Structural Engineering Documents

7

Thomas Keller

Use of Fibre Reinforced Polymers in Bridge Construction

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

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Born in 1959, Thomas Keller obtained his civil engineering degree from the Swiss Federal Institute of Technology (ETH) Zurich in 1983. Following this, he worked as a research assistant at the Structural Engineering Institute with Professor Christian Menn. He then worked for several years at the architecture and engineering office of Dr Santiago Calatrava. Upon leaving in 1990, he returned to the ETH Zurich and received his doctoral degree in 1992 under the supervision of Professor Menn. In 1996, Thomas Keller was elected to the position of Assistant Professor of Structures in the Architecture Department at the ETH Zurich and, in 1998, he was elected Professor of Structures at the EPF Lausanne. Professor Keller is the Director of the Composite Construction Laboratory (CCLab), which he founded in 2000. His research work at the CCLab examines the application of fibre reinforced polymer composites in bridge and building construction. He is also Chair of the Research Committee of the School of Architecture, Civil and Environmental Engineering at the EPF Lausanne. Furthermore, he is Vice-President of the International Institute for FRP in Construction (IIFC) and Executive Committee member of the Composite Bridge Alliance Europe (COBRAE).

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Foreword

Due to their useful properties, fibre reinforced polymers are finding ever-increasing use in bridge engineering. Developments are motivated mainly by the problems of the corrosion of steel reinforcement and of the need to strengthen structures to withstand earthquake loads.

With this background, the Swiss Federal Roads Office (FEDRO) commissioned the Composite Construction Laboratory (CCLab) at the Swiss Federal Institute of Technology Lausanne (EPFL) to prepare a state-of-the-art report on the use of fibre reinforced polymers in bridge construction with corresponding applications and research recommendations. The present report summarises the development up until the end of the year 2000.

I wish to acknowledge the support of the FEDRO and to express my thanks to the members of the commission closely connected with this research project, namely P. Matt (President), M. Donzel, H. Figi, H. Fleischer, Prof. Dr. A. Muttoni and P. Wüst for their valuable contributions. I thank also my co-workers Julia de Castro, Sean Dooley and Dr. Véronique Dubois for their support. Finally, I would like to thank the IABSE for the publication of this Structural Engineering Document.

Lausanne, July 2003 — Prof. Dr Thomas Keller, EPFL-CCLab

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1 Introduction and Background

Fibre Reinforced Polymers (FRP) have been applied in a variety of ways in bridge construction because of the many advantages they offer. They are used as reinforcing bars for concrete, in all possible shapes of prestressing members (internal prestressing in concrete and external prestressing for new bridges and for strengthening purposes, stay cables, cables for suspension bridges, ground anchors, etc.), as strips and sheets for strengthening, as beams sections or in the form of trusses and as bridge deck slabs both for repair work and for new bridges.

Some applications are already well established, above all for strengthening, for example adhesive strips or the sheet technology for strengthening columns. Otherwise their use is still mainly in the form of pilot projects. But since about 1996, however, their number has exhibited an accelerated growth in all areas.

In the USA, for instance, approximately 42% of the roughly 575,000 highway bridges are in need of repair, mainly due to the corrosion of reinforcement of the deck slabs. Within the framework of the ten year CONMAT research and development programme (CONstruction MATerials) started in 1995 about 2 billion US$ have been invested in developments for rehabilitating the infrastructure. Of this over 40% are FRP applications allocated with the goal of developing a new generation of bridges with improved durability, reduced life-cycle costs and reduced construction times. In 1996, the first FRP bridge deck slab in the USA came into operation and up to the end of the year 2000 thirty-two of them will have been completed. In Japan, on the other hand, the use of FRP sheets for strengthening purposes increased threefold in1996 compared to 1995 after the Kobe earthquake (around 600,000 m^2). Whereas at the beginning of the 1980s only about 30 research centres were active worldwide in the development of FRP materials for civil engineering structures, today there are more than 300.

The reasons for this development lie in the following useful properties of FRP materials:
- excellent strength/self-weight ratio (approx. 40–50 times better than structural steel),
- easily formed into any shape,
- largely corrosion-free,
- largely resistant to fatigue.

Further, FRP structural components can be industrially produced and can be erected on the construction site in a very short time without the need for heavy lifting equipment. This reduces the high labour costs and the construction time (period of traffic disruptions) and considerably simplifies the quality assurance.

In view of this rapid development, in 1999 the Swiss Federal Roads Office FEDRO commissioned our research unit CCLab to prepare a state-of-the-art report on the application of FRP materials in bridge construction including application and research recommendations having specific reference to Switzerland.

2 Overview and Classification

Due to the wide range of FRP applications in bridge engineering the main difficulty in this report was to develop an appropriate classification permitting a simple overview and in which all applications could be suitably included. In table 2.1 the resulting and proposed classification is shown. The individual chapters of this report are arranged according to this classification.

The classification also clearly shows the scope of the report: It is limited to non-metallic fibre reinforcement combined with synthetic and cement matrices. Metallic and natural fibres and polymer concrete are not treated. In chapter 3 the properties of the basic materials as well as their composite behaviour are described. Then there follows a basic division into two groups: applications with synthetic matrices (polymers) and applications with cement matrices (concrete).

In the group with synthetic matrices, i.e. in chapters 4 and 5, firstly structural components are dealt with, which can usually be produced industrially. Chapter 4 describes flexible tension elements like strips, pin-loaded straps, reinforcing bars, cables, sheets and shell elements. Chapter 5 deals with stiff elements like structural profiles and sandwich constructions, which together with the corresponding joining techniques and sensors integrated in the material are also available as building systems in their own right.

In chapters 6 to 9 the state of the art on the application of these structural components in bridge construction is presented.

Chapter 6 deals with the cement matrices group and is entitled "FRP Reinforced Concrete." Here a classification is made according to short fibres, textile and bar reinforced concrete as well as internal prestressing of concrete.

Chapters 7 to 9 deal with the synthetic matrices group; they are given the following titles: chapter 7 "Repair and Strengthening," chapter 8 "New Hybrid Structures," chapter 9 "All-Composite New Structures."

Chapter 7 "Repair and Strengthening" describes essentially the state of the art on the repair and strengthening of bridge deck slabs, beams and columns of existing bridges using FRP constructional components (strips, pin-loaded straps, bars, external cables, sheets and shell elements).

In chapter 8 "New Hybrid Structures" new bridge structures are treated, which consist of components made of FRP and components made of traditional materials (steel, concrete, timber), e.g. FRP deck slabs resting on steel beams.

Chapter 9 "All-Composite New Structures" gives the state of the art on the construction of "pure" FRP bridges.

3 Fibres and Matrices

3.1 Overview

In chapter 3 the most important properties of the basic materials – fibres and polymer and cement matrices – are briefly summarised. The production methods are not treated. Then the most important aspects of the composite action of FRP materials is described (bonded fibres – polymer matrices) together with textile reinforced concrete (bonded fibres – cement matrices). Finally, the chapter is concluded with the topics durability, long-term behaviour and fire resistance of FRP materials.

3.2 Fibres

3.2.1 Properties

FRPs consist of load-bearing fibres and a matrix in which they are embedded. In bridge construction today the three main fibre types are glass, carbon and aramid. Their mechanical properties are summarised in table 3.1. Of particular interest are the so-called specific values shown in fig. 3.1, which are related to the density and highlight the real potential of this kind of material in comparison with traditional materials. (If one divides the ordinate values in fig. 3.1 by the factor 10 one obtains the limit lengths of the materials in km.)

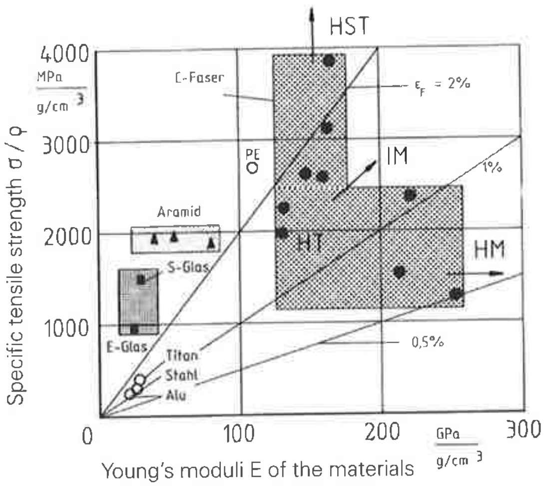

Fig. 3.1: Specific tensile strength σ/ρ and Young's moduli E of the materials.

Glass fibres are usually manufactured by the extrusion method. Different types exist, but in the building industry above all the fairly inexpensive E-glass fibres are used. The disadvantages of glass fibres are the relatively low Young's modulus, the low humidity and alkaline resistances as well as the low long-term strength due to stress rupture (cf. table 3.4). For applications involving concrete a more alkaline-resistant so-called AR fibre (also called CemFil fibre) has been developed with an increased zircon oxide (zirconia) content.

4 Tensile Elements

4.1 Overview

In chapter 4 flexible FRP tensile elements for FRP reinforced concrete, bridge strengthening and hybrid and all-composite new structures are treated. The corresponding state of the art of the applications are presented in chapters 6 to 9. The list of elements includes strips, pin-loaded straps, bars and cables as well as unidirectional sheets (unidirectional non-woven fabrics). The most important products on the market are dealt with together with their main properties. For more detailed information one should refer to the documentation of the manufactures.

The difference between untensioned and pretensioned rods and cable wires is not always evident since both are manufactured by the pultrusion process, cable wires are only of smaller diameter. Particular attention is drawn to the corresponding anchor systems. Two basic types can be distinguished: wedge anchors for short-term loading and bond anchors for long-term loading.

For the greatest efficiency mainly unidirectional sheets are used for two-dimensional strengthening elements. If more than one direction has to be strengthened (e.g. bending and shear), the sheets are applied in several layers in alternating directions. As a rule sheets are provided with protection against UV radiation.

4.2 Strips

Reinforcing strips were among the first applications of FRPs in bridge construction. There are different products. In the following as a typical example Sika CarboDur strips have been chosen; they exhibit the following properties:

- pultruded strips with unidirectional carbon fibres in an epoxy matrix,
- dimensions: width 50–150 mm, thickness 1.2 or 1.4 mm,
- tensile strength 1,300–2,800 MPa, Young's modulus 165–300 GPa, elongation limit 0.45–1.7%, data according to the types S, M or H,
- attached with epoxy adhesives,
- fast curing possible by heating (current flow in the strip).

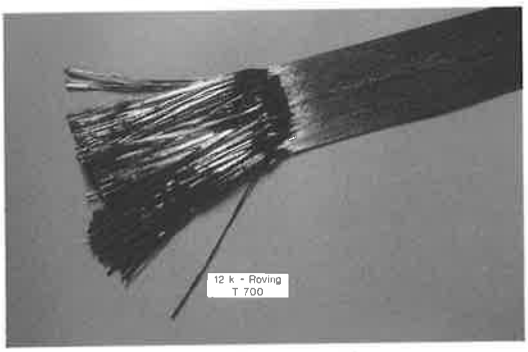

Fig. 4.1: CFRP reinforcing strips.

5 Structural Components and Systems

5.1 Overview

Chapter 5 deals with FRP structural components which are stiff in bending such as profiles exhibiting linear structural behaviour, as well as sandwich elements. The latter are used in bridge construction above all for FRP decks. Depending on the manufacturer both are available as components of structural systems: the profiles with the corresponding joining technology, the bridge decks with the various joining technologies, integrated guide rails, road surfacing, etc. Included in this chapter therefore is also a basic treatment on joining technology. In the last section a further technological aspect is handled, namely the possible integration of sensors in FRP materials.

5.2 Profiles

Basically the pultrusion technique produces profiles of any desired shape. In this process the continuous fibres are drawn through a die, into which a liquid thermoset is pressure pumped to impregnate the fibres (fig. 5.1). Heat treatment and added catalysts are used to cure the liquid thermoset. The bundle of longitudinal fibres is supplemented by complex woven mats and/or fabrics, which help to increase the shear and tensile strength in the transverse direction. In contrast to steel profiles with isotropic material properties, the profiles made of fibre composite materials exhibit a strongly anisotropic behaviour. Table 5.1 gives an overview of the material properties of the standard GFRP profiles available today.

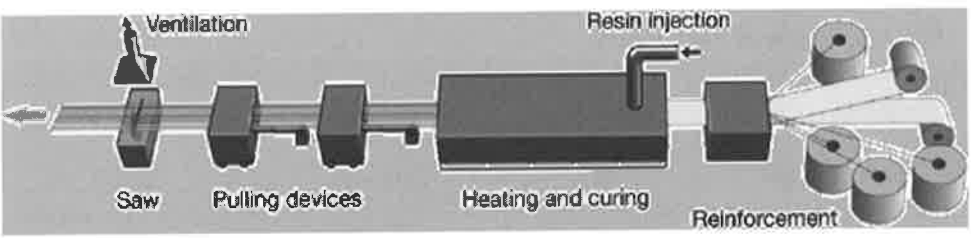

Fig. 5.1: Fiberline pultrusion process.

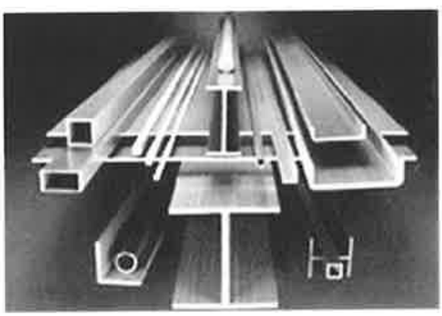

Fig. 5.2: Strongwell profiles.

Fig. 5.3: Hybrid C/GFRP double web profile (Strongwell, depth of profile 91 cm).

6 FRP Reinforced Concrete – State of the Art

6.1 Overview

In this chapter the state of the art of FRP reinforced concrete in new bridge structures (above all the superstructures) or parts of bridges (e.g. a replacement deck) is presented. FRP reinforcement, according to definition, comprises short fibres, textiles, bars and internal tendons. Applications with external cables are either treated under "Strengthening" in chapter 7 or under "Hybrid New Structures" in chapter 8.
Textile reinforced concrete is still in the stage of development and has not yet been used in bridge construction, there having been only experiments with precast formwork. This topic therefore will not be dealt with in the following.

6.2 Short Fibre Reinforced Concrete

Short fibres in concrete can be effective in limiting cracking, above all in green concrete. Significant increases of the load bearing capacity can not be achieved by this means. (In Canada a max. of 10% increase in bearing capacity in slabs was observed.) Short fibre reinforced concrete is thus suitable mainly for repairing concrete structures as a replacement of the old concrete, as has already been done in many places including Switzerland.
Another application form is being developed in Canada – the so-called "steel-free decks" – concrete decks without steel reinforcement. By means of arching action in the transverse direction the traffic loads are transmitted through short fibre reinforced concrete to longitudinal steel girders (distance between girders is max. 3.0 m). The upper flanges of the steel girders are connected in the transverse direction by welding to exterior steel ties, which are easy to replace (fig. 6.1). Polypropylene fibres are generally used, after also having tested nylon, polyolefin, polyvinyl and carbon fibres. The technology has been applied so far to 4 bridges (cf. table 6.1).

Fig. 6.1: Salmon River Bridge: steel girders with ties.

7. Fibre Reinforced Polymers – State of the Art in Repair and Strengthening

7.1 Overview

In chapter 7 the state of the art is presented of the retrofitting (i.e. strengthening and repair) of existing, mostly prestressed concrete or steel-concrete-composite bridges using FRP components. For this purpose strips, bars, external cables, sheets and shell elements and deck slabs are used. In this chapter the individual sections are again organised according to the main countries of application: Japan, Canada, USA and Europe.

7.2 State of the Art in Japan

In Japan mainly deck slabs and columns have been strengthened. The need to strengthen bridge decks is due above all to the increased live loads (maximum truck weight increased from 20 to 25 t) and the problems of punching shear which have thereby arisen. Accordingly, the undersides of the deck slabs are being reinforced over the whole area between the beams. In the case of columns, mainly the structural resistance to earthquake effects is being increased.

Basically, in Japan three different methods of retrofitting are being used:

- prestressed rods and cables,
- winding of tows for columns,
- use of fibre sheets for beams, slabs, columns, walls (mainly carbon fibres, and less frequently aramid).

Technora prestressing cables, for example, were used to strengthen the Sone Viaduct in 1995 (transverse prestressing).

In 1983 a robot was developed by Obayashi/Mitsubishi for the tow winding technique, but it is losing ground in bridge construction compared to the sheet technology, especially because in Japan mainly the bending resistance of columns has been increased by applying fibres in the vertical direction. (This is in contrast to the USA, where mainly the deformational capacity has been increased by means of winding techniques). First applications of the sheet technology were already in 1984 for the strengthening of deck slabs. The sheets are applied in two different ways:

- complete covering of the concrete with overlapping, or in
- the Sho-Bond method: application in a grid form with the possibility of checking the concrete surfaces in the spaces in between as well as any outflow of water (fig. 7.1).

In Japan there are two associations for promoting FRP for strengthening purposes:

- CFRRA (Carbon Fibre Repair and Reinforcement Research Association), and
- ARS (Society of Aramid Reinforcement Systems).

The CFRRA was founded in 1994 and comprises about 250 companies, of which fibres are manufactured by Tonen, Toray, Mitsubishi Chemical and general contractors like Obayashi, Shimizu, Kajima. There is close cooperation with the Public Works Research Institute (PWRI) of the Ministry of Construction, the Japan Highways Corp., the Hanshin Expressway Authority, etc. They are jointly preparing appli-

8 Fibre Reinforced Polymers – State of the Art in Hybrid New Structures

8.1 Overview

By hybrid new structures is understood the following: components of the bridge superstructure (beams, deck slabs, pylons, stay cables, etc.) consisting, on the one hand, of traditional materials (steel, concrete, wood) and, on the other hand, of FRP. The abutments and piers usually consist of traditional materials.
A survey of the hybrid new structural systems constructed up to now permits a classification into two main categories: traditional bridge concepts, in which traditional materials are simply substituted by FRP, and new concepts which tries to take into account the new properties of the FRP materials (material-adapted concepts).
In traditional concepts structural components like stay cables, beams or deck slabs are merely substituted. In material-adapted concepts the basic idea is not to give preference to any material, but to use it where its advantages can be best utilised.

8.2 Hybrid Concepts with Material Substitution

8.2.1 Hybrid Bridges with External FRP Cables

Here we classify bridges with bridge decks and pylons made of traditional materials, for which external cables made of FRP are employed.

Bridge	Country	Type	Year	System	Appendix 1
Akashi Kaiko (suspension bridge)	Japan	Highway	1996	Aramid cable $1 \times 1 \varnothing 10$ mm	–
Storchen Bridge (cable-stayed bridge)	Switzerland	Highway	1996	BBR $2 \times 241 \varnothing 5$ mm	–
Kleine Emme (underspanned) FOS integrated in cable	Switzerland	Pedestrian	1998	BBR $2 \times 91 \varnothing 5$ mm	–
Dintelhaven Rotterdam (external prestressing)	Netherlands	Highway	1999	BBR $4 \times 91 \varnothing 5$ mm	–
Passerelle des Neigles (suspension bridge)	Switzerland	Pedestrian	1999	CFCC	–
Herning Bridge (cable-stayed bridge)	Denmark	Pedestrian	1999	CFCC 16 cables	p. 121

Table 8.1: Hybrid bridges with external FRP cables (new bridges).

Table 8.1 gives an overview of the structures completed up to now. Of particular interest is the Akashi Kaiko suspension bridge with the current longest main span of 1992 m. To produce the cables for the first time an aramid cable was drawn over the

9 Fibre Reinforced Polymers – State of the Art in All-Composite New Structures

9.1 Overview

By all-composite new structural systems is understood the bridge superstructure (beams and deck) being made exclusively of FRP. Usually the abutments and piers consist of traditional materials.

If one analyses the all-composite bridges built today, as in chapter 8, one can differentiate between two categories: the concepts of material substitution with the replacement of traditional materials and the new material-adapted concepts. The bridges with material substitution can be further subdivided according to the substituted structural components. In the material-adapted concepts widely differing approaches are met with. The tendency in general is away from linear components to surface structures more suited to the material properties.

Numerically, the projects with material substitution predominate over those based on new concepts. This has to change in the medium or long term, because only with the new material-adapted concepts can the potential that lies in the new materials be fully utilised.

9.2 All-Composite Concepts with Material Substitution

9.2.1 All-Composite Bridges Made of FRP Profiles and FRP Gratings

Here, above all, pedestrian truss and beam bridges made up of pultruded FRP profiles are classified. A number of such bridges have already been built (cf. overview in table 9.1). The profiles used have identical shapes of cross-section to steel profiles (cf. section 5.2). The profile connections and joints are usually bolted. Only in the case of the Pontresina Footbridge material-adapted adhesive connections were employed.

Bridge	Land	Type	Year	System	Appendix 1
Techtonics bridges ca. 80 up to now	USA, Canada	Pedestrian	throughout 1980s	Strongwell Creative Pultrusion	p. 98
Clear Creek Bridge	USA	Pedestrian	1996	Strongwell	p. 105
PWRI test bridge	Japan	Pedestrian	1996		p. 106
Fiberline bridge	Denmark	Pedestrian	1997	Fiberline	p. 111
Pontresina Bridge	Switzerland	Pedestrian	1997	Fiberline	p. 115

Table 9.1: Bridges consisting of FRP profiles with FRP gratings.

9.2.2 All-Composite Bridges Made of FRP Decks

Here the bridges with (single span) FRP deck slab superstructure are considered. The bridges built so far are listed in table 9.2.

10 Design, Codes and Guidelines

10.1 Overview

No doubt due to the great variety of fibre types, possible fibre architectures, matrices, combinations of fibres and matrices as well as application possibilities, universal mandatory and easy-to-use design procedures and application codes are still missing today. In contrast to traditional materials, whose properties do not vary greatly, for FRP the choice of composition material introduces additional design parameters.

In some countries (above all in Japan and Canada) the first codes for specific applications have been prepared (mainly for FRP reinforced and strengthened concrete), while in others such are still in preparation (cf. section 10.3). For specific products application guidelines or manufacturers' design handbooks are available, e.g. for strips or profiles (Creative Pultrusion, Fiberline, Strongwell, etc.).

The key to a more widespread use of FRP materials is to have manufacturer-independent application codes geared to civil engineering practice. The problem of the wide variety of materials and possibilities of application could be overcome by their classification in so-called Application Categories, for which in a first step application recommendations could be worked out (cf. section 12.3).

10.2 Design

Due to a lack of widely accepted design procedures in the following only a few specific aspects of FRP are drawn attention to:

• Structural Safety

Due to possible stress rupture one has to distinguish between short-term and long-term structural safety, especially in the use of glass fibres whose long-term strength is only about 25–30% of the short-term strength (cf. tab. 3.4). The problem is lessened by the relatively low Young's modulus of glass fibres, due to which usually the serviceability at a relatively low stress level is decisive (e.g. in the case of profiles or FRP decks). However, special attention regarding stress rupture must be given to the use of glass fibres in prestressing systems or as untensioned reinforcement in the case of crack formation in concrete.

• Ductility

FRP materials behave linear-elastically up to failure. The properties considered under ductility – possible redistribution of sectional forces as well as a forewarning of problems of structural safety due to large deformations – are usually not (carbon and aramid fibres) or only partially (glass fibres) present. In the case of glass fibres one often (falsely) speaks of ductile behaviour, since the deformations due to the relatively low Young's modulus from the serviceability state up to failure can easily increase by a factor 10 to 20. The behaviour however remains linear-elastic.

Different strategies have been developed to obtain a nearly ductile behaviour:

- Hybrid fibre arrangements: mixture of carbon fibres with smaller and glass fibres with greater failure strain (e.g. roughly 20% carbon and 80% glass fibres). At the failure of the carbon fibres the forces are transferred to the glass fibres, accompanied

11 Application Recommendations

11.1 Overview

Based on the state-of-the-art reports presented in chapters 6 to 9 we have prepared the following application recommendations, which are basically subdivided as follows:
a) possible short-term applications: period 0–5 years,
b) possible medium-term applications: period 5–15 years,
c) possible long-term applications: period 15–50 years.
It is important to distinguish, especially for short-term applications, between applications which are already economic together with pilot applications and technologies with future potential, which, however, still require a certain amount of investigation and support.
To have a broader base for these application recommendations, an e-mail survey of the opinions of recognised international experts on the use of FRP in bridge construction was carried out (cf. appendix A2.2). The next section will begin with the results of the survey. In the subsequent sections we present our own assessment.

11.2 Results of a Survey

Thirteen experts responded to the following questions:
Which applications of FRP materials in bridge construction for repair, strengthening and new structures are conceivable, reasonable and realisable for a) the short term (0–5 years), b) the medium term (5–15 years), c) the long term (15–50 years)?
The answers were summarised in categories which are ordered according to the percentage of the number of responses per category. These rankings, due to the limited sample, should be taken with caution, but they do show fairly definite tendencies for the short- and long-term periods.
The results of the survey for the short-term period of 0–5 years can be summarised in the following six categories:
- repair and strengthening (46%),
- concrete deck replacement by FRP decks (21%),
- non-loadbearing, secondary elements (13%),
- footbridges (8%),
- concrete reinforced with FRP bars (8%),
- others (only one answer given, 4%).

The applications in the area of repair and strengthening, particularly strips and sheets for strengthening purposes, already predominate. The others include pilot applications, for which a corresponding development potential is acknowledged.

The medium-term period of 5–15 years includes, on the one hand, the same categories as for the short term as well as, on the other, answers, which one can consider to be precursors of the long-term categories. Thus the categories are not ordered according to percentages, but in two blocks according to the rankings of the short- and long-term periods:

12 Research Requirements and Recommendations

12.1 Overview

In order to provide a broad basis for defining research requirements for furthering the use of FRP in bridge construction, we have included questions concerning this in the survey presented in chapter 11. The results are given again in the following sections. The answers received are summarised in so-called key topics which are ordered according to the percentage of the number of responses.

Within these key topics there is already a great deal of work being carried out worldwide in many research centres. Due to the limited research resources available in Switzerland, in the last section only those research recommendations are listed, which raise specific questions for Switzerland or which really involve breaking very promising new ground.

12.2 General Research Requirements

The second question in the survey reported on in chapter 11 was:

In which areas is there a need for research to promote the use of FRP materials in bridge construction?

The evaluation of the answers provided the following key topics, whose ranking is based on the number of times they were mentioned:

- durability (23%),
- design methods, codes (18%),
- new material-adapted structural concepts (hybrid and all-composite) (15%),
- sensor technology (advanced monitoring, intelligent sensing, smart structures) (13%),
- economic manufacturing methods (8%),
- anchorage systems (8%),
- pilot projects (5%),
- others (10%).

According to our assessment this list comprises the most important topics. It is only necessary to add the topic of sustainability and the related question of recycling. Already in the medium term, in our opinion, thermosetting matrices have to be replaced by thermoplastics, which allow a complete recycling (no downcycling). The individual key topics in our estimation specifically include the following (order as above):

• **Durability**

FRP materials are frequently praised today because of their good durability. This however only relates to the favourable resistance to frost/de-icing effects. As shown in section 3.5, there are still open questions regarding other types of attack which require clarification. The most widely discussed question concerns the alkaline resistance of glass fibres. Since such clarifications can be carried out only by means of accelerated laboratory tests, the preparation of generally recognised test standards is of immediate relevance (cf. section 3.5). In order to obtain reliable answers, however, at least in the medium term, much importance has to be attached to outside storage in

Appendix 1

A1.1 Typical Examples of FRP Bridges

(Order according to year of construction)

Appendix 2

A2.1 List of References

The most important references for this report are listed in the following. In addition, standard documentation from the manufacturers of the FRP structural elements given in chapters 4 and 5 was available. Detailed information was requested via e-mail. Further specific references are included in the bridge data sheets in appendix 1.

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Use of Fibre Reinforced Polymers in Bridge Construction

The aim of the present Structural Engineering Document, a state-of-the-art report, is to review the progress made worldwide in the use of fibre reinforced polymers as structural components in bridges until the end of the year 2000.

Due to their advantageous material properties such as high specific strength, a large tolerance for frost and de-icing salts and, furthermore, short installation times with minimum traffic interference, fibre reinforced polymers have matured to become valuable alternative building materials for bridge structures. Today, fibre reinforced polymers are manufactured industrially to semi-finished products and complete structural components, which can be easily and quickly installed or erected on site.

Examples of semi-finished products and structural components available are flexible tension elements, profiles stiff in bending and sandwich panels. As tension elements, especially for the purpose of strengthening, strips and sheets are available, as well as reinforcing bars for concrete reinforcement and prestressing members for internal prestressing or external use. Profiles are available for beams and columns, and sandwich constructions especially for bridge decks. During the manufacture of the structural components fibre-optic sensors for continuous monitoring can be integrated in the materials. Adhesives are being used more and more for joining components.

Fibre reinforced polymers have been used in bridge construction since the mid-1980s, mostly for the strengthening of existing structures, and increasingly since the mid-1990s as pilot projects for new structures. In the case of new structures, three basic types of applications can be distinguished: concrete reinforcement, new hybrid structures in combination with traditional construction materials, and all-composite applications, in which the new materials are used exclusively.

This Structural Engineering Document also includes application and research recommendations with particular reference to Switzerland.

This book is aimed at both students and practising engineers, working in the field of fibre reinforced polymers, bridge design, construction, repair and strengthening.