

Bridge on the River Thames

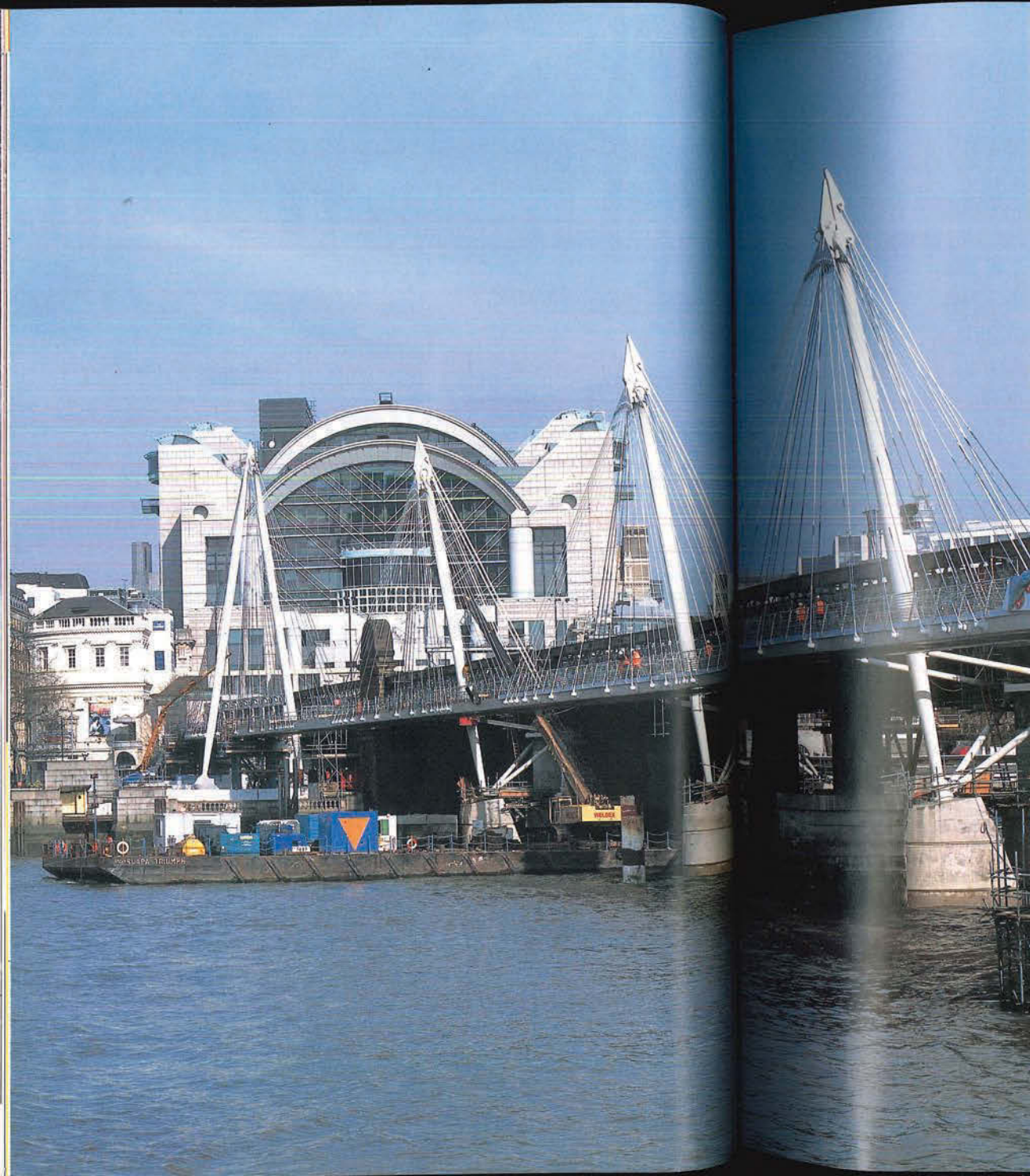
This is the epic tale of time bombs, divers, and the courage of a small band of engineers in the face of overwhelming odds. Yes, we are talking about the construction of a footbridge. **Andy Pearson** explains. Photographs by Adam Wilson

TWO SPECTACULAR FOOTBRIDGES ACROSS THE THAMES WILL soon be framing and shaming the lumbering Hungerford Rail Bridge, presently the only link between Charing Cross Station and the South Bank Centre. On the upstream one, seven steel pylons rise from concrete piers strung across the river. At the tip of each, threadlike steel rods fan out to support the deck 20 m below. On the deck itself, workers are busy installing stainless steel handrails and deck lights ready for the bridge's 13 May opening.

Construction is less advanced on the downstream crossing. An army of workers, dwarfed by mobile cranes and massive box girders, swarm about a temporary working platform above the river. A truss supporting the partially complete bridge deck spans from the platform across the river. The construction team are upbeat about completing this bridge for a November opening.

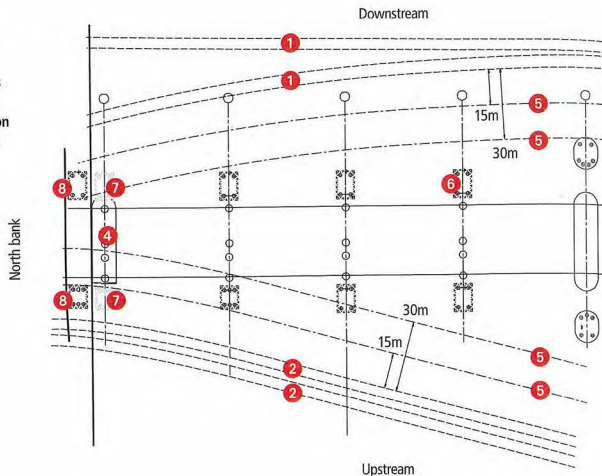
A pedestrian taking an easy stroll over its elegant, cable-stayed form after it opens would have no idea that they were standing on the site of a battlefield over which the bridge builders and London Underground struggled bitterly for more than a year, and which had conjured up visions of the apocalyptic drowning of central London.

The story began in conventional fashion with architect Lifschutz Davidson, working with structural engineer WSP and quantity surveyor Davis Langdon & Everest, winning an international ▶



Plan of bridge foundations and Tube lines

- ① Northern Line
- ② Bakerloo Line
- ③ Existing rail bridge
- ④ Middlesex Pier
- ⑤ LU restriction zones
- ⑥ Piled foundations
- ⑦ Planned pile location
- ⑧ Actual pile location



► design competition in 1996. The client for the project was Cross River Partnership – a consortium of local authorities and Railtrack – and it awarded the construction tender to a Costain/Norwest Holst joint venture partnership in July 1999. A price of £21m was agreed for construction under an ICE design-and-construct contract.

Under the ICE form, the contractor has responsibility for completing the design within a fixed price. "Certain elements of the design were mandatory, such as the pylon's dimensions and spacing of the support cables – anything that had an architectural significance," says Gordon Clark, a director of consulting engineer Gifford, the contractor's structural engineer on the scheme. Clark says the contract was "adopt and build and not design and build", although, crucially, it did not specify how the pylon foundations were to be constructed.

The contractor won the scheme based on its proposal to

How the bridge decks were constructed

The concrete bridge deck was constructed on temporary casting platforms using a process known as incremental launching.

After the first 50 m long section of concrete deck was cast, it had to be strengthened by bolting a huge, temporary steel truss to it before it could be moved. The first section of deck was then pulled outward across the river to rest on a temporary pier so that it bridged the first span.

The next section of deck was cast on the tail of the first section and then this 100 m long section was pulled further out across the river. The process was repeated for all seven sections of the deck.

With the deck now spanning the river, the pylons were installed. The steel rods that connected the deck to the pylons were fitted next and adjusted to support the deck. Finally, the temporary supports and truss were removed and the bridge was complete.

construct both the 325 m long bridge decks using a construction technique known as incremental launching. Instead of precasting the decks in 50 m sections and transporting them up the busy river on barges, the contractor proposed to cast the deck as a single unit on site. "They were the only team we considered alternative methods of construction," says Peter Hardwick, project director and project manager for the Westminster (see "How the bridge decks were constructed"). The construction programme was devised to ensure that pedestrian crossing was open at all times. Once the new bridge was open, the old walkway over Hungerford Railway Bridge would be removed and replaced by the new downstream bridge. But first the concrete piers on which the pylons would be constructed. By October 1999, mechanical plant had arrived on site and construction began.

The contractor knew the pile installation was not going to be easy. First, the river had to be kept clear, so the piles had to be constructed without the boring equipment blocking the bridge's centre spans. However, this paled into insignificance compared with the problems it encountered with the Tube lines under the Thames in two arcs that almost intersect the bridge when it nears the north bank (see diagram above). Hardwick says London Underground was told about the project in advance, before the detailed design work on the foundations had been done – standard procedure in civil engineering. LU's response was to demand approval over any work that would take place within 15 m of the tunnels. This would probably confine the contractor to "engineering hours" after dark, which would be an inconvenience, but not a disaster.

The contractor designed the pylon foundations as clusters of four piles bored up to a depth of 42 m into the river bed. Each cluster was crowned with a pile cap, on top of which a large concrete pier. Work started on the south bank



Temporary steel truss supports the bridge while the piers are installed.

where the LU restrictions did not apply; at the same time, the design of the foundations continued to evolve. When LU was eventually shown the detailed designs, it became nervous about what was being proposed. Its main concern was that the works could detonate a bomb left over from the Second World War. One had been found nearby in the 1950s, and although the contractor carried out a detailed ground survey, partly conducted by divers with magnetometers, it could not say for sure that there were no leftover munitions under the river bed.

As the piling approached the north bank, and the all-important 15 m and 30 m zones were reached, LU increased the restrictions. Now it wanted all work to take place during engineering hours. This meant the contractor would take control of the track underneath the Thames, closing the floodgates at either end of the tunnels. No work was reached on a working method for the 3-15 m

zone, and work within 3 m of the tunnels was banned outright. Nonetheless, work on the bridge continued.

When the contractor was ready to begin work on the piers closest to the northern bank, the battle began in earnest. LU looked at the design and said, in effect, that it couldn't build its foundations there. The contractor offered to hand-dig the piles within the 15 m zone, but LU was adamant. The two sides reached an impasse. "The final straw was when LU decided that some of the bombs might have a 96-hour delay fuse, which meant the work could not be carried out, even if LU closed down the underground lines over a weekend," explains Hardwick. Tube bosses were kept awake at night by the prospect of an explosion emptying the Thames into the Tube system. To avoid any risk of this, the tunnels would have had to remain closed for four days after work finished – which was unacceptable to LU. What was more, LU wasn't going to consider closing the ►

How the structural engineering works

The most obvious structural element for the bridge is the seven pylons that stand high above the pedestrian walkways. The pylons are inclined and lean outwards, away from the rail bridge. The base of each of the pylons is connected to a pinned joint mounted on top of a concrete pier rising up from the riverbed. The foundations for the two footbridges are independent of the existing railway bridge because Railtrack was insistent that the new footbridges should not increase the load on the existing rail bridge.

The bridge deck itself is suspended on two fans of slender steel rods, called deck stays, which hang from the top of the inclined pylon. The pylon is held in its inclined position by four rods, called backstays. These connect the top of the pylon (on the opposite side of the pylon to the bridge deck supports) to a circular collar placed around the top of the existing rail bridge caissons.

Because the pylons lean, the backstays are under tension, which would tend to pull the collar upward. To counteract these forces, the collar itself is tied back to the pylon's foundations by two additional tie-down rods.

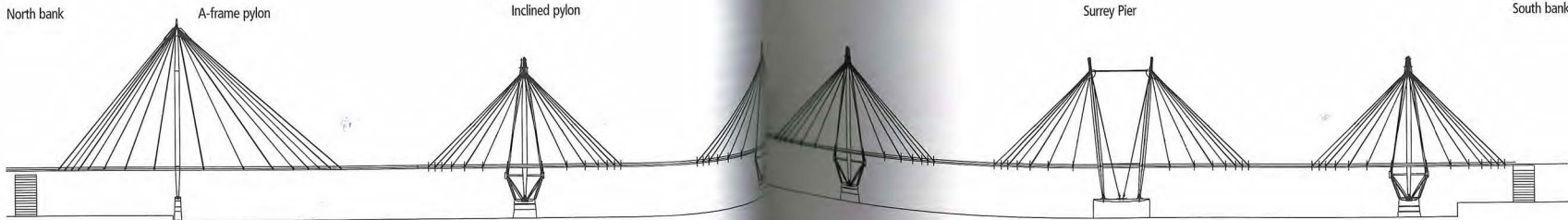
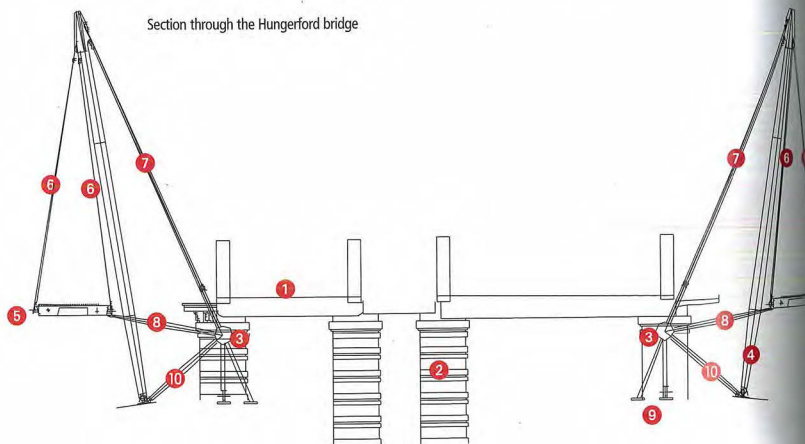
A steel tube, called the deck strut, holds the deck in position to

stop it swaying. The strut ties the inside edge of the bridge deck to the same collar to which the backstays are connected.

A backstay strut links the base of the pylon to the collar by the backstay rods.

Cross-section through the bridge

- 1 Existing rail bridge
- 2 Existing caisson
- 3 Collar
- 4 Pylon
- 5 Bridge deck
- 6 Deck stay
- 7 Backstay
- 8 Deck strut
- 9 Backstay tiedown
- 10 Backstay strut



The final pylon had to be put on the north bank, rather than in the river, as originally planned. It had to be taller than its sisters to support the extra 10 m span. The solution was to change it to an A-frame structure.

...some lives at all until November 2000 – the date at which the pedestrian crossing was supposed to open. "They [LU] got us into a whole lot of difficulties in late spring, early summer," Hardwick recalls bitterly.

Not surprisingly, LU has its own view of these events. In a statement issued in August 2000, it pointed out that "at no point did the contractor for the construction of Hungerford bridge withdraw the contract for the construction of Hungerford bridge or signed off the Cross River Partnership. ... Westminster council or any other engineering contractors submit to London Underground full details of their engineering proposals." And if they had, LU went on, they could have told them at the outset that they could not pull the final pylons in that position.

Back on the south bank, construction of the upstream bridge deck was due to begin when it finally dawned on the project team that London Underground's restrictions were so onerous that they would not build their bridge.

The contractor halted work while it made one last attempt to agree to an agreement with LU over the final pier. "We had huge meetings with LU all through February and March [2000], where everybody and his mother came," says Hardwick. The meetings were to no avail: "The issue was London Underground's giving that party approval to do the piling work, but with the third party [the contractor] having no responsibility for the consequences," says Hardwick. "Under these circumstances, why would they agree to change anything?"

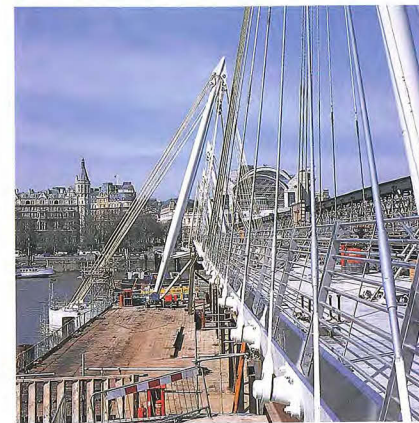
Even if agreement could have been reached, the contractor

The final straw was when London Underground decided that some of the bombs might have a 96-hour delay fuse

Gareth Hardwick, project manager, City of Westminster council

...would have another problem. This was with the "Middlesex Pier," a brick structure close to the north bank that was a remnant of an 1846 bridge designed by Isambard Kingdom Brunel and was incorporated into the Hungerford Rail Bridge. There were concerns that it was not strong enough to withstand piling work in the vicinity.

In November, the client decided that the bridge would have to be redesigned, the final pylons relocated to the north bank, rather than in the river, and the pile in the river in LU's 15 m to 10 m zone hand-dug, with a single 4.8 m shaft replacing the



Above The slender bridge deck is suspended from the inclined pylons.

cluster of four 1.5 m diameter bored piles. But even without the threat of detonating a bomb and flooding the Tube system, it was proving difficult to find a suitable location for the final pylon. "We were still looking for somewhere to land the bridge," explains Clark. Eventually, a site was found close to the road running parallel to the river.

Moving the pylon created a new problem. Its new location meant that the final span would have to be extended by 10 m. This meant the pylon would have to be taller if the engineer was to keep its fan of steel rods to the bridge deck at a consistent angle with the others. But increasing the height of the pylon created yet another problem: the backstay rods that hold the pylon inclined clashed with the railway bridge.

The solution was to change the design of the pylon from an inclined post to an A-frame structure, with the deck suspended between the frame's legs like a swing (see diagram below). But LU still insisted the foundations be hand-dug, during weekend track closures with the floodgates closed. ▶

What happens if a ship hits the supports?

The Port of London Authority stipulated all the piers supporting the new footbridge should be able to survive the impact of a 3000-tonne vessel (that is, heavier than any boat currently using the Thames), travelling at 12 knots at an angle of 15 degrees to the bridge. This is a feat the old rail bridge was incapable of, and explains why Railtrack was prepared to contribute to the cost of the footbridge.

The contractor had to meet the PLA's criteria with minimal narrowing of the navigable opening between the cast iron piers of the Hungerford bridge. Rather than increase the size of the supports either side of the bridge, the contractor devised a novel method of linking the upstream and downstream piers so that the impact load is shared between both. Huge concrete beams, more than 45 m long, up to 4 m high and weighing about 250 tonnes, tie the piers together.

The original idea was to construct a cofferdam around the base of each pair of supports and cast the beams in situ. However, the limited headroom available beneath the rail bridge made construction of the cofferdam a virtual impossibility, so the contractor opted to precast the beams in Costain's yard, down Thames at Erith.

The beams were raised from the barge and suspended in pairs beneath the railway bridge, either side of the rail bridge caissons. Shuttering was then installed beneath the beams to form a trough, with the beams acting as its sidewalls. Shuttering was also placed around the rail bridge caissons passing through the centre of the trough before the assembly was filled with concrete. The whole 600-tonne assembly was then lowered onto the riverbed and divers locked the beam into position by inserting a steel pin.

► For the client, such a fundamental change to the contractor's scope of works when construction was well under way would have left Cross River Partnership open to enormous legal claims. "A year into the contract, if I were to issue an instruction for such a change I would be at large for a claim of God knows how many millions of pounds," laughs Hardwick. With the additional expense incurred by hand-digging the foundations, the contractor was in no mood for charity.

If the bridge was to be finished, both the financial and technical difficulties would have to be resolved quickly. The man who solved the first of these problems was Ken Livingstone. The mayor came to the rescue with £16.7m through the Greater London Authority's Transport for London arm. This, along with £3m provided by

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Gordon Clark, director, consulting engineer Gifford

Westminster and Lambeth councils and Railtrack, saved the project. "The financial side was rescued by Ken in the main," says Hardwick.

In January 2001, the contractor signed up to a new form of contract for a revised cost of £39.5m. This time an Engineering Construction Contract type C was used, which protects the contractor against unforeseen ground risks.

With the paperwork now resolved, the pressure was on the contractor's structural engineer, Gifford, to revise the bridge design to incorporate the new A-frame supports. In addition to designing the new structural elements, the engineer had to check that



Above The slip-impact beams are just visible at low tide. The concrete at each end of them will be removed once the deck installation is complete.

completed parts of the bridge could withstand the new load. An A-frame would impose. "We had to go right back to the beginning to see if the change affected the foundations we'd already explained," explains Clark.

There was no quick solution for the engineer; the entire structure had to be analysed. This was no easy task: "The analysis was difficult because the worst-case scenario was different for every element of the bridge," says Clark. Time was not on the engineer's side: "We were 12 months into the project, the contractor was shouting and our backs were against the wall. It was quite a hairy time," Clark says. Eventually it was proved an extended span could be accommodated with only minor changes to the steelwork.

On the positive side, the redesign created the opportunity to save money. The link bridges, designed to provide additional access from the South Bank, were dropped along a proposed visitor centre, which Clark describes as "part of the exercise to get a price for the bridge Westminster could stand." Other modifications included replacing the granite deck with cheaper reconstituted granite slabs and simplifying the lighting system – something the contractors now rushing to complete the upstream bridge in time for its opening will appreciate. Once this is open, work can finally start on downsizing the existing dilapidated footbridge and construction of the new crossing can begin in earnest.

Project team

client Westminster council on behalf of Cross River Partnership
 architect Lifschutz Davidson
 concept engineers WSP
 quantity surveyor Davis Langdon & Everest
 main contractor Costain/Norwest Holst joint venture partnership
 contractor's structural engineer Gifford
 technical advisor to Westminster council Halcrow