A REVIEW ON THE APPLICATION OF FIBRE REINFORCED POLYMER IN REINFORCED CONCRETE STRUCTURES

Inderpreet Kaur, Hardeep Singh Rai and Harvinder Singh

Abstract Fibre Reinforced Polymer (FRP) has extensive engineering application where high strength to weight ratio, low cost and ease of fabrication are required. The material has extraordinary mechanical properties such as tensile modulus, impact strength and important in-service properties which when combined with other materials are utilised to improve the stiffness/strength, durability, the whole-life cost benefit and the environmental impact. In recent times FRP in Reinforced Concrete (RC) structures have been established as highly efficient, high performance structural materials and their use is increasing rapidly. The investigation of the applications of FRP in RC structures has been of deep interest to the researchers as evident from reports. The paper concludes by summarising key successes of the FRP in RC structures in the civil infrastructure. Previous experimental studies of RC structures with FRP is reviwed in this paper.

Key words: Fibre Reinforced Polymer,Reinforced Concrete,Slab,Beam

1 Introduction

Reinforced concrete structures are most commonly constructed in these days but deterioration of RC structures due to harsh environmental conditions leads to premature deterioration of structures before completing expected service life due to corrosion of steel reinforcement bars within the concrete. The premature deterioration of structure is an economic burden not only on owners but also to the munici-

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palities and nation as a whole. India loses more than USD 40 billion a year about 4 percent of the size of the total economy due to corrosion in infrastructure and industry segments, reported by ONGC,CMD Sudhir Vasudeva in 2012. It has been widely reported that approximately 40 percent of India's bridges are either structurally deficient or functionally obsolete. In case of newer bridges, deteriration caused by unforeseen service condition, adverse environmental actions and inadequate maintenance is causing great concern to bridge engineers. To overcome this problem, a promising solution is offered by using fiber-reinforce polymer (FRP) composites, which have clear advantages such as lightweight, noncorrosive, nonmagnetic, and nonconductive [1]. Fiber reinforced polymer (FRP) plates or sheets were firstly introduced into civil engineering for the repair and rehabilitation purposes of existing damaged and inadequate structures since 1990s. In recent times FRP in reinforced concrete (RC) structures have been established as highly efficient, high performance structural materials and their use is increasing rapidly. The FRP shell can protect the concrete and interior steel rebars from external corrosion.

2 Fibre Reinforced Polymer-Reinforced Concrete (FRP-RC) Structures

2.1 General

In modern era, FRP composites are widely used in structural elements as strong and light material always fascinate mankind for typical applications. Due to this, FRP composites are the matter of extraordinary attention of researchers and building producers in the technical world. Composite Material is an advanced engineering material incorporating a variety of materials that act together on a macroscopic scale. Composite material consists of filament (e.g., E-glass, carbon, and aramid) and matrix (e.g., epoxy, polyester, and vinylester resins). Advanced fibre composites was originally developed in the military and defence industry in 1940s, particularly in aerospace and naval applications but have been gaining acceptance in other industries such as automotive, and more recently in civil infrastructure. Composites were broadly use in the aerospace industry during the 1960s and 1970s due to their remarkable properties such as lightweight,noncorrosive, nonmagnetic, and nonconductive [1]. FRP materials were widely accepted in infrastructure construction industry during the late 1980s and throughout the 1990s [1].

Since then, a wide range of applications of FRP materials have been implemented including strengthening of damaged structures using FRP sheets for the repair and rehabilitation purpose and using FRP rods as reinforcement instead of steel rods. Composites have the applications range from non-structural gratings and claddings to full structural systems for industrial supports, buildings, long span roof structures, tanks, bridge components and complete bridge systems [2]. Composites consumption in India posted an impressive growth in the last few years. Pipe and tank, transportation, wind energy, construction, and electrical and electronics are the major market segments of composites in India. By the end of 2018, the composites market is expected to grow 2.3 fold and reach the level of 1.5 billion pound, with double digit compounded annual growth [3]. There is enormous scope of use of FRP in construction due to seismically deficient buildings, long coast line and long monsoon season needs the non-corrosive FRP. After Gujarat earthquake occurred in 2001, FRP application for retrofitting is gaining attention in India [4].

New prospective possibilities of applying FRP composites could be observed in hybrid structural members and structural systems. Hybrid system is formed by combining the polymer composites with other conventional structural materials. The combination can take many structural forms, these are FRP composite bridge decks and bridge superstructure, the rehabilitation of reinforced concrete and steel beams by the techniques of external plate bonding, retrofitting of reinforced concrete columns by using unidirectional FRP composites, the FRP rebar used to reinforce concrete beams and slabs and the construction of a structural member to enable two or more materials to advantage of their merit properties [5]. The alternative use of FRP in FRP-Concrete hybrid structural elements shows a development for new constructions by taking the inherent benefits of each material in such a manner as to optimise the overall performance of the combination of materials to overcome the corrosion related problem in conventional reinforced concrete beam.

Now a days FRP is widely used in bridge construction. To provide new bridge systems that can be cost- competitive with conventional bridge construction practice, various systems for different span bridges had been developed. The Modular Hybrid Tube System consists of pultruded hybrid rectangular girders connected along their tops with a polypropylene fibre reinforced concrete arching deck was developed [6]. Also the research activities are oriented in the field of creation of new beams by combining the FRP with concrete.

2.2 Experimental Investigation of FRP-RC Structures

Due to lightweight and durability characteristics of FRP, some new innovative development have been introduced as stay-in-place (SIP) forms for one-way simply supported concrete slabs and girders [7,8,9]. An innovative FRP-RC beam composed of a low cost construction material, (namely concrete), ductile steel rebars and a high specific strength/stiffness FRP composite was presented by Wu et al.[10].

2.2.1 Slab

High performance FRP can now be found as composite in bridge deck construction to support beams of highway bridges. The concept of SIP structural forms simplifies and accelerates construction to a great extent in bridge deck. Two-way SIP form-concrete slab performance was also evaluated using simply supported boundary conditions with additional FRP grid reinforcement [11]. Fatigue performance of the SIP form-concrete system was examined and found to be satisfactory [12].

Nelson [9] developed new system where corrugated Glass Fibre Reinforced Polymer (GFRP) pultruded plates were used as SIP structural formwork as well as acts as the bottom layer of structural reinforcement for the concrete slab supported by precast concrete girders. The system was compared to a control steel-reinforced specimen designed using the Canadian Highway Bridge Design Code (CHBDC) [13]. The system was also assessed in terms of ultimate strength, deflection, and stress levels.

The experimental program consisted of five full scale bridge deck specimens (S1 to S5). The four specimens (S1 to S4) were designed as a single span with a center to center girder spacing of 1780 mm, while specimen S5 designed as an exterior span with a cantilevered overhang deck of 1070 mm beyond the edge of the outer girder. GFRP hat shaped section as shown in Fig.1 was produced by Creative Pultrusions, Inc., comprising E-glass fibres and polyester resin and different thicknesses, namely 3.2 and 4.2 mm, were used. The average tensile strength and modulus were 353 MPa and 24.5 GPa, longitudinally, and were 89 MPa and 9.2 GPa, transversely, for the 3.2 section. For the 4.2 mm section, these values were 344 MPa and 24.5 GPa, longitudinally, and 94 MPa and 9.26 GPa, transversely.

The concrete of grade M35 was used for the support girders and the deck. V-Rod number 4 (12.7 mm) GFRP bars were used as top reinforcement in specimens S2 to S5. 10M (11.3 mm) black steel bars were used in the support girders and in the deck of control specimen S1. Specimens S2 to S4 used the GFRP SIP form , where four modules connected together through the pin-and-eye connections were used in each specimen.

In this study, the SIP form completely replaced the bottom layer of reinforcement, while a top GFRP mesh was provided. The 410 mm wide supports had a rough surface finish along with protruding steel stirrups. All specimens, except the cantilevered one that failed in flexure, had a punching shear failure while the GFRP pin-and-eye connections remained intact. The system demonstrated excellent performance, with safety factors ranging from 3.5 to 4.9, relative to the half-axle service load, including impact factor, of standard design trucks. Deflections requirements at service were less than span/1600. The system also displayed significant deformability associated with gradual loss of strength beyond punching shear, a major advantage over conventional decks. Adhesive bond improved stiffness but had little effect on strength. A specimen with a larger width would had promoted a higher failure load and less deflections as indicated in Fig.2. Results of this study suggest that this corrugated FRP SIP formwork system is a safe and efficient system for constructing composite concrete bridge decks.

2.2.2 Beam

The deck unit bridge is clearly based on assembling a number of beams. The beam can also be used individually as flexural members, for example as replacement timber girders in existing timber structures. Now a days, the research activities are oriented in the field of creation of new beams by combining the FRP with concrete. A novel FRP/RC hybrid flexural member was proposed [10] in order to lower the initial cost and take full mechanical and cost advantages of different types of fiber sheets The specimens of FRPRC hybrid girders were fabricated with wet-bonding. Carbon/glass FRP (C/G FRP) sheets were axially and wetly bonded on the bottom surface of the concrete core to carry tensile load. GFRP sheets were hoop-directionally and wetly wrapped to carry shear load. The external FRP shells can effectively protect the interior steel reinforcements, the steel corrosion of normal RC structures can be effectively mitigated or even avoided for the FRPRC hybrid structures. The reinforcement ratio of FRP shells was decreased to lower the cost of the hybrid structures. The FRP shell was fabricated with a hand lay-up process on a mold with a cross-section size of 150 mm x 300 mm and cured at a room temperature, wherein epoxy resin was used to impregnate the fiber sheets. High strength carbon fibres have tensile strength and modulus of elasticity of 3400 MPa and 2.4 x 10^5 MPa respectively whereas high ductile glass fibres have tensile strength and strength of modulus of 1500 MPa and 8.0 x 10^4 MPa respectively.

Five types of FRPRC specimens were fabricated and studied with a main variable of tensile steel reinforcement ratio. The steel reinforcements include stirrup, compressive and tensile reinforcements, among which the tensile steel reinforcement ratio was selected as a variable to study the mechanical properties of different types of FRPRC hybrid girders. The tensile steel reinforcement ratios of the five specimens are 0.29 percent, 0.43 percent, 0.77 percent, 1.20 percent and 1.73 percent, respectively.All the specimens are subjected to a 4-point bending experiment with supporting and loading spans of 1700 mm and 400 mm, respectively as shown in Fig. 3. The specimens were loaded under a load control manner at a loading rate of 2 kN/min.

The wet-bonding technique was confirmed to be effective in obtaining an excellent composite effect and bonding between FRP shell and concrete core. The initiation of flexural concrete cracks occurs during a load range of 23.5 26.7 kN under the loading points. The stiffness of the structure becomes a little smaller after the initiation of concrete cracks. The number of the concrete cracks increases with the increase in load. Around the yielding of steel reinforcements, the cracks propagate quickly and the number of cracks does not increase although the load still increases. It is seen that at the yielding of steel reinforcements there is a relatively larger decrease in stiffness. The shear cracks initiate at the ends of flexural cracks when the strain of CFRP sheet under loading points increases to about 7000 , and then the debonding of FRP sheet initiates.For the FRPRC hybrid girders, the minimum steel reinforcement ratio was about 0.77 percent, and at this ratio the stiffness of the FRPRC hybrid girder approximated the RC girder with a steel reinforcement ratio of 2.38 percent before the cracking of concrete. An integrative property of FRPRC hybrid structures was obtained, including initial and secondary stiffness, load carrying capacity, yielding load and ductility. Compared with the girder with a steel reinforcement ratio of 2.38 percent, the load carrying and ductility capability could be enhanced by more than 27.6 percent and 81.3 percent, respectively.

2.3 Bonding Techniques

Various techniques have been developed for bonding FRP reinforcements on concrete structures. One is conventional bonding technique, in which concrete cores are precasted first, then fibre sheets are bonded on the external surface of the concrete cores which is similar to Externally Bonded FRP, or EB-FRP technique which involves the adhesive bonding of the FRP to the external surface of the existing Reinforced Concrete (RC) members [10]. Another one is wet bonding technique, the FRP shell is firstly fabricated with different types of fibre sheets by applying epoxy resins on them. Then a thin layer of resins is sprayed on the inner surface of the FRP shell. Before the full curing of resins, concrete is encased as a core, and the FRP shell is used as a mold. Generally, the resin is cured to a half-hardening state, and a sound composite and bonding effect between FRP shell and concrete core can be obtained through wet bonding. By this, robust hybrid system can be obtained by proper bonding [14].

3 Conclusion

This paper has presented a brief applications of FRP composite materials in construction. Advanced fibre composites have been gaining acceptance in the civil infrastructure industry. Composites can also make substantial contributions to improving the sustainability of engineered structures. There is great scope for the further development of these materials .It is believed that the continuing development of these systems and others like them to provide engineers with necessary design guidance, will see composites gain an increasing foothold in the civil engineering market over the coming years.

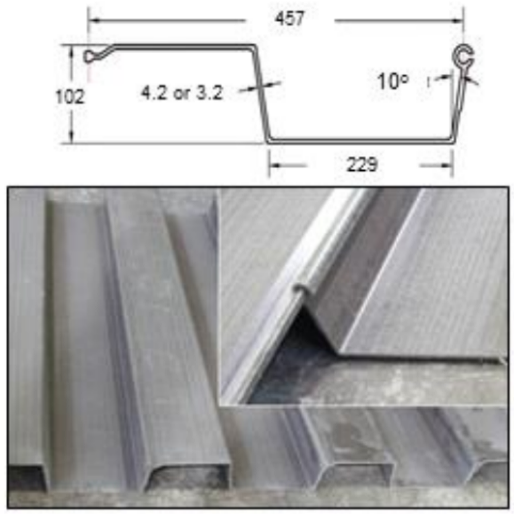

Fig. 1 Corrugated GFRP panels with pin-and-eye connections

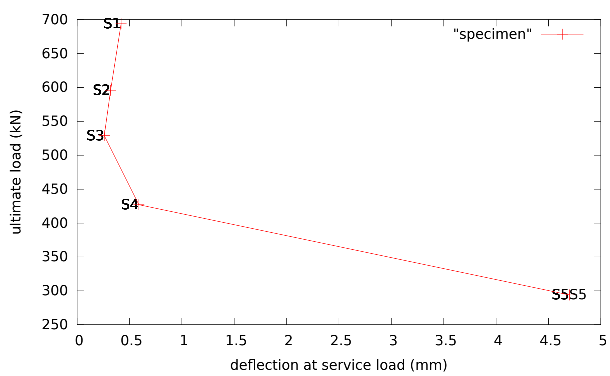

Fig. 2 Load deflection responses of test specimens

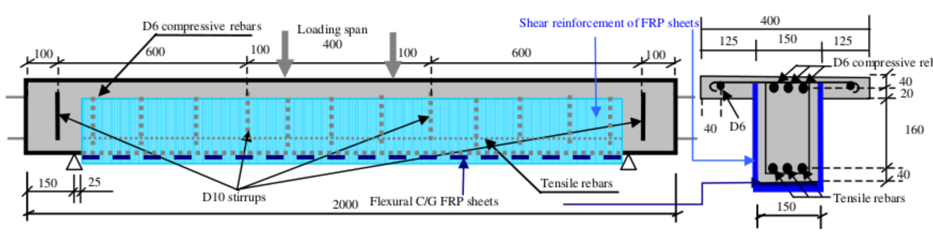

Fig. 3 Schematic view of girder