RESEARCH PAPER | Engineering | Volume : 5 | Issue : 8 | August 2015 | ISSN - 2249-555X

Use of Frp Composites in Civil Engineering

KEYWORDS

M. M. Deshmukh
PG Student, Department of Civil Engineering, SKN Sinhgad College of Engineering, Pandharpur

D. D. Mohite
Assistant Professor, Department of Civil Engineering, SKN Sinhgad College of Engineering, Pandharpur

Dr. C. P. Pise
Associate Professor & HOD, Department of Civil Engineering, SKN Sinhgad College of Engineering, Korti, Pandharpur, Dist. Solapur.

S.S. Kadam
Assistant Professor, Department of Civil Engineering, SKN Sinhgad College of Engineering, Pandharpur

Y. P. Pawar
Assistant Professor, Department of Civil Engineering, SKN Sinhgad College of Engineering, Pandharpur

C. M. Deshmukh
Assistant Professor, Department of Civil Engineering, SKN Sinhgad College of Engineering, Pandharpur

ABSTRACT *Advanced composite materials or fiber reinforced polymer (FRP) composites are very attractive for use in civil engineering applications due to theirlight weight, high strengthtoweight and stiffnesstoweight ratios, corrosion resistance and high durability. Their application is of most importance in the renewal of structural member (slab, beam, columns) such as buildings, bridges etc. Recently, their use has increased in the rehabilitation of concrete structures, mainly due to their ease for application, high durability and low costs.This paper presents an overview of the research and development of applications of advanced composites in civil engineering.*

1) Introduction

A structure is designed for a specific period and depending on the nature of the structure, its design life varies. For a domestic building, this design life could be as low as twenty-five years, whereas for a public building, it could be fifty years. Deterioration in concrete structures is a major challenge faced by the infrastructure and bridge industries worldwide. The deterioration can be mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultraviolet radiations. As complete replacement or reconstruction of the structure will be cost effective, strengthening or retrofitting is an effective way to strengthen the same.

The most popular techniques for strengthening of RC elements have involved the use of external epoxy-bonded steel plates. It has been found experimentally that flexural strength of a structural member can increase by using this technique. Although steel bonding technique is simple, cost-effective and efficient, it suffers from a serious problem of deterioration of bond at the steel and concrete interphase due to corrosion of steel. Other common strengthening technique involves construction of steel jackets which is quite effective from strength, stiffness and ductility considerations. However, it increases overall cross-sectional dimensions, leading to increase in self-weight of structures and is labour intensive. To eliminate these problems, steel plate was replaced by corrosion resistant and light-weight FRP Composite plates. FRPs help to increase strength and ductility without excessive increase in stiffness. Further, such material could be designed to meet specific requirements by adjusting placement of fibres. So concrete members can now be easily and effectively strengthened using externally bonded FRP composites.

Advanced fibre reinforced polymer (FRP) composite is very effectively being used worldwide for strengthening structures. It provides a cost effective and technically more superior alternative to the traditional techniques in many specific situations. It offers high strength with low self weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry. Conventional strengthening methods such as external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are very expensive. In addition to that these methods are time consuming; require extensive equipment and significant labour. FRP repair systems provide an economical and technically better alternative to traditional repair systems and materials.

2) Repair of Structural Member

The effectiveness of the application of advanced composite materials or fiber reinforced polymer (FRP) composites for seismic repair and retrofitting of structural member such as slab, beam and column.

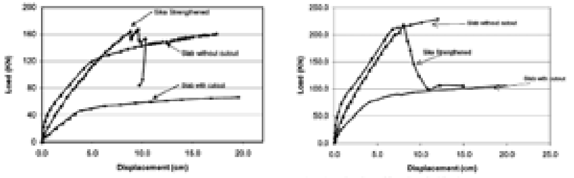
A. Slab

The use of Carbon FRP (CFRP) composites in theformof strips or overlays, offers a cost-effective techniquefor the flexural strengthening of substandardreinforced concrete slabs. The efficiency of this applicationhas been demonstrated through numerous experimentalinvestigations and field applications [3,4].A recently completed experimental test program atUCSD investigated the effectiveness of the CFRP stripstrengthening method on large scale slabs weakened bythe introduction of a rectangular hole at the center ofthe slab [5].

A series of four tests on large-scale slabs with arectangular cutout in the center retrofitted with CFRPstrips was conducted to evaluate the use of this strengtheningmethod for typical slab upgrades. The four testunits that were considered for this project, two slabswere used as base-line references, one loaded in three point bending and the other in four point bending. Theremaining two specimens were reinforced with carbonstrips in the two principal directions and were tested inthe two respective loading configurations. The dimensionsof the slabs considered were 6 m length, 3.2 min width and 0.18 min thickness. A rectangular openingmeasuring 1 m X 1.6 m andcentered with respect to the slab was later introduced.The dimensions of the cutout were chosen as half thewidth of the slab such that, the main reinforcement ratiowas reduced by half and 1 min the longitudinal directionto maintain a reasonable strength capacity. The test setupfor the two flexural slabs tested in three-point bendingis shown in fig. 1(a). A steel distribution beamover thecutout allowed introduction of load at mid-span [5].

An overview of the test results for the three andfour-point bending tests is provided by the load–displacementcurves in fig. 1(c) and (d) respectively. Thefigures demonstrate that the ultimate strength of the slabwas increased to more than twice that of the weakenedslab with cutout. Under both loading conditions, thestrengthening measure was successful in recovering theinitial strength of the previously tested slab without thecutout [5], while also increasing the stiffness. In additionto a higher load carrying capacity, the CFRP strengthening reduced the strain levels in the steel reinforcementand enhanced the development of a more evenly distributedcrack pattern. Failure of the strengthened test unitswas due to delamination or peeling-off of the strips as shown in fig. 1(b)

(a) 3-point flexural slab test setup (b) Onset of strip debonding near cutout



(c) 3-point bending load-displacement response (d) 4-point bending load-displacement response

Fig. 1CFRP Strengthening of large-scale slabs with openings.

B. Beams / Girders

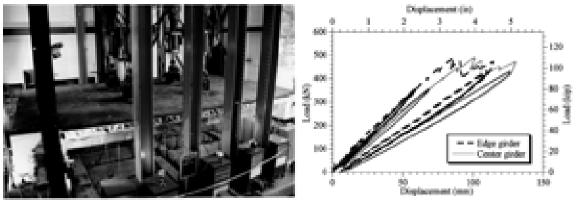
i) 3 - Girder System Test: -

To validate the overall performance of the CSS system, a full - scale superstructure system consisting of three carbon shell girders and a FRP deck system was constructed and tested in the laboratory at UCSD [9]. The test specimen simulated one half of the width and the distance between the support and the inflection point for one span of the prototype Kings Storm water Channel Bridge in California.

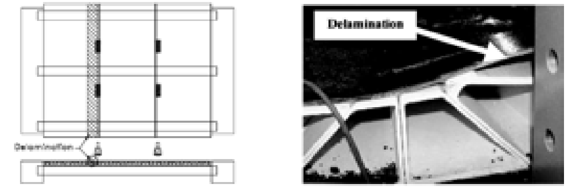
Characterization of the systemdurability in terms ofstructural integrity and damage tolerance was investigatedby subjecting the bridge superstructure first tostiffness characterization tests up to service load levels and then to 2 million cycles of fatigue service loading.A photograph of the test setup is shown in Fig. 11(a).The loading pattern consisted of four servo-controlledactuators applying simultaneously a load of 56 KN eachat a frequency of 1 Hz. This load level duplicates theshear force demand on the prototype bridge at thegirder - deck interface under full service loads. Testresults show that the strength of the structure did notdegrade during fatigue loading. This conclusion wasfurther validated when the stiffness characterization testswere repeated after completion of the 2 million fatiguecycles without any noticeable change in structuralresponse [9].

The load–displacement response of the system up tofailure at mid-span is shown in Fig. 11(b). The systemremained primarily linear up to failure, which occurredin the top face sheet of the deck panel. At the peak load(490 KN per actuator), which is equivalent to approximately8.8 times the service demand level, the facesheet of the deck delaminated from the core and thecore material buckled near its connection with theinclined web as shown in fig.2(c) and (d).

After failure, the specimen was unloaded and thencycled three times with a load of 445 KN force peractuator. The final permanent settlement at the completion of the test was less than 5 mm. No visual damageto other components, such as girders, end blocks andconnections was observed [9] [11].



(a) Test setup (b) Load-displacement response



(c) Locations of deck failure (d) Close-up of the delamination

Fig. 2 Beam and slab assembly test (3- Girder system-test).

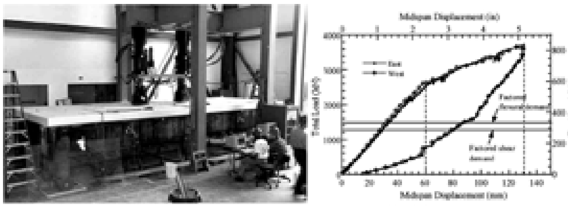
ii) Two- Girder Test

A two-girder assembly test wasalso conducted at UCSD to verify the potential applicationof the HTS concept. The test specimen wassimply supported and the hollow rectangular girderswere locally filled with concrete near the pin supports,FRP deck panels were installed between the two girdersand a polypropylene fiber reinforced concrete slab waspoured on top[10]. Theload cases for the test were designed to evaluate theresponse of the systemunder loads equivalent to thedemands of a prototype bridge and to assess potentialfailure mechanisms and sequences in the system assembly.Fig. 14(a) shows a photograph of the test under asimulated wheel load condition. Results from one of theflexural loading cases are provided in as shown in fig. 3(b).

The two-girder systemshowed significant strengthreserves over the demand of the proposed prototypebridge. The systemand its concrete slab behaved linearlyunder wheel and global flexural loads up to factoredload levels. Even after the concrete slab was severelydamaged at multiple

Volume : 5 | Issue : 8 | August 2015 | ISSN - 2249-555X

locations (frompunching sheartests) and showed signs of slippage (bilinear point inas shown in fig. 3(b) at 60 mm), the systemwas still able to carryloads greater than the demand with minimal stiffnessloss. The girder-to-deck connection displayed goodintegrity up to 150% of the factored shear demand. Thedeflection and strains in the deck between girders werecompared with those obtained from simply supporteddeck tests [10]. It was concluded that under an AASHTOHS 20 truck wheel load [11], a significant strengthreserve existed in the deck system [12].



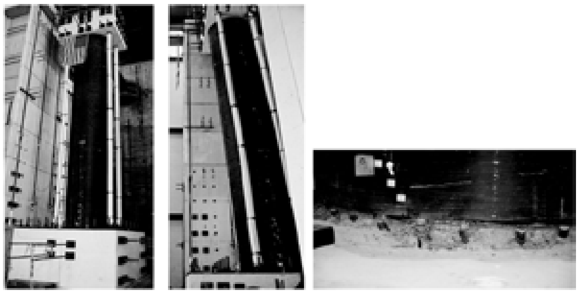
(a) Test setup (b) Load-displacement results

Fig. 3 Two- Girder hybrid tube system (HTS) test.

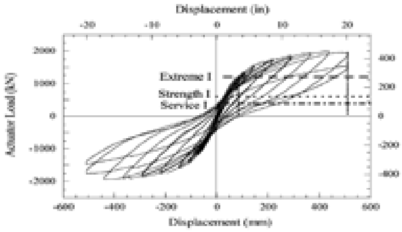
c) Column / Pier

The Bridge pier is composed of 1.5 m diameter; 9.75 m long filament-wound cylindrical carbon composite tubes filled with concrete that are spliced together up the pylon height. As part of a validation test program for the bridge, a Pylon Splice Connection Test was conducted [13] to validate the design and analysis methods used to develop the connection splice reinforcement details, to examine the ductile failure of the mild steel reinforced splice section, to assess the confinement effects of the carbon shell and to evaluate strain levels in the carbon composite shell in comparison with targets set forth in the Design Criteria[14] for the bridge. The design of the pylon leg for the bridge requires that failure will occur in the splice region by yielding of the mild steel reinforcement rather than brittle failure in a typical composite section. The final design details for the 'typical' splice connection in the pylon connection test resulted in thirty 29 mm diameter longitudinal bars with 1.83 m splice length, confined by 13-mm diameter hoops that were spaced at 0.12 m [13].

A photograph of the test setup is shown in fig. 4(a), while the test specimen at extreme drift is depicted in Fig. 16(b). The axial load was applied using four external tendons, each composed of 27–15 mm diameter strands. The force vs. displacement hysteresis is provided as shown in fig.4(d) [13]. Also included as shown in fig. 4(d) are the SERVICE I (395 KN), STRENGTH I (622 KN) and EXTREME I (1222 KN) demand levels which were based on AASHTO LRFD toad combinations [15] for the pier of the bridge. At the end of the test, 15 of the 30 longitudinal bars in the splice region had fractured as shown in fig. 4(c), but the overall global capacity of the specimen only degraded approximately 20%. The pylon splice connection test was successful in demonstrating that the design satisfied the performance objectives. The compression and tension strain levels in the composite shell were well below the limit states set forth in the Design Criteria [14]. The development length provided in the splice region was sufficient in transferring the forces to the composite shell. The amount of transverse reinforcement provided by the composite shell and steel hoops in the splice region was able to resist pull-out failure of the lap splice longitudinal bars and sufficiently confine the plastic hinge region for adequate ductility capacity. Preliminary assessments of the strain levels as well as acoustic observations during testing indicate that slip of the longitudinal splice reinforcement was avoided [13].



(a) Test setup (b) Extreme drift (c) Ruptured splice bars



(d) Load-displacement response

Fig. 4 Pylon splice connection test.

3. Summary

Worldwide research and application of FRP compositesin civil engineering construction demonstrate theneed for new construction materials in support of civilinfrastructure renewal. The demonstrated advantages ofFRP composites have shown that they will play asignificant role in future civil engineering projects [3]. Thestructural effectiveness of FRPs in the repair of constructedfacilities, strengthening of structural walls, slabsand retrofitting of concrete columns with shear, flexureand lap-splice problems has been validated with largeor full scale laboratory tests. However, the use of fiberreinforced composites for the rehabilitation of structuresrequires that appropriate design philosophies, guidelinesand detailing be established and that the design isconducted using a methodology that ensures appropriateuse of the material [5]. With suitable design criteria forFRPs in structural rehabilitation, significant advantagescan be derived fromthe lightweight properties of thesenew materials and their ease of handling and installation [9].

Innovative FRPconcrete bridge systems, such as thecon-crete filled carbon shell system (CSS) and the hybridtube system (HTS) effectively use FRPs for new constructionby combining them with conventional materialssuch as concrete and steel. Systemcharacterization anddesign studies are providing the basis for designapproaches for FRP bridge systems in terms of deformationand strain limit states. It is expected that modularFRP bridge systems of this type will lead to fasterconstruction and less traffic interruption due to theirlight weight, as well as lower life-cycle costs due toreduced maintenance [11] [13].

The extent of these FRP applications in support ofcivil engineering renewal will depend on (1) the resolutionof outstanding issues such as reparability, fire,durability and environmental concerns; (2) the extent towhich automation in the manufacturing process canreduce cost; (3) the availability of validated codes,standards and guidelines that can be used as designreferences and tools by the civil engineering community;and (4) the degree of quality control and quality assurancethat can be developed and provided during themanufacturing and installation phase utilizing unskilled generalconstruction labour [7] [3].

REFERENCE

1. Weeks J, Seible F, Hegemier GA, Priestley MJN. The USTCCMAR Full-Scale Five-Story Masonry Research Building Test: Part V – Repair and Retest. Structural Systems Research Project. SSRP- 94/95. University of California, San Diego, La Jolla, January, 1994. | 2. Laursen PT, Seible F, Hegemier GA. Seismic Retrofit and Repair of Masonry Walls with Carbon Overlays. Structural Systems Research Project. SSRP-95. University of California, San Diego, La Jolla, January, 1995. | 3. Meier U, Deuring M, Meier H, Schwelger G. Strengthening of Structures with CFRP Laminates: Research and Applications in Switzerland. Proceedings of Advanced Composite Materialsin Bridges and Structures: First International Conference, Sherbrooke, Canada, 1992; pp 243–251. | 4. Nanni A, Focacci F, Cobb C. Proposed Procedure for the Design of RC Flexural Members Strengthened with FRP Sheets. Proceedings of Second International Conference on Composites in Infrastructure, Tucson, Arizona, 1998; pp 187–201. | 5. Vasquez A. The use of carbon fiber reinforced polymer strips for the external strengthening of slabs. San Diego, La Jolla: M.S. University of California, 1999. | 6. Seible F, Priestley MJN, Hegemier GA, Innamorato D. Seismicretrofit of RC columns with continuous carbon fiber jackets. JCompos Construction 1997; pp 52 –62. | 7. Karbhari VM, Seible F, Hegemier GA, Zhao L. Fiber ReinforcedComposite Decks for Infrastructure Renewal – Resultsand Issues. Proceedings of International Composites Expo 97,Nashville, Tennessee, 1997. | 8. Seible F, Karbhari VM, Burguen˜o R, Seaburg E. ModularAdvanced Composite Bridge Systems for Short and MediumSpan Bridges. Proceedings of Fifth International Conferenceon Short and MediumSpan Bridges, Calgary, Canada, 1998. | 9. Karbhari VM, Seible F, Burguen˜ o R, Davol A, Zhao L. DamageTolerance and Durability of an Advanced Composite BridgeSystem. Proceedings of First International Conference onDurability of Composites for Construction, Sherbrooke, Canada,1998; pp 57–68. | 10. Zhao L, Karbhari VM, Seible F, Burguen˜o, R, La RovereH,Brostro¨mM, Godonou P. Experimental Investigation of PrototypeTransverseSystemfor the Gilman Drive AdvancedTechnology Overcrossing. Structural Systems Research Project.SSRP 2001/04. | 11. AASHTO. AASHTO LRFD Bridge Design Specifications. 2ndEdn. American Association of State Highway and TransportationOfficials, Washington, D.C., 1998 (including 1999 and2000 interims). | 12. UCSD. Design and Analysis of the I-5Gilman AdvancedTechnology Bridge. Department of Structural Engineering,University of California, San Diego, La Jolla, February, 2000. | 13. Hose YD, Zhao L, Oiler E, Karbhari VM, Seible F. SeismicPerformance of the Concrete-Filled Carbon Shell Pylon SpliceConnection for the I-5Gilman Advanced Technology Bridge. Structural Systems Research Project. SSRP-2001, Universityof California, San Diego, La Jolla, April 2002. | 14. UCSD. Design Criteria for the I-5Gilman Advanced TechnologyBridge. University of California, San Diego, La Jolla,September 2001. | 15. AASHTO. AASHTO LRFD Bridge Design SpecificationsModifications to Chapter 11 (abutments, walls, earth pressure).2nd Edn. American Association of State Highway and TransportationOfficials, Washington, D.C, 2001. |