# 6. New Moss Road Overbridge – CFRP Plates bonded to cast iron

**Step 1.**
**Type of structure**

The structure is located at 25 miles 14 chains on the Liverpool to Manchester line in Irlam, Greater Manchester. The bridge is a two span structure carrying New Moss Road, an unclassified single carriageway road. The original bridge was constructed in 1873 consisting of a single span structure of six simply supported cast iron beams with brick masonry jack arches spanning between the beams. In 1956, the bridge was extended to the south by the provision of a second span of reinforced concrete construction, although the track under this span has now been taken up. The spans are named north (cast iron) span and south (reinforced concrete).

Both spans are square to their supports. The north span has a clear span of 7.89m and is supported by dressed sandstone sills on a massive brick masonry abutment and central pier. The south span has a clear span of 4.89m and is supported on the central pier and south abutment. The bridge has masonry wing walls parallel to the road. The bridge carriageway has a clear width of 6.1m with a single verge 1.5m wide. The condition of the carriageway surfacing was considered poor (this has implications on the loading of the bridge using Highways Agency DMRB BD21/01). The transverse tie-rods in the structure had corroded in a number of locations in the external bays, reducing the lateral stability of the jack arches.

The structure was assessed to BD 21/97 (The Assessment of Highway Bridges and Structures) showing the internal beams of the cast iron span to have an assessment live load rating of 17 tonnes and the reinforced concrete span to have an assessment live load rating of Group 1 Fire Engine at 7.5 tonnes.

**Figure 1. Approach photographs of New Moss Road Bridge**

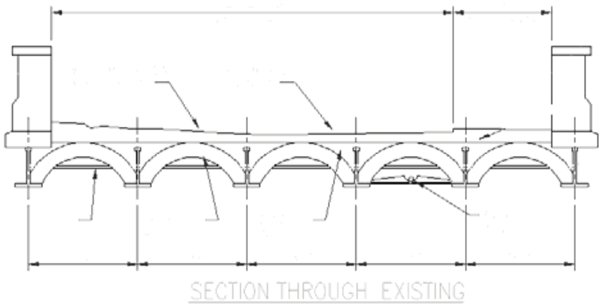



**Figure 2. Section through existing deck structure of North Span of New Moss Road Bridge**

**Step 2.**
**Design conditions**

New Moss Road Bridge was the only suitable access for HGVs to an industrial estate and as such the local council could not impose a permanent weight restriction on the structure. The bridge had a required capacity of full HA and 30 units of HB to carry the large industrial vehicles. To increase the capacity, several options were considered, including complete deck reconstruction and infill replacement, both of which required prohibitively expensive service diversion. The most appropriate solution was to strengthen the bridge with externally bonded reinforcement, which did not require works to the deck top.

The bridge spans a busy railway line and therefore all works had to be performed within time limited possessions which only provided 4 hours of usable working time from any available 8 hour period (time is taken to set up the possession and then hand it back afterwards).

The North (cast iron) span had headroom clearance from track (rail) level of 4.18m. This is less than the minimum headroom clearance for straight and level track of 4.64m as set out in Network Rail Group Standard GC/RT5204 and thus any further reductions in headroom had to be agreed with a Network Rail gauging engineer.

For an increase in flexural capacity in the cast iron and concrete spans, the soffit of the cast iron beams was to be strengthened with ultra high modulus carbon fibre composite laminates, and the soffit of the concrete span was to be strengthened with high strength, standard modulus carbon fibre composite laminates. The soffit is not in direct contact with a constant source of moisture and will not suffer from direct solar heat gain as internal beams (only) were strengthened. The ambient high air temperature (BD37/01) is 34°C and the ambient low air temperature is -14°C.

The scheme was designed by Mouchel Parkman and independently checked by TGP, a pre-requisite of the Network Rail process, described in the Network Rail Structures Advice Note (SETAN) for advanced composites.

**Step 3.**
**Initial testing and investigation**

An initial investigation was carried out on the concrete span, which included taking core samples to test the concrete compressive strength, to check for levels of chlorination and carbonation, and pull-off tests to test tensile strength. The cast iron beams were inspected for their straightness, flatness, pitting and cracks any of which could render strengthening by plate bonding ineffectual. Following review of the test results and inspection, the bridge was deemed appropriate for composite plate strengthening.

**Step 4.**
**Materials selection**

To increase the stiffness and flexural strength of the structure, the stiffest fibre system was chosen, carbon. In particular, to reduce the critical tensile stressed in the cast iron beams, ultra high modulus carbon fibre reinforced polymer laminates were chosen. The resin to protect the fibres in transit and use and to transmit the forces from the adhesive bond to the composite strengthening was chosen to be epoxy-based because it presents a good range of mechanical properties at low cost while being easy to cure and handle. It was not appropriate to use materials of the same stiffness for both north and south spans as the north (cast iron) span required a much stiffer material to increase its strength within more limited headroom conditions (the south span no longer accommodates railway lines).

Within the design, the approximate characteristic material properties for the external reinforcement required on the cast iron span (classification PBU/1/CI/S) were assumed as:

Ultimate Tensile Strength > 1100MPa
Modulus of Elasticity = 420GPa
Ultimate Strain > 0.3%
Dimensions: Width =140mm, thickness = 4mm multiples

The available working time in the possessions (less than 6 hours) favoured the use of pultruded or pre-formed laminates due to their relatively quick installation compared to wet lay-up or other installation methods. During the design generic material properties were assumed, however it was known that several materials were commercially available to provide the assumed characteristic material properties. A suitable material is manufactured by Epsilon and supplied by MBT.

Within the design, the approximate characteristic material properties for the external reinforcement required on the concrete span (classification PBU/1/C/S) were assumed as:

Ultimate Tensile Strength = 2800MPa
Modulus of Elasticity = 150GPa
Ultimate Strain > 0.8% (based on TR55 requirement)

Dimensions: Width = 150mm, thickness = 2mm multiples

A suitable material is also manufactured by Epsilon and supplied by MBT, the MBrace Laminate MM. This material has the following properties:

Minimum Ultimate Tensile Strength = 2700MPa
Minimum Modulus of Elasticity = 165GPa
Ultimate Strain > 1.4%
Dimensions: Width = 150mm, thickness = 2mm multiples

The adhesive had to be thixotropic epoxy adhesive recommended by the manufacturer of the FRP laminates (classification PBU/1/CI/S). The adhesive has to have a $T_g$ in excess of 55°C and an initial curing time of at least 45 minutes, in addition to being suitable for use in temperatures ranging from –10°C to 45°C. The material properties assumed matched the MBT Mbrace Laminate Adhesive HT65 (classification PBU/1/C/S).

The concrete strength is $f_{cu}$=15Nmm$^{-2}$ and the internal reinforcement is Grade 230 ($f_y$=230Nmm$^{-2}$) from the available record drawings.

**Step 5.**
**Partial factors**

**For the south span:**
The structure to be strengthened is concrete, thus the partial safety factors are taken from The Concrete Society Report, TR55 (2004 edition). These are as follows:

| Material | Partial safety factor, $\gamma_\varepsilon$ |
|---|---|
| Carbon FRP | 1.25 |

| Type of system (and method of application or manufacture) | Additional partial safety factor, $\gamma_{mm}$ |
|---|---|
| *Laminates* **Pultruded** | 1.1 |

| Material | Factor of safety, $\gamma_E$ |
|---|---|
| Carbon FRP | 1.1 |

Factor of safety for steel stress check, $\gamma_{ms}$ = *1.25* (TR55 Recommends 0.8$f_y$ for high yield steel)

Material safety factors (from BS5400 Part 4) used:

Concrete $\gamma_c$ = *1.5*
Steel $\gamma_s$ = *1.15*

The conditions in TR55 clause 5.6.8 Adhesive are satisfied.

**For the north span:**
The structure to be strengthened is cast iron, thus the partial safety factors are taken from CIRIA Report, C595. These are as follows:

| Material | Partial safety factor, $\gamma_\varepsilon$ |
|---|---|
| Carbon FRP | 1.4 |

| Type of system (and method of application or manufacture) | Additional partial safety factor, $\gamma_{mm}$ |
|---|---|
| *Laminates*<br>**Pultruded** | 1.1 |

$\gamma_{me}$ = 1.41, using T (operating temperature) = 40$^o$ C, $T_{ref}$ = 20$^o$ C, and $T_g$ = 60$^o$ C.

$\gamma_{mt}$ = 1.0, based on Table 6.7, as the composite strengthening (and adhesive) only takes transient loading.

Cast Iron is assessed to a permissible stress methodology using BD21/01 and thus has a series of stress limits rather than partial factors (see Clause 4.10).

**Step 6.**
**Design calculations**

The design calculations were performed using TR55 and BS5400 Part 4 for the concrete span and BD21/01 and CIRIA C595 for the cast iron span.

**For the south span:**
The design calculations resulted in 150mm wide, 2mm thick MBT Laminate LM at 300mm centres for the width of the deck soffit.

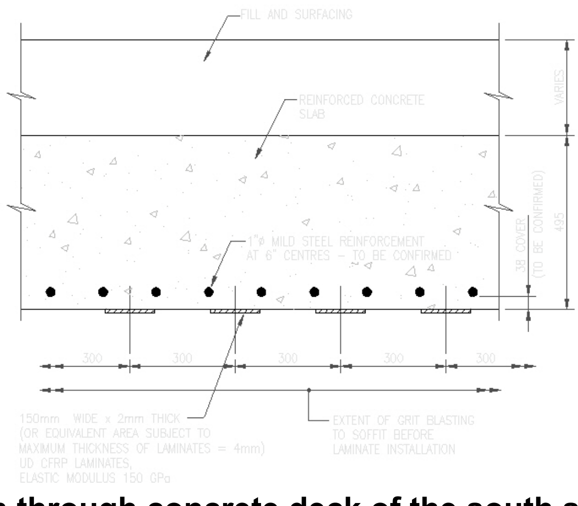



**Figure 3. Section through concrete deck of the south span showing the internal and externally reinforcement**

**For the north span:**
The design calculations resulted in using 2 No. 140mm wide (UHM laminates) laminates per lower flange of each beam. The laminates were factory bonded up to 6 No. 4mm thick layers in centre span, tapered towards the ends to reduce shear and peel stresses.

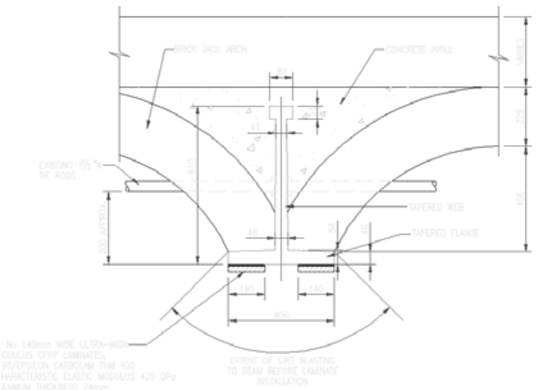


**Figure 4. Section through cast iron beam of the north span showing the externally applied reinforcement**

**Step 7.**
**Design conformance checks**

**For the south span:**

1. Resin $T_g$ = Not listed, but manufacturer tests show 80-100$^oC$
2. Adhesive $T_g$ = Not listed, but manufacturer tests show 60$^oC$
3. The dimensions of the reinforcement are appropriate for the structure as it will not overhang the edge of the soffit or impede on the headroom by an unacceptable amount.
4. ULS and SLS Stress and Moment Checks
   a. The applied ULS bending moment is 345kNm, the capacity of the strengthened beam is 485kNm, - ok
   b. The concrete stress under serviceability load is 7.35 $Nmm^{-2}$, compared to an allowable of 7.5 $Nmm^{-2}$ ($0.6f_{cu}$), - ok
   c. The stress in the internal reinforcement under serviceability load is 170 $Nmm^{-2}$ and the allowable stress is 184$Nmm^{-2}$ ($0.8f_y$), - ok
   d. The stress in the external reinforcement under serviceability load is 91.6$Nmm^{-2}$ compared to the allowable of 1550$Nmm^{-2}$ ($0.5f_y$), - ok
   e. Fatigue check of the FRP ok using 80% of the serviceability design strength, 91.6$Nmm^{-2}$ compared to 1610$Nmm^{-2}$, - ok
   f. Stress rupture check of FRP ok, using 65% of the serviceability design strength, 91.6$Nmm^{-2}$ compared to 1308$Nmm^{-2}$, - ok
   g. FRP separation failure check ok, factor of safety of 1.3 when longitudinal shear stress is limited to 0.8$Nmm^{-2}$, - ok
5. Appropriate level of strengthening achieved.

**For the north span:**

1. Resin $T_g$ = Not listed, but manufacturer tests show 60°C
2. Adhesive $T_g$ = Not listed, but manufacturer tests show 60 °C
3. The dimensions of the reinforcement are appropriate for the structure as it will not overhang the edge of the soffit or impede on the headroom by an unacceptable amount (after negotiation with gauging engineer).
4. Stress checks:
   a. Strain in FRP at midspan = 0.016% compared to allowable of 0.3%
   b. The live load tensile stress in the strengthened cast iron beams is 11.3 N/mm$^2$, compared to the allowable live load tensile stress of 10.8 N/mm$^2$ ok as reduction factor is 0.96 > 0.91 (40T ALL for heavy traffic, poor surfacing).
5. Appropriate level of strengthening achieved.

**Step 8.**
**Prepare specification**

Extracts from the specification for concrete can be found in the case study 'St Michael's Road'. Extracts of a specification for CFRP materials bonded to cast iron are show below, however the concrete and cast iron specifications share common clauses of workmanship, FRP laminate, adhesive and independent testing (however the pull of strength to be achieved is 20N/mm$^2$).

*Cast Iron Substrate*

1. *The surface of the metal to be bonded shall be dry, sound and uncontaminated. This involves removing any loose paint and corrosion, inspection/repair of any cracks then grit blasting to a level of SA2.5.*

**Step 9.**
**Specific materials selection**

No requirements in addition to those outlined in Step 4.

**Step 10.**
**Method Statement for application of reinforcement**

The Method Statement was prepared by the contracting company Makers Ltd – Civil Engineering Repair Division. This document details:

- The scope of works, identification of hazards
- Railway interface arrangements (e.g. possession types etc.)
- Protection from railway infrastructure

- Environmental protection
- Required plant and equipment
- The bonding methodology
- The materials to be used
- Emergency arrangements
- Contractor qualifications.

The document was checked, commented on and then approved by the Employers Representative.

Makers Ltd. was the sub-contractor who prepared the method statement and carried out the works. Initially the method statement was too brief and contained insufficient information about the methodology to which they were planning their work, their experience in performing similar jobs and also contained inconsistencies with the specification. The Method Statement comments were sent to Makers and the method statement revised and later approved.

Within this activity stage, the designer was able to check that the contractor-selected material system for the strengthening was appropriate to project requirements. It is possible that the contractor may have suggested materials different to those referenced in Step 4 which would have then been confirmed to match the specified properties and design criteria.

**Step 11.**
**Site activities prior to installation**

These processes are detailed within the pre-approved method statement:

1. Arrive at site
2. Set up lights, heating and enclosure
3. Await ES/COSS permission to begin
4. Check cast iron surface and prepare
5. Apply adhesive to laminates, cast iron and concrete
6. Apply laminates to bridge soffit, install temporary clamps, and check minimum headroom
7. Clear site and hand back possession.

These activities took place over a series of possessions over a number of weeks, so the setting up site and other related activities were repeated more than once. During bonding works, an Employers Representative was present on site to maintain and confirm the bonding record and approve ‘check points’.

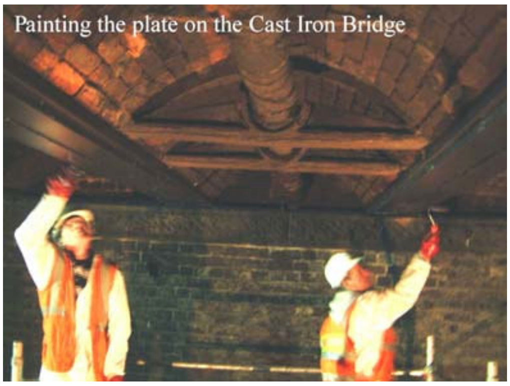
**Step 12.**
**Surface preparation**

Prior to bonding the surface was prepared to be clean and free from contaminates. The cast iron was vacuum blast cleaned to SA2.5. It was then repaired using an appropriate, compatible repair material that had been approved prior to commencement of activities. The priming material was then applied to the surface. Steel dollies were then bonded on for subsequent pull-off tests that were performed after a cure of at least 24 hours, but prior to application of composite system. 9 No. pull off tests were performed on the concrete soffit, each yielding a stress value greater than the limit set within the specification.

These steps are detailed within the method statement and had prior approval of the Employers Representative.

**Step 13.**
**Application of composite materials system**

The peel ply was first removed from the laminate and the cast iron surface was degreased. A thin layer of adhesive was applied to the laminate and the laminate was then applied to the bridge soffit in the correct position, under pressure to remove air voids. The laminates were then clamped into position with the temporary support device. Simultaneously, the testing samples were prepared. These steps were detailed within the Method Statement and had prior approval of the Employer's Representative.




**Step 14.**
**Final QA checks, inspection and approval**

The laminates were tap tested after cure to ensure any entrapped air was within the limits within the specification. However, the tap testing found that there were voids bigger than those allowed by the specification. The contractor had to inject a low viscosity resin to fill the voids and then bond a plate over the injected area. The Employer's Representative was consulted on this and approval was given to proceed.

Off site testing by Oxford Brookes University on dumb bell samples of adhesive (for tensile modulus and strength), adhesive $T_g$, single lap shear for different batches. The results were as follows:

$T_g$ = 64.1°C Pass

| | | | |
|---|---|---|---|
| Ultimate tensile strength | = | 20.2MPa | Pass |
| Tensile modulus | = | 6.6GPa | Pass |
| Lap shear strength | = | 8.7MPa | Pass |

**Inspection/Maintenance/Monitoring Regime**
A maintenance manual was produced, with inspections scheduled at regular intervals after the installation of the laminates to ensure:

- There is no visible evidence of cracks developing in the cast iron;
- There is no visible evidence of the laminates becoming debonded, determined by visual inspection of the edges of the laminates, with no attempt to pry the laminates from the flanges/deck soffit;
- By tapping the laminates with a light metallic object (e.g. a light metal hammer), there is no audible evidence of the laminates having become debonded;
- There is no evidence of mechanical damage to the laminates, from accidental impact or vandal attack.

This system of inspection was at three monthly intervals for the first six months, then yearly until year three and then finally at five yearly intervals for the remaining life of the bridge.

## Appendix: For Construction Drawing (as issued to the subcontractor)