

USING STRESSED AND UNSTRESSED COMPOSITE PLATES FOR STRENGTHENING EXISTING STRUCTURES

Dr Sam Luke, Mr John Darby, Mr Andrzej Skwarski

Mouchel Consulting Limited, West Hall, Parvis Road, West Byfleet, Surrey, KT14 6EZ
UNITED KINGDOM

Abstract

Advanced composite materials are increasingly being used in many major industries because of their lightness, strength, durability, ease of transportation, ease of erection, low whole life costs and their ability to be pre-fabricated in the factory. This paper will outline in detail the pioneering collaborative research work that Mouchel Consulting Ltd, UK have led in the use of Carbon Fibre Reinforced Polymer (CFRP) plates for strengthening and rehabilitation of existing bridges and other structures. Following the completion of the UK Department of Trade and Industry sponsored ROBUST project on carbon fibre plate bonding, over 150 structures in the UK have been strengthened using this novel technique in the two years. The paper will include case histories of some of the recently completed projects using both pre-stressed and unstressed CFRP plates to strengthen concrete as well as metal structures, and outline the cost benefits that have accrued by using this technology.

1. Introduction

The use of composite materials for strengthening and rehabilitation of bridges and buildings has quickly gained momentum in Europe, America, Canada & Asia due to its many inherent advantages over the conventional methods of strengthening, not least in terms of durability and whole life costs. The main applications of composites in the construction industry over the last 7 years have been bridge enclosures and storage tanks using GFRP, but more recently using CFRP pultruded plates and pre-preg plates to increase the flexural and shear capacity of existing structures. CFRP plates are now being accepted in the UK construction industry as an effective alternative to replacement and other traditional methods of strengthening. Over the past 18 months over 150 bridges and other structures have been strengthened with CFRP plates in the UK. Around 15,000 metres of plates have been used to strengthen bridges, culverts, shopping centre structures, industrial plants, power stations and marine structures. This number is set to grow dramatically over the next few years as a result of the production of a best practice guide by the Concrete Society in the UK, due to be published by the end of 2000.

All bridges in Europe were supposed to carry 40 tonne vehicles by 1st January 1999, however, following assessment, many of the bridges in the UK have been found to be in need of strengthening or replacement and have not met this requirement. This has led to weight restrictions being imposed on many bridges across the UK, causing re-routing and severe disruptions, resulting in loss of trade. Extensive research work undertaken in the UK under the ROBUST project has demonstrated that CFRP plates can be used more economically than steel plates. Composite materials offer advantages such as low weight, excellent handleability, a range of elastic moduli, high resistance to corrosion, high strength, availability in long lengths avoiding the need for lapping, and good fatigue, creep and fire resistance characteristics. In addition the CFRP plates can be pre-stressed, a technique which was successfully demonstrated under site conditions in the ROBUST project.

2. The ROBUST Project

As lead partner and manager of this recently completed project, Mouchel has been responsible for initiating and implementing one of the most comprehensive investigations ever undertaken into the use of advanced composite materials in the construction industry. The consortium was set up involving all facets of the construction process to develop the technique. It included a client authority, three academic partners, designers and project managers, material suppliers, specialist contractors and composites advisors.

The testing programme was devised to address as many of the potential risks to implementation as possible in order to allow development of realistic and practical design rules. Approximately 130 flexural tests using pre-stressed and unstressed plates were carried out on model beams in the laboratory and also on actual beams removed from an existing deteriorating bridge at a purpose built test facility in Oxford. In addition 110 tests on the composite materials were carried out to characterise the materials and to examine them for long term durability. To supplement the experimental work, Mouchel carried out non-linear, 3 dimensional finite element analysis to calibrate the performance of the beams in the laboratory tests and to provide sufficient data for development of design guidance. The consortium has drawn up a specification for CFRP plate bonding. The results of the ROBUST project have indicated that plate bonding using CFRP plates is a viable and cost effective alternative to other methods of strengthening. The method can be applied to a wide range of structural types to increase their flexural capacity.

3. Actual CFRP plate bonding projects

Mouchel has recently been involved in providing carbon fibre strengthening design solutions to a number of building and bridge structures. Listed below are a few examples of current or completed CFRP strengthening schemes.

Hythe Bridge, Oxfordshire, UK

Mouchel was appointed by Oxfordshire County Council to investigate the possibility of strengthening Hythe Bridge, a historic cast iron structure, constructed in 1861 and servicing a



major arterial route into Oxford (Figure 1). Assessment of the existing structure showed that it was capable of carrying 7.5t and needed to be strengthened to 40t. It was thus necessary to

Figure 1: Hythe Bridge, Oxford

stress the plates to mobilise locked-in dead load stresses in the cast iron beams to enable them to carry live loads. Alternative techniques such as steel plate bonding or unstressed CFRP

plate bonding proved expensive and impractical due to limited headroom requirements. Re-construction was by far the most expensive option, and would have involved road closures presenting unacceptable costs and disruption.



Mouchel developed an all-purpose pre-stressing device to undertake this strengthening scheme. Trials were carried out on a site in Oxfordshire to demonstrate the newly developed device and its applicability to cast iron, before approval was given to go-ahead with the contract. The bridge was successfully strengthened with the pre-stressed plates, 4.5mm thick ← (Figure 2) with no interruption to traffic flow, thereby saving the client thousands of pounds, in installation and traffic delay

costs. This was the first metallic structure in the world where pre-stressed CFRP plates were used. As a result of the innovative nature of this project and the commercial and long-term benefits it offered the client, the project was awarded the first prize in the British Construction Industry Awards (small projects) for 1999.

Slattocks Canal Bridge

Figure 3 shows Slattocks Canal Bridge, a steel bridge built in 1936 that was recently strengthened by Mouchel using conventional CFRP plates from 17T to 40T. Again the cost advantages over conventional strengthening techniques was the main reason for the client choosing this technique. At no time during the strengthening operation was it necessary to restrict traffic flows.



Figure 3: Slattocks Canal Bridge



Figures 4 & 5: installation and temporary clamping of steel beams on Slattocks Bridge

This is the first early steel Highway Bridge to be strengthened with laminated CFRP plates in Europe. Two 4mm thick CFRP plates were factory bonded prior to installation on site. Figure 4 shows the plates, 7.5m long being bonded onto the steel beams. As can be seen from the picture, no heavy equipment was required to lift the plates, although temporary clamps were installed (Figure 5) to support the plates during adhesive cure as a preventive measure, bearing in mind the bridge was carrying traffic during the operation

Gulf House

Advanced composites' strengthening has not only been limited to bridges. In fact more buildings than bridges have been strengthened in recent months. Gulf House in London, originally a 7 storey 1950's reinforced concrete framed office building, with shops below, was being refurbished to modern standards, and involved demolishing 5 floors and rebuilding them in steel. two floors required most cost-effective achieving this proved concrete beams and pultruded plates carried out the of the prestigious involved using over plate.



However, the bottom strengthening and the and quickest method of to be strengthening the slabs with CFRP (Figure 6). Mouchel assessment and design office block, which 2000 linear metres of

Figure 6: Strengthening floor slabs with CFRP plates

Haversham Bridge, UK

Mouchel was appointed by Milton Keynes Council to strengthen Haversham Bridge to the new 40 Tonne EC weight limit. The Bridge carries a single carriageway over a river and has a three span concrete beam and deck slab spanning 50 metres. The longitudinal beams were strengthened using CFRP plates bonded to their top surface to give extra hogging flexural capacity, the first application of its kind in the UK. Figure 7 shows the CFRP plates (Fig 7➔) being bonded on the top of the deck on one side of the road.



The other lane was kept open during this operation. 768 m of CFRP plates were bonded to the deck using a specially developed structural adhesive. The CFRP plate bonding method proved to be much cheaper than the steel plate bonding technique, with the added value of a much improved durability.

Devonshire Place Bridge, UK

Mouchel was appointed by North Yorkshire County Council to repair Devonshire Place Bridge in Skipton, North Yorkshire. The bridge has a pre-cast pre-stressed concrete hollow sectioned edge beam. A number of the tendons in the edge beam were damaged during an inspection, weakening the edge of the bridge. Using knowledge gained from the extensive work done on project ROBUST, a single sheet of Carbodur plate was bonded to the underside of the bridge to replace the lost flexural capacity. The traditional approach of bonding steel

plates was clearly not suitable for this bridge due to access restrictions, and the fact that the existing concrete was not thick enough to support bolting. The plate bonding required no bolts or scaffolding, and the bridge remained open during the process, which was completed within one day.

Chocolate Factory, Tutbury, UK

The main beams supporting floors in a chocolate factory in Tutbury were strengthened using CFRP plates as shown in Figure 8. 11 beams were required to have their flexural capacity increased by 30% to cater for installation of new plant and processing equipment. This was achieved by bonding CFRP plates to the soffits of the beams. No heavy scaffolding equipment was required, keeping disruption to the factory operations to a minimum, which was a major requirement of the contract.



Figure 8: Nestle Factory, Tutbury

Leisure Centre, Wales

Beams in a swimming pool in Gwent were strengthened using 100 metres of CarboDur plates. In this instance, corrosion of the reinforcement and loss of section of the concrete due to chloride ingress had weakened the structure considerably, so carbon fibre strips were bonded to the soffits to re-instate the lost capacity, following remedial works on the concrete. This solution was particularly welcomed, as carbon fibre is very resistant to aggressive environments.

4. Conclusions

Advanced composites are increasingly being used in the construction industry due to their inherent advantages over traditional materials including their lightweight, high strength, ease of application and low maintenance costs.

CFRP plate bonding has been shown to be a viable alternative to steel plate bonding, with savings in both cost and time. The benefits of the technique for rehabilitation of structures have been demonstrated within the extensive programme of laboratory and field-testing. Design procedures and a specification have been developed, and the Concrete Society in the UK together with infrastructure owners, consultants, contractors and material suppliers is developing a best practice guide for strengthening concrete structures using composite plates.

The performance of composite materials when subjected to harsh environmental conditions has shown to be superior to steel. The technique can be applied to materials other than concrete. Confidence among clients is growing rapidly following implementation of early applications in the UK, to the extent that major asset owners are now developing outline business cases to demonstrate the economic advantages of using composites in place of traditional materials. Further research is being proposed to study in depth the general

applicability of composite strengthening to metallic structures, particularly wrought iron riveted structures, of which there are thousands on the rail infrastructure in Europe.

5. References and bibliography

- EUROCOMP (1996) *Structural Design of Polymer Composites, Part 1, Design Code, Part 2, Handbook, Part 3 Test Reports*, Ed, J C Clarke, Chapman & Hall, London
- HANCOX N L, MAYER R M (1994) *Design data for reinforced plastics – A guide for engineers and designers*, Chapman & Hall, London
- HOLLAWAY L C, LEEMING M B (1999) *Strengthening of reinforced concrete structures using externally bonded FRP composites in structural and civil engineering*, Woodhead Publishing, UK.
- LANE J S, LEEMING M B, LUKE P S (1997) *Using advanced composite materials in bridge strengthening: introducing project ROBUST*, The Structural Engineer Journal, UK.
- LANE J S, LEEMING M B, LUKE P S (1997) *Testing of strengthened reinforced and pre-stressed concrete beams*, Construction Repair Journal Vol. 10, UK.
- LUKE P S, SKWARSKI A J (1998) *Strengthening with carbon fibre plates*, Reinforced Plastics Journal, UK.
- LUKE P S (1999) *Composites in Civil Engineering – An Overview*, Ingenia Journal, UK.
- LANE J S, LEEMING M B, LUKE P S (1997) *Role of 3D FE analysis in composite plate bonding*, Structural Faults & Repair Conference, Edinburgh, UK
- LANE J S, LEEMING M B, LUKE P S (1997) *Field testing of 18.0 m PC beams strengthened with CFRP plates*, Structural Faults & Repair Conference, Edinburgh, UK
- MAYS G C, HUTCHINSON A R (1992) *Adhesives in civil engineering*, Cambridge University Press, UK.
- QUINN J A (1998) *Composites design manual*, James Quinn Associates, Liverpool, UK