Application Summary Sheet 7

Title: Strengthening

Target Audience: Civil and Structural Engineers

Keywords: Strengthening, reinforcement, confinement, carbon fibres, glass epoxy rods, column wrapping.

Overview of application / summary:

The use of FRP materials in strengthening structures such as beams, floors, bridges, columns, silos, cooling towers and chimneys has rapidly gained acceptance worldwide since the development of the technique in the 1980's. For beams and bridges, generally, the technique involves bonding either unstressed or pre-stressed carbon fibre reinforced polymer (CFRP) plates to the underside (soffit) or bottom flange of the beam. Alternatively reinforcing rods may be imbedded. This has the effect of increasing the capacity of the lower part of the beam which is under tension. For materials such as reinforced concrete and cast iron, which are strong in compression but weak in tension, this is usually the most critical area. Pre-stressing the CFRP plates has the effect of further reducing the tensile stress on the bottom flange, hence the load capacity is increased. CFRP plates can also be bonded to the sides of beams near to the supports to increase the shear capacity. For structures such as columns, silos and cooling towers the reinforcement is applied cross-wrapped or in bands, with the tensile capacity of the carbon, aramid or glass fibres acting as confinement. Complete FRP shells can be also be used to strengthen columns.

The most obvious advantage of the use of FRP materials over the more traditional use of bonded steel plates is the relative ease of handling and application. In some cases a reduction in dead load on the structure will also be of benefit. Carbon fibres have much higher tensile strength than steel but with much less weight. They are also non-corroding. Glass fibre reinforcement is a lower cost alternative to carbon fibres. The bonding between the CFRP plates and the structure is of great importance for the technique to be successful. Non-destructive test methods for the detection of voids indicating bond failure such as the use of ultrasonic and transient pulse thermal imaging have been developed.

Case Studies:

Case Study 1: Boots Building, Nottingham

Taylor Woodrow used advanced composites technology to strengthen two principal steel beams at the Boots Building, Nottingham, a Grade II listed, skeletal-framed structure. The building was constructed in two phases in 1903 and 1921. The earlier section has a frame consisting of cast iron columns and wrought iron beams, while the 1921 section has a steel frame.
Both phases are clad in terra cotta, fitted close to the underlying frame. The 1921 section of the façade was suffering signs of distress typical of steel frame corrosion.

Investigations for a change-of-use confirmed that two principal steel beams, which support the floors at second and third storey levels, had suffered a 30% loss of flange and web section due to electrochemical corrosion. To fulfil the change-of-use requirements the beams required reinstating with enhanced flexural capacity to allow for future changes in floor loading. The options were either to replace them or strengthen them.

The beams are curved in plan, which made the manufacture of replacement beams non-viable due to long lead times. There were also issues of cranage and access in a congested town centre location associated with full replacement. Taylor Woodrow identified advanced composites technology as an alternative solution that would strengthen the beams and satisfy cost and programme constraints.

Laminating curved beam

The company specified a pre-impregnated, carbon fibre-based composite that will cure at low temperatures. Supplied to site as rolls of flexible material, prepreg composites mould easily to complex shapes. Once the composite is laid up, vacuum bag technology is used to hold it close against the beam's profile and heat is then applied locally to cure the resin. The cured resin is solid, so the prepreg composite remains bonded in the formed shape.

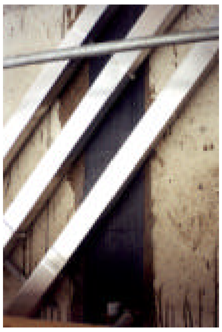
The thickness of the composite material added to the original steel section is just 5mm, which had no impact on the positions of the terra cotta units placed back on the structure. The technology therefore complied with the requirements of the heritage authorities.

Using advanced composites technology, Taylor Woodrow was able to provide a rapidly installed reinforcement system that allowed the work to be undertaken within the strict time scale of two weeks. This ensured there was no delay to the main contract, which included the installation of extensive cathodic protection – also designed and supervised by Taylor Woodrow.

Case Study 2: Nuclear Power Station

Taylor Woodrow was able to apply composite strengthening techniques on behalf of a client who was seeking a ten-year life extension for an operating nuclear facility. A satisfactory Safety Case had to be submitted in order for the facility to gain the desired life extension. Under these requirements a number of safety-critical structures had to be capable of withstanding hazard-loading events including earthquakes. Remedial work and upgrades to the structural fabric were necessary to meet the operating safety criteria.

Some of the structures had deteriorated due to combinations of mechanical and thermal loading and reinforcement corrosion. Cracking was thought to have caused yielding of some of the embedded horizontal steel reinforcement in the walls. Seismic acceptability under hazard loading could only be demonstrated for an undamaged condition, so the reinforcement needed supplementing with additional materials.


Strengthening of concrete walls at nuclear power station

Major factors influencing the selection of the repair material included a strict time scale to coincide with the scheduled shut-down or ‘outage’ period, cramped working conditions, cost and the coastal environment in which the facility is located. Taylor Woodrow proposed bonding pultruded CFRP strips to the concrete walls in line with the yielded rebars. CFRP was chosen because it could be located directly over the embedded reinforcement in the specific locations required, providing aligned rehabilitation and an economical approach. Also, the light weight of the CFRP strips, which needed to be only 1m long, allowed installation by roped access which was faster, easier and cheaper than the use of scaffolding in the high-level areas.

Case Study 3: Upgrading Manitoba Bridge

To upgrade a timber bridge in order to accommodate increased vehicle weights Rotaflex glass epoxy rods were installed in the underside of the principal 600mm x 200mm beams, with four routed slots in each beam, using staples and thixotropic adhesive. Each glass epoxy rod was 10mm in diameter and 10m long. In total the bridge upgrading used 1600 linear metres of epoxy glass rod, resulting in a 38% increase in strength. All contract work was preceded by small scale and full size tests carried out at the University of Manitoba.

Installing glass epoxy rods in timber beams

Synergy with traditional materials:

Variations of the technique have been applied to concrete, brick, timber, and cast iron structures.

Impact of Application

Financial:

Highly cost effective method of maintaining or upgrading existing structures.
Quick application results in lower disruption and shorter contract periods.
Reasons for the strengthening of structure may include upgrading to accommodate higher loads (such as traffic), loss of pre-stress in existing reinforcement, or degradation of structure (eg corrosion of reinforcement or beam caused by de-icing salts)
The technique may allow continued usage of structure or facility during strengthening works.
Higher material costs of carbon fibres are outweighed by the numerous advantages over steel such as low self-weight and less requirement for plate surface preparation. Glass or aramid fibres offer lower cost alternative, in some instances, to carbon fibres.

Environmental:

CFRP plates are an alternative to other forms of strengthening such as use of steel plates, or the provision additional support members. Column wrapping with FRP can be an alternative to jacketing additional reinforced concrete, or complete replacement of structure, with obvious savings in materials and energy.

Social:

May enable preservation or upgrading of heritage structures (eg Hythe Bridge)


Strengthening of Hythe Bridge, Oxfordshire

Engineering:

Increases the capacity with minimal addition of dead load to the structure.
Materials are easy to transport and handle - no lifting gear required.
Easy to use at height.
Ability to work in confined areas and in situations with difficult access (eg tunnels, basements)
Technique is relatively quick - reduced disturbance and installation time.
Minimal plate preparation required - by use of peel ply plates
Plates may be any length with no lap joints needed.
For wall strengthening overlaps are simple.
Plates may be thinner than alternative steel - less reduction in headroom.
Durable, corrosion resistant.
Good fire performance

Robustness:

Extensive worldwide research and testing (eg ROBUST project), including aspects such as durability, long term performance and fire.
Numerous examples of strengthened structures in service, with performance monitoring.

Future Developments and Potential Market:

Further broadening of strengthening applications together with development of new CF structures and CF strengthened composite materials (eg wood/CF composites)
Further availability of long term performance data.

The technique is already well established. Infrastructure repair is a multi-billion pound problem worldwide, in particular for reinforced concrete highway bridges damaged by de-icing salts. Strengthening of structures to resist earthquakes and to conform to new seismic design codes is another major application (eg bridge columns). Bridge columns can also be strengthened to improve resistance to vehicle impacts.

Where to get further information

References:

Strengthening of reinforced concrete structures (The ROBUST book)
Hollaway, L.C. and Leeming, M.B. (1999)
Woodhead Publishing, Cambridge, England
www.woodhead-publishing.com.

Review: This is the definitive work on the subject of strengthening reinforced and pre-stressed concrete beams, presenting a detailed study on the research (including full scale tests) carried out under the DTi-Link funded ROBUST project. The book also details design, specification and site construction techniques, including several case studies.

Strengthening of structures with carbon fibre plates - case histories for Hythe Bridge, Oxford and Qafco Prill Tower, Qatar
Luke, S.
Network Group for Composites in Construction First Annual Conference, BRE, Watford, England, 30-31 October 2001
http://www.ngcc.org.uk/

Strengthening of Engineering Structures with Carbon Fiber Reinforced Plastics - An Overview of History and Current Worldwide Usage
Ballinger, C. A.
INTERNATIONAL SAMPE SYMPOSIUM AND EXHIBITION 1997 p927-932
This paper presents information on the development of CFRP and FRP systems to strengthen reinforced concrete structures including chimneys, buildings and bridges in Japan, Switzerland and the US, together with on-going research.

Seismic Strengthening of Circular Bridge Pier Models with Fiber Composites
Saadatmanesh, H., Ehsani M.R. and Limin J.
ACI Structural Journal nov/dec 1996 p639-647

Review: The paper details an investigation into the seismic behaviour of reinforced concrete columns strengthened with fiber reinforced plastic (FRP) composite straps consisting of unidirectional glass fabric impregnated with polyester resin which were applied in the plastic hinge zone of the columns. Full scale test results showed that seismic resistance (strength and ductility) of retrofit concrete columns was improved significantly due to the confining action of the FRP composite straps on the concrete matrix and, additionally, the buckling restraint on the steel reinforcement.

FRP for Flexural Strengthening of Timber Bridge Beams
Gentile C, Svecova W, Salzberg W, Rizkalla S H. (1999)
International Conference on Advanced Engineered Wood Composites, Bar Harbour, Maine, 5-8 July 1999. p 29-30

Review: The paper presents the results of an experimental programme to strengthen using GFRP bars creosote treated Douglas Fir beams recovered from an old bridge. The impetus for the research was the need in Canada to strengthen a large number of timber bridges in response to increased vehicle loadings. The GFRP bars were inserted into machined slots on the underside of the beams and bonded in place with epoxy. Results showed increases in strength of up to 56%, with no failure of the bond between the epoxy and the treated wood taking place.

Shear Reinforcement of Wood Using FRP Materials
Triantafillou, T.C.,
ASCE Journal of materials in Civ Eng 1997, 9,2 p65-69

Review: The paper presents a study of the mechanical behaviour of wood members reinforced with FRP sheets (either laminated or fabrics) externally bonded to the shear zones. A number of wood beams designed to fail in shear were reinforced with CF fabrics at various configurations and area fractions and tested to failure. The FRP reinforcement was found to be most effective when placed with the fibres orientated in the longitudinal direction. It was concluded that the reinforcement method could be cost effective, with little effect on the aesthetics of the structure when transparent matrix resins were used.

Strengthening of Cast Iron Struts
Dier A F
Carbon Fibre Composites for Structural Upgrade and Life Extension
ICE Seminar 11th May 2000

FRP Composites - life extension and strengthening of metallic structures
Moy SSJ (Ed),
Thomas Telford, ISBN 0 7277 3009 6, 2001.

Advanced Polymer Composites for Structural Applications
Proceedings of ACIC 2002 (http://www.cosacnet.soton.ac.uk), Thomas Telford, London, 2002

Use of high-modulus carbon fibres for reinforcement of cast-iron compression struts within London Underground: project details.
Hill P S, Smith S and Barnes F J, (1999)
Conference on Composites and Plastics in Construction, Nov 1999, BRE, Watford, UK
RAPRA Technology, Shawbury, Shrewsbury, UK, paper 16 1-6

Thermographic blister detection in FRP strengthened RC elements and degradation effects on section performance
Delpak, R, Shih, J. K. C., Andreou, E., Hu, C. W. and Tann, D. B. (2001),
In "FRP Composites in Civil Engineering", Elsevire, pp1135-1142.

Strengthening metallic structures using externally bonded fibre reinforced polymers
CIRIA report RP645
(WORK UNDERWAY)

Design guidance for strengthening concrete structures using fibre composite materials
THE CONCRETE SOCIETY (2000), Technical Report 55, The Concrete Society, UK

FRP composites - Life extension and strengthening of metallic structures
ICE DESIGN AND PRACTICE GUIDES (2001)
Thomas Telford, UK

Websites:

International Technology Research Institute
http://wtec.org/loyola/compce/toc.htm

ConFibreCrete
http://www.shef.ac.uk/~tmrnet/

FRPRCS-5 Conference (5th International Conference on Fibre Reinforced Plastics for Reinforced Concrete Structures)
Cambridge, July 16th-18th, 2001
http://www-civ.eng.cam.ac.uk/frprcs5/proceedings.htm