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FRP: Research, Education and Application in India and China in Civil Engineering

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***Abstract*- Engineers throughout the world including India and China have used FRP to solve their structural problems in an efficient and economical manner. In the field of civil engineering, most of the use of FRP is confined to repairing and strengthening of structures. FRPs offer an added advantage over conventional materials and methods of retrofitting. Like other materials, FRP also has its limitations. After presenting a brief review on these dimensions, this paper provides a thorough survey of the research, education and application field of FRP in civil engineering in India and China. The paper also indicates pitfalls in the field and furnishes suggestions for improvement.**

I. PROLOGUE

India and its neighbor China are the two big emerging and developing economies. While they started making use of composites almost simultaneously about more than 30 years ago, the progress made by China is rather astounding [1]. Fibre reinforced polymer (FRP) in India has taken shape in 1960s with a single resin manufacturer and a lone source of fibre glass. Over the years, the industry has grown steadily, but at a slower pace [2]. FRP materials were developed primarily for aerospace and defense industries in the 1940s and are widely used in many industries today, including aeronautic, marine, automotive and electrical engineering. With the continuing cost reduction in high-performance FRP materials and the growing need for new materials to renovate civil infrastructures, FRP materials are now finding wider acceptance among civil engineers [3]. Research on FRP in construction in the mainland of China may be traced back to the end of 1950s when China was in short supply of steel [4]. Construction is a major part of development plan of developing countries including India. To meet the large demand for infrastructure development, maintenance and life enhancement of existing structures are very important. After many years of use, an existing structure often needs to be repaired or upgraded because of so many reasons like damage due to corrosion or increased load demand etc. There are several methods for retrofitting of structures like- guinting, post tensioning, externally bonded steel plates, steel or concrete jackets etc. Epoxy injection and newly developed methods like advanced techniques for corrosion affected RCC and methods of modifying structural properties using active or passive mass damper for high rise buildings are also there [5].

The technique of externally bonding FRP to reinforced concrete (RC) structures was introduced into China in 1997.[6] In India, field application of FRP for structural strengthening could be traced as early as in 1999. However, FRP is being used for new construction also in many countries; none could be traced in India. The material is still considered relatively new in this part of the world. China is working on use of FRP in new construction in many directions like FRP bridges, GFRP breakwater, FRP space structure, concrete filled FRP tube columns. There exist many FRP footbridges in China.

II. FRP COMPOSITE

Composite materials are made by combining at least two different constituent materials with one or more materials as reinforcements, and one or more materials as the matrix. FRP composite is similar to RC, with a fiber (such as glass, carbon or aramid) as the reinforcement and a polymer (polymer resin matrix such as epoxy, polyester) as the matrix. The fiber reinforcement carries load in pre-designed directions and the polymer matrix serves as a binder, a medium to transfer loads between adjacent fibers and to provide protection for the fiber. Current FRP composite materials typically have high-strength and high-stiffness structural fibers embedded in lightweight, low-cost, and environmentally resistant polymers; which have better mechanical and durability properties than either of the constituents alone. [3] FRP products produced for use in structural engineering can comprise significantly more ingredients than just the primary constituents: fiber and polymer resins.

Advantages and Limitations

FRP has tremendous potential and has great advantages over conventional materials and techniques of retrofitting of RC structures. The increase in use of FRP for retrofitting of RC structure may be attributed to their advantageous properties mainly - high corrosion resistance, light weight, extremely high strength to weight ratio, ease of handling and installation (hence substantially reduced working time). However, there are some factors limiting its frequent use such as very high material cost, lack of design codes on FRP in many countries like India, unawareness of or reluctance to accept existing reports, guidelines and technical publications currently being used worldwide [7, 8].

III. FRP IN CIVIL ENGINEERING: INDIA VERSUS CHINA

The overall composites market in India is relatively small, compared to per capita consumption in other parts of the world. A few years ago consumption level of composites in India was only about 30,000 MT, as compared to about 2,00,000 MT in China [1]. There is enormous scope of use of FRP in India, because of seismically deficient buildings, long coast line and long monsoon season pressing the use of non-corrosive FRP. Traditional materials, such as wood, are in short supply. There are a few examples of FRP application for retrofitting before Gujarat earthquake (2001) and after this earthquake only, the technique is gaining attention in India. However, the same is not to the extent warranted by potential of the FRP that exist. As the material is still considered relatively new in this part of the world, most of the works had been carried out in accordance to available guidelines and published literature like ACI 440.2R-02

The composite market in China is developing rapidly with construction as the largest end-use market. . The technique of externally bonding FRP composite plates or sheets to RC Structures was introduced into China in 1997. After extensive research and promotion since then, it has now become a major method for retrofitting concrete structures; and consequently, the first specification for FRP in civil engineering in China, "Technical specification for strengthening concrete structure with carbon fibre reinforced polymer laminate CECS-146" (CECS-146 2003), was published in 2003. A national standard, "Standard for FRP in Civil Engineering", is also being developed [6, 9].

A. FRP: Research and Education in India and China

In India, in the field of education and research related to FRP in construction, IIIts, IISc, Structural Engineering Research Center (SERC) Chennai, FRP institute Chennai, Indian Society for Advancement of Materials and Process Engineering (ISAMPE) (headquarter- Bangalore), Research Design and Standards Organization (RDSO) under the Ministry of Railways at Lucknow, Technology Information Forecasting and Assessment Council (TIFAC) a unit of DST, Composites Technology Centre (at IITM) are among others, participating actively. For the composites industry a monthly magazine-'FRP Today' is being published in India since the year 2000.

The Department of Science and Technology, Government of India, in collaboration with the universities, is developing standards for FRP in construction. Focus is placed on the rate of degradation of glass FRP in view of the South Asian environment and the concrete mix typically used in India. The application is targeted at corrosion damaged structures and seismic retrofitting [10]. Composites Technology Centre (formerly -Fibre Reinforced Plastics research Centre) was established in 1974 at IITM as an interdisciplinary centre for carrying out teaching, research, design and development in the field of composite materials and their applications. The centre was renamed as Composites Technology Centre in 1997 [11].

In china, various educational and other bodies involved in education and/or research on FRP include-Dalian University of Technology. Fuzhou University, Guangdong University of Technology, Hong Kong Polytechnic University, Hong Kong, Southeast University, Nanjing , Tsinghua university, *Beijing* Tongji University, Shanghai, Association of Chinese Civil Engineering (ACCE), National Engineering Technique Research Center of Industrial Building (NETRCIB)., the Chinese Science and Technology Ministry and the Chinese National Science Foundation., Natural Science Foundation of China , Royal Society, The China Association for Engineering Construction Standardization in China, Chinese Science and Technology Bureau, Beijing FRP institute, Nanjing GFRP institute,, Shanghai Research Institute of Building Sciences, Shanghai

The first research of FRP in civil engineering in China was conducted in Tsinghua University in 1958. The test was intended to use GFRP bars instead of steel bars as there was limited amount of steel in that time in China. But the beam failed in very brittle style with a sudden rupture of GFRP bars, so that the research was not continued. From 1970s, there were some research institutes in China began the research on the GFRP bridge and there were some GFRP bridges were built. Besides, there some researches and application of GFRP water tanks for buildings [9]. Systematic research on FRP in construction was begun in 1997, when the external bonded CFRP sheets strengthening technique for RC structures was introduced in China. The first test to demonstrate the effectiveness of this new strengthening method was conducted in 1997 by NETRCIB. In 1998, a subcommittee of FRP in construction was founded under the Chinese Civil Engineering Association. After that, there has been more and more research on FRP strengthening of structures [4]. From 1997 to 1999, the researches were mainly to demonstrate the effectiveness of the strengthening method. Under the support of Chinese Science and Technology Bureau, a series of experimental researches on flexural strengthening of RC beams and slab, shear and seismic strengthening of RC columns were conducted in Tsinghua University and NETRCIB to establish the design method for the RC structure strengthening with CFRP sheets and plates [9].

The research of GFRP bridges in China began since 1970s; consequently 1982 witnessed the first trial in Miyun, Beijing. Since 1998, more than 40 concrete filled GFRP tube columns were tested to determine the static and seismic behaviors in Tongji University. After the first test demonstrating the effectiveness of the strengthening method using external bonded FRP, in 1999, research on RC structures using FRP bars began, at Southeast University, Nanjing, followed by Tongji University, Shanghai. Since 2000, series of experimental researches on steel structure strengthening with CFRP were conducted by NETRCIB. A test was done in Tsingua University in 2000, demonstrating use of CFRP in self structure monitoring. Beijing FRP institute developed a FRP sandwich panel breakwater. NETRCIB also conducted a test on a containment shell structure of a

nuclear power station strengthened with CFRP sheets. To use FRP to make super large span space structure, the CFRP tubes were developed for the research of space truss structure in Tsinghua University. Southeast University studied RC beams prestressed with FRP tendons and developed some anchorage devices for prestressed FRP tendons. The basic compressive behaviors of confined concrete by FRP and hybrid FRP jackets, including round, square and rectangular sections were researched in several universities in China. There were also research reports and publications about strengthening with FRP sheets and plates for two-way slabs, torsion members and beam-column joints. The four universities researched on the seismic strengthening of masonry wall using FRP, under cyclic lateral load in the wall plane [9]. There are many specific research for example a new form of hybrid FRP concrete- steel double skin (FCSDS) columns has recently been proposed by Prof. J.G. Teng. The column consists of an outer FRP tube, an inner steel tube and concrete in the annular space between the two tubes. They have many advantages over simple concrete-filled steel or FRP tubes [12].

To evaluate the current trends in the FRP education, a survey of universities around the world was carried out between November 2001 and February 2002. The Editorial Board of the American Society of Civil Engineers Journal of Composites for Construction (Lawrence C. Bank, Editor) sponsored the survey of the civil/structural engineering programs. Among others, 35 universities from Asia were included in the survey, out of 35 only 12 participated in the survey including 4 from China, 3 from Japan, and 2 from Thailand, 1 each from Korea and Singapore and 1 from India i.e.-IIT Bombay. In the survey participants from People's Republic of China were, Dalian University of Technology, Fuzhou University, Guangdong University of Technology, and Hong Kong Polytechnic University, Hong Kong [13]. According to the survey, despite a significant number of field applications and laboratory research on FRP, the research results have not yet been fully translated into teaching curricula, and civil engineering graduates for the most part are not sufficiently trained to design or specify FRPs for construction projects [13]. This situation is improving now, however at a very slow pace.

B. Civil Engineering Applications of FRP in India

There are many Indian projects to the credit of FRP systems by various companies like Fyfe (India) Pvt Ltd, Fosroc Chemicals (India) Pvt Ltd, Krishna Conchem Products Pvt Ltd, BASF, Sika India Pvt Ltd etc. Field scenario in India is illustrated below -

Following are some of the Indian application of Tyfo Fiberwrap System by Fyfe(India) Pvt Ltd, in buildings, the list is not exhaustive and only representative applications are mentioned here- In August, 1999, structural strengthening of circular columns & flat slab at Shah House, Worli, Mumbai. In September, 1999, slab strengthening at Sudharkar Building, Mumbai. In 2000, at various MTNL TE buildings at Fountain/ Gamdevi Mumbai - structural strengthening and protection of beams/ columns/ slabs; at Voltas Sagar Building, Parel, Mumbai-structural strengthening of peripheral columns due to increased loads. In 2001, at St. Thomas School, New Delhi.; at Casa Grand Society, Mumbai.- one or the other work like structural strengthening / protection/ corrosion protection of beams/ columns/ slabs; –at Amreli/ Laxmi Motors Showroom Gandhidham, Gujarat.- structural repairs & strengthening of columns distressed due to seismic event; -at Phoenix Mills Ltd., Parel, Mumbai-strengthening of masonry walls for structural integrity. In 2002, at Reserve Bank of India, Staff Quarters Chakala, Mumbai. (Phase I) -localised strengthening of beam column junctions; In 2003, at Panchratna Building, Opera House, Mumbai - structural strengthening of beams and columns for ductility enhancement. In 2004, at IT Software Park, Hyderabad- strengthening of columns due to low grade concrete. In 2005, at CST Airport Terminal 1B, Mumbai (Phase 1) - column /beam joint retrofit [14].

In 2006, at Narora Atomic plant, Narora- containment wall strengthening; at Prestige Tech Park, Marathalli, Bangalore- strengthening on flat slab drop panels to enhance capacity; at BSNL TE building, Raipur, Chhattisgarh- repair and strengthening of columns and beams. In 2007, at Shreyans Motors Mumbai- strengthening/integrating brick piers and RC columns; at Reliance Industries Ltd, Hazia, Gujarat- beam retrofit for enhanced equipment load. In 2008, at Hotel leela palace Udaipur, Rajasthan- retrofit of columns and beams due to structural alteration; Columbia Asia Hospital, Bangalore- strengthening of MRI room slab for enhanced loads. At Hyderabad, Pune and many other places strengthening work is going on [15].

Following are some of the Indian applications of Tyfo Fiberwrap System in bridges/ water tanks/ brick walls-In 2003, at Road Over-Brigge 235A, KRCL Madgaon, Goa -beam strengthening and corrosion protection. In 2004, at Janak Setu Flyover, Municipal Corp Delhi (1 span) - structural strengthening of bridge girders. In 2004, at BSNL Staff Qtrs, Elevated Water Tank, Ahmedabad.- structural strengthening of water tank staging columns and beams; at Jindal House, New Delhi - seismic retrofit to load bearing brick wall structure [14].

Following is the list of some projects where Nitowrap (CF/GF) by Fosroc has been used- Sap Labs, Software Park, Apotex Dharmachem, Bangalore; Rochees Breweries, Rajasthan; Gujarat ambuja Cements, Himachal Pradesh; Raheja Tech Park, Hyderabad; KTPCL Chimney, Andhra Pradesh; Mangalore Airport, Mangalore; Karur Hospital, Tamil Nadu; Textile Mill Complex, Sun Pharmaceuticals, Tata Chemicals Ltd., Gujarat; Nagpur Tunnel, Nagpur; JNPT, Navi Mumbai; Noble Corporation Projects, Maharashtra; Ranbaxy Laboratories, Madhya Pradesh; FTPS Chimney, Faridabad, Ansal Plaza, Delhi; AMTI and ELCOT, Chennai; Salt Lake City Building, Kolkata; Rajamundry Railway Bridge. [16]

Following is the list of some of the Indian projects where various types of Sikacarboudur/ Sikawrap from Sika India Pvt Ltd have been used. In 2002- Raymonds

Ballard Estate, Raymonds J.K.House and Phenix mill – in Mumbai. In 2003- Shurshusha Hospital**,** Shalaka CHS, Chandramukhi – in Mumbai In 2004- Asian Paints, IIT, Island Heights- in Mumbai; DLF; Adobe Software– in Delhi; Veeranam W.B.Project – in Chennai; Pumping station- in Rourkella. In 2005- Junglighat- in Portblair; Pion Young, AAI- in Chennai; Unitech, Sheikh chulli tomb- in Delhi; Santosh Associates- in Ahmedabad; ASI Building, Lord viceroy lodge - in Simla. In 2006- Infosys- in Bangalore; Manikaran- in Kolkata; Residential building (L&T) - in Chennai; TCS in Trivandum. In 2007-Mind Space Raheja - in Hyderabad; Ansal Plaza, India Bulls, API Mal, NDTV- in Delhi; Great Eastern Hotel, Minerva Theatre- in Kolkata; Shopping Mall- in Maldaha; Alpha City IT Park, Air Cargo Building AAI- in Chennai; LSG Skychef - in Bangalore. In 2008; KDA Hospital, Residence Antilia, Piramal House, Centre Point, Peninsula Developers in Mumbai. There are a few bridge projects also-. In 2003, Bata ROB – Kolkata; In 2005**,** Ghaghar Bridge, Chandigarh; In 2006, Roon bridge, Chandigarh and a Bridge in H.P; In 2007, Karjon Bridge [17].

Details of many projects are given elsewhere [8], following are the some glimpses. Rehabilitation of a vertically cracked masonry bridge pier of a major steel plate girder bridge on Vijayawada-Visakhapatnam section of South Central Railway using Nitowrap CF sheet was completed during July, 2005, saving Rs 6.93 crore of Indian Railways.[18] One of the major applications of Fiber Reinforced Composites has been in earthquake damaged structures in Gujarat. A severely damaged fertilizer plant in Gujarat has been rehabilitated using this application. About forty-five days were taken to complete the repair process of around 5000 sq m area, and the plant was able to come back to full production within three months. All the components used in repair were procured in India from Indian manufacturers [19]. Inferior grade of concrete in some RCC members, primarily beams; while construction of a residential multi-storied tower in Pune, was compensated by strengthening these members using BASF's MBrace FRP composites. Investigations using NDT technique showed that the actual compressive strength developed was in the range of 15 to 20 MPa in place of 25 MPa. The project was implemented in the year 2006 [20] Confinement using GFRP (along with epoxy adhesive) enhanced the strength of columns to bear the load coming from two additional floors added to the existing five storeyed structure of a well known hospital in Mumbai. [21]

C. Civil Engineering Applications of FRP in China

China constructed the first FRP composite bridge deck [3]. The first trial to use FRP in bridges in China was in 1982. A highway bridge of 20.7m in span and 9.2m in width in the form of a box-beam made of GFRP honeycomb plates was built in Miyun, Beijing. After about one year's service, a local depression was observed in the bridge due to the instability of the honeycomb and local buckling The GFRP beam was then strengthened into a GFRP-concrete composite beam in 1987. It is well in service till now [4]. After that, many footbridges completed in Sichuan province, China including Jiaoyuan Bridge, Chenjiawan Bridge, Guanyin Bridge. The superstructure of the Jiaoyuan Bridge is a box-beam made of GFRP honeycomb sandwiched plates. Guanyin Bridge is the other bridge in the same city. The GFRP elements in these bridges were made by hand lay-up. In 2001, the Jiaoyuan Bridge was repaired and the Guanyin Bridge was demolished due to large deformations [9].

However, same as the other countries, the most application of FRP in civil engineering in China is the RC structure strengthening using external bonded CFRP sheets or plates. At the late of 1990s the FRP was found its popular application in civil engineering in China when the external bonded techniques of structure strengthening using CFRP sheets became accepted in Chinese civil engineering. The Chinese engineers, after that, began to acknowledge merits of this new building material [9].

Other research and application in China using FRP includes- in Flexural strengthening of RC beams and slabs with external bonded CFRP sheets and plates, both prestressed and unprestressed, in prestressed FRP tendons, in Shear strengthening of RC beams and columns ,in RC bridge slab strengthening, in seismic strengthening of RC columns with CFRP sheet, in strengthening of masonry structure (such as masonry wall), steel and wood structures, in FRP-concrete composite structures such as concrete filled FRP tubes and FRP slabs, box-beam made of GFRP honeycomb plates, in FRP strands for prestressing, in making super large span space structure like CFRP cable stayed bridge, in an innovative large-span structural system FRP woven web structure (FRPWWS), in FRP sandwich panel breakwater (developed in Beijing FRP institute), in special structures like a safe containment shell structure of a nuclear power station strengthened with CFRP sheets, in repair or strengthening of existing traditional timber buildings in China, in road reinforcements such as fiberglass geogrid and TruPave engineered paving mat (China has been first to adopt these on a large scale in order to meet its specific needs around highway paving and maintenance). There are now well developed design methods for many applications like RC structures using FRP bars, but perhaps there has been no application so far, because there is not much demand in construction compared to FRP strengthening

Following are some of the applications of Tyfo Fiberwrap System by Fyfe in China, the list is not exhaustive - In 2000, Beam strengthening- at Hangzhou Wahaha Primary School; - at Lishui Hydro-Power Station; Repair and strengthening of T-beams due to shear and flexure deficiencies and of columns due to deficiency in axial capacity- at Kunshan-Tongcheng River Bridge. In 2001, strengthening of beams and slabs- at Hangzhou Hydro Power College; Seismic retrofit to 20 columns –at Shanghai Natieta Factory; Strengthening of concrete sluice gate –at Wenzhou Sluice Gate. In 2002, Strengthening to beams and slabs to increase loading capacity –at Zhejiang Huangyantiandai Health and fitness centre. In 2003, Strengthening to office beams, columns

and slabs –at Hangzhou youjia advanced mechanics factory. In 2004, Structural strengthening of T Beams -at Su Zhou North Bridge. In 2005, 20m Span box girder strengthening – at No. 320 National Highway Shanghai XinZhiShiJin Bridge [14].

As per some estimate, the usage amount of CFRP sheets used in structure strengthening is about 500,000 m^2 in 2002 [9] and, at present, over 600,000 m^2 FRP sheets are used to retrofit concrete structures every year in China [6]. The composite market in China is developing rapidly.

IV. Epilogue

India is the second fastest growing economy after China. In spite of all the potential of India, .rapid use of FRP in civil infrastructure is difficult because of local code restrictions There is an urgent need to develop Indian standards for use of FRP and more production facilities. For use of FRP, China has Technical specification CECS-146, and a National Standard is also underway. China is far ahead of India in the field. With less than 5% of the Asian FRP market, there is plenty of room for growth in India [9].

The application of FRP in civil engineering is showing upward trend in India and China, however, FRP is still a specialty item. To improve this situation, civil engineering and their extension programs must provide sufficient training on unique features of FRPs so that engineers could design or specify them in construction [17]. At this juncture, there is a need of Government-Industry-Institute partnership to exploit full potential of FRP. The increase in use of FRP for retrofitting is inevitable because of its potential.

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