4. Ealing Road Bridge – CFRP resin wrap and plates bonded to concrete

Introduction
Ealing Road Bridge is a reinforced concrete portal frame bridge carrying the A4005 over the Grand Union Canal in north London. The deck was strengthened with fibre composites in both sagging and hogging and the abutments were strengthened by the addition of a new reinforced concrete fascia.

Step 1.
Type of structure

Ealing Road Bridge is a reinforced concrete portal frame bridge with a skew span of 13.68m built around 1924. It is over a canal and towpath and carries vehicular and pedestrian loads. The bridge comprises of 190mm thick slab with ten down stand beams, two service troughs and two edge beams. The down stand beams are typically 1070mm by 355mm and spaced at 1.52m centres under the roadway and 1.83m centres under the footways. The abutments are of similar construction to the deck, being a relatively thin wall with counterforts on the buried face.

The bridge had been assessed to have a live capacity of 17 tonnes to BD21 and it was required to strengthen it to carry 40 tonnes assessment live loading (BD21/97).

Step 2.
Design conditions

Partial record drawings were available, which provided details of existing reinforcement in the deck and abutments. Record drawings of the wing-walls were not available. There was record of the existence of a strengthening over-slab on top of the deck at the edges of the carriageway, which had been installed when the road was widened onto what had previously been very wide footways. However, details of the overslab size, extent and reinforcement were not recorded.

An existing assessment had identified the deficiency in the deck beams and slab spanning transversely between the beams and at the top of the abutments.

Third party constraints were particularly onerous:

> British Waterways specified that the canal could not be blocked to traffic, and works must occur during the winter maintenance period.
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> The bridge is immediately north of the Hanger Lane gyratory system, and the Metropolitan Police required that the bridge be always open to two-way traffic and that the works be undertaken during the school summer holidays when road traffic is at a minimum.
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> Further complicating traffic management, signal controlled junctions were immediately (60m) north and close (150m) south of the bridge, and traffic was frequently queued across the bridge in both directions. A busy bus depot was located on the corner at the north junction, and large numbers of busses used the bridge. There was no alternate route suitable for busses or HGVs across the canal without a diversion of approximately 5 miles.
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> Since the bridge was the only road across the canal for some distance, a very large number of services crossed the deck, including large water gas and sewer mains and electric cables.
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> The towpath contained high-voltage electric cables and fibre optic cables.

Step 3.
Initial testing and investigation

In light of the many constraints, some conflicting, the structure owner (London Borough of Brent) commissioned TGP to produce a detailed feasibility study, which included inspection of the structure, with break-outs to expose reinforcement and trial-pits in the road and on the towpath.

Strengthening options examined included over-slabbing or complete replacement of the deck and additional reinforcement added to the buried counterforts or new concrete added to the exposed face of the abutments.

The cost of services diversions and the police traffic requirements ruled out deck replacement and some very disruptive strengthening options.

The result of the feasibility study was a proposal for a strengthening scheme adopting a combination of fibre composite and conventional strengthening and repairs:

- Pultruded CFRP strips to strengthen the main beams in sagging
- In-situ lay-up fabrics to strengthen the main beams in shear at locations near the abutment faces
- In-situ lay-up fabrics to the soffit of the deck slabs to strengthen these in transverse flexure
- In-situ lay-up fabrics round the corner from the top of the deck to the back of the abutment to strengthen this location in flexure
- New concrete face to the abutment walls to strengthen these in flexure
- New drainage cored through existing wing-walls to relieve loading due to water pressures
- Extensive conventional concrete repairs to address spalling and corroded reinforcement throughout the structure.

The strengthening works on top of the deck were limited to the width of deck between service bays and thus did not require and services diversions. Resolution of some conflicting constraints (such as works timing) was not considered at this stage, but these issues were identified and highlighted for resolution during detailed design.

Following development of the outline proposal, further inspection and testing was undertaken to examine the quality of the existing concrete and confirm suitability for surface-mounted strengthening. The soffit of the entire deck was coated in a cementitious render that masked some areas of deficient concrete. The soffit was tap-tested throughout (working from a boat-mounted platform) to attempt to quantify the areas requiring repair, and pull-off tests were completed both to the render and to the parent concrete. Chloride content and depth of carbonation testing was also undertaken.

Step 4.
Material selection

Since the works were to be competitively tendered, the design was based upon generic material properties, which could be sourced from a number of suppliers:

Strip for flexural strengthening

- Pultruded carbon fibre strip, with properties
- Young's modulus, *E*, at least 150kN/mm^2
- Tensile strength at least 2000N/mm^2
- Ultimate tensile strain 1.5%

Fabric for flexural and shear strengthening

- Carbon fibre unidirectional fabric

Young's modulus, *E* at least 230kN/mm^2
Tensile strength at least 3000N/mm^2
Ultimate tensile strain 1.5%

Adhesives for each case were assumed to be epoxy, meeting the requirements set out in Concrete Society Report TR55.

Under the proposed classification scheme the strips would be classified as PBU/1/C/E, and fabrics as RW/1/C/E

Step 5.
Partial factors

The following partial factors were adopted, in accordance with the recommendations of TR55:

Strips for flexure
- Material type factor - 1.4 (carbon)
- Method of manufacture factor - 1.1 (pultruded plates)
- Young's Modulus factor - 1.1

Fabrics for flexure
- Material type factor - 1.4 (carbon)
- Method of manufacture factor - 1.4 (wet lay-up sheets)
- Young's modulus factor - 1.1

Fabrics for shear
- Material type factor - 1.4 (carbon)
- Young's modulus factor - 1.1

For design of new reinforced concrete, methods and partial factors were in accordance with BS5400 Part 3.

Step 6.
Design calculations

The strengthening was designed following guidance set out in TR55. The geometric, material and loading data already determined were used to find the area of reinforcement required in flexure. Checks were performed with regards to peeling and debonding failures.

For a typical main beam in flexure a CFRP strip 100mm wide by 1.2mm thick Sika CarboDur S was selected. Beams towards the deck edges had greater requirement. To simplify material supply, a single size strip was adopted, so 2 or 3 strips were applied to some beams.

For the same reasons of simplifying material supply, a single type of fabric, being 600mm widths of unidirectional carbon effectively 0.13mm thick. The flexural fabric applied to the top of the deck was up to 3 plies of, with a 1200mm width (two pieces) per counterfort. The transverse strengthening to the slab required two plies over the entire surface. The shear strengthening was relatively small requirement and was achieved with a single ply of the same fabric to each face of the beam (installed as a 'U-jacket').

Step 7.
Design conformance check

Material properties were part of the input criteria.

Anchorage checks indicated that that the reinforcement could fit within the span of the beams and slabs. The width of the beam (355 mm) was greater than the width of the strip required.

Over the top of the deck, the cross-section of fabric required was too great to fit on the width of counterforts available, so infill concrete sections were designed which were dowelled into the existing counterforts and the fabric anchored onto these. The curing of this concrete became the 'critical path' item in the above-deck works, so rapid hardening concrete was specified.

Outline example methods of working (including traffic management schemes and access platform operational specifications) were developed by TGP, and approval in principle was obtained from British Waterways and the Metropolitan Police. The compromise on sequencing adopted was that works over the deck (in the roadway) would commence at the start of the school holidays, and works beneath would commence in September. Since works beneath were outside the normal winter maintenance period, the soffit access platform would be demountable and allow the passage of canal boats within 30 minutes of their arrival at the bridge.

Step 8.
Prepare specification

The majority of the specifications clauses were typical of CFRP applied to concrete substrates, although they were complicated slightly by the number of different applications, so it was necessary to distinguish between pultruded strips and in-situ laminated fabrics on various different cementitious substrates.

Special requirements were imposed with respect to the sequencing and time periods between casting new concrete or cementitious repairs and installing CFRP strengthening materials over the top. In general, more test cubes than would normally be required were cast, so the contractor could monitor the rate of strength gain and install strengthening material as soon as sufficient strength was achieved. Cube tests were supplemented by a large number of pull-off tests, since each casting of cementitious material was tested before FRP was bonded to it.

Step 9.
Material selection

The contractor (Makers) selected materials for all parts of the strengthening works that fell within the assumptions made at design stage. There were thus no changes required to design assumptions.

Step 10.
Method Statement for application of reinforcement

Method Statements were prepared by the contractor (Makers) and were submitted for approval by TGP (designers), British Waterways, the police, and L B Brent.

The contractor adopted traffic management and sequencing above the deck exactly as the outline scheme developed by TGP. However, for works below the deck they elected to use a smaller platform that provided access to only one third of the deck width at any one time. This made sequencing more critical, but made it easier to meet the requirements for allowing canal traffic.

Step 11.
Site activities prior to installation

Site establishment was completed in accordance with the approved Method Statements.

Traffic management was implemented by a specialist sub-contractor. Traffic signal rephrasing was undertaken by the local authority's contractor. The access platform (partly supported on the towpath, and partly on a barge anchored to the canal bank) and the excavation above the bridge were undertaken by sub-contractors under the supervision of the main contractor. All other works were completed by the main contractor.

Step 12.
Surface preparation

Surface preparation was generally by grit-blasting, taking particular care to contain spent grit and dust, due to the proximity of live traffic and the environmentally sensitive canal.

Surface preparation was checked by pull-off testing, using 50mm steel dollies bonded to the various parts of the structure. Values in the range 2.9 to 5.1N/mm^2 were obtained, with mean value 4.1N/mm^2 and standard deviation 0.7 N/mm^2. These values easily satisfy the acceptance criterion that all values should exceed 1.5N/mm^2.

Step 13.
Application of composite materials system

Installation was strictly in accordance with the approved Method Statements.

TGP supervised installation of composites and reviewed the contractors QA records as installation progressed.

Step 14.
Final QA checks, inspection and approval

Since TGP (as designer) supervised all the works and bi-weekly progress meetings addressed technical matters as the contract progressed, there was no separate inspection and approval process.

Future inspection will be on the usual bridge inspection cycle.