3. Maunders Road Bridge – CFRP plates bonded to cast iron

Introduction
Maunders Road Bridge consists of 6 cast iron girders with brick jack arches carrying a minor road over a disused railway line. The bridge is owned by Network Rail, and although the line is currently disused, there are aspirations to re-open the line and the structure needed to be strengthened to meet 40 tonne assessment load while removing existing props.

Step 1.
Type of structure

The bridge is located in the Milton area of Stoke on Trent, Staffordshire. The bridge was built in the1900's and carries an unclassified road over a disused railway line, which runs in a cutting below the surrounding ground level. The effective span of the bridge is 7.84m with a carriageway width of 5.0m and a 1.1m wide footway to only one side of the carriageway.

The bridge comprises of 6 cast iron girders. The middle girders spaced at approximately 1.43m centres and the edge girders at 1.23m. These beams support brick jack arches, which in turn support road base and asphalt pavement.

Step 2.
Design conditions

Bridge assessment identified that main girders had capacity of 7.5 tonnes and the edge girders had 3 tonnes capacity. One edge girder (that without a footway) had been propped by the addition of a brick wall with steel beam capping the wall and supporting the cast-iron beam. However, the steel beam was badly corroded with perforated web and was assessed as providing no support to the bridge beam.

Although the road was unclassified and within a residential area, it was the only route to a small industrial area that included a galvanising factory. The bridge was therefore regularly trafficked by 40 tonne HGVs, although the road layout was such that such vehicles could cross the bridge only slowly, and normally when oncoming traffic stopped to allow the HGV to negotiate bends immediately beside the bridge. The highway authority required the bridge to be strengthened to carry 40 tonne vehicles and also 30 units of HB loading.

Step 3.
Initial testing and investigation

Most existing parameters for the structure were obtained from the existing inspection and assessment reports, which included an outline AIP (approval in principle) document for the works.

Various options for strengthening the bridge were evaluated. The options examined included:

- New propping scheme (rejected due to aspirations for rail line)
- Reconstruction with steel/concrete composite or reinforced concrete deck
- CFRP laminate bonding on cast iron beams
- Several schemes for CFRP strengthening were examined because the strength gain required was not easily achieved. For reasons of risk and cost the scheme taken forward was to relieve dead load by installing temporary preloaded props while the CFRP was installed.

Although deck reconstruction was considered to provide the most improvement to the structure, since it would allow widening and realignment of the difficult adjacent bends, considering the built cost and the disruption to travel, CFRP strengthening was proposed as the best option.

A further inspection was undertaken to examine the extent of corrosion of the girders and survey the flatness of the cast-iron beams. From this inspection it was concluded a suitable surface for bonding laminates was achievable and hence detailed design could proceed.

Step 4.
Material selection

Since cast iron is a brittle, elastic material the stiffest possible fibre composite material was adopted, since this minimised the required cross-section and hence loss of headroom.
At the time of the design being undertaken, the stiffest suitable material was Sika/DML ultra-high-modulus carbon fibre laminate. This uses bespoke laminates tailored to the particular requirements of each project, so also allowed smoothly tapered laminates which would minimise anchorage and end-effect stresses whilst also minimising the quantity of material used. Under the proposed classification scheme the strips would be classified as PBU/1/C.

The adhesive adopted was a trowelled epoxy adhesive, recommended by Sika/DML for the laminates.

From existing manufactures data sheets the following properties were adopted for the design:
CFRP laminate
- Young's modulus, E - 360kN/mm^2
- Ultimate tensile stress - 1115N/mm^2

Cast Iron
- Allowable strength as BD21
- Young's Modulus 100kN/mm^2 based upon experience with similar age material

Step 5.
Partial factors

Since the design basis was that set out in BD21, which describes an allowable live-load stress for a given dead-load stress in the iron, partial factors are not appropriate.

A factor of 1.4 was notionally applied to the strength of the carbon fibre laminate, but because the design is stiffness limited this did not affect the design.

Step 6.
Design calculations

The design was carried out by Tony Gee and Partners (TGP) based upon linear-elastic analysis adopting conventional assumptions (such as plane sections remaining plane) in a manner compatible with BD21/97. Limiting stresses were taken from BD21/01.

For the carriageway girders the design resulted in 2 no 140mm wide laminates with a maximum thickness of 37mm. Edge girders required 2 no 90mm wide laminates with a maximum thickness 32mm.

Step 7.
Design conformance check

Since the design was prepared for a specific material, conformance of the proposed material to the design assumptions was part of the input conditions. Since the laminates were tailored to the specific requirements of the project issues such as fit of the laminates were also part of the input requirements.

An independent check of the design was carried out by MouchelParkman Ltd.

Step 8.
Prepare specification

The specification was prepared by the designer and was typical of CFRP on cast-iron substrates, with the addition of particular items addressing the sequencing of works and some additional testing to reflect the dead load relief aspects of the scheme.

Step 9.
Specific material selection

As discussed in Step 4, the specific material to be used in the scheme was already defined and the particular parameters for this material were used in the design calculations, so this step is not applicable to this structure.

Step 10.
Method Statement for application of reinforcement

The contractor (Concrete Repairs Ltd) prepared a comprehensive Method Statement, which gave details with regards to a procedure for installing the CFRP laminates. It included grit blasting, delivery of laminates, preparation, mixing and application of adhesive and bonding to cast iron beam and temporary works to be used to facilitate the works.

The Method Statement also named the personnel in charge and listed their qualifications including appropriate previous experience. Assigned responsibilities included the operation of the QA system to ensure adequate records of the installation were produced.

Step 11.
Site activities prior to installation

Since the rail line was disused, a site compound with secure storage was established in the track-bed immediately adjacent to the structure.

A reinforced concrete pad foundation was installed in the track-bed beneath the deck. The temporary props were installed onto this foundation, then an access scaffold erected around the props. The scaffold was fully boarded and sheeted, so encapsulated the working area and all the beams. This contained grit and dust during surface preparation operations, and permitted a controlled environment during the bonding and cure operations, when heaters were installed.

Step 12.
Surface preparations

Surface preparation involved grit blasting as stated in the specification. The designer was present during these operations to inspect the procedure and confirm compliance with the specification. Pull-off tests specified in the specifications were performed by the contractor and demonstrated adequate performance of the prepared surface.

Step 13.
Application of composite materials systems

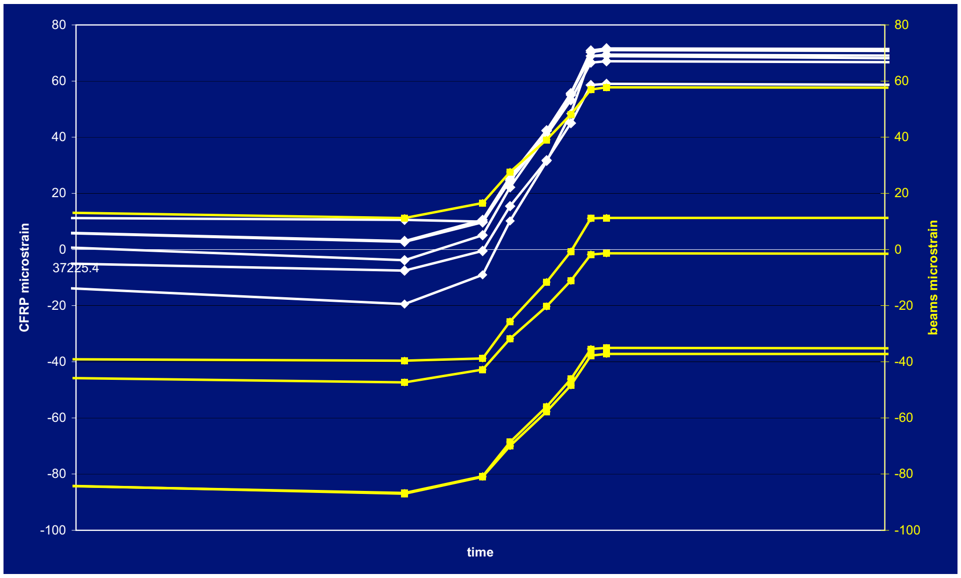
Installation was completed strictly in accordance with the method statement. After the surface preparation was inspected, a thin layer of epoxy adhesive was applied to the beam by trowel, ensuring full wetting of the surface and that all local pitting was filled. A peaked layer of adhesive was applied to the laminates, thicker in the middle than at the edges, so that as the laminates were pressed into place air would be expelled and not trapped within the bond line.

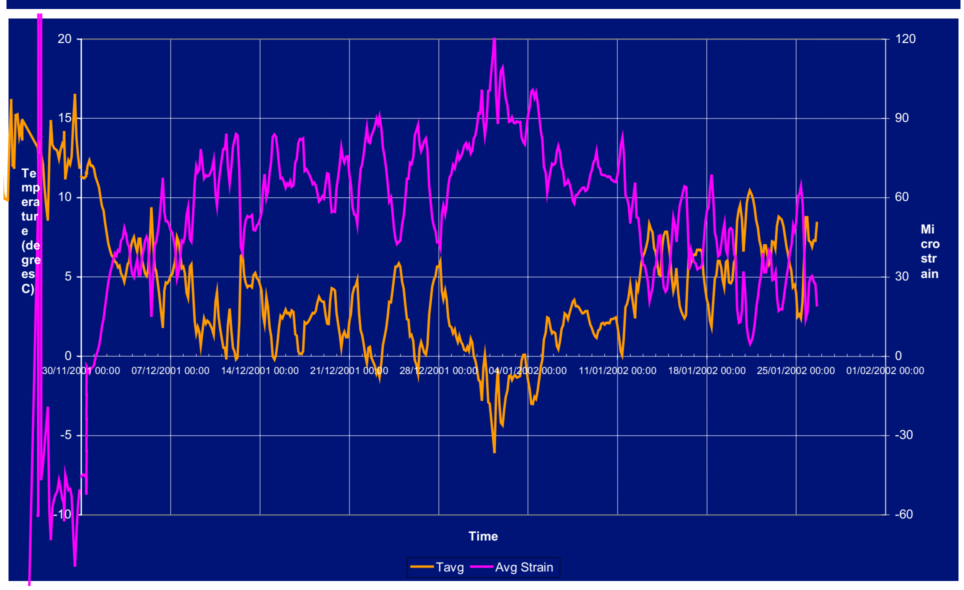
A temporary supports scheme had been developed so that the laminates were lifted into place and forced into the adhesive in a controlled manner. The supports remained in place as clamps, supplemented by additional clamps, until the adhesive had cured. Combining the lifting, positioning, and clamping arrangements to use the same system ensured that there was no possibility of support to the laminates being relaxed as one system was changed over to another. This ensures that air is not drawn into the bond line after excess adhesive has been expelled.

Step 14.
Final QA checks, inspection and approval

A data logger was installed before works commenced, and was running throughout prop preload, laminate installation and during the removal of the props. The logger recorded data from a strain gauge on every beam, and on at least one laminate of each beam. It also recorded the surface temperature on two of the beams. This level of monitoring would not be considered necessary for a typical unstressed strengthening scheme, but was considered prudent because of the innovative nature of the project at the time it was undertaken.

Following completion of the works the information from this was compared with theoretical predictions and also cross-referenced with the contractor's records of environmental conditions. The correlations were very good. For example, the measured stiffness of the strengthened beams was approximately 2.5 times that of the unstrengthened beams, and the theoretical prediction was between 2.4 and 3.2 times (within the likely range of properties for the existing materials). The measured strain profile indicated the neutral axis of the strengthened beam at 90mm above the soffit, and the theoretical range was 112 to 92mm.





Adhesive testing results were as follows:

Tensile strength and modulus values (9 tests) showed tensile modulus between 6.34 and 10.01GPa, with a mean of 7.81GPa and standard deviation 1.39. Tensile strengths were between 18.17 and 25.10MPa, with a mean of 21.20 and standard deviation 2.29. These figures show good correlation with the manufacturers stated values of 8.6GPa for modulus and 21.8MPa for tensile strength. The acceptance criterion for modulus was that it should fall between 4 and 10GPa.

Glass transition temperatures (9 tests) were in the range 54.1 to 56.1°C. The acceptance criterion was that the values should lie within 5°C of the manufacturers quoted mean value. This criterion approximates to a control value minus four standard deviations. A few of the lap shear specimens showed very low failure values, with large voids in the bond line. Those that had adequate fabrication quality showed values in the range 8.55 to 13.19 average shear stress at failure, which exceed the acceptance criterion of 8N/mm^2.

Comparison of the full set of test results was considered to demonstrate adequate material performance. The poor quality of some of the lap-shear specimens reinforces the importance that should be applied to QC specimen production, not all of which was supervised by the designer on this project.

Inspection / maintenance and monitoring

Since installation, the bridge has been subject to periodic visual inspection, and one detailed inspection during which the laminates were tap-tested to confirm that no delamination had occurred. All such inspection and testing has reached satisfactory conclusions.