using relatively small pieces of equipment on multiple work fronts and with many interfaces between the different disciplines common to all railway projects. Planning and co-ordinating activities to meet key handovers at the end of an overnight or weekend possession is a persistent challenge. To encourage the highest levels of co-ordination between Alliance members, all are co-located on site. “It’s a very fast programme, but with 375 people here in the project’s site office, we can focus our minds on working efficiently and make decisions quickly,” says Tim.

The WIT was the UK terminus for Eurostar trains using the Channel Tunnel from 1994, but in 2007, with the completion of High Speed 1, services moved to St Pancras. The WIT’s five platforms, its spectacular snaking blue tubular steel roof and all its other facilities were put to sleep, to be brought back to life in April 2016 as part of the current project.

“Remodelling Waterloo Station and bringing the International Terminal back into use is like carrying out open-heart surgery: we need to keep the station fully operational throughout this transformation,” says Alliance architecture design director Erik Behrens.

“Balancing the conservation aspects of the original building with new operational requirements and proposed new retail spaces all within the programme cost and timeframe has been a tremendous challenge for the team,” he adds.

Converting the WIT for domestic service isn’t as simple as just putting new trains on existing tracks. An international terminal is more like an airport with distinct areas to control passenger movement, whereas a national train service operates very differently. Where the public would have used check-in desks and walked to departure gates in a controlled way to join a waiting Eurostar train, the domestic setting allows people to arrive just minutes before the train leaves, or wait on the platform before a train arrives with any number of buggies, bicycles, luggage and mobility needs, creating a very different set of requirements. “The new 10-car trains will be shorter than the Eurostar trains which used to use the WIT and will also operate a more frequent service with 18 trains arriving every hour, instead of six. This has meant that track, signalling and platforms have had to be completely reconfigured,” says Alliance lead engineer David Otohwo.

Reinstating the former WIT platforms has required passenger flow, security and overcrowding to be assessed ahead of designing capacity upgrade structures and infrastructure. “Our solutions have been developed by first considering how people move around the station and then working out how to provide the best possible passenger experience,” says Tony Wilkins, a member of the Wessex Capacity Alliance leadership team.

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Member of the Wessex Capacity Alliance leadership team

Aerial view
The WIT with its snaking blue tubular steel roof sits alongside mainline platfoms one to 19

Innovation and value engineering in abundance

The Alliance has also been able to influence the amount of work that needs to be implemented before 2018 to bring about maximum benefits on the route.

Within Waterloo Station and the WIT itself, scrutinising how much demolition was necessary, and the extent of new structure and infrastructure needed, has reduced costs. Shorter trains using the WIT platforms have led to a reduction in 'live' loads on some structures and, elsewhere, demolition of redundant back-of-house WIT structures has freed up capacity to support loads from the new works. Balancing loads in this way has led to scaling back on the amount of new structure that has to be built (see page 12). By maximising capacity on existing foundations, columns and walls, there is also much less disruption to the London Underground tunnels running underneath the WIT and the Victorian brick arches which support the mainline. This has also resulted in a pared-back asset monitoring regime, leading to further cost savings.

Another major innovation developed by the Alliance has been the introduction of an at-grade connection from Waterloo's main Victory Arch entrance (see page 15). This footbridge provides an improved, step-free route directly to the WIT platforms. Not only does this suit all passenger mobility needs, it is being installed without the need for any new foundations due to the 'load-balancing' exercise carried out by designers.

Light and spacious
Refurbishment of the WIT will reduce congestion and make the station more inclusive

Every project needs a little 'thinking time'

The mammoth £65M of savings made to date on the WIT required an initial outlay of £250,000 of 'thinking time' to discover these solutions, a luxury perhaps only afforded within an alliance environment where all parties are aligned to deliver the best solutions. The main savings came from:

- Remodelling the WIT track and platforms and avoiding the need for additional piled foundations for widened approach viaducts
- Redesigning the WIT infill roof using more standard components and reusing existing structures for support
- Reducing the amount of asset monitoring due to load-balancing
- Reducing the amount of demolition and new construction to achieve the capacity increase
- Upgrading signalling instead of replacing
- Scheduling work in the most time and cost-efficient way

Planned possession – December 2016

Not all work can be carried out when the station is closed overnight or around an operational railway during the day, so railway possessions (when lines are closed) are scheduled across various weekends, including a four-day period over Christmas 2016 and 24 consecutive days in August 2017. Much of the work carried out over Christmas 2016 involved bringing the WIT platforms into service.

The five WIT platforms will be needed during the summer possession to provide extra capacity at Waterloo when platforms one to nine are closed for capacity upgrade work. “Work carried out during possessions allows significant bulk works to be undertaken safely and efficiently. From 8pm on Christmas Eve until normal service began on 27 December, cables and wires were removed, replaced and rerouted, parts of the concourse demolished and significant structural work carried out to connect platforms one to four and the Underground,” says Network Rail senior sponsor Paula Haustead.

Time is undoubtedly this project’s biggest challenge and maximising the opportunities for work during these possessions has led to some activities being programmed early to free up time later. The connection between the mainline concourse and London Underground will not be required until 2018, but the Christmas possession allowed an opening to be created in the concourse slab and for it to be safely covered over afterwards, without disrupting the public.

Planning ahead
The Waterloo Station concourse slab being demolished to create a new connection to London Underground

99M

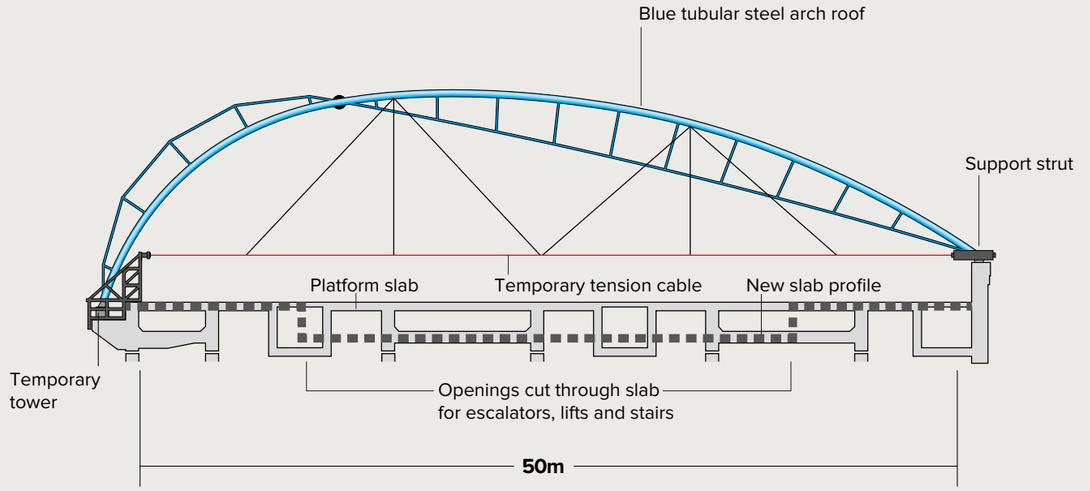
Waterloo Station was used by 99M passengers in 2014/15, which represents a 70% increase since 1998, despite there being very little change to its infrastructure for 30 years.

Supporting the WIT arch roof

Some of the trickiest work over Christmas 2016 involved installing two tension cables to support the blue tubular steel WIT arches. These three-pinned arches are restrained by the 50m wide concrete slab spanning between their springing points.

The slab also supports the WIT platforms and track. Converting the WIT for domestic services requires new stairs and lifts to be built through this slab, but creating these openings undermines the slab’s structural continuity. Until the openings were properly framed out, the slab’s restraining function had to be transferred to tension cables. “These openings are made by removing concrete in a controlled way, using hydro-demolition,” explains Wessex Capacity Alliance contracts engineering manager Chris Kitching. “This means that the reinforcement remains intact and can be manipulated to frame the opening with additional reinforcement and concrete.”

During the Christmas possession, as the openings were created and stiffness in the slab diminished, the stress in two temporary tension cables was stepped up. Installation of three other tension cables and further openings in the slab were also made in early 2017.

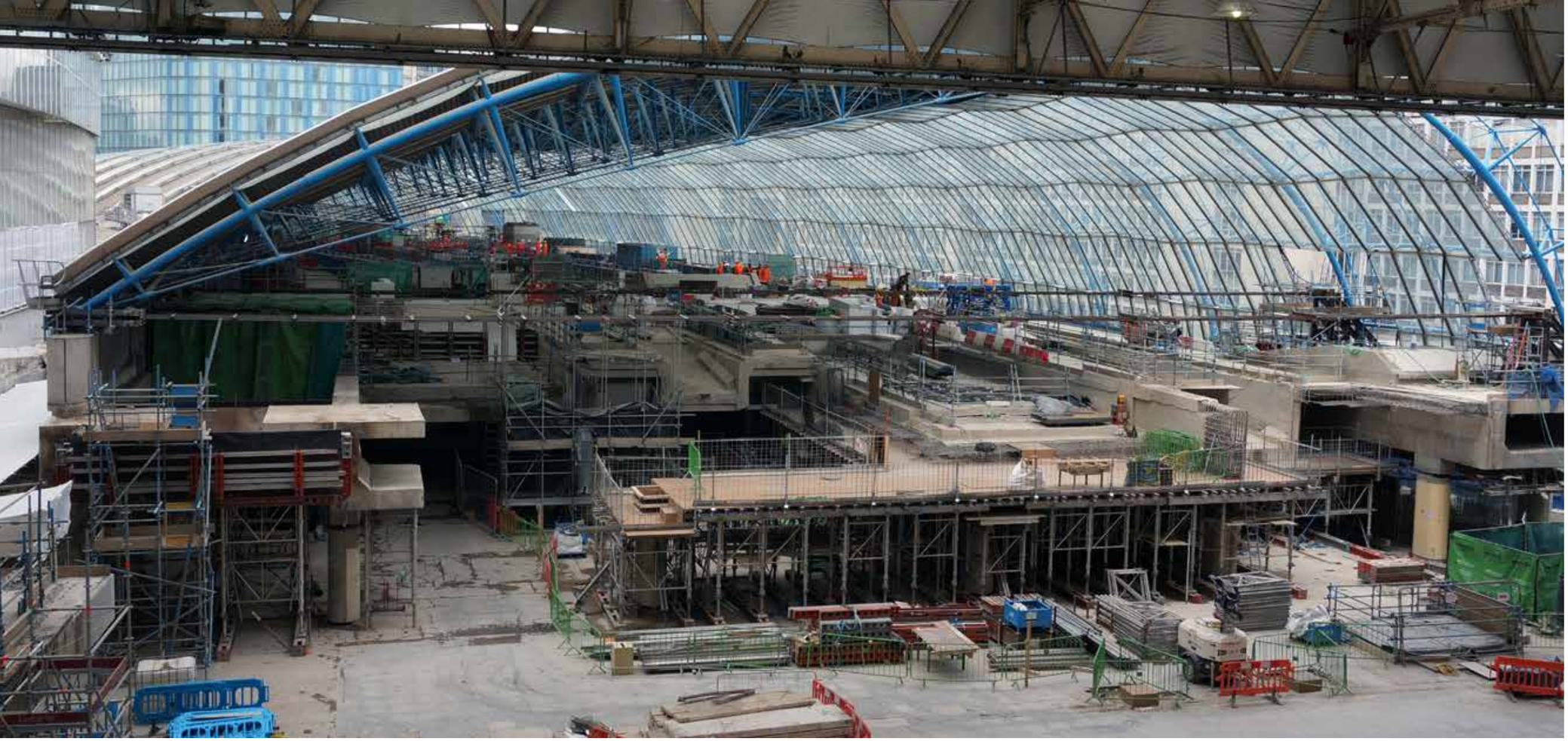


Temporary tie
Tension cables brace the arch roof at five locations while new openings are made in the platform slab

Working hard 24/7

In preparation for services to run on platforms 20 to 24 during summer 2017 (while platforms one to eight are modified), an immense amount of work was done to upgrade signalling and power. To ensure the live railway was unaffected, changes during the day were made off-line and tested at night when the station was closed. With only three to four hours available to carry out work at night, upgrading cables at Waterloo was a relentless process, especially as the original system had to be reinstated within this time to allow normal service to resume in the morning. During the Christmas 2016 possession, work was carried out to supply power to platforms 20 to 24, which required new connections to be made to switch rooms on the other side of the station. Cables were threaded underneath the station (through the brick arches) or redirected via newly constructed overhead gantries.

Beyond Waterloo Station, at Queenstown Road in south-west London, engineers worked flat-out during weekend possessions in November and December 2016. “A typical weekend possession involves working from 00.40 on Saturday night until 03.24 on Monday morning, during which time large Kirov cranes, heavy equipment and our team of engineers remove and replace track to suit the longer 10-car trains. They then return the track back for normal use,” says Wessex Capacity Alliance director Riccardo Zampieri.



Optimised engineering
The WIT's blue tubular steel arch roof is supported by tension cables while the platform slab is being demolished

Planned possession – August 2017

Work carried out during the August 2017 possession has been planned hour-by-hour using building information modelling (BIM). The majority of work carried out on site over this period involves reconfiguring platforms one to eight and realigning track. Platform nine will also be closed during this time.

While these nine platforms are out of use, the WIT platforms will provide extra line capacity. BIM was used to determine the amount of work that could be done in the 24-day possession – one of the longest undertaken on the network.

"The length of this railway possession has dictated much of how the work will be done. For example, track panels have been sized so that the correct number can be fitted in the time available," explains Tony Wilkins.

Precast concrete units will extend platforms one to four by 40m during the possession. Due to the curving and tapering nature of the site, each unit has to be unique. Each also has to be detailed for manufacture far in advance of the works. Prefabrication has been preferred to speed up construction and ensure a 'right first time', high quality finish.

Unlike a normal linear construction programme, demolition, construction, installation, testing and commissioning all take place concurrently at Waterloo Station. The work inevitably means that some areas of the station have been opened up for the first time in decades, throwing up the potential for even more work needing to be done. Teasing out which activities are essential to the official remit of 'capacity increase', and deciding how, when and at what pace the work should be done to meet delivery milestones, make this project more complex than most.

Fortunately, the nature of working in an alliance highlights the synergies that naturally exist between different disciplines, giving the opportunity to maximise the outcome of every bit of work being done. Its existence has been essential to the success of this project and, perhaps, was the only way of meeting the current and future needs of the route's rail users, the train operator, asset owners and, ultimately, the taxpayer's purse.

"Some £6-7M has been saved by removing the need to build new supporting structures or monitor existing structures for movement."

Chris Kitching
Wessex Capacity Alliance contracts engineering manager

Waterloo Station upgrade

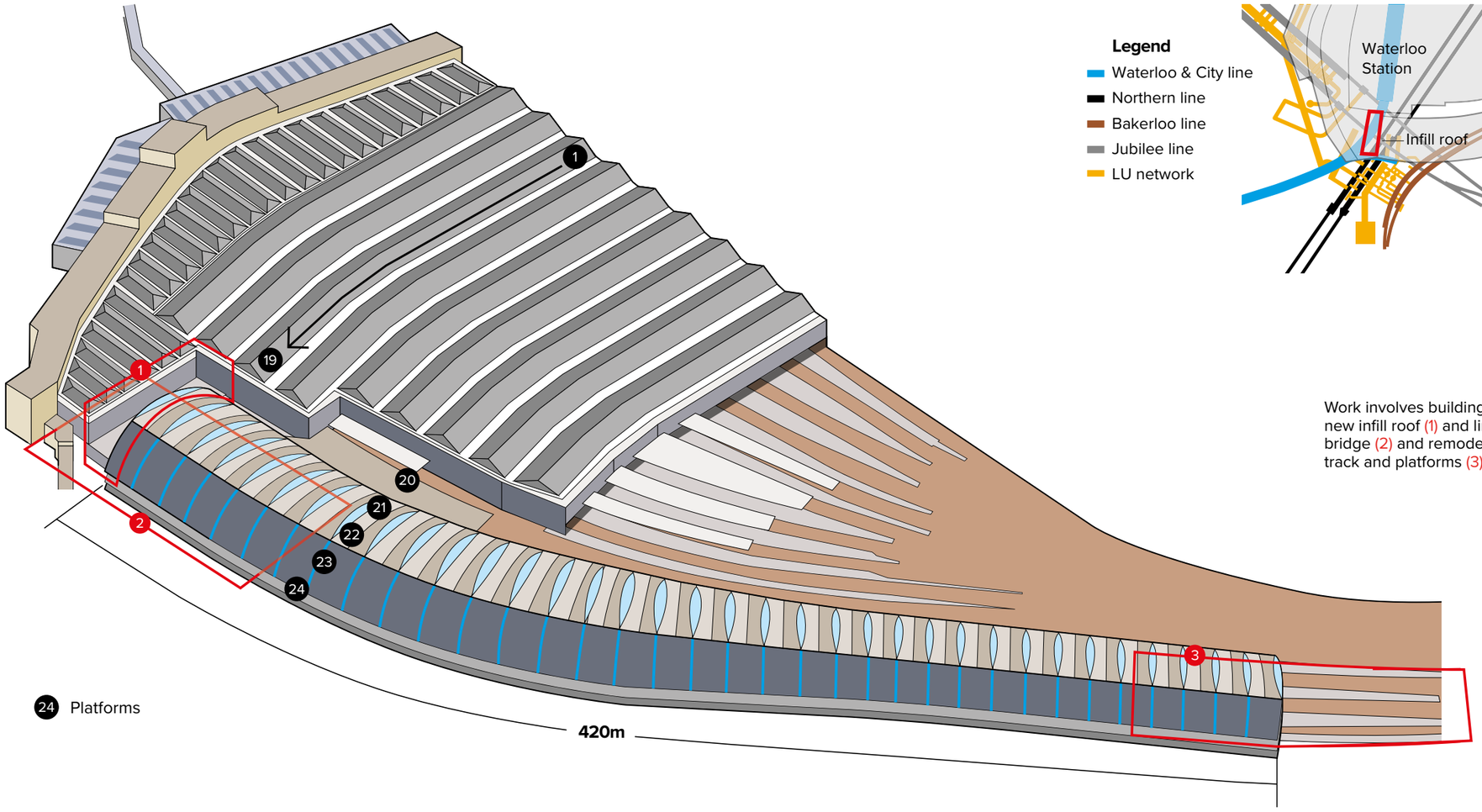
The former Waterloo International Terminal (WIT) is being brought back into service to increase capacity on the Wessex route.

Load-balancing

The complexities of refurbishing the WIT are magnified by the fact that the station sits on top of Victorian brick arches and the Northern, Jubilee, Bakerloo and Waterloo & City Underground lines. Controlling how capacity upgrade work affects existing structures has been a significant challenge for designers.

One of the Alliance's first exercises was to scrutinise existing 'as-built' plans and drawings, carry out its own surveys and inspect the condition of existing supporting structures to understand their load-carrying capacities. By also calculating the magnitude of load from structures due to be demolished as part of the refurbishment work, engineers could identify which structures would have spare capacity to take loads from new works.

"This was particularly important for London Underground since the process of demolition followed by the relatively quick reloading of assets and the ground creates minimal disturbance," explains Alliance contracts engineering manager Chris Kitching.



"This is extremely desirable as soil and substructures can undergo this kind of unloading and reloading without experiencing any real effect, which removes the need for excessive movement monitoring. The key to this scheme was to come up with a 'load-balancing' strategy which puts load back where it has just been removed." In doing so, some £6-7M has been saved by removing the need to build new supporting structures or monitor existing structures for movement.

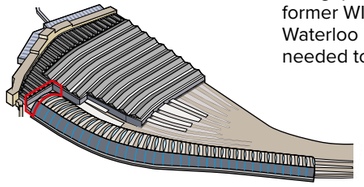
This concept of spare capacity was also exploited on the WIT platforms. Since the new domestic trains are shorter than Eurostar trains, buffer stops are positioned 50m further up the line (away from the station). This means that the 'live' loads associated with trains arriving and departing will affect a smaller area than before, freeing up capacity at the station end of the track to support greater static loads.

A large area within the WIT was previously used to support heavy, reinforced concrete service routes for baggage, catering and other back-of-house facilities. Since these are no longer needed, removing them has led to a net reduction in loads, which has meant that their supporting columns, walls and foundations can sustain loads from new works. Load-balancing has influenced where new loads can be accepted, including a new ramp between platforms 19 and 20, a 14m wide canopy to connect the WIT and Waterloo Station's 'shed' roof and a footbridge to provide step-free access.

London Underground network below the works

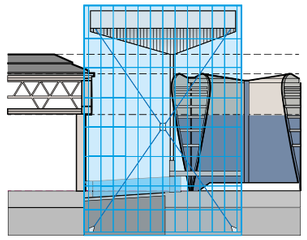
Work involves building a new infill roof (1) and link bridge (2) and remodelling track and platforms (3)

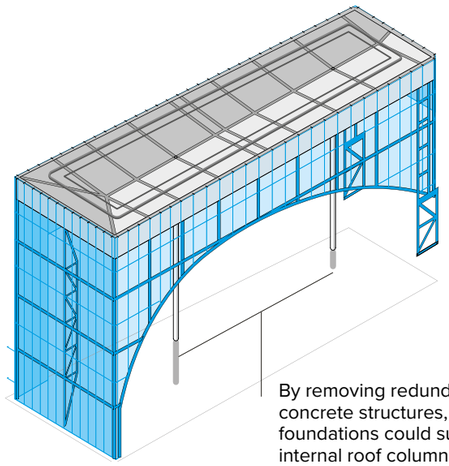
1 Infill roof structure



The gap between the former WIT roof and Waterloo Station's roof needed to be covered

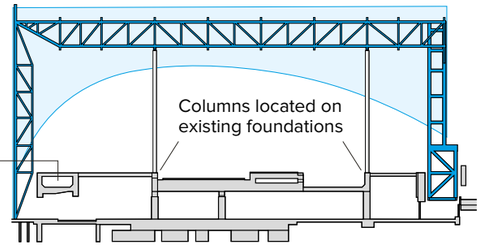
Infill roof elevation





By removing redundant concrete structures, foundations could support internal roof columns

Infill roof in section



When the WIT was built, a covered check-in area marked the transition between the old station and the new. The check-in was a storey lower than the main station concourse and platforms.

Under the upgrade, the old check-in roof now forms part of the concourse for the newly repurposed platforms, and a new weatherproof envelope was needed. All loads from the new roof have to be supported by existing structures and foundations due to Tube tunnels and stations running below ground.

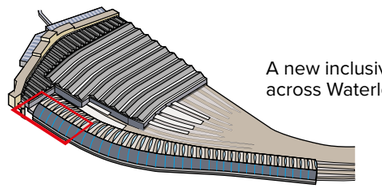
One of the original ideas was to replicate and continue the WIT roof to meet the mainline station's roof. However, this came in at an unfeasibly high cost, due to its many bespoke features. Instead, a much simpler 53m span steel trussed roof was proposed, which would oversail both the WIT and shed roofs. Louvres in the new roof assist in cooling the space and provide ventilation for the station's fire strategy.

Initially, the loads at each end of the roof exceeded the bearing capacity of the structure below, so two intermediate columns (supported off existing structures) were suggested. This sparked a complete architectural redesign of the roof to echo the ridgeline of the shed roof over platforms one to 19.

"Columns have been located so that the load from the infill roof is supported by existing assets to achieve as near-perfect load-balancing as possible," says Chris Kitching.

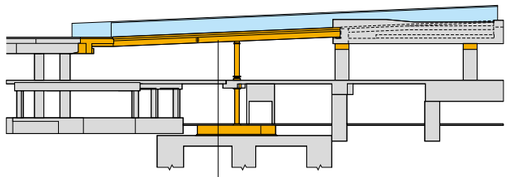
"We carried out a time-history analysis to understand the impact of demolition and construction on the structure and soil. Around £4M has been saved by not having to install new foundations and £2-3M has been saved by reducing the scope of monitoring of the existing structure," adds Chris.

2 Link bridge

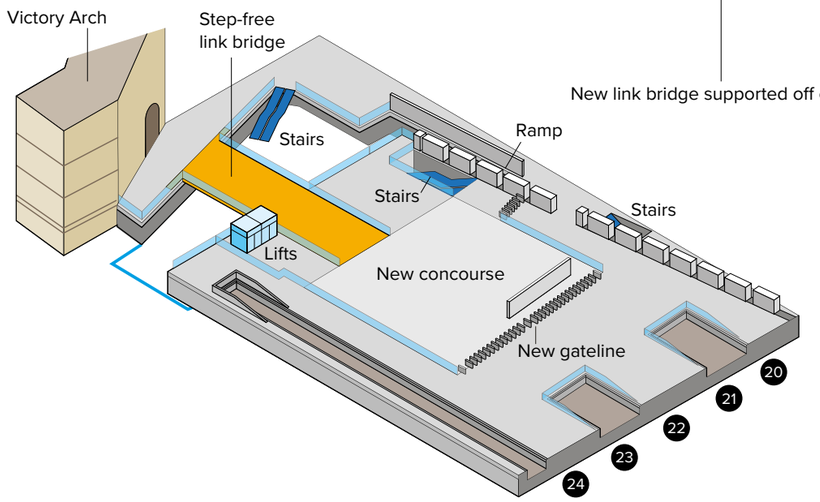


A new inclusive route across Waterloo Station

Link bridge in section



New link bridge supported off existing foundations



24 Platforms

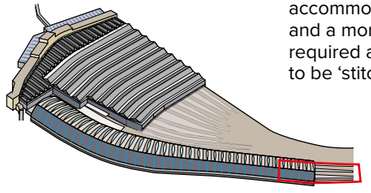
Remodelling the WIT has involved understanding how passengers will move around the station. A tangible benefit of the Alliance's work has been the introduction of a pedestrian walkway connecting platforms 20 to 24 to the main concourse of Waterloo Station.

This was not part of the original scheme due to concerns over how any new structure would be supported. Originally, passengers would have had to descend to a lower level concourse by escalator or lift and then travel back up to platform level.

By understanding the load-carrying capacity of the station's substructures and carrying out load-balancing, a footbridge has been incorporated in the design, which does not require new foundations and rests on existing columns, walls and foundations.

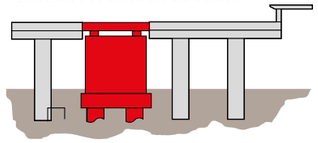
The walkway brings together the two parts of the station, taking in a 1.6m discrepancy in height between the WIT and main concourse and offers a more intuitive and inclusive route into the station than previously conceived.

3 Viaduct deck

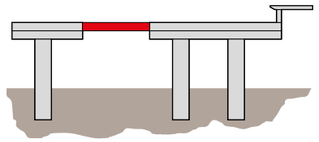


A new track layout to accommodate shorter trains and a more frequent service required approach viaducts to be ‘stitched’ together

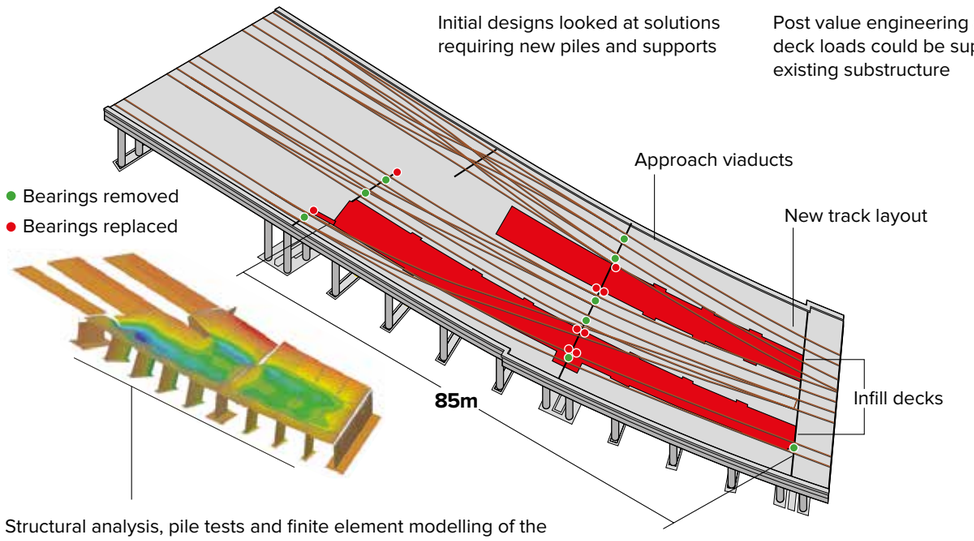
Viaduct works in section



Initial designs looked at solutions requiring new piles and supports



Post value engineering analysis showed deck loads could be supported by existing substructure



Structural analysis, pile tests and finite element modelling of the bearings and amalgamated viaduct proved that new train and deck loads could be supported by existing substructure. Some bearings were modified to suit the new loadings

The stitch-up

To accommodate a more frequent domestic service of 18 trains per hour – some 12 more than before – the former WIT track layout needed remodelling and its approach viaducts to be significantly modified. Despite the challenging work, savings of £4.9M were achieved through value engineering.

Eurostar trains used to arrive at the WIT on three approach viaducts, separated by 5m wide platforms. To suit the shorter length of new domestic trains, these platforms have been shortened and the space left between the viaducts filled to allow more flexible track layouts.

The addition of infill sections of viaduct deck combined with new train movements creates a completely different loading pattern. There were concerns that the new maximum loads could exceed the capacity of the existing viaduct deck, its piers and foundations.

Two options emerged: to build new supports and foundations to take the new loads or find a way to ensure the existing structure could cope.

Build new or reuse?

Building a new support structure for two infill sections of viaduct, some 100m long, would be costly, time-consuming to build and extremely disruptive to the railway and public. Their construction would involve disturbing contaminated soil (due to the area’s industrial land-use) and require the diversion of many services. Large diameter piled foundations about 35m long would also need to be installed using a piling rig which would need to fit under the viaduct. With headroom limited to 5m, progress would be slow. There was also the added complication that the busy Westminster Bridge Road runs under the viaduct. Supporting the infill section in this location would require the road to be closed while new foundations were built. From early 2015, approach viaduct design work was carried out and planning applications pursued for both the ‘new pile’ (though not desirable) and the ‘pile re-use’ options to make sure time was not lost in the programme whichever proved most viable.

The first step in the design process, common to both options, involved minimising the distance over which the viaducts needed to be crossed. Successful track remodelling reduced the length of infilling by half as well as the number of new piles needed for support.

“This meant that a 32m length of infill deck across Westminster Bridge Road was not required. Constructing its substructure would have been horrendous for traffic and would have required months of planning to allow the work to take place,” says Wessex Capacity Alliance

1480t

£5M and 1480t of carbon has been saved by reusing existing piles and not constructing any new ones on the approach viaduct widening work.

design lead for Waterloo Approach Stuart Bee. However, one attraction of the new pile option was its low impact on existing structures compared to the reuse option. The infills, without new supports, would push the viaducts apart and the team had to verify that they could sustain these additional lateral loads. Bearings between piers and deck had only been designed for longitudinal movement and so would also need to be re-evaluated and possibly replaced to suit the new loading pattern.

As-built detailed drawings were sourced from archives to build up a picture of the capacity of the viaduct structure, but Mott MacDonald had another trick up its sleeve: it had been involved with carrying out independent checking on the original viaduct design in the 1990s. There were even engineers still with the firm who had worked on it and recalled that the structure had been designed with some degree of spare capacity. By retrieving calculations from its own archive depository, confidence in the reuse option grew.

Information gathered from these archives combined with physical inspections of the viaducts to verify their condition, provided assurance that they could support the infill deck sections. However, there was still one last piece in the jigsaw: in the absence of in situ pile testing information, conservative strength capacities could only be assumed for the existing piles. “We found that 90% of the scheme would work without constructing new piles, but that a few piles would still be needed,” recalls Stuart. To get around this, three test piles were constructed on site and tested to understand their true capacity in the ground. Using these figures, no new piles would need to be constructed.

Savings and minimal disruption

“Removing the need to install 65 new piled foundations saved £1.5M, as well as the disruption caused by construction and related carbon emissions,” he explains.

“Working under the Alliance, gave us the breathing space needed to look into these options and come up with the most appropriate, cost-effective and least disruptive solution.”

The final design involved a great deal of complex analysis using a finite element model. This allowed the stresses generated by the infill section bearing onto the viaducts to be understood and distributed in a way that did not exceed the capacity of the structure in any location. This went hand in hand with the bearing design, which was also scrutinised to permit or restrict different degrees of directional movement in the pier-deck connections.

There was still one area, between platforms 19 and 20, where a new infill section of track was needed. To support it required the 20th century viaduct to be connected to a 19th century masonry arch (which supports the mainline). But creating this connection would cause immense disruption to train services as well as to the tenants of the arches below.

Track designers had already created a layout which could provide 18 trains per hour without using this area. “So we asked whether this section of track was absolutely necessary given how expensive and disruptive it would be,” recalls Stuart.

Network Rail and train operator South West Trains responded by removing the need for this section of track from the scope of the project. The viaduct sections were stitched together by first removing the concrete to expose the reinforcement on the relevant sides of each viaduct using hydro-demolition, inserting new reinforcement and then casting the concrete infill sections. This work was carried out in 2016.

Ingenious engineering and collaborative working on the approach viaducts has resulted in saving several months on the programme.

“Removing the need to install 65 new piled foundations saved £1.5M, as well as the disruption caused by construction and related carbon emissions.”

Stuart Bee
Wessex Capacity Alliance design lead for Waterloo Approach

Opening opportunities with connected thinking.

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