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Scope of application of composite materials in bridge construction from Bangladesh perspective

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Abstract

The paper after giving a brief review of the current practices of composite bridge construction in the country, discusses on the scope of using the new materials e.g. GFRP, CFRP, AFRP, etc. side by side with the traditional materials e.g. concrete, steel, etc. It then discusses how the innovative structural concept including hybrid forms using the composite high strength but light weight material may enable to construct elegant medium to long span bridges. Further, the country needs to avoid close spacing piers in its river crossing structures from consideration of the river hydraulics and the morphology. Thereafter, the scope of using these new materials in strengthening, repair & rehabilitation of bridge decks, girders, railings, and pier columns is discussed. The initial cost might be high but the whole life cost considering the indirect benefit of aesthetics, and environmental friendliness might justify its use. The essential R&D needs are highlighted in the end.

Abbreviations

AFRP	-	Aramit fiber reinforced polymer
BWDB	-	Bangladesh Water Development Board
CFRP	-	Carbon fiber reinforced polymer
CRC	-	Compact reinforced composite
FRP	-	Fiber reinforced polymer
GFRP	-	Glass fiber reinforced polymer
HPC	-	High performance concrete
IABSE	-	International Association of Bridge and Structural Engineering
LGED	-	Local Government Engineering Department
PC	-	Prestressed concrete
RC	-	Reinforced concrete
R&D	-	Research & development
RHD	-	Roads & Highways Department
RPC	-	Reactive Powder Concrete
f_c'	-	28 days compressive strength in cylinder
MPa	-	Mega Pascal

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1. Introduction

In the bridge structures of Bangladesh, composite construction is related to its superstructure only. It's in the following form: cast-in-situ RC deck shear-connected to the steel or precast RC/PC girders or steel trusses. A few of the composite steel truss and concrete deck bridges are: 133 m Lamakagazi Bridge on Sylhet-Sunamganj Road, Sherpur Bridge on Sylhet-Dhaka Highway. Recently one arch bridge has been constructed across Crescent lake connecting ZIA Musoleum in the Dhaka Metropolitan city, using Glass block panels as deck.

Besides, several long continuous span PC box girder bridges have been constructed in the country namely, Meghna and Meghna Gumti Japan Bangladesh Friendship Bridges, Jamuna Multi-purpose Bridge, Bhairab Bridge, Pakshi Bridge and Gabkhan Bridge. Segmental free cantilever method of construction using traditional materials e.g. concrete, high yield reinforcing bars, high strength prestressing steel, etc. were used for these bridges. These are modern bridges but can't be categorised as composite bridges.

Further, plenty of the country's permanent bridges are located on the rural roads, which are constructed by LGED. Most of these bridges are traditional RC deck girder bridges, and some are PC girder bridges. The construction uses cast-in-situ deck shear-connected to the precast PC girders. These are also categorised under composite construction as noted earlier.

The traditional material and the structural forms are being used beneficially in the country's bridge construction. It's necessary now to examine whether new materials and concepts can modernise our bridge construction technology further.

The subsequent sections discuss on this aspect of bridge engineering.

2. What are the new/composite materials?

2.1 General

Nowadays different types of FRPs e.g. GFRP, CFRP, AFRP, etc. are being used as engineering materials. In Bangladesh some of these materials are being used in boating industry for example, in making speed boats; in furniture industries, in wrapping gas pipes, etc. and there is one example of retrofitting building structure using poly-carbon fibre. Globally in bridge engineering these materials are used in deck slabs, girders, and in repair and rehabilitation of structures.

The traditional concrete used in the country is in the strength range f_c' =18 ~35 MPa. The recently developed HPC may be of very high strength say, f_c'>80 MPa. Other types of fibre concrete also have been developed having f_c'> 200 MPa. In addition to compressive strength their direct and flexural tensile strength are also be very high. This type of concrete may also be categorised in the new material group.

2.2 FRPs

FRP elements are normally made of both metallic and non-metallic fibers. The FRPs made by using glass, carbon and aramid fibers impregnated in polymer matrices e.g. polyester, epoxy, etc. are called GFRP, CFRP, and AFRP respectively. The FRPs impregnated in cement matrix is called FRP reinforced concrete. This may contain short fibers, textile or bar reinforcement or may even be prestressed.

The non-metallic FRPs impregnated in polymer matrices are used for making tension elements e.g. strips, straps, bars, cables, sheets, shell elements, etc.; and also stiff elements e.g. profiles, sandwiches, sensors, etc.. The profiles may be of innumerable shapes e.g. U-sections, box sections, I-sections. At present different manufacturers make shapes of the profiles identical to the standard steel sections. Some of the tension elements mentioned above are popularly used for repair and strengthening of columns, beams, and deck slab. The hybrid structures and all-composite new structures may be designed using both the tension and stiff elements.

Two types of polymers are available namely, thermoset and thermoplastics. Currently thermosets are mostly used. For thermosets after hardening or polymerization reaction, their shapes cannot be changed, and these cannot be welded also. But thermoplastics have advantages of easily moulding into different shapes, and it's also easy for bonding together. This is making it increasingly popular. The commonly used thermosets are unsaturated polyester (UP resins), vinylester (VE resins), and epoxy resins (EP resins). The tensile strength of UP and EP resins ranges from 20-70 MPa and 60-80 MPa respectively [1].

The patented strand cables, anchorages, shear plates, etc. are also available now from different manufacturers. Exhibit-1 shows the available forms of reinforcing fibers [1].

2.3 RPC

This reactive powder concrete (RPC) has been newly developed in Korea. This is formed of HPC, reinforced with steel fibers, and it allows to build slender long span bridge structures of high durability. This concrete minimises micro cracks and pore spaces in concrete. A typical composition for 200 MPa concrete as given in RPC200 is as follows: Using the mix composition having fiber 200 μm 161 kg/m^3, fine sand 310 μm 1066 kg/m^3, cement 10 μm 746 kg/m^3, quartz powder 12 μm 224 kg/m^3, super plasticizer 9 kg/m^3, and water 142 kg/$m^{3,}$ the manufacturer obtained the compressive strength of the mix 170 – 230 MPa, flexural strength 30 – 60 MPa, Young's Modulus 50 -60 GPa [2].

In Seoul, Korea the symbolic new millennium structure the Sun-Yu Pedestrian Arch Bridge crossing Han River has been constructed using this RPC. The main arch span of the bridge is 120 m long. The bridge has been opened in May 1995). Exhibit-2 shows the overview of the bridge [2].

2.4 CRC

Chalmers University of Technology, Sweden has developed this high performance concrete CRC [3]. The goal was to design a joint which will make the surrounding concrete continuous. It's a silica-fume-based concrete, formed by fine and ultra fine particles in combination with steel fiber reinforcement. Its water/binder ratio is about 0.16 and the silica fume content is 20-25%. Quartz sand with particle diameters up to 4 mm is used as aggregates. Its characteristic compressive strength at 28 days is normally about 150 MPa. The fiber content is normally about 6% by volume or more than 450 kg per m^3 of joint concrete. This compound is used in moment stiff joints between precast modules.

Exhibit - 3 shows the moment stiff high performance joints for prefabricated RC deck panels made of CRC side by side with the conventional joint [3].

3. One example of an all-composite GFRP bridge

This is located at about 2 km from the city of Leida in Spain. This cable suspended bridge crosses a roadway, and a railway line. Another new high speed railway line connecting Madrid and Barcelona will be added in near future. The footbridge has been opened in October 2001. Exhibit -4 shows the bridge overview and details[4].

The double-tied arch of 38 m span length with a rise of 6.2 m was selected as the structural form of this 3 m wide footbridge. This dimension was selected to suit the properties of the GFRP profiles. The arch configuration minimised the serviceability problems likely to be arisen due to the low modulus of elasticity (E=23-27 GPa) of the profiles. The total weight of the bridge was only 19 metric ton. All of the profiles were made of E-glass fibers and woven and complex mats with a minimum glass fiber content of 50%. The tensile or compressive strength of the profiles in the longitudinal direction was 240 MPa and in the transverse direction 50 to 70 MPa. Both arches and the tied longitudinal members were rectangular hollow sections of two U300 x 90 x 15 mm profiles joined with glued flat plates of 180 x 12 mm (Ref. Exhibit – 4).

GFRP pultruded profiles used in the deck panel of this 38 m long bridge has the advantages that it has no magnetic interaction with the adjacent electrified railway line, it has minimum maintenance cost and it’s easy to build [2]

4. Strengthening of structures

In the tropical humid climate of Bangladesh concrete deteriorates faster particularly in the cover zone. This is truer particularly when the concrete isn’t dense. For strengthening of deck slab and even for new deck, the light weight GFRP panels are beneficial.

Fiber Composites e.g. FRP plates and fabrics are used for strengthening RC columns, beams, masonry walls, etc. They can be formed in place to any complicated shapes. They are significantly lighter than steel plates of equivalent strength; it doesn’t need temporary support for the plates while the adhesive gains strength. They are stronger than steel and so they can be applied in much thinner sections, which can be fitted in curved sections.

Exhibit – 5 shows wrapping fabrics winding around columns for its strengthening. This may be used for rehabilitation of the columns also [1].

5. Use of GFRP panels in temporary structures

The light weight GFRP panels may be used as a permanent or temporary/removable formwork for constructing deck slab of bridges. Photo 1 shows the photograph of the under construction Hazrat Shah Paran Bridge. The photograph shows the precast concrete slab which was used by the contractor as temporary shutter of the deck concrete, supported over the adjacent precast PC girder flange. The light weight GFRP panels would have been more appropriate for this purpose.

Photo 1. Under construction Sylhet Shah Paran Bridge showing precast deck forms

6. Making of FRP products

The FRP products are made mainly by pultrusion process as shown in Exhibit – 6. The VARTM technique using vacuum pumps for intake of resins are also used. Besides, hand laminated technique is also used. For example, some of the FRP manufacturers located at Pagla, Dhaka producing FRP products for boating industries. .

7. R&D need

R&D is needed on two issues namely, on the behaviour of the composite material e.g. FRPs, artificial concretes, etc., and their products; and concept R&D to develop the areas and the structural forms where these can be beneficially used.

FRP products are susceptible to deterioration when exposed to the ultra violet (UV) rays. R&D should be done on the climatic conditions including the sun shine prevalent in Bangladesh. Research is needed to develop the design and construction guidelines on achieving adequate ductility of the FRP structures against wind and earthquake loading given in BNBC'93.

The R&D may include pilot structures using the FRP products, where its deformational behaviour against sustained and environmental loading may be monitored by readings from sensors. In FRP structures particularly using thermoplastics, installing FRP sensors made of optical fibers is easy.

9. Conclusions

The use of FRP in composite bridges is till now in the infant stage. In 2002 only 36 bridge structures were constructed using the FRP panels [1]. In 2005 about 175 vehicular bridges and 160 pedestrian bridges have been constructed using FRPs [5].

The composite construction using traditional and new materials along with the hybrid construction, if found feasible by further R&D on our environmental conditions, and if found cost effective will be immensely beneficial. FRP being high strength but lighter material its use in the medium and long span bridges should be advantageous. Besides it needs less maintenance.

For structural strengthening particularly of the bridge deck this appears to be efficient and time saver as regards construction/erection time. For deck construction its use as deck form, permanent or temporary, should be tried. Use of GFRP as deck form appears to be a feasible option both from practical and economic consideration.

The country's both public and private sectors are weak in R&D. The country's research organizations always lack adequate funds, and also lack initiative. Appropriate measures should be taken to develop the R&D sector in this regard. Also manufacturer and material independent standards and guidelines will be necessary.

This R&D should be done in the country's research laboratories. HBRI's scope may be extended to conduct this R&D. It may be done developing the partnership with the academic institutions and the private sectors.

References

[1] Thomas Keller, Use of Fiber Reinforced Polymers in Bridge Construction, Structural Engineering Documents Nr 7, IABSE-AIPC-IVBH, 2003.

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[3] Peter Harryson, High Performance Joints for Concrete Bridge Applications, Structural Engineering International, IABSE, SEI Vol. 13, Nr 1, February 2002, pp. 69-75.

[4] Juan A. Sabrino, M Dolores G. Pulido, Towards Advanced Composite Material Footbridges, Structural Engineering International, IABSE, SEI Vol. 12, Nr 2, May 2002, Pg. 84-86.

[5] Sara Black, How are Composite Bridges Performing?, December 2003, High Performance Composites Source Book 2005, Internet

Appendices

Exhibits 1-6

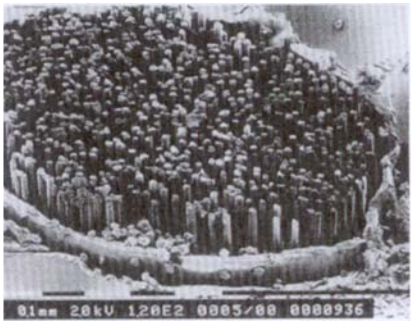

Exhibit - 1a Roving

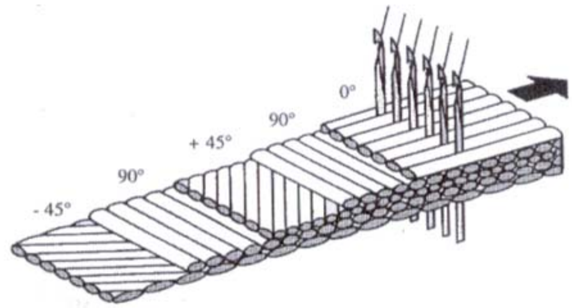

Exhibit - 1b .Multiaxial non-woven fabric

Exhibit - 1c Hybrid fabric of carbon and aramid fibers

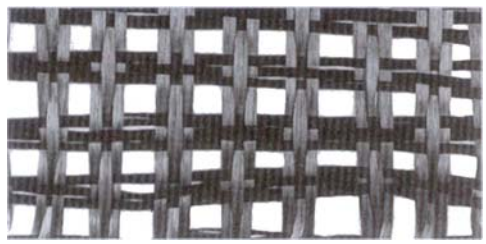

Exhibit – 1d Grid fabric

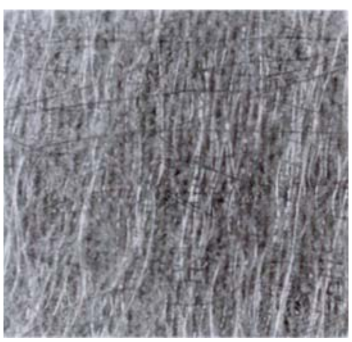

Exhibit – 1e Mat of continuous fabric

Exhibit – 1f Fleece of chopped glass

Exhibit – 1. FRP fibre elements

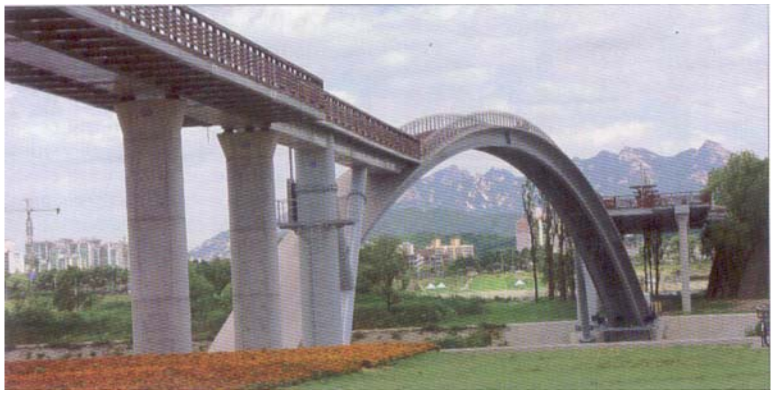

Exhibit – 2. Sun-Yu pedestrian arch bridge, Seoul, Korea [2]

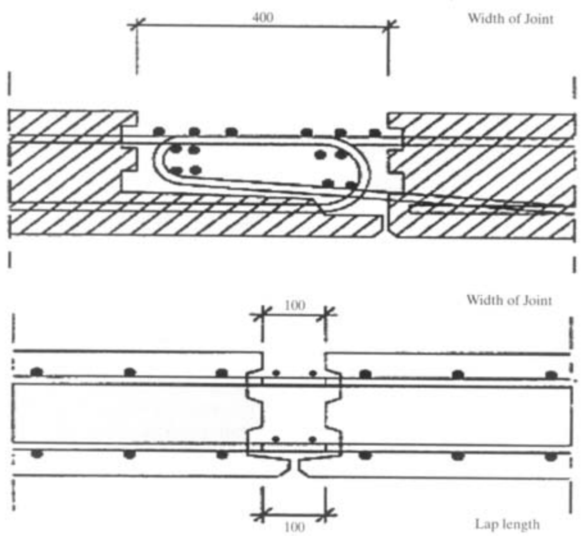

Exhibit – 3. Conventional joint (top) and the CRC filled joint (bottom) [3]

Exhibit – 4a General view of the GFRP footbridge, Leida, Spain

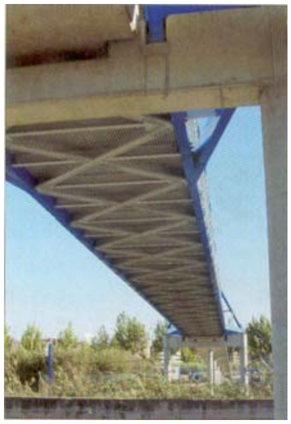

Exhibit – 4b Floor system   Exhibit – 4c   GFRP profile

Exhibit – 4. GFRP Bridge at Leida, Spain

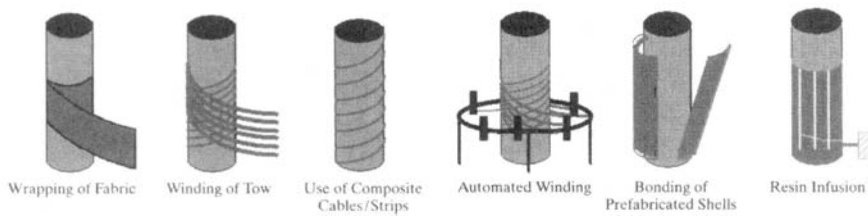

Exhibit – 5. Wrapping fabrics [1]

Exhibit – 6. Pultrusion process for making FRP products