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Use of Fibre Reinforced Plastics in Bridge Structures

Emploi des plastiques renforcés de fibre de verre dans la construction des ponts

Anwendung von Faserverbund-Kunststoff im Brückenbau

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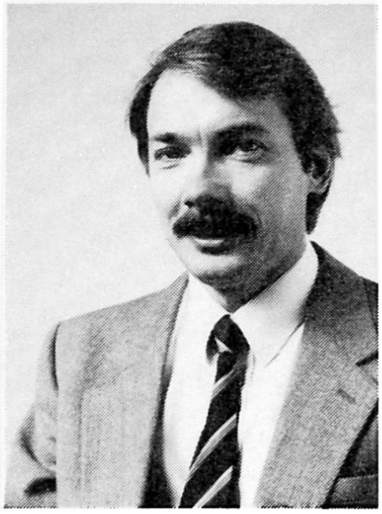

Peter Head, born 1947, graduated from Imperial College, London in 1969. He has been involved in the design and construction of major steel and composite bridges for nearly 20 years, and lectures widely on this subject. He was a founding Director of Maunsell Structural Plastics Ltd, formed by the Maunsell group of civil engineering consultants in 1982, and is responsible for designs of Advanced Composite Structures.

SUMMARY
Fibre reinforced plastics are being increasingly used in bridge construction. The reasons for this are explained and the materials currently available are introduced. Existing applications and research for a wide range of bridge types are described and the potential for future developments are discussed.

RÉSUMÉ
Les plastiques renforcés de fibre de verre sont de plus en plus utilisés dans la construction des ponts. Les raisons en sont expliquées, et les matériaux habituellement disponibles sont présentés. Les applications actuelles et les recherches pour une large gamme de ponts sont exposées, et le potentiel en vue de développements futurs est discuté.

ZUSAMMENFASSUNG
Faserverbundkunststoff kommt im Brückenbau mehr und mehr zur Anwendung. Die Gründe hierfür werden erläutert und die zur Zeit zur Verfügung stehenden Materialen angeführt. Bestehende sowie künftige Anwendungmöglichkeiten auf eine Vielfalt von Brückentypen werden beschrieben sowie die weiteren Entwicklungen in diesem Bereich.

1. INTRODUCTION

The history of bridge engineering is a history of the development of structural materials. Until Ironbridge was built in England in the year 1780, timber and stone had been used almost exclusively in bridge construction. The invention of wrought iron and then the development of steel and reinforced concrete changed bridge engineering completely in the 19th century. The 20th century has so far seen many developments in design and construction methods but relatively few fundamental changes in the materials used. Bridge spans and the number of bridge structures have increased dramatically to meet the demands of the rapid growth of infrastructure, but no new materials have found widespread use in bridges.

Fibre reinforced plastic (FRP) has already been used in prototype bridge structures (Fig.1) but the materials did not have the immediate and obvious advantages that iron and steel offered over timber and stone in the 19th century, except perhaps their potential for the construction of extremely long span bridges. (Although they have very high relative strength to weight ratios they have low stiffness unless expensive high modulus fibres are used. Materials and manufacturing methods for FRP are diverse and design methods are not fully developed.)

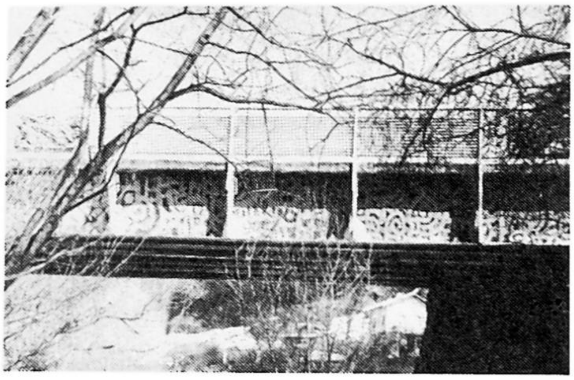

Fig.1 The world's first GRP highway bridge in Ginzi, Bulgaria

As a consequence, FRP had not been seen as a material likely to make an impact on general bridge engineering until the last ten years when the full implications of corrosion of steel in modern bridges was appreciated. FRP was then seen to have major advantages because of its excellent durability particularly in marine and industrial environments, and it is this characteristic which is currently leading to a significant step forward in its use in bridges.

2. WHAT ARE FIBRE REINFORCED PLASTICS?

FRP is a composite material which consists of two discrete phases, a continuous resin matrix surrounding a fibrous reinforcing structure. The reinforcement has high strength and stiffness while the matrix binds the fibres together.

The materials with potential for structural use in bridges are Advanced Composites in which high strength and high modulus fibres are used in relatively high volume fractions and the orientation of the fibres is controlled to enable high stresses to be carried. The reinforcement can be tailored and orientated to follow the stress patterns in the structural members leading to greater design economy than can be achieved with traditional isotropic materials. Varying combinations of flexural, tensile and shear strength and stiffness can be provided either with one reinforcement type or by combining fibres with different moduli.

Different fibre types and resin matrices have been continually developed over the last thirty years and together with many different highly automated manufacturing techniques they offer considerable scope to the designer.

There are three main types of fibre which are currently available for Advanced Composites, glass fibres, aramid fibres and carbon fibres. Resins could be polyester, vinylester or epoxy. Typical properties of composites made from these materials are compared in Table 1 for static load conditions.

Fibre Reinforcement		Glass	Carbon	Aramid	High Tensile Steel Wire
Fibre Fraction	%wt	80	72	67	-
Relative Density	ρ	2.31	1.57	1.36	7.86
Tensile Strength T	GPa	0.95	1.61	1.59	1.82
Tensile Modulus E	GPa	50	136	64.3	200
Specific Strength	T/ρ	44	105	119	24
Specific Modulus	E/ρ	21.6	86.6	47.3	25.4
Materials Cost Ratio* on a weight basis		6	16-20	10-15	1
Materials Cost Ratio* on a strength basis		3	4-5	2-3	1
Materials Cost Ratio* on a stiffness basis		7	5-6	5-8	1

* Materials cost ratio here is the 1987 cost relative to steel wire for use in cables or ropes.
Cost ratios for other applications will be different.

Table 1 Properties of composites with high proportions of unidirectional fibre reinforcement

3. APPLICATIONS OF FIBRE REINFORCED PLASTIC IN BRIDGES

3.1 Reinforced Concrete Bridges and Columns

One of the first uses of glass reinforced plastics (GRP) in bridges was in permanent formwork for concrete. The GRP was often manufactured using hand lay-up techniques with poor quality control and many engineers' early experiences with these materials has given GRP a bad reputation. However, recently developed manufacturing techniques now enable high quality economic structural GRP members to be produced.

Since GRP has high tensile strength and excellent durability it is logical to consider whether Advanced Composite GRP panels could be economically used not only as permanent formwork, but also as part of the structure to resist external loads and to protect against corrosion. These possibilities have been the subject of research work [1] and as a result helically wound GRP tubes have now been used in column construction for marine structures as a replacement for steel tubes filled with concrete. A GRP tube, having a high proportion of helical reinforcement, is an ideal material for encasing concrete because the concrete takes the entire axial load, the Poisson expansion in the circumferential direction is smaller than the concrete and the tensile strength in the circumferential direction is very high. Thus the GRP casing counteracts lateral expansion of the concrete under load and when used in a short column the axial strength of the concrete core increases over its uniaxial value and can reach a triaxial failure strength of up to four times the uniaxial value. It has been proposed that fibre reinforced plastic casings could be used in 'T' and 'I' bridge beams to improve the strength and ductility of the concrete in the compression zone in addition to providing formwork and corrosion protection. Tests on rectangular concrete beams with GRP casings and unidirectional GRP reinforcement have showed encouraging results and further research is being undertaken [1].

3.2 Prestressed Concrete Bridges

Severe corrosion of bridge prestressing strands in structures built only 20 years ago has been discovered and failures have occurred. Research into alternative non-corrosive materials has increased considerably as a consequence and the most advanced developments have been in the use of glass fibre reinforced plastic strands called Polystal.

A considerable research and development programme has been undertaken in West Germany on the use of Polystal strands for post tensioning concrete bridges. The first highway bridge to be constructed using these materials was a continuous two-span structure Die Brücke Ulenbergstrasse, also in Düsseldorf, which was completed in 1986 [2]. This 15 metre wide bridge has spans of 21.3 and 25.6 metres and consists of a 1.57 metre deep slab which was cast insitu with steel reinforcement. The slab was post-tensioned with 59 Polystal prestressing tendons, each made up from 19 glass reinforced plastic rods (nominal diameter 7.5mm) anchored in a specially designed block, and each tensioned to a working load of 600kN. 1300m^3 of concrete was used in the bridge, with 125 tonnes of steel reinforcement and 4 tonnes of glass reinforced plastic prestressing tendons. The bridge was built as part of a research project undertaken jointly by Strabag Bau-AG and Bayern AG.

3.3 Bridge Enclosure and Aerodynamic Fairings

The concept of 'Bridge Enclosure' was a prizewinner in the 1981 Civil Engineering Innovation Competition organised in the United Kingdom [3]. The proposal was to suspend a floor beneath the girders of steel composite bridges to provide inspection and maintenance access and to enclose the steelwork to protect it from further corrosion (Fig.2) [4]. A cellular GRP floor is being used in the world's first major bridge enclosure currently being installed on the A19 Tees Viaduct in the United Kingdom (Fig.3). The floor area is 16,000m^2 and contains 250 tonne of Advanced Composite materials.

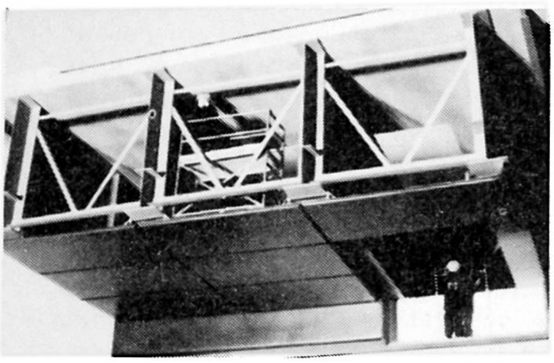

Fig.2 Model of a bridge with a GRP enclosure fitted

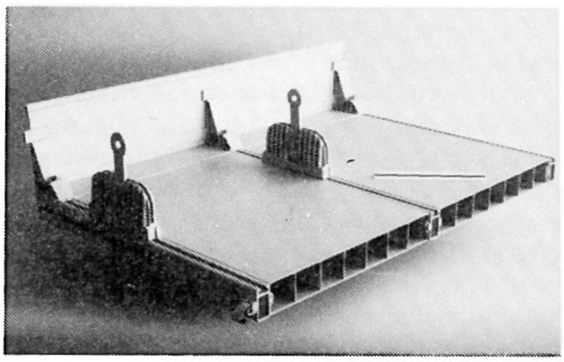

Fig.3 Model of the GRP enclosure floor for the A19 Tees Viaduct

The concept of bridge enclosure may have even more important implications for the future design of long span bridges. Currently steel box girders are often used for the deck girders of such bridges in order to provide an aerodynamic shape, to minimise exposed steel areas and to give good torsional stiffness.

However the development of cable-stayed bridges has resulted in a recent increase in the use of plate girders for long span bridges. The addition of fibre reinforced plastic enclosures around such structures would not only enable maintenance costs to be greatly reduced, but would also enable the shape of the cross section to be optimised by extending the enclosure into a fairing to give minimum drag consistent with aerodynamic stability (Fig.4a). The concept could be further extended to complete enclosure of the deck and traffic for extremely long span bridges in which the design for lateral wind is likely to dominate the structural form (Fig.4b).

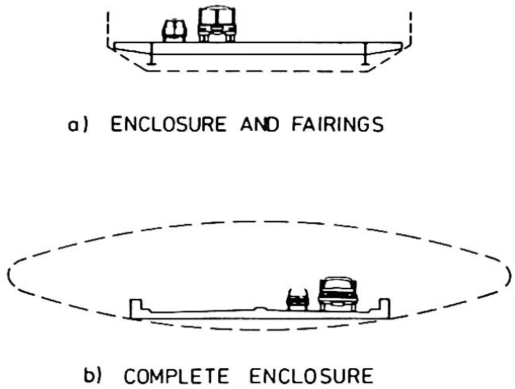

Fig.4 Enclosures around long span bridge decks

3.4 Glass Reinforced Plastic Bridges

The development of bridges constructed entirely out of fibre reinforced plastic started with the construction of prototype footbridges in Europe and North America in the late 1970s. The first GRP highway bridge is believed to be a 10 metre span bridge constructed in Bulgaria in 1981/82 using hand lay-up techniques (Fig.1). The second all GRP bridge is the 20-metre span Miyun Bridge in Beijing, China which is a prototype structure completed in October 1982 [5]. This bridge is the culmination of 25 years of Chinese research into the structural use of plastics.

Although the materials for GRP bridges are always likely to be more expensive than steel or concrete, the savings in fabrication cost may be considerable if highly automated production of large advanced composite members is developed. It is possible that complete box girder structures may be pultruded in the future, with a manufacturing facility being set up on site for large projects. The pultrusion process is shown schematically in Fig.5. Speed of construction, savings in erection costs and savings in foundations will also contribute to economy. However the biggest attraction is likely to be the low maintenance costs of such structures.

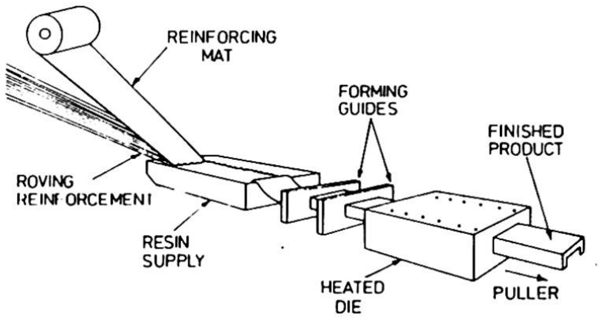

Fig.5 Diagram showing the pultrusion process

3.5 Cable Supports for Long Span Bridges

The advantages of the high strength to weight ratio of FRP are most important in very long span structures and are best illustrated by their potential for forming the main cables of suspension bridges. The theoretical limit of suspension bridge spans constructed from currently available high strength steel wire is around 5000 metres because the cables can only just support their own weight. If the full properties of Kevlar or carbon fibre reinforced plastic cables were able to be exploited the theoretical limiting span would increase to over 10,000 metres. Recent investigations indicate that the economic span for use of FRP cables in suspension bridges may be about 4000 metres [6]. However the lateral loading effects of wind and aerodynamic stability may be difficult to design for in bridges with such long spans.

4. CONCLUSIONS

Fibre reinforced plastics have many potential uses in bridges, either on their own, or compositely with steel or concrete and their use is certain to grow rapidly in the future. New forms of bridge structure are likely to develop and eventually the materials may enable the frontiers of long span bridge technology to be pushed further than current steel materials permit.

Many of the possible developments described are a long way in the future and first it will be necessary to continue research and development into the long term behaviour of FRP materials through the construction of more prototype structures in addition to laboratory work. It will also be necessary to develop design codes of practice and materials standards and specifications which will enable reliable and economic use to be made of FRP. Advances are now being made in these areas in the United Kingdom [7] and this may contribute to a wider understanding and use of fibre reinforced plastics in bridges of the future.

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