# STRENGTHENING STRUCTURES USING CARBON FIBRE REINFORCED POLYMER

*E Bohloulzadeh: Chairman, Parsan Group. Managing Director, Yoldings Ltd*
*A Broad: Development Manager Yoldings Ltd & Executive Committee Concrete Repair Association*
*Dr S Mehrkar-Asl: Associate, Gifford Consulting Engineers*

## INTRODUCTION & HISTORY

The development of Carbon Fibre composites as a viable construction material really began to take off in the 1980's. Prior to this time, concrete structures that had developed a structural weakness, or were required to be upgraded to take (for example) heavier grades of traffic, were either demolished and rebuilt or strengthened with steel plates that were held in place by a combination of adhesive compound and mechanical fixings.

The problems inherent in this situation were; that demolition and rebuild was both expensive and time consuming, while the cost of transporting and installing steel plates was itself becoming prohibitive. Not only that, but steel, even when protected by paint, is liable to corrosion and in aggressive environments can be compromised in a comparatively short time.

The solution therefore was to find a product that met the same strengthening specifications as steel but without the problems inherent. Alternative metals and alloys were examined, but were found to be either too expensive or possessing the same disadvantages as the original steel.

Carbon fibre had been known as a material that had applications in the aviation industry for some time, but the manufacturing process made it extremely expensive. However, in the late 1980's manufacturing techniques improved to the extent that it became cost effective to produce carbon fibre reinforced polymers as construction grade materials.

Testing carried out in several countries confirmed that the construction grade material gave tensile strengths far in excess of that given by a similar mass of steel. In fact a strip of Civil Engineering grade carbon fibre polymer measuring 120 mm wide by 1.4 mm thick gives a tensile strength of 269kN – almost ten times that of conventional mild steel.

Practical tests followed. Because of the comparative lightness of the material it was much simpler to transport it to site, often a small van being sufficient, and there was no need to use special equipment to unload and store the reinforcement. The spin off to this meant that the reinforcement could be easily manoeuvred into position without the need for heavy duty propping. Because the material was solely adhesive fixed, the difficulties usually experienced in lining up the shear bolts in steel reinforcements were completely avoided.

There were of course areas that had to be carefully monitored. The adhesive that bonds the CFRP to the structure is immensely strong and once the reinforcement is in place there is no second chance. Unlike steel, where you can do a dry run with CFRP you have to get it right first time – or you are back in the demolition business!

It is therefore vital that prior to commencement on site, a thorough design is undertaken and the materials manufactured to the highest possible tolerances. Because of the one time only nature of the material, it is also vitally important that a properly trained and qualified contractor undertakes the application of the material.

Fire resistance of CFRP as an inert material is high. However, the glass transition temperature of adhesive is of concern and could lead to premature failure of the system. The system is also exposed to vandalism and accidental damage. A fire protection system and clear marking are required to increase the fire rating and reduce the likelihood of any damage.

Material cost as compared to steel was in order of ten times in the 1980's basically because there was then only one manufacturer. Price competition with other manufacturers and with steel has reduced this difference dramatically.

We shall cover the exact bonding process later on in this paper when the reasons for these statements will become apparent. To conclude this section, let us recap the advantages and disadvantages of carbon fibre over steel.

Advantages

- It is easy to transport
- It is easy to manoeuvre
- It will not corrode or decay
- It resists aggressive environments
- It provides ten times the tensile strength of steel

Disadvantages

- Material is more expensive
- Protection is required against fire and accidental damage

## SOME PRACTICAL APPLICATIONS

We discussed in the first section the general benefits of CFRP strengthening. To illustrate this further, these are some actual applications that have made use of the properties of carbon fibre.

1. The Oil and Chemical Industry: apart from the conventional requirements of strengthening bridges and road ways within refining installations, the chemical and oil industries have in common the need to keep stocks in fluid form within metal or concrete tanks. In many cases these fluids are volatile in nature. With the passage of time, both natural decay and the corrosive actions of the stock lead to structural weaknesses in these holding vessels. Conventionally, the tank has to be emptied and cleaned to allow strengthening work to be undertaken. This process is costly in terms of lost production and involves expensive heavy machinery and the transport and installation of heavy-duty steel sections. The alternative of providing strengthening using carbon fibre strapping was first developed by Yoldings Ltd in response to a problem at the Alumina Processing Plant at Aughinish in the Republic of Ireland. Here the preferred solution enabled strengthening work to take place while production continued unaffected, despite the need to maintain the affected tank at an internal temperature of 90 degrees Celsius.

2. Transport Infrastructure: roads and bridges were the original areas in which CFRP was substituted for steel strengthening. Such has been its success that carbon fibre is now the preferred option on motorway and major road bridge refurbishments throughout the United Kingdom and most of Europe. The benefits of carbon fibre as a non degenerating strengthening system that is capable of being applied swiftly and with minimum disruptions means that traffic is diverted away from the repair site for a minimum period. In some cases where the design allows for application beneath a bridge structure, it may be possible to carry out the strengthening works without impeding the normal flow of traffic.

3. Marine and Coastal applications: one of the major problems inherent in strengthening jetty piles and dock platforms has been that even coated steel is prone to rapid corrosion in a marine environment. Many solutions have been proposed involving everything from plasticised paints to sacrificial anode technology. Again, with the problem of potentially rising sea levels, many coastal areas have been forced to adopt barrier sea defences; these again need maintenance and strengthening and have, to a lesser degree, the same corrosive environment as the jetty structures. The carbon fibre solution removes the root cause of the problem and in addition is far easier to install from floating platforms than the steel alternative. In fact equivalent strengthening using CFRP may be manhandled into position whereas steel would in all probability require dockside or floating crane facilities.

From the preceding examples it can be seen that the versatility of carbon fibre allows its use in all extremes of climate and industrial emission. This is due to the virtually indestructible nature of the CFRP material. The ultimate flexibility comes from the use of bonding resin technology which combining with a proper design and a skilled applicator ensures that a suitable bonding agent for the CFRP / structure interface is properly applied. Currently available products allow work to continue in temperatures from 5 degrees Celsius to 25 degrees Celsius with specialist resins being able to withstand temperatures up to 110 degrees Celsius.

## THE PRACTICALITIES OF INSTALLATION

So what are the practicalities of a successful CFRP installation? A step-by-step guide would be as follows.

**Step 1:** The identified project is subjected to a thorough investigative survey in which the problems (current or expected) are fully examined and options for repair and upgrade are tabulated.

**Step 2:** Following evaluation of the survey data, the decision to proceed with a carbon fibre solution is taken. This will bear in mind the location of, and environmental conditions at the site. It will consider the desired life of the completed project and take into consideration the cost implications of the solutions proposed. The specialist contractor will be able to provide budget costing for each outline solution to allow for proper evaluation.

**Step 3:** The Project Engineer creates a design and specification. This will involve the detailed calculations as to the desired strength of the refurbished structure thus enabling the designer to specify the most suitable grade and size of CFRP. Depending on the design, it may be required that the CFRP is supplied in flexible strips or as rigid planks. Both forms have the same properties regarding strength and durability and the decision as to which format to employ is invariably dependent on a combination of handling requirements and physical limitations at the site.

**Step 4:** The specialist contractor prepares a site programme. With the specification and design to hand, the specialist contractor is able to programme the delivery of the prefabricated component parts and arrange for suitable storage on site. The mobilisation and welfare of the workforce is organised ready for commencement.

**Step 5:** Site works begin. Preparation of the surface to be bonded (usually described as roughened to a texture similar to medium sandpaper) is by means of a mechanical abrasion process involving either abrasive wheels or grit blasting. The prepared area has its resin coat applied and the specified CFRP unit is offered in to place and smoothed into position so that the bond thickness is 2 to 3 mm. While curing the CFRP may be held in place by suitably positioned temporary props. The positioning of these props is part of the design work done prior to start on site. After curing the laminate should be finally checked for voids by gently tapping the bonded surface.

**Step 6:** Checking that the installation of the CFRP material in accordance with the design and specification has taken place is the responsibility of the specifier or their agent. They also make checks on the progress of the work to ensure that the design is being followed and to maintain a productive liaison between the designers and the contract team.

**Step 7:** Work is completed and a final inspection and survey pronounces the job to be completed properly.

Through the actions of the seven-step process, it is important that all the interested parties work together as a team. By the client, designer and specialist contractor working together from step 1 it is ensured that the whole potential of knowledge and experience available to the project may be brought to bear on problems as they arise.

Atypical problems to be surmounted will be: transport and delivery of materials, storage facilities on site, the need for on site expertise – remember you have to get it right first time! And the availability of technical back up if required.

## DESIGN

There is yet to be standardisation on manufacturing of CFRP. Therefore, designs are specific to CFRP specification from manufacturers. Initial work, which was carried out my Meier and Kaiser (1991) in the 1980's, has shown that the calculation of flexure in reinforced concrete elements strengthened with CFRP can be performed in a similar manner to that of a conventional reinforced concrete element albeit with special attention to development of shear cracks in the concrete which can lead to a premature peeling-off of CFRP. Holloway and Leeming (1999) edited the results of a coordinated research work funded by Department of Trade and Industry of the United Kingdom on Structural Composite Programme. In terms of adhesives Mays and Hutchinson (1992) have published a significant contribution in unravelling the principles behind their behaviour and application.

However, none of the work above mentioned provides a design guide to be used by engineers. The Concrete Society Technical Report 55 is the first useful design guide that cover the strengthening concrete structures using fibre composite materials which has been based on the work by Holloway and Leeming (1999) and Mays and Hutchinson (1992). FIB Bulletin 14 published in 2001 has significantly more information. However, Technical Report 55 of the Concrete Society is a more practical design guide. The Institution of Civil Engineers of United Kingdom has also published a design and practice guide for FRP Composites (2001), which is more relevant to strengthening metallic structures with composite materials.

## SPECIFICS TO IRAN

So how can this technology benefit projects in Iran? We have seen that carbon fibre is resistant to heat, chemicals and extreme weather both on land and in a marine environment. Using this technology will enable the upgrading of the Iranian infrastructure with minimal disruption to the daily lives and occupations of the people of Iran. The oil and chemical industries will be able to strengthen structures without long and costly closures of important machinery.

The materials used in this process are freely exported from their points of origin within the European Union, with the proviso that the resin must be carried by sea or overland to comply with the EU Safe Handling Regulations. This does not present a major problem with direct shipping routes available and the possibility of transhipment via Dubai or Kish Island. The CFRP itself, being chemically inert, may be transported by the most cost effective manner available.

The other benefit comes from the introduction of new skills to the construction industry workforce. As was said earlier in the paper, it is important to create a successful and co-operative team to maximise the amount of skill available to this project. An important part of this is the training and development of the workforce in these skills to allow them to participate fully in the projects that develop over time.

## REFERENCES

FEDERATION INTERNATIONAL DU BETON (2001). *Externally bonded FRP reinforcement for RC structures,* bulletin 14, Lausanne, 130 pp.

Holloway, L.C. and Leeming, M.B. (Eds.) (1999). *Strengthening of Reinforced Concrete Structures using externally-bonded FRP composite in structural and civil engineering,* Woodhead Publishing, Cambridge, 327 pp.

INSTITUTION OF CIVIL ENGINEERS (2001). *Design and practice guides – FRP composite – Life extension and strengthening of metallic structures,* The Institution of Civil Engineers, London, 64 pp.

Mays, G.C., Hutchinson, A.R. (1992). *Adhesives in Civil Engineering,* Cambridge University Press, 333 pp.

Meier, U. and Kaiser H. (1991). *Strengthening of Structures with CFRP Laminates,* Proc. ASCE Speciality Conference on Advanced Composite Materials in Civil Engineering, Las Vegas, Nevada, Jan. 31-Feb. 1, 224-232.

THE CONCRETE SOCIETY (2000). *Design guidance for strengthening concrete structures using fibre composite materials,* Technical Report 55, The Society, Crowthorne, 72 pp.