Review on Bridge Strengthening by Advanced Composite Material

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Abstract— There different bridge strengthening methods are available but use of advanced composite material for bridge strengthening is a relatively advanced phenomenon. Application of composite materials for bridge strengthening has larger market as it can be used for strengthening of columns which are most likely to be deteriorated by the corrosion. It is relatively easy to clean and repair these columns and encase them with the non-corrosive composite materials. This paper provides a review on use of advanced materials for bridge strengthening. In this paper, different aspect of use of composite materials for bridge strengthening has been revealed.
Key words: Composite Material, Bridge Strengthening

I. Introduction

In today's world, construction engineers are faced more and more frequently with the task of strengthening existing bridges in order to secure or even increase their load bearing capacity. Many different strengthening techniques are available, such as installing additional steel, external post tensioning, bonded reinforcement, increasing the concrete cross-section, etc. The use of bonded steel plates has been used successfully since the late 1960's. External plate bonding is a method of strengthening which involves adhering additional reinforcement to the external faces of a structural member.

As a result of extensive research and development projects at the Swiss Federal Laboratories for Materials Testing and Research (EMPA), Dübendorf, Switzerland it was proven that the use of steel plates can be replaced with composite materials. The high-strength Carbon Fiber Reinforced Polymer (CFRP) plate system was applied for the first time outside the laboratory in 1991 for strengthening the Ibach Bridge in Lucerne, Switzerland.

In virtually all applications for bridge strengthening, advanced composite systems have been proven to be structurally efficient, easy to handle and install on job site, and cost competitive when compared to other conventional strengthening methods.

The most highly developed application to date is the use of advanced composites in repair of bridge columns and other supporting elements to improve their ductility for seismic resistance.

Both epoxy impregnated fiberglass and carbon fiber materials have been tested in the laboratory on half-scale models of bridge columns to determine the ductility that can be achieved in an older, non-ductile concrete column. The tests have confirmed the viability of these materials for strengthening existing structures and field application quality specifications have been developed.

II. Relevance

Qualifying well documented composites materials and processes for structural applications is the ultimate goal of this study. In order to achieve such level of confidence, the following objectives are made:

In adopting the technique of advanced composites systems it is possible to:

– Increase the flexural strength
– Increase the shear strength
– Increase the seismic resistance
– Increase the confining strength

Advanced composite systems are comprised of fibers (typically carbon, glass, or aramid) and resins (typically epoxy resins). Only long term tested (fatigue resistant) and approved systems should be recommended for strengthening purposes in Bridge Engineering.

III. Literature review

New bridges are being built with materials that have significantly higher strength in comparison to steel, are lighter, and are more durable for longer service life. The use of fibre reinforced polymer (FRP) bars and tendons is considered to be one of the most promising solutions to overcome the deterioration problems associated with concrete bridges due to the Corrosion of steel reinforcements.

The following literature reviews concentrate mainly on Bridge Strengthening by Advanced composite material.

Sami RIZKALLA(1999), presents the Canadian experience in the design and construction of highway bridges built with these new materials. The paper reviews the design and construction of the Taylor Bridge in Headingley, Manitoba, where FRPs were used to prestress four of the main girders, as well as stirrups for the shear reinforcements. The use of FRPs to reinforce the deck slabs and the barrier walls for the same bridge and other bridges across the country is also discussed.

The high strength and light weight of these materials and the fact that they are now available in the form of very thin sheets provide an attractive and economical solution for strengthening existing concrete bridges to increase their ductility, flexure and shear capacity in response to the increasing demand to use heavier truck loads.

This paper reviews some of the Canadian projects which have been completed using these materials. The paper presents a new technology for remote monitoring of bridges to minimize the need for frequent site inspections. Monitoring is based on using a new generation of fibre optic sensors which have already been implemented in the construction of new bridges in Canada, as well as in the strengthening of existing ones.

JAMES E. ROBERTS. et al (2000) paper states that the use of various composite materials for different bridge component, such as epoxy impregnated fiberglass sheets to wrap around older, non-ductile concrete bridge columns as an alternative to the already proven steel jacket technique, The jackets provide sufficient confinement in the concrete to allow them to perform in a ductile manner under seismic loading, also the prefabricated resin impregnated-fiberglass shells which can also be used as the form for concrete in the repair process.

The paper also state the material testing program, program was set up to identify the critical parameters and procedures which need to be monitored or controlled to assure the reliable performance of composite retrofitted columns or bridge decks. Cost considerations are an important part of this program. It would be very easy to define tests, inspections, and quality checks that would increase the price of manufacturing composite jackets to the point where they would not be cost competitive with conventional materials. Because of the variations in composites, some testing is unavoidable. However, this program is designed to minimize the testing required to assure a quality product.

ICE Manual of Bridge Engineering Institution of Civil Engineers (2008) this paper will concentrate upon the areas of bridge engineering where these materials are utilized; their advantages over the more conventional civil engineering materials will be discussed. Areas where the material might be vulnerable if used in certain bridge situations will also be given.

This will focus on the utilization of FRP composites in bridge engineering under 11 topic areas:

- New bridge structures, fabricated entirely from FRP composite material
- FRP–concrete beam constructions
- Bridge decks, manufactured from FRP composite material
- Steel-free bridge decks
- Bridge enclosures
- Rehabilitation of existing bridges
- Seismic retrofit
- FRP confining of concrete columns
- Internal reinforcement to concrete members
- Elastomeric bearings
- Intelligent structures.

URS MEIER Swiss Federal Laboratories for Materials Testing and Research (EMPA)(2000) This paper seeks to demonstrate how advanced polymer matrix composite materials developed for high-performance aircraft can offer major advantages for repairing ageing infrastructures. It focuses on the development and first applications of advanced rehabilitation; retrofitting, strengthening and field monitoring technologies for civil engineering structures based on unique combinations of corrosion-resistant fibre-reinforced polymers and integrated fibre optic structural sensing.

IV. VARIOUS ADVANCED COMPOSITES MATERIAL

- Glass Fibres, Aramid, and carbon
- Carbon fibre reinforced polymer
- Carbon fibre reinforced epoxy resin composites
- Fiberglass sheet
- Carbon fiber tubes
- Prefabricated resin impregnated-fiberglass shells
- Vinylester resin
- Pre-preg carbon fiber
- Polyester Polyurethane

V. DETAILS OF SOME COMPOSITES MATERIALS SYSTEM

A. *CRFP Plate Systems:*

The CFRP plates consist of individual carbon fibers, each having a diameter of approximately one five thousandth of a millimeter. The fibres are aligned longitudinally and manufactured using the pultrusion process. CFRP plates exhibit linear elastic behaviour up to the point of failure. Using different carbon fibers allows plates to be manufactured with different material properties.

	E-modulus N/mm^2	**Tensile strength N/mm^2**	**Elongation at break %**
Standard (S) Modulus	165000	2800	> 1.7
Medium (M) Modulus	210,000	2,400	> 1.2
High (H) Modulus	300,000	1,300	> 0.45

Table 1 Properties Of material

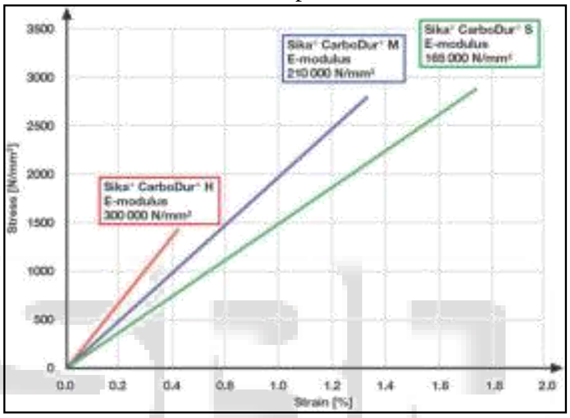

Fig. 1: Typical Stress-strain diagram

The chemical resistance of CFRP plates against pollutants is very good. The carbon fibers and the epoxy matrix have long-term resistance against concrete pore water, de-icing salts and hydrous acid solutions. CFRP plates are available in different widths between 50mm to 150mm and thickness of 1.2mm to 1.4mm. CFRP plate systems are particularly suitable for flexural strengthening, in-situ rehabilitation as well as for pre-stressing.

B. *Epoxy Adhesive*

Two component epoxy resin systems are well suited for the bonding of CFRP plates to concrete, steel, wood or masonry. This type of adhesive has very high mechanical strengths as well as good chemical resistance against aggressive media. Good wetting properties on concrete, wood, etc., ensure good bond characteristics. The main function of the adhesive layer is to transfer the forces between the composite material and the substrate, such that they will act monolithically.

The following properties are important for high strength structural bonding:

- High bonding strength
- High cohesive strength
- Low creep
- Good resistance against humidity and alkalinity

C. Adhesive bonding of polymer composites to concrete surfaces:

In discussing this topic it is assumed that the surface of the concrete has been correctly prepared, grit-blasted and cleaned Solvent-free adhesive polymers such as epoxies and their hybrids (e.g. epoxy-polysulphides, epoxy-urethanes) are used for bonding FRP composites to concrete surfaces; the physical properties of these adhesives are given in

Table.2 these adhesives are generally formulated from epoxy resin, an amine or polyamide curing agent, reactive diluents, and organic fillers and thixotropic agents.

Property	Epoxy	Polyester	Poly-urethane
Tensile strength: MPa	28–90 4000–13000	4–90 600–13000	1.2–70 175–10 000
Tensile elongation, %	3–6	2–6	100–1000
Compressive strength: MPa	105–175 15000–25000	90–205 13000–30000	140 20 000
Comp. modulus: 103 MPa	-	2–3 300–400	70–700 10–100
Heat deflection temperature: 8^0 C	45–260	60–200	–

Table 2 Properties of adhesives

The strength of an adhesive depends upon:

- The cohesive strength of the adhesive material
- The cohesive strength of the substrate materials; the strength of
- The concrete is weaker than that of the adhesive polymer and therefore the concrete will generally be the failure criterion
- The adhesion of the adhesive to the substrate material (bond Strength).

VI. Advanced Composites in Bridge Applications

The epoxy impregnated fiberglass sheets to wrap around older, non-ductile concrete bridge columns as an alternative to the already proven steel jacket technique. The jackets provide sufficient confinement in the concrete to allow them to perform in a ductile manner under seismic loading. It was known that the it is used high strength carbon strands to similarly reinforce industrial stacks and chimneys but the use of glass fiber sheeting had not been used. The major unknown was the durability of the fiberglass materials under cyclic loading and to what level of ductility the columns could be designed. Caltrans technical staff and the principal investigator at UCSD visited the Swiss National Laboratory in Zurich to observe the many durability tests they have performed on composite materials. The testing program at UCSD was conducted under the same conditions that were used in the testing of steel plate jackets. Half scale models of the prototype bridge columns were constructed, wrapped with the desired layers of glass fiber sheets and tested through several cycles of loading at various levels of ductility until the column failed due to shear failure and consequent degradation of its hysteretic performance. These laboratory tests proved that the epoxy impregnated fiberglass column wraps could develop nearly the same ductile performance as the steel plate jackets.

Material properties are readily available from the manufacturers but there remained the issue of adequate quality control specifications for the field application. These early applications were rather crude, being hand laid in a similar manner as hanging wallpaper. The carbon fibers are applied by automatic wrapping machines which wrap several 1/4 inch strands simultaneously and can fully wrap a typical four to six foot diameter, 20 foot long bridge column in two hours. Because of the higher strength to weight ratio these materials are very competitive with the steel shell retrofit technique, and they can be applied with much less heavy lifting equipment. The materials are much more resistant to corrosion than the steel jackets and they will require very little maintenance.

A. Column Strengthening:

The most widely used application of advanced composite materials for bridges in now a day, to date, is the seismic strengthening of bridge columns to improve their ductile performance in an earthquake. However, there is a larger market for this technology in the simple repair and strengthening of columns which have deteriorated from corrosion. It is relatively easy to clean and repair these columns and encase them with the non-corrosive composite materials. This application will undoubtedly increase the life of the columns or piers. Three manufacturers have developed prefabricated resin impregnated-fiberglass shells which can also be used as the form for concrete in the repair process. Many States have followed Caltrans lead and are using these composite shells for both seismic strengthening and non-seismic repair.

VII. Conclusion

Application of the advanced composite materials in seismic retrofit strengthening of bridge columns and other structural members. The goal is to increase the shear capacity and develop ductile performance in these members during a seismic event. It seems obvious that, in the current economy, these composite materials are not competitive with the more common bridge materials now being used, unless accurate life cycle costs are considered. We know the advantages of these advanced composite materials from the testing and field applications to date.

References

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